ROUGH-TERRAIN GROUNDSPEED MEASUREMENT: A RADAR-BASED COMMERCIAL SOLUTION.

VOLUME TWO OF TWO VOLUMES

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SECTION TWO

SUPPLEMENTARY MATERIAL

CHAPTER 12

DATA RECORDINGS
COMPANY REPORTS

CHAPTER TWELVE

LITERATURE REVIEW: DETAIL.

"One of the major unsolved problems of electromagnetic theory is that of the interaction of electromagnetic waves with non-uniform surfaces. "

R L Cosgriff
Terrain Handbook, 1959

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12.0. INTRODUCTION

This chapter forms the first of the supplementary material sections of this thesis. Chapter five contained the introduction, discussion and conclusions of each of the topics covered in the literature review from a viewpoint of the usefulness of the findings for this project. For the sake of brevity, chapter five contains tabularised resumes of the major researchers and their work. This chapter provides the 'detail' of this work, and provides a non-mathematical description of the findings of the major researchers.

12.1 DEFINITIONS

It is imperative to standardise the necessary phraseology before commencing the review proper. This section will define, for the purposes of this thesis, the adjectives used to describe a terrain surface, the various angles used, and examine the unit of measurement of backscatter.

Unfortunately there exists a wide range of adjectives prone to vagueness and/or subjectivity: the major offenders are 'rough', 'smooth' and 'contour'. In the absence of any agreed definition of these words, it is useful to summarise the definitions proposed by the major workers in the field.

This report uses 'contour' in the sense of general ground shape in cross-section, and only includes irregularities far greater than one wavelength. Such irregularities, however, must not affect the nominal radar axis angle. 'Roughness'is a measure of irregularities similar in size to a few wavelengths or less. Thus, a surface is characterised by the average value of the surface roughness: a value that decreases for smoother surfaces (for critical applications, the standard deviation is stated). The definition of a 'smooth' surface is difficult. The writer has found the general guide of a 'roughness value of less than one wavelength' to be of use in empirical work. For more accurate purposes, this does not suffice: asphalt, pebbles, concrete etc all fall into this definition of smooth for X band, yet backscatter from them varies by up to a factor of twenty (Cosgriff,1959).

The three major definitions of 'smoothness' are summarised in fig 5.5B: this review uses the Barrick definitions.

The single most important angle in such work is that between the radar beam axis and the ground. Yet this angle does not have a standardised name. For geometry that does not take into account of the curvature of the earth, the tilt, depression or grazing angle equal ninety degrees minus the incidence, look or view angle. The papers reviewed later use all six names.

Similarily, the measure of backscatter, the scattering coefficient, would seem to have no agreed definition. Care must be taken to distinguish the scattering coefficient (SC), also called the differential scattering cross-section (DSCS), which correctly means the scattering cross-section per unit area (SCSA); from the scattering cross-section (SCS). The latter is used for discrete targets as it's value varies with the illuminated geometric parameters of the radar. The scattering coefficient, SC is independent of these parameters. Berger (1957) and Cosgriff (1959) define the SC as the ratio of power backscttered by a perfectly reflecting isotropic radiator. Thus, their definition for the SC is that of the SCSA and not the SCS per unit ground area. Fortunately the two are easily interchangeable: the ground area is related to the measured beamwidth by the cosine of the look angle.

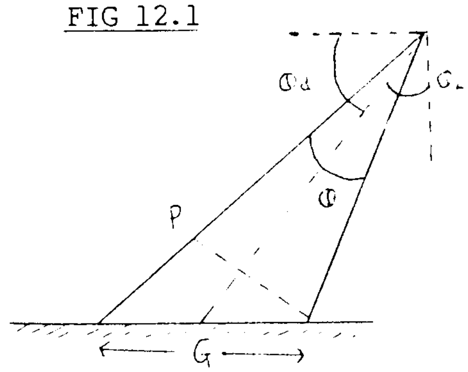
The use of the DSCS implies that ground return is characterised by return from a large number of scattering centres, each with independent phase (the phase effect being due to the differences in radar-to-scatterer distance throughout the radar footprint) which, although a small fraction of the mean distance (0.001 for X band), can be a multiple of the radar wavelength. Thus the average radar return can be computed by the vector sum of each contribution. For a very smooth surface this can produce misleading results, but for off-highway terrain it suits the purposes of this report adequately.

The radar footprint was referred-to above. This is defined as the area of ground illuminated by the beam at some nominal reduction of main-axis power. This project, in line with common use, uses the half-power points to compute the nominal footprint.

In summary the angles used are:

@d: depression, tilt, grazing angle
@l: incidence, look, view angle
@ : beamwidth at -3dB power points
P : projected area
G : ground area (footprint)

FIG 12.1



12.2 BACKSCATTER.

12.2.1. Backscatter experiments.

The importance of backscatter has "long been noted the parameter that determines the amplitude of the returned signal, and hence the signal-to-noise ratio of the system" (Skolnik,1970). Amongst the first researchers in this field were Clapp (1946) who examined the relationship between Sc and depression angle; Gunn (1954), whose work is covered in the section dealing with backscatter from rain and snow; and Macdonald, whoe examined sea returns from the air, considering waves to be surface imperfections. Grant, in 1957, a year of great activity and progress in experimental work on backscatter, measured the backscatter from water and various categorisations of terrain at several wavelengths, and calculated the values of the average SCSA. This was performed by determining the ratio of received and transmitted power for a range of given incidence angles. His results showed that the RCS of a surface is a complex function of surface conditions (for water, being produced by wind,; for land, produced by terrain contour, surface roughness, transmsitted frequency). Berger (1957) also discussed several factors influencing radar return from land and sea, and stated that the backscattering properties of surfaces were functions of the incidence angle. He continues by describing backscatter over land as independent of this angle and unaffected by transmitted beam polarisation. Wiltsche (1957) however, found a strong relationship between these parameters: he measured backscatter from land and sea at X band for angles of depression ranging from zero to ninety degrees, and found the SCSA to be nearly constant with frequency, increasing with depression angle but peaking at sixty degrees. These results, when compared to a simple scattering model, correlate well up to an angle of seventy degrees. Of notable interest was his finding that the percentage fluctuation of the received signal amplitude about the mean value were greater for large depression angles. Peake (1957a,1957b) was the first researcher to examine near-homogenous surfaces, and took plaster casts of sample areas of concrete and tarmac roads to estimate the mean square roughness, and hence the correlation function. He then compared this data to a theoretical model developed from the information derived from the plaster casts. A correspondence to within a few decibels was noted: the accuracy of correlation being dependent upon an accurate knowledge of surface roughness. The depth of the samples used is not stated, but the work implies the subsurface does not contribute to returned scatter.

Cosgriff (1959) used a radar radiometric system to perform data gathering; the equipment being mounted on the rear of a truck which was then driven over the terrain of interest. This work set the standard for road surface research: gravel, smooth and rough asphalt, smooth and rough concrete were all researched. He found that smooth concrete gave a return twenty-five decibels down on gravel at all tilt angles, and that for angles of thirty to fifty degrees, SC remained almost constant; gravel being an exception, being linear for a random rough surface and X band system. Beam polarisation was also researched: vertical polarisation was found to give both a marked increase in signal return on smooth surfaces, and a more linear relationship between backscatter and tilt angle at mid-angles. A bistatic configuration was assessed; and angle of fifteen degrees proved to be optimum, and this result, unlike monostatic geometry, was found to be independent of polarisation.

Ament (1959) also studied the effects on SC by measuring the backscatter from terrain for a range of angles, finding a marked increase in return for larger incidence angles. This relation was further studied by Reitz (1959) who used an airborne system; the target terrain was categorised by noting selected surface parameters: the nature of the technique is not divulged. Ament found a near-linear relationship between backscatter and tilt-angle, roughly that each increase in angle of ten degrees produced three decibels more returned signal. Again, the means of terrain categorisation are unstated and care must be taken in interpreting the results. Edison (1959) for example, analysed terrain by ground-based observers; determining a correlation by direct data comparison. He also (1960) used air-based measurements at low angles of incidence, and found a distinct relation between surface type, angle of incidence and SC; certain gound types having almost constant SC over a reasonably wide range of angles.

Katz (1960b) found backscatter to be constant for grazing angles of between thirty and sixty degrees, but observed a decrease below thirty degrees due, he states, to the almost vertical incidence angle of the beam onto surface imperfections. Thus he describes the returned signal behaviour in terms of facet theory. Long (1865) found that backscatter measurements from complex surfaces, specifically sea, but also certain terrain, can be explained by consideing the surface as a number of large (ie greater than a wavelength) facets, providing a background to which is added small scatterers.

The consideration of available ground models by all researchers during the early 1960's is not coincidence: this period parallels with significant activity in the theoretical aspects of radar systems; much of this work 'riding of the back' of American military research, which commenced in earnest in the late fifites.

A more rigorous scientific method was adopted by Lundien (1966) who studied the backscatter/frequency/tilt angle relationship by mounting the radar on a moveable platform over a 4 by 2 metre sample area, upon which laboratory-prepared soil samples were placed, thus the effect of moisture in (as distinct from 'on') the samples was examined. The sample thickness is important: Lundien is almost unique in considering the terrain subsurface. The implications of this point are discussed in the conclusion sections of chapter five.

The late sixties saw much airborne research: Krason (1966) found a transition from diffuse scattering at normal grazing angles to specular scattering at shallow angles (six to ten degrees at X band). Daley (1968) performed airborne measurements over a range of terrain from marsh to desert, and noted a linear relationship between backscatter and grazing angle for angles between eight and sixty degrees, with scatter decreasing by five decibels per doubling of grazing angle. These results agree with Ament (1959).

Broderick and Hayre (1969) showed that statistical properites of rough surfaces (neglected by many researchers, notably Berger, 1957) must be accounted-for, and produced a detailed analysis of a stationary 1-D rough surface model, over which a transmitter was moved. Their results indicated that, in addition to the expected near-Gaussian spectrum, incoherent components of the surface contour produce two additional types of spread frequency component, the amplitude of which depends upon antenna beamwidth and surface irregularities. For a very rough surface, they stated, an almost even power density is obtained across the previously expected Gaussian curve. For less rough surfaces, Broderick (1969) described a downward shift in Doppler spectrum; the degree of shift being proportional to the gradient of the backscatter curve.

The effect of grazing angles approaching the Brewster angle (for typical terrain, fourteen degrees) is recorded by Jordan and Balmain (1968) who report a reflection coefficient amplitude decrease to a low value at this angle, notably for a vertically polarised beam. Moore (1969), in an attempt to simplify the state of knowledge, stated that relatively smooth surfaces tend to reflect radar in accordance with the Fresnel reflection principle (angle of incidence equals angle of reflection), and that backscatter is pronounced only for near-normal viewing angles, whilst rough surfaces tend to reradiate almost uniformly in all directions. These findings agree with Ruck (1970) who performed experiments to illustrate his theory that a rough surface produces the greatest quantity of backscatter at, or close to vertical, and a rapidly falling amount near grazing; but continues to say that a slightly rough surface produces most backscatter at angles near grazing.

A controlled series of experiments to determine terrain backscatter in the EHF band using asphalt, both dry and wet, concrete, gravel and soil was undertaken by King (1970). The SC was determined from normal to 45 degree angles of incidence. His results indicated returns of a specular nature; wet surfaces having a sightly higher SCSA, although gravel (an exception to the results of many researchers) showed no change. Sand and soil was also examined by Cook (1972) who measured their reflectivity with various values of moisture content and surface roughness and for various transmitted frequencies. He also used both vertical and horizontal polarisation and a swept-frequency bistatic reflectometer, showing that adding moisture to soil results in making the surface appear rougher to radar due to the cohesion of small particles. It was also found that patches of moisture provided a discontinuous rough surface, which reduced specular reflectivity.

Broderick's (1969) 1-D model was improved by Sohel (1972) who used a 2-D version to demonstrate the Doppler spectrum shift produced by considering shallow angles, and that an asymmetric spectrum is produced around the nominal Doppler frequency. The extent of this assymmetry was found to be determined by the surface roughness, the main lobe becoming more rounded and symmetric for decreasing roughness.

Chadwick (1972) continues this theoretical vein by considering the ground as a distributed target , assuming the radar footprint to be a collection of idependent scattering centres. The topic of surface roughness is of importance: Broderick (1973) categorised surfaces into three generalised types, listed in fig 5.5B.

Hyltin (1973) found that both rougher surfaces and steeper tilt angles increase backscatter, and gave figures for various road surfaces at two angles of tilt. He also found that vertical polarisation produces a shallower SC curve (as a function of incidence angle and road type). Dickey (1974) noted that much research performed indicated a strong dependence on tilt angle and the quantity of backscatter, and used various ground coverings and angles to ascertain whether backscatter can be made independent of tilt angle. He found that an angle of less than 45 degrees was required, although this figure relates to cropped fields. He also stated for the first time (other workers merely noted a 'dependence') that surface moisture was by far the overriding factor in determining backscatter amplitude. DeLoor (1974) also found that at small incidence angles, backscatter depended mainly upon surface moisture, whilst at larger angles, the radar penetrated the soil and was thus affected by subsurface moisture, material type and structure. He experimented mainly at X band, by mounting the radar on a platform directed towards the target area. His results also showed that a single surface covering behaves as a Rayleigh scatterer and that the backscatter coefficient is a parameter capable of distinguishing such surface coverings. His argument refers mainly to vegetation coverings and he does not extend it to track, road or other types of ground.

The effect of moisture in soil on the SC was also examined by Ulaby (1974) who measured the spectral response of slightly rough and very rough surfaces for angles of incidence between 0 and 70 degrees, for all polarisations. The moisture range examined was 4 to 36% by weight. His results indicated that radar response to the moisture content is highly dependent upon surface roughness, frequency and tilt angle. He did note, however, that moisture in the range 15-30% produced a near-linear response against varying all other parameters. This work agrees with Dickey (1974). Ulaby contined by stating that the received power is significantly reduced for tilt angles of less than 15 degrees and that shifts in Doppler frequency due to the varying radar-target distance throughout the beam further complicates interpretation; and this, with the effect of tilt angle, produces a power spectrum shift towards lower frequencies.

The importance of understanding the effect of terrain type on radar return was stressed by Nagy (1974), who, in research on the prevention of vehicular collisions, performed scattering experiments on various road surfaces using an X band bistatic configuration. He found that horizontal polarisation produced less nulling (points of signal cancellation) and that such a system produced results similar to those obtained from a smooth dielectric surface (Jordan,1968 and Kerr,1965). He therefore concluded that the exact surface composition does not produce an appreciable effect on the returned signal, and that surface imperfections like small holes and bumps are effectively invisible for small tilt angles. Since he used terrain such as asphalt, concrete and gravvel, these results are important in the context of this thesis, although yet again, contradictory to other researcher's findings.

Bush (1975) experimentally determined the fading characteristics of backscattered signal from agricultural targets and bare ground using a platform-mounted system. He showed, by plotting the mean value of scattering coefficient against incidence angle, that the surface type determines the quantity of backscatter; and that for a typical planted surface, signal fading (fluctuation) followed a Rayleigh distribution. It is, perhaps, worth pausing at the recurrence of this distribution. Beckmann (1967, p119-133) provides a detailed description;

Schwartz (1968) found that the Rayleigh distribution assumption is invalid for uncultivated ground due to the probability of specular scatter at very small and very large incidence angles. Bush (1975) points out that care must be exercised when assuming such scattering. Hamid and Stuchly (1977) both use Skolnik (1970) to derive an expression relating backscatter to multiple scattering centres, and found experimentally that the velocity of such scatterer groups relate to measured backscatter (assuming constant moisture, temperature and scatterer size). This finding is discussed later.

The effect on backscatter of snow in the atmosphere is covered in a later section, but snow ON the ground falls into this section. Only one paper has been traced: Ulaby (1977) who performed work using an X band unit on snow-covered ground. He found that the return depended upon the nature of the underlying surface and the depth and wetness of the snow. Indeed the snow wetness was found to be more important than depth: 15cm of dry snow did not affect backscatter whilst 12cm of wet decreased the returned amplitude by up to 10dB for grazing angles between 30 and 80 degrees. Ulaby does not venture to describe the categorisation of snow's surface roughness, but his results would seem to indicate that dry snow acts as a slighty rough surface, and wet snow as a smooth surface.

Stuchly (1978) used an agricultural tractor to determine the effect of returned signal amplitude and spectrum variation with different viewing angles. He found smooth surfaces gave the smallest signal amplitude variation, but the largest spectrum centre variation. A tilt angle of 30 degrees was found optimum for spectrum error using one make of transceiver, and 43 degrees for another. Both radar were supposedly identical: Stuchly does not explain this result.

The backscatter from gravel and tarmac was researched by Kiyoto (1978) who gives SC values for numerous types of hard surface. He found that gravel produced a return 10dB down and tarmac 27dB down, the average return from all surfaces being -18dB. Although he states that a tilt angle of 45 deg was used, the method of derivation is not divulged, and the implications of the readings are not discussed. Interestingly, Baba (1978) quotes identical SC values to Kiyoto, and also does not discuss the experimental method! Baba continues to say, however, that water-covered terrain gave a return dependent upon rippling of the water surface, but again does not offer supporting evidence.

Funke (1978) found that complex targets act as a large number of interacting scatter centres, whilst simple targets act as a single centre; and that by sweeping transmission frequency, targets can be thus distinguished.

Wavetanks provide a useful means of simulating radar return: their use is discussed under section 12.3. Weissman (1979) found the degree of spectrum resolution of radar return to be inversely proportional to the radar footprint length (in the direction of travel). This result needs careful consideration: waves artificially produced have a constant wavelength and give substantial and predictable variations in reflectivity across each wave. Thus, including more waves in the beam increases the predictability of the spectrum shape.

Cox (1982) examined the relationship between SC and moisture content of materials by irradiating a sample with X band, claiming an accuracy of plus or minus 4%. It is necessary, though, to know the bulk density of the material, or to have control samples that are perfectly wet and dry!

12.2.2 Backscatter from rain

The one early outstanding paper is by Ryde (1946) who calculated back-scatter amplitude for various precipitation rates, and published graphical representations of this information. These graphs are still quoted, being essentially correct for all but the most extreme rain-fall rates. Marshall (1947) and Haddock (1948) evaluated the RCS for railfall at various intensities using the drop-size distribution results of Laws (1943) and also showed that backscatter from rainfall followed a Rayliegh distribution for all but torrential downpour.

Hooper (1950) confirmed these results; Austin (1951) obtained similar results but found greater deviation from Rayleigh laws for heavy rain. Marshall (1953) showed that instantaneous observations of backscatter from precipitation gives no information: a large number of independent returns must be averaged due to returned signal fluctuations caused by the large number of scattering centres with continually changing pos-itions. These positions were researched by Jones (1953) and Magono (1954) who found that colliding raindrops join and oscillate about a mean centre, thus providing non-spherical targets, and partly expla-ining the divergence from Rayleigh laws at heavy rainfall rates. Gunn (1954) described the SCSA for various rainfall rates, but adds nothing to the understanding of the Rayleigh divergence. Backscatter cross-sections per unit volume are given for both rain and snow at various frequencies and temperatures, and the average divergence for heavy rain is quoted as around 5dB.

Van de Hulst (1957) and Kerr (1965) deal in depth with rain attenu-ation but only touch on backscatter in the near-field region. Jones (1973, 1974) summarised this work and pointed out its applicability to X band, stating that heavy rain presents an almost perfect rough surface giving returned similar to that from true solid rough targets. He also notes that backscatter diminishes at lower frequencies (Skolnik,1970, also notes this: due to each drop being most reflective when its circumference is one wavelength). Smith (1974) challenged the assumption of the Rayleigh characteristics of rain, and defined an 'equivalent radar reflectivity factor'. This factor, however, is given a constant value of unity for most practical applications.

Chandler (1975) provides detailed graphs of backscatter from rain and precipitation, quoting figures from light to heavy rain. He also notes the lesser backscatter at lower frequencies (for heavy rain, as defined by Crane, 1969, 10GHz gives 15dB less return than 20GHz) and concluded that X band is an optimal compromise in frequency range for minimising precipitation backscatter.

On a more practical note, Johnston (1979) found experimentally that spray from a wet road surface introduced significant amounts of noise into the received signal, producing errors of several percent. He found that snow or slush on the road surface did not increase noise, but by increasing terrain backscatter, improved signal-to-noise. A covering of snow on the antenna, however, increased noise by a significant amount.

12.2.3 Backscatter from snow.

Langille (1951) reported that backscatter from falling snow followed the by now ubiquitous Rayleigh distribution closely; Marshall (1952) agrees, finding scattering from snow to be at least five times down from that obtained from the same 'rate of fall of water' as rain. Saxton (1958) reports similar results, listing hail as snow-like in return type. Sackinger (1973) examines the effect of snow and ice on terrain backscatter using a bistatic laboratory rig. He notes that for the two metre target range used, a correction factor of two must be incorporated into the mean tilt angle, and quotes frozen terrain as possessing an almost constant backscatter coefficient. Dyer (1977) explores the consequences of backscatter from snow, and concludes that a complex assessment of all appropriate factors must be made to assess backscatter: he particularily emphasises the need to categorise all variables in the case of automotive radar. Takehana (1981) finds that scatter from snow can be 'considerable', but notes difficulty in being quantitative, as size, density, direction and velocity are difficult to establish. Currie (1982) evaluates a snow-covered ground clutter model for wet and dry snow, finding a reflectivity increase of 10dB in the latter case. He finds backscatter to be constant, and independent of tilt angle, for very high transmission frequencies.

12.3 GROUND MODELS.

Clapp (1946), the first major researcher, questioned earlier assumptions that ground return obeyed the laws of optics (undergoing a variation in intensity corresponding to Lambert's law, ie the DSCS is proportional to @ squared), an assumption later finding use for mid values of tilt angle on very rough random surfaces. Clapp's model involved considering spheres with and without a corresponding ground plane. He reported that DSCS is proportional to between cos and cos @ squared, but failed to explain the increase in amplitude of backscatter at angles approaching the vertical. His models do not fit real surfaces as the assumptions made of parameter values and types were designed merely to assist development of the model. This point was highlighted by Ament (1956) who continued to show, in the first of a series of theoretical papers on surface clutter, that backscatter amplitude was a function of sin @ squared. Davies (1954) carried out a series of experiments and used statistical techniques to explain the dependence of backscatter on surface roughness; finding an agreement for midrange incidence angles. However, his theory sharply disagreed with findings for small angles. Carpenter (1956) and Hoffmann (1955) were amongst the first workers to consider backscatter from surfaces taking into account the frequency dependence of the scattered field on a non-uniformly conducting surface.

Moore (1957) combined Lambert's law and the Fresnel law to give an expression for the fraction of power specularily reflected from a rough surface. This fraction was shown to be dependent upon the standard deviation of the imperfection height of the surface: for X band the deviation must be less than 4mm. Twersky (1957) continues Clapp's work by proposing a ground model with superimposed spheres; an unrealistic model. Katzin (1957) showed that facets whose dimensions are of the order of the radar wavelength produce most backscatter, and that for independent distributions of size and slope, the backscatter is, for most angles, frequency independent. He proposes a scattering mechanism whereby the target receives direct and indirect signals from scatterers. The combination of contributions produces irregularities at certain angles and conditions due to destructive interference.

Peake (1957a, 1957b) and Rice (1951) approached the formulation of a model from a different viewpoint, and calculated the return from a 'slightly rough' surface by considering an almost plane surface with random irregularities for wavelengths smaller than that of the transmitted wave. In effect, then, their approach follows Rayleigh. Peake's model held up well when compared to experimental data (see section 12.2).

Berger (1957a) combined scatter theory with a statistical approach to show that the returned signal has an associated frequency spectrum characterised by a Gaussian distribution centred upon the mean Doppler frequency. He explained this phenomenon by describing the summation of returned signals from a large number of independent scatter centres illuminated by the transmitted beam. Although his work provides a useful basis for later research and is widely quoted, the effects of statistical properties of random rough surfaces was not considered.

The hitherto alternative approaches of scatter or facet models were combined by Katz and Spetner (1960a), who modfied the Clapp model by including recent developments in specular-point models, and thus took into account the effect of different wavelengths on the backscatter curves. Their model consisted of a background of near-isotropic scatterers with a number of superimposed small flat surfaces at various angles. They found that a decrease in transmitted frequency gives a reduction in the toal number of effective isotropic scatterers, as one wavelength can encompass integer number quantities of these specular points; and more importantly, for any selected wavelength, the radar return is the sum of two types of backscatter: large facets and small facets (acting as specular reflectors and isotropic scatterers respectively).

Schooley (1962) re-examined a theory several decades old and proposed a model based on geometric optics, whereby the ground surface is represented by a number of flat plane segments, and the returned amplitude is assumed to occur mainly for facets arranged normal to the plane of transmission. Thus by knowing the orientation of each facet, the fraction of reflected signal in any direction can be ascertained. Such a model, it would seem, only works for wavelengths comparable to that of light. So, whilst large facets give a return according to geometric optics (scatter resulting from a combination of specular returns from smooth areas and diffuse scattering from rough areas: see Keller, 1962), small facets may give return in directions other than that predicted. Further, small facets may effectively combine and be seen as one larger facet, or vice-versa. The theory does, however, give a 'feel' for the principles of ground return.

The mid-sixties saw a rapid development in a new model approach based on the Kirchoff-Huygens principle. Briefly, this states that the current flowing at each point on a rough surface is that which would flow on the same surface if it were flat and oriented tangentially to the rough surface: this allows the assumption that current over a rough plane is the same magnitude as that over a smooth plane but with a phase variation introduced by the differing distances of individual points from the plane surface. This approach, however, requires a defined autocorrelation function of the surface height. It is interesting that if a Gaussian function is used (Davies, 1954 for example), the result is the same as that given for geometric optics (Fung,1966). This highlights the failure in selection of the correct correlation function rather than strengthening the claim of either theory. Other, more realistic functions were proposed by numerous researchers: Beckmann (1965) approximated true surfaces by describing the total surface as the vector sum of random processes, each having different characteristics (see also Beckmann and Spizzichino, 1963, where simpler assumptions are made). Beckmann's work was challenged by Broderick and Hayre (1969) who described a 1-D rough surface model: a model improved by Sohel and Hayre (1972) who added the concept of spectrum asymmetry (see Simpson and Taylor,1972, for a discussion of this paper).

Kodis (1966) meanwhile, presented a surface scatter model based on specular reflection from points for which the SCS is proportional to the average number of such points and to their radii of curvature. The data now accepted as accurate was not made available until Barrick (1968) derived suitable results, allowing full evaluation of Kodis's work. Chadwick and Cooper (1972) utilised the SCS information in their distributed target model, which considers the radar footprint as a collection of independent scattering centres. They stated that a radar must resolve each scatter point in order to consider the target 'discrete'; and thus a typical footprint on typical terrain will see a distributed target with rigid (ie each scatter point remains in the same relative position to all others) components. They continued by proposing that a random-signal radar would be the optimum means of measuring scatter density; utilising noise for transmission, and a correlator for detection.

Valenzuela (1972) defined terrain backscatter as having a statistical variation capable of being described by a Gaussian probability distribution function.

Hamid and Stuchly (1975) used a multiple spherical scattering centre model to relate backscatter to material type, and found that for uniform particle size, the scatterer velocity with respect to the transmitted signal linearly relates to the returned amplitude. Uniform scatterer size is, however, a poor assumption: Funke (1978) found that complex targets can be modelled as a large number of interacting scatter centres (Chadwick and Cooper, and Hamid and Stuchly used 'independent' scatter assumptions); and a simple target modelled as a single centre. Bach Anderson (1979) furthered the 'interacting' scatter concept, stating that for a large target superimposed upon a discrete scatter model, large errors result. He points out that the effects of a large target superimposed upon point scatterers has not been modelled, and his treatise also assumes that the reflection is local only (ie no multiple interactions exist).

Much work has been performed on complex models: Storwick (1977) gives a useful bibliography of fifty papers covering many approaches: perhaps one worth relating is the oft-quoted Mitchell (1974) who considered a complex target consisting of scattering centres superimposed onto a series of extended targets. But this work does not lend itself to assisting with the aim of understanding terrain/radar interaction, and does not offer any explanation of typical experimental results.

Various researchers have incorporatd 'scale wave' models for obtaining experimental data. Edison (1961) used ultrasonic waves in water (an acoustic frequency of 0.4mHz corresponds to an EM TX of 85GHZ due to the differing propagation velocities). This simulation, though, is only valid for non-oblique angles of incidence and for plane surfaces. Parkins (1966) noted that acoustic waves obey the specular reflection theory: the peak of the return obeys the optical laws but the reflected beam is wider than that transmittted (scatter is reflected in directions other than the true specular direction). Henn (1982) reviews previously described models, and continues to propose a modified scatter model which requires coefficients best ascertained by a computer assessment of ground returns. Currie (1982) proposes a similar model based upon the previously noted dependence of return from given depression angles and surface roughness.

So far, only general models have been discussed. Much work exists on the relevance of the selection of model type for specific circumstances. Such work is of interest, but does not warrant an extended discussion: papers include: Gent (1963): examined rain and land clutter at X and K band; Nathanson (1967) who surveyed clutter parameters and illustratd the effect of considering different models on the interpretation of results; Ward (1971) who describes a model in terms of a fixed, uniformly distributed point series.

12.4 TERRAIN CATEGORISATION.

This section deals with macroscopic contour only. Copious literature exists on this topic: Beckett (1969) reviews much pertinent literature, but the majority of researchers relied upon a macro-view of terrain for purposes of geological surveys. Much work has been performed on the analysis and synthesis of ground areas by the examination of terrain features, and its categorisation into recurrent patterns of sub-features. Such a technique is proposed by Beckett (1975) who defines the basic feature unit as the 'facet' (being the smallest reasonably homogeneous area of categorisation). This technique is not easily applicable to off-highway terrain due to the limitations on the size and quantity of facets. The AMC programme (Rula,1971) identified the need for a system of classification to assist in design and operation of off-highway combat vehicles. Of interest to this review is the 'terrain database' section of the report, which describes the technique of terrain categorisation into 'patches', each with a reference number where the number corresponds to a quantity of predefined terrain features. A computer is required to deal with the mass of information. Heal (1964), Wenderborn (1966) and Bogdanoff (1966) attacked to problem of classifying off-highway profiles by using a technique based upon spectral density (mean square amplitude per unit bandwidth). Thus for a given 'wavelength' the overall roughness of the terrain is characterised by the mean-square amplitude. Van Deusen (1967) proposed a means of off-highway terrain evaluation and analysis specifically intended to gather data into a form suitable for computer processing.

Rula (1973) expanded the 'patch' concept, dividing each patch into factors. However, useful as such techniques are, they cannot be used when 'defined' features change with weather or physical alterations: the use of terrain by vehicles may also alter its defining characteristics.

12.5 RADAR PARAMETERS.

Berger (1957a) describes the effect of roll and pitch on the measurement of velocity by Doppler-based radar, and proposed several methods of reducing their influence: most are suitable only for airborne applications, although the source of such errors are relevant to more 'down to earth' applications. He derives an expression for the percentage error in measured velocity per degree of tilt for both single and dual beam systems and describes the returned Doppler spectrum in detail. Comparisons of 'microscopic' scatter returns and 'macroscopic' footprint area returns are made: Berger stresses that both give rise to a spread spectrum, this itself being superimposed upon a background of broadband noise. Fried (1957) also describes the returned Doppler signal as "possessing a noise-like spectrum due to the finite beamwidth", and states that changes in tilt angle produce an error in measured velocity due to both the mean tilt angle variation and the commensurate change in ground backscatter characteristics.

Berger (1957B) delves further into the characteristics of the returned spectrum, stressing the need for narrow beamwidths to reduce the power density width (he does not consider scanning noise, which imposes a limit of the smallness of this width). He states that overland the spectrum is symmetric, as the scattering coefficient of land is constant for all tilt angles within the nominal beamwidth (surely false for non-pencil beamwidths?). Bushnell (1958) also describes, although does not name, fluctuation noise, stating that the velocity data provided by a Doppler system is subject to a random error proportional to the beam geometry.

Some work has been performed on the consequences of vibration in farm tractors: Matthews (1964) identifies some typical sources of vibration and angular oscillations, and provides data on acceleration amplitudes for a range of ground types and speeds. The ground category nearest to the requirements of this project topic are a rough cinder track and a deep-furrowed field crossed perpendicularily, at eight and three mph respectively. Young (1975) continues this work; his research, however, tends to be biased towards the lower roll and pitch frequencies; and are thus of interest for purposes of comparison only.

Ehrman (1965) states that one of the most significant sources of error in Doppler radar is the random nature of the signl reflected by terrain, and describes the means by which a discrete transmitted frequency is returned as a spectrum; naming the prime causes as the orientation of the antenna with respect to the ground, the backscatter characteristics of the ground and the antenna beamwidth. In the ubiquitous text on the Doppler effect, Gill (1965) derives expressions for a finite-width beam directed towards terrain, and notes two resultant effects: the spread in frequency of the reflected beam and the change in nominal frequency of return. The latter effect, he explains, is a systematic error, negligible for small beamwidths at medium values of tilt angle (his example states a 6 degree beam inclined at 30 degrees).

So far, all papers have pointed to errors in measured velocity due to beam and vehicle geometry. The consequences of imperfections in the processing circuitry has been examined: Kalmus (1967) notes that any amplitude modulation in the transmitter or generated by fluctuating target return, will cause signals that can simulate true Dopper return. Broderick (1969, 1973) also refers to this modulation, caused by rough terrain within the beam footprint, and ascribes the term 'scann ing noise' (also coined by Fried, 1969). Pawula (1968) describes the problem of correctly ascertaining the centre frequency of a continuously varying power spectrum; a problem also noted by Milner (1968) who claims, interestingly, that although vehicular-mounted Doppler radar is prone to much clutter (unwanted signal, frequency and amplitude deviation etc), a trained human observer can readily distinguish the nominal Doppler frequency.

Further performance limitations deriving from electronic processing were considered by Walsh (1972), who describes six factors which must be considered when designing vehicular radar systems: cost sensitivity and servicing difficulty, wide voltage fluctuations, temperature variations, and longevity. The effect of both electrical circuit noise and unwanted signal due to clutter on Doppler velocity measuring systems is considered by Bryant (1973) who stresses that all controllable noise sources must be minimised for optimum operation.

Jones (1973) describes the consequences of a slight change in tilt angle as strongly affecting the radar return; an increase in angle producing both the expected decrease in nominal Doppler frequency, and increasing the received spectrum and hence the percentage error. He also points out that smaller radar-to-terrain distances produce less fluctuation noise and greater scanning noise (the writer disagrees with the former point: surely the tilt angle, which is proportional to the quantity of fluctuation noise, is constant for any radar-terrain spacing?). He continues to describe the inherent limitation of zero-crossing detectors when dealing with phase-nulls in the received signal. Scanning noise and fluctuation noise are also noted by Hyltin (1973) who illustrates the development of a vehicular speedometer, and indicates the Doppler spread expected; scan and fluctuation errors (the latter said to be eight times the induced error of the former for a typical system), and the effect of signal averaging. Amongst the conclusions given are that the correlation time is inversely proportional to the beamwidth and velocity of the platform. The effect of terrain bias shift is discussed for smooth and rough terrain; the shift favouring lower frequencies on smooth surfaces. It is worth summarising the problems noted by Hyltin: those related to the writer's project include: the reflecting properties of the terrain, vehicular motion-induced modulation of the returned signal, bias effects (non-constant terrain-radar range within the footprint), variation of tilt angle and scattering coefficient within the nominal beamwidth, changes of surface scattering characteristics, selection of transmission frequency and the required compromises.

Grimes (1974) describes several factors affecting the accuracy of Doppler radar systems in vehicular applications. Vehicular tilt, he notes, results in altered values of measured velocity; this error becoming a second-order cause if two such sensors are used in an opposed view configuration (ie Janus). He gives expressions for the fluctuation noise of a beam given tilt angle, velocity and beamwidth; and for scanning noise, given the above factors and the platform height. Scanning noise is described as resulting from 'statistical target variations as the beam moves over a rough surface'. The practical problems encountered are also referred-to: he notes that the radar makes, in practice, a good vibration detector when mounted on a vibrating platform (such as a vehicle). The problems of vibration are also covered by Augustine (1975) who states that it is possible for a vehicle to have sufficient vertical oscillation due to engine vibration to produce an erroneous Doppler frequency due to the varying radar-to-target distance producing a phase shift interpreted as true target movement. His solution to this problem is discussed in the 'automotive radar' section. The errors arising from vehicular tilt, or from apparent change in tilt angle due to specular reflection are dealt-with by Kiyoto (1976) who claims that these errors may be neglected in practice. He does not dismiss the consequences of finite beamwidth, but illustrates how this parameter produces, for a complex target (eg a road surface) a signal resembling narrowband noise rather than a discrete frequency.

Saw (1976) describes how noise and ripple on the unit power supply cause frequency and amplitude modulation of the oscillator output, which in turn modulates the received signal; he also stresses how amplifier noise must be kept to a minimum as must the unit vibration, which is seen as a corresponding frequency at the unit's output.

The late seventies saw great activity in the area of vehicular radar, and research into ground effects: one prime cause being the widespread use of velocity-measuring systems by police in the USA (over seven thousand in use: Mennie, 1978) which were found to have severe limitations. Thus the National Bureau of Standards commenced an extended study of vehicular Doppler radar (Fisher,1980); the publicity of which launched many researchers into this area of study.

Stuchly (1977) found problems similar to those found in vehicular applications when utilising Doppler radar in the field of particulate velocity measurement (beamwidth effects, phase nulls etc) and he stresses that the appropriate selection of means of frequency counting is crucial. He recommends a zero-crossing detector with variable integration time. This selected method was examined by Krage (1977) who describes the result of noise on such a detector, showing how it produces an over-reading of frequency. He does not continue to consider sources of under-reading such as phase-nulls, signal dropout etc. Millard (1977) describes a method of dealing with Doppler signals which, he says, "can be accompanied by very substantial noise".

The sources of error in velocity measurement are discussed by Weiss (1977) who describes how radar platform movement must be quantified to allow optimal filtering of unwanted signals. Angwin (1977) explains how any nominal tilt angle acts as instantaneous varying angles, producing commensurate errors. He also notes that loss of signal due to phase nulls and spurious noise both cause further error. Whetton (1977) also identifies these sources of inaccuracy, and notes that signals undergo substantial amplitude modulation caused by rough reflective terrain and the vertical motion of the vehicle. Neininger (1977) notes that dirt covering the radar horn reduces performance and that the unit should be mounted as near to terrain as possible.

Chandler (1977) reviews the selection of transmission frequency, and states that 35GHz is optimum for automotive use. It is interesting that Hyltin (1973) selected 60GHz and Stuchly (1978) recommended 10GHz for the same application. Stuchly also describes the use of Doppler radar for the measurement of velocity of agricultural tractors: he derives expressions for scanning and fluctuation noise (due, respectively, to statistical variations of the terrain surface producing a 'homing-in' effect onto any large surface features, and beam divergence producing a range of tilt angles). He deals with both the theoretical limitations of such a system, and the practical problems; comparing means of compromise. The requirements for a balanced system are presented as contradictory. For example, narrow beamwidth allows decreased fluctuation noise, but increases scanning noise and requires a large horn; small viewing angles minimise reading error, but signal amplitude decreases. Higher fequencies favour returned signal amplitude but increase spectral spread. An expression for the instantaneous Doppler frequency is derived, taking into account vehicular tilt, pitch, vibration and displacement of the centre of gravity.

Baba (1978) claims that for vehicular velocity measuring applications, changes in tilt angle can be ignored (!). His comments refer to angle alterations met in vehicular suspension bounce for normal roads (for which, the writer presumes, the errors produced are not the limiting factor in accuracy).

Johnson (1979) exposes further probable causes of error in Doppler velocity measurement: mud and water on the antenna case. He also names vibration, beamwidth, phase nulls etc, and concludes that a small tilt angle produces a higher Doppler frequency which is "easier to process" and minimises Doppler components due to vertical vehicle motion and pitch, reduces spectrum width and backscatter. Greneker (1980) discusses similar factors, and specifically notes poor frequency filtering in the processing circuitry which allows interference frequencies derived from radar platform movement and vibration to confuse the derived nominal signal. He continues by highlighting the dangers of using an automatic gain control (AGC) to condition the signal input, as a momentary lack of wanted signal will allow undesirable (and normally of small comparative amplitude) signals to be amplified. He also names CB radio and UHF/VHF local transmsitters as potential causes of inteference. Aker (1980) notes that fading effects are produced by multipath cancellations of the microwave signal off road surfaces; and Fritzlen (1980) refers to the spectrum produced by a finite beamwidth looking at the ground (specifically a railway trackside). This beamwidth, Skolnik notes, would ideally produce a delta-function frequency spectrum; and a reduction in sensitivity to tilt angle can be obtained by using multi-beam systems.

Holford (1980) and Hosking (1977) both describe the effect of power supply ripple and circuit noise on the received Doppler signal, and advocate minimising both causes in order to increase signal-to-noise.

Gautschi (1981) considers the returned signal as interspersed with signal dropouts and phase nulls due to terrain roughness, having a finite spectrum, often skewed due to vehicle tilt and beamwidth interacting with backscatter characteristics. He relates how even a complex multi-microprocessor data interpretation system fails for certain terrain types. Levanon (1981) describes a technique for deriving the velocity of a target from Doppler return for an unknown (or constantly changing) tilt angle. The effect of variations in this angle was also examined by Richardson (1982) who highlights the improvement in error obtained by utilisation of dual transmitters. He also criticises previous research in the field of vehicular movement for assuming the vehicle centre of gravity, the radar, and the rotational centre occur at the same place. An expression for the instantaneous Doppler frequency considering a 'true' geometric layout is derived, and experiments utilising Doppler radar for agricultural use (tractor-based) were performed. Pertinent conclusions are that a narrow beamwidth is preferable in order to narrow the Gaussian distribution of the return, and that a zero-crossing detector can introduce significant bias shift in the measured velocity of up to ten pecent. Of additional interest is the use of a microprocessor to perform a statistical derivation of true groundspeed.

Berry (1982) and Mawhinney (1982) both describe causes of error in velocity measurement and interpretations, naming beamwidth, intrinsic noise and phase nulls. Egawa (1982) discusses spectral spread due to beam divergence, mixer and amplifier noise, and considers the statistical characteristics of the returned signal and scanning noise. The paper, in fact, presents a statistical technique of data interpretation to derive a true velocity.

Statistical methods are also advocated by Tsuha (1982), who outlines a groundspeed measuring system using a microprocessor, and recommends the sensor be mounted at the vehicle dynamic centre in order to minimise yaw, roll, pitch and vertical movement effects. The sensor should also be mounted at a specific angle, to reduce scanning and fluctuation noise. He describes the use of shock-absorber mounting to minimise shock and vibration interference. It was this system tested by the writer, and found to under-read velocities by up to a factor of five.

Mayhan (1982) describes six radar types, from basic CW to pulse, for automotive use, and highlights the relative advantages of each.

12.6 FREQUENCY STABILITY

The effect of both long and short-term frequency stability of Doppler radar will now be briefly reviewed.

Brady (1959) investigated the effect of short-term fluctuations and found them to be significant: this source of error is commonly produced in the USA courts as defence evidence (Carosell,1964). However, courts now accept, in general, that a 'typical' Gunn diode transceiver is accurate enough for police radar speedometer evidence, which implies an accuracy consistency of around one percent (Greneker,1980; refs 1 to 9), although no reference can be found to the stability of frequency with temperature, humidity etc. The influence of such factors is further investigated in the 'off-highway environment' report (Wallace,P24).

Few papers deal specifically with CW Doppler systems: Kelley (1961) for instance, in an oft-quoted paper, derives velocity error equations for pulsed radar, and deals mainly with signal-noise effects. Craig et al (1962) examines such CW system errors in a superficial manner, and Mayer (1964) and Feurstein (1964) discuss many causes of velocity error but not transmission frequency deviations. Cowley (1971) and Fisher (1980) both deal with the result of AM noise, and state this as the

limiting factor in short-term transmitter frequency stability and of receiver sensitivity. Acker (1975) also finds AM noise a source of transmission fluctuation, as is, to a lesser extent, FM noise.
Bushnell (1958) deals with longer-term stability, and derives a proportionality between received frequency variance and system noise spectral density. However, this paper extends the topic deep into theory. Ishii (1965) states that the fractional change in transmission frequency is directly proportional to the velocity measurement error, although this relation is empirically obvious, it is important.

12.7 VEHICULAR RADAR LITERATURE REVIEW

The earliest work of specific interest is by Boyer (1963), who outlines a technique of range and velocity measurement by diplex configuration; the technology is outdated (klystron) and no application data is given. Nilssen (1962) also discusses range and velocity measurement, but the first work pertaining specifically to the measurement of velocity is that by Milner (1968) who, although using a klystron, acknowledges the problems of ground clutter and gives a detailed technical description.
Fathauer (1969) outlines a technique of speed measurement and display, although the unit described is static. He provides circuit details and describes the use of an 'enable' timer and counter. A very complex technique can be found in Berry (1972) who uses well over one hundred integrated circuits to achieve a similar aim to Fathauer, claiming, rather rashly, that the system is immune to noise and missed pulses. Barker (1970) reviews Doppler radar detection in a general manner, giving circuit details.
The first work utilising a solid-state oscillator traced is that by Gupta (1972) in a Diplex configuration to detect range and relative velocity. Similar systems are reported by Stevens (1972) and Ives (19 73). Ives also reviews work performed at Lucas on collision avoidance radar. Harokopus (1971) outlines a technique of vehicle speed control by radar and suitable processing. A diplex technique with automatic frequency switching is advocated by Watanabe (1974): he claims a significant increase in accuracy. This technique was improved by Nissan Co (1975) who sweep the transmission frequency over a wide range (no generic term for this radar type seems in general use: it is effectively an ultra-slow FMCW system).
Lewis et al (1972) propose a system consisting of five radar units per vehicle: one per wheel and one to measure groundspeed. This unit is intended to detect, and compensate for, wheel slip. Augustine (1972) suggests two units in Janus configuration, claiming vehicle velocity

measurement accurate to one percent. No data is given to support this claim. He later (1974) improved this design by using a horn with dielectric lens. Circuit details for this are given in Augustine (19 75) where a general discussion on the advantages of a Janus configuration can be found, notably reduction of vehicular vibration and of platform tilt effects.

Many researchers describe radar ranging techniques for vehicle collision prevention that utilise the existing vehicle speedometer for velocity information. Flannery (1973), for example, utilises a complex microwave system linked to a conventional speedometer cable. Ives (1972), Neininger (19..), Heiden (1977) and Weinstein (1977) outline similar systems. Weinstein, however, also includes a useful general discussion of radar anticollision techniques. Hopkins (1972) reports an X band crash sensor but derives vehicle velocity from the same unit; as does Stevens (1974) who uses a diplex technique. Stevens states that the effects of beamwidth, horn design and backscatter etc are still being studied, as his unit "works in the laboratory but not very well in-situ".

Hyltin (1973) describes the development of a radar speedometer, and discusses the choice of system components, selecting a 60GHz impatt oscillator. A comprehensive review of radar in automotive applications can be found in Grimes and Jones (1974): speed sensing, predictive crash sensing and obstacle detection are covered, as are modulation techniques and system configurations. Johnston (1973) uses a bistatic system to measure vehicle velocity and claims a one-percent accuracy. Wood (1973) describes a diplex velocity and ranging system, and is the only researcher traced who stresses the importance of system cost and the compromises necessary. He also details, in a mathematical manner, the consequences of rainfall on such a system.

Shefer (1972) and Kaplan (1976) describe an X band vehicle location system; Tole (1974) and Kunz (1973) chart the development of a static vehicle speed monitor. Both utilised a large parabolic dish for an antenna. Kunz claims his equipment to be "foolproof"! Shefer (1974) outlines range and velocity radar for collision avoidance that uses teo radar (FMCW and CW respectively). This paper also provides a useful discussion of radar and antenna parameters such as beamwidth, gain, harmonics, and noise. He claims an accuracy of one percent on dry roads, but admits that the unit is a prototype and not suitable for highway use due, in part, to the printed circuit antenna used.

So far, all Doppler units have been CW or FMCW. Ross (1974), Tamama (1978) and Dull (1978) describe the use of pulse radar for ranging.

Ross examines the problems of interference and discusses techniques of combatting them; advocating a CFAR technique. Such work deviates from this review brief, although the CFAR methodology is briefly noted in report INT P7.

Chandler (1975) outlines research by the National Highway Traffic Safety Admin, highlighting work into system philosophies, and provides a technical feasibility study. The work does not cover the measurement of vehicle speed by radar: this task is left to the speedometer. In a later paper (1977), Chandler reviews sensors for automotive braking systems, and provides a brief analysis of ground geometry effects and environmental factors; as does Jones (1975) who utilises FMCW radar and a computer to derive the necssary data. Codd (1977) also reviews the use of radar in automotive applications, stating that as range information is required for collision prevention, an FMCW system is preferable, from which vehicle velocity can also be derived. Storwick (1977) outlines the problems associated with interpreting radar return in vehicular applications, but deals mainly with the identification of known targets.

A basic velocity measuring system is described by Fathauer (1975) who suggests a typical application as a farm tractor wheel slip detector. He gives full circuit details. Kiyoto (1976) and Thansandote (1976) outline a technique for measuring vehicle speed for the puropose of antiskid control: the latter researcher briefly reviews backscatter, tilt and vibration; and describes a prototype system. A patent held by Angwin (1977) details a speedometer and milometer based on a duty-cycle detector claimed to reject noise (which has no defined duty-cycle) and to compensate for changing platform angle. Krage (1977), Pacozzi (1979) and Johnson (1976), the latter of whom provides an interesting description of the radar environment, incorporate frequency tracking: Krage uses a zero-crossing detector, Pacozzi uses a 'discriminator' circuit and a means to hold the previous valid signal during signal loss. Millard (1977) also utilises tracking in conjunction with an AFC and AGC, and a crystal oscillator. A very complex technique of measuring target vehicle speed independent of platform speed is related by Aker et al (1977) which also uses a storage and update technique claimed to ensure consistency of measurement.

Whetton and Goodall (1977) point out possible consequences of returned signal amplitude modulation and describe a feedback filter system to combat this. A far more complex solution is proposed by Fishbein et al (1980) which advocates the correlation of two returned signals in order to accurately assess range: the radar are of the diplex type. A diplex system is also outlined by Monds et al (1980) to assess the direction of traffic. Direction sense is incorporated into a patent by Endo (1978) who claims a microwave unit for velocity measurement that incorporates two mixers a quarter wave distant. Funke (1978) uses a swept frequency radar for automotive target discrimination based on the principle of return frequency correlating with the number and position of scatter centres. A Doppler transceiver operating at 24GHz is used by Baba et al (1978) to measure vehicle speed for antiskid purposes: a ten percent accuracy of measurement is claimed.

Troll et al (1977) describe work on experiments concerning radar anticollision systems, and assess three antenna beamwidths and three radar types. Their preferred system, however, derives groundspeed data from the vehicle speedometer. Practical problems are noted, such as heavy rainfall, and Troll acknowledges that more research is required in this area. Velocity information from the speedometer is also advocated by Belhoubek et al (1977) who suggest a microprocessor controlled FM range radar. Such a radar is also proposed by Ross (1978) and Dull (1978). The researchers report no problems with EMC, shock and vibration etc, and vehicle speed once again is speedometer derived. This technique is even used by Flannery et al (1979) who describe a pulse-mode microprocessor-controlled configuration. The most complex system traced is that by Gautschi (1981) who discusses the design philosophy and practical realisation of a velocity measurement unit: he utilises a bit-slice processor to evaluate the returned signal. A microprocessor is also used by Acker (1980) in a frequency tracking system for velocity measurement which, he claims, tolerates significant clutter noise by means of transmitting in short bursts. He gives full circuit details, algorithms and even software listings.

Fisher (1980) reviews the techniques by which the police measure vehicle speed by radar, and highlights possible sources of error: a theme developed by Mennie (1978) who lists numerous ways of utilising basic Doppler transceivers as radar trap detectors, both active and passive. Takehana (1981) utilises speedometer information in conjunction with a complex microwave unit to prevent automotive collisions, and notes certain aspects of the environment: weather types, road surfaces etc. A radar-based velocity measurement technique is advocated by Johnston (1979) who discusses the application of a Doppler transceiver to provide a reference speed for an antilock braking unit: a basic configuration is used. Such a basic system is also proposed by Fukumori (1979) in which an unconventional system of detecting overspeed by the det-

ection of noise superimposed on the received signal is described.
A more complex topology is utilised by Fritzlen (1980), in the only paper to quote real spectra, in which a system utilising a multi-track filter is outlined. The technique requires an 'intelligent' frequency band selector and AGC, and Fukumori claims the unit tracks the required spectral component of the radar return, and hence provides accurate velocity information. A conceptual discussion of automotive range and speed measurement is given by Tomiyasu (1981) in which a bistatic configuration is advocated.
Various velocity measurement processing techniques appear in the USA patents: Stauers (1980) advocates velocity measurement by counting pulses in a preset time period, and calculating the rate of change of Doppler frequency as a check. Hiroto (1982) claims a multiple frequency transmission system which prevents interference of the measured velocity information; whilst Mawhinney (1982) outlines a narrowband tunable filter topology, driven by a sweep generator, peak detector and voltage controlled oscillator. Berry (1982) also uses a locking filter, but adds a signal to modulate the received signal; filters, and then demodulates: he claims this technique reduces the effect of noise and phase nulls. Brown et al (1982) uses a harmonic detector to assess target vehicle velocity, but advocates the use of a speedometer for a reference.
Richardson (1982) describes a series of experiments and development work to design an agricultural tractor wheelslip meter, incorporating a groundspeed measurement unit. The attainable accuracy of single and dual beam systems is compared in theory and practice, and crude spectra are quoted. The researchers state that a dual beam system is less prone to problems of pitch, yaw, roll etc. Tsuha (1982) also discusses agricultural velocity measurement, recommending a microprocessor to allow selection of data integration time and to control the digital display. He identifies the main problems associated with magnetic transducer velocity measurement as driving wheel slip, hop, difficult installation and calibration; and notes potential uses of the system in areas of mining, off-highway equipment etc, although admits that several aspects of the advocated system would require modification for such use. The problems of the environment (eg salt spray, vibration etc) are briefly noted, and an accuracy of around five percent is claimed over a variety of terrain types.
Egawa (1982) outlines the use of a radar velocity meter for construction machinery applications, and constructs a statistical model to justify the 'diversity' techniques employed. Whilst he identifies

common design constraints such as antenna size and beamwidth, he does not discuss environmental problems; stating that little appropriate literature exists.

The advantages of radar speed measurement are discussed by Cox (1982) who states that in agricultural applications ".. motion is sometimes more upward or downward than forward". His book, in fact, introduces modern agricultural techniques, and highlights the general acceptance of such technology. Agricultural and commercial applications are also suggested by Kopp (1983) who describe the development of a radar speed sensor: this work parallels that by Tsuha (1982) described above.

12.8 TRUCK ELECTRONICS.

Taylor (1963) proposed the utilisation of the Doppler effect to measure the velocity of earthmoving equipment. Having first identified pitch, yaw, roll and wheelslip as difficulties in measuring speed by conventional means, he advocates an ultrasonic Doppler system. Stuchly (1976) outlines a radar-based slip monitor for agricultural use, and claims a three percent measurement accuracy. He describes the development of a laboratory prototype, and although tilt and vibration are considered in geometric terms, practical applications are not dealt-with. Stuchly (1978) also describes a velocity measurement system, and followed an experimental procedure involving a 'fifth wheel'. Gruben and Heino (1980) describe an electronic system mounted on a scraper to control all transmission and scrape functions using a microprocessor, which also provides an on-board facility. The system allows manual or automatic control of transmission shift sequence. Although notable advantages are claimed, no mention is made of the intrinsic problems in utilising electronics on large off-highway vehicles, or of means of overcoming them. Kays (1980) describes a similar system.

The application of microprocessors to trucks in the mining industry is reviewed by Dickson (1980) who, amongst many suggestions, advocates remote control of such trucks. Such a system is also the subject of a patent held by Steel (1981b) who also describes an electronic system designed to prevent truck over-revving by engaging the retarder system. Masai (1981) covers microelectronics in off-highway environments to control the retarder sequence: a technique of setting a constant cruise speed is described. He acknowledges difficulty in obtaining proprietary sensors and activators, and of achieving noise immunity: the latter problem was reduced by using distributed processors and a complex error correction algorithm. Remote control of truck functions is also advocated by VanSchoiack (1982) who describes a radio link to control the truck's electrohydraulic valves.

Jones et al (1982) and Ullrich (1982) both outline possible and typical applications of electronics to agricultural and construction vehicles. The total production of such vehicles worldwide is given as approaching a quarter million annually, and Ullrich considers the advantages of fitting all such vehicles with modern equipment as standard. He notes a product manufactured by RDS which uses a radar for groundspeed measurement of agricultural tractors designed to ensure even crop spraying. Kruse (1982) also suggests the use of a speed sensor for agricultural use, but advocates the incorporation of a magnetic transducer and a microprocessor.

Several electronic systems for off-highway trucks are available: Weber (1982) reviews a simple system that monitors hydraulic functions; one of the few available designed to operate over a wide range of temperatures and under high shock environments. Johanningmeir (1982) similarily outlines a transmission controller for such trucks which includes a diagnosis package. Weiss et al (1982) discuss a speed sensing and speed limiting unit for commercial vehicles using electronic means.

12.9 NON-AUTOMOTIVE VELOCITY MEASUREMENT.

Berger (1957a, 1957b), in the most quoted papers in the field of Doppler radar, describes airborne velocity measuring systems. The advantages of single, dual and multiple beams are compared, and he provides a clear insight into the problems of spectrum effects, noise and frequency fluctuations, pitch and roll. In the same year, Fried (1957) describes velocity measurements by radar for airborne applications; considering Janus and monostatic configurations. Apart from Kelly (1961) who reviews the theoretical use of Doppler units for measurement of range and velocity, the next work of interest is that by Darboven (1973) who outlines techniques of airborne speed assessment using a frequency tracker and AGC.

Turning to non-airborne applications, Cowley (1971) quotes several low-cost Doppler module applications, including vehicular velocity measurment, and discusses in general terms the problems and advantages of such modules; as does Merriman (1974). Appleyard (1971) describes a unit designed to assist the berthing of ships, although the unit is of large and static design.

Brown (1973) illustrates how the velocity of "almost anything" can be measured by Doppler systems, giving the example of a gun muzzle mounted system. Balsiger (1973) outlines a technique of measuring the velocity of an object such that a camera shutter can be operated automatically; whilst Saw (1976), Klein (1974), Solfan (1979), Holford

(1977, 1980) and Charters (1973) all describe Doppler radar intruder alarm systems: many such units are reported in the literature but the quoted authors are a representative sample of relevant work in the general field of data processing in low-cost Doppler systems. Burglar alarms are also covered by Bryant (1973) who reviews the detection of signals in noise, pointing out that both internal and external noise sources must be minimised. Interestingly, he states that low quality microwave horns are prone to microphony.

Stuchly et al (1976) describe the use of a low-cost Doppler unit for the measurement of particulate flow rate and density (proportional to the Doppler shift and the ampliture respectively). He states that the problems encountered are very similar to those found in navigation and automotive applications. Clifford (1975) presents a technique for measuring ship velocity by the utilisation of the Janus configuration looking at the sea bed; he, importantly, acknowledges that phase locked loops are detrimental when the required signal is present for only a small percentage of the time. Holford 81974) describes a general system for Doppler velocity measurement, and gives suitable processing circuitry. A more complex technique is proposed by Berger (1975) who states that his system topology is almost independent, in terms of accuracy, of tilt angle. The intended application is avionic; as with work by Bates (1976) who reviews the development of a velocity sensor using tracking filters, mentioning antishock and vibration measures. And finally, Bhartia 81977) describes how rotating shaft velocity can be determined by a simple Doppler radar, giving an appropriate block-diagram.

This review would not be complete without a brief overview of simulators. Milner (1978) cunningly utilises a bicycle wheel with blades attached to the spokes to simulate a moving target of defined speed, in order to assess vehicular velocity measuring systems. Baba (1978) uses a far more complex technique: a hybrid simulator, using analogue and digital techniques. Little detail is given. Tsuha (1982) describes a rolling road simulator that allows velocity accuracy of 0.01mph over a speed range of 1 to 40mph. The road controller and radar output are fed to a computer. The test schedules undertaken are not discussed, or any results derived.

Hyltin (1973) outlines the use of a rotating roller covered in sandpaper as a road simulator: a wave analyser is used to interpret the incoming spectra, and a frequency counter used to simulate the processing electronics. The grain of sandpaper can be changed to simulate the terrain microsurface; fine grain giving poor backscatter and considerable reading error. Variations in the tilt angle were assessed, as were different roller speeds. It should be noted that a similar test schedule was undertaken by Giles and Saw (1972) to measure the rotational velocity of shafts.

VOLUME TWO: SECTION ONE:

DATA RECORDINGS

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SECTION

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ABBREVIATIONS:
RA: Returned amplitude
RS: Returned spectrum
AV: Antivibration mounts
PLL: Phase locked loop
Proto: Prototype

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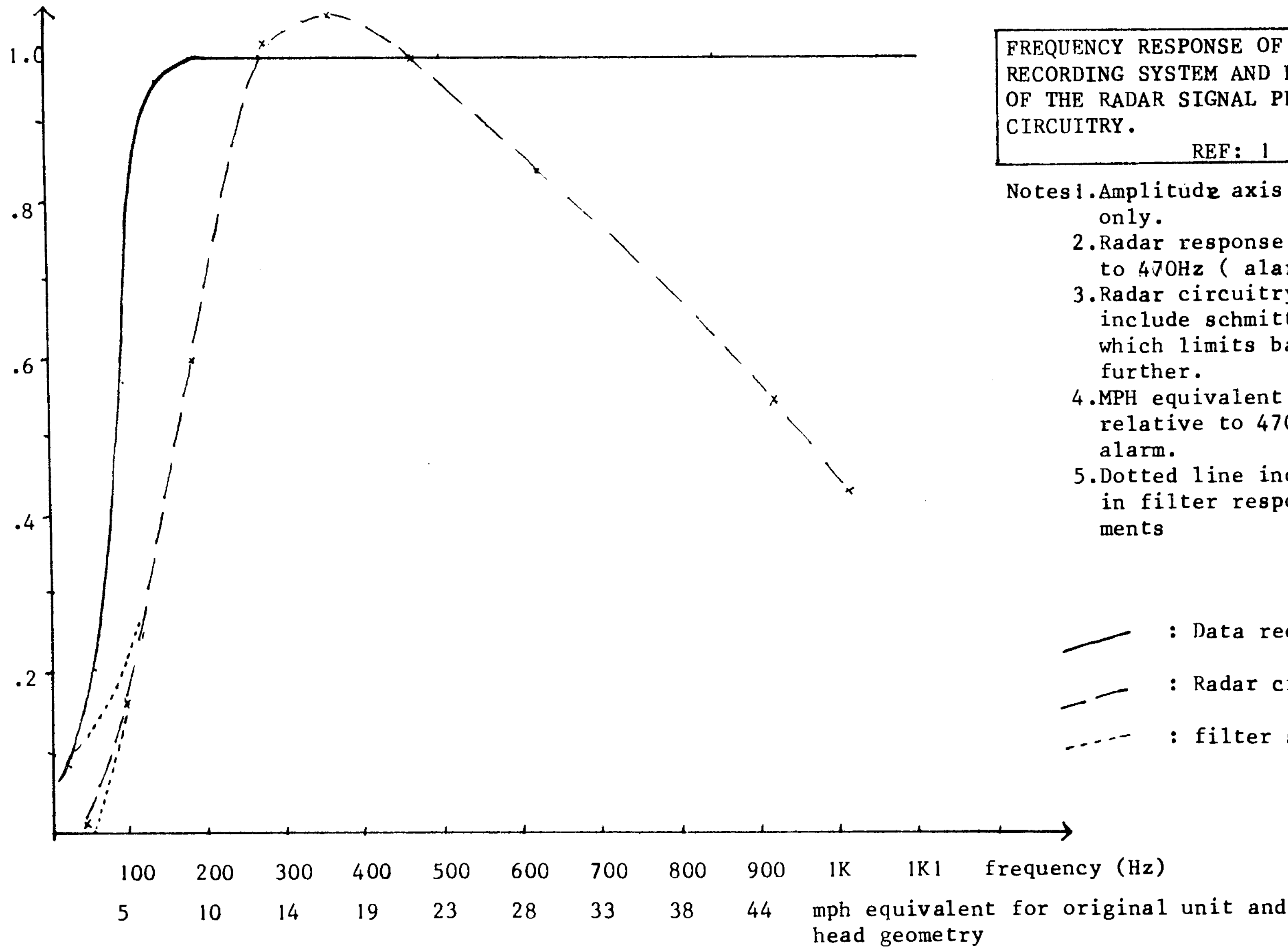
FREQUENCY RESPONSE OF THE DATA RECORDING SYSTEM AND BANDWIDTH OF THE RADAR SIGNAL PROCESSING CIRCUITRY.

REF: 1



Notes 1. Amplitude axis is relative only.

2. Radar response is relative to 470Hz (alarm speed).

3. Radar circuitry does not include schmitt or PLL, which limits bandwidth further.

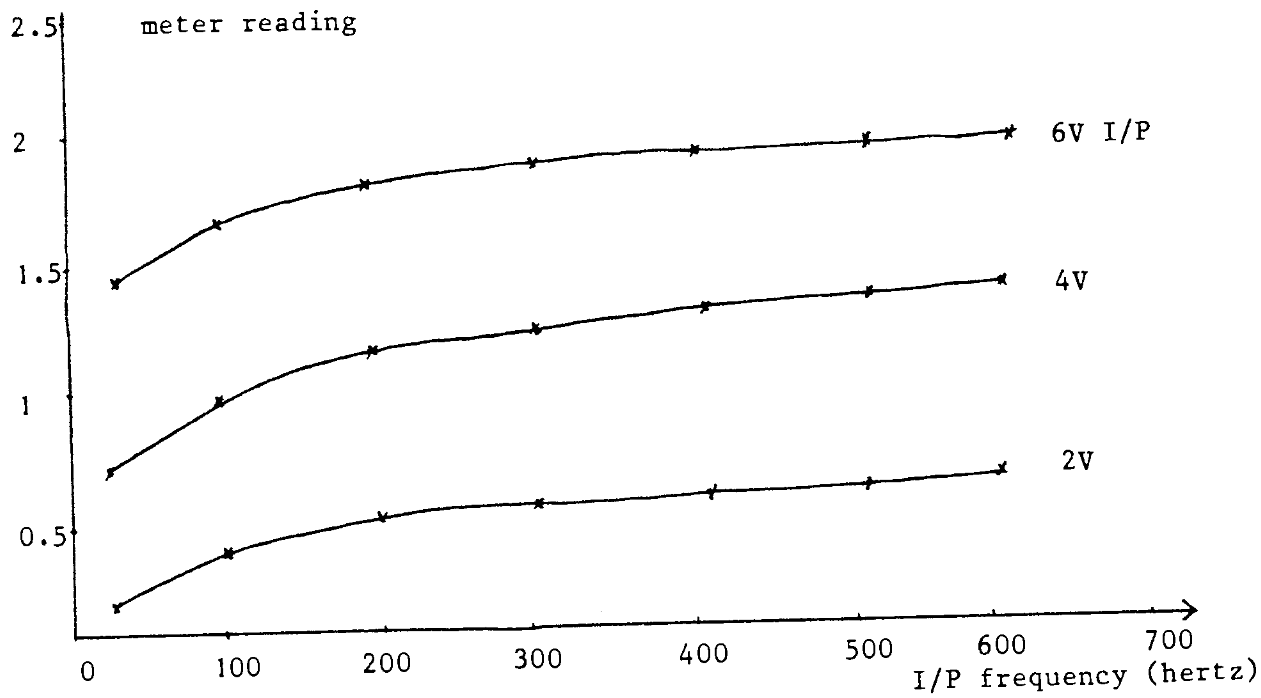
4. MPH equivalent axis is relative to 470Hz = 22mph alarm.

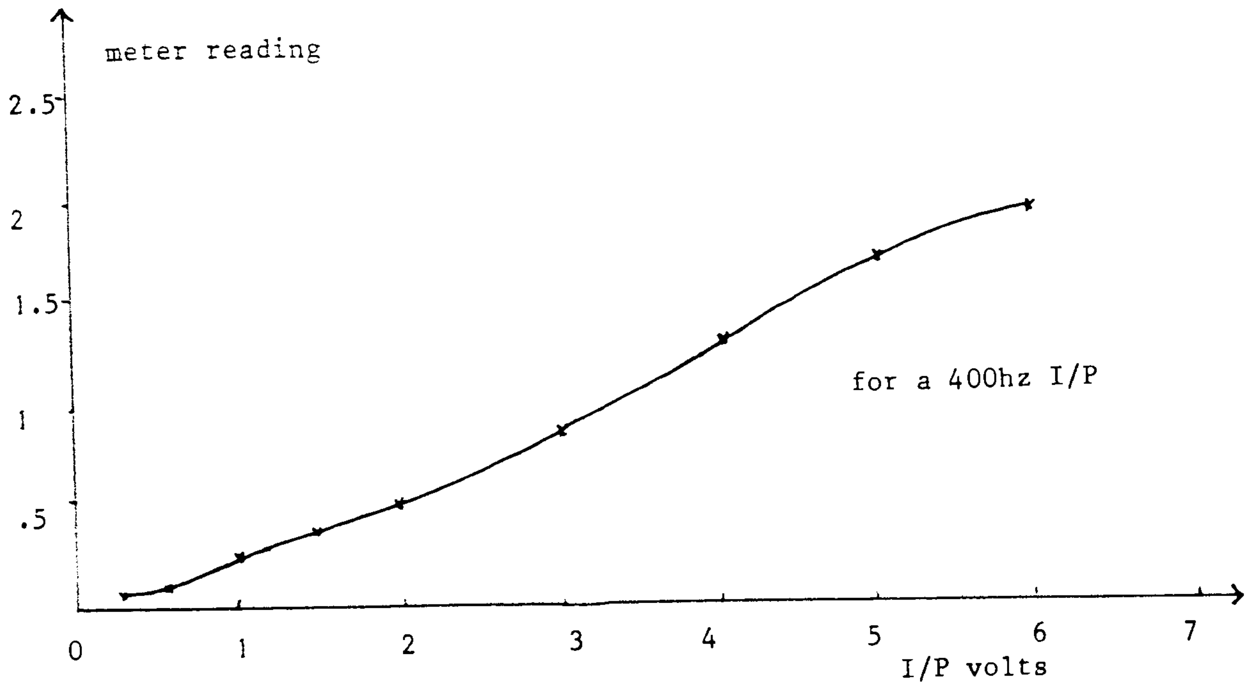
5. Dotted line indicates spread in filter response measurements

: Data recording system

: Radar circuitry

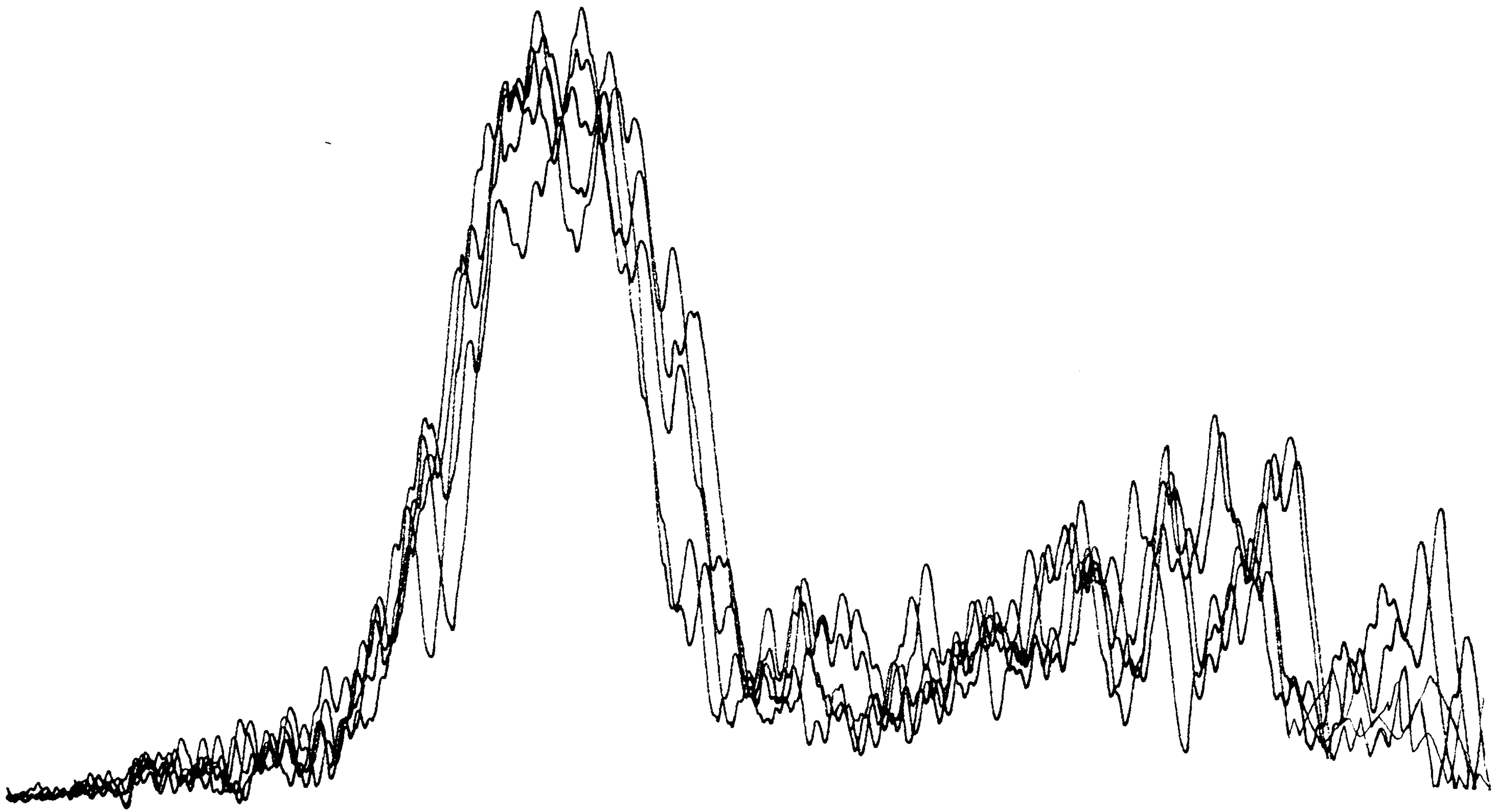
: filter spread





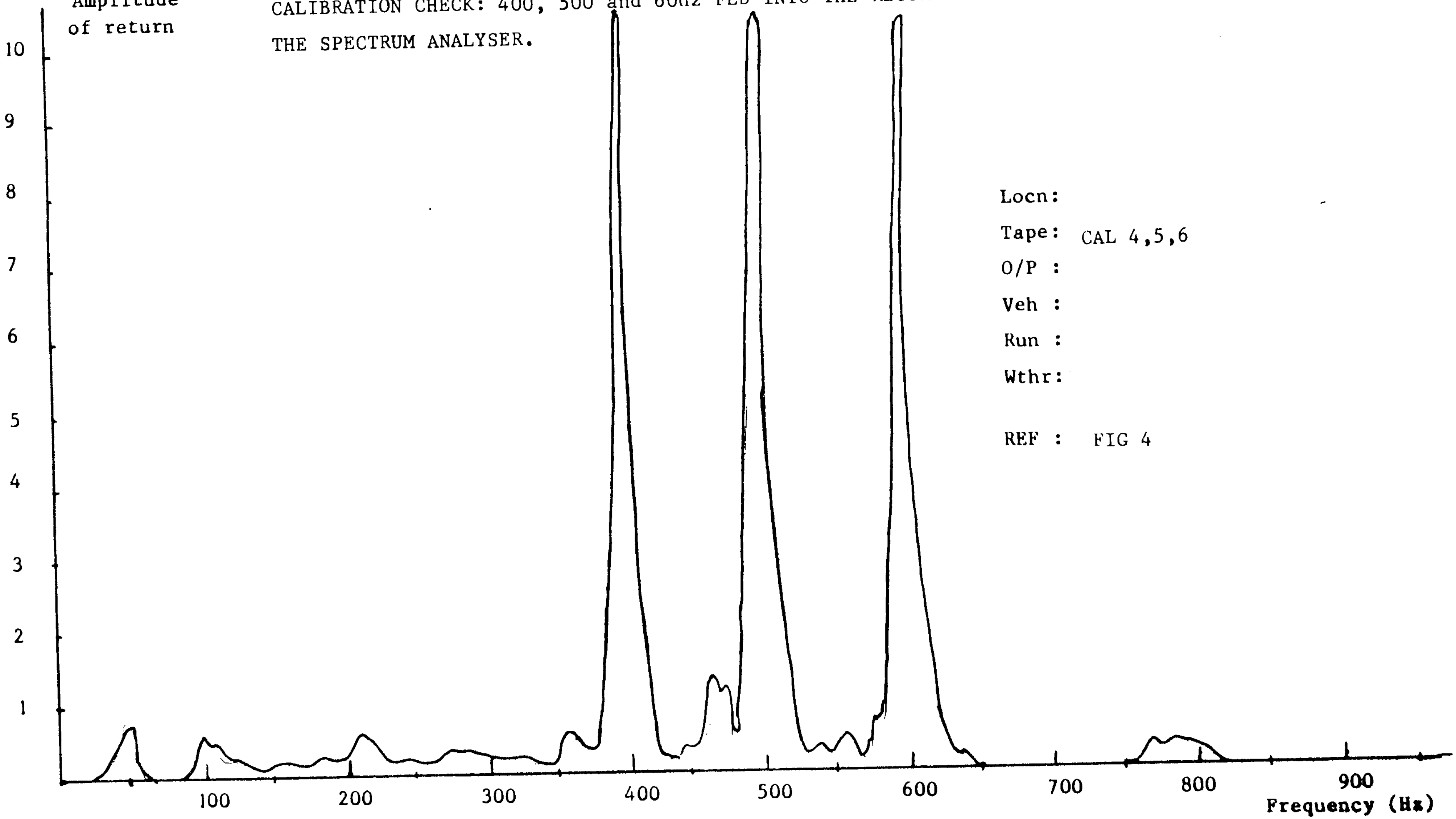
METER CALIBRATION TEST. The oscillator was fed into the calibration input of the interface box, set to the setting X1. The system is adequately linear.

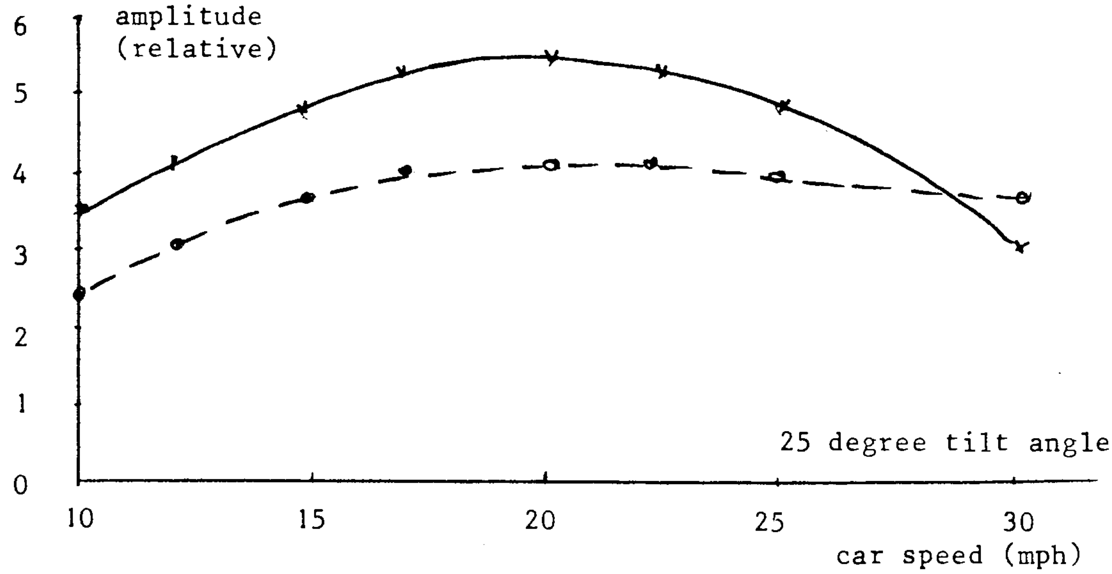
FIG 2a and 2b

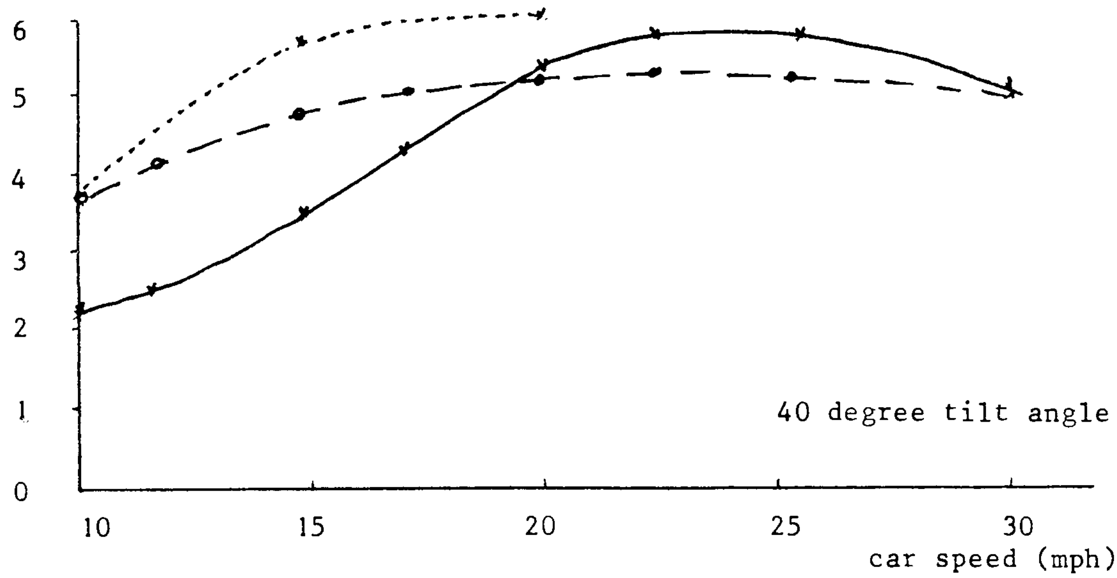


DATA REPRODUCTION TEST: THIS PLOT IS THE SUPERIMPOSITION OF FIVE RUNS ON THE SAME SECTION OF ROAD. FIG 3

CALIBRATION CHECK: 400, 500 and 60hz FED INTO THE RECORDING SYSTEM AND REPLAYED THROUGH THE SPECTRUM ANALYSER.







Tape: T1S2 15.8.83

Run : Otley, Pool road

Unit: ARO standard

Veh : car, roof rack

Wthr: wet

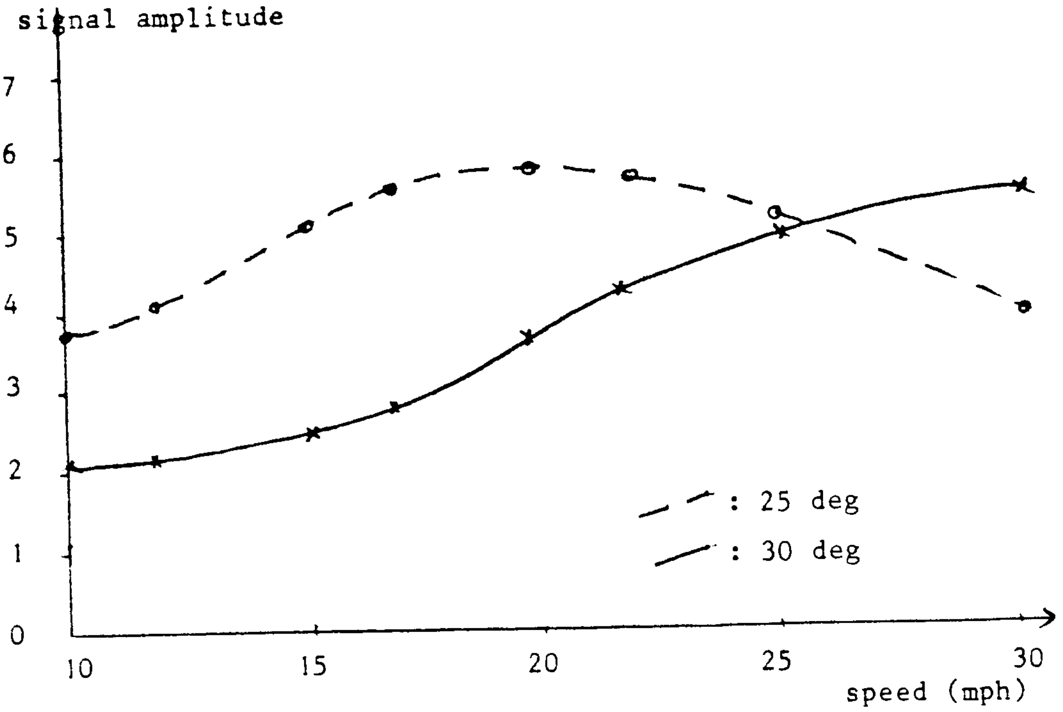
Plot: post-filter

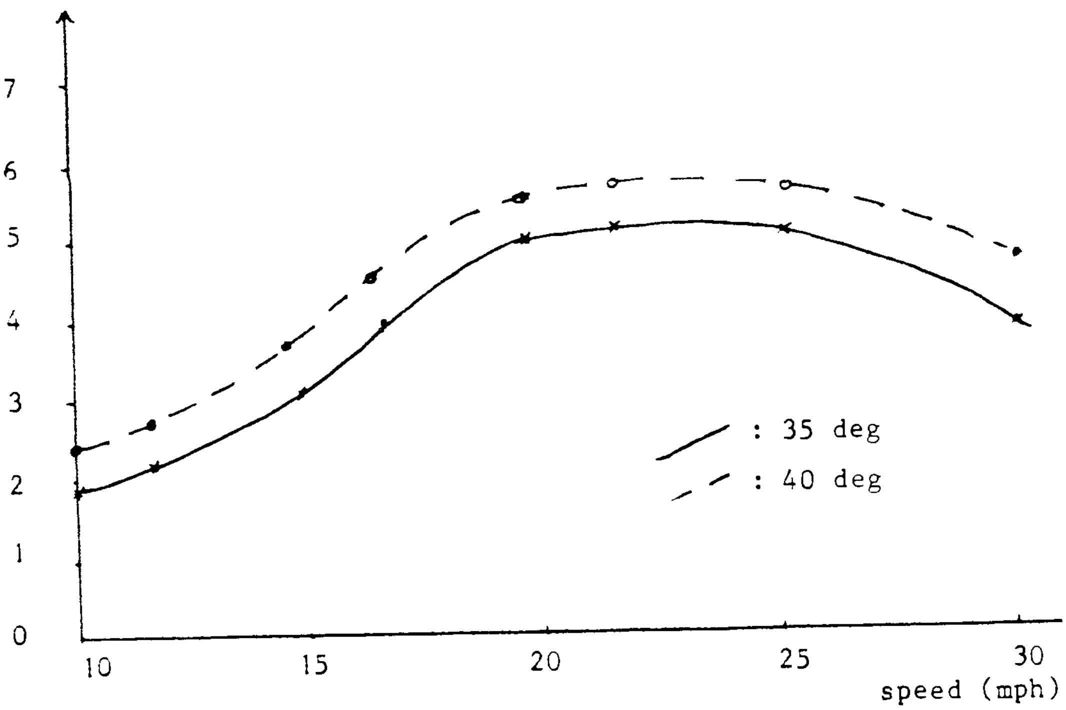
Key : - - - : dry tarmac; —— : wet tarmac; ······ : wet cobbles

REF : FIG 5a

NOTE: amplitudes plotted are those measured with an analogue meter with an integration time of 2 seconds, and represent the average of several readings. The units of measurement are relative only.

AMPLITUDE OF SIGNAL RETURN FROM TARMAC, WET AND DRY, FOR TWO TILT ANGLES. DERIVED USING A STANDARD ARO UNIT MOUNTED ON A CAR.





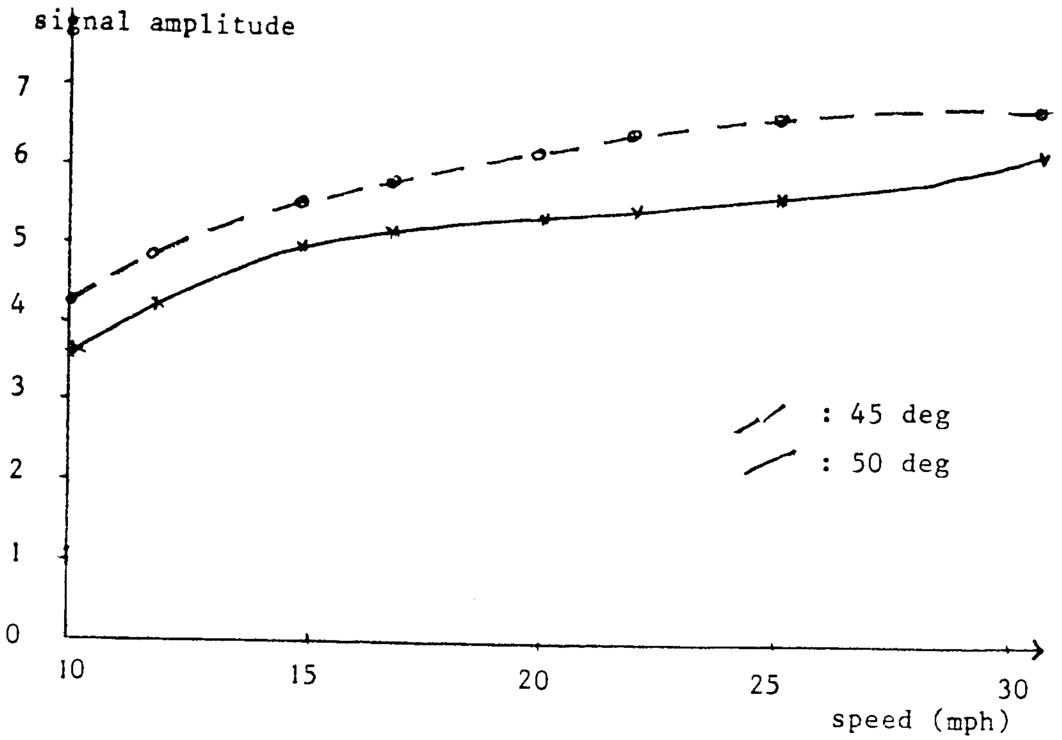
Tape: TIS2 15.8.83
Run : Otley, Pool Road
Unit: ARO, standard
Veh : car, roof mounted
Wthr: wet
Plot: post-filter

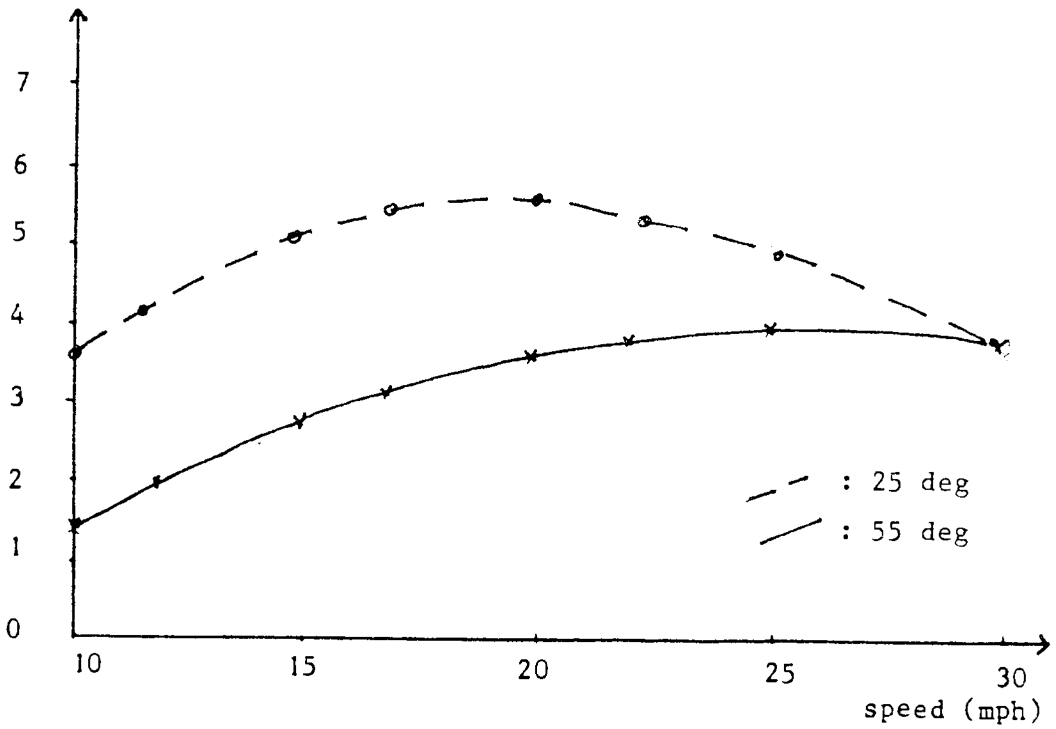
NOTE. Amplitudes are derived by analogue meter with an integration time of 2 seconds, and represent the average of several readings.

Amplitude units are relative only

REF : FIG 5b

AMPLITUDE OF SIGNAL RETURNS FROM WET TARMAC FOR A RANGE OF TILT ANGLES. DERIVED USING A STANDARD ARO UNIT CAR-MOUNTED





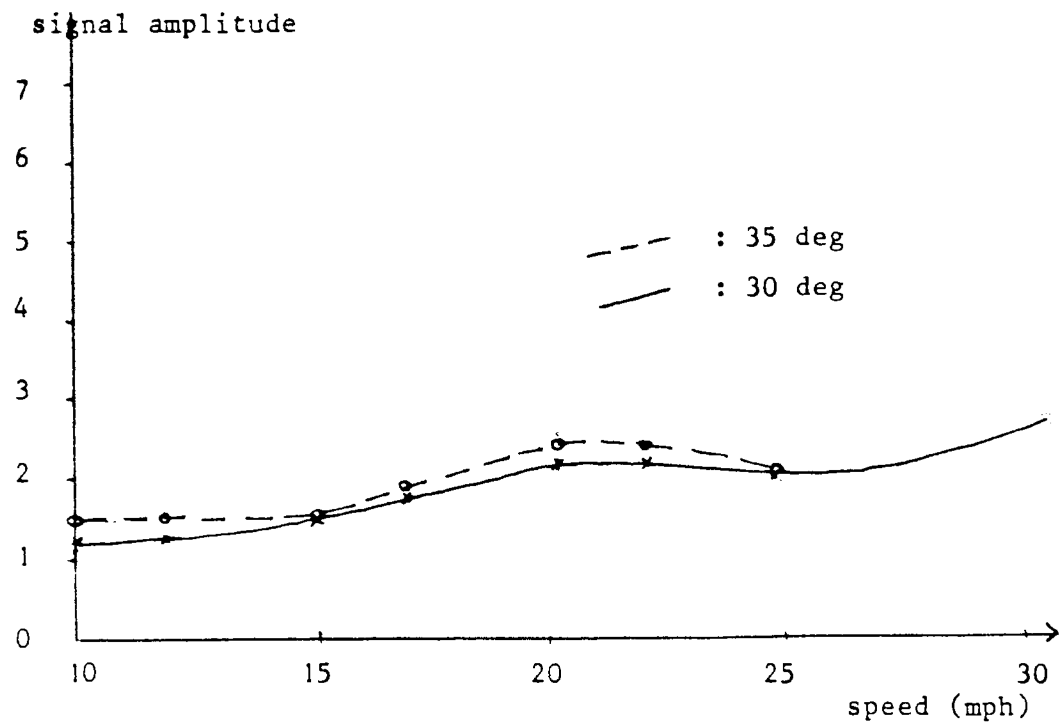
Tape: T1S2 15.8.83
Run : Otley, Pool Road
Unit: ARO, standard
Veh : car, roof mounted
Wthr: wet
Plot: post-filter

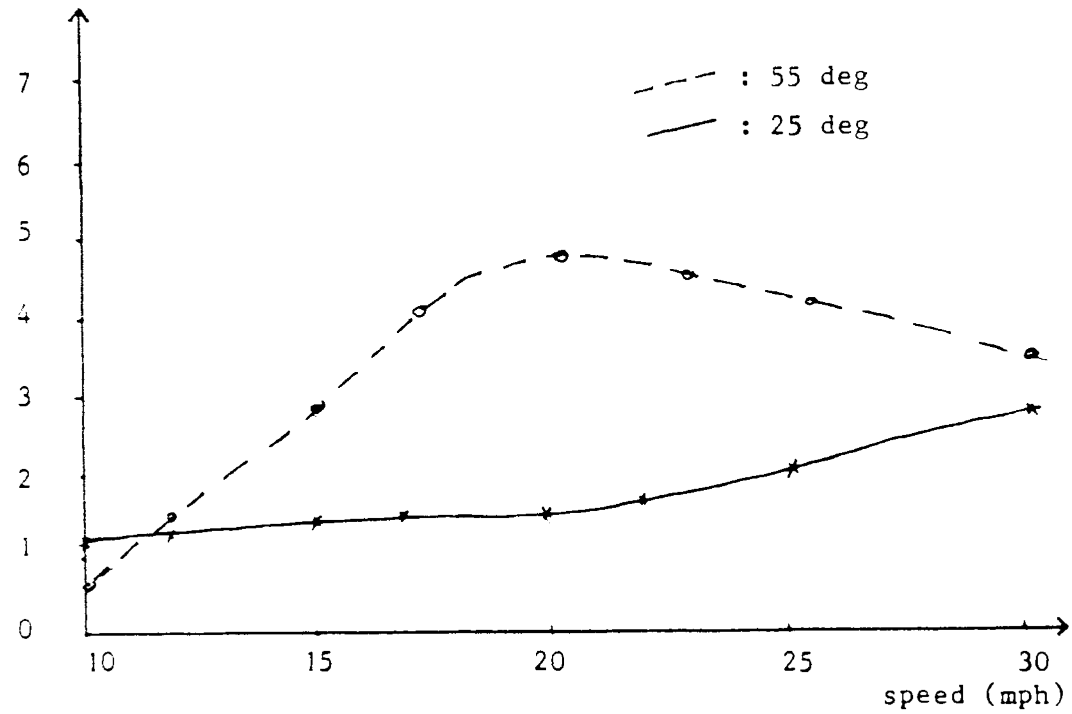
REF : 5C

NOTE. Amplitudes are derived by analogue meter with an integration time of 2 seconds, and represent the average of several readings.

Amplitude units are relative only

AMPLITUDE OF SIGNAL RETURNS FROM WET TARMAC FOR A RANGE OF TILT ANGLES. DERIVED USING A STANDARD ARO UNIT MOUNTED ON A CAR.





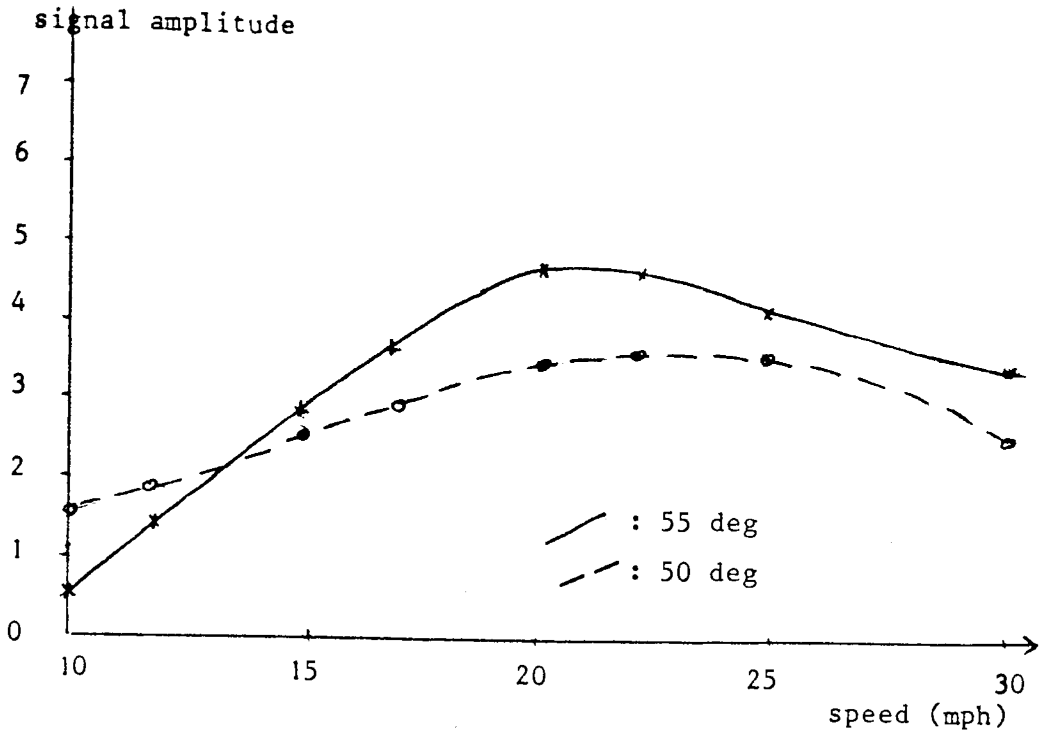
Tape: 1A 16.9.83
Run : Otley, Pool Road
Unit: ARO, standard
Veh : car, roof mounted
Wthr: Dry
Plot: post-filter

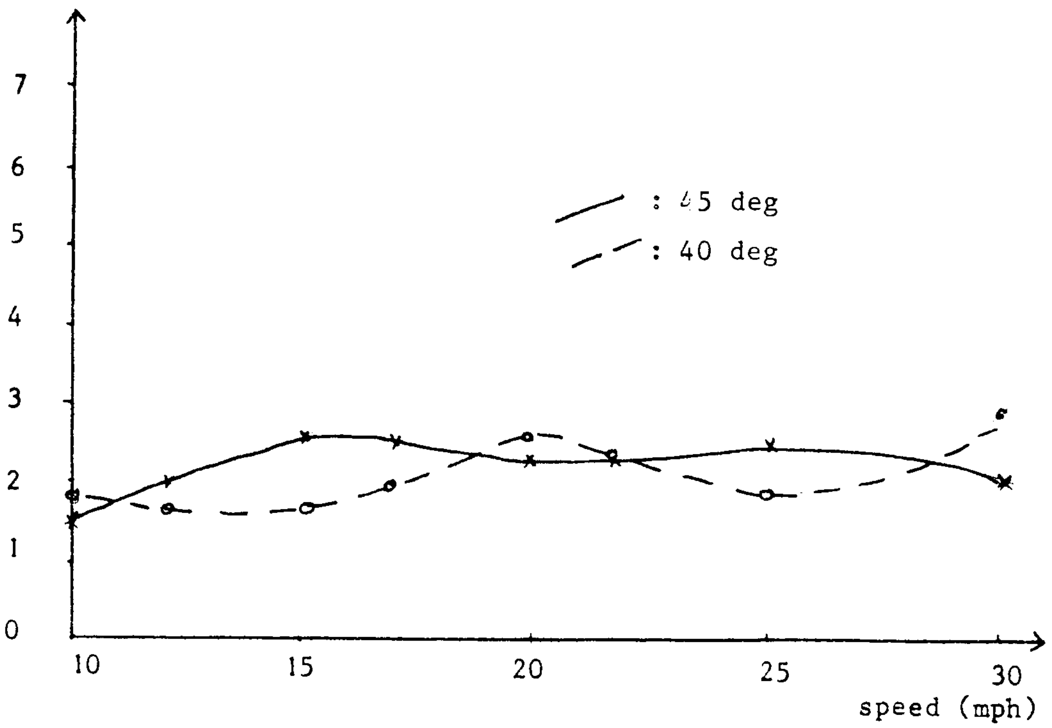
REF : 6A

NOTE. Amplitudes are derived by analogue meter with an integration time of 2 seconds, and represent the average of several readings.

Amplitude units are relative only

AMPLITUDE OF SIGNAL RETURNS FROM DRY TARMAC FOR A RANGE OF TILT ANGLES. DERIVED USING A STANDARD ARO UNIT MOUNTED ON A CAR.





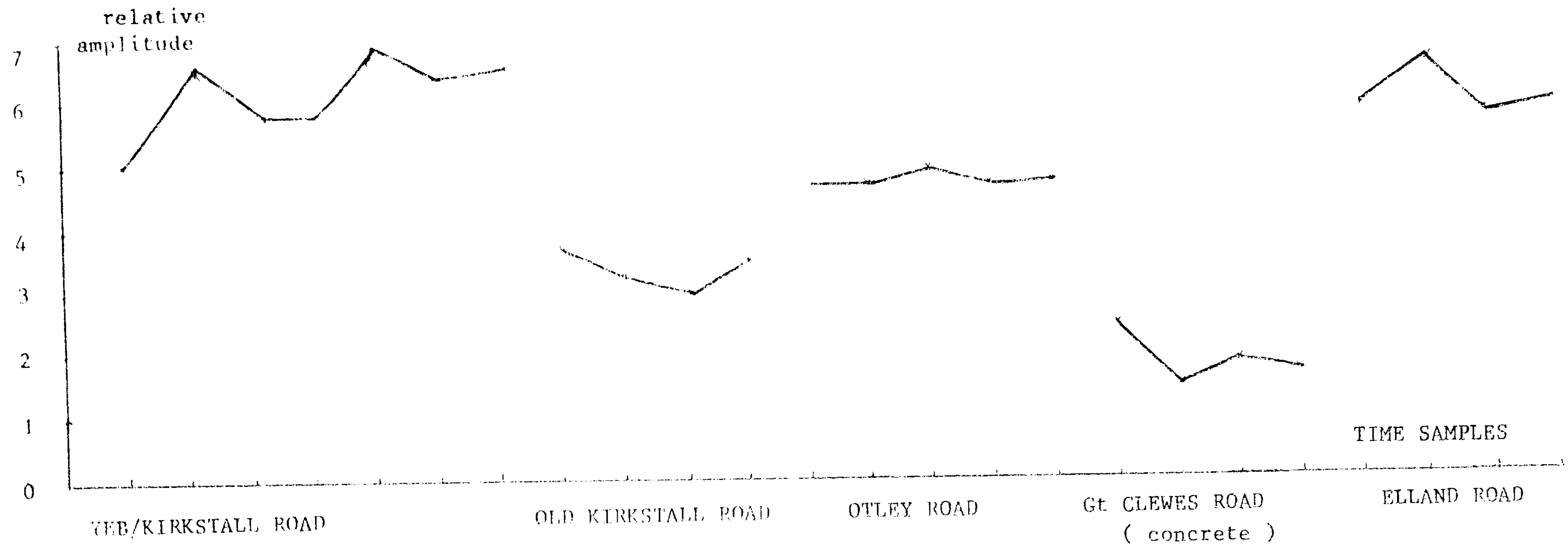
Tape: 1A 16.9.83
Run : Otley, Pool Road
Unit: ARO, standard
Veh : car, roof mounted
Wthr: dry
Plot: post-filter

REF : 6B

NOTE. Amplitudes are derived by analogue meter with an integration time of 2 seconds, and represent the average of several readings.

Amplitude units are relative only

AMPLITUDE OF SIGNAL RETURNS FROM DRY TARMAC FOR A RANGE OF TILT ANGLES. DERIVED USING A STANDARD ARO UNIT MOUNTED ON A CAR.



Tape: R1 27.9.83

Run : Otley to Leeds by road

Unit: ARO, standard

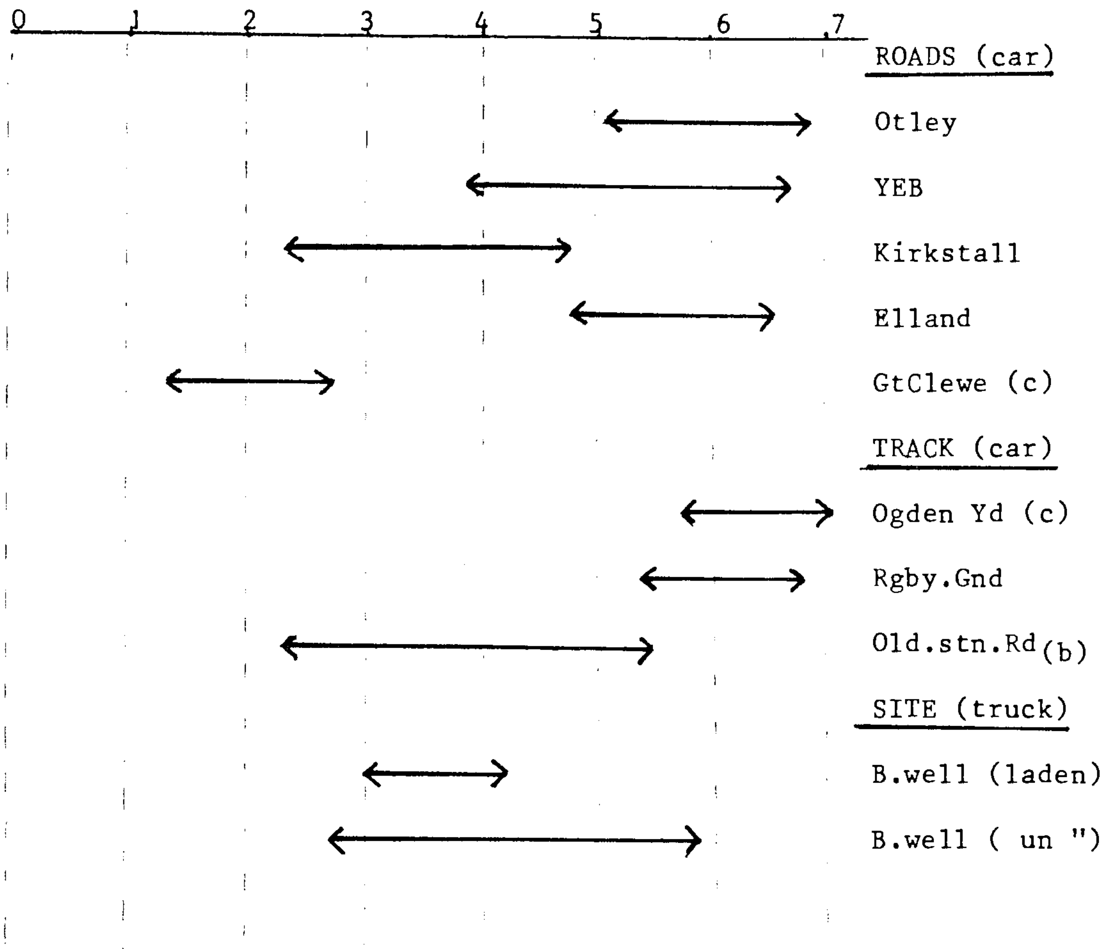
Veh : car, roof-rack

Wthr: fairly dry

plot: post-filter, averaged

REF : 7A

SIGNAL AMPLITUDES RETURNED FROM FIVE TERRAIN SURFACES: EACH READING IS A TWO-SECOND INTEGRATED AVERAGE AND READINGS WERE TAKEN AT FIVE SECOND INTERVALS. A STANDARD ARO RADAR UNIT, CAR-MOUNTED, WAS USED.



Notes: amplitudes are relative only and are derived using a meter with an integration time of one second. The ranges plotted represent the maximum and minimum readings obtained on a typical example of the stated terrain type.

Tape: numerous

Run : 20mph,40degree tilt

Unit: ARO, standard

Veh : car (roof mount) and truck (Cat 777)

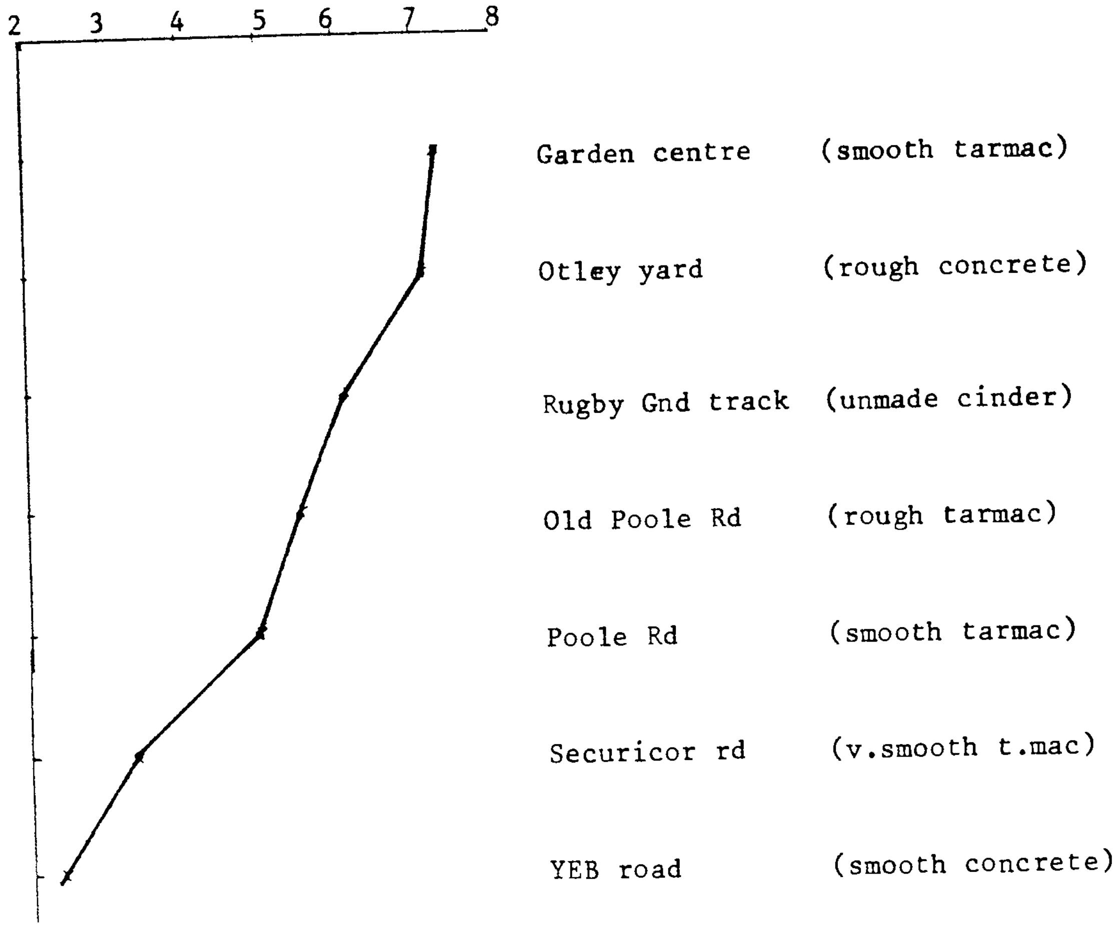
Plot: post-filter; integrated over 1 second.

wthr: damp

Key : c: concrete road
b: cobbled road

REF : 7B

THE RANGE OF RETURNED SIGNAL AMPLITUDES FOR NUMEROUS TERRAIN TYPES. RECORDED ON A TYPICAL RUN AT 20mph USING A STANDARD ARO RADAR UNIT.



Tape: numerous (incl RdB and R1)

Run : 20mph, 40 deg tilt

Unit: ARO, roof-mounted

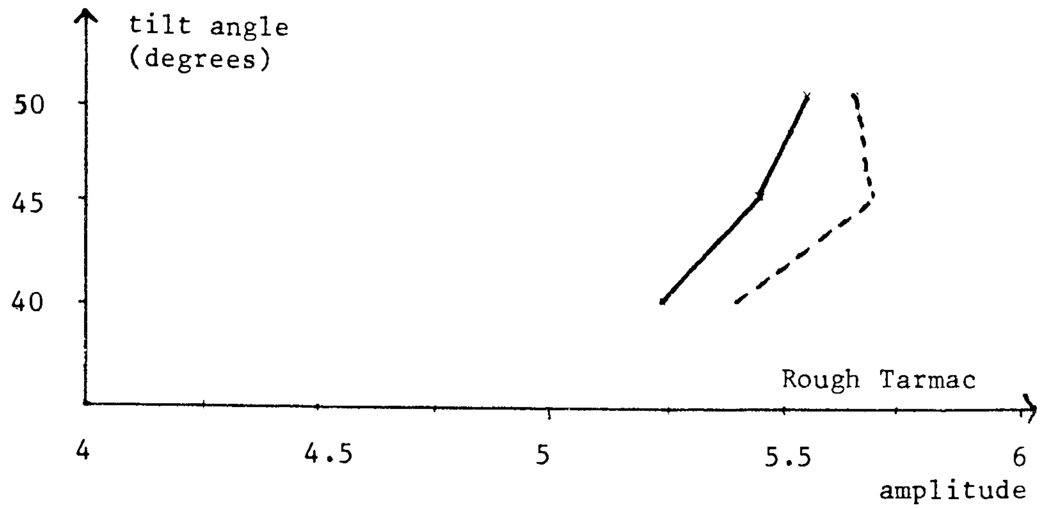
Veh : car

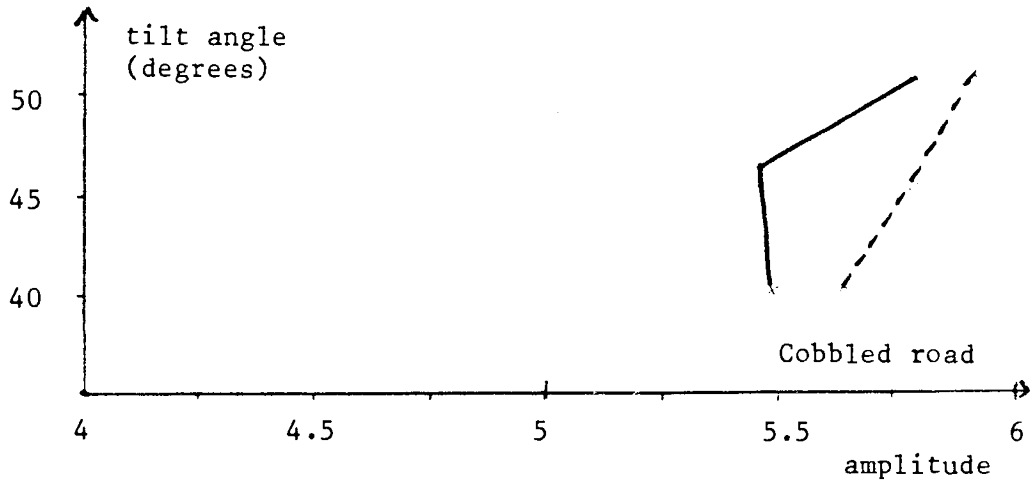
Plot: post-filter, integrated

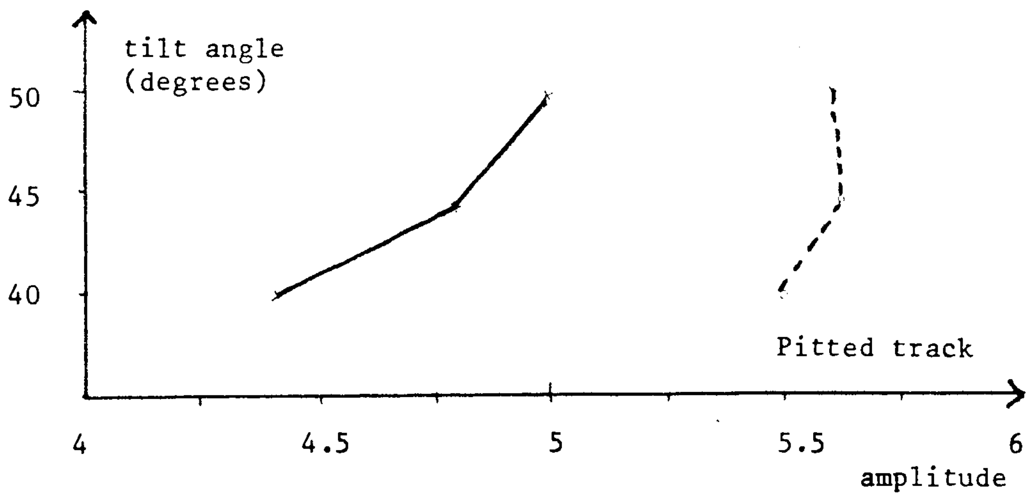
Wthr: damp

REF : 7C

AVERAGE RETURNED SIGNAL AMPLITUDE FROM A RANGE OF SURFACES; THE INDICATED AMPLITUDE (RELATIVE ONLY) IS THE MEAN OF SEVERAL RUNS AT 20mph.





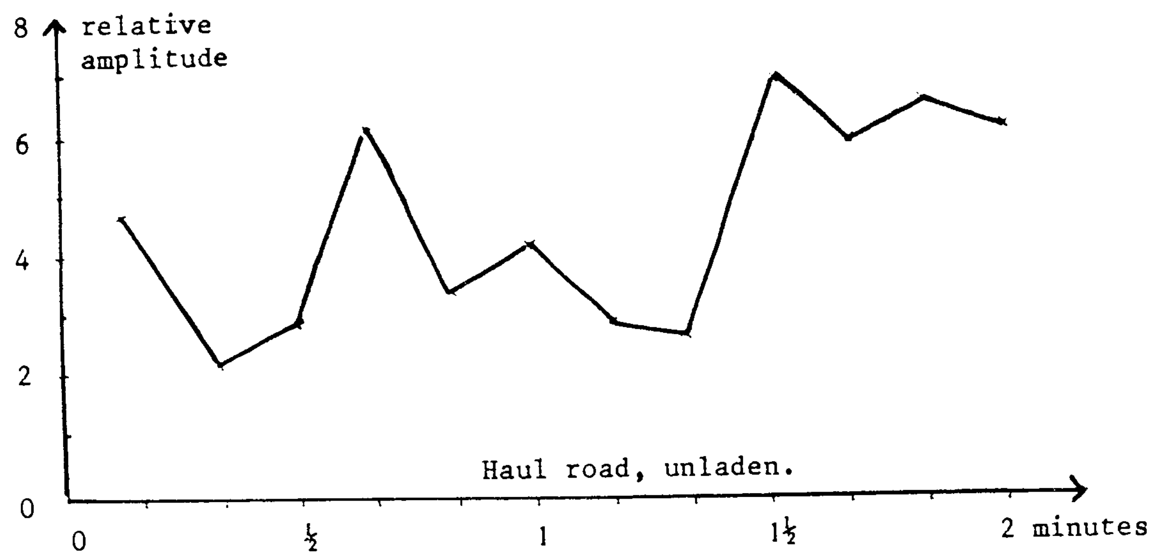


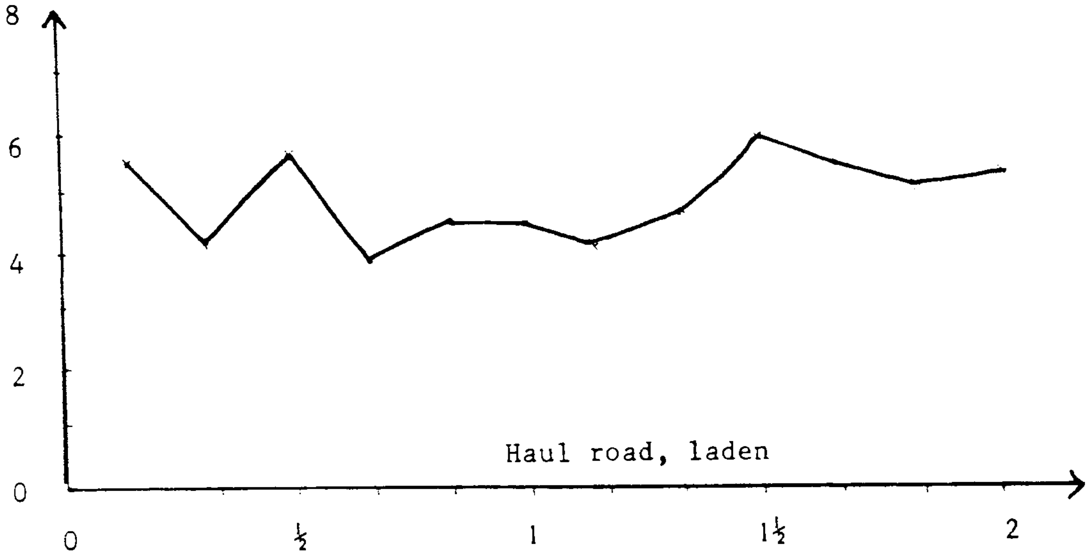
REF : 8
Tape: TRA a-j 26.9.83
Locn: Otley: Old Station area
Unit: ARO, standard
Veh : car, roof-mounted
Run : 20mph
Wthr: dry
Plot: post filter

NOTES: meter reading derived using an averaging meter. Readings are average of several runs.

KEY: (solid line) : meter ave
(dashed line) : meter max

AMPLITUDE OF SIGNAL RETURN FROM THREE SURFACES AND THREE TILT ANGLES. DERIVED USING A STANDARD ARO RADAR UNIT.





Tape: 2AB 23.9.83

Run : Butterwell site

Unit: ARO standzrd

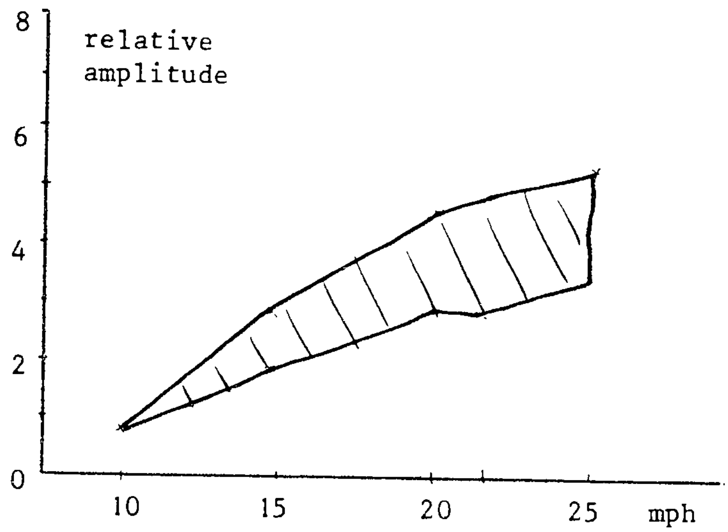
Veh : Cat 777

Wthr: damp

REF : 10

Note: units of amplitude are relative only.

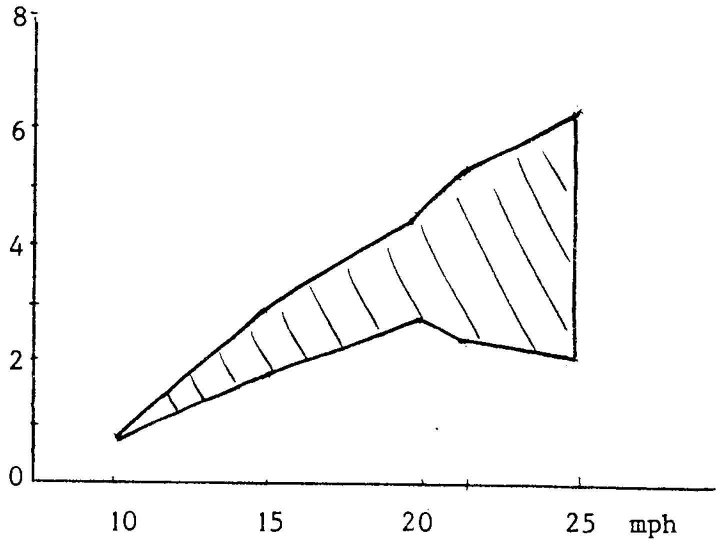
AVERAGED AMPLITUDE OF RETURN FOR A TYPICAL SECTION OF HAUL ROAD, FOR LADEN AND UNLADEN TRUCK: The amplitudes were measured every ten seconds with a meter (integration time of two seconds).



Site haul road,damp.

Truck laden.

Flat section, typical run.



Site haul road, damp.

Truck laden.

Hilly section (not bumpy),

typical run.

Tape: 2AB

Run : Haul road, 10 to 25mph

Unit: ARQ standard

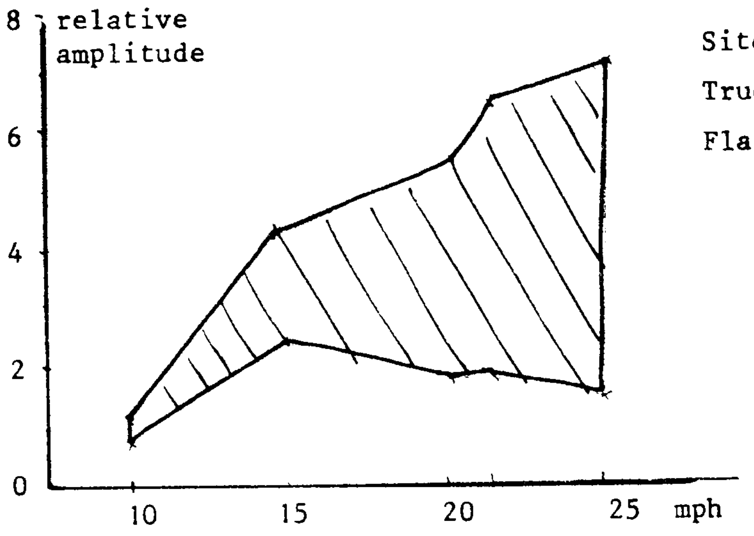
Veh : Cat 777

Plot: post-filter, integrated over 0.5 sec

Wthr: damp

REF : 11A

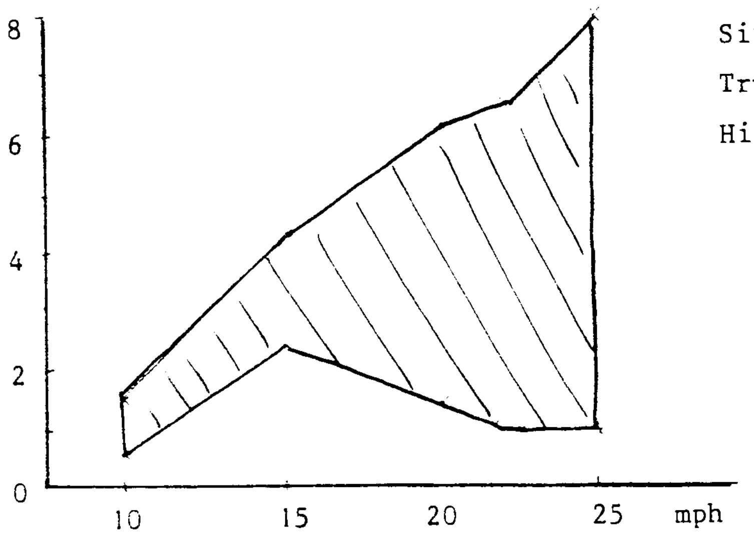
RANGE OF SIGNAL AMPLITUDES RETURNED FOR A LADEN TRUCK ON SMOOTH AND UNDULATING HAUL ROAD SECTIONS. Max and min readings are plotted.



Site haul road, damp.

Truck unladen.

Flat section, typical run.



Site haul road, damp

Truck unladen,

Hilly section (not bumpy), typical run.

Tape: 2AB 23.9.83

Run : haul road, 1- to 25 mph

Unit: ARO, standard

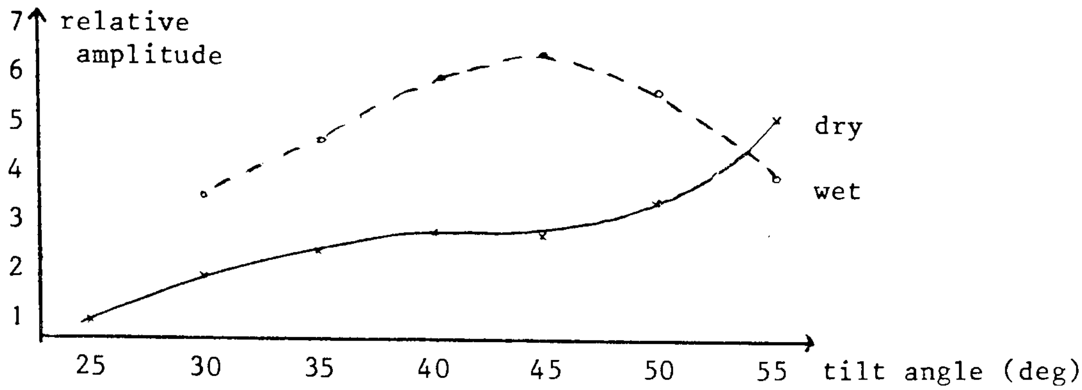
Veh : Cat 777

Plot: post-filter, integrated over 0.5 seconds

wthr: damp

REF : 11B

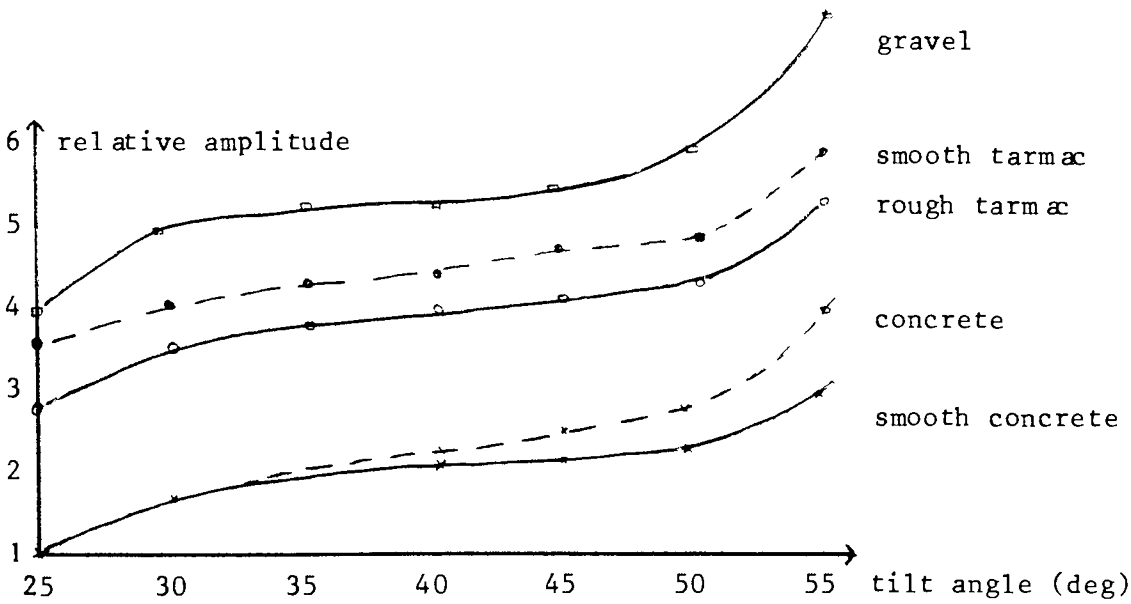
RANGE OF SIGNAL AMPLITUDES FOR AN UNLADEN TRUCK ON SMOOTH AND UNDULATING HAUL ROAD SECTIONS. Max and min readings are plotted.



Tape: TS12 15.8.83; 1A 16.9.83
Run : Otley, Pool Road
Unit: Aro standard
Veh : Car, roof-mounted

Wthr: wet and dry
Plot: Post-filter
Vel : 20mph all runs
Ref : 12

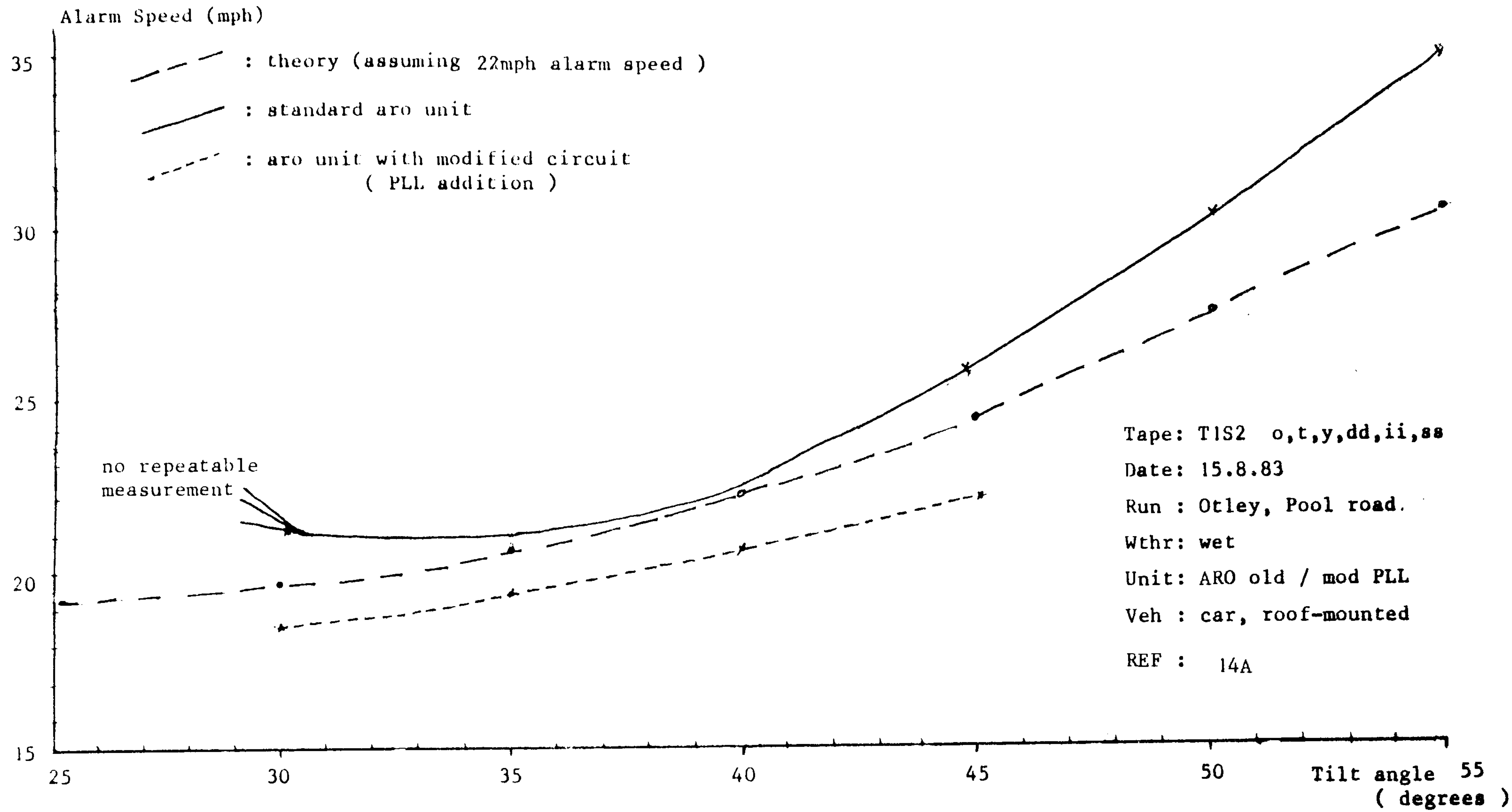
RESUME OF RETURNED AMPLITUDE FROM AN ARO UNIT FOR A RANGE OF TILT ANGLES FROM WET AND DRY TARMAC.



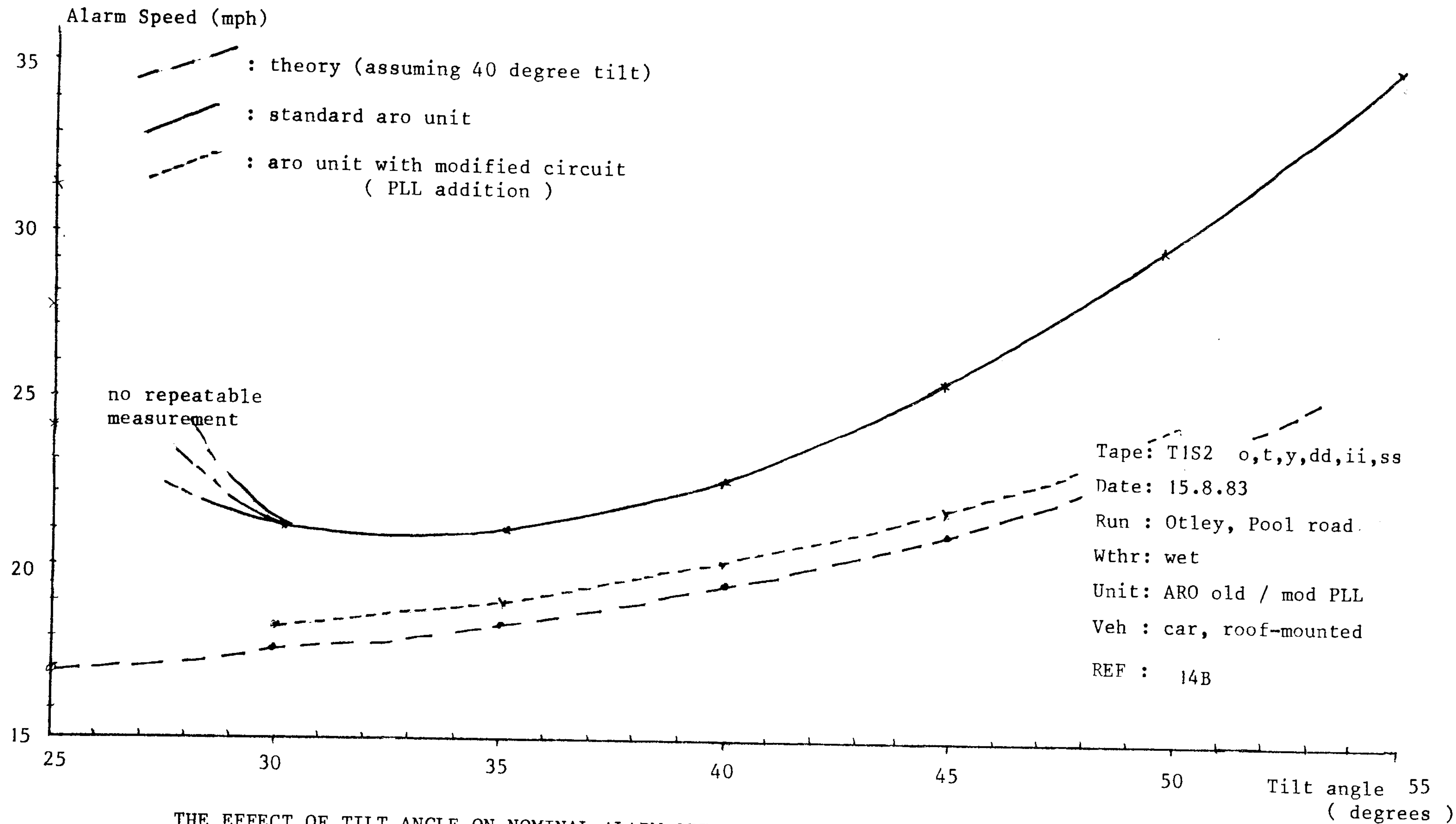
TYPICAL LITERATURE RESULTS: RETURNED AMPLITUDE FOR X-BAND SYSTEM, HORIZONTAL POLARISATION, FOR A RANGE OF TILT ANGLES AND SURFACES.

Derived from Cosgriff (1960) (reference in main literature review)

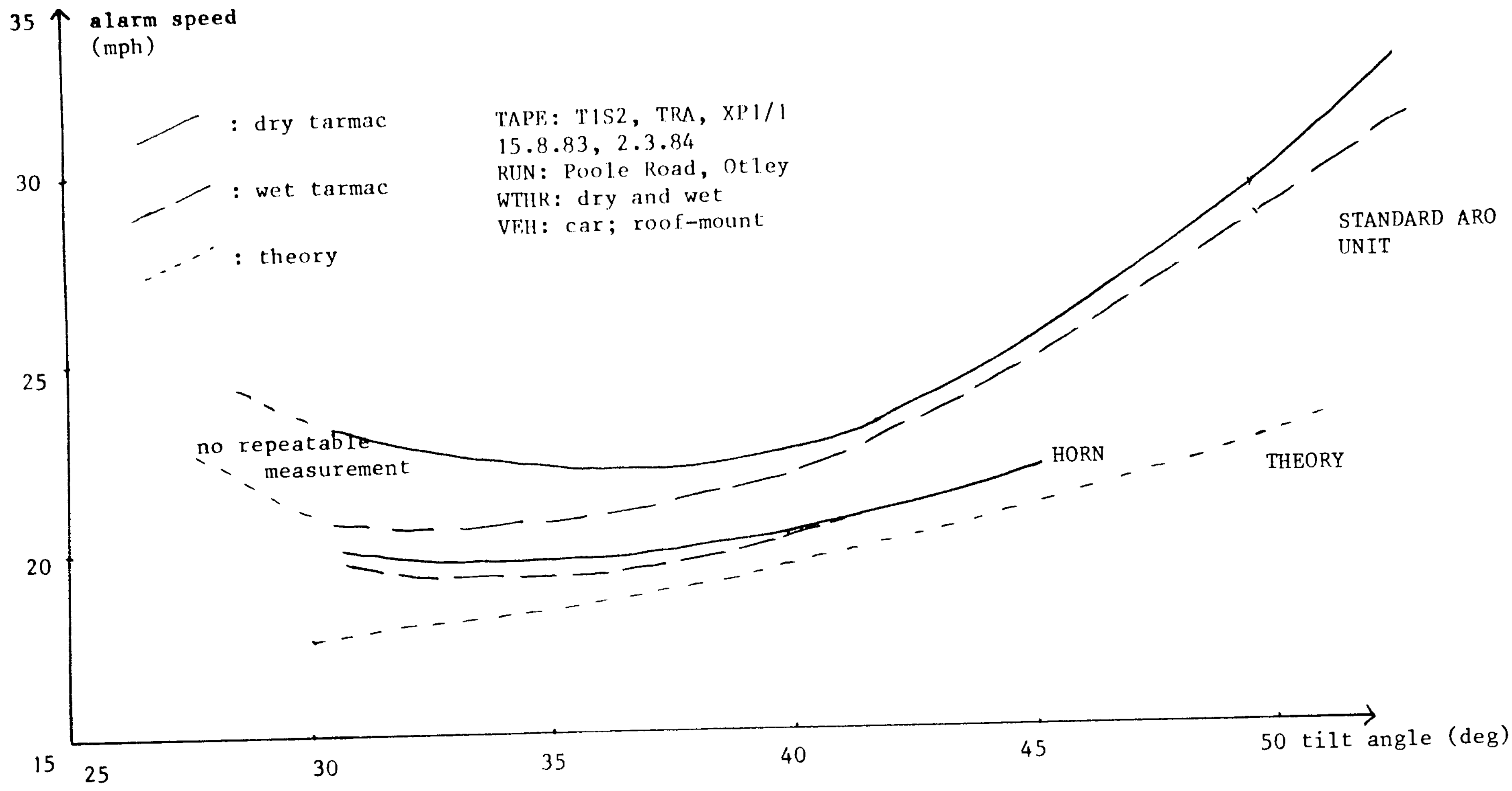
Fig 13.



THE EFFECT OF TILT ANGLE ON NOMINAL ALARM SPEED. THE THEORETICAL RELATION IS INDICATED, AND EXPERIMENTAL RESULTS WITH AN ARO UNIT (EXISTING CIRCUIT AND MODIFIED CIRCUIT) PLOTTED.

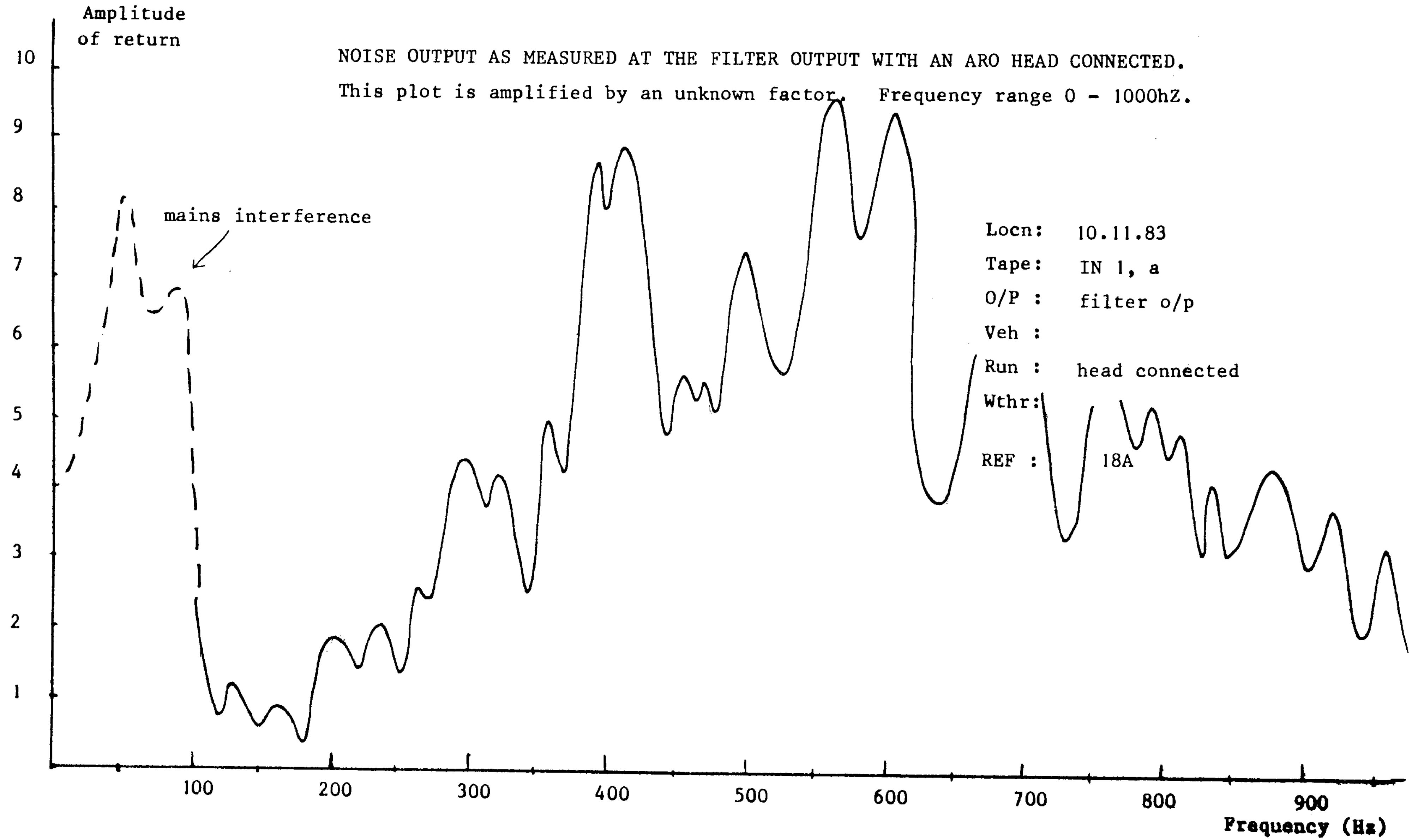


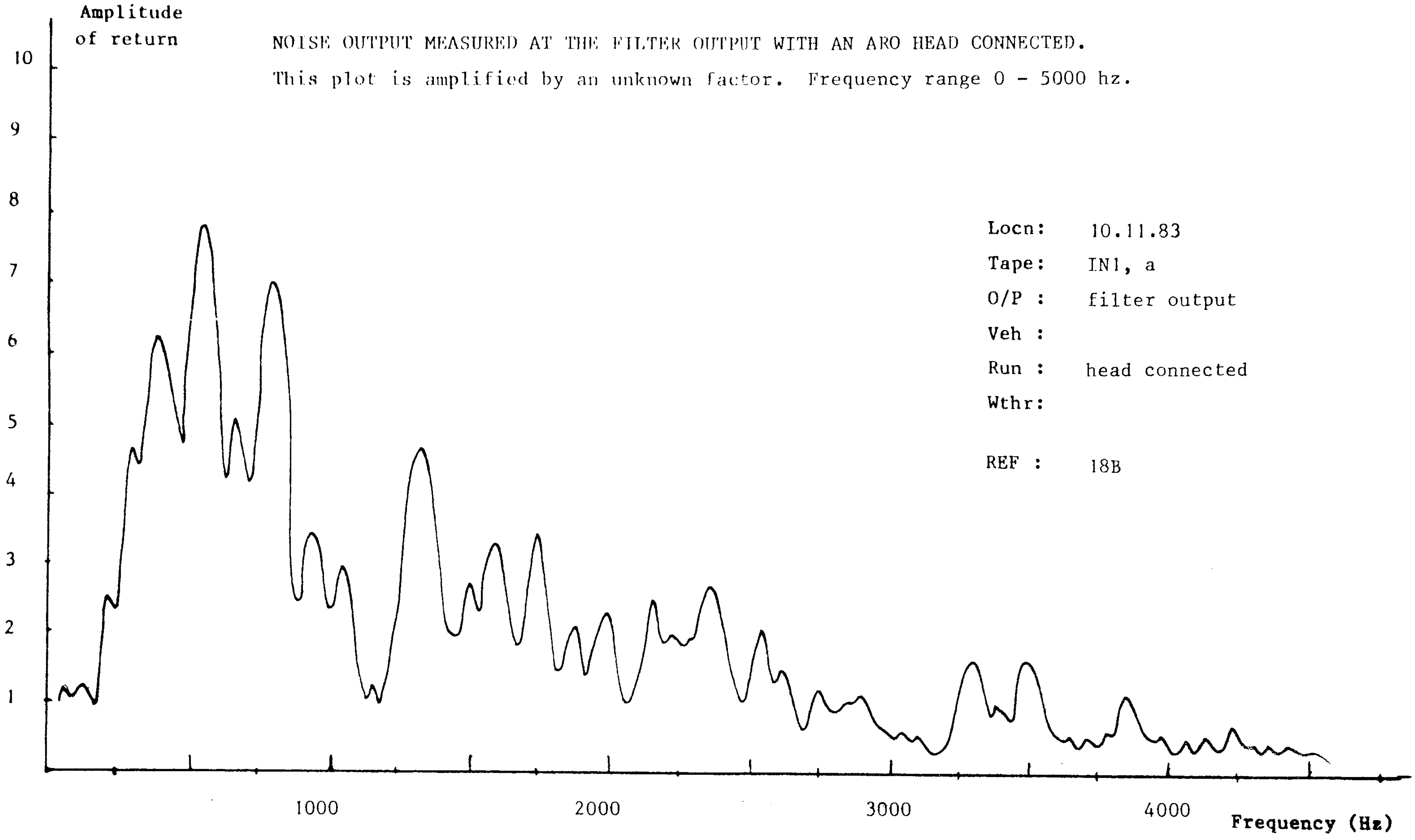
THE EFFECT OF TILT ANGLE ON NOMINAL ALARM SPEED. THE THEORETICAL RELATION IS INDICATED, AND EXPERIMENTAL RESULTS WITH AN ARO UNIT (EXISTING CIRCUIT AND MODIFIED CIRCUIT) PLOTTED.

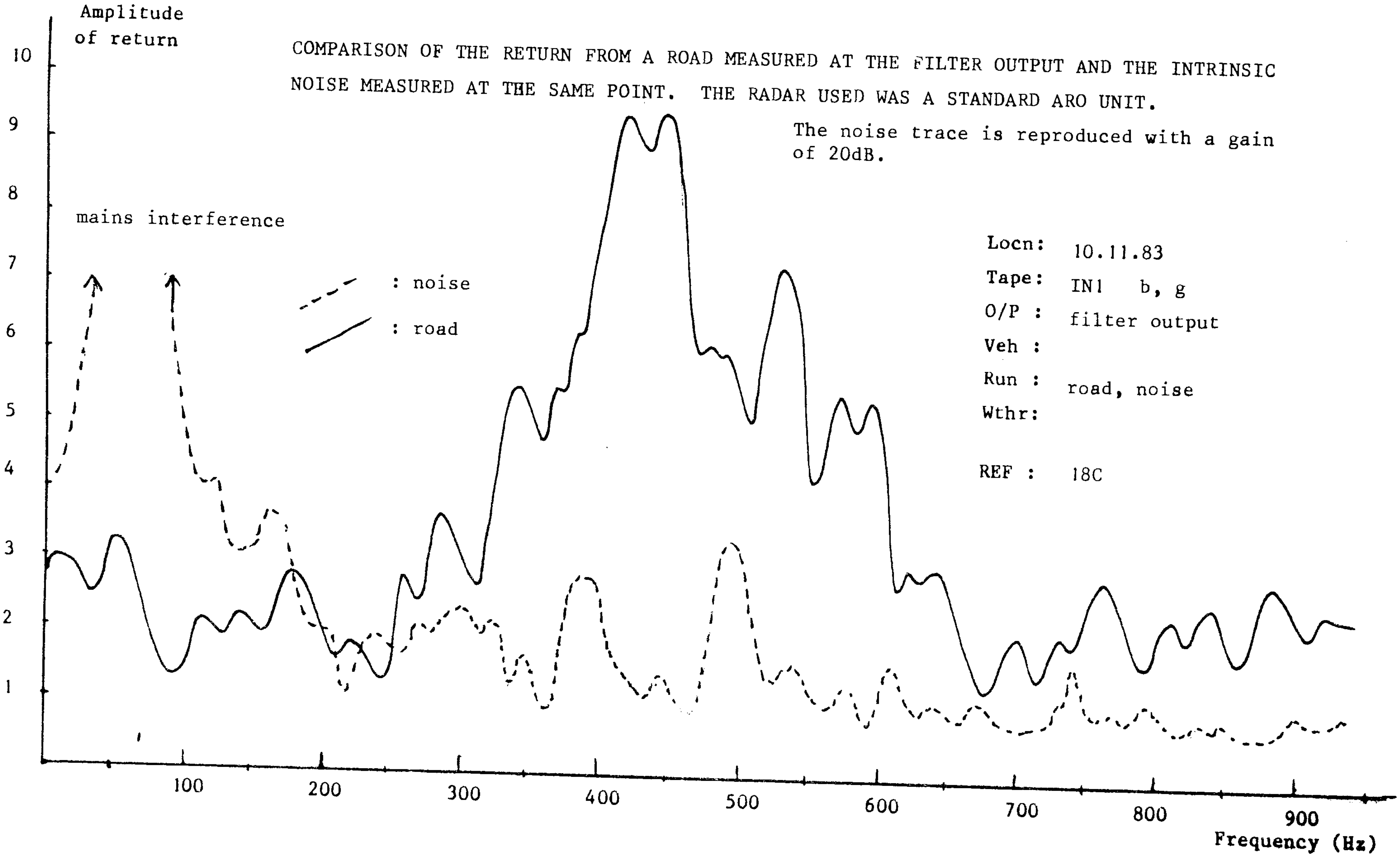


THE EFFECT OF TILT ANGLE ON NOMINAL ALARM SPEED FOR THE STANDARD ARO UNIT, THEORY AND THE PROTOTYPE HORN UNIT: IN BOTH WET AND DRY CONDITIONS.

REF: 14C

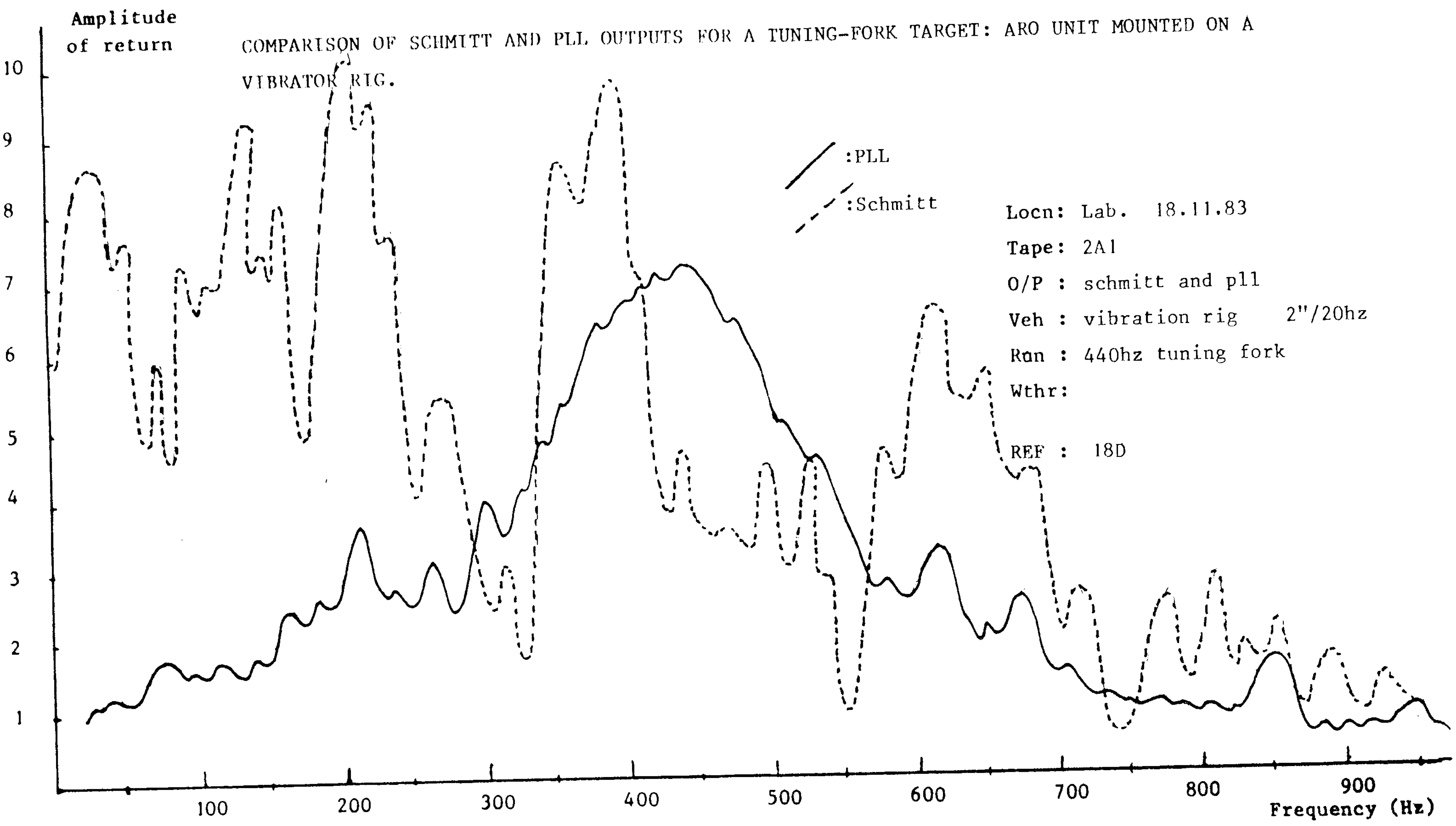

Amplitude
of return
NOISE OUTPUT AS MEASURED AT THE FILTER OUTPUT WITH AN ARO HEAD CONNECTED.
This plot is amplified by an unknown factor. Frequency range 0 - 1000hZ.
mains interference
Locn: 10.11.83
Tape: IN 1, a
O/P : filter o/p
Veh :
Run : head connected
Wthr:
REF : 18A
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)

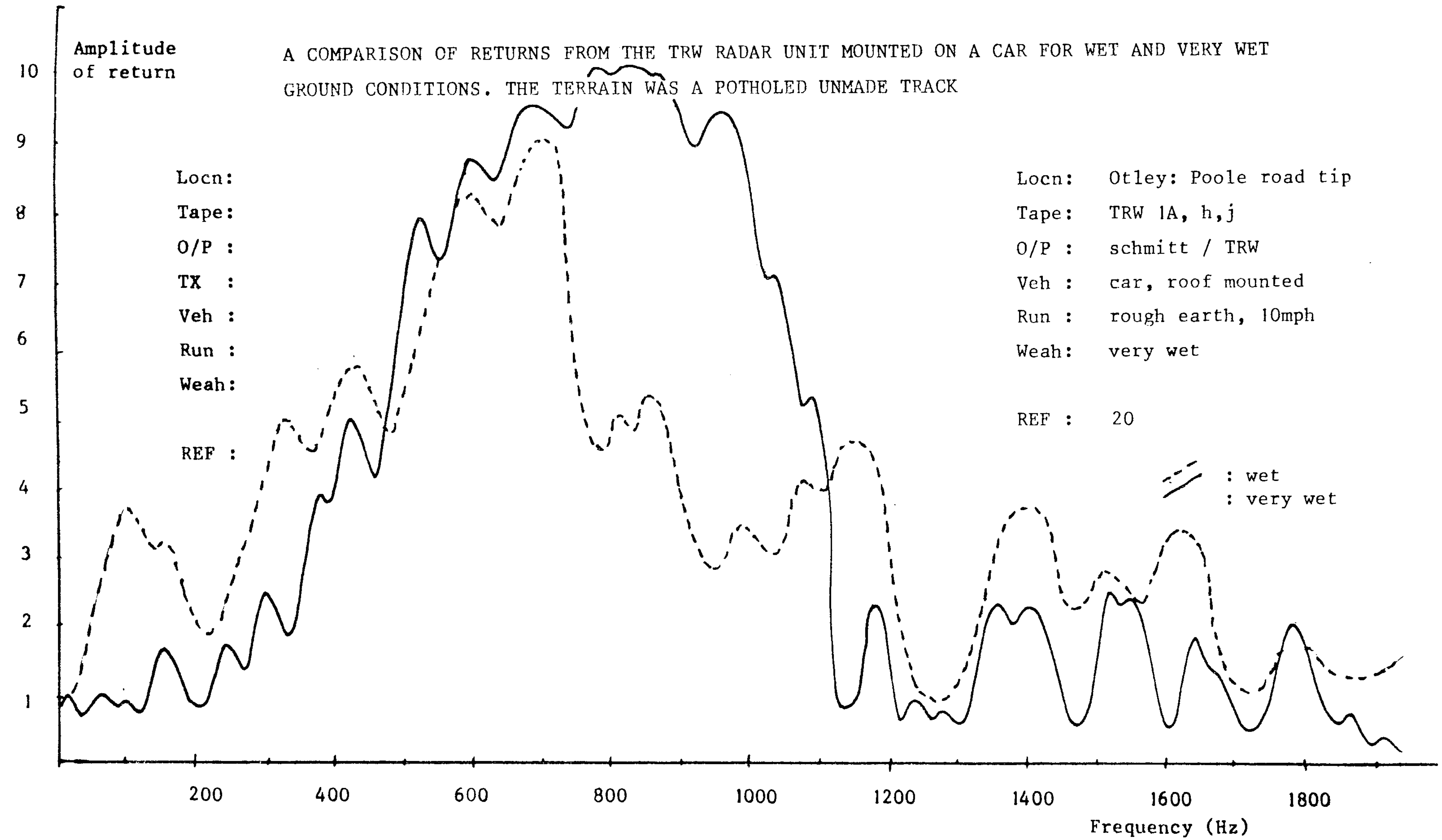

Amplitude of return
NOISE OUTPUT MEASURED AT THE FILTER OUTPUT WITH AN ARO HEAD CONNECTED.
This plot is amplified by an unknown factor. Frequency range 0 - 5000 hz.
Locn: 10.11.83
Tape: IN1, a
O/P : filter output
Veh :
Run : head connected
Wthr:
REF : 18B
10
9
8
7
6
5
4
3
2
1
1000
2000
3000
4000
Frequency (Hz)

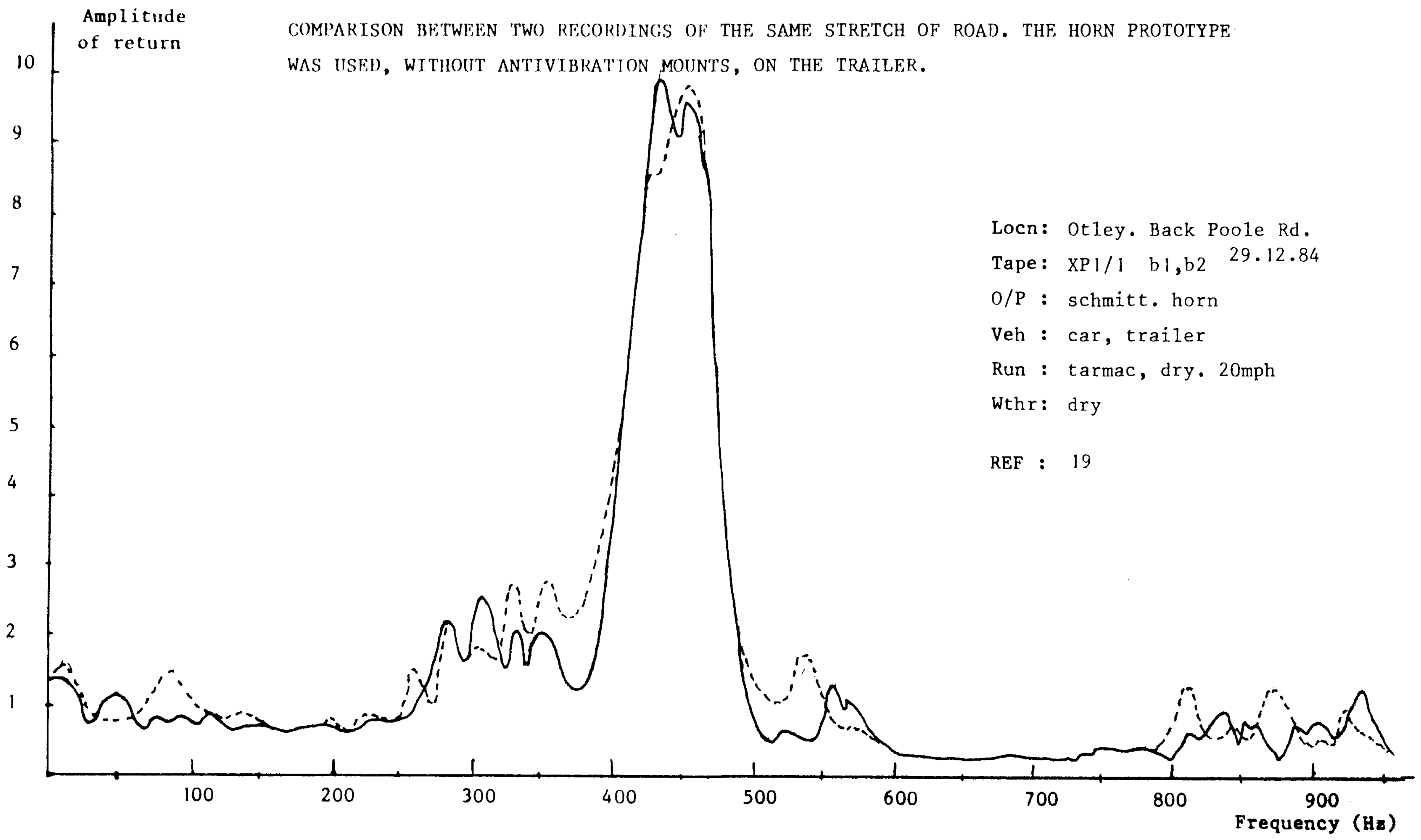


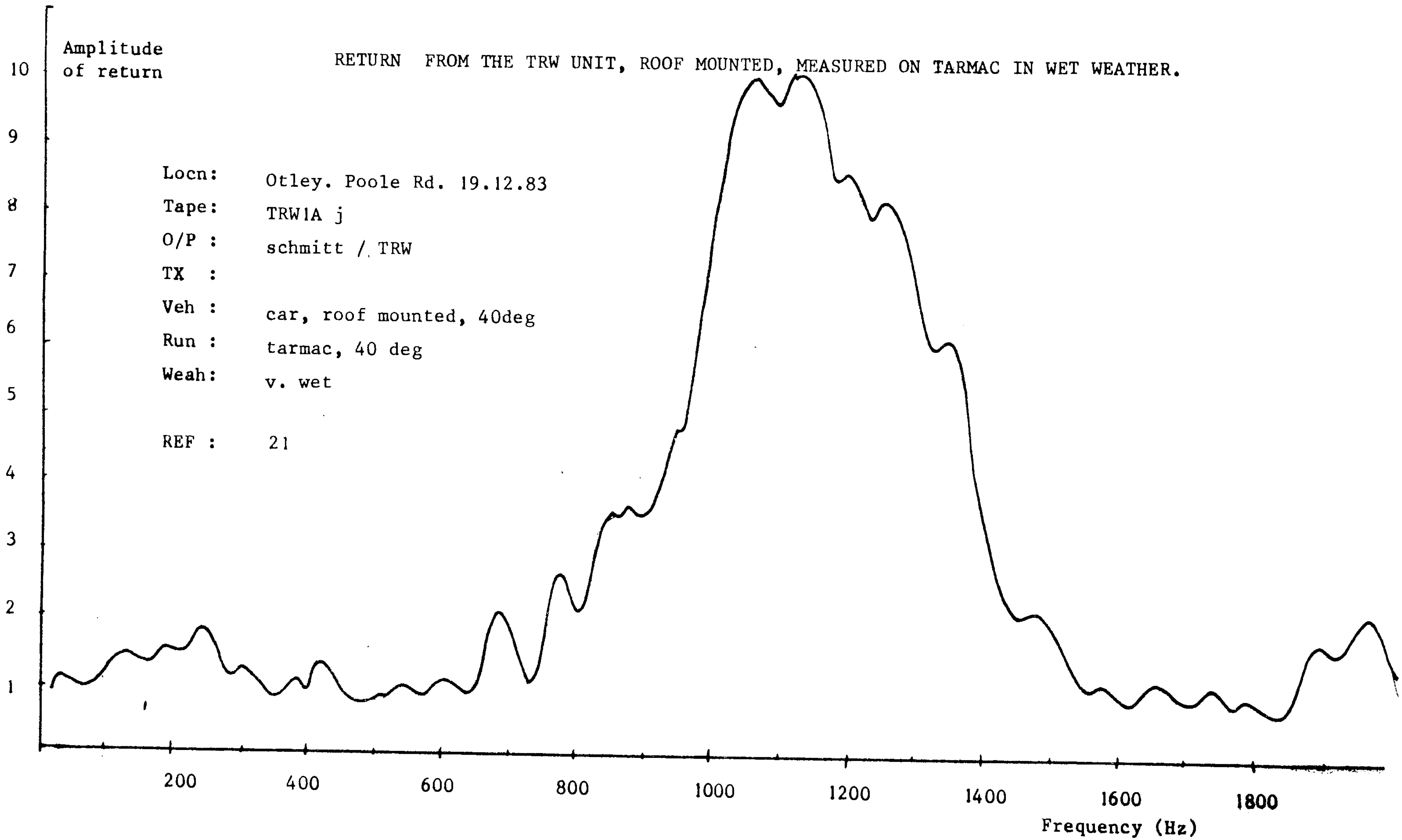
COMPARISON OF THE RETURN FROM A ROAD MEASURED AT THE FILTER OUTPUT AND THE INTRINSIC NOISE MEASURED AT THE SAME POINT. THE RADAR USED WAS A STANDARD ARO UNIT.

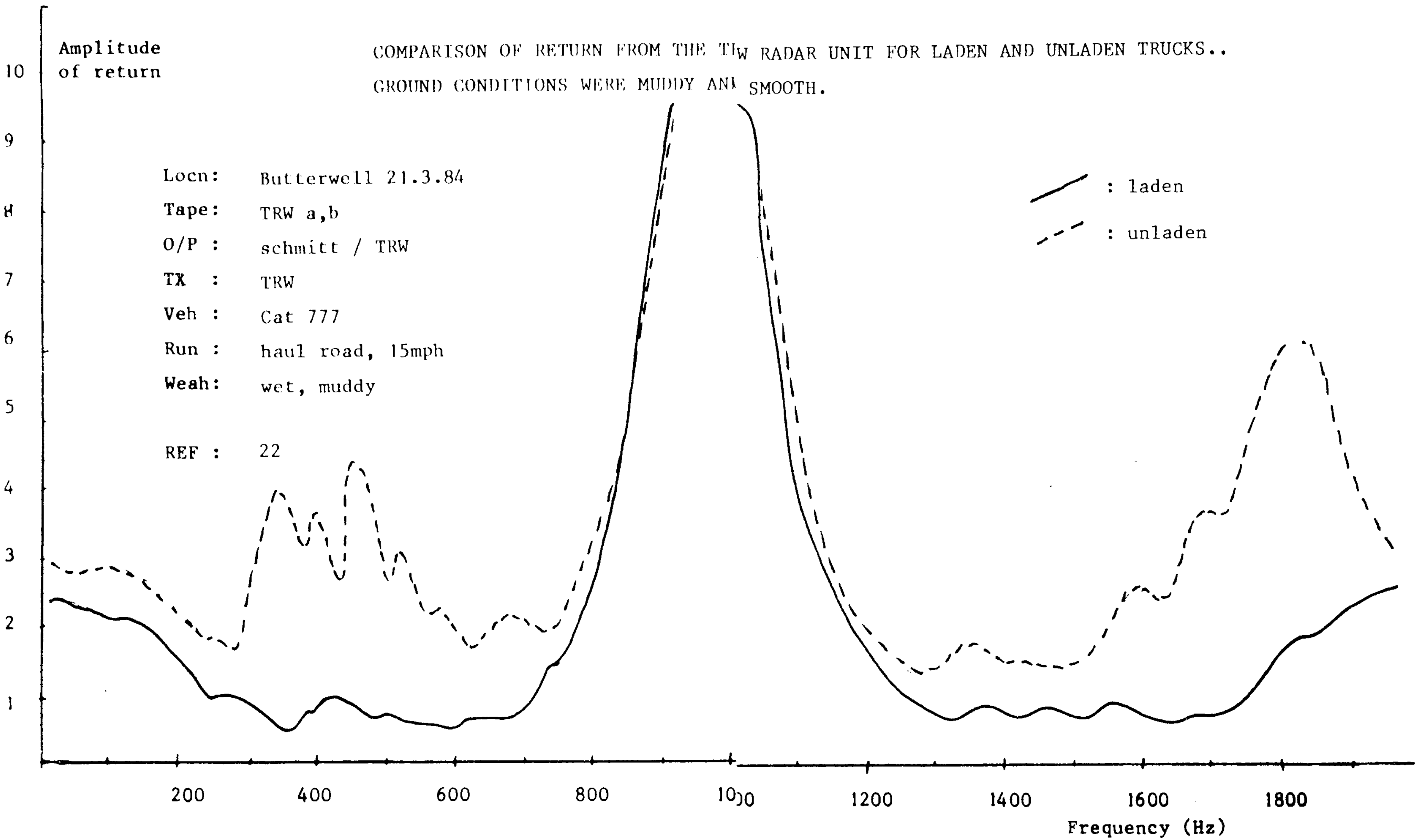
The noise trace is reproduced with a gain of 20dB.

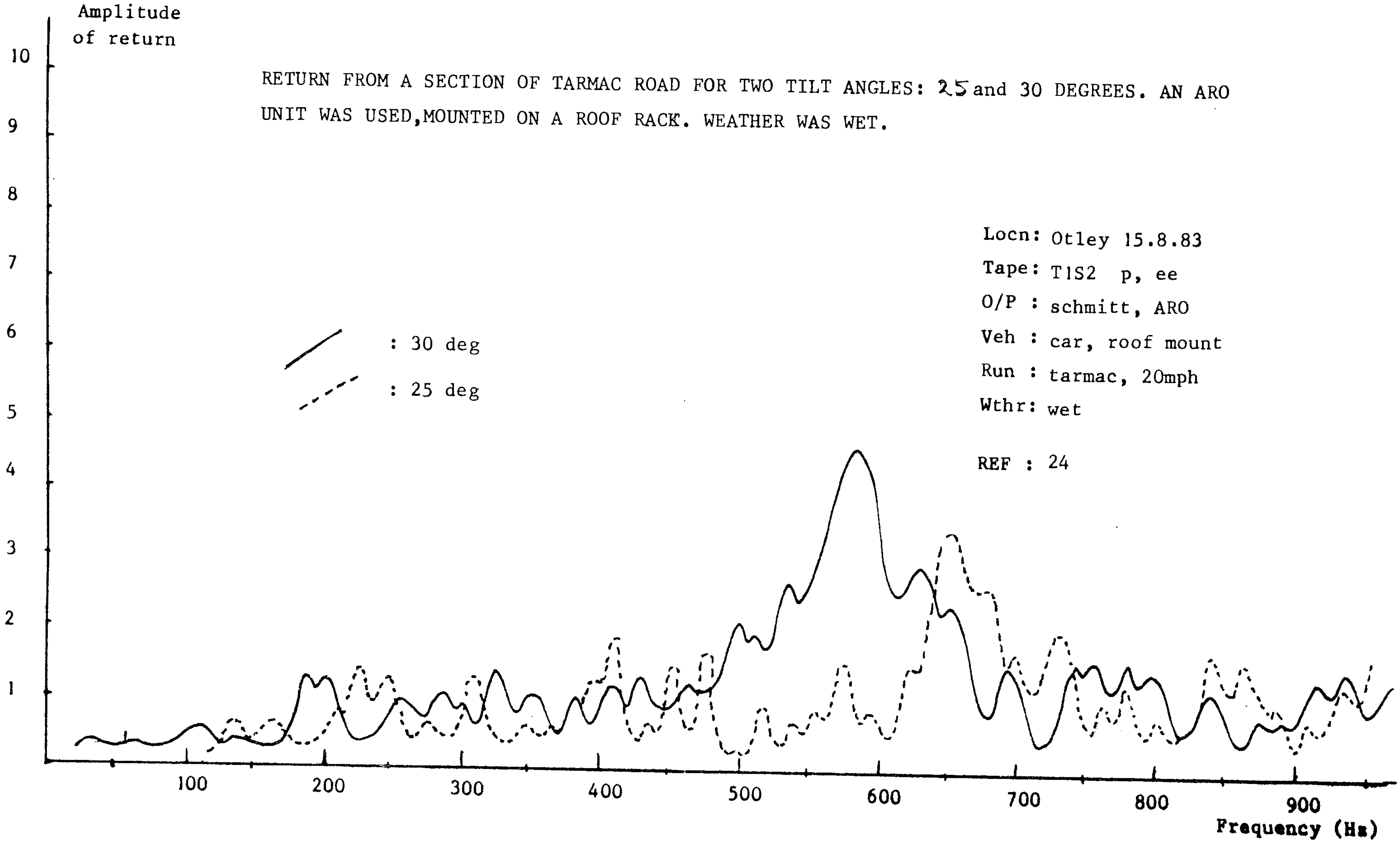

Amplitude of return
COMPARISON OF SCHMITT AND PLL OUTPUTS FOR A TUNING-FORK TARGET: ARO UNIT MOUNTED ON A VIBRATOR RIG.
:PLL
:Schmitt
Locn: Lab. 18.11.83
Tape: 2A1
O/P : schmitt and pll
Veh : vibration rig 2"/20hz
Run : 440hz tuning fork
Wthr:
REF : 18D
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)


Amplitude
of return
A COMPARISON OF RETURNS FROM THE TRW RADAR UNIT MOUNTED ON A CAR FOR WET AND VERY WET GROUND CONDITIONS. THE TERRAIN WAS A POTHOLED UNMADE TRACK
Locn:
Tape:
O/P :
TX :
Veh :
Run :
Weah:
REF :
Locn: Otley: Poole road tip
Tape: TRW 1A, h,j
O/P : schmitt / TRW
Veh : car, roof mounted
Run : rough earth, 10mph
Weah: very wet
REF : 20
: wet
: very wet
10
9
8
7
6
5
4
3
2
1
200
400
600
800
1000
1200
1400
1600
1800
Frequency (Hz)

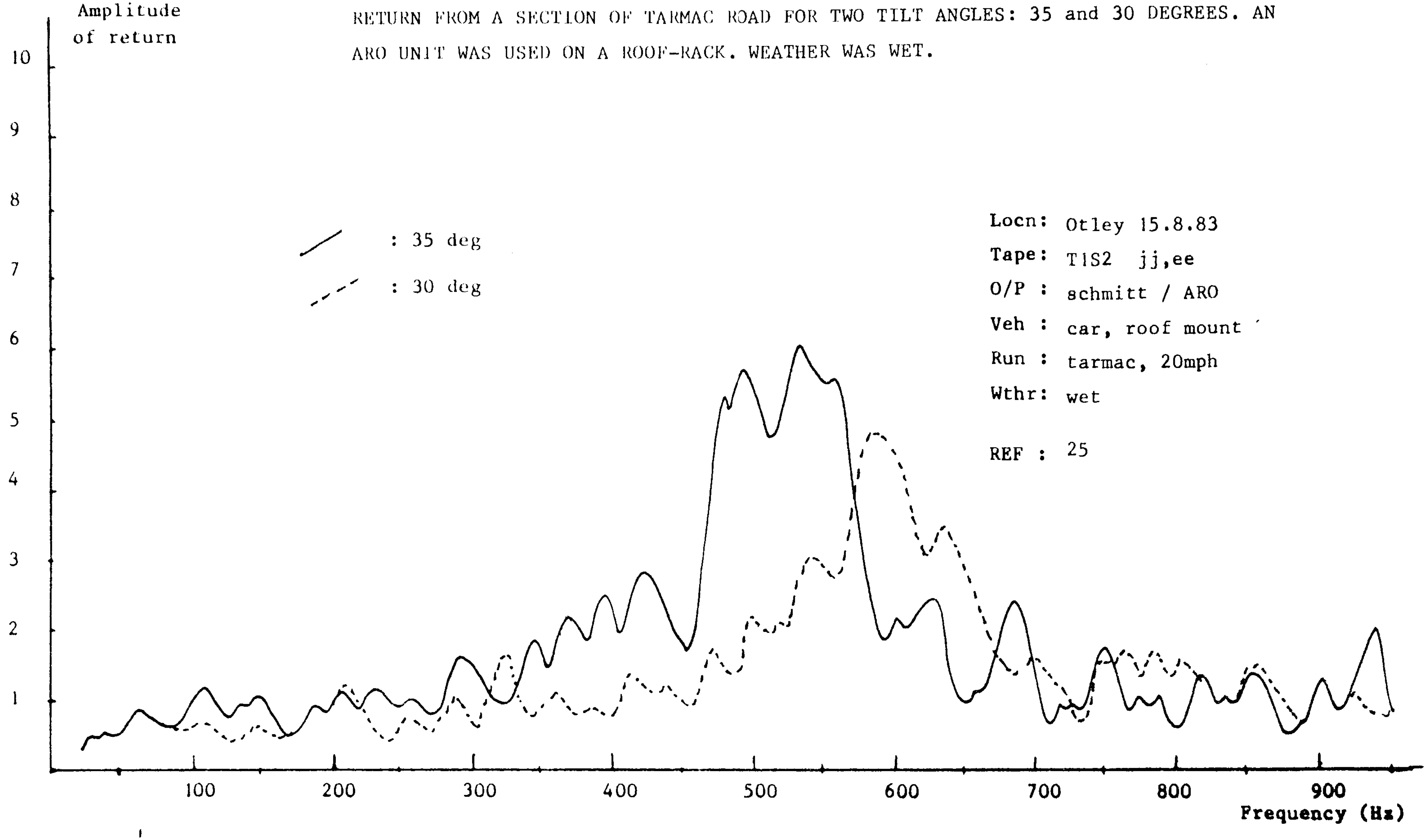

Amplitude of return
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)
COMPARISON BETWEEN TWO RECORDINGS OF THE SAME STRETCH OF ROAD. THE HORN PROTOTYPE WAS USED, WITHOUT ANTIVIBRATION MOUNTS, ON THE TRAILER.
Locn: Otley. Back Poole Rd.
Tape: XP1/1 b1,b2 29.12.84
O/P : schmitt. horn
Veh : car, trailer
Run : tarmac, dry. 20mph
Wthr: dry
REF : 19


RETURN FROM THE TRW UNIT, ROOF MOUNTED, MEASURED ON TARMAC IN WET WEATHER.
Amplitude of return
Locn: Otley. Poole Rd. 19.12.83
Tape: TRW1A j
O/P : schmitt / TRW
TX :
Veh : car, roof mounted, 40deg
Run : tarmac, 40 deg
Weah: v. wet
REF : 21
1
2
3
4
5
6
7
8
9
10
200
400
600
800
1000
1200
1400
1600
1800
Frequency (Hz)

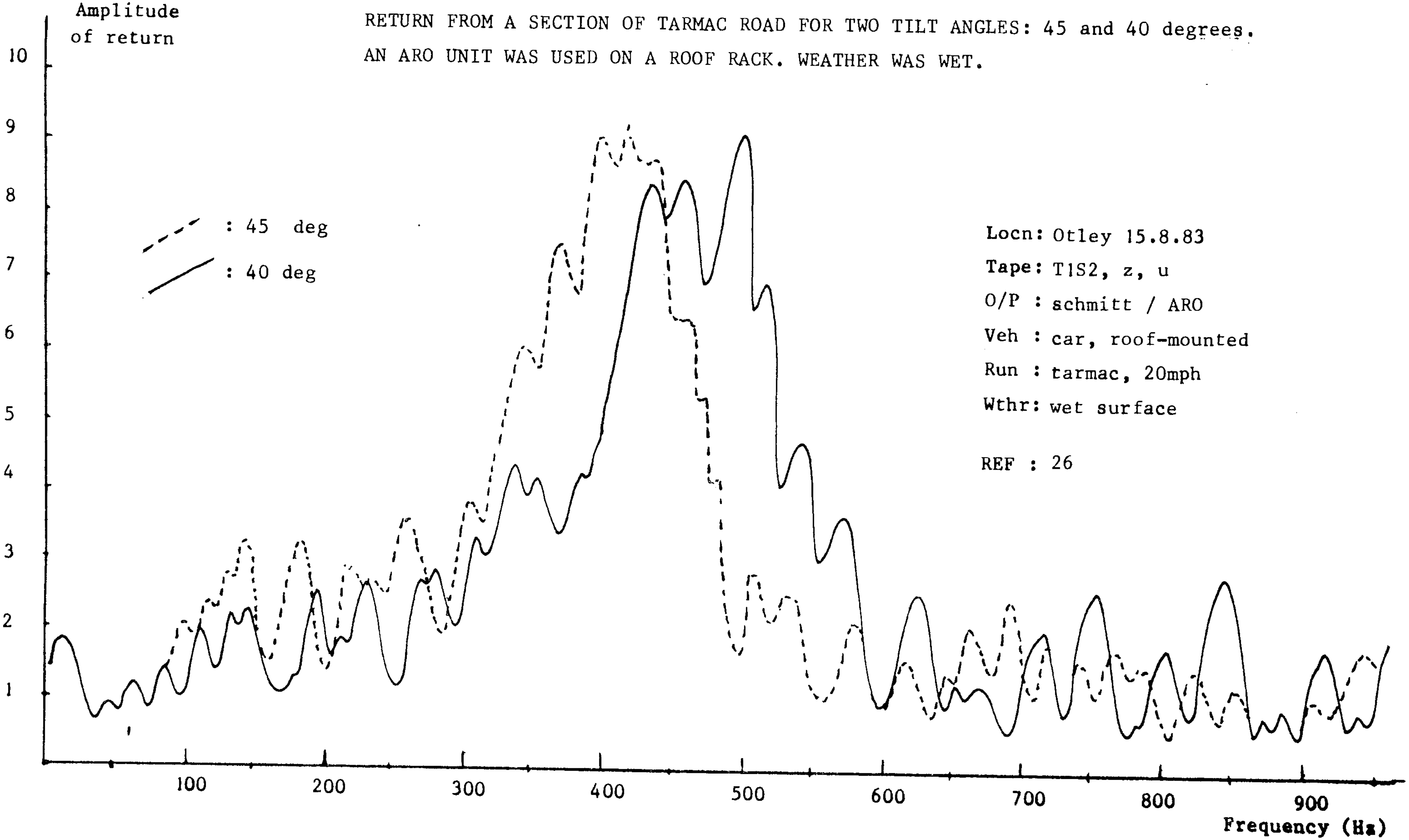

Amplitude of return
COMPARISON OF RETURN FROM THE TW RADAR UNIT FOR LADEN AND UNLADEN TRUCKS..
GROUND CONDITIONS WERE MUDDY AND SMOOTH.
Locn: Butterwell 21.3.84
Tape: TRW a,b
O/P : schmitt / TRW
TX : TRW
Veh : Cat 777
Run : haul road, 15mph
Weah: wet, muddy
REF : 22
: laden
: unladen
1
2
3
4
5
6
7
8
9
10
200
400
600
800
1000
1200
1400
1600
1800
Frequency (Hz)


Amplitude
of return
RETURN FROM A SECTION OF TARMAC ROAD FOR TWO TILT ANGLES: 25 and 30 DEGREES. AN ARO
UNIT WAS USED,MOUNTED ON A ROOF RACK. WEATHER WAS WET.
: 30 deg
: 25 deg
Locn: Otley 15.8.83
Tape: T1S2 p, ee
O/P : schmitt, ARO
Veh : car, roof mount
Run : tarmac, 20mph
Wthr: wet
REF : 24
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)

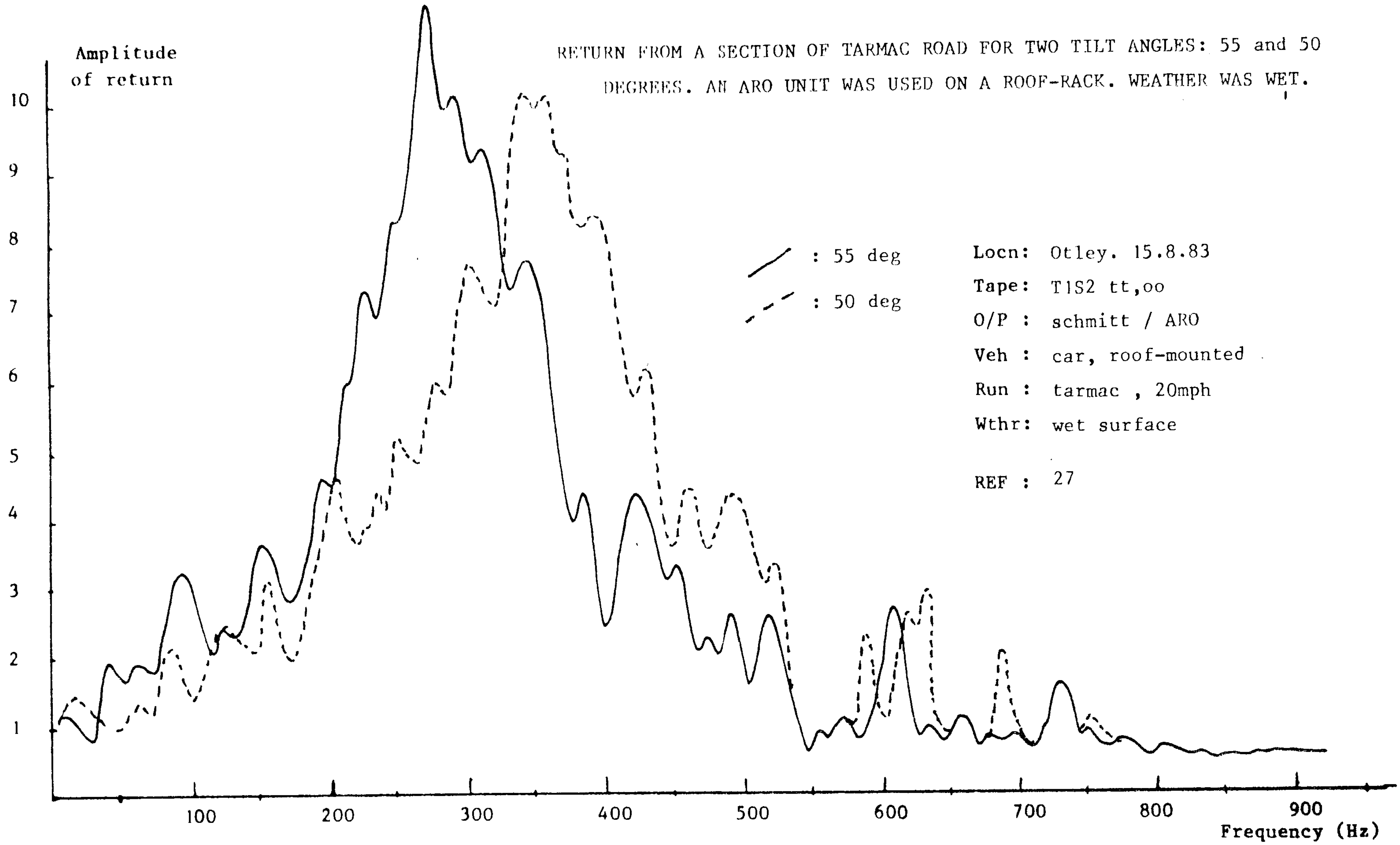
RETURN FROM A SECTION OF TARMAC ROAD FOR TWO TILT ANGLES: 35 and 30 DEGREES. AN ARO UNIT WAS USED ON A ROOF-RACK. WEATHER WAS WET.



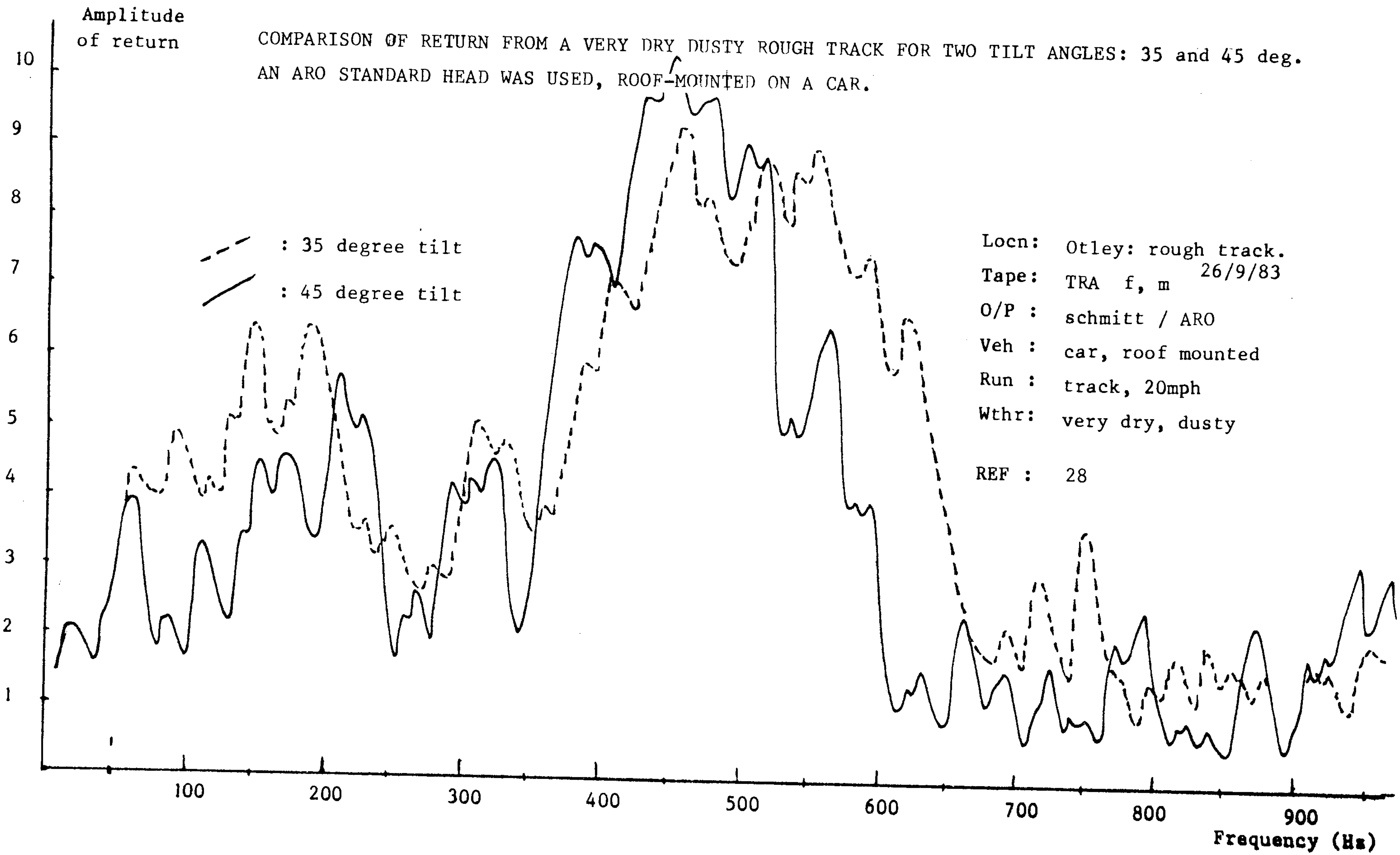
RETURN FROM A SECTION OF TARMAC ROAD FOR TWO TILT ANGLES: 45 and 40 degrees.
AN ARO UNIT WAS USED ON A ROOF RACK. WEATHER WAS WET.



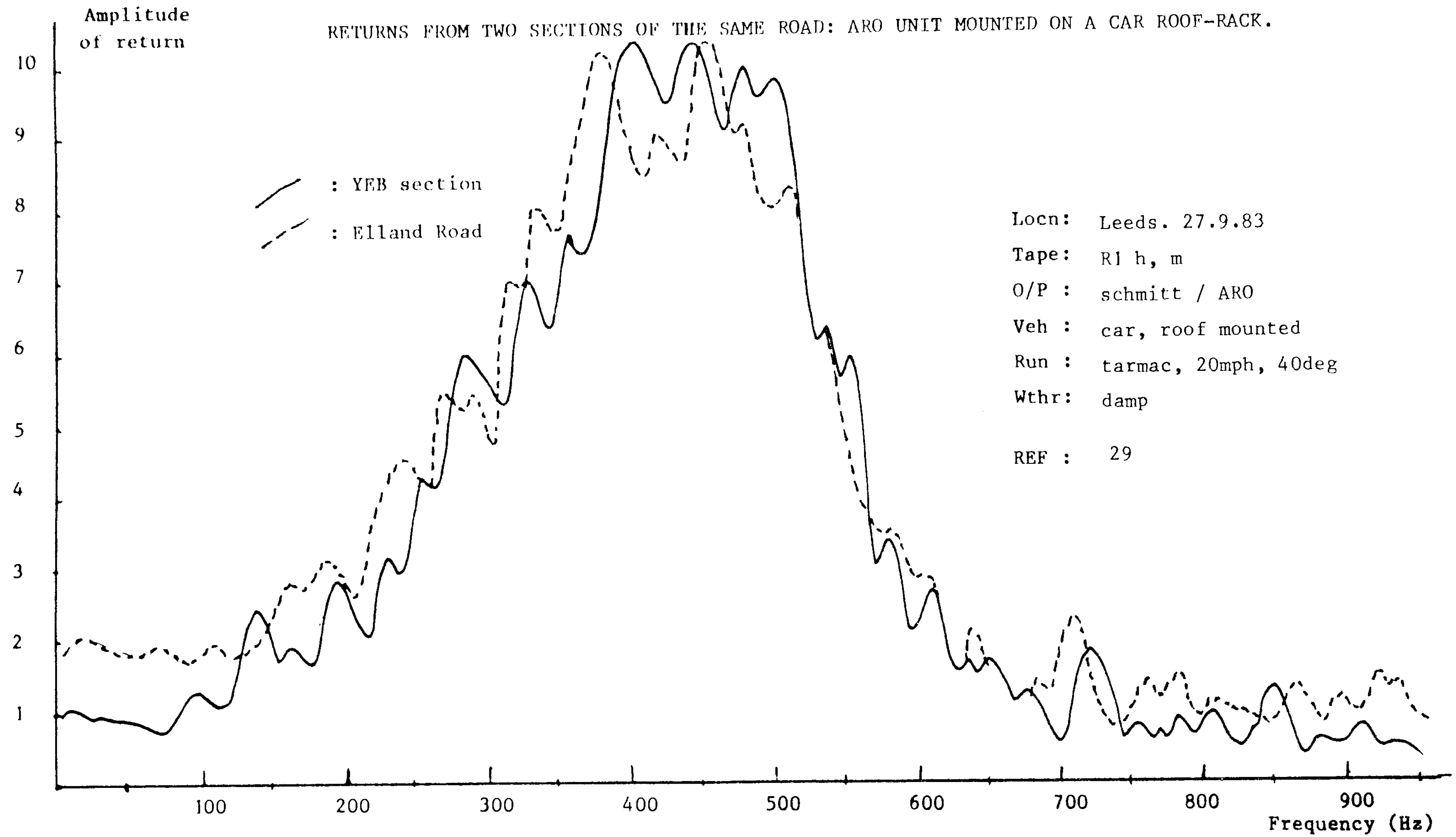
RETURN FROM A SECTION OF TARMAC ROAD FOR TWO TILT ANGLES: 55 and 50 DEGREES. AN ARO UNIT WAS USED ON A ROOF-RACK. WEATHER WAS WET.



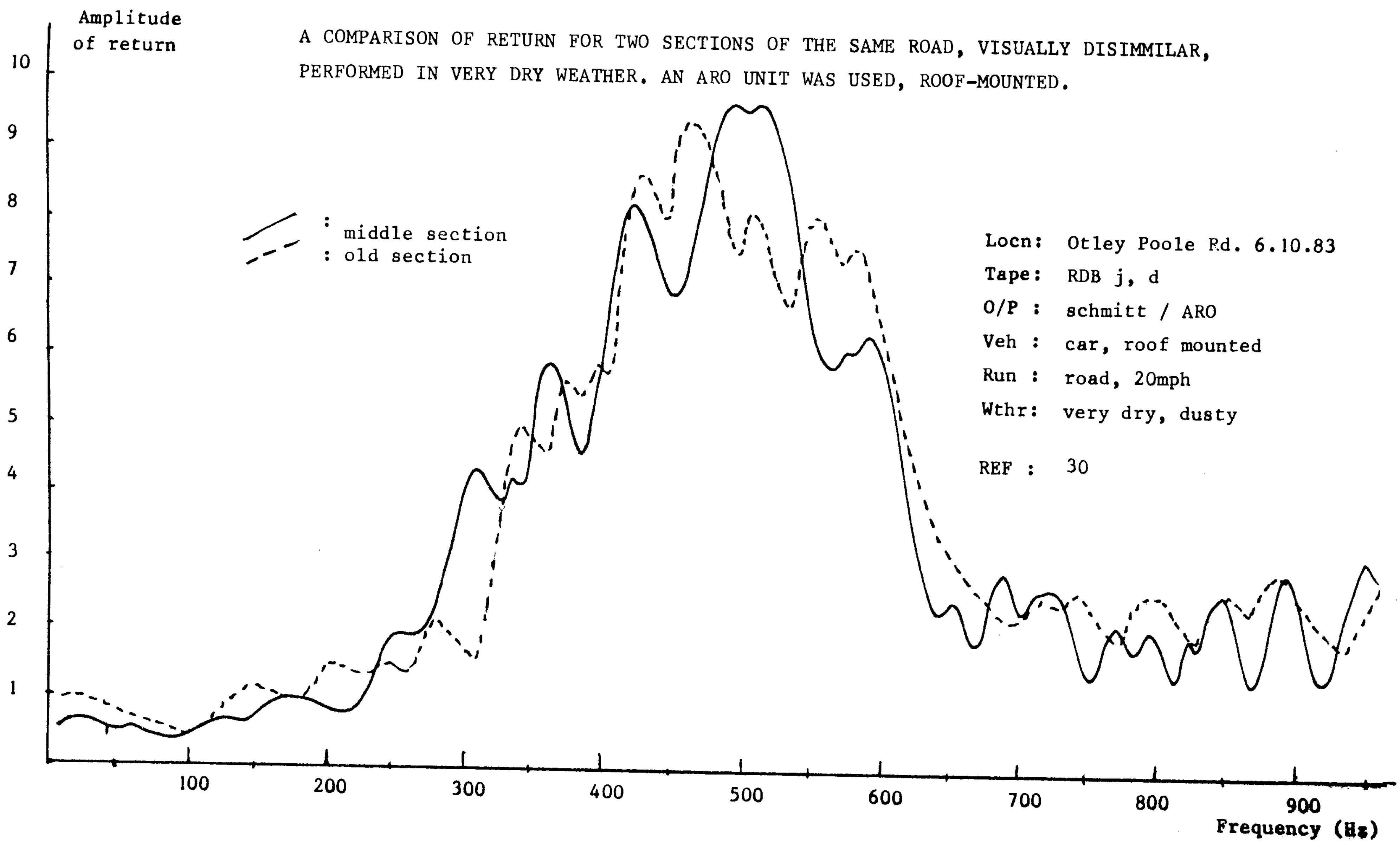
COMPARISON OF RETURN FROM A VERY DRY DUSTY ROUGH TRACK FOR TWO TILT ANGLES: 35 and 45 deg.
AN ARO STANDARD HEAD WAS USED, ROOF-MOUNTED ON A CAR.

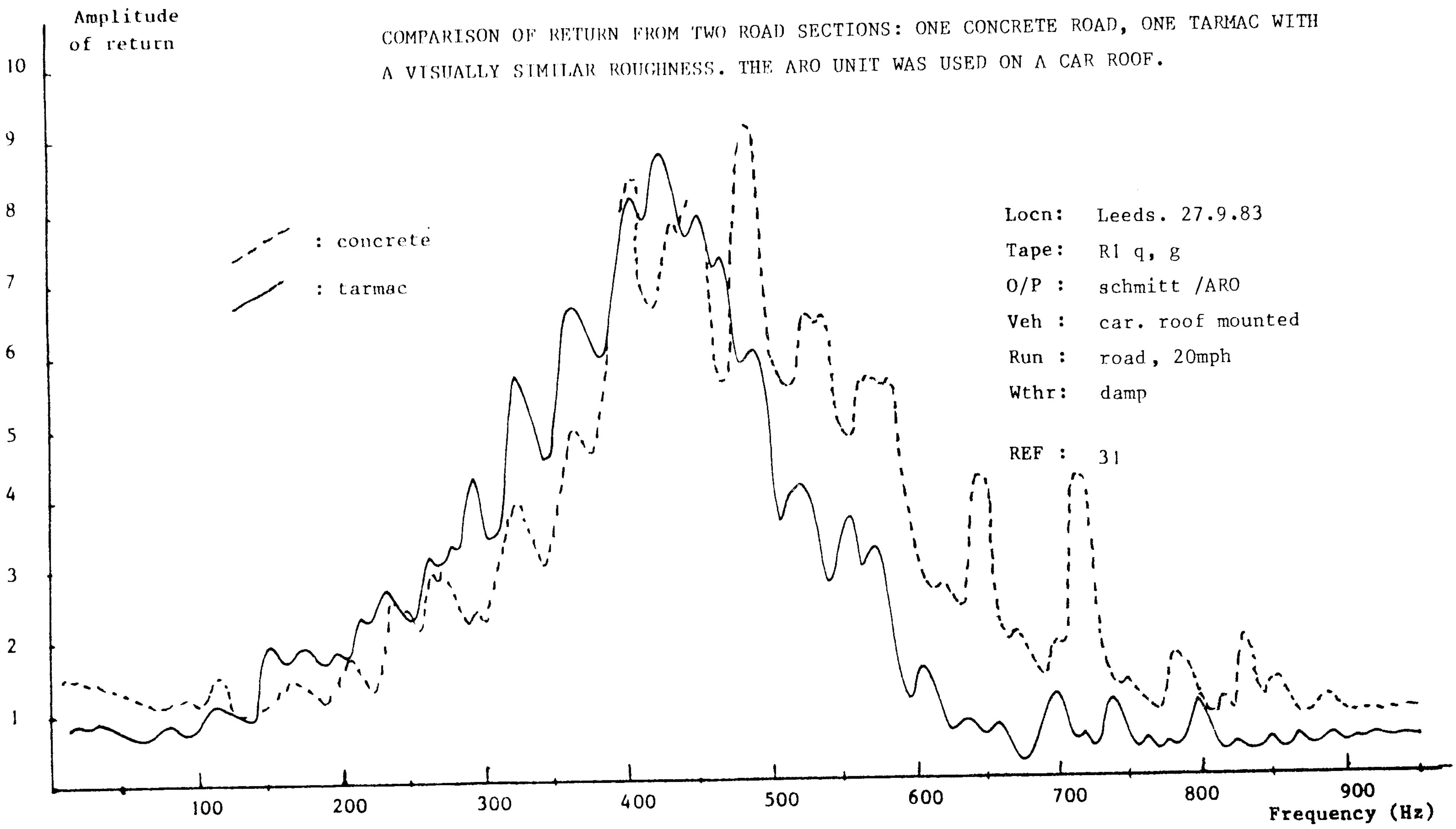


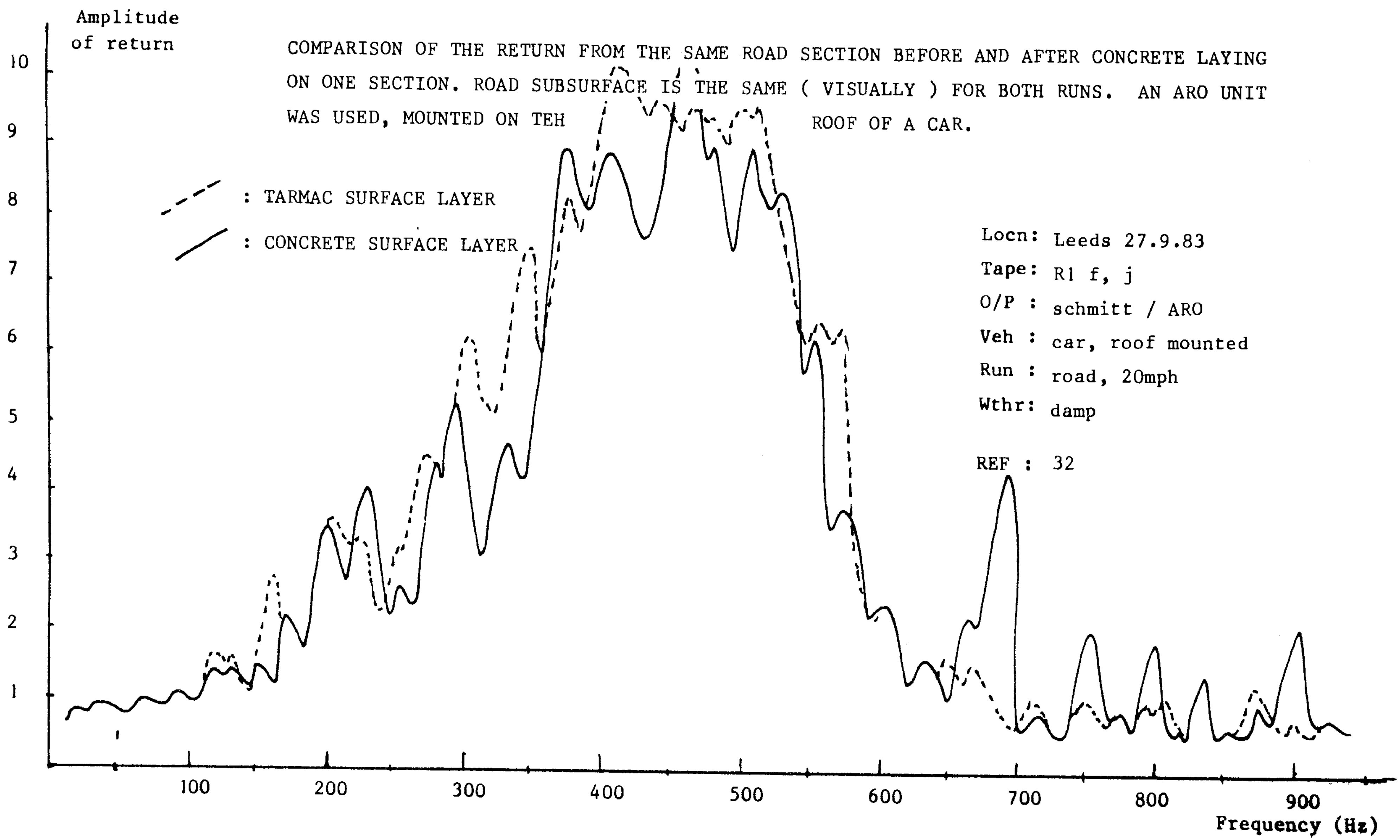
RETURNS FROM TWO SECTIONS OF THE SAME ROAD: ARO UNIT MOUNTED ON A CAR ROOF-RACK.

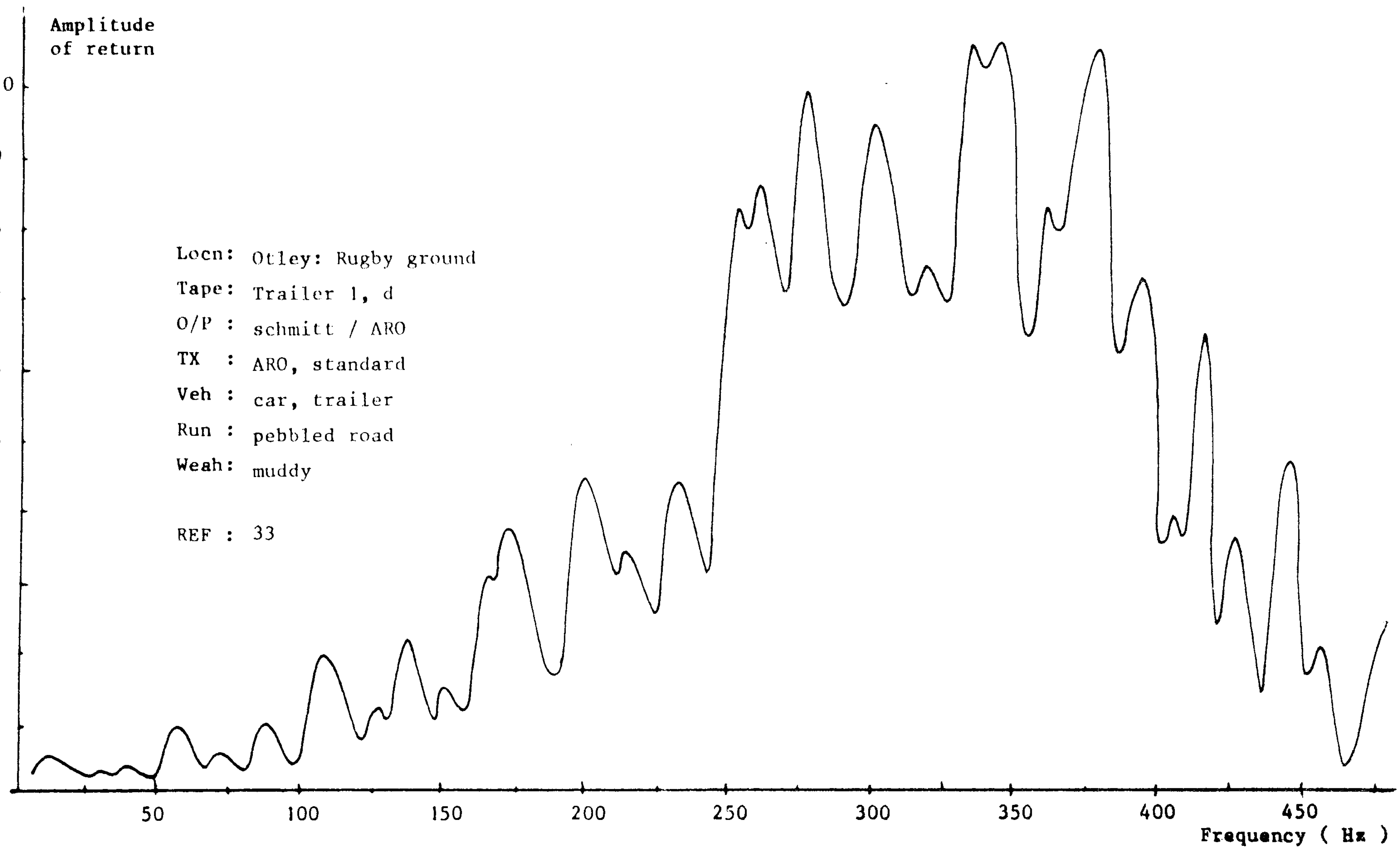


A COMPARISON OF RETURN FOR TWO SECTIONS OF THE SAME ROAD, VISUALLY DISIMMILAR, PERFORMED IN VERY DRY WEATHER. AN ARO UNIT WAS USED, ROOF-MOUNTED.

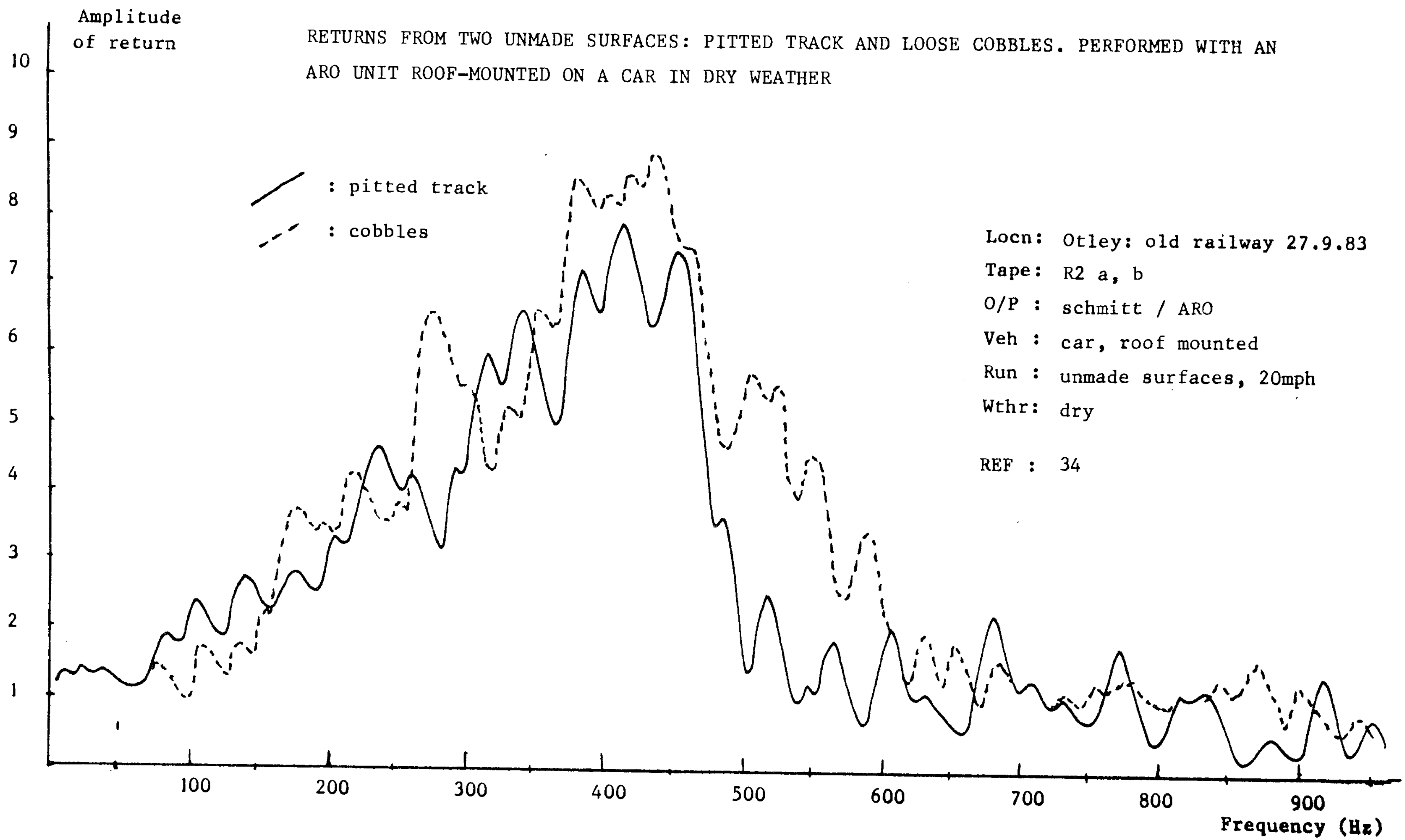


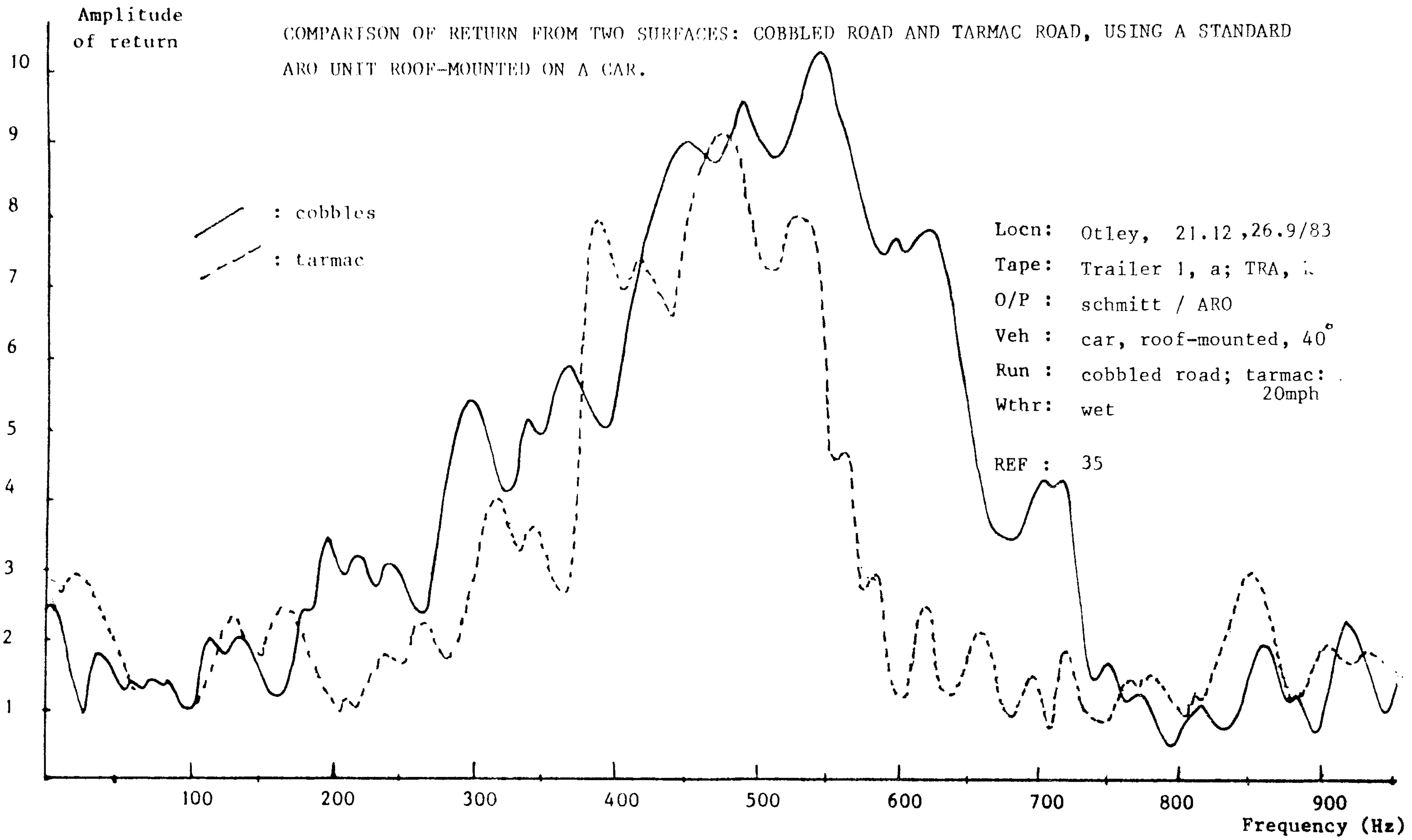

COMPARISON OF RETURN FROM TWO ROAD SECTIONS: ONE CONCRETE ROAD, ONE TARMAC WITH A VISUALLY SIMILAR ROUGHNESS. THE ARO UNIT WAS USED ON A CAR ROOF.
Amplitude of return
10
9
8
7
6
5
4
3
2
1
: concrete
: tarmac
Locn: Leeds. 27.9.83
Tape: R1 q, g
O/P : schmitt /ARO
Veh : car. roof mounted
Run : road, 20mph
Wthr: damp
REF : 31
100
200
300
400
500
600
700
800
900
Frequency (Hz)

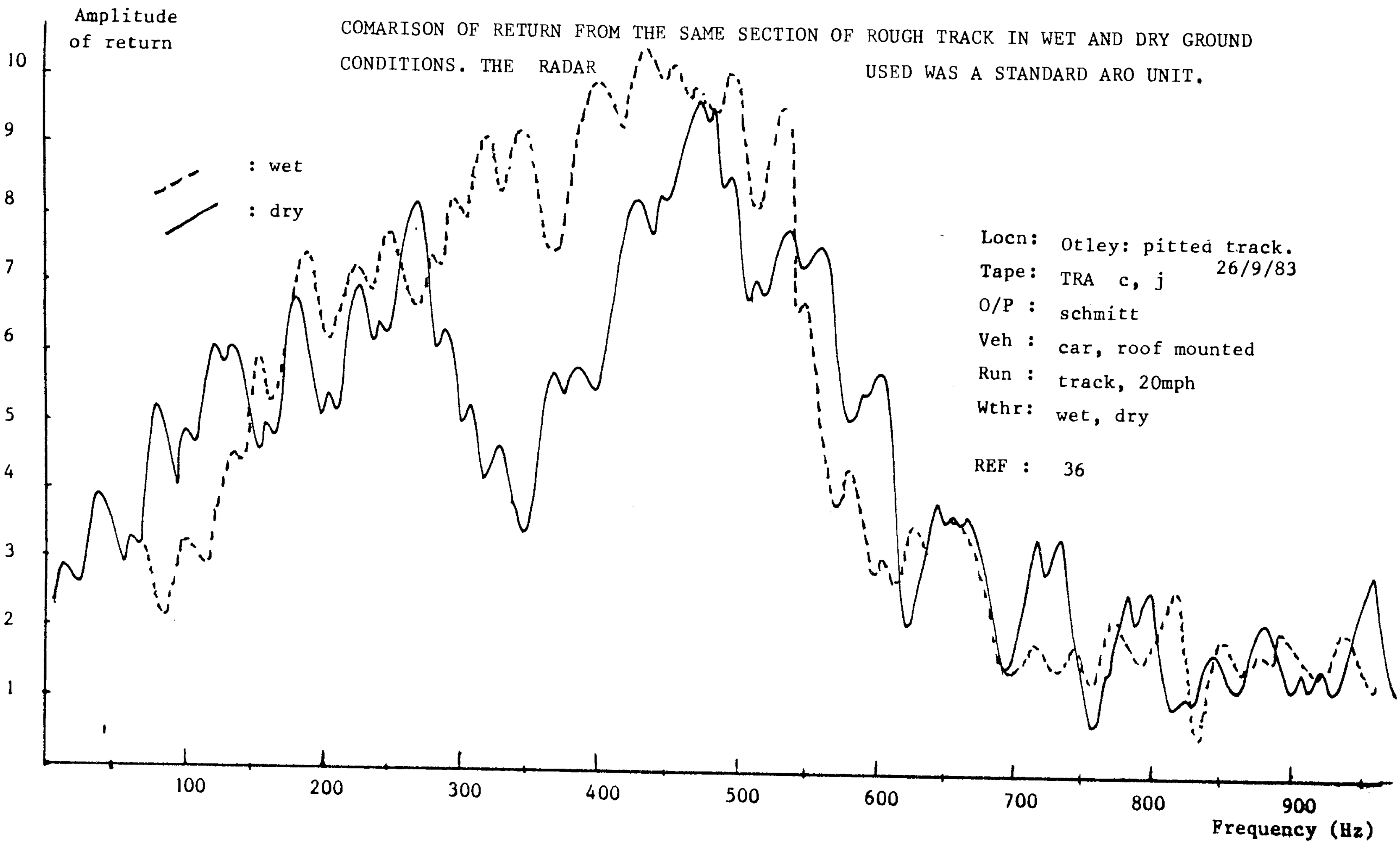

Amplitude
of return
COMPARISON OF THE RETURN FROM THE SAME ROAD SECTION BEFORE AND AFTER CONCRETE LAYING
ON ONE SECTION. ROAD SUBSURFACE IS THE SAME (VISUALLY) FOR BOTH RUNS. AN ARO UNIT
WAS USED, MOUNTED ON TEH ROOF OF A CAR.
: TARMAC SURFACE LAYER
: CONCRETE SURFACE LAYER
Locn: Leeds 27.9.83
Tape: Rl f, j
O/P : schmitt / ARO
Veh : car, roof mounted
Run : road, 20mph
Wthr: damp
REF : 32
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)

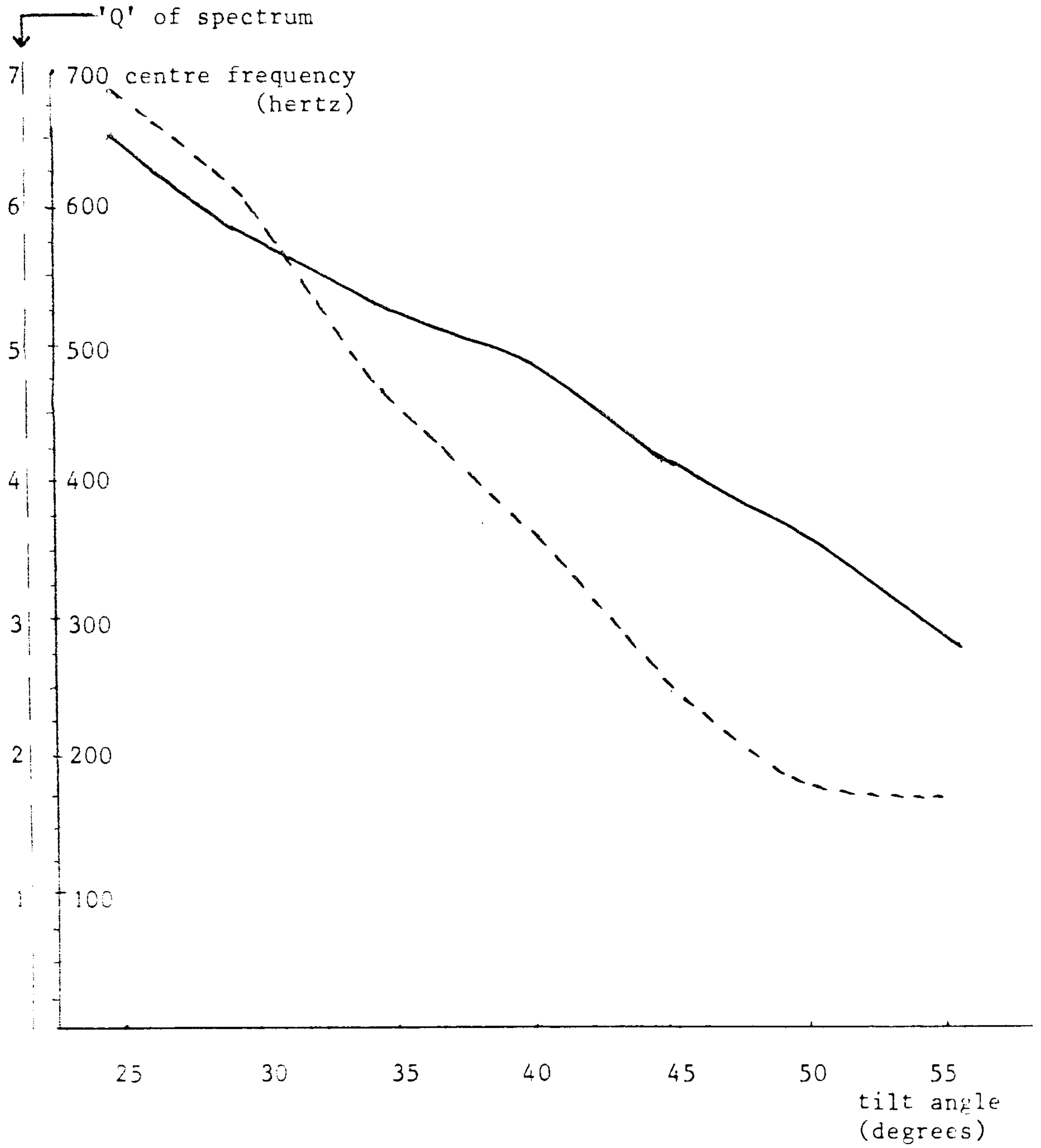


Amplitude
of return
10
9
8
7
6
5
4
3
2
1
50
100
150
200
250
300
350
400
450
Frequency (Hz)
Locn: Otley: Rugby ground
Tape: Trailer 1, d
O/P : schmitt / ARO
TX : ARO, standard
Veh : car, trailer
Run : pebbled road
Weah: muddy
REF : 33


Amplitude of return
RETURNS FROM TWO UNMADE SURFACES: PITTED TRACK AND LOOSE COBBLES. PERFORMED WITH AN ARO UNIT ROOF-MOUNTED ON A CAR IN DRY WEATHER
: pitted track
: cobbles
Locn: Otley: old railway 27.9.83
Tape: R2 a, b
O/P : schmitt / ARO
Veh : car, roof mounted
Run : unmade surfaces, 20mph
Wthr: dry
REF : 34
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)


COMPARISON OF RETURN FROM TWO SURFACES: COBBLED ROAD AND TARMAC ROAD, USING A STANDARD ARO UNIT ROOF-MOUNTED ON A CAR.
Amplitude of return
: cobbles
: tarmac
Locn: Otley, 21.12, 26.9/83
Tape: Trailer 1, a; TRA,
O/P : schmitt / ARO
Veh : car, roof-mounted, 40°
Run : cobbled road; tarmac: 20mph
Wthr: wet
REF : 35
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)


COMARISON OF RETURN FROM THE SAME SECTION OF ROUGH TRACK IN WET AND DRY GROUND
CONDITIONS. THE RADAR USED WAS A STANDARD ARO UNIT.
Amplitude
of return
10
9
8
7
6
5
4
3
2
1
: wet
: dry
Locn: Otley: pitted track.
26/9/83
Tape: TRA c, j
O/P : schmitt
Veh : car, roof mounted
Run : track, 20mph
Wthr: wet, dry
REF : 36
100
200
300
400
500
600
700
800
900
Frequency (Hz)



Tape: TIS2 15.8.83

Locn: Otley, Poole Road

Veh : Car, roof-rack

Unit: ARO standard

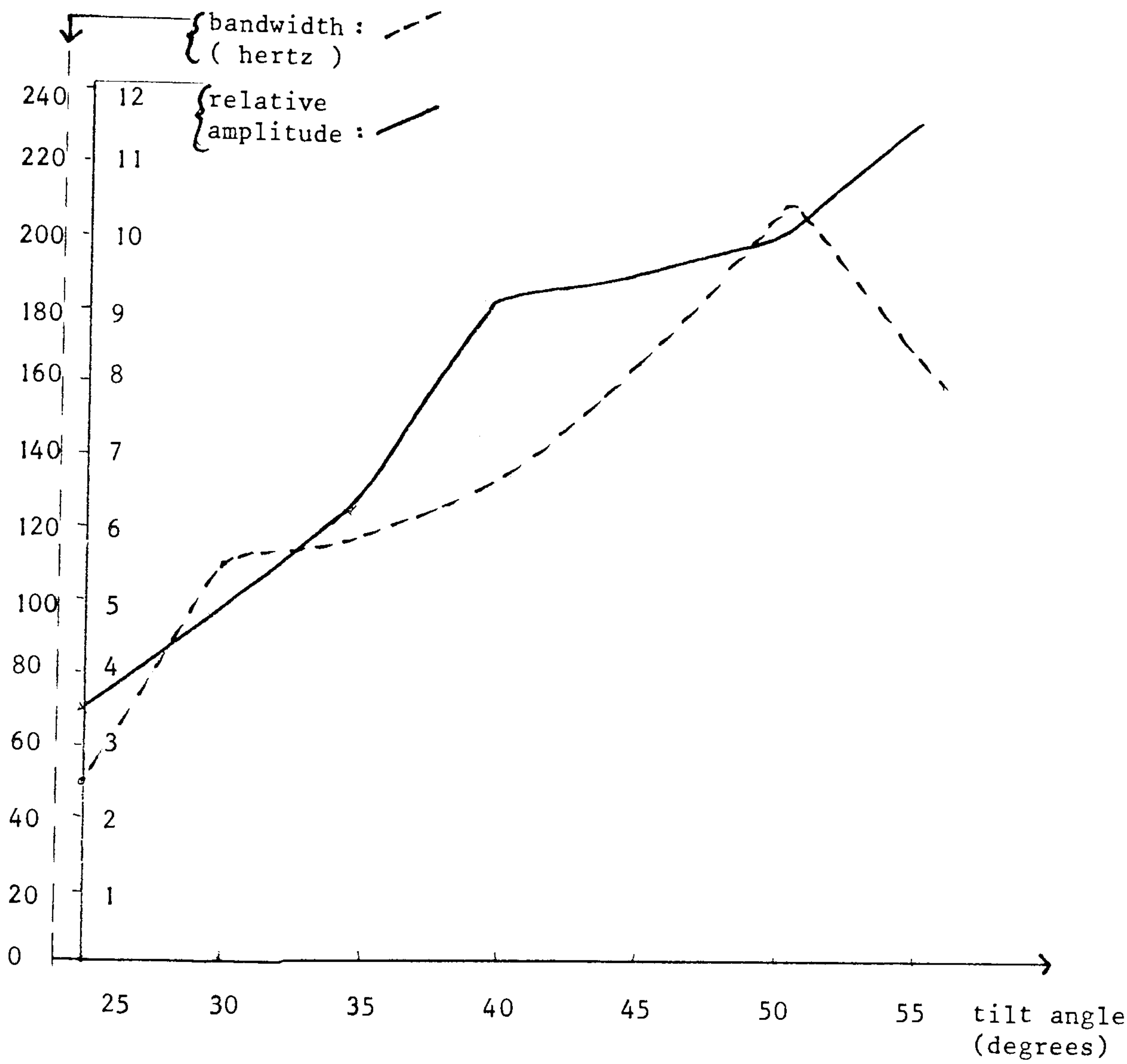
Wthr: wet

Run : tarmac, 20mph

Note: The 'Q' of the spectrum is defined here as the centre frequency divided by the bandwidth of the curve at the half-amplitude point.

REF: 37A

PLOT OF THE CENTRE FREQUENCY AND 'Q' OF THE RETURNED SIGNAL FROM TARMAC FOR A RANGE OF TILT ANGLES. AN ARO STANDARD UNIT, CAR-MOUNTED, WAS USED.



Tape: T1S2 15.8.83 REF: 37B

Locn: Otley, Poole Road

Veh : car, roof-mounted

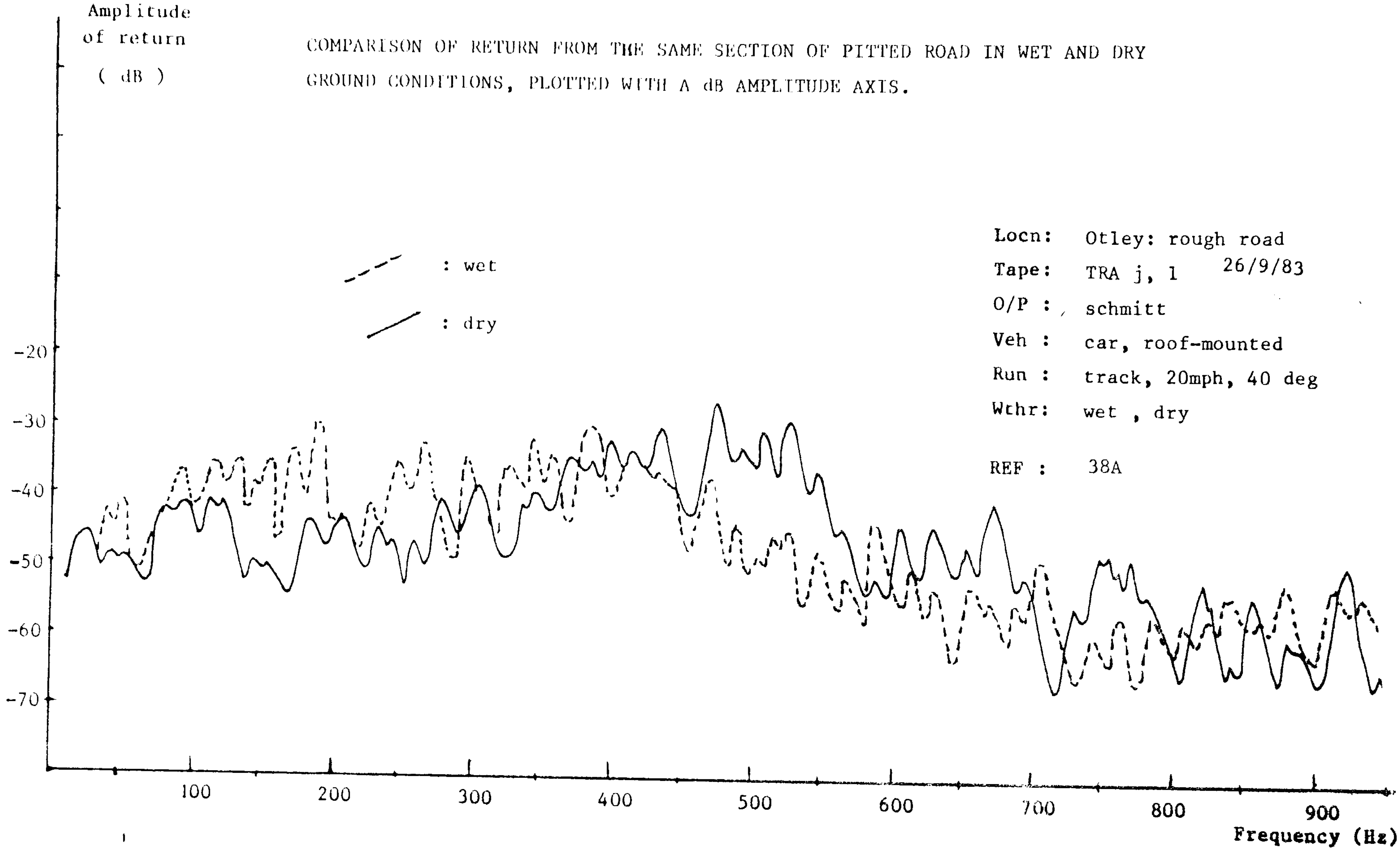
Unit: ARO standard

Wthr: wet surface

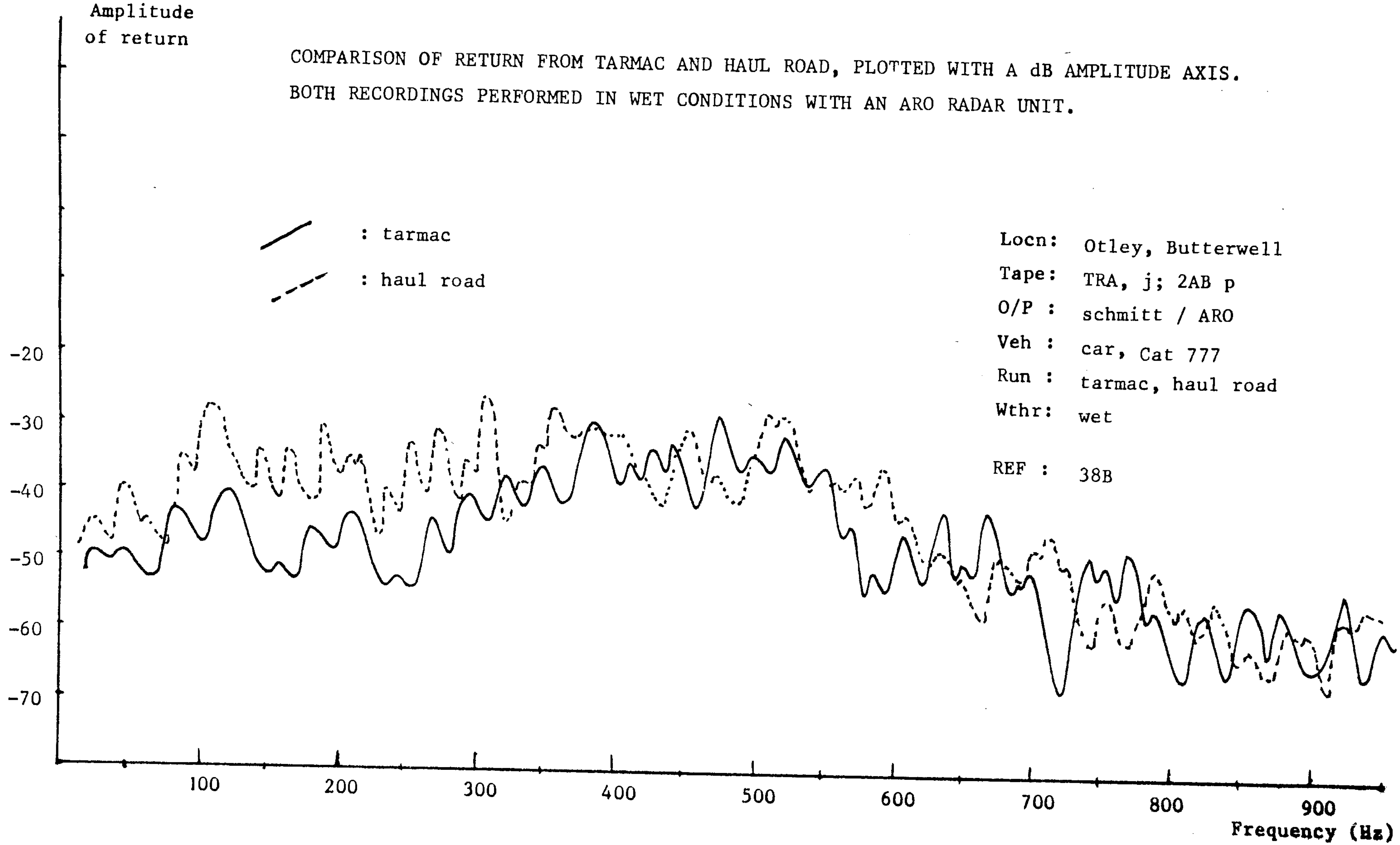
Run : tarmac, 20mph, 25 to 55 deg tilt

PLOT OF THE AMPLITUDE AND BANDWIDTH (at half-peak amplitude) OF RETURNED SIGNAL SPECTRA. AN ARO STANDARD UNIT, CAR MOUNTED, WAS USED ON A TARMAC ROAD.

COMPARISON OF RETURN FROM THE SAME SECTION OF PITTED ROAD IN WET AND DRY GROUND CONDITIONS, PLOTTED WITH A dB AMPLITUDE AXIS.

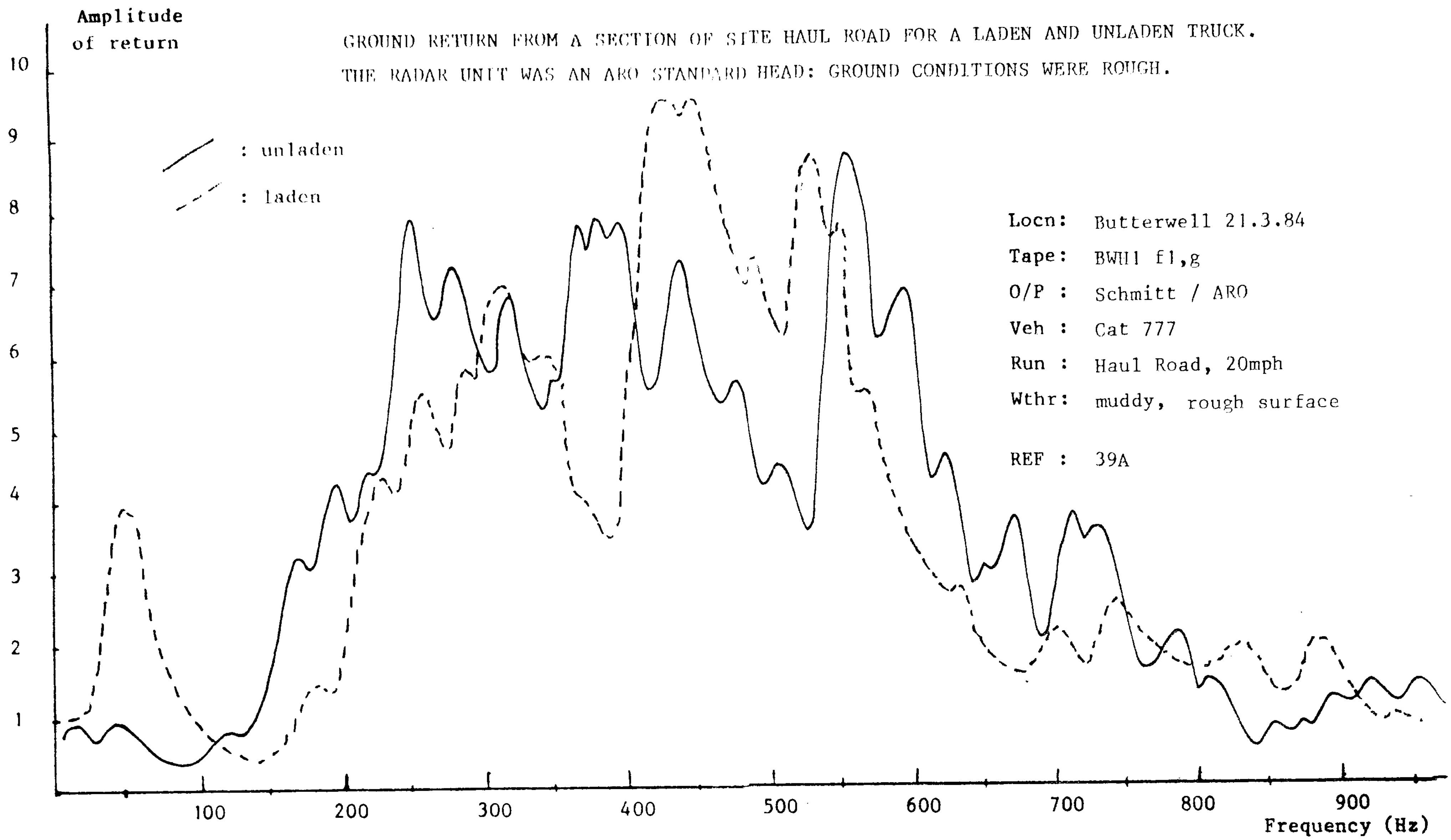


COMPARISON OF RETURN FROM TARMAC AND HAUL ROAD, PLOTTED WITH A dB AMPLITUDE AXIS.
BOTH RECORDINGS PERFORMED IN WET CONDITIONS WITH AN ARO RADAR UNIT.

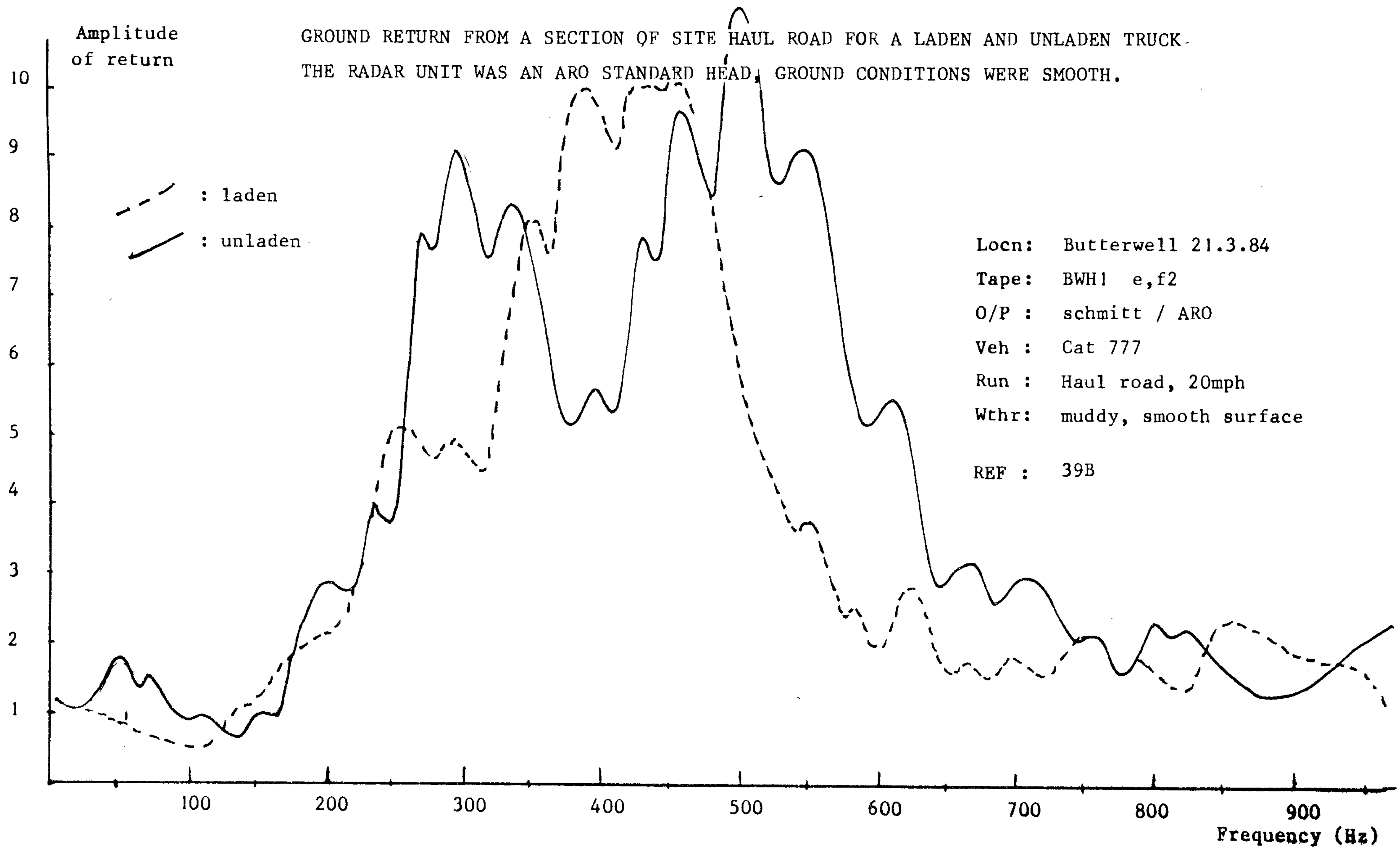


Locn: Otley, Butterwell
Tape: TRA, j; 2AB p
O/P : schmitt / ARO
Veh : car, Cat 777
Run : tarmac, haul road
Wthr: wet

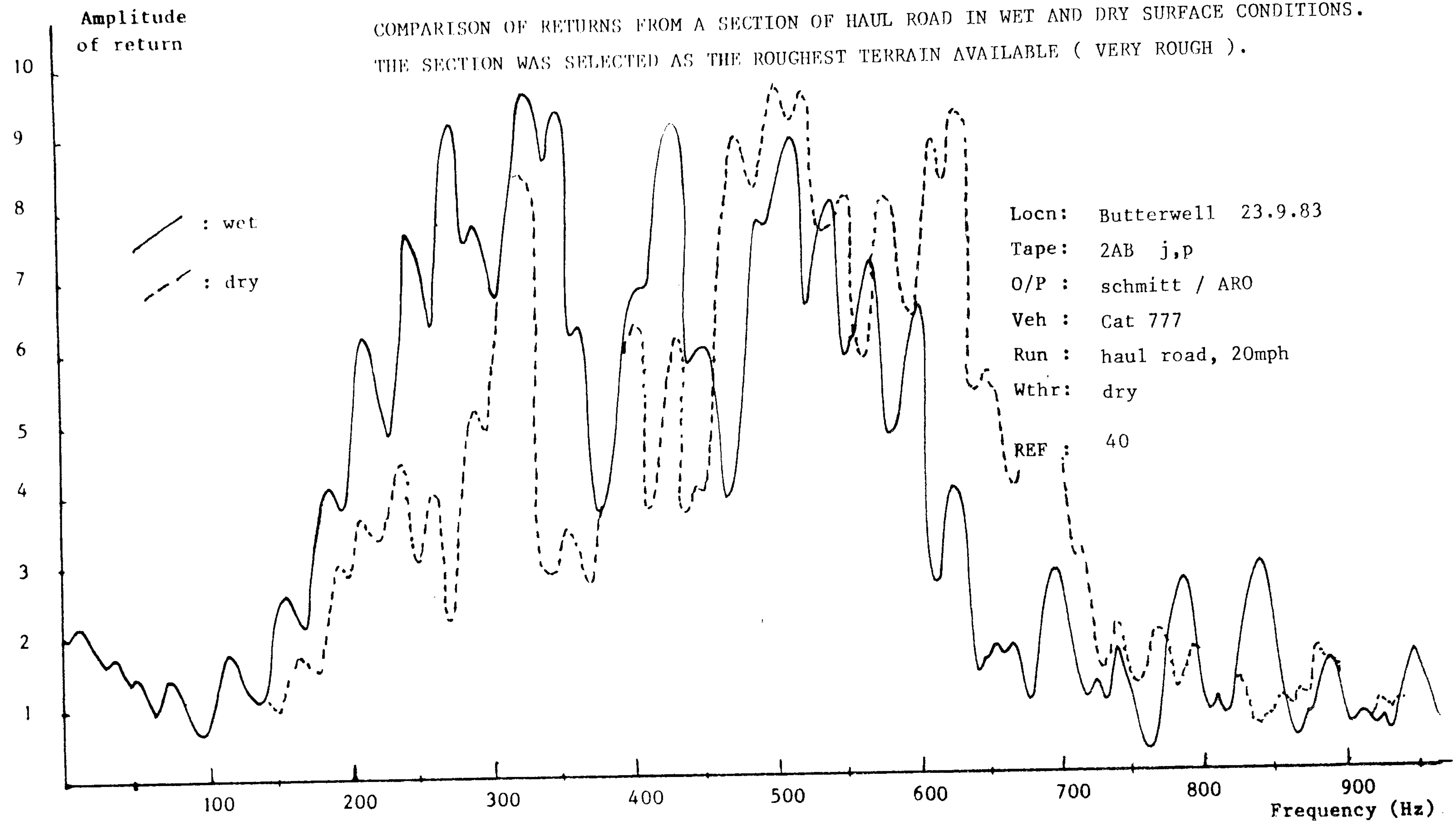
REF : 38B


Amplitude of return
GROUND RETURN FROM A SECTION OF SITE HAUL ROAD FOR A LADEN AND UNLADEN TRUCK.
THE RADAR UNIT WAS AN ARO STANDARD HEAD: GROUND CONDITIONS WERE ROUGH.
: unladen
: laden
Locn: Butterwell 21.3.84
Tape: BWH1 f1,g
O/P : Schmitt / ARO
Veh : Cat 777
Run : Haul Road, 20mph
Wthr: muddy, rough surface
REF : 39A
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)

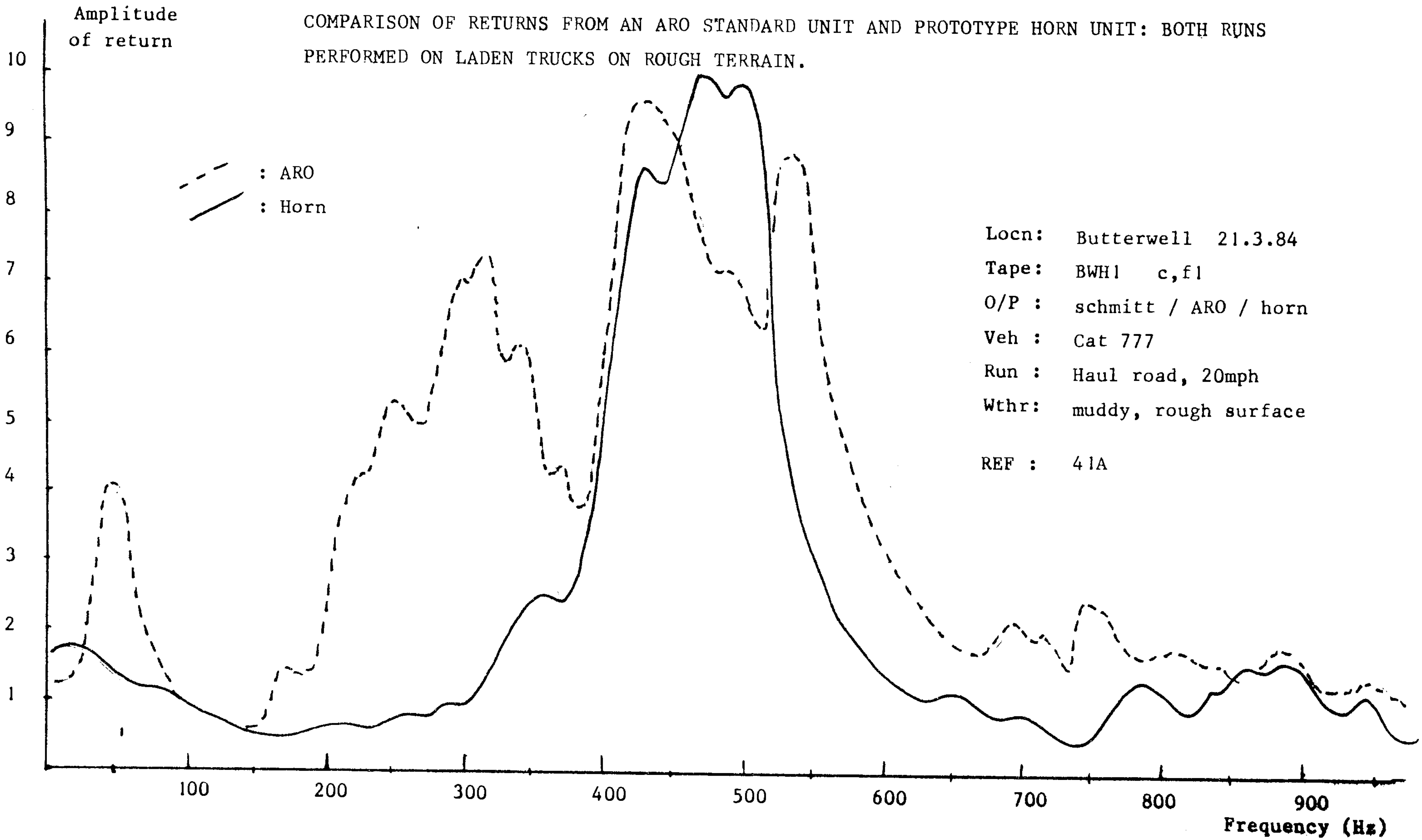
GROUND RETURN FROM A SECTION OF SITE HAUL ROAD FOR A LADEN AND UNLADEN TRUCK.
THE RADAR UNIT WAS AN ARO STANDARD HEAD, GROUND CONDITIONS WERE SMOOTH.



COMPARISON OF RETURNS FROM A SECTION OF HAUL ROAD IN WET AND DRY SURFACE CONDITIONS.
THE SECTION WAS SELECTED AS THE ROUGHEST TERRAIN AVAILABLE (VERY ROUGH).

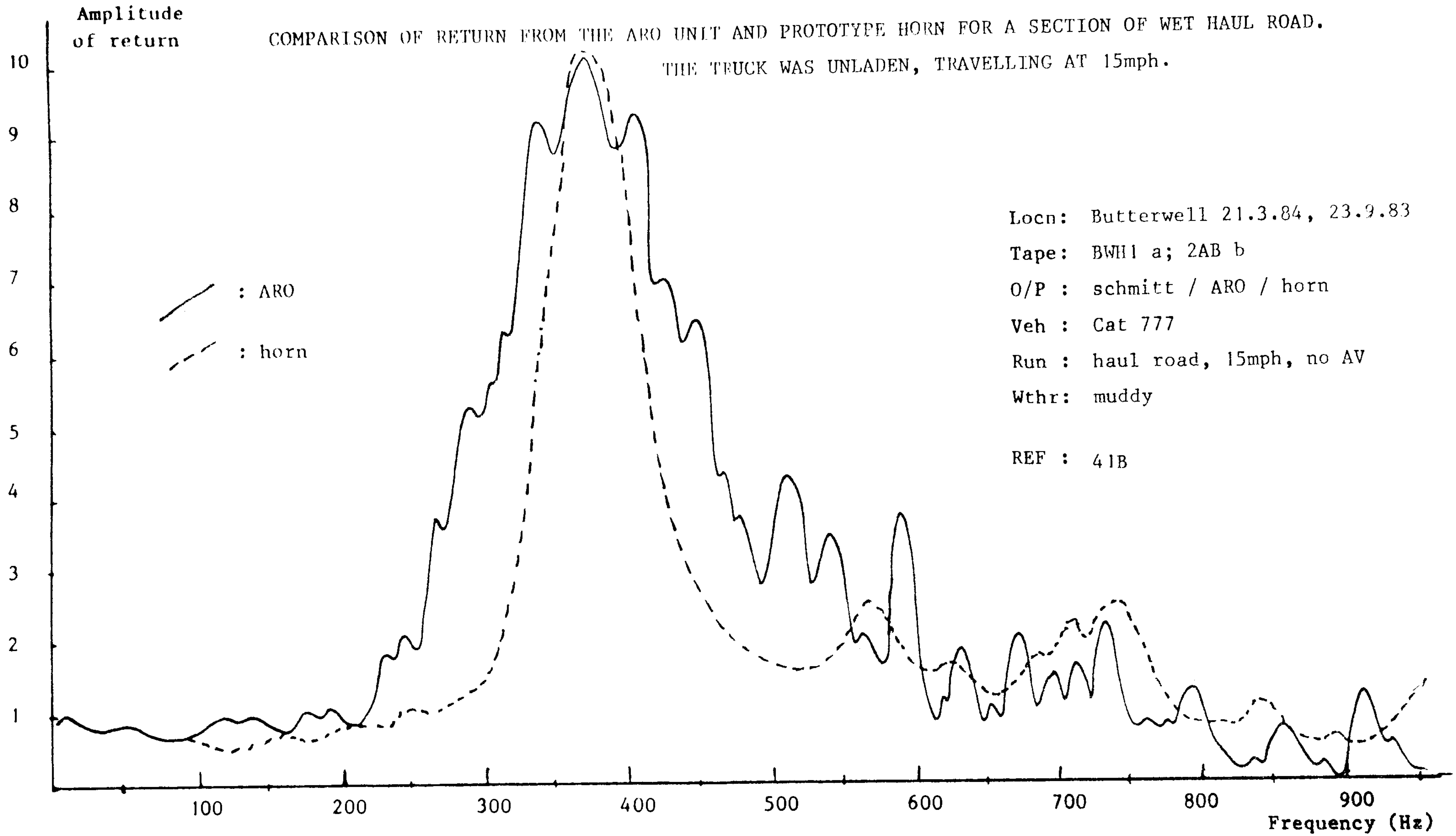


COMPARISON OF RETURNS FROM AN ARO STANDARD UNIT AND PROTOTYPE HORN UNIT: BOTH RUNS PERFORMED ON LADEN TRUCKS ON ROUGH TERRAIN.

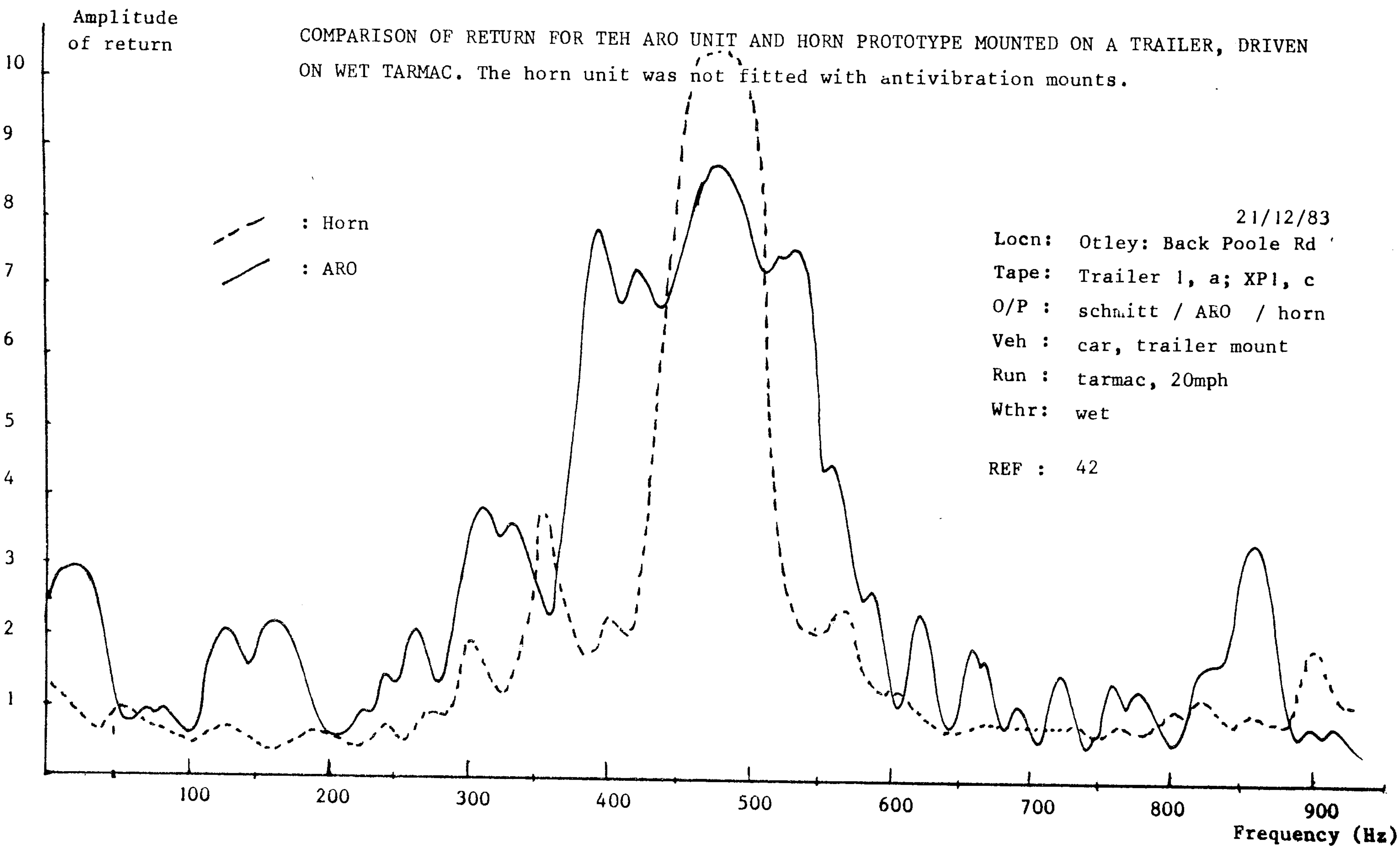


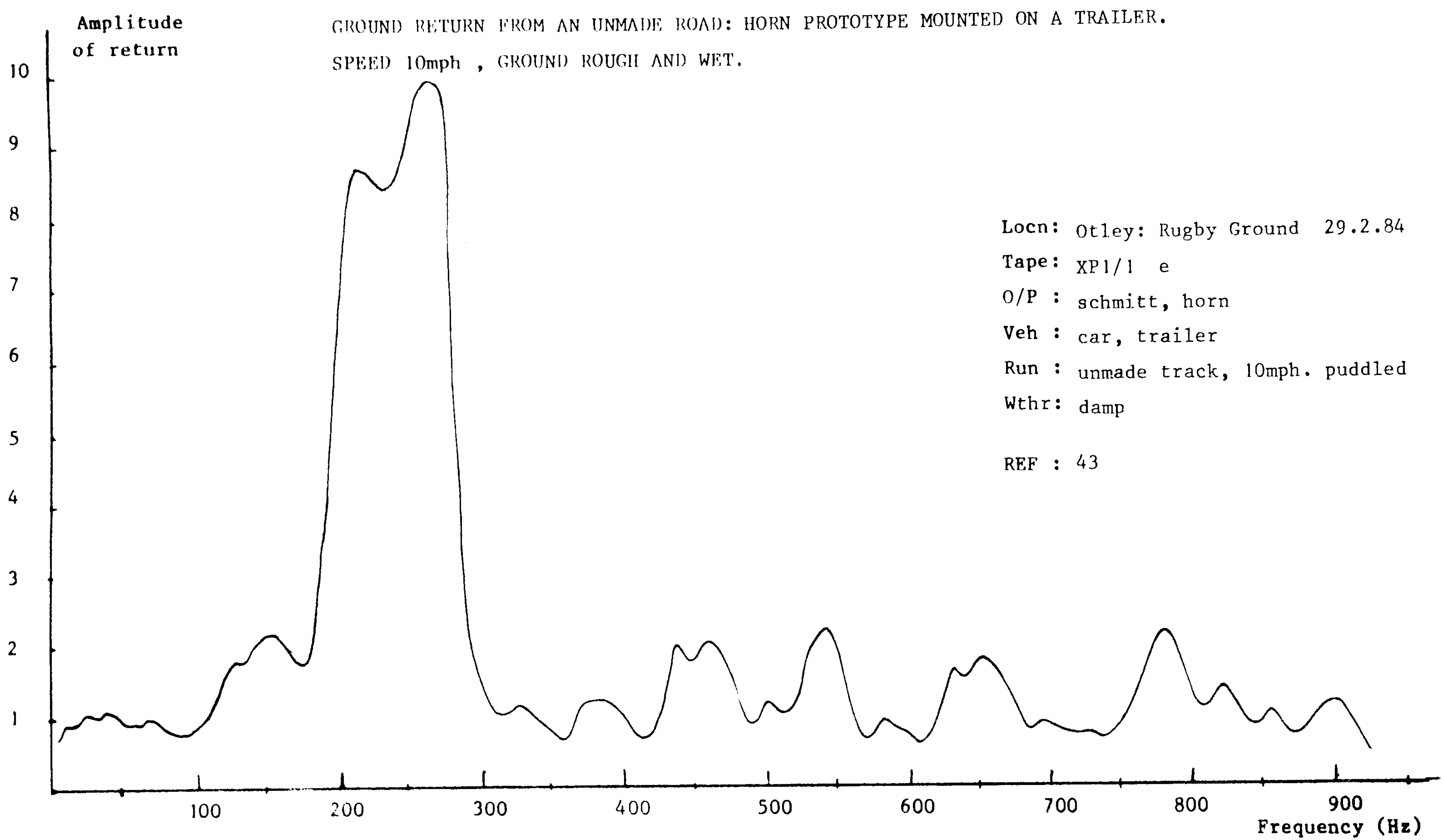
Locn: Butterwell 21.3.84
Tape: BWH1 c,f1
O/P : schmitt / ARO / horn
Veh : Cat 777
Run : Haul road, 20mph
Wthr: muddy, rough surface

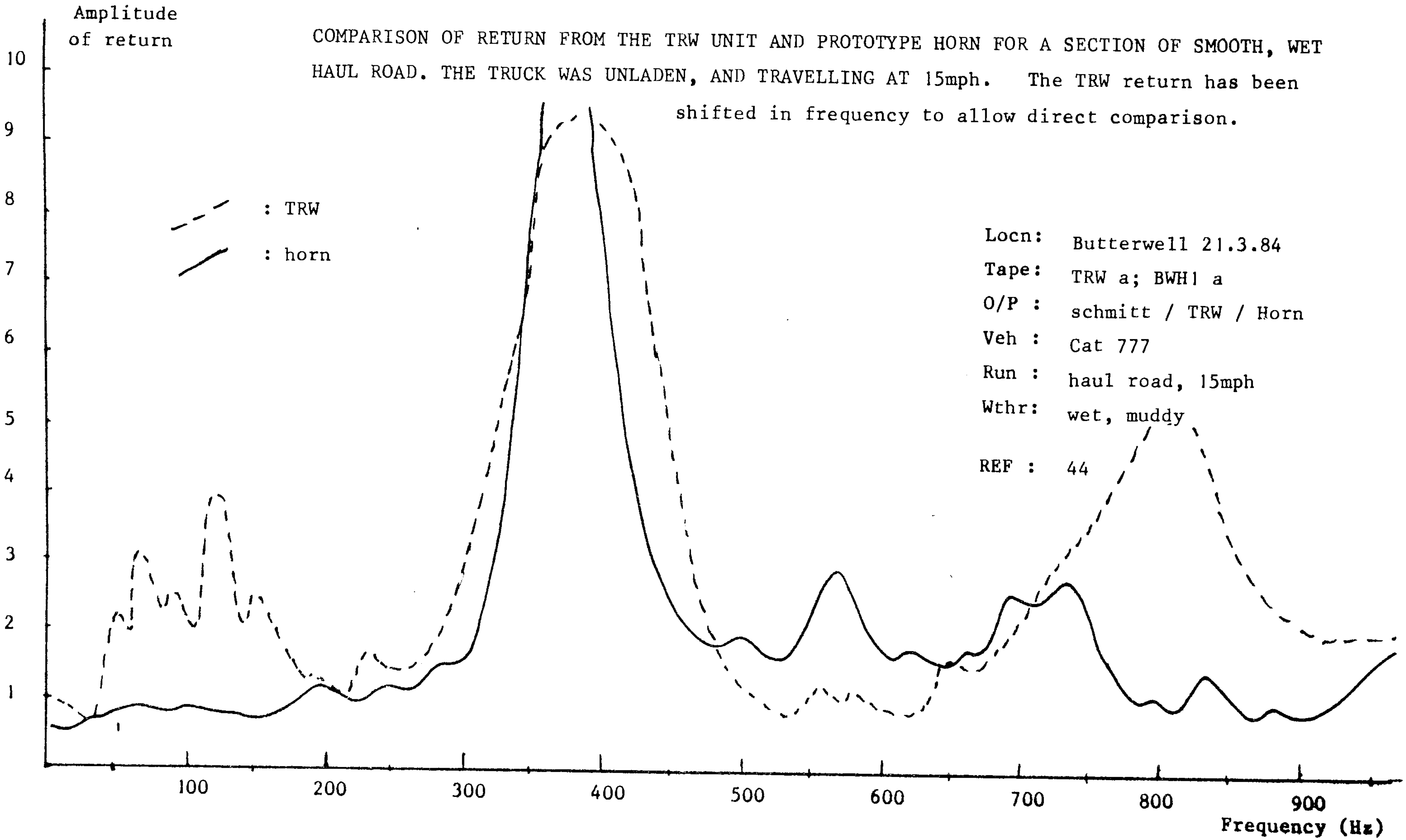
REF : 41A


COMPARISON OF RETURN FROM THE ARO UNIT AND PROTOTYPE HORN FOR A SECTION OF WET HAUL ROAD.
THE TRUCK WAS UNLADEN, TRAVELLING AT 15mph.
Amplitude of return
Frequency (Hz)
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
: ARO
: horn
Locn: Butterwell 21.3.84, 23.9.83
Tape: BWH1 a; 2AB b
O/P : schmitt / ARO / horn
Veh : Cat 777
Run : haul road, 15mph, no AV
Wthr: muddy
REF : 41B

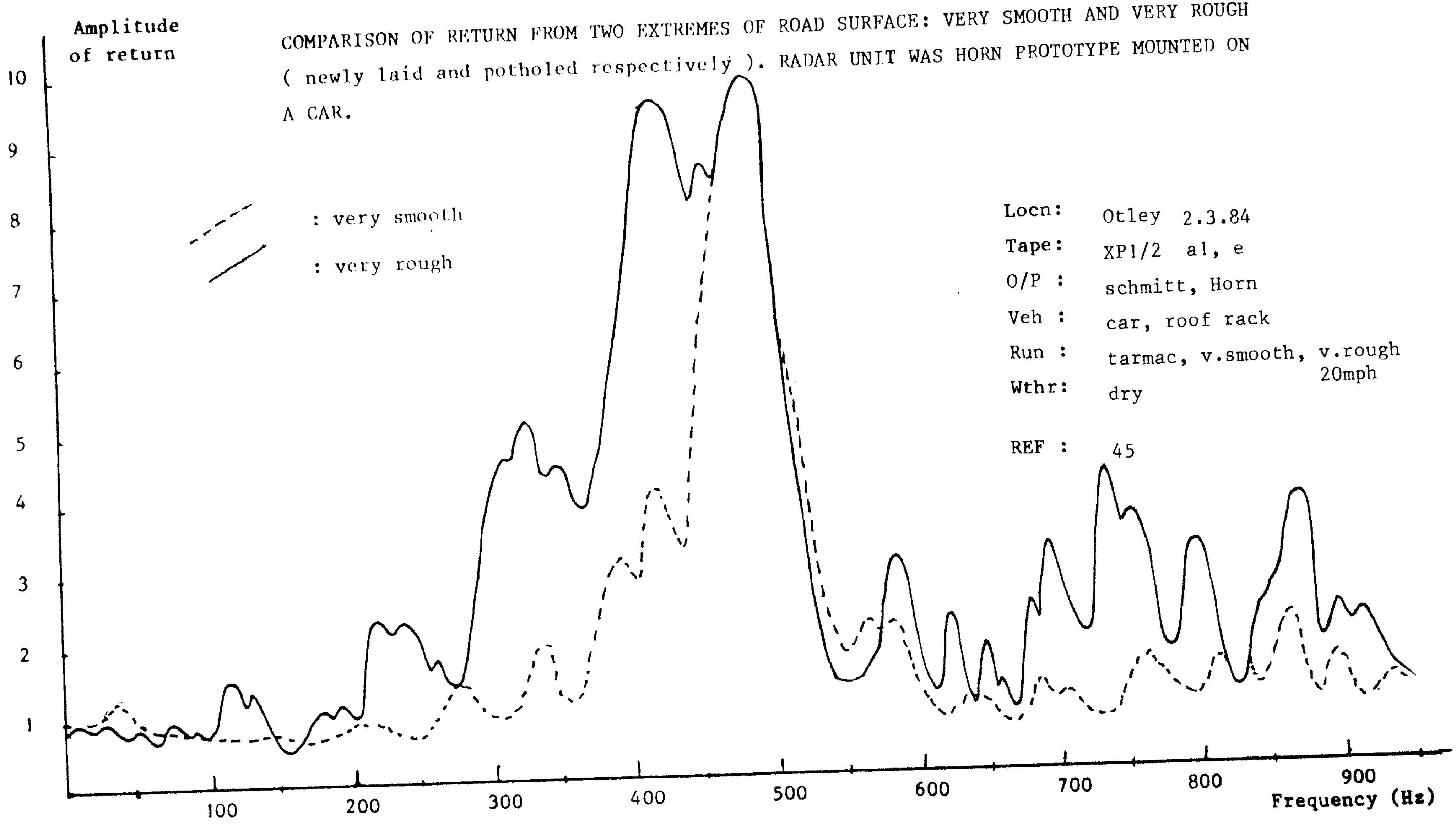
COMPARISON OF RETURN FOR TEH ARO UNIT AND HORN PROTOTYPE MOUNTED ON A TRAILER, DRIVEN ON WET TARMAC. The horn unit was not fitted with antivibration mounts.



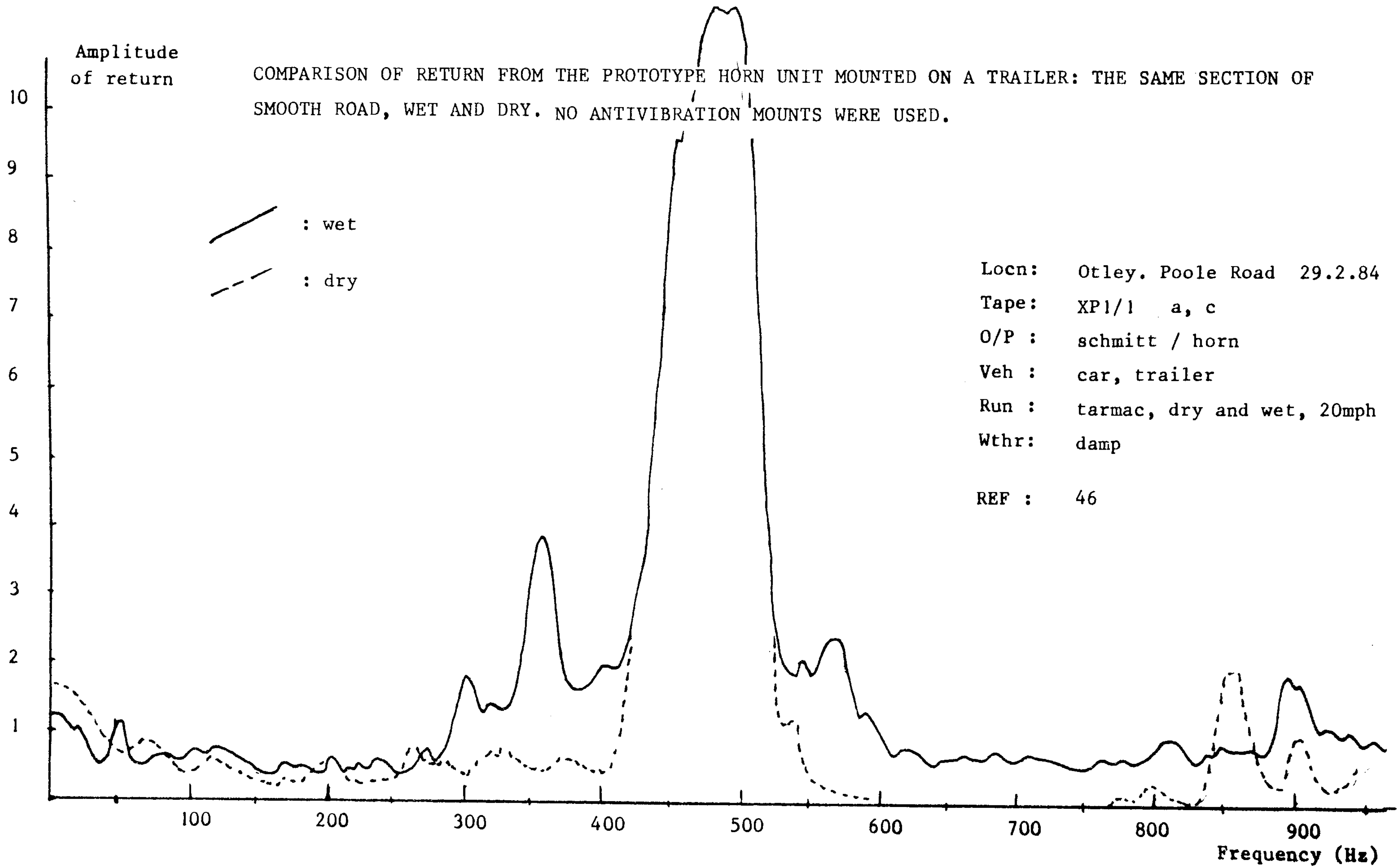

Amplitude of return
GROUND RETURN FROM AN UNMADE ROAD: HORN PROTOTYPE MOUNTED ON A TRAILER.
SPEED 10mph , GROUND ROUGH AND WET.
10
9
8
7
6
5
4
3
2
1
Locn: Otley: Rugby Ground 29.2.84
Tape: XP1/1 e
O/P : schmitt, horn
Veh : car, trailer
Run : unmade track, 10mph. puddled
Wthr: damp
REF : 43
100
200
300
400
500
600
700
800
900
Frequency (Hz)


Amplitude of return
10
9
8
7
6
5
4
3
2
1
: TRW
: horn
COMPARISON OF RETURN FROM THE TRW UNIT AND PROTOTYPE HORN FOR A SECTION OF SMOOTH, WET HAUL ROAD. THE TRUCK WAS UNLADEN, AND TRAVELLING AT 15mph. The TRW return has been shifted in frequency to allow direct comparison.
Locn: Butterwell 21.3.84
Tape: TRW a; BWH1 a
O/P : schmitt / TRW / Horn
Veh : Cat 777
Run : haul road, 15mph
Wthr: wet, muddy
REF : 44
100
200
300
400
500
600
700
800
900
Frequency (Hz)

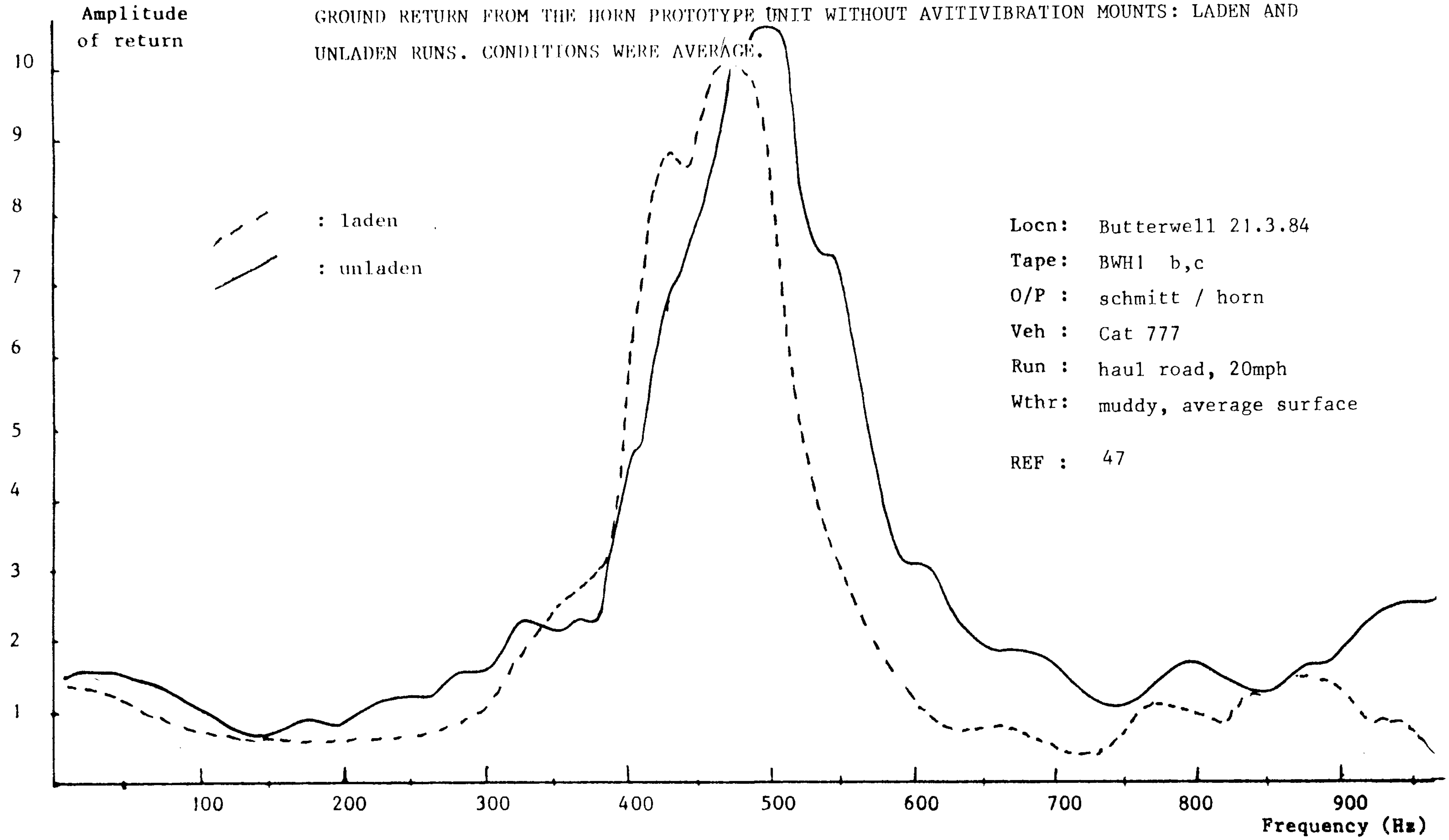
COMPARISON OF RETURN FROM TWO EXTREMES OF ROAD SURFACE: VERY SMOOTH AND VERY ROUGH (newly laid and potholed respectively). RADAR UNIT WAS HORN PROTOTYPE MOUNTED ON A CAR.

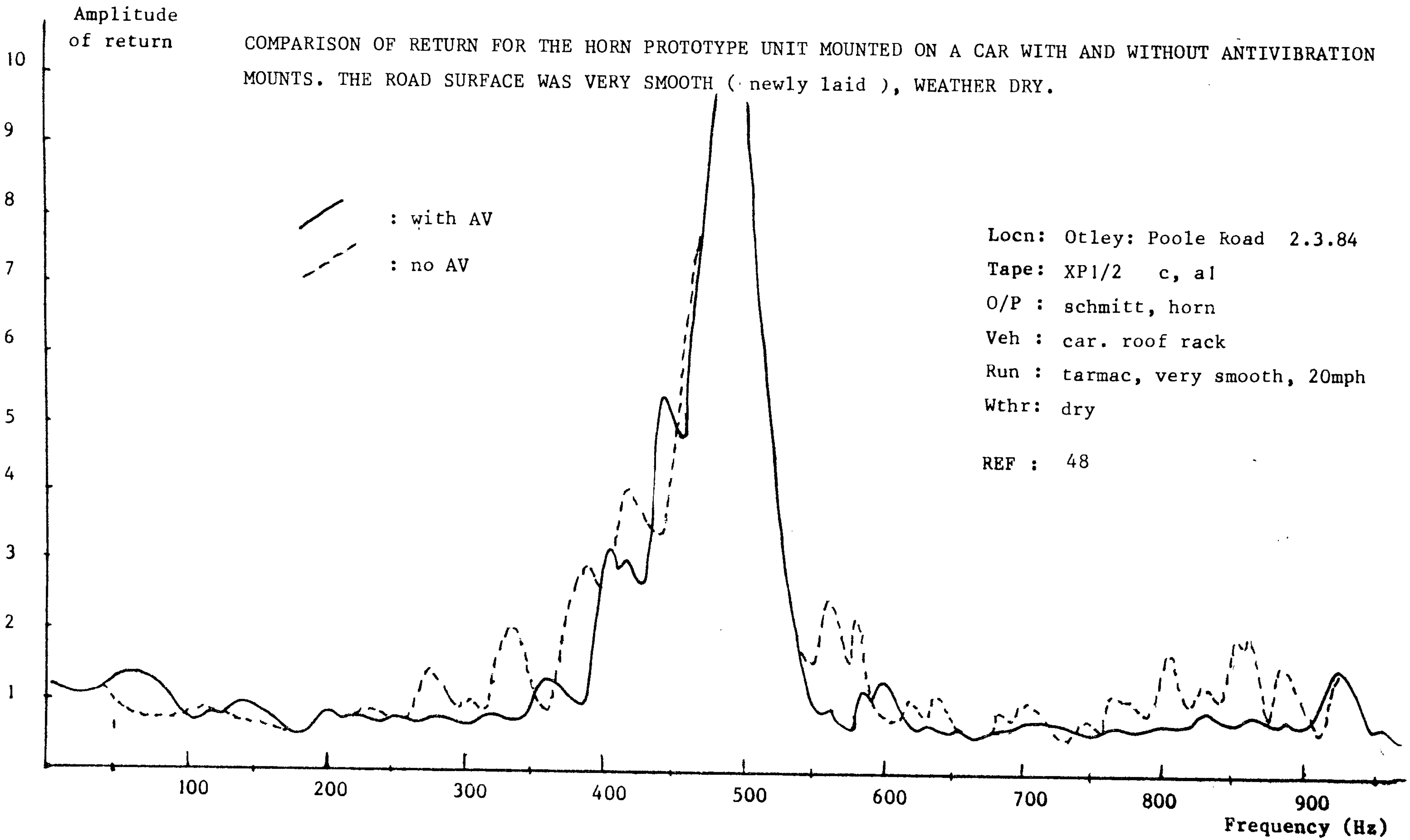


COMPARISON OF RETURN FROM THE PROTOTYPE HORN UNIT MOUNTED ON A TRAILER: THE SAME SECTION OF SMOOTH ROAD, WET AND DRY. NO ANTIVIBRATION MOUNTS WERE USED.



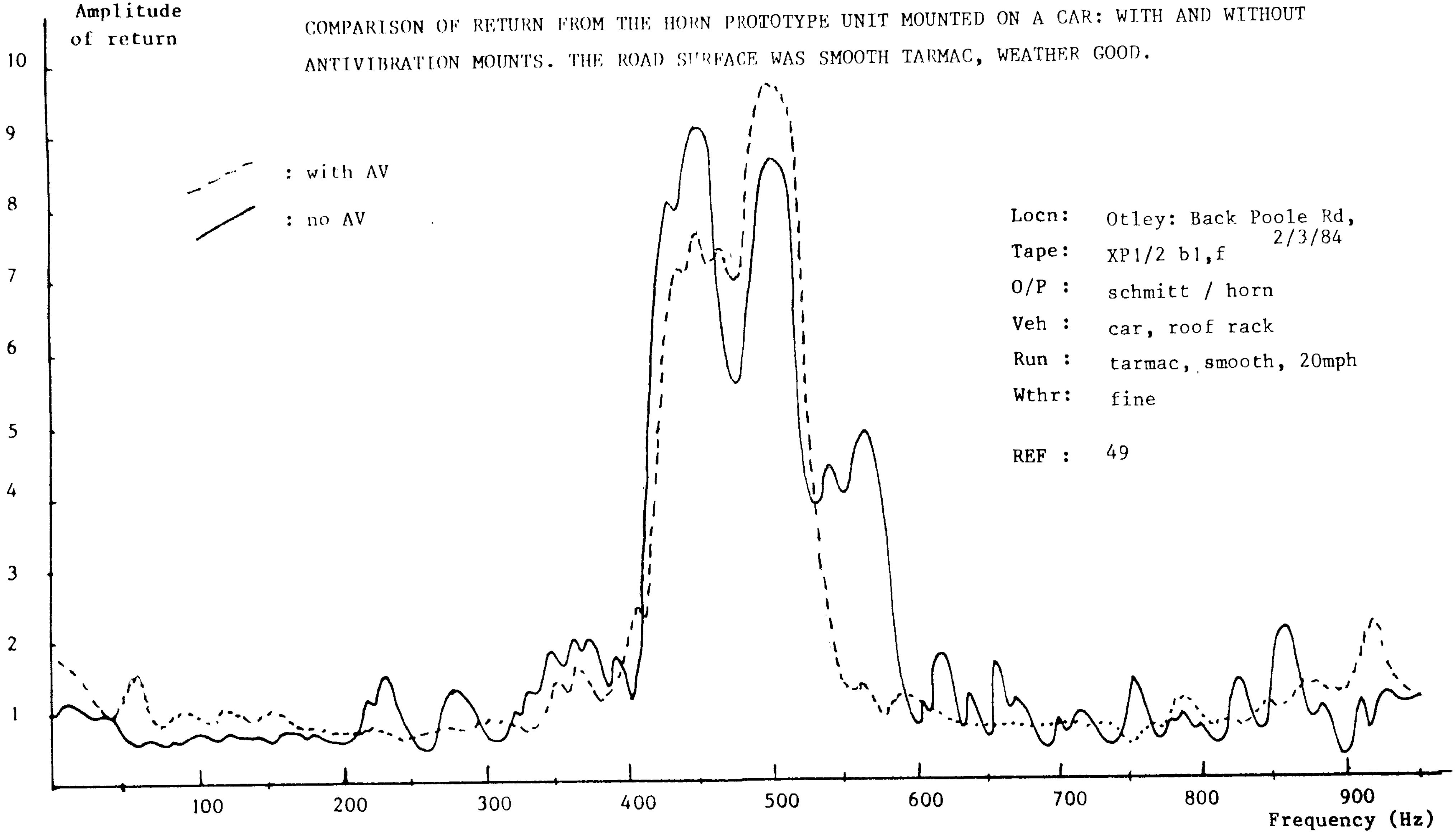
GROUND RETURN FROM THE HORN PROTOTYPE UNIT WITHOUT AVITIVIBRATION MOUNTS: LADEN AND UNLADEN RUNS. CONDITIONS WERE AVERAGE.

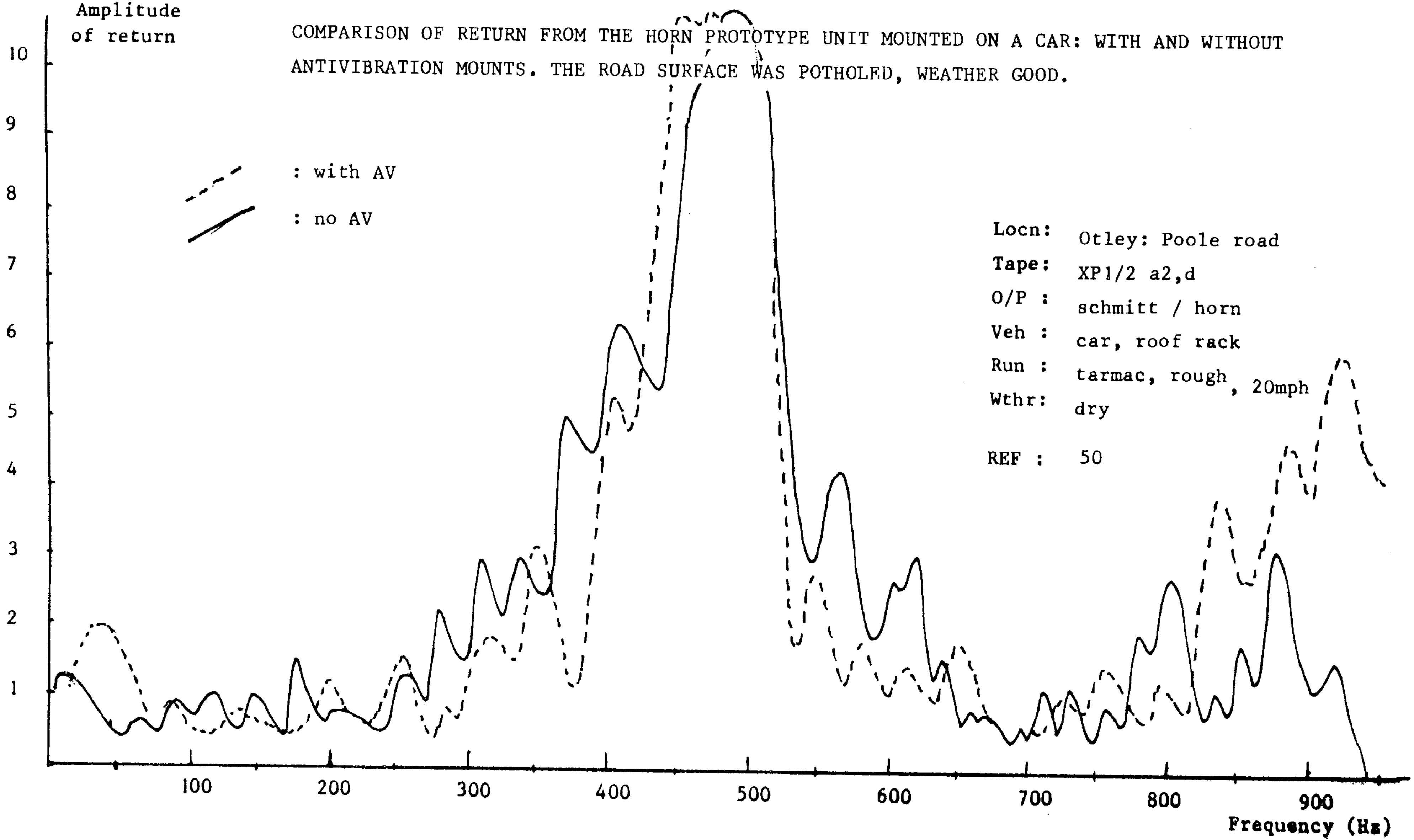




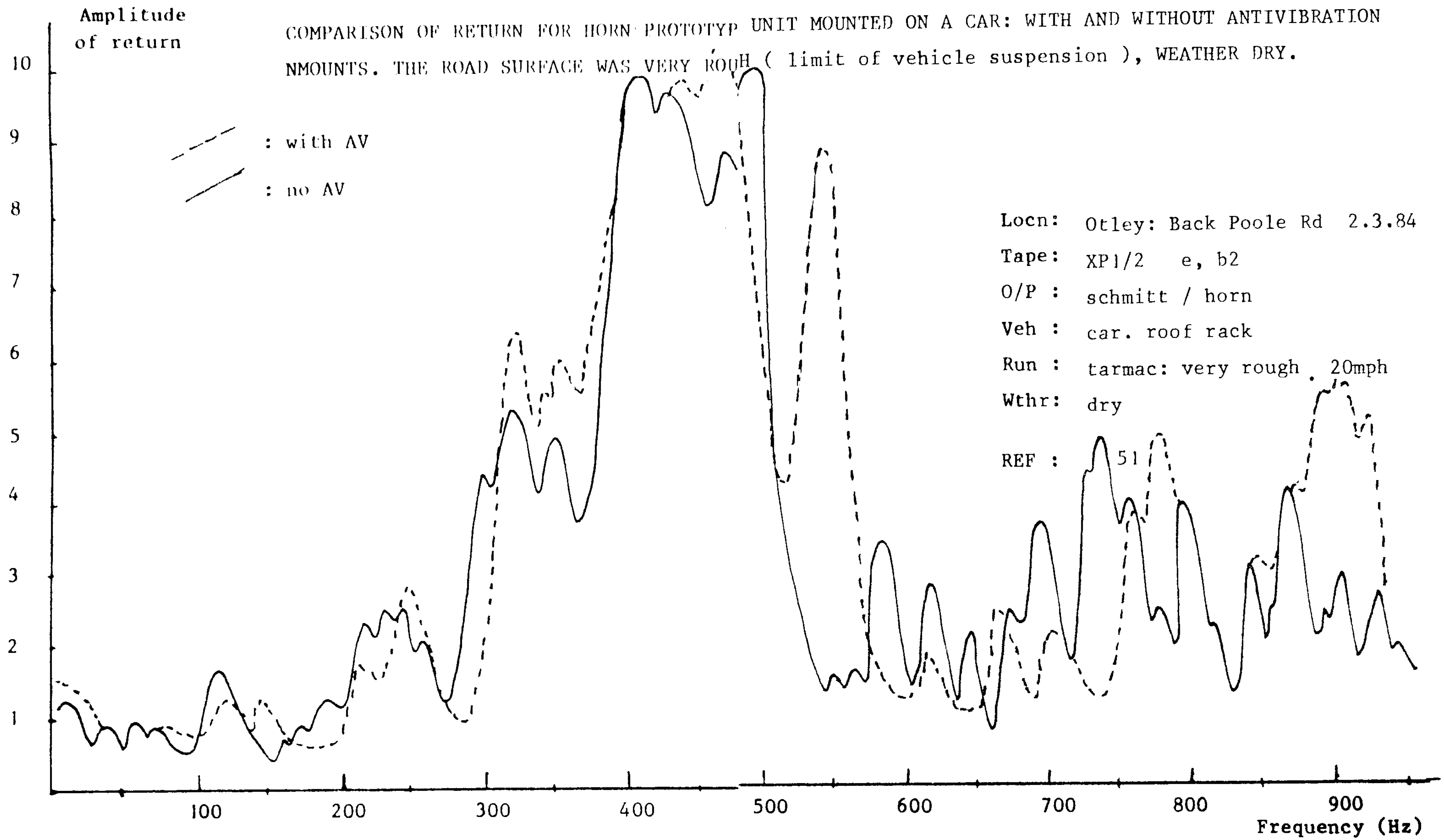
COMPARISON OF RETURN FOR THE HORN PROTOTYPE UNIT MOUNTED ON A CAR WITH AND WITHOUT ANTIVIBRATION MOUNTS. THE ROAD SURFACE WAS VERY SMOOTH (newly laid), WEATHER DRY.

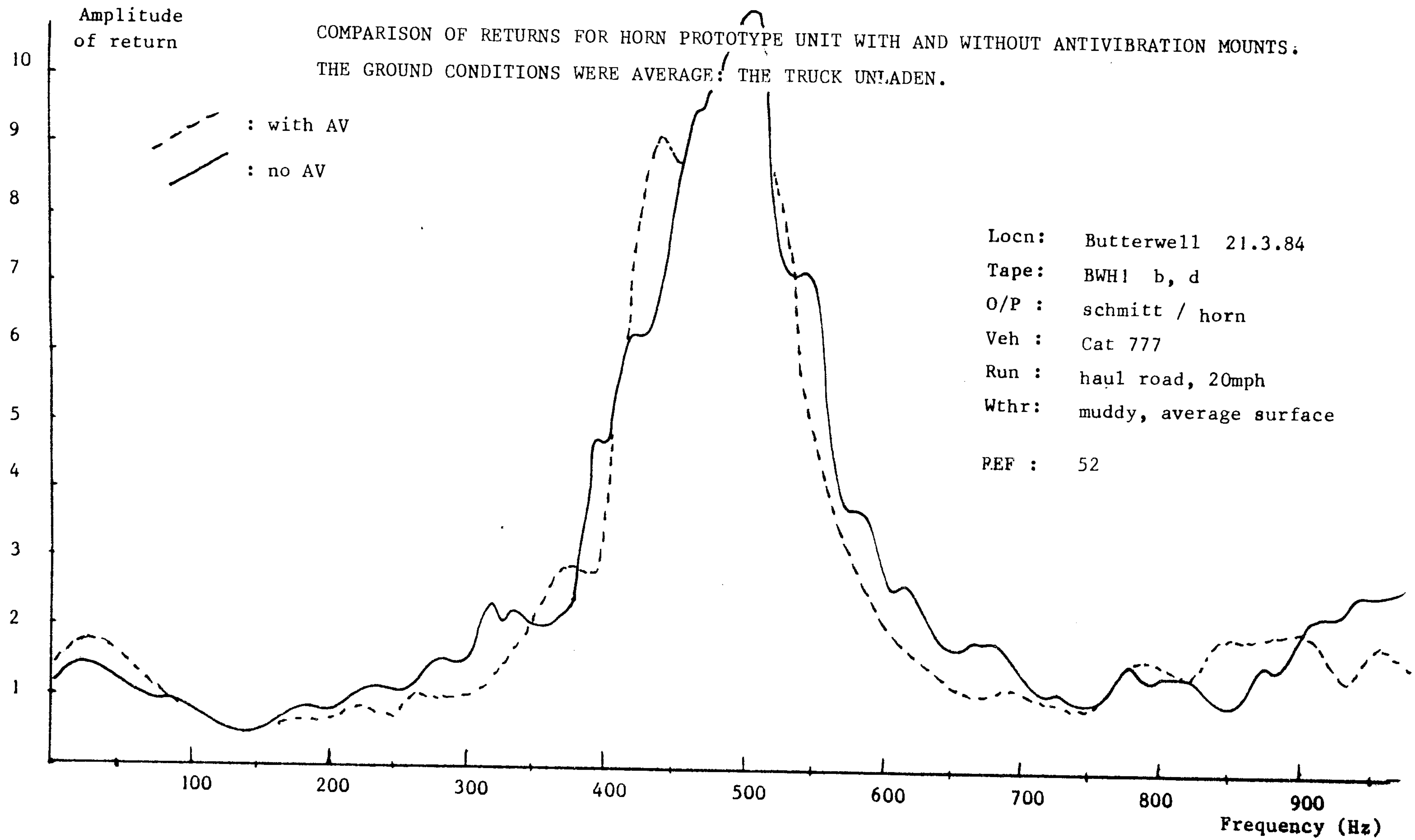
COMPARISON OF RETURN FROM THE HORN PROTOTYPE UNIT MOUNTED ON A CAR: WITH AND WITHOUT ANTIVIBRATION MOUNTS. THE ROAD SURFACE WAS SMOOTH TARMAC, WEATHER GOOD.



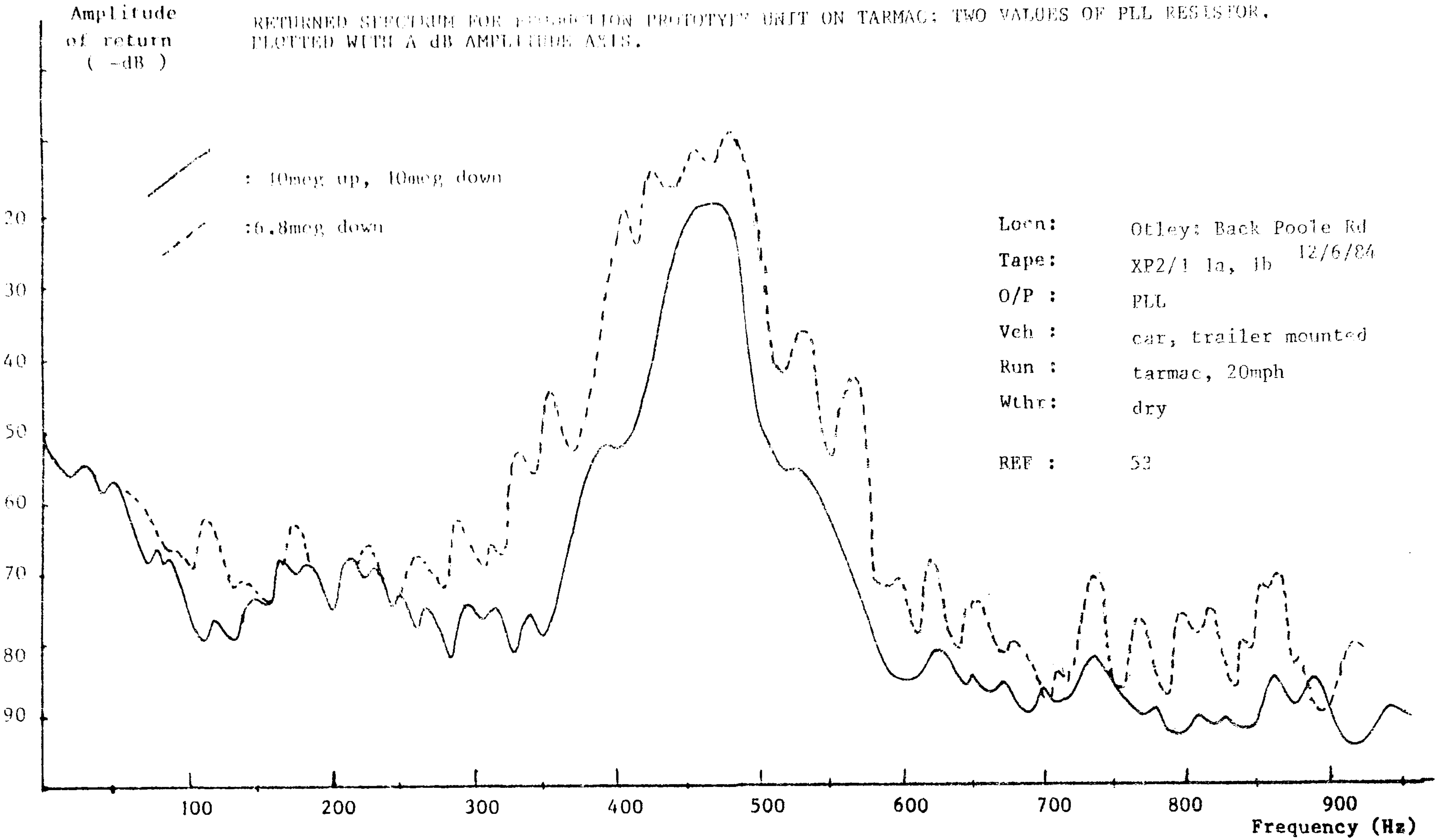


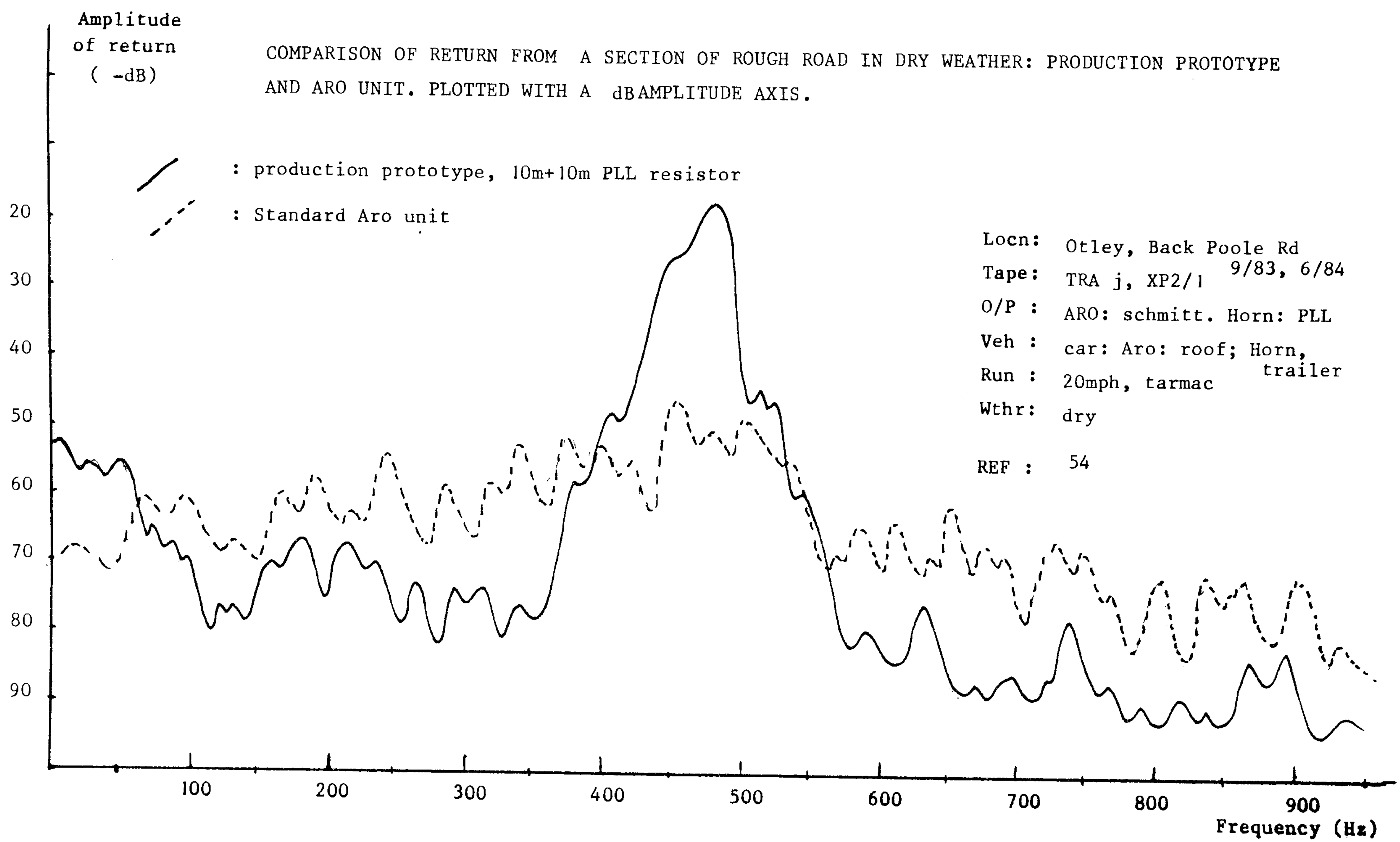
Amplitude of return
10
9
8
7
6
5
4
3
2
1
COMPARISON OF RETURN FROM THE HORN PROTOTYPE UNIT MOUNTED ON A CAR: WITH AND WITHOUT ANTIVIBRATION MOUNTS. THE ROAD SURFACE WAS POTHOLED, WEATHER GOOD.
: with AV
: no AV
Locn: Otley: Poole road
Tape: XP1/2 a2,d
O/P : schmitt / horn
Veh : car, roof rack
Run : tarmac, rough, 20mph
Wthr: dry
REF : 50
100
200
300
400
500
600
700
800
900
Frequency (Hz)


Amplitude of return
COMPARISON OF RETURN FOR HORN PROTOTYP UNIT MOUNTED ON A CAR: WITH AND WITHOUT ANTIVIBRATION
NMOUNTS. THE ROAD SURFACE WAS VERY ROUH (limit of vehicle suspension), WEATHER DRY.
: with AV
: no AV
Locn: Otley: Back Poole Rd 2.3.84
Tape: XP1/2 e, b2
O/P : schmitt / horn
Veh : car. roof rack
Run : tarmac: very rough , 20mph
Wthr: dry
REF : 51
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)

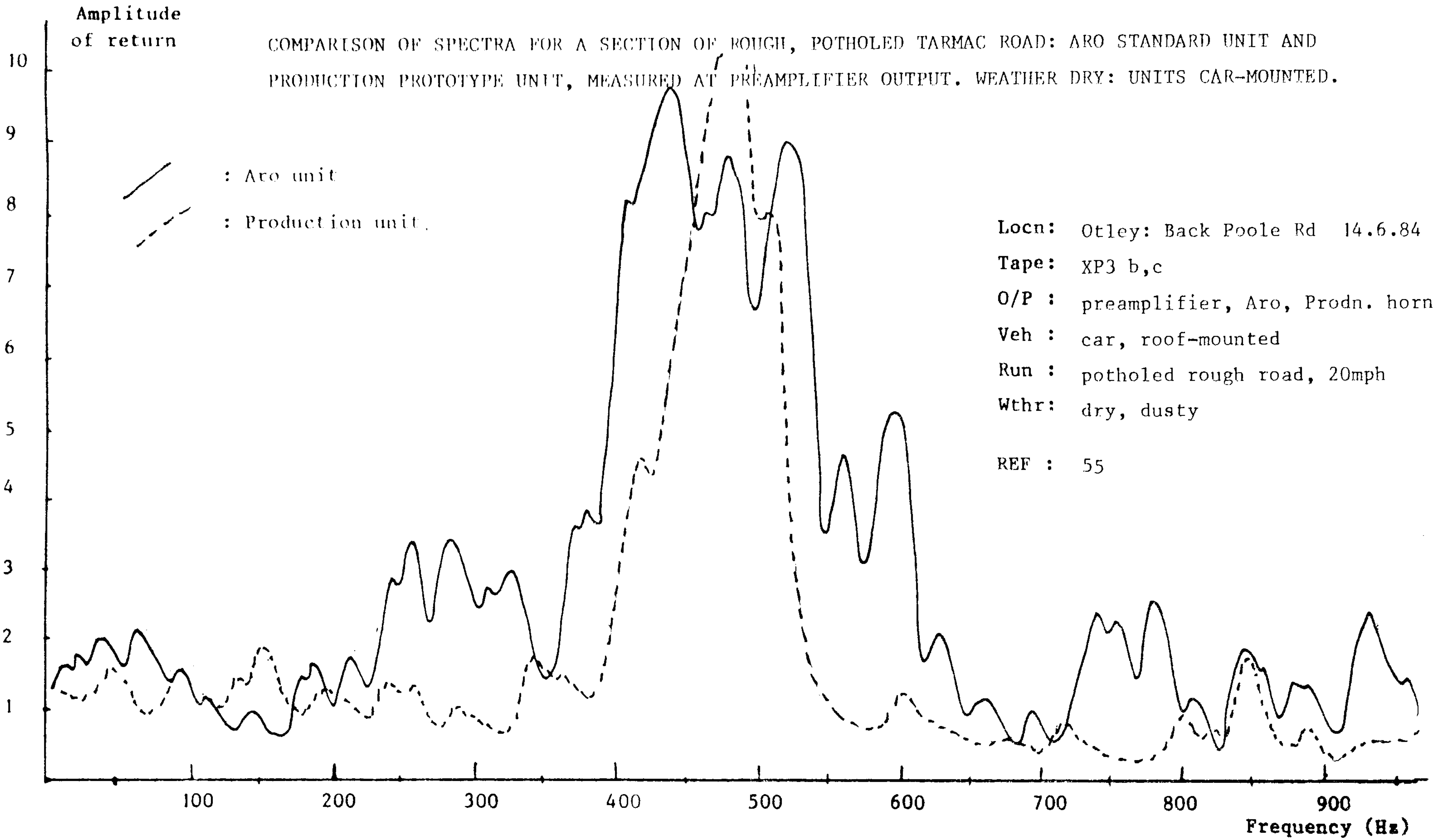

Amplitude
of return
COMPARISON OF RETURNS FOR HORN PROTOTYPE UNIT WITH AND WITHOUT ANTIVIBRATION MOUNTS.
THE GROUND CONDITIONS WERE AVERAGE: THE TRUCK UNLADEN.
: with AV
: no AV
Locn: Butterwell 21.3.84
Tape: BWH1 b, d
O/P : schmitt / horn
Veh : Cat 777
Run : haul road, 20mph
Wthr: muddy, average surface
REF : 52
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)

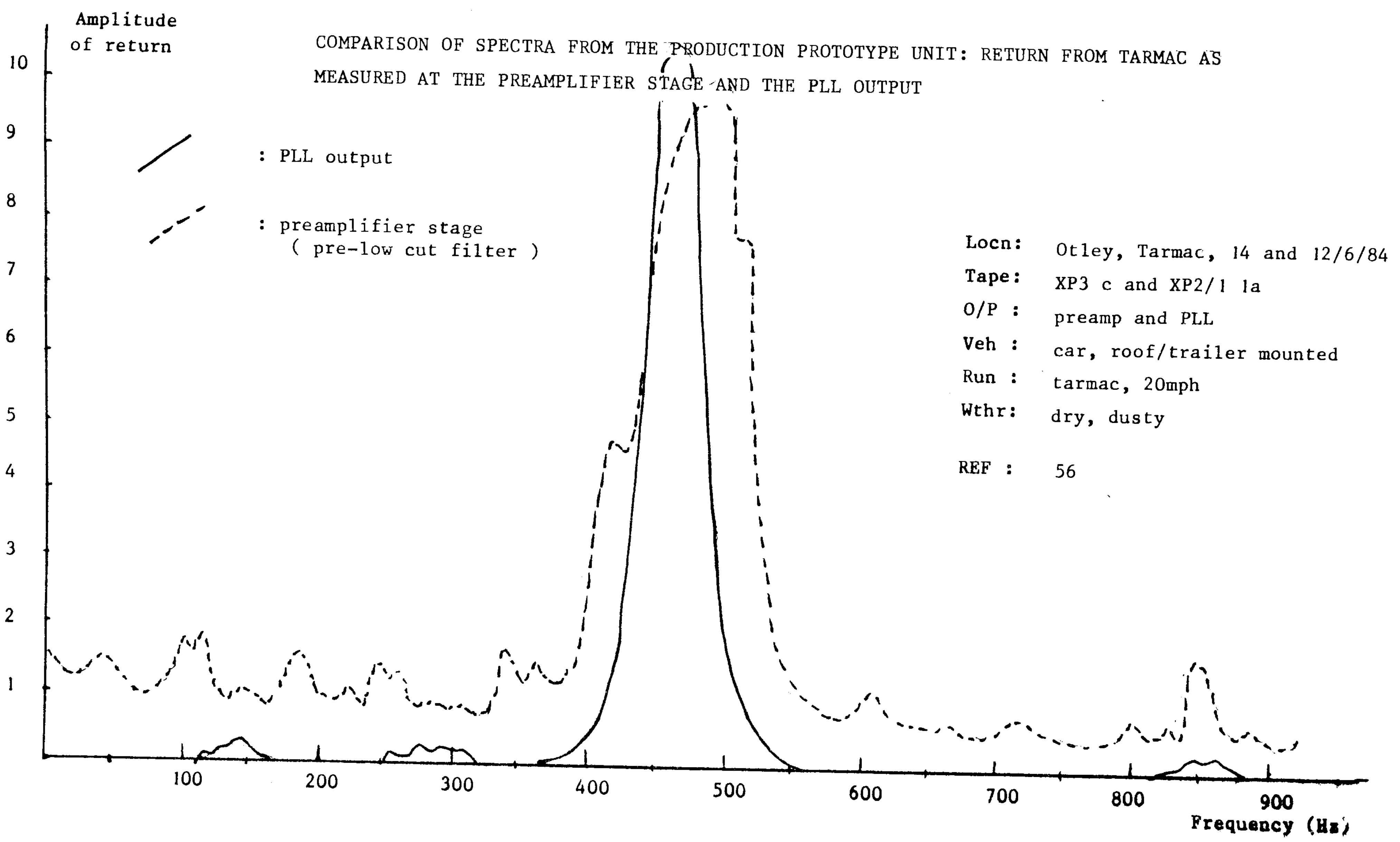
RETURNED SPECTRUM FOR PRODUCTION PROTOTYPE UNIT ON TARMAC: TWO VALUES OF PLL RESISTOR.
PLOTTED WITH A dB AMPLITUDE AXIS.

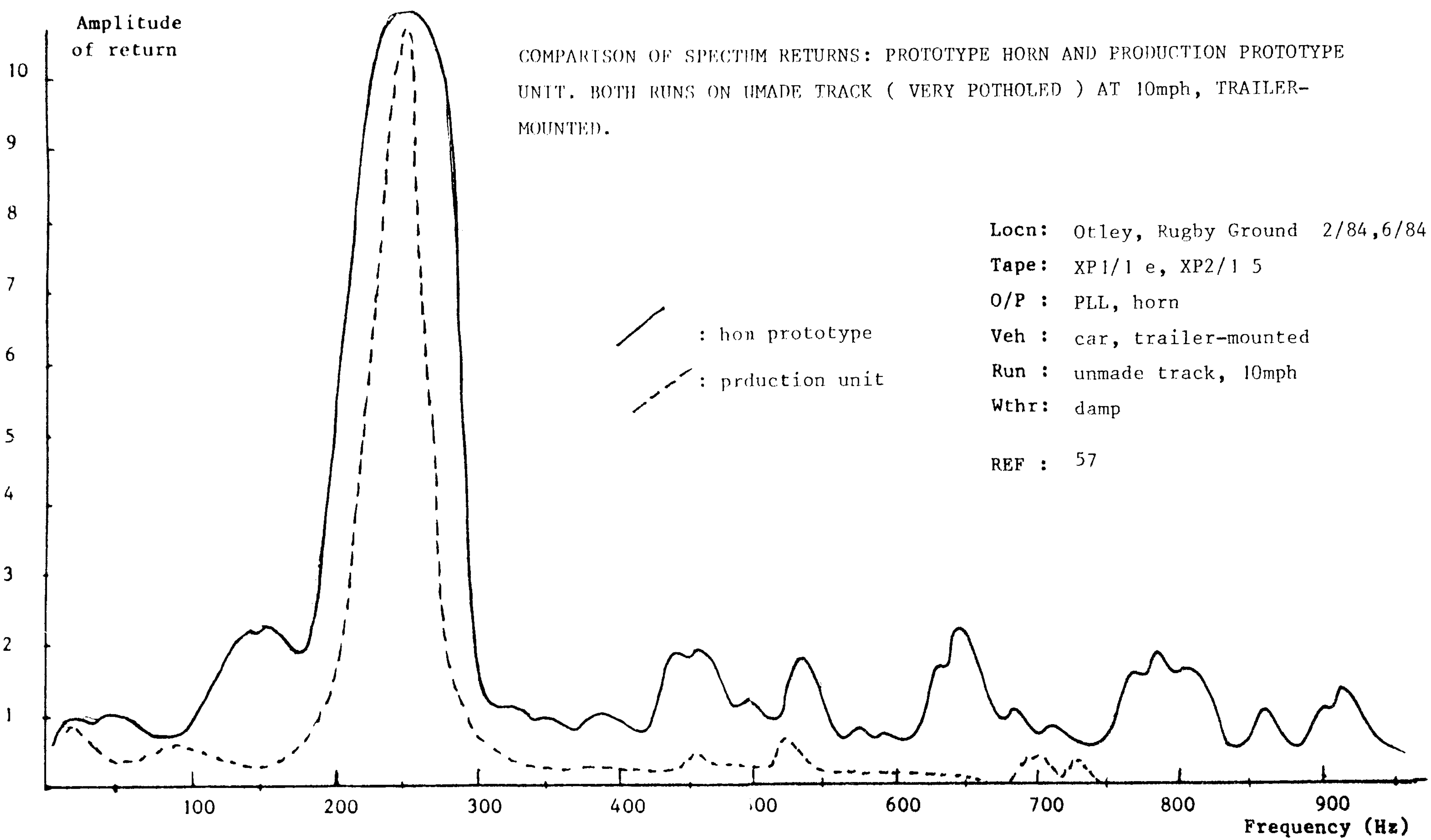



COMPARISON OF RETURN FROM A SECTION OF ROUGH ROAD IN DRY WEATHER: PRODUCTION PROTOTYPE AND ARO UNIT. PLOTTED WITH A dB AMPLITUDE AXIS.
Amplitude of return (-dB)
: production prototype, 10m+10m PLL resistor
: Standard Aro unit
Locn: Otley, Back Poole Rd
Tape: TRA j, XP2/1 9/83, 6/84
O/P : ARO: schmitt. Horn: PLL
Veh : car: Aro: roof; Horn, trailer
Run : 20mph, tarmac
Wthr: dry
REF : 54
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
Frequency (Hz)

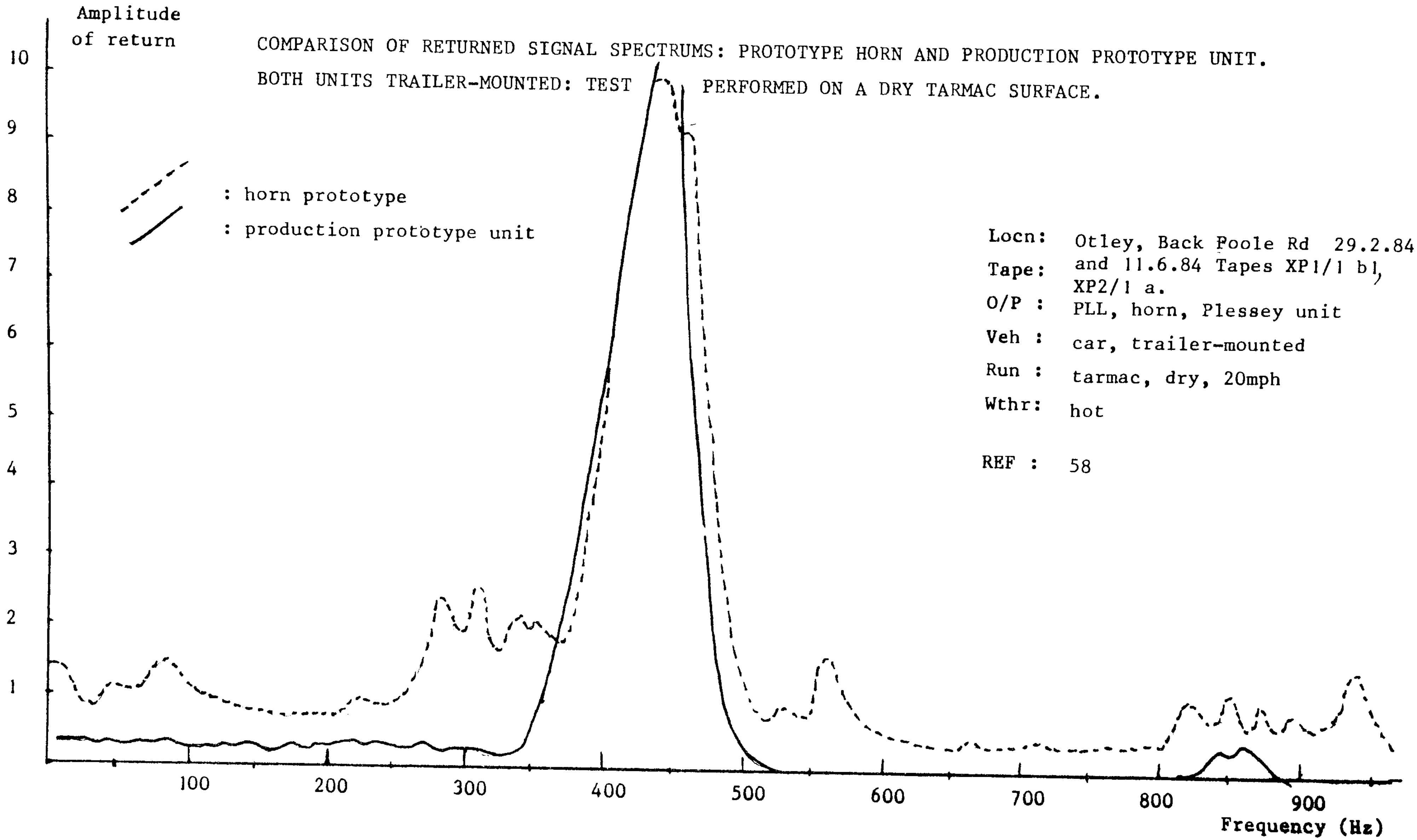
COMPARISON OF SPECTRA FOR A SECTION OF ROUGH, POTHOLED TARMAC ROAD: ARO STANDARD UNIT AND PRODUCTION PROTOTYPE UNIT, MEASURED AT PREAMPLIFIER OUTPUT. WEATHER DRY: UNITS CAR-MOUNTED.

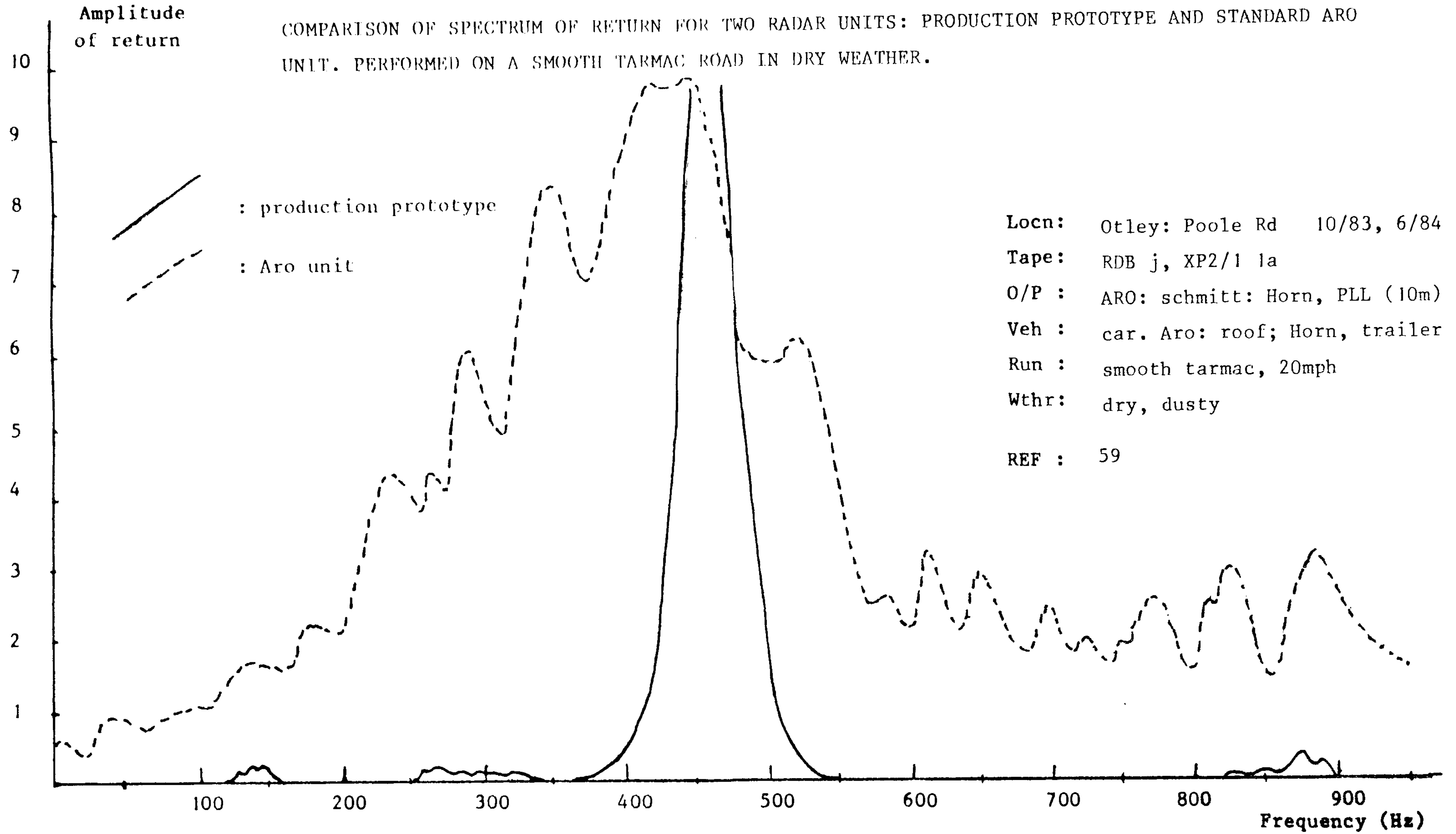



Amplitude
of return
10
9
8
7
6
5
4
3
2
1
COMPARISON OF SPECTRA FROM THE PRODUCTION PROTOTYPE UNIT: RETURN FROM TARMAC AS MEASURED AT THE PREAMPLIFIER STAGE AND THE PLL OUTPUT
: PLL output
: preamplifier stage
(pre-low cut filter)
Locn: Otley, Tarmac, 14 and 12/6/84
Tape: XP3 c and XP2/1 1a
O/P : preamp and PLL
Veh : car, roof/trailer mounted
Run : tarmac, 20mph
Wthr: dry, dusty
REF : 56
100
200
300
400
500
600
700
800
900
Frequency (Hz)



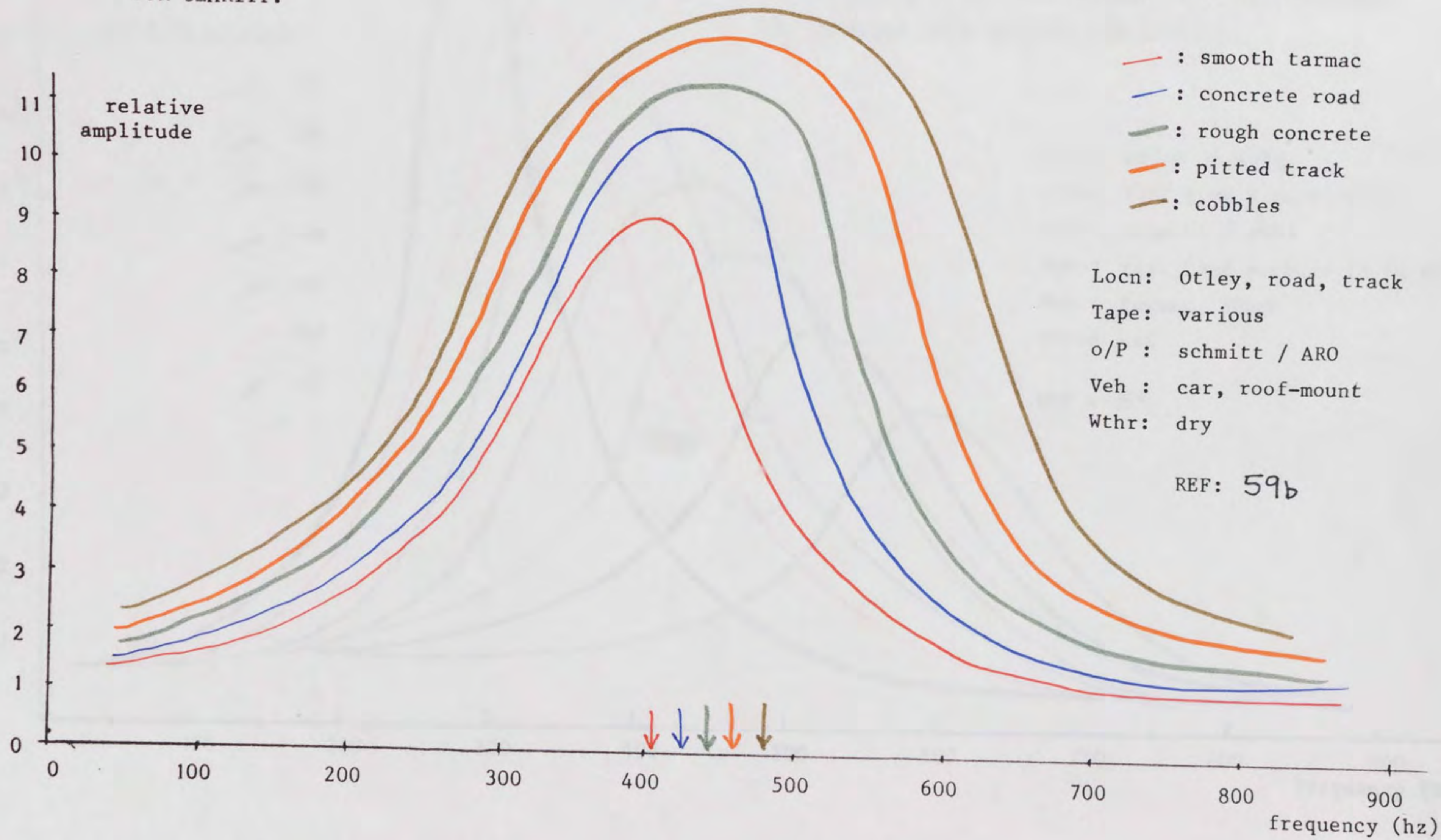
COMPARISON OF SPECTUM RETURNS: PROTOTYPE HORN AND PRODUCTION PROTOTYPE UNIT. BOTH RUNS ON UMADE TRACK (VERY POTHOLED) AT 10mph, TRAILER-MOUNTED.

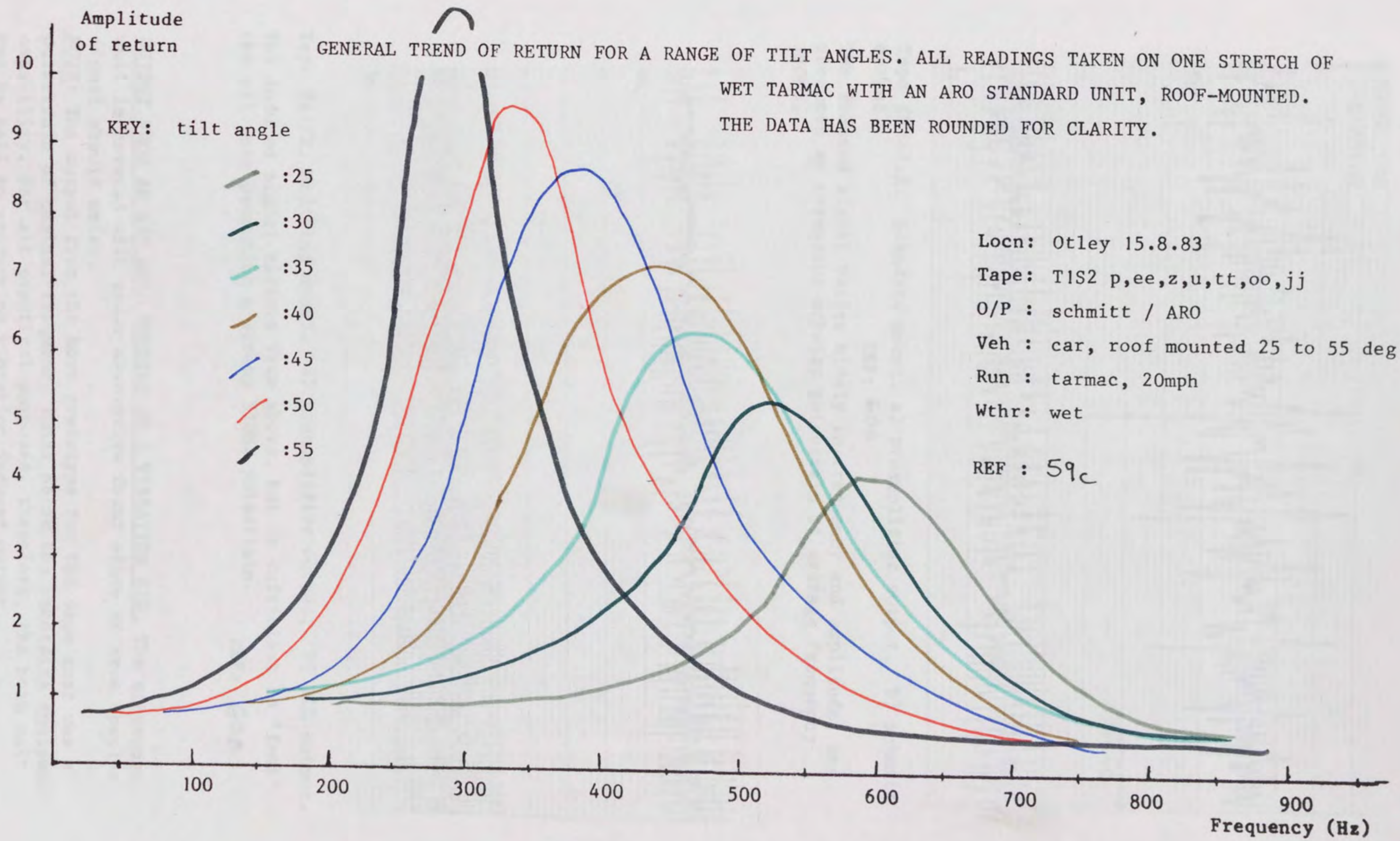

COMPARISON OF RETURNED SIGNAL SPECTRUMS: PROTOTYPE HORN AND PRODUCTION PROTOTYPE UNIT.
BOTH UNITS TRAILER-MOUNTED: TEST PERFORMED ON A DRY TARMAC SURFACE.
Amplitude of return
10
9
8
7
6
5
4
3
2
1
: horn prototype
: production prototype unit
Locn: Otley, Back Poole Rd 29.2.84
Tape: and 11.6.84 Tapes XP1/1 b1, XP2/1 a.
O/P : PLL, horn, Plessey unit
Veh : car, trailer-mounted
Run : tarmac, dry, 20mph
Wthr: hot
REF : 58
100
200
300
400
500
600
700
800
900
Frequency (Hz)

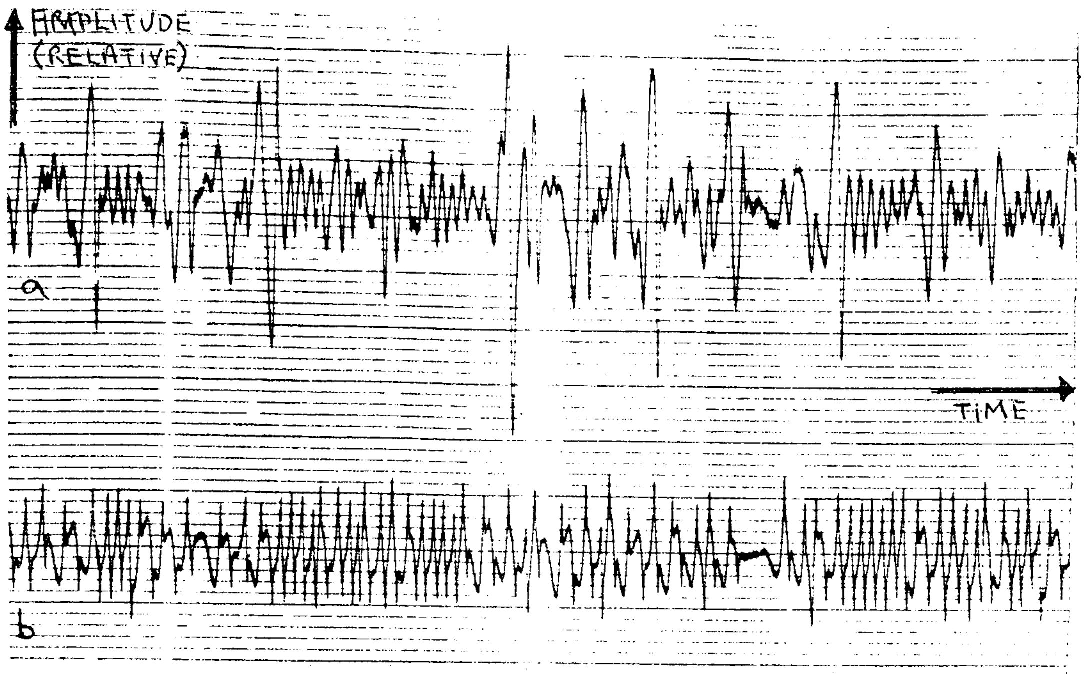


Amplitude of return
COMPARISON OF SPECTRUM OF RETURN FOR TWO RADAR UNITS: PRODUCTION PROTOTYPE AND STANDARD ARO UNIT. PERFORMED ON A SMOOTH TARMAC ROAD IN DRY WEATHER.
: production prototype
: Aro unit
Locn: Otley: Poole Rd 10/83, 6/84
Tape: RDB j, XP2/1 1a
O/P : ARO: schmitt: Horn, PLL (10m)
Veh : car. Aro: roof; Horn, trailer
Run : smooth tarmac, 20mph
Wthr: dry, dusty
REF : 59
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)

GENERAL TREND OF SPECTRUM OF RETURN FOR PROGRESSIVELY 'ROUGHER' TERRAIN SURFACE TYPES. TRACES ARE DERIVED FROM SPECTRA OBTAINED WITH AN ARO UNIT, CAR-MOUNTED IN DRY WEATHER, AND ARE SMOOTHED FOR CLARITY.

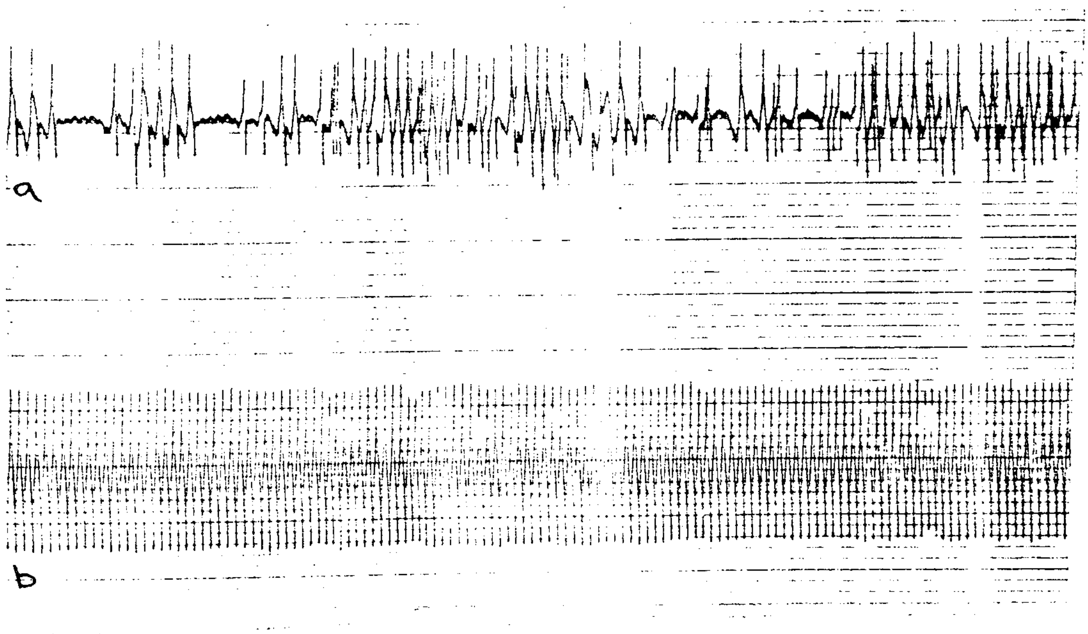



Amplitude
of return
GENERAL TREND OF RETURN FOR A RANGE OF TILT ANGLES. ALL READINGS TAKEN ON ONE STRETCH OF
WET TARMAC WITH AN ARO STANDARD UNIT, ROOF-MOUNTED.
THE DATA HAS BEEN ROUNDED FOR CLARITY.
KEY: tilt angle
:25
:30
:35
:40
:45
:50
:55
Locn: Otley 15.8.83
Tape: T1S2 p,ee,z,u,tt,oo,jj
O/P : schmitt / ARO
Veh : car, roof mounted 25 to 55 deg
Run : tarmac, 20mph
Wthr: wet
REF : 59c
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
Frequency (Hz)



Tape IN1/2.5. Standard mount. a) preamplifier output, b) schmitt output. REF: 60A

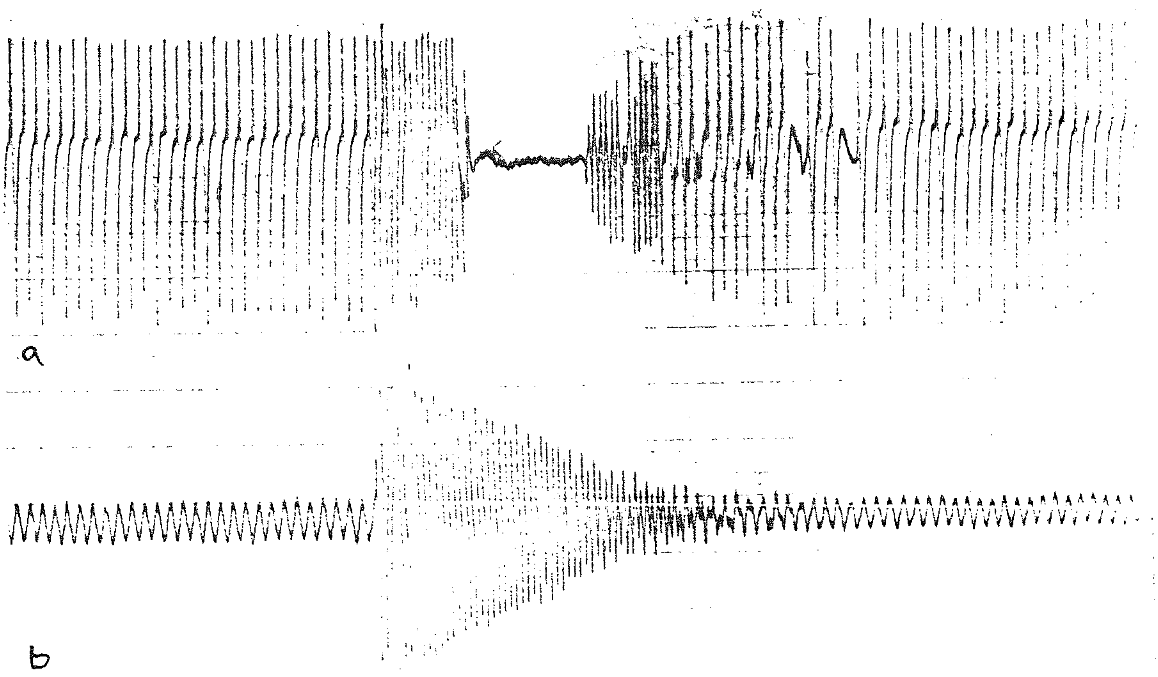
The induced signal varies widely in frequency and amplitude, and produces an erroneous schmitt pulsetrain of average frequency 160Hz.



Tape 2A1/2. Modified mount. a) preamplifier output, b) PLL output.

The induced signal differs from above, but is sufficient to 'fool' the pll into producing a strong 370Hz pulsetrain. REF: 60B

OUTPUT FROM AN ARO HEAD MOUNTED ON A VIBRATION RIG. The microwave unit is covered with radar absorptive foam: hence no true doppler signal should exist.
NOTE: The output from the horn prototype for the same test was a pulsetrain of nominal frequency 10Hz: below the recording equipment capability. For all practical purposes, therefore, the horn unit can be said to produce no vibration induced output.



Tuning fork (440Hz) held in front of ARO unit & struck.
Tape 2A1. a) schmitt output, b) preamplifier output. REF: 61A

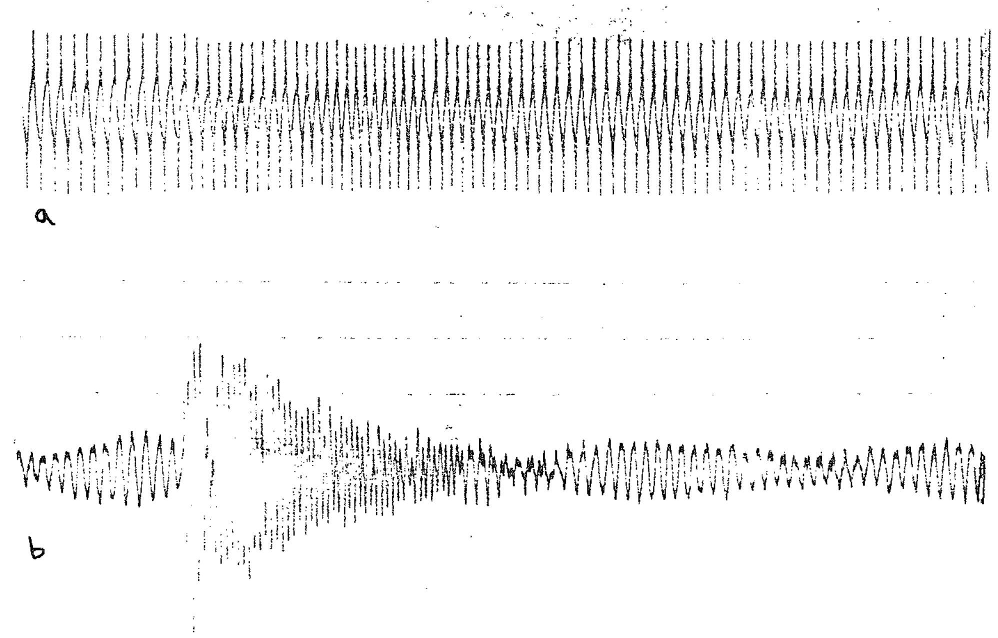
The schmitt initially follows the preamplifier output, and then zeros, before restarting again for a lower amplitude preamplifier output. Over this whole period, the average frequency of the schmitt is approx that of the fork only.

Tuning fork (440Hz) held in front of ARO unit mounted on a vibrator. Tape NI1/VIB. a) schmitt output, b) PLL output

The fork produces, from a vibrating head, a modulated output, with a nominal frequency of 390Hz. The PLL restores this to the correct 440Hz.

REF: 61B

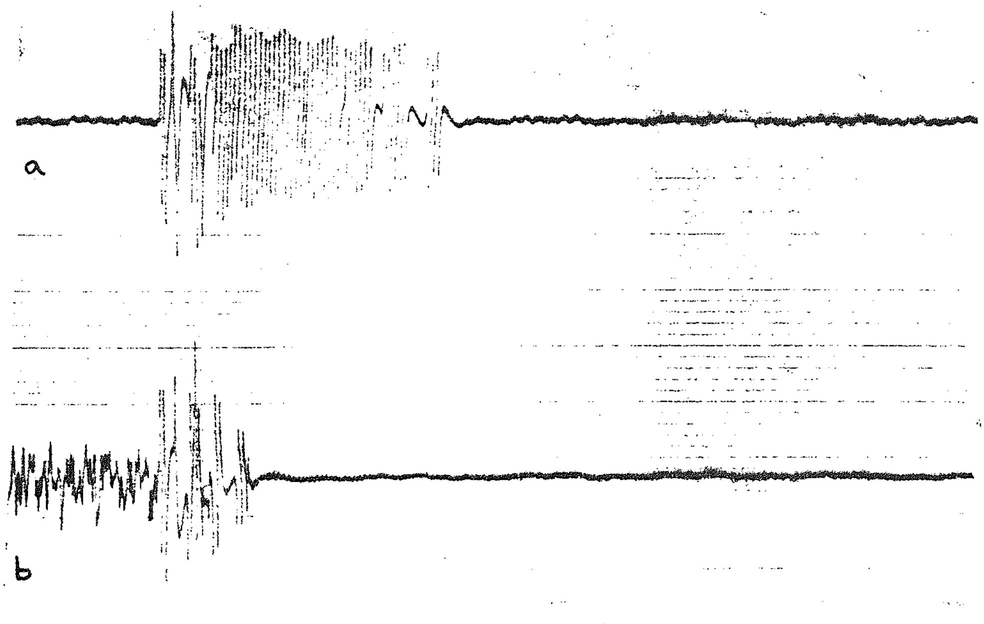
TUNING FORK TESTS ON ARO UNITS.



a) PLL output b) preamplifier (post-filter) output

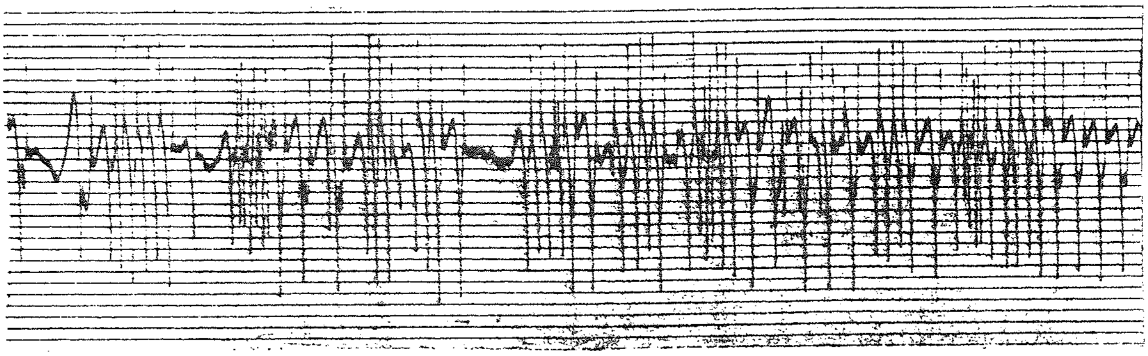
COMPARISON OF OUTPUT TYPE FOR AN INPUT OF 440Hz TUNING FORK AND A STRIKE ON THE UNIT OUTER CASING REF: 62A

TAPE: IN1.2 DATE: 10.11.83. UNIT: ARO + PLL module

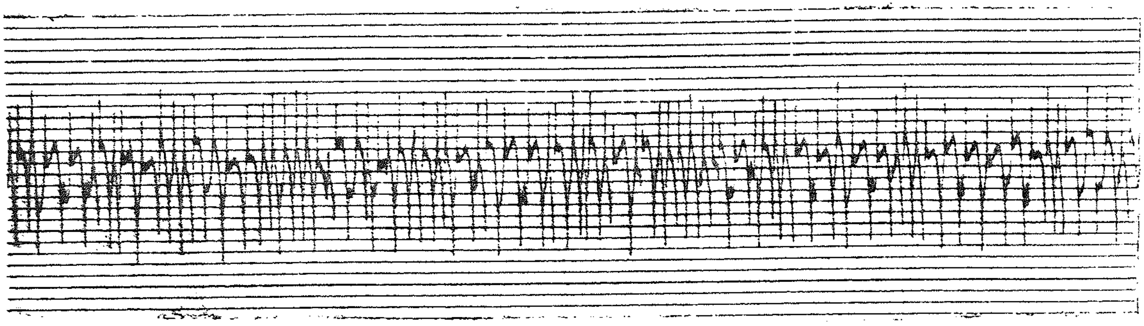


a) schmitt output b) preamplifier output

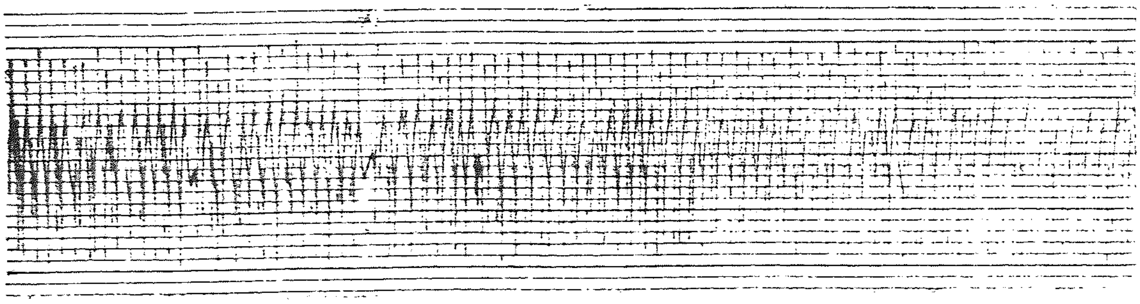
COMPARISON OF OUTPUT TYPE FOR AN INPUT OF A STRIKE ON THE UNIT OUTER CASING. The microwave unit mouth was covered with absorbing foam. TAPE: IN1.VIB DATE: 10.11.83
UNIT: ARO standard, incl AV mount
REF: 62B



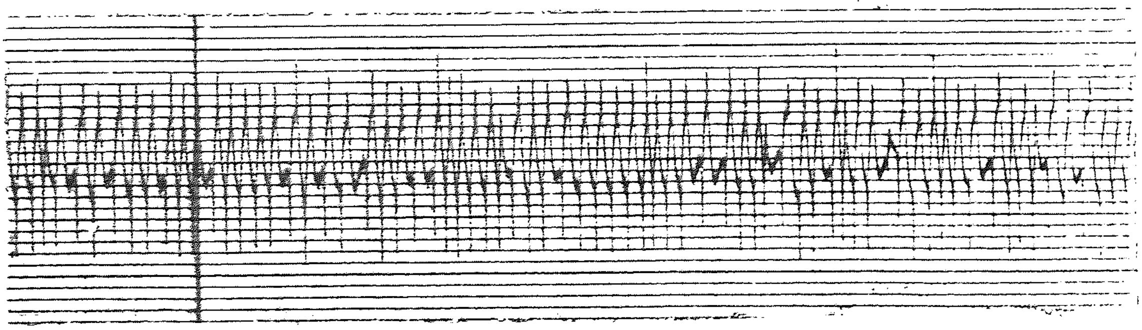
a



b



c



d

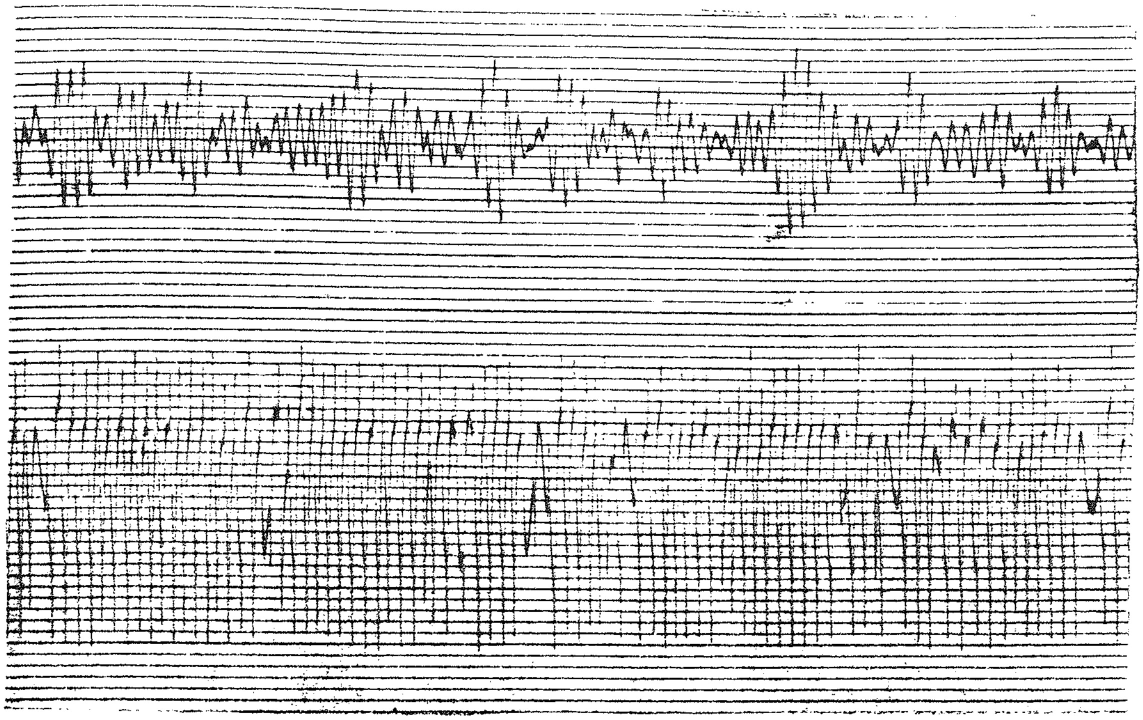
TAPE REF: T1A
DATE: 16.9.83
ROAD: Pool Rd
UNIT: Aro, roof-mounted
COND: dry tarmac

KEY: recordings using a tilt angle of:

a) 25 deg
b) 30 deg
c) 40 deg
d) 50 deg

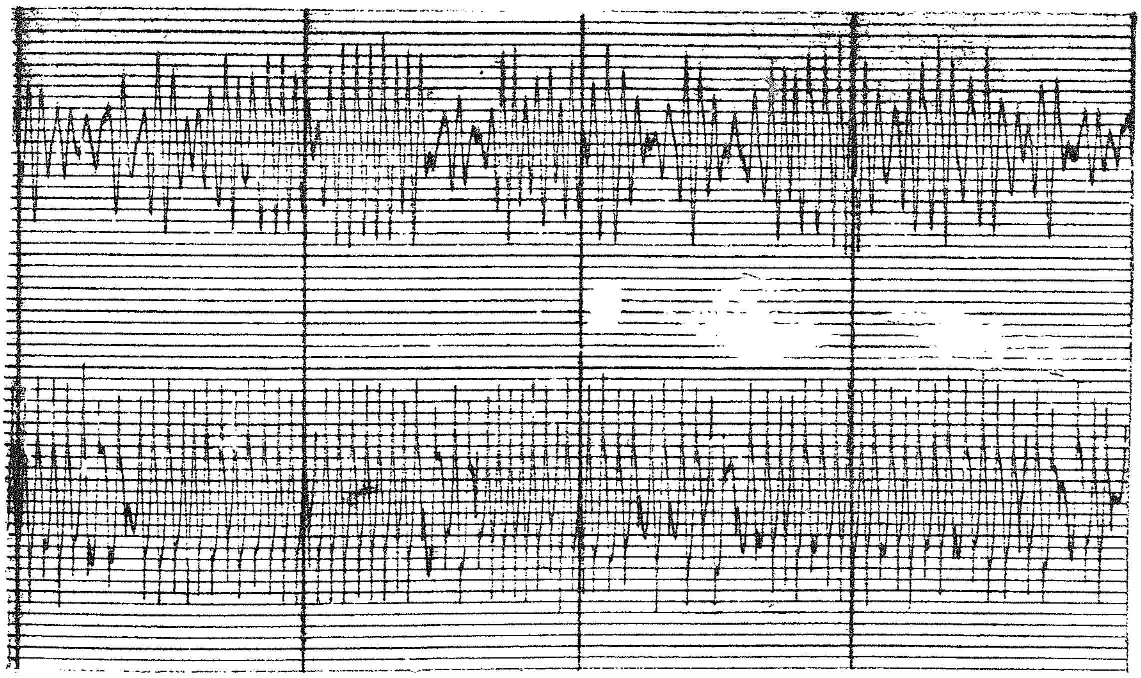
SQUAREWAVE OUTPUT PULSETRAINS FROM A STANDARD ARO UNIT MOUNTED AT FOUR TILT ANGLES. Note the significant breakpoint between 25 and 30 degrees tilt. The nominal 40 deg can be seen to be the optimum tilt angle for this arrangement.

REF: 63



ARO unit on a smooth tarmac road. 20mph, tape TR1/2. REF: 64A
a) preamplifier output, b) schmitt output. Trailer mounted.

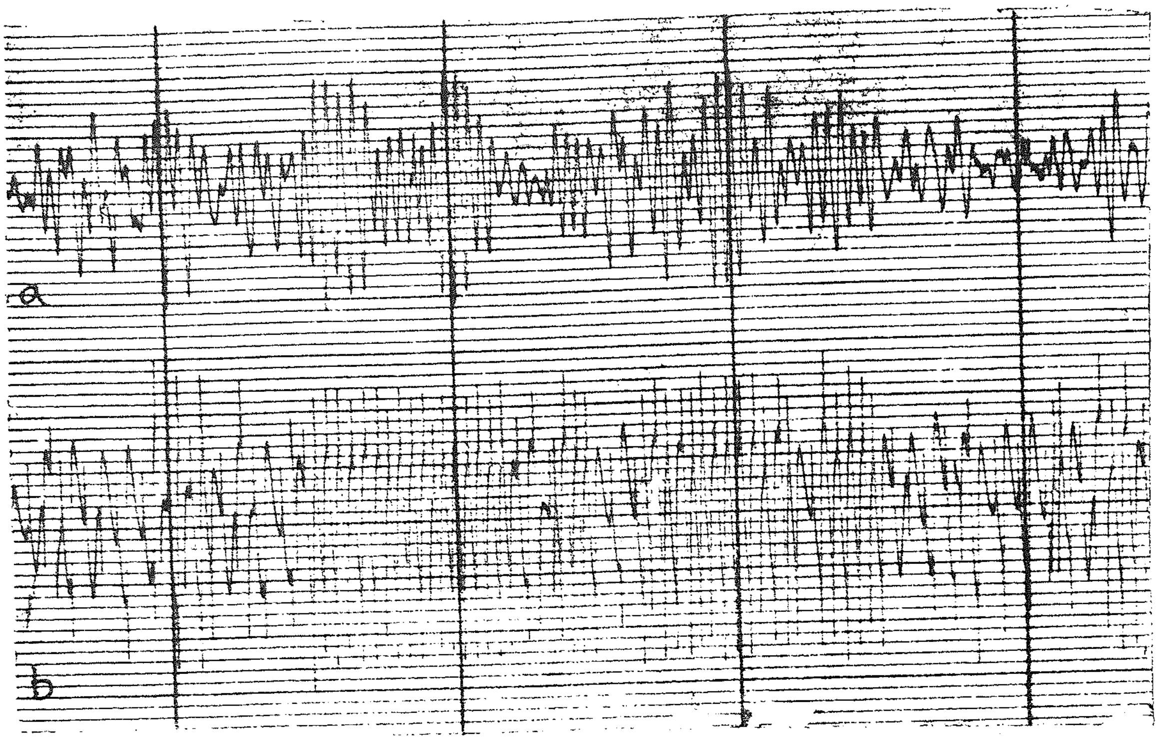
On a smooth road, the schmitt output is reasonable. The trailer mounting produces a result resembling site runs.



ARO unit on concrete, 20mph, tape RDB/6 REF: 64B
a) preamplifier output, b) schmitt output.

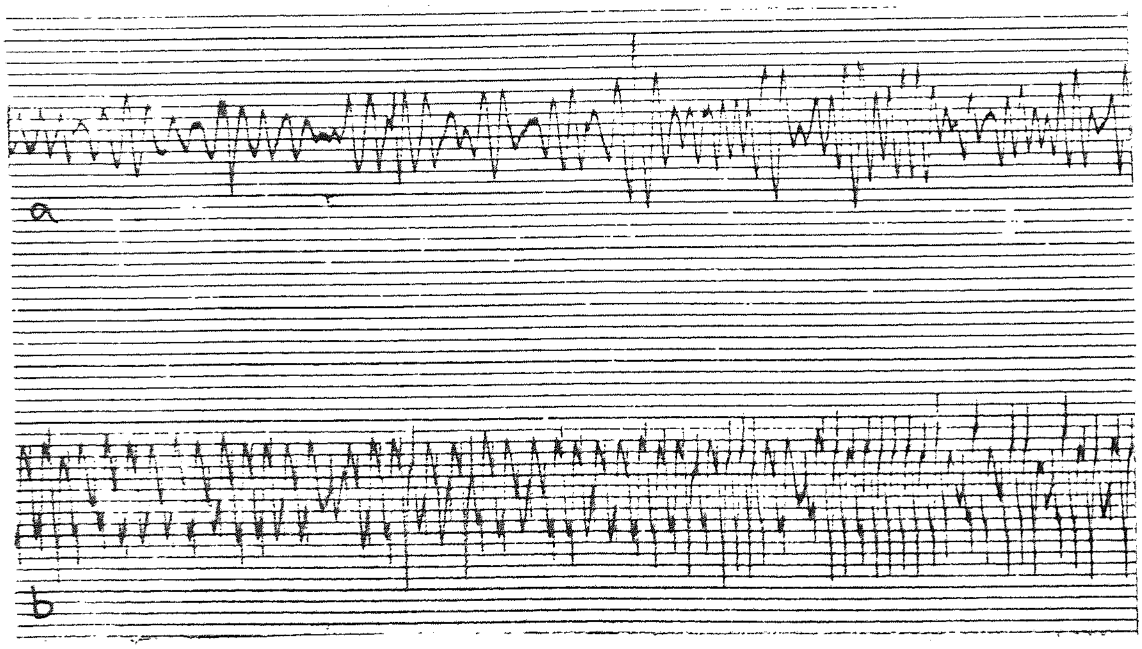
This surface gives greater frequency fluctuation.

COMPARISON OF OUTPUT FROM AN ARO HEAD ON A RANGE OF SURFACES.



ARO unit, car-mounted on a pitted metalled road. 20mph. Tape TRA/1A2. a) preamplifier, b) schmitt output REF: 64c

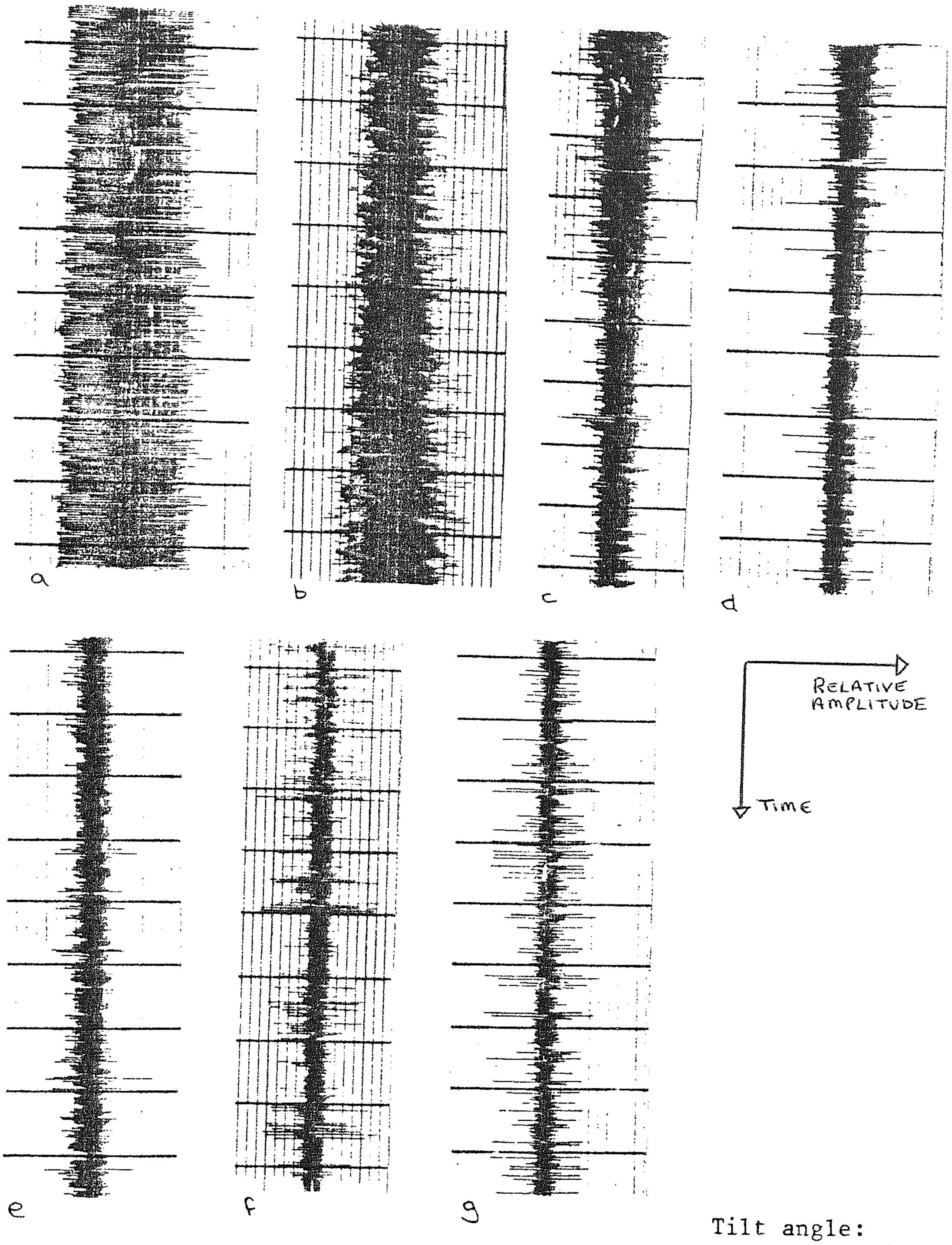
Significant frequency fluctuations occur in the pulsetrain output.



ARO unit, car-mounted on a potholed dirt track, 15mph (limit of vehicle suspension). Tape TR1. a) preamp, b) schmitt.

fluctuations, but not as severe as above. This is thought to be due to the dirt track producing 'jerks', whilst the road produced 'lunges'. Note the lack of signal return from the dirt surface. REF 64D

COMPARISON OF OUTPUTS FROM ARO UNIT ON A RANGE OF SURFACES.

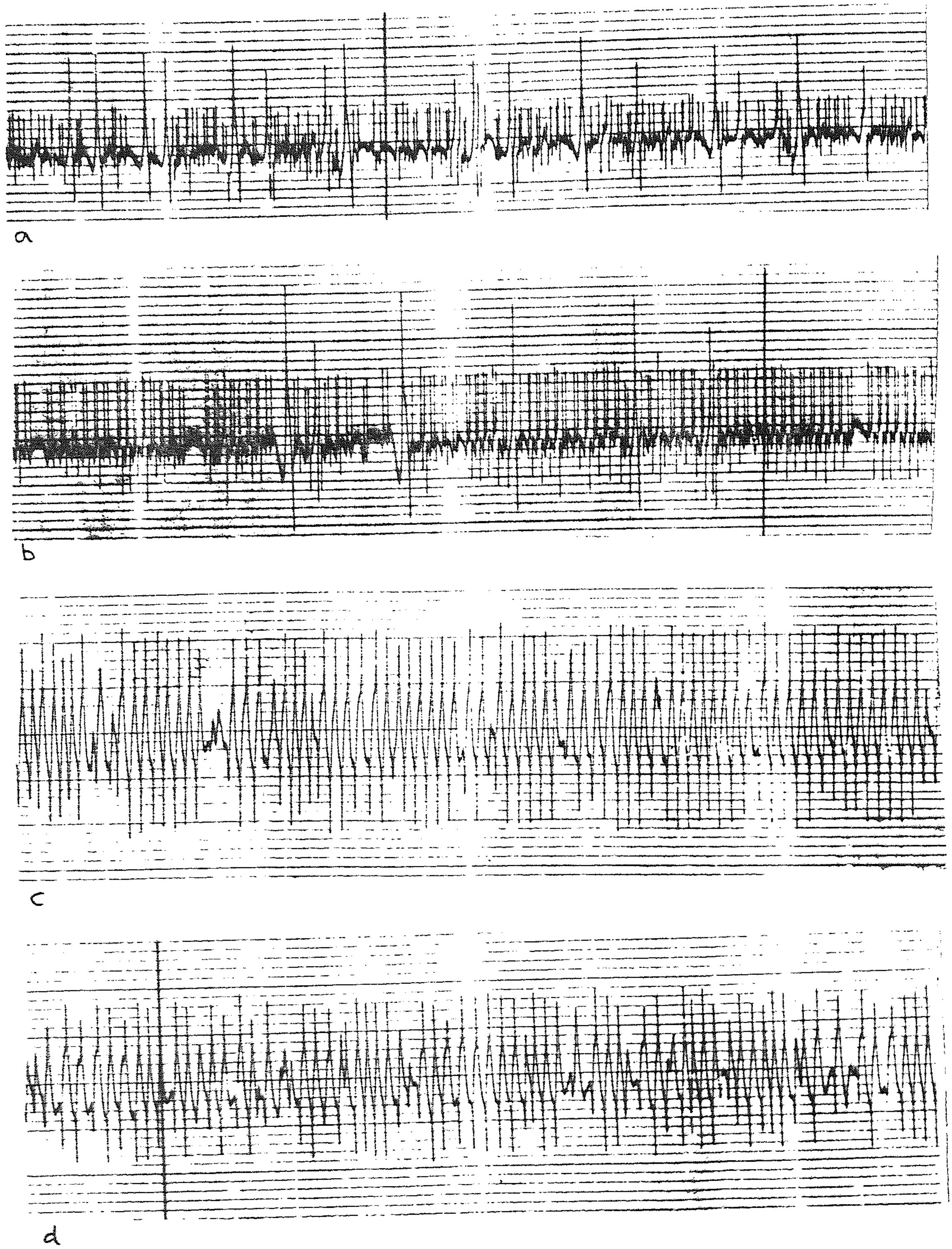


Tilt angle:

a) 55 REF: 65A
b) 50 REF: 65B
c) 45 REF: 65C
d) 40 REF: 65D
e) 35 REF: 65E
f) 30 REF: 65F
g) 25 REF: 65G

TAPE:
UNIT: Aro, standard
MOUNT: car roof, tilt 25-55 deg
RUN: road (Old Poole)
COND: dry, smooth tarmac.
SPEED: 20mph.

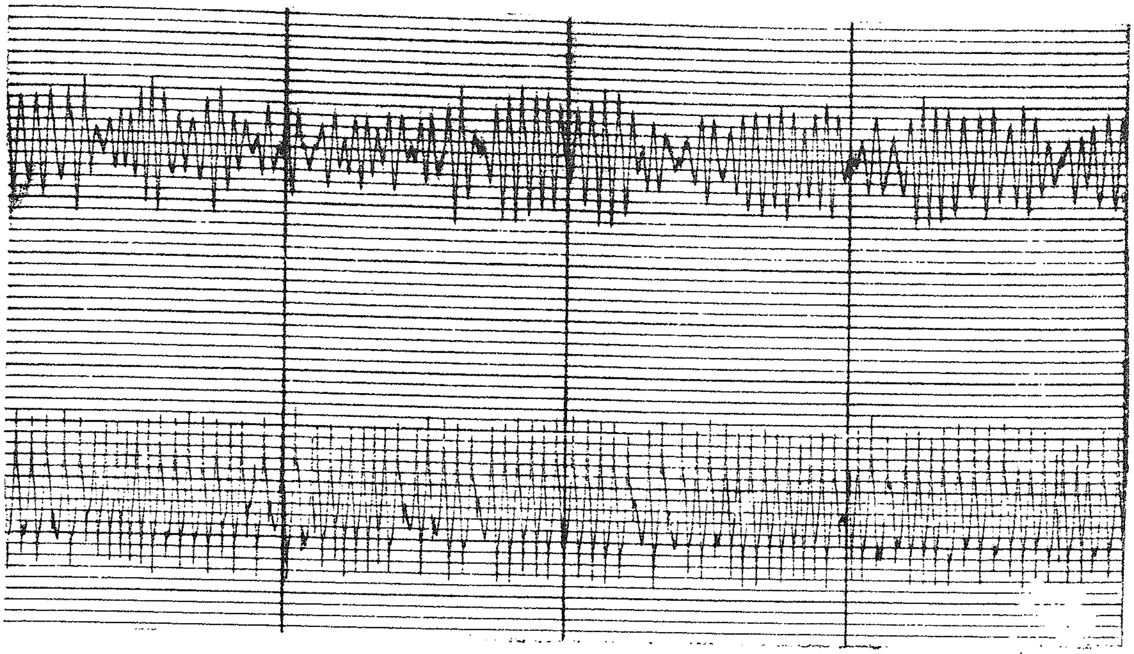
PREAMPLIFIER OUTPUT FROM AN ARO UNIT CAR-MOUNTED ON A DRY, SMOOTH ROAD. The write speed is compressed to allow the averaged amplitude and dynamic range of the signal to be appreciated.



TAPE: TRA
ROAD: Pool Road; tarmac
COND: wet
RUN: roof-mount, 20mph

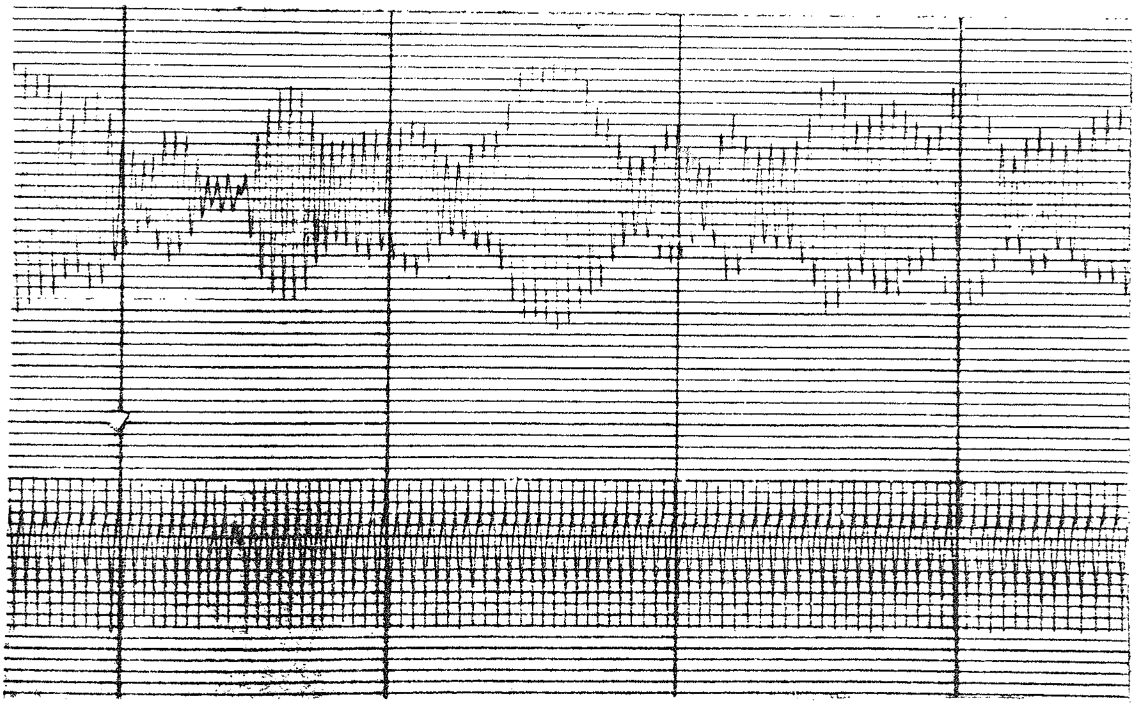
KEY: Tilt angles of:
a) 30 deg REF: 66A
b) 35 deg REF: 66B
c) 40 deg REF: 66C
d) 50 deg REF: 66D

PREAMPLIFIER OUTPUT FROM A STANDARD ARO UNIT MOUNTED AT FOUR TILT ANGLES. Note the frequency and amplitude change with tilt angle, and signal consistency.



ARO unit on a tarmac road. Tape RDB/5. 20mph. Trailer mounted.
a) preamplifier output, b) schmitt output REF: 67A

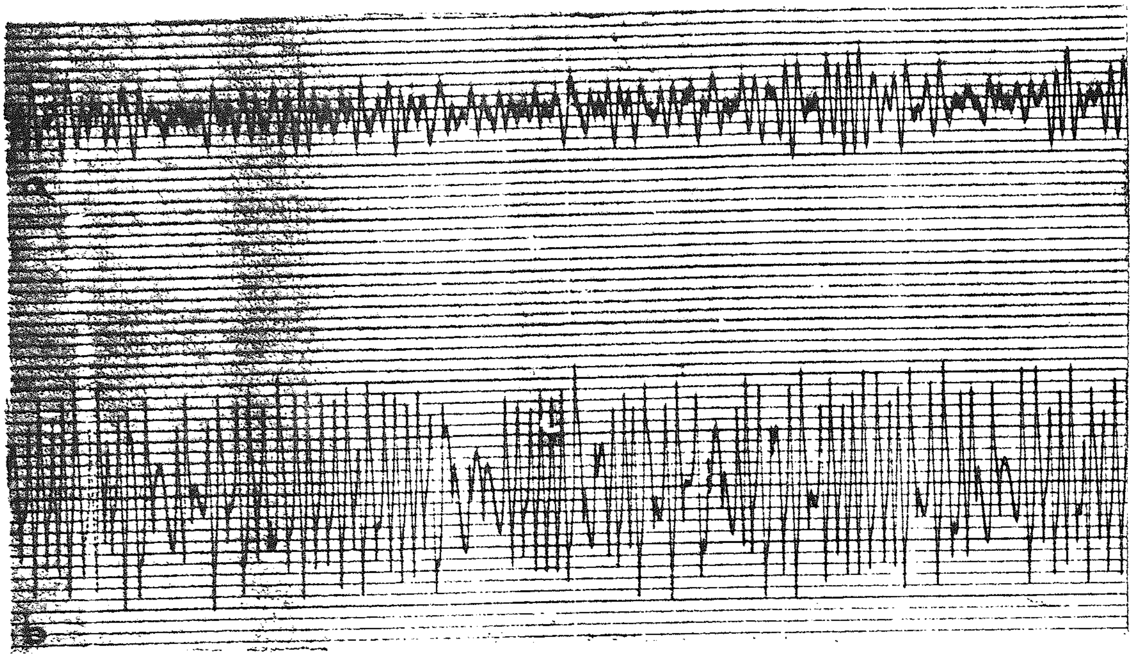
The schmitt pulsetrain is far better than that produced from a truck-mounted unit, but still contains anomalies.



Prototype horn on same tarmac road. Tape XP1A, 20mph, trailer mounted. a) preamplifier output, b) schmitt output REF: 67B

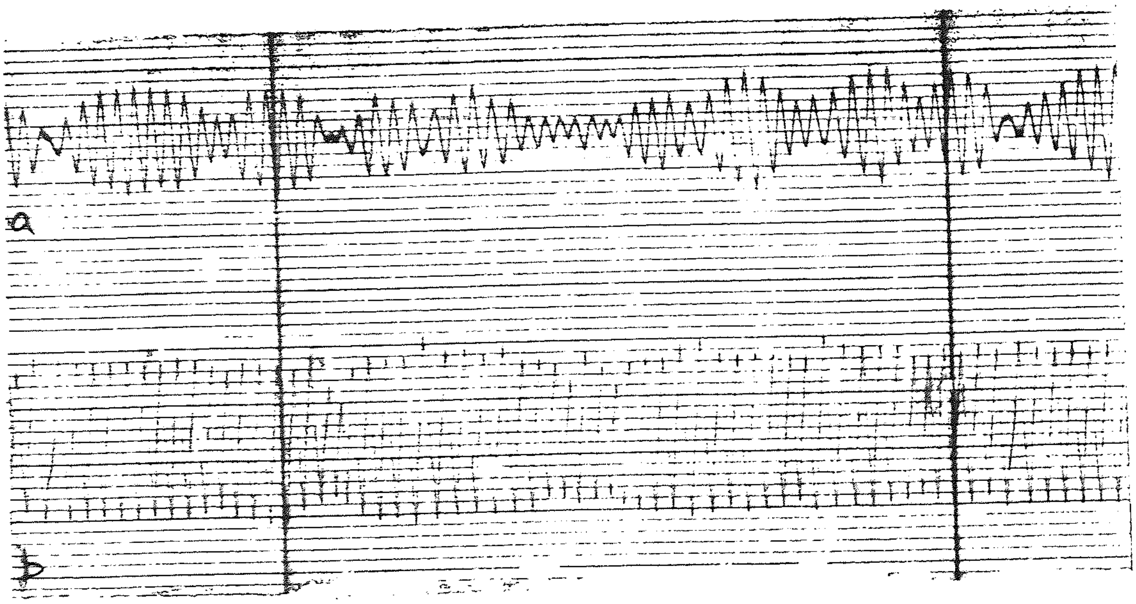
The modulation frequency is the same as above, but very few phase nulls exist, giving an excellent output pulsetrain, which resembles that produced from a truck-mounted unit.

COMPARISON OF OUTPUTS FROM A ROAD, FOR ARO AND HORN UNITS.



ARO unit at Butterwell, unladen truck. Tape 2A/6B. 20mph.
a) preamplifier output, b) schmitt output Ref 67C

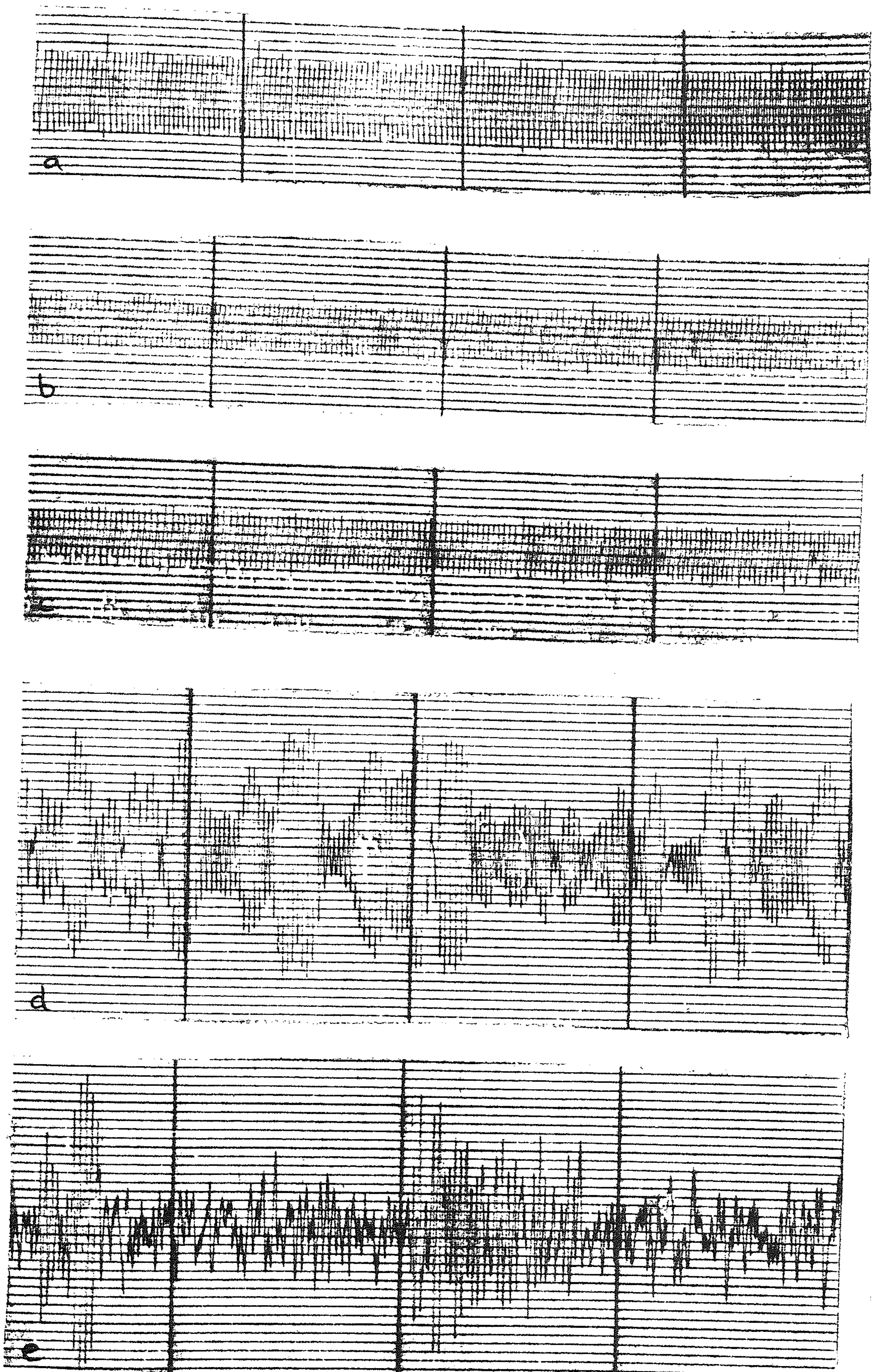
The preamplifier output errs in amplitude and frequency to a significant degree, and thus the frequency count from the schmitt is wildly erroneous.



Prototype horn at Butterwell, unladen truck. Tape BWH1/c,20 mph, no AV. a) preamplifier output, b) schmitt output

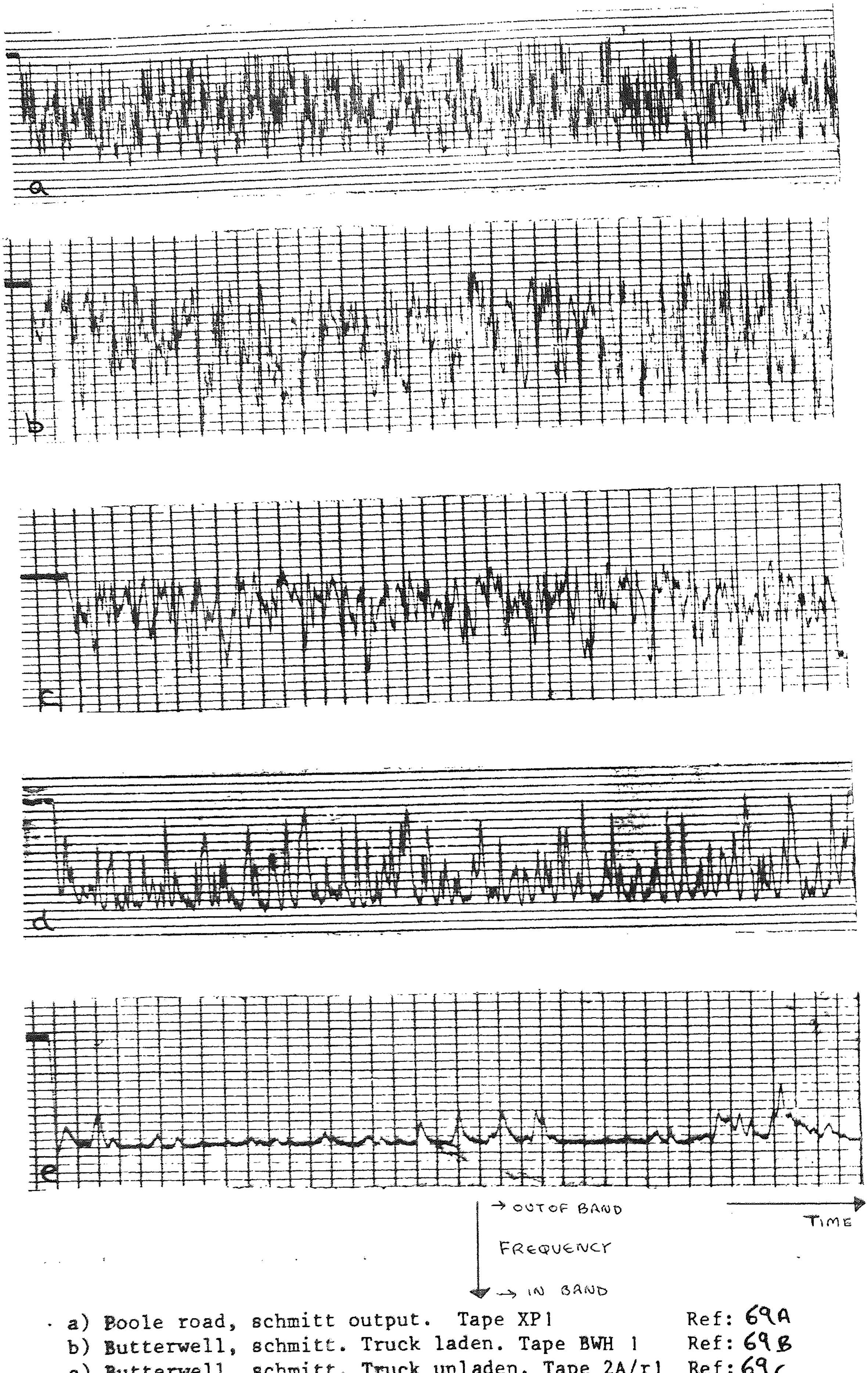
The schmitt output is almost perfect, and in this instance does not require the smoothing of a PLL. Ref 67D

COMPARISON OF OUTPUTS ON-SITE, FOR ARO AND HORN UNITS.



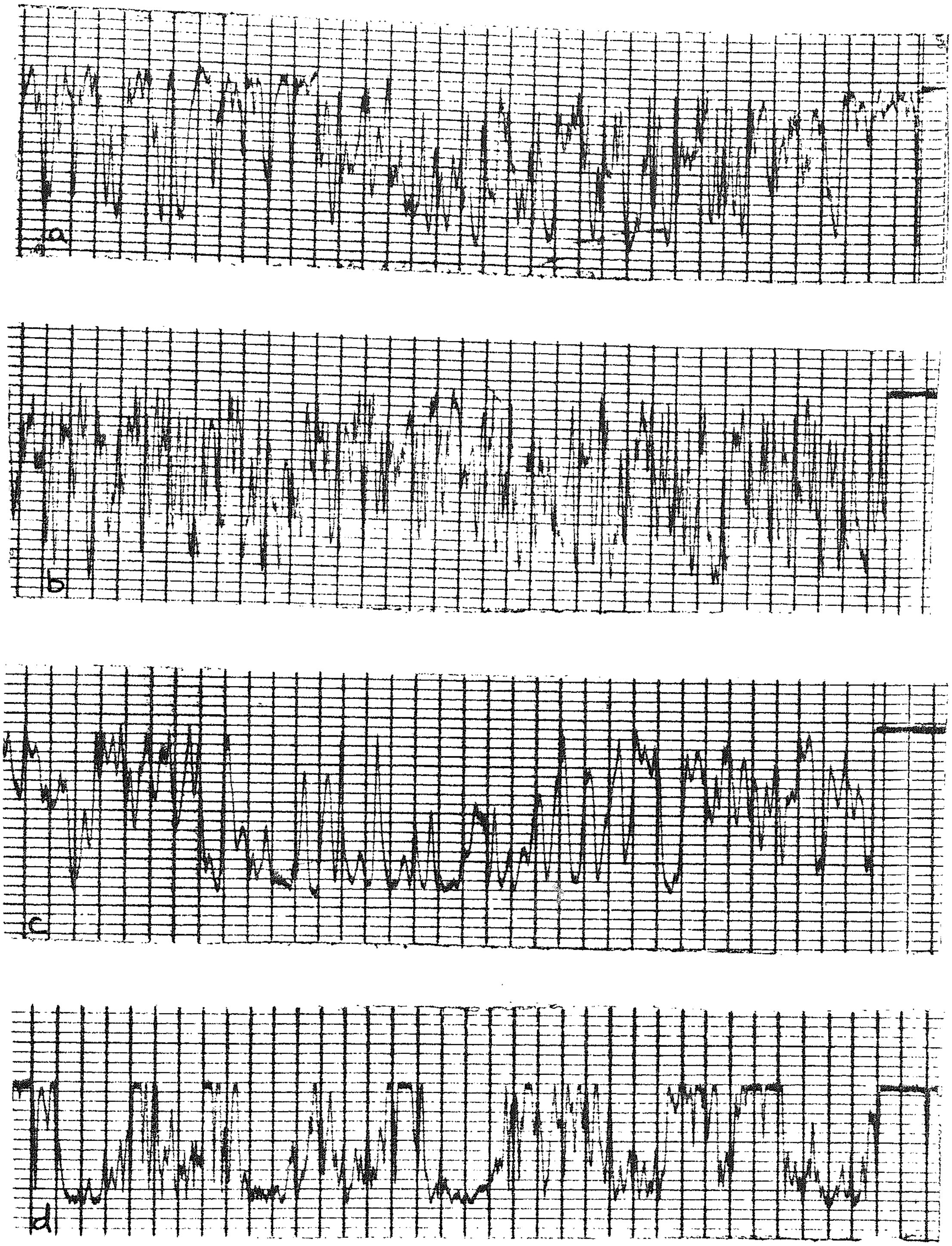
a) Horn prototype, no AV, Butterwell. Tape PP1 Ref: 68A
b) Horn prototype, AV, Butterwell. Tape PP1 Ref: 68B
c) Horn proto. AV (soft + foam), BWell. Ref: 68C
d) Horn proto, no AV, tarmac. preamp output. Ref: 68D
e) ARO unit, tarmac, preamp output. Tape XP3 Ref: 68E

COMPARISON OF OUTPUTS FROM HORN PROTOTYPE WITH THREE MOUNT TYPES ON-SITE: AND OF PREAMPLIFIER OUTPUTS FROM ARO AND HORN UNIT FOR A TARMAC ROAD. All runs performed at 20mph,



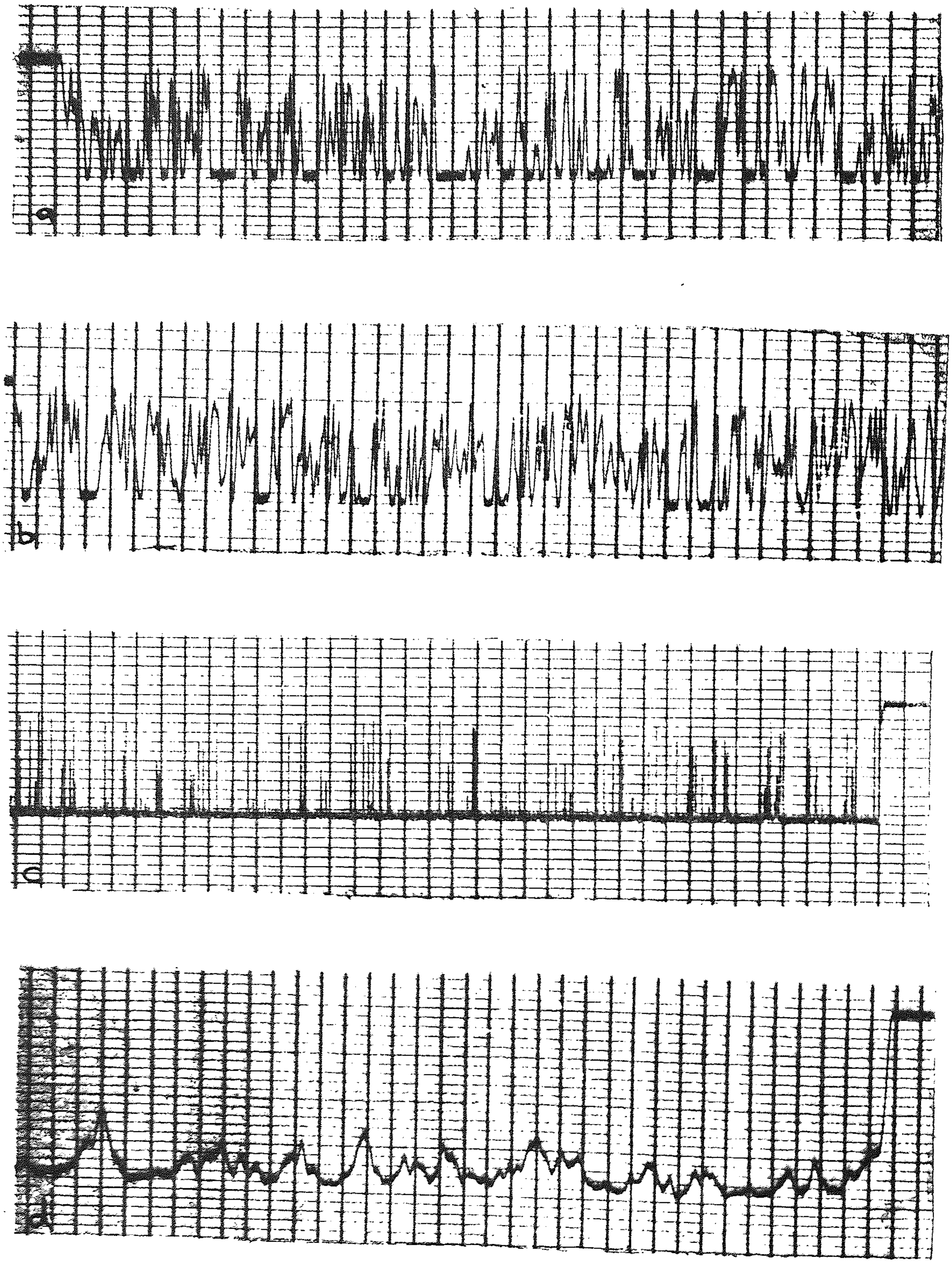
a) Poole road, schmitt output. Tape XP1 Ref: 69A
b) Butterwell, schmitt. Truck laden. Tape BWH 1 Ref: 69B
c) Butterwell, schmitt. Truck unladen. Tape 2A/r1 Ref: 69C
d) Poole road, PLL output, 3meg loop. Tape XP1 Ref: 69D
e) Poole road. PLL output, 6meg loop. Tape XP1 Ref: 69E

COMPARISON OF OUTPUTS FROM ARO UNITS ON SITE AND ON ROADS, WITH AND WITHOUT PLL ADDITION. All runs performed at 20mph, analyser bandwidth 30Hz on centre frequency of 470Hz. Signal strong and present indicated by trace to bottom of graph.



a) Pitted track, schmitt output. Tape TRW1A Ref: 70A
b) Pitted track, PLL output. Tape TRW1A Ref: 70B
c) Butterwell, truck unladen, schmitt output Ref: 70C
d) Butterwell, truck unladen, PLL output Ref: 70D

COMPARISON OF OUTPUTS FROM TRW UNIT ON SITE AND ON A POTHOLED ROAD, BEFORE AND AFTER THE PLL. All runs performed at 20mph, analyser bandwidth 70Hz on centre frequency of 1080Hz. Signal strong and correct is indicated by trace to bottom of graph.



a) Schmitt output, no AV mounts. Tape BWH1
b) Schmitt output, with AV mounts. Tape BWH1 Ref:71A
c) PLL output, Tape BWH1 Ref:71B
d) Horn prototype, PLL output (10+10Mohm) Tape XP2/1. Ref:71C REF:71D

COMPARISON OF OUTPUTS FROM HORN UNIT MOUNTED ON AN UNLADEN TRUCK AT BUTTERWELL SITE, WITH AND WITHOUT PLL AND ANTIVIBRATION MOUNTS. All runs performed at 20mph, analyser bandwidth 30Hz centred on 470Hz. Trace d run affected CA sequence (time constant of PLL too great).

VOLUME TWO: SECTION TWO.

REPORTS PRESENTED TO THE COMPANY.

This section is a collation of reports presented to the company during the course of the project. Only those reports directly applicable to the final project brief are included.

To assist in the location of the required report, page numbers reflect the report number.

Report P36 (circuit modifications and additions) is not included for commercial reasons.

SECTION TWO: COMPANY REPORTS.

2.1 LIST OF INTERNAL COMPANY REPORTS PRODUCED DURING THE PROJECT.

REPORT	DATE	PAGES	INCL	TITLE
P0	17.12.81	57	no	A feasibility ctudy concerning the enforcement of the copyright laws pertaining to cassette tapes.
P1	3.83	35	no	Active filters: a simple design algorithm and computer program
P2	22.3.83	10	(3,11)	The Phase-locked loop and validation logic: a preliminary assessment
P3	29.5.83	19	yes	Report on the incorporation of a phase-locked loop into the existing speed sensor circuit.
P4	3.5.83		(8)	Literature review: backscatter expe-riments
P5	22.7.83		(8)	Literature review: terrain ground models
P6	14.6.83	12	(19)	Radar data acquisition, processing and interpretation: preliminary discussion
P7	14.6.83	33	yes	The design and development of a proposed addition to the sensor: overspeed validation logic
P8	27.7.83	59	(ch5)	Literature review: ground effects
P9	25.9.83		(12)	Company profile: discussion paper
P10	24.9.83	28	no	Initial views on the possibility of updating ALBERT to include vehicular information management
P11	28.9.83		yes	The interface box
P12		8	yes	Competition and market potential of the ALBERT system
P13	4.6.84	19	yes	Shock and vibration simulation: present design and alternative mount system evaluation
P14	14.5.84	22	(ch5)	Literature review: automotive radar and truck electronics
P15	3.11.83	29	yes	The effects of beam geometry
P16			no	Notes for the first annual review
P17	2.1.84	37	yes	Configurable speed sensor: alarm speed prediction and auto-selection
P18	12.12.83	59	yes	Design and evaluation of an altern-ative speed sensor: horn, case and mount
P19	13.12.83	34	yes	An evaluation of the Aro microwave unit

REPORT	DATE	PAGES	INCL	TITLE
P20	19.1.84	43	yes	Microwave windows: effect of material and design on unit performance
P21	16.1.84	12	yes	Alternative speed measurement techniques: the magnetic transducer
P22	13.11.83	8	yes	Specification for the groundspeed sensor
P23	24.1.83	18	yes	Roadspeed unit test schedule (full regime)
P24	13.3.84	76	yes	The off-highway vehicle as an environment for the speed sensor
P25	3.4.84	7	yes	Resume of an assessment of the TRW agricultural groundspeed measuring radar
P26	8.4.84	19	yes	Terrain return signals and method of processing ground return data
P27	7.4.84	7	yes	Microwave radiation: conformance to legislation and safety levels
P28	23.4.84	18	yes	Minimal speed sensor unit (MSS).
P29		130	(ch6)	Spectra results: graphical presentation and discussion
P30	18.6.84	1	yes	Roadspeed production test schedule
P31	1.9.82	55	(ch3)	Report on a preliminary assessment of the sensor system
P32	13.7.84	6	yes	Infrared, beacon, controller system.
P33	22.7.84	4	(24)	Resume of truck and terrain effects on speed measurement accuracy
P34	30.7.84	24	(ch6)	UV trace results and discussion
P35	24.7.84	34	( )	Literature references and bibliography
P36	1.8.84	4	(P28)	Speed sensor: modifications and upgrades.

NOTES:
1. DATE: date of final issue
2. PAGES: no. of pages in issued form
3. INCL: included in this section of the thesis?
   (chx): forms the basis of chapter x
   (x): forms the basis of report x

SECTION 2.2

REPORT INT P3
29.5.83
C. WALLACE

A REPORT ON THE INCORPORATION OF A PHASE-LOCKED LOOP INTO THE EXISTING SPEED SENSOR CIRCUIT.

CONTENTS.

1. INTRODUCTION
2. REQUIREMENTS
3. INTERPRETATION OF THE INPUT SIGNAL
4. CIRCUIT REQUIREMENT
5. SELECTION OF THE CIRCUIT AND PLL
6. IMPLEMENTATION
7. PRELIMINARY ASSESSMENT: BENCH AND ROAD TESTS
8. CONLUSION
9. APPENDIXES:
    1,2 PROBLEMS COVERED BY THE PLL
    5 CD 4046 COMPARISON
    6 OTHER PLL RESULTS
    7 SIGNAL SIMULATION

INTRODUCTION

The intention of this report is to summarise the work performed on thr requirement for, the design of, and the effectiveness of, a phase-locked loop (PLL) modification to the existing sensor unit.

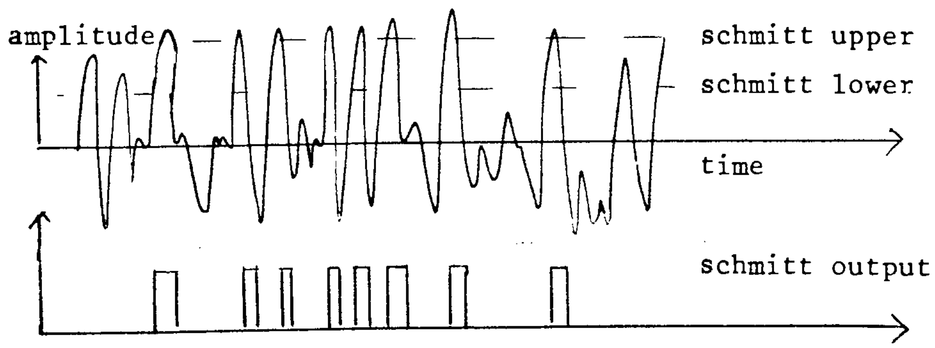
REQUIREMENT

A means of 'rationalising' a squarewave input pulse train is needed. This means must correctly interpret all terrain/radar/circuit non-linearities and inaccuracies, such that the squarewave output bears a linear relationship to the platform velocity. The unit must be cheap and easy to produce, be capable of being retrofitted to old units, and to form the basis of a new design.

INTERPRETATION OF THE RADAR SIGNAL

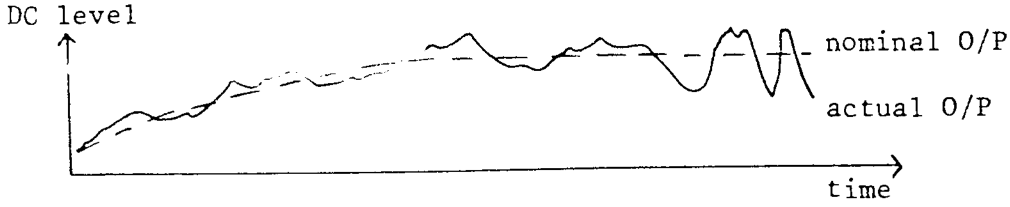
Consider a typical high-pass filtered analogue signal, as fed to the schmitt trigger stage. Three factors affect this signal:

1. The phase transition of discrete targets moving relative to the mean radar-target axis produces nulls in the signal. The result is to produce an envelope effect, similar to amplitude modulation (the true signal being the carrier, the phase change amplitude envelope being the modulator). Unlike amplitude modulation, however, the carrier is the required output and cannot be derived by demodulation. Thus, the effect of removing the envelope would be to leave a doppler frequency representative of the nominal ground speed. This effect is almost independent of other radar parameters such as beamwidth, as the effect persists even with a 'pencil' beam. In fact the narrower the beam the more pronounced the envelope effect of each illuminated area capable of producing a phase change. The result of nulls in the analogue signal is to produce missing squarewave pulses. For example:

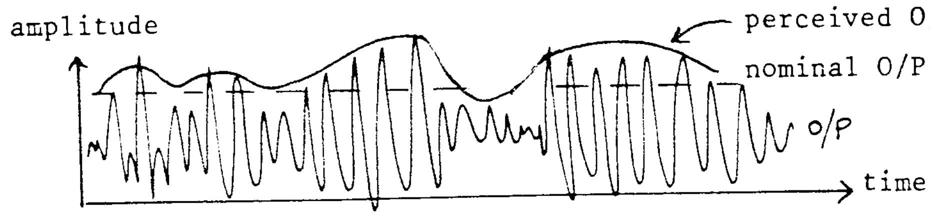


2. The finite beamwidth produces frequency variations in the analogue signal. These variations produce a spectrum of doppler returns; the highest amplitude component is that seen at the circuit output. Due to the scanning effect of the radar footprint, the spectrum and moninal centre frequency will be continuously varying in amplitude and frequency. The exact nature of this spectrum is examined elsewhere. Its effect, however, is best illustrated by considering the F/V output which is a DC level proportional to the input frequency. Whether the actual frequency is above, equal to, or below the

nominal frequency, is a function of ground contour, surface material, subsurface type and material, and beamwidth. If this effect is examined in detail, the mechanisms producing the frequency fluctuations can be further subdivided: again this topic is dealt-witlh elsewhere, but for reasonably small beamwidths, the effect is minimised. For very small beamwidths the effect increases, as it does for large angles. Diagramatically:



3. The compound nature of the surface illuminated within the footprint produces fluctuations in amplitude; the mechanism is similar to effect two, and produces a signal of the form:



The effect produced by the addition of these factors is that of a waveform highly dependent upon antenna and ground parameters, and due to their nature these cannot be eliminated (and for effect one cannot be reduced). In reality this picture is simplistic: other factors also contribute:

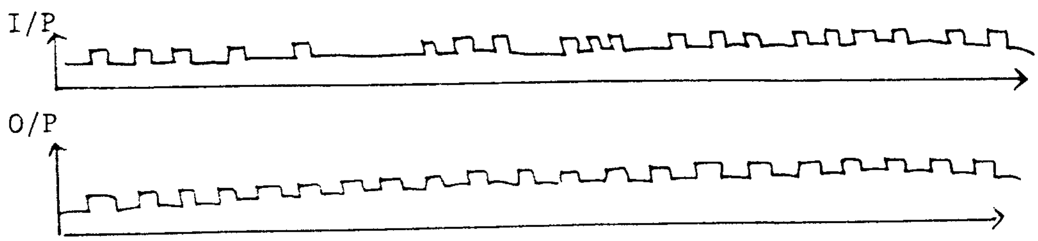
a) circuitry: clipping, noise, nonlinearity, supply modulation, interference, pickup

b) backscatter changes due to angle, surface, composition etc

c) microwave unit fluctuations in power, frequency, sensitivity

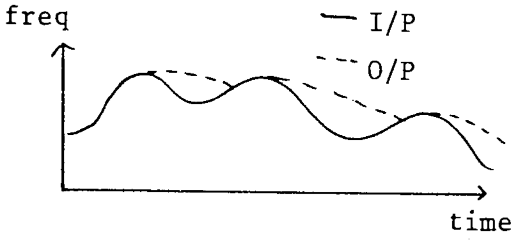
d) platform bounce, unit resonance, vibration etc

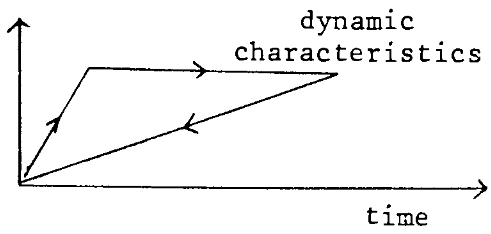
However, it is imperative that for a correct interpretation of the input signal, some means of compensating for these effects must be incorporated. Care must be taken, however, to distinguish between a true varying frequency input and a more constant frequency input affected by these effects. The former must not be converted into a fixed frequency output. Crudely the required action looks thus:



CIRCUIT REQUIREMENT

The circuit must rationalise frequency and amplitude fluctuations. The schmitt trigger converts amplitude fluctuations to frequency error, so only frequency need be considered. For a speed sensor, an increase in frequency is of greater probable importance than a lowering or no alteration, so a circuit is needed that detects a change to a higher input frequency, ie





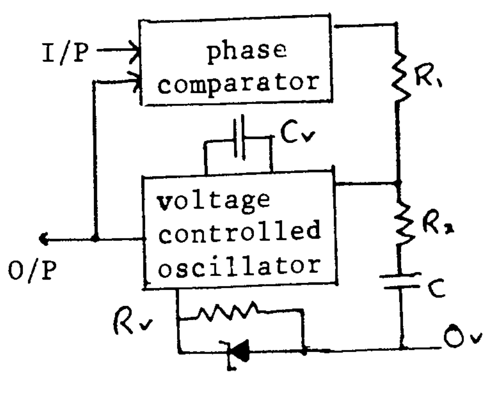
Care must be taken to allow true frequency variation to pass unaltered: for Cat 777, for example, the maximum upward change is: R.S.Cos T where R is the radar conversion factor (32Hz/mph for X band), S is the maximum speed change in any one second (is 0.5mph) and T is the tilt angle (40 deg). Thus, the circuit must allow upward changes of 13Hz/sec. Appendix two reconsiders this figure. The circuit must accept squarewave pulse trains of 12 to 14V pk-pk, of frequency 0 to 1000Hz, operate on an unregulated 12V nominal supply, use negligible current and produce no output for no input.

The obvious contender for this circuit is thus a PLL. The ubiquitous NE500 series and the CMOS 4046 are the most common devices: their characteristics are summarised below:

		*1	565	567	4046
max lock range	%f	40	120	14	-
supply current	ma	9-39	8	6	0.01
I/P Z	Kohm	2-3	5	20	10000
O/P volts max	V	5	5	5	12
I/P for no O/P		y	y	y	no

*1: 560, 561, 562, 564 devices. Refs: Sig 500, RCA 72, RCA 6101.

Appendix 5 covers the internal features of the CD4046, which was chosen as the basis for this circuit. The schematic for the circuit is:



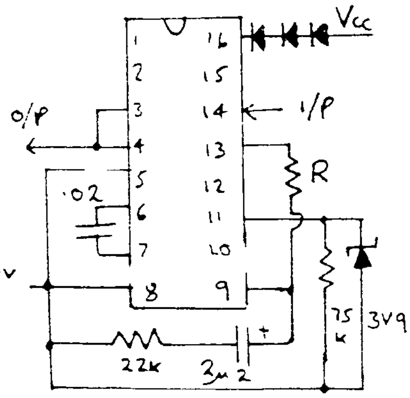
where Cv and Rv determine the VCO lock and capture range. R1 and R2 determine the loop time constant with C.

From Lancaster (1977)

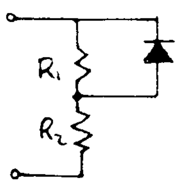
In brief the circuit operates thus. The squarewave input is applied to phase comparator two (edge-triggered +ve; so the duty cycle of the I/P is unimportant). If the input frequency is greater than the comparator input frequency, or if the phase of the input leads the phase of the comparator, an output is applied to the VCO via a low pass filter which limits the change of output. The VCO output is compared with the applied input. This loop continues ad infinitum. A problem encountered not mentioned in the available literstute is that of a non-locking output for no input. A zener diode in series with the loop resistor cured this. Loop components are selected to limit the phase comparator output rate of change. The 4046 was found to perform best with an input 0.5V or greater than the supply voltage, so as the input is equal to this supply, three diodes were placed in series with the supply line. Thus the circuit and a comparison of required and obtained parameters are:

	required	obtained
lock range	0-1KHZ	0-1KHZ
time 8ve up	LT 1sec	0.3sec
time down	GT 2sec	2.5sec
supply	12/neglig	12/0.01mA
in V	12V sq	12V sq
out V	12V sq	12V sq
O/P. no I/P	0	0
lock *1	no	no
O/P duty cyc	20-80%	50%
comp count	cheap	*2

NOTES: *1: lock on harmonic
*2: 1IC, 9 other. Cost 65p tot.

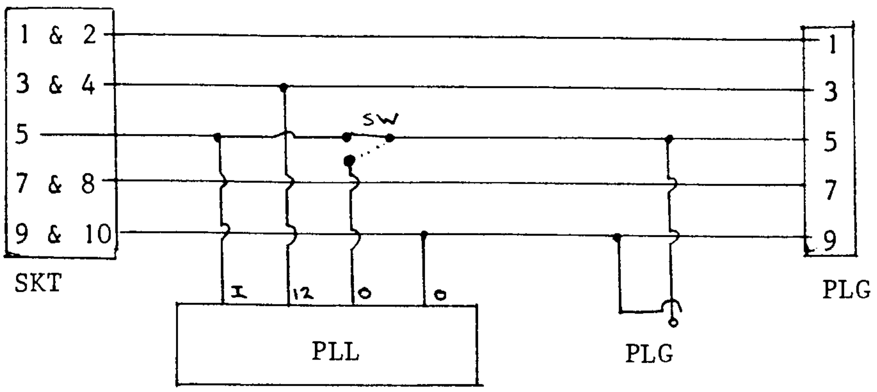


In this circuit, R, which determines the rate of change of output, is best repl-aced by this circuit, which allows alteration of up and down rates of change independently. This is required if, for example, a divider is used in the PLL feedback loop. Such a divider will alter the response times of the PLL assymetrically and rather unpredictably.



IMPLEMENTATION.

For in-line insertion into an existing speed sensor unit, the PLL module is ideal: power consumption is negligible and very little space is needed. The in-line wiring diagram is given overleaf. The 3.5mm plug is for tape-recorder monitoring and recording: the socket connects to the head unit, the plug to the control board



PRELIMINARY ASSESSMENT.

The effectiveness of such a module was estimated by driving over a selection of road surface types, and noting the improvement with the PLL in-line. The ground on which the tests were performed covered the widest possible range of surface types. Laboratory tests were also applied by summing two intermodulating oscillator outputs and applying intermittent breaks in this input. The results of both tests are tabulated overleaf.
Only one paper relating to speed measurement using doppler radar and PLL circuitry has been traced, and a summary of the findings in this paper are given in appendix 6.

Vehicle test run 1. The radar was mounted on a tilting bracket on a roof-rack . The head was resting on thick foam, and thus could 'wobble' by up to ± 15 deg. Twenty runs were performed over a variety of surfaces. The results were:

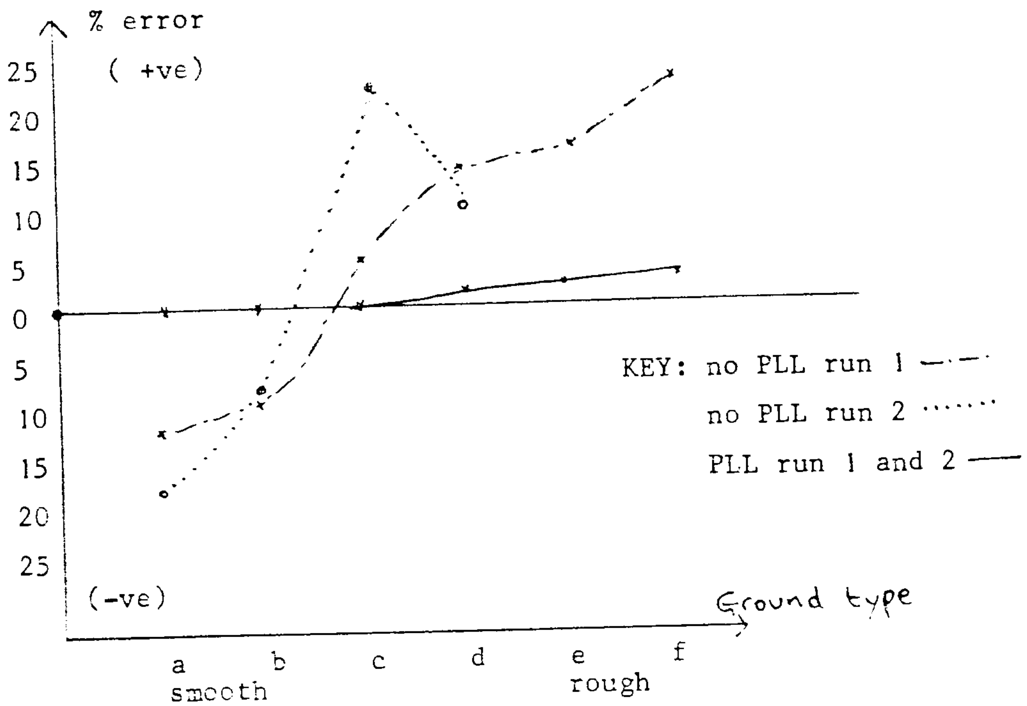
surface	alarm speed		% error	
	-PLL	+ PLL	- PLL	+ PLL
a: smooth new tarmac	18,18, 18,19	21,21, 21,21	-13.1	0
b: smooth tarmac	18,19, 18,20	21,21, 21,21	-10.7	0
c: poor tarmac	21,23, 22,22	21,21 21	+4.8	0
d: cobbled road, wet	24,24	21,22	+14.3	+2.3
e: very wet, poor tarmac	24,24, 25	21,22, 21,21	+15.9	+2.3
f: tarmac: potholed	24,27, 26	22,22, 22	+22.2	+4.8

Vehicle test run 2. The head was rigidly mounted. Each reading given is an average of three

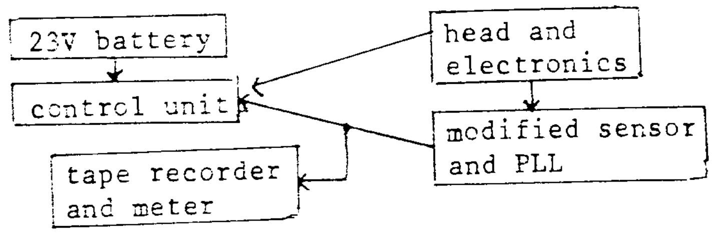
The effect of rain was surprising. Although the radar equation predicts rain to be a near-perfect random rough target, the amplitude of backscatter was far greater than expected.

surface	alarm speed		% error	
	PLL	no PLL	PLL	no PLL
smooth tarmac	18	22	-18.2	0
rough tarmac	20	22	-9.1	0
pitted track	26/27	22/23	+18/23	0-4
rough track	24	22/23	+9.1	0-4
raining, 0mph	0	to 25	0	100

Plotting runs one and two highlights the improvement with PLL:

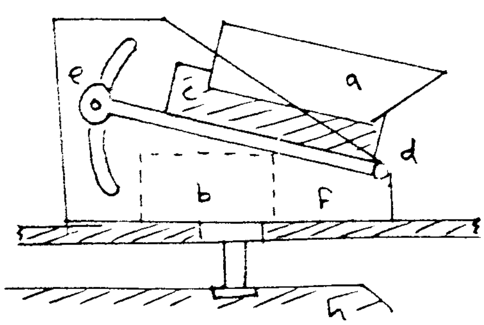


The topology of the equipment and mounting details were thus:



KEY:

a: radar head
b: electronics
c: foam
d: pivot
e: tilt adjust
f: bracket
g: roof rack
h: car roof



INPUT				OUTPUT				
osc 1		osc 2		no PLL		PLL		
Hz	ampl	Hz	ampl	freq	%err	freq	%err	imp%
500	0.01			131	74	173	65	9
	0.02			154	69	192	62	7
	0.1			437	13	459	8	5
	2.5			86	83	122	76	7
	3.0			262	48	306	39	9
	3.5			428	14	455	9	5
	3.0	40	6	167	67	198	60	7
	4.0	150	10	314	37	351	30	7
470	5	400	5	390	22	440	12	10
470	5	160	5	400	20	420	16	4
500	5	480	5	265	47	335	33	14
500	5	430	5	350	30	380	24	6
500	5	380	5	220	56	310	38	18
700	5	710	5	195	61	255	49	12
500	0.1 sec break per 1.0 sec of input			179	64	316	37	27
				215	57	420	16	41
				205	59	405	19	40
				255	49	410	18	31
				200	60	395	21	39
				215	57	405	19	38
700	0.2 sec/sec break			364	48	546	22	26
700	0.5 sec/sec break			154	78	483	31	47

Notes: Imp%' is the improvement with the PLL. The counter used had a time constant of 2 sec (a faster counter would have given even better PLL results in the IM tests). The break test simulates loss of signal (truck bounce etc). It can be seen that the PLL gives a significant improvement to such break tests, but can be fooled with 'continuous' intermodulated inputs, although gives results better in every instance than the conventional circuit.

A further indication of the improvement made by the PLL is that if a cassette recorder is used in 'monitor' mode, the pitch of replay signal is defined, even if the vehicke is travelling over very rough terrain. With no PLL the signal resembles white noise, and although the centre frequency manifests itself as a 'whoosh', the frequency is difficult to define, and varies considerably with vehicle bounce etc.

CONCLUSION.

The PLL addition produces a significant improvement is the interpretation of sensor output pulses. Given the very low cost, low complexity and small size, it would seem wise to both retrofit the module, and to base any new design around this module.

APPENDIX ONE.

The ground effects and antenna effects described in the text are not the only factors bearing on input integrity: at high vehicle speeds, other factors (mainly bounce) predominate. The PLL, however, is designed for short-term fluctuations happening continually (say for an error in squarewave count of up to 20%). Vehicle bounce can produce no squarewaves for several fractions of a second and the PLL is incapable of correctly interpreting such gaps (although the slugged response certainly assists a true frequency count). Electronic methods of dealing with, effectively, errors of 50-80% signal loss are dealt with in the paper dealing with validation logic.

APPENDIX TWO

There are reasons why the PLL circuitry should have the fastest upward response possible: for a vehicular application, bounce will remove all input. It is thus important to obtain the true frequency when input is restored as soon as possible. The modified logic circuit works by accepting short non-continuous alarm frequency pulse trains. These trains must be allowed to register in the first stege of the logic (set at present for a time constant of one second). Thus for an input change of 250-500Hz, a max time of 0.5 sec is desirable.

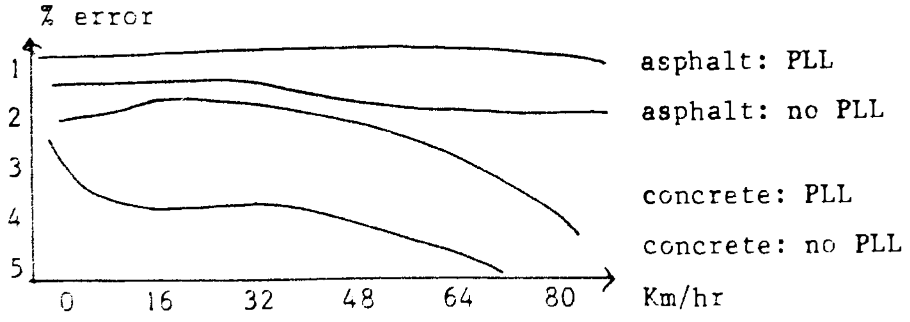
APPENDIX FIVE

PLL parameter comparison: CD 4046 dual input PLL. Ref RCA 6101, 72.

parameter	wideband	low noise
max track range	2000:1	±30%
noise immunity	poor	good
I/P type/waveform	any/any	50% duty/square
O/P for no I/P	mon freq	centre freq
o/P phase/hmonic sens	0 deg/yes	90 deg/no
loop filter function	sample & hold	integrator
I/P / O/P pins	14/13	14/2

APPENDIX SIX

From Hyltin et al (1973). Their results were obtained using a very narrow beamwidth on a stable platform on good surfaces, using two transducers with averaged inputs. Thus measurement errors are far below typical conditions. Their graphical results are presented below.



SECTION 2.3

REPORT INT P7
14.6.83
C. WALLACE

THE DESIGN AND DEVELOPMENT OF A PROPOSED ADDITION TO THE EXISTING SPEED SENSOR CIRCUITRY: OVERSPEED VALIDATION LOGIC.

CONTENTS.

1. INTRODUCTION
2. REQUIREMENTS
3. LIMITATIONS OF THE PRESENT SYSTEM
4. POSSIBLE IMPROVEMENTS:
   A SELECT HIGHER
   B DUAL PLL
   C INTELLIGENT PLL
   D SOFTWARE ALGORITHM
   E REGISTER
   F WINDOW
5. DETAILED DESIGN OF VALIDATION LOGIC
6. FURTHER OPTIONS:
   A EMERGENCY CANCEL
   B POWER FAIL/SWITCH-ON INDICATOR
   C CANCEL OVERRIDE
7. CIRCUITRY:
   A CHOPPER
   B DELAY TIMER
   C WINDOW TIMER
   D DELAY 'AND' GATE
   E EVENT TIMER
   F POWER-UP TIMER
   G LATCH, CA, RESET LOGIC
8. APPENDIXES:
   1 RETRIGGERABLE DELAY
   2 LATCH
   3 IC PINOUTS
   4 TIMESCALES
   5 BIBLIOGRAPHY
   6 CIRCUIT DIAGRAMS

INTRODUCTION

The intention of this report is to describe the evolution of a circuit capable of distinguishing between valid alarm pulse trains and non--valid sequences. The aim is both to incorporate such a circuit into the present sensor system with a minimum of adaptation, and to provide a basis for a new design. In both cases, the ability of the circuit to interpret and respond to true alarm conditions should be enhanced. Many techniques for achieving this aim are compared.

REQUIREMENT

A method of distinguishing true, yet broken, pulse trains and random pulse trains is required. This will lead to greater certainty of consistent performance by eliminating erroneous false alarms, and allowing alarms that would otherwise be misinterpreted.

The requirements for the design can be summarised thus:

1. An alarm is required when:
   a) the input is a true alarm frequency (ie derived from an overspeeding vehicle), and not a spurious alarm frequency generated by antenna/ground contour/vibration effects,
   or b) the input is not an alarm frequency, yet if it were not for the limitation of the circuitry and the above effects (see Report P3 for a fuller description, and below for a discussion of F/V characteristics), it would be

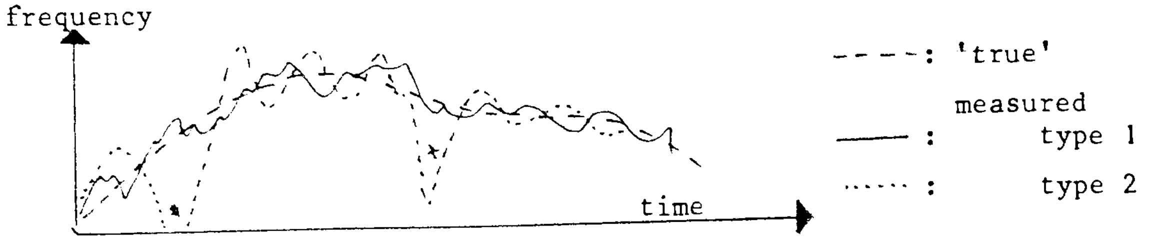
2. An alarm cancel indication (CA) is required when:
   a) there exists at present an uncancelled alarm indication,
   and b) there is no present alarm condition pending or alarm signal being processed

3. An alarm cancel is required when:
   a) the conditions for CA are fulfilled,
   and b) if in normal mode of operation (not autocancel), the cancel biutton is depressed.

In reports P3 and P6, various effects on radar system performance due to complex terrain contours, antenna parameters, vehicle suspension parameters etc were described, and it was suggested that in order to cope with such derogatory effects, two types of measures should be taken:

1. to combat short-term effects (eg, irregular continuous signal deviations of up to 20%, a PLL should be used,
2. to assist in the interpretation of long-term effects and inconsistencies (irregular discontinuous signals), a logic circuit capable of the interpretation described at the beginning of the section should be developed.

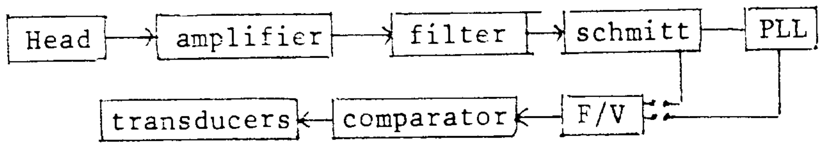
In diagrammatic form, the two types of error can be illustrated thus:



The null points (indicated thus: *) are due to such effects as vehicle bounce, large changes in reflection coefficient etc.

LIMITATIONS OF THE PRESENT SYSTEM

In block-diagram format, the present system topology is:

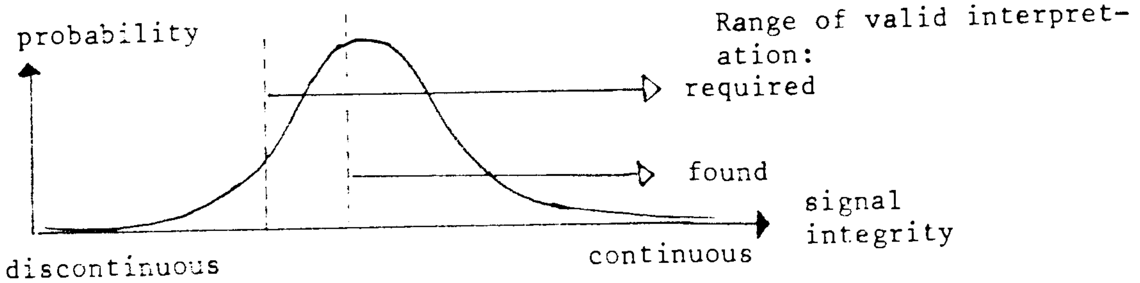


(the PLL is not part of the present operational system but forms part of the recommended additions: its use will thus be assumed. Such a circuit type can cope adequately with continuous pulsetrains, and regular discontinuous pulsetrains (C and RD signals respectively). The limitation of the topology is apparent when considering irregular signals (ID). It is stressed that the limitations of the present system are intrinsic: a better design of the same system would not significantly improve signal interpretation. As the D signal is presented to the electronics via the radar head (and thus is a function of ground/antenna/vehicle/environment parameters), any solution must attempt to reinterpret the required signal, and not merely measure it. It might, indeed, be claimed that an optimum design of the present topology would highlight the input signal discontinuities.

The present circuit utilises a F/V converter that has an associated time constant (intrinsically very small) extended by an RC network. In order to average the DC output (the level of which is reqiured to be proportional to the frequency of thei input), the normal technique is to provide a time constant greater than any expected pulsetrain discontinuity. For a waveform of nominal frequency f, and expected discontinuity time td, means that the chosen time constant, tc, is

$$tc > td \gg 1/f \quad ...... \quad \text{eq } 1$$

A normal discontinuity distribution (Gaussian) is easy to consider:

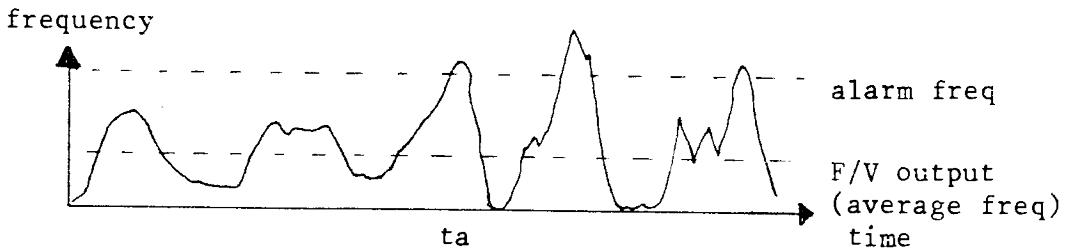


Such an easily analysable distribution is rarely met in practice, and almost never in off-highway applications. In such cases the frequency abberations can far exceed the time constant tc that would be chosen on the basis of the Gaussian distribution. Now,

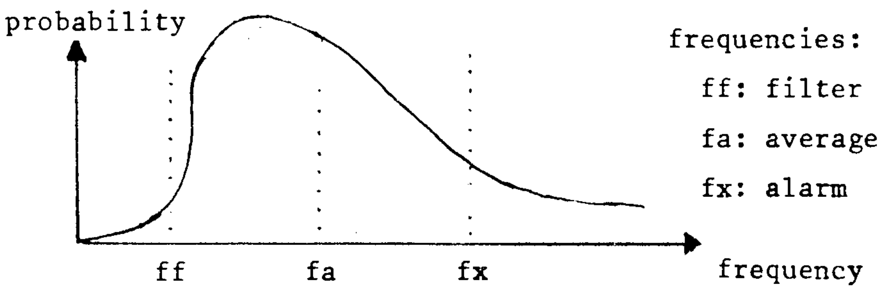
$$td \gg tc \gg 1/f \quad .... \text{eq } 2.$$

If this condition did not occur, the PLL addition (described in P3, which deals with a method of rationalising a varying frequency pulse-train) would be adequate. If the time constant tc is increased (this seems an obvious solution to the problem), the circuitry will compensate for instantaneous pulsetrain abberations, but will consistently underread both RD and ID signals (conforming to eq 2). For a practical complex ground contour, the time constant would have to be varied in real time in order to track the varying input signal conditions, and thus remain an optimal circuit design.

The situation is further complicated by the required F/V assymmetry. A time constant is required that does not slow down changes to a higher frequency (these may well be true alarm signals), yet fills in for nulls, which may be considered an instantaneous drop in frequency to zero. Consider the waveform:



The average frequency remains almost constant, yet at time ta the vehicle exceeded the preset alarm speed and this waveform from this point represents an alarm frequency. Ironically the higher the vehicle speed the greater the nulls and often the lower the average frequency. For significant truck bounce, the nulls may well completely mask the alarm frequency signal. As there is no corollary to this nulling, the frequency-probability curve has the form:



Hence the F/V averaging system must be applied with care: the time constant for an upward change is increased as the required downward time constant increase is implemented.

This basic F/V technique of signal averaging can, of course, be demonstrated to work adequately in a laboratory or during controlled tests (such as car roof-mounted trials) as the pulsetrain produced in these circumstances is category C and partial RD. Indeed, by performing a sequence of trials over a stated surface (on which the system will eventually be used), and ascertaining the extent to which the F/V underreads the signal, the true groundspeed can be derived by taking into account an appropriate 'scaling factor'. Such a system would work, however, if the following remain constant:

1. moisture variations in the air (humidity, rain, fog, snow) on the ground (ice, snow, puddles, dampness etc) and in the ground subsurface,
2. temperature variations,
3. surface alterations due to the elements, load spillage, other road users, different paths driven on same road, dust, dirt etc
4. geometry variations (distribution of load, vehicle suspension setc).

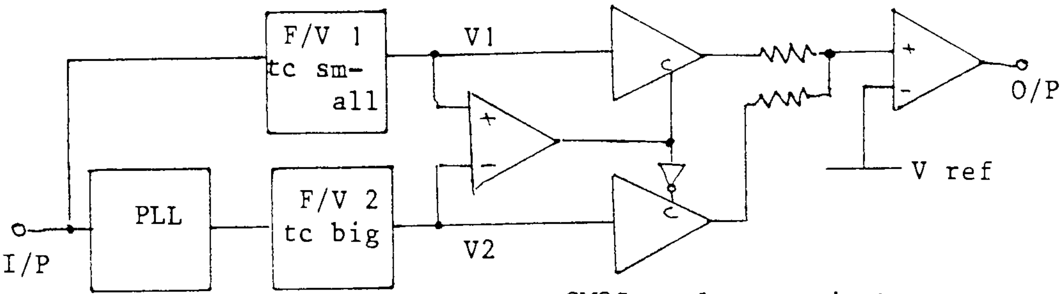
Clearly the listed factors do not remain constant for any practical application, and hence it can be stated with reasonable confidence that a basic F/V averaging system will not give certainty of correct performance.

POSSIBLE IMPROVEMENTS

In this section, six of the methods considered for improving upon the basic F/V circuit will be examined. Some methods have been developed and found to be inadequate and/or impractical (the latter due to various criteria: cost, ease of calibration, stability etc). One idea has been further developed, and detailed circuitry descriptions are given in the next section.

1. Select Higher. This circuit uses the higher of two readings in ascertaining whether the I/P signal is an alarm: one reading uses a F/V with small time-constant, the other uses a PLL and F/V with large time constant. For a continuous input, both outputs will be identical and the comparator output is a true groundspeed-related output. For a prolonged signal loss (ID) V2 reduces slower than V1 and V2 becomes the comparator input. When the signal is regained, V1 latches quickly and becomes the new comparator input. For a typical input falling between these two extremes, the output will alternate between V1 and

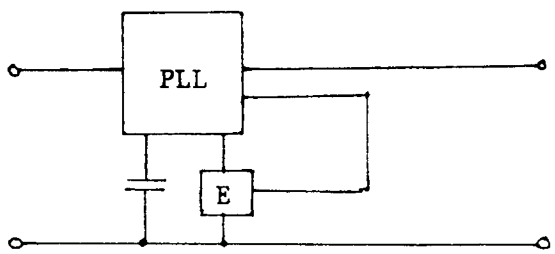
V2. This allows the circuit to respond to higher frequency signals almost instantaneously whilst commensurately compensating for signal nulls of extended duration. One means of realising this circuit is:



This circuit is cheap, requiring few components and no calibration. It does not, however, distinguish between true overspeed and instantaneous above-alarm input frequencies. One spurious alarm is enough to trigger the system. Thus this circuit is not ideal.

2. Dual PLL. By utilising two PLL's, each with carefully selected characteristics, pulse sequences containing both small and large nulls (eq 1 and 2) can to some extent be reconstituted. Such a circuit has a topology similar to the 'select higher' technique, with PLL1 replacing F/V1 and PLL2 replacing PLL1 and F/V2. PLL1 is tuned to a narrow lock and capture range, just below true alarm frequency, and posessing a small RC time. PLL2 is the reverse. For an RD or C input, PLL1 locks and holds (PLL2 will contribute only for an average trend upward). For ID inputs, PLL1 will lose lock and PLL2 takes precedence, although PLL1 will regain lock near alarm frequencies. The technique works fairly well, but still does not distinguish false alarm conditions.

3. Intelligent PLL. It is possible, by the use of the CD4046 PLL, to design a circuit capable of ascertaining its own optimum operating conditions. By using the PLL circuit as desctibed in report INT P3, a feedback system can be incorporated that alters the lock range outward until lock occurs. The lock range is then shortened, thus ensuring accuracy of lock and interpretation. US patents 4052722 and 4335383 use a basic version of this technique. In block diagram:

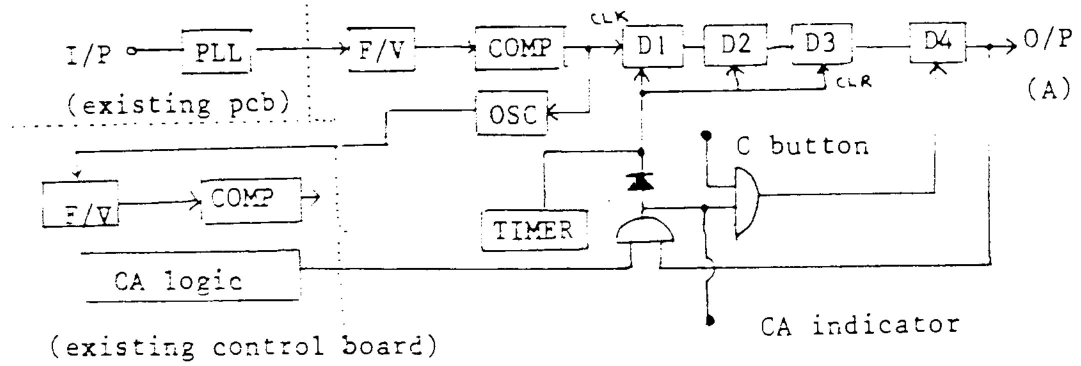


E: electronic resistor or electronic switch between resistors

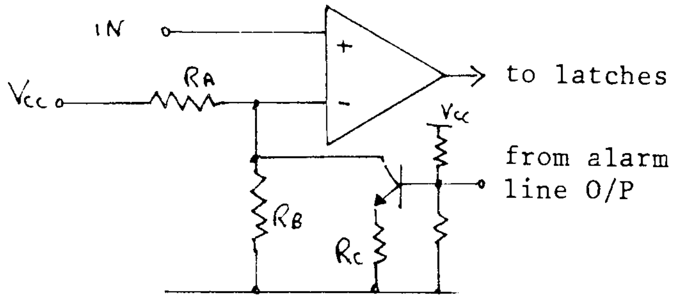
4. Software algorithm. It is certainly feasible to design a microprocessor-based system that would be cheap to produce, and be effective in use. Development time, however, would be extended as several design requirements do not lend themselves to software solutions. Long-term averaging, for example, is easily achieved by analogue means. System interfacing would require reasonably complex hardware. A full microprocessor implementation of the ALBERT system, however, would reap significant benefits: such an algorithm based module could contain a:

a) long-term frequency 'average' calculator
b) short-term " " "
c) " " amplitude " "
d) long-term " " "
e) peak-frequency detector and latch
f) amplitude " " "
g) past history store (average and exceptional conditions)
h) store: max speed, acceleration, deceleration, state of retarder etc.

5. Register-based. UBy using a sequence of self-locking latches with a common clear-line, a circuit can be designed that effectively monitors an alarm sequence, and alarms only for valid inter-alarm timings. A basic register IC (with self-clock modification) will suffice, though for simplicity three latches can be used (more latches are preferable, but one IC can contain the total of four used here) Such a circuit looks thus:



For n latches, n overspeed pulses are needed within the clock generator timeout period, tg. If this condition is fulfilled, D4 holds the alarm output high. In the absence of further valid input pulses the timer tg times out and clears D1-Dn. D4 holds high until cleared by the C button (for which a CA state must be pending). The oscillator allows the control board to see a logic alarm in terms of frequency. tg, and the number of latches are clearly critical: the larger n the more certainty of a valid alarm detection, although the circuit is far from foolproof. The CA can be falsely enabled for an alarm input sequence containing ID signals, and this may if td ≫ tg, prematurely clear the latches. It may be possible to use two timers, tg1 and tg2, the former feeding the latch CLR by means of ANDing with tg2, whilst the alarm line is fed by tg2 only. In this case, tg2 > tg1 > td. Alternatively the comparator may be adjusted to a lower trigger level thus:

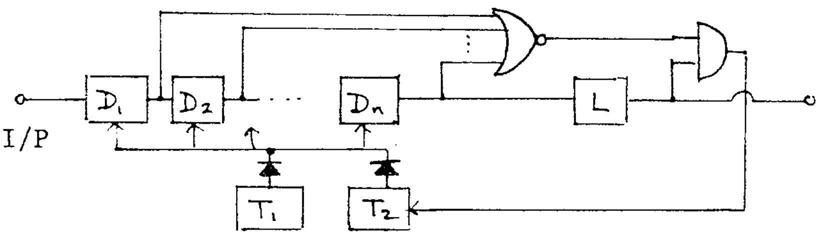


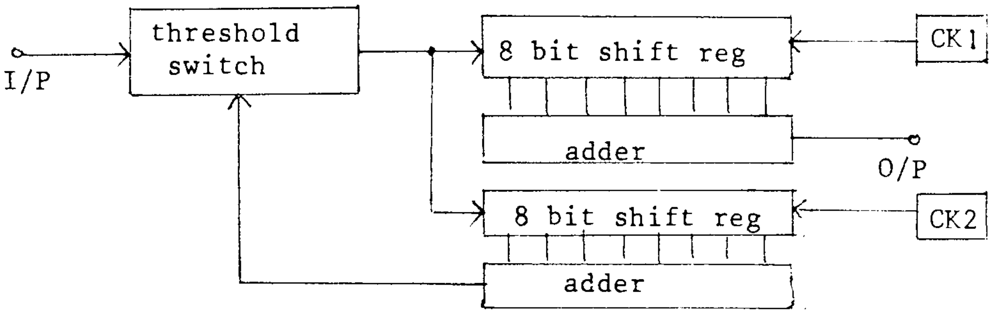
$$V_1 = \frac{R_B . V_{cc}}{R_B + R_A}$$

$$V_2 = \frac{R . V_{cc}}{R_A + R}$$

$$R = \frac{R_B . R_C}{R_B + R_C}$$

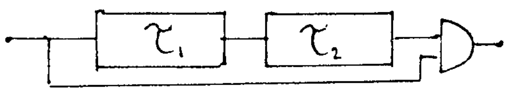
Both methods, however, mask the symptoms and do not effect cures. A better modification is to examine all latches, and if all empty to take the above measures. If combined with an adder, and a second register and adder, we have a simple CFAR (constant false alarm rate) system (refs Nicholson, 1973, Ross, 1974, Skolnik 1962). Typical circuits might be:



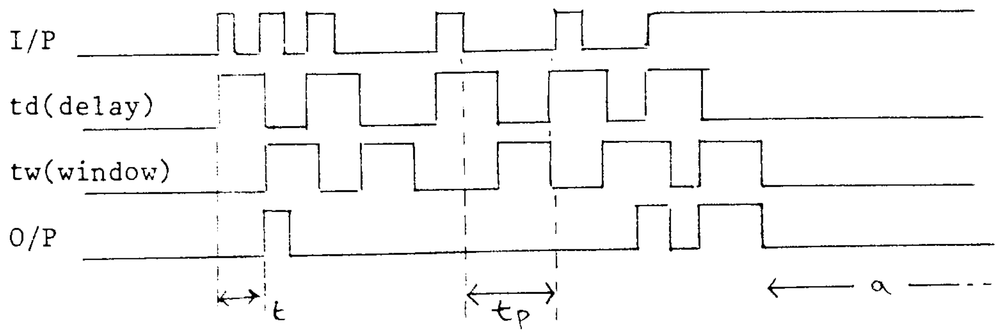


The latter circuit evaluates the system clutter and adjusts the threshold circuit proportionally. For CFAR the threshold is usually amplitude adjusted: for this application, many possibilities present themselves: changing filter frequencies, PLL response times etc.

<u>6. Window.</u> By using a delay and window timer, another method of delaing with poor-quality pulse-trains can be derived. For instance this circuit uses two monostable IC's. The



operation is simple and effective: if both delays are set at t seconds, an output is present for an input containing pulses separated by gaps of the form: output for $2t > t_p > t$, for gap spacing t_p. The propagation time is t seconds, and can be minimised by triggering the first timer on +ve edges, the second on -ve. For example:



As this circuit will not alarm for two pulses input in isolation, it provides, in principle, the required intention of signal/noise discrimination. However, it is not quite correct: time a is early alarm curtailment.

DETAILED DESIGN: THE WINDOW METHOD.

The window circuit would seem to acieve the original objective of assisting in distinguishing valid nulled signals and short-term invalid alarm signals. A more rigorous design procedure will now be adopted.

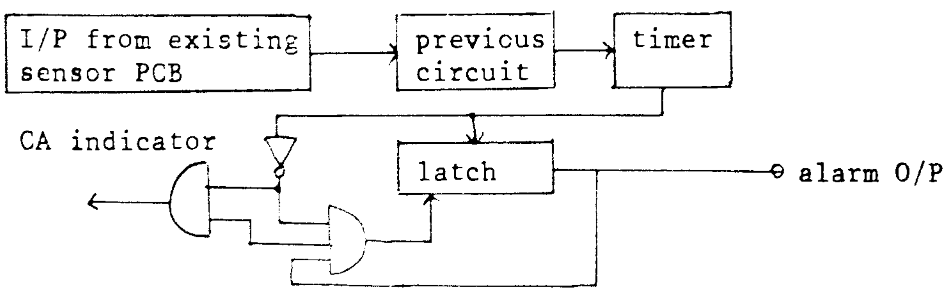
To summarise the conditions of input for an alarm output:

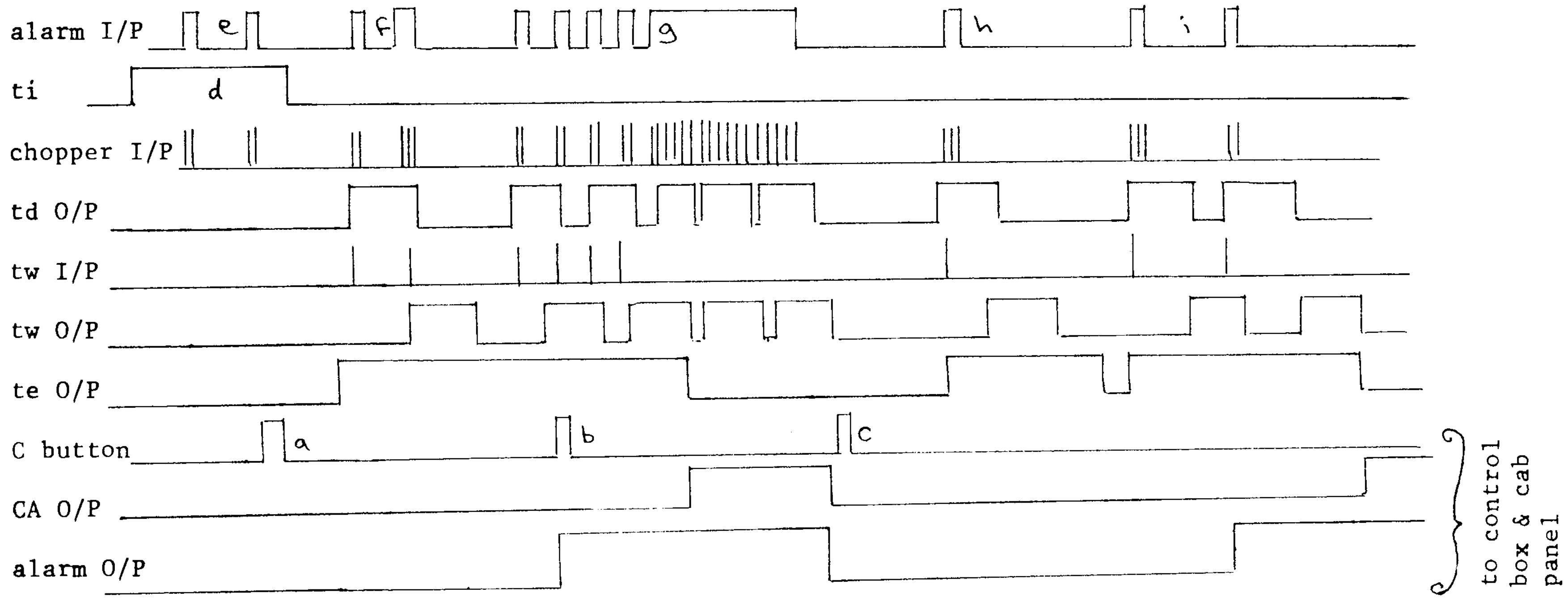
1. a delay between any two pulses, tp, such that $(td+tw) > tp \geqslant td$
2. a continuous sequence of pulses, where $td > tp$, but for which an input pulse appears during tw
3. a continuously high pulse level that exceeds the duration of the delay time.

The CA criterion are:

1. the input pulses must conform to the input conditions 1 to 3 above, AND
2. the timers preceding the alarm latch must not hold a possible alarm state.

For autocancel, the CA input is held high permanently. An additional timer provides the means of ensuring no imminent alarm states: in diagrammatic form we have, so far:



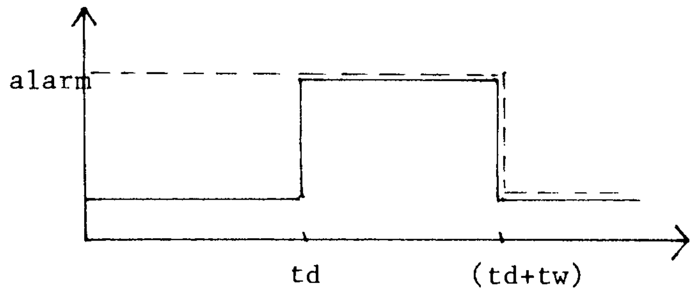


NOTES: a: Cancel button has no effect (no alarm state)
b: " " " " (delay timer high)
c: Alarm cancelled (alarm state and delay timer low)
d: power-up timeout
e: I/P masked by ti
f: pulses too near together: no alarm output
g: pulses near and repetitive: alarm output
h: single pulse: no alarm
i: pulses correct spacing: alarm output

——: any 2 pulses in isolation

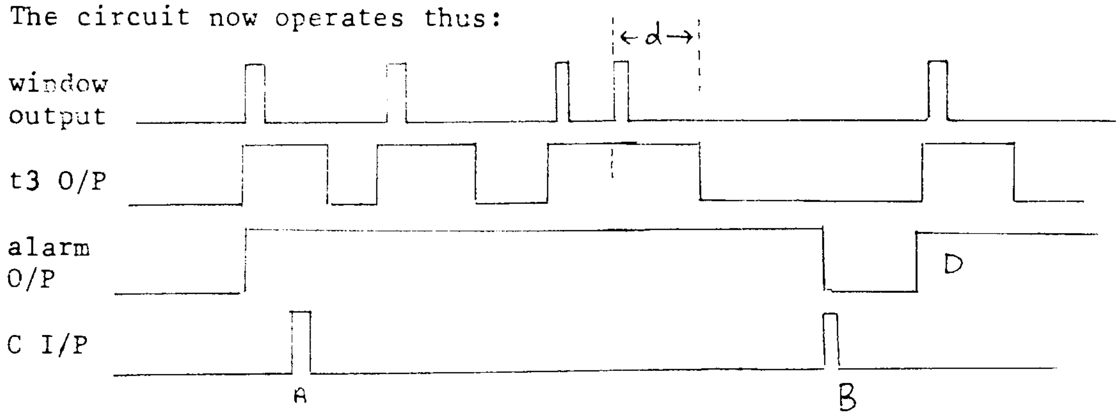
– – –: pulse trains

The validation logic can be considered as a filter with step-cut of the form:



<u>WINDOW LOGIC TIMING DIAGRAM.</u> An example pulse input is given, with suitable Cancel action taken.

The circuit now operates thus:



At A, the C input has no effect as t3 is high. At B, alarm cancel is achieved, as an alarm is output but t3 is low. The alarm is re-engaged at D. From the termination of input there exists a delay d, equal to timer period t3. This circuit is now a true validation logic type. However, td and tw timers are non-retriggerable, so a chopper must precede them (a 555 oscillator, self-powered: see appendix). Timer te therefore is retriggerable, so if refresh pulses are applied within its timeout, the output will remain high. CA is output for:

a) te output low (no pending alarm state)
b) alarm state O/P (latch high)

Thus the CA sequence is identical to the initial alarm validation criterion, but requres LACK of an alarm pulse in period te. If C is continuously depresses, the system can only cancel when all other criterion are fulfilled, and thus the system in this respect is fail-safe. For autocancel (alarm cancelled automatically upon removal of the alarm condition) this is very useful.

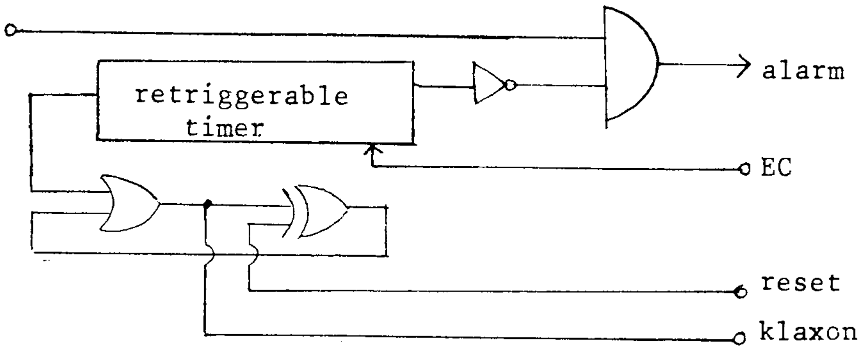
A turn-on delay, ti, is required as + and - edge triggering is used. This is a retriggerable leading edge triggered monostable with ti > te. From the timing diagram, the system maxima and minima times can be seen to be:

1. The time from overspeed to alarm is:
   Max: (td+tw) Min: td
2. The time between I/P pulses for alarm is:
   Max: (td+tw-t) Min: (td+t)
3. The time for CA after an alarm is:
   Max: te Min: te
4. For true alarm smoothing: $te \geq tw$
5. Relation between delay and window: tw $>, =, <$ td
6. The time from power-on to readiness is: ti.

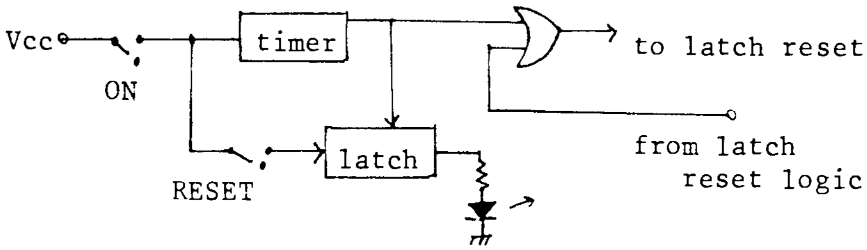
(t is a small time to enable a pulse to coincide with the true logic state of the following device).

FURTHER OPTIONS

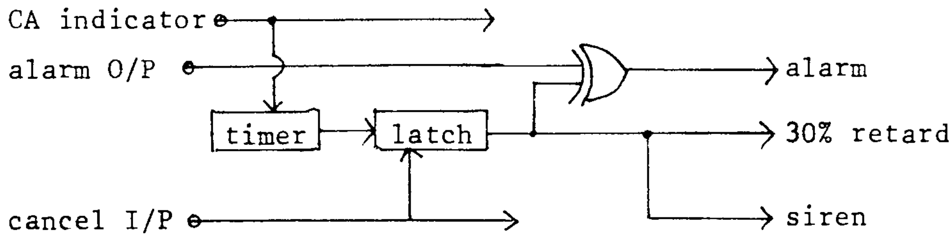
1. Emergency cancel. If the retarder sequence would cause a hazardous situation, an emergency cancel, EC, state can be entered. EC disables the retarder by holding at a nominal 30% capacity, and sounds the vehicle klaxon. Reset is performed by master key. Logic:



2. Power-fail and/or switch-on indicator. This addition indicates power applied; or, after power-on, if reset, power fail (even if instantaneous).



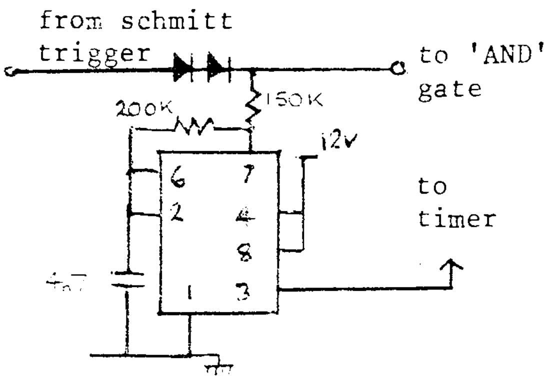
3. Timeout cancel. The EC option can be extended by ensuring a time after cancel is available: if none received the retarder sequence is automatically modified. Thus if, for example, the driver is unable to depress the cancel button due to vehicle control problems, he is not put in a potentially dangerous situation of underspeeding with the retarder sequence fully engaged. A klaxon is sounded simultaneously to warn other site personnel.



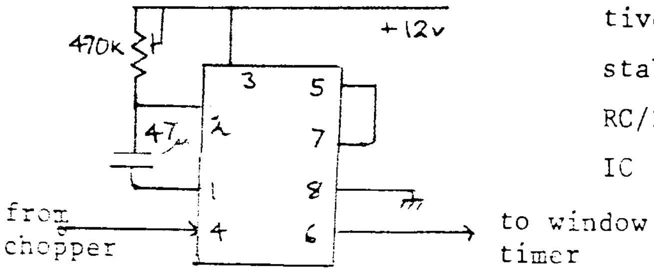
CIRCUITRY

In this section, the various modules described above are illustrated at component level. Only those modules not covered by other reports are included.

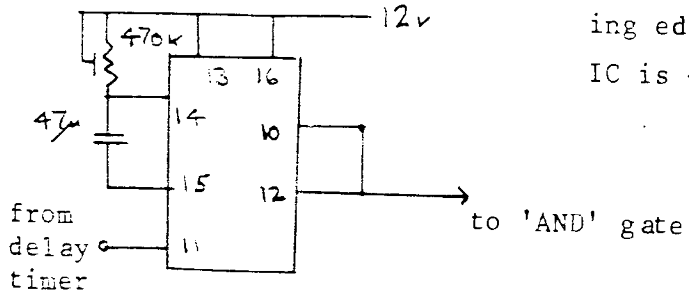
1.Chopper. The diodes prevent an output from the oscillator when a low logic level is input. Oscillation frequency is not critical, and is set at around 500Hz. The mode of use is rather unique: self-powered. IC is a CMOS 555.



2. Delay timer. The mode of operation is non-retriggerable, positive edge transition monostable. Time period approx RC/2. Design for ti te.
IC is ½ CD 4098

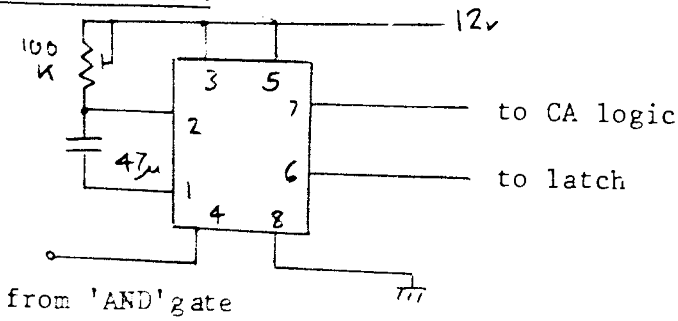


3. Window timer. The mode of operation is non-retriggerable, falling edge trigger timer.
IC is ½ CD 4098

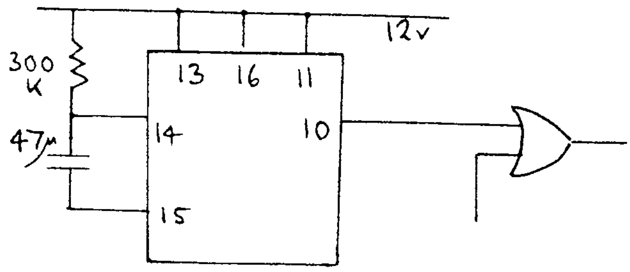


4. Delay AND gate. IC used is ¼ CD 4081. One input from chopper diodes, other from window timer.

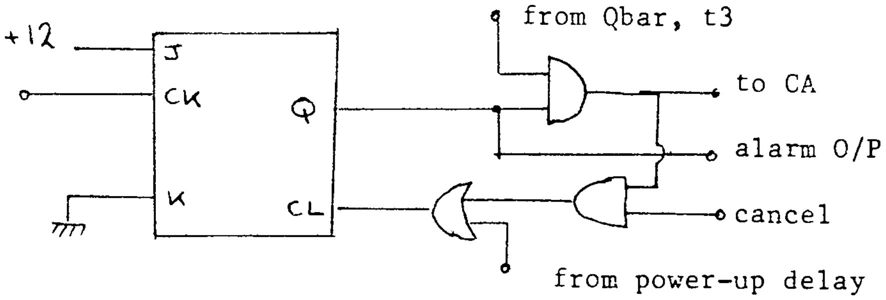
5. Event timer.



6. Power-up delay. IC: ½ CD4098 and ¼ CD 4071

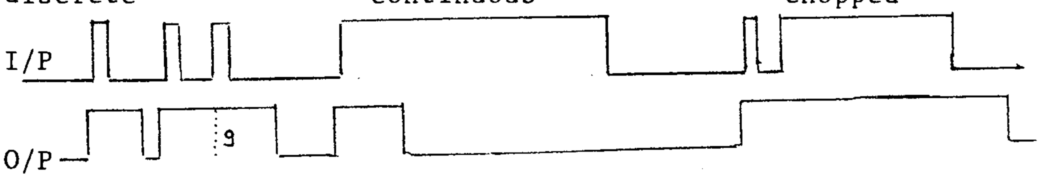


7. Latch, CA and reset logic.



APPENDIX ONE.

RETRIGGERABLE DELAY. Timer te is a retriggerable monostable. This bears further consideration. No IC meets our requirements: for discrete input pulses, the CD 4098 suffices, although with glitches (point g below), but for a continuous input the circuit does not perform. Thus the input to the timer is 'chopped' by using a bistable multivibrator. In diagrammatic form:

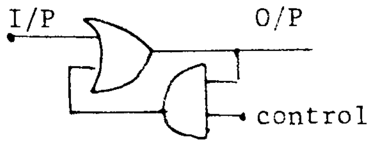


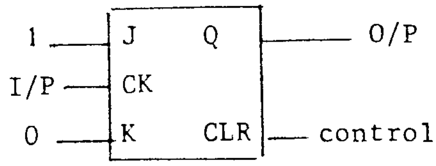
APPENDIX TWO

LATCH. The logic truth table required for the latch is:

I/P	control	O/P	notes
0	0	0	I/P = O/P
0	1	0	I/P = O/P
1	0	1	latch sets
1	1	1	
0	1	1	stays set
0	0	0	reset

Thus the control acts as an enable line. The two obvious methods of achieving this logic are:

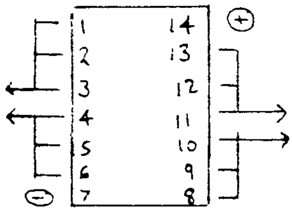




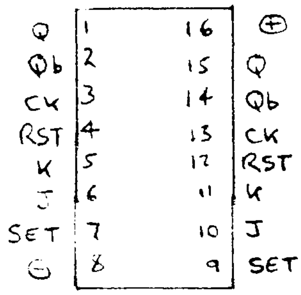
The Qbar output of the latch replaces an inverter in the circuitry described earlier, and thus is the technique used.

APPENDIX THREE. IC PINOUTS.

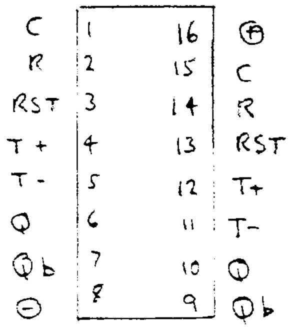
4071 OR
4081 AND



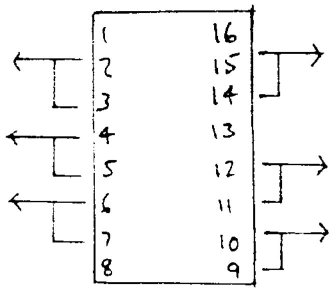
4027 JK



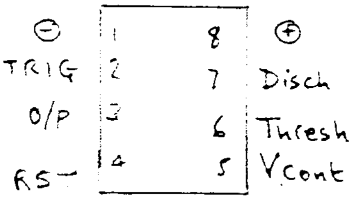
4098 programmable monostable



4050 buffer
4051 inverting buffer



555 timer



SECTION 2.4

REPORT INT P11A,B
29.9.83
C. WALLACE

SIMULATOR BOARD: A MEANS OF TEST AND DEVELOPMENT FOR THE PROPOSED SPEED SENSOR CIRCUIT.

CONTENTS.

1. INTRODUCTION
2. REQUIREMENT
3. CIRCUITRY
4. CONNECTION DIAGRAMS:
   - A BOARD CONNECTIONS
   - B SYSTEM INTERCONNECTIONS
   - C ADJUSTMENTS AND TEST POINTS
   - D MODULE CONNECTIONS
5 APPENDIXES
6. REPORT 11B: INTERFACE BOX
   - A DESCRIPTION
   - B CIRCUITRY
   - C SYSTEM CONNECTION DIAGRAM
   - D ADJUSTMENT AND TEST POINTS

1. INTRODUCTION

The purpose of this report is to describe the evolution and define the circuitry of a simulator board. This board must be capable of acting in several capacities: as a development tool, test circuit and demonstration unit for:

a) the existing sensor circuit
b) a new sensor circuit
c) additions to either of the above

It is intended that this unit will be stand-alone and modular.

2.REQUIREMENT

The board is required to fulfill the following criterion. It must:

a) be able to accept signals from an:
   1. internal calibrated oscillator
   2. an external oscillator
   3. a Doppler head, via suitably modified processing circuit
   4. an existing sensor unit and associated circuitry
   5. an existing unit, plus additions (for development)

b) provide outputs for:
   1. appropriate test and calibration points
   2. existing control board circuitry
   3. a means of data recording

c) be capable of being powered by:
   1. on-board recharceable battery
   2. control board power line
   3. external battery (on-site use)
   4. mains PSU

d) indicate speed/alarm conditions by:
   1. on-board meter, calibrated in mph
   2. led indicators, colour-coded
   3. logic level output for modified control board
   4. oscillator (alarm frequency) output for existing unit

e) allow on-board calibration/alteration/test of:
   1. all delay periods (switch-on, delays for validation logic, window timers, pulse extenders etc)
   2. all oscillator frequencies
   3. amplifier gains
   4. all PSU voltage rails
   5. high-pass filter cutoff point (if reasible)
   6. option of low-pass filter
   7. F/V alarm point
   8. all comparator trip points
   9. all Schmitt hysteresis points

The design requirements for the circuitry are, briefly,

a) all components must be tolerant of associated component tolerances, and require no specific accurate calibration, or careful layout

b) all components must be readily available and preferably second-sourced (ideally available from present stocks)

c) all components must be cost-effective, and be selected with performance/cost compromises in mind

d) the circuit must be easily assembled and must interface with all existing circuitry.

3. CIRCUITRY

Before delving into the circuit design, the development history of the board will be briefly reviewed.

The simulator, excluding the validation logic (VL) section, was originally designed conceptually several months previous to the final version and took the form of a motherboard and six processing boards. Several costly features were incorporated (capacitorless filters, by utilising telecommunications IC's, and discrete component PSUs). The unit was road tested and proved satisfactory, but the cost was too high. Replacement of the boards with cheaper components proved unsatisfactory, so an extended period of design was undertaken. Each aspect of the design was examined and several dozen test boards tried. During this period the VL circuit was incorporated, necessitating further modifications. Finally, only two boards were used:

board one: power supplies, preamplifiers, filters

board two: PLL, F/V, VL and control board functions.

Thus board two can be used direct from an existing speed sensor unit. The resesigned circuit thus uses monolithic regulators, discrete component filters and 'production prototype' components in genteral. As an addition, LED displays, a meter and an inbuilt calibration facility were incorporated.

This unit, after several further modificatins, was also successfully road-tested, and used to assess the performance of the PLL and VL. The design and development of these modules is covered in reports P3 and P7 respectively.

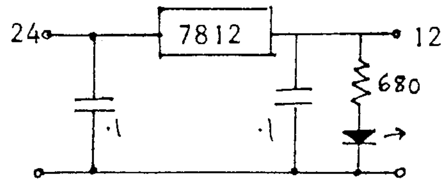
The modules, excluding the VL circuitry, will now be examined.

1. LED indicators. For circuit driven LEDs, a CD4050 buffer was used. Current-limiting resistors (to ensure similar light intensity) were: red, 1K5; orange, 1K2; green, 610R, unbuffered red, 1K2. Colour coding as follows:

Red: overspeed alarm indicator (new circuit configuration)
12V line indicator
Green: window timer
Orange: cancel available indicator, cancel depressed LED (and 'auto-cancel' mode), delay timer on (overspeed, for old circuit configuration), expander timer

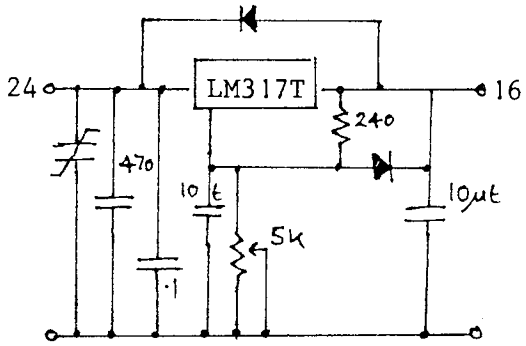
2. POWER SUPPLY. To enable either board to be used in isolation, seperate PSU units are used: the driving voltage is either obtained from the control PCB via a 10-way connector, or by external PSU, both nominally 24V and ranging 16 to 40V (assuming spike suppression).

Board one: A 12V regulated supply (for 13IC's)



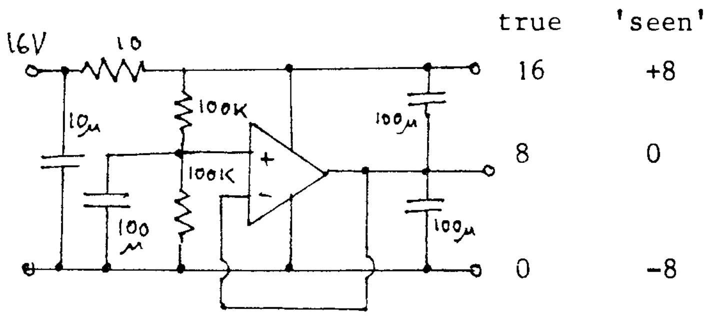
This PSU is non-critical, and layout is unimportant. One 0.1uF capacitor (6 in total) is used near each digital IC

Board two: This PSU is in three sections: 16V, 'V and 4V. The 16V, in



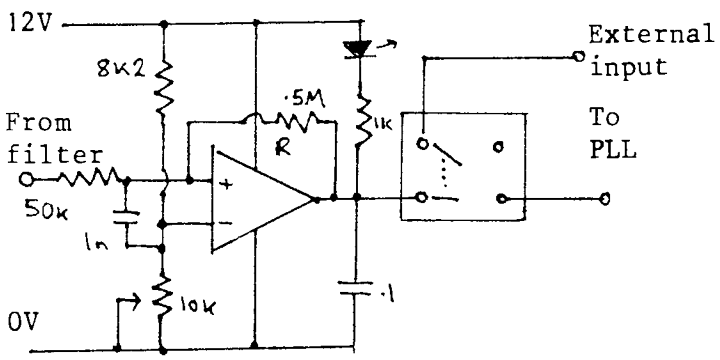
order to provide easy adjustment and good specification, used a LM317T. Requires heatsinking, as 1A is supplied. Diodes protect potentially destructive situations. Tantalum capacitors are used to ensure low impedance and noise.

The 8V regulator is as above but excluding the protection diodes and the zenamic. The variable resistor is a 1K5. The input to this regulator is the 16V derived from the above circuit. The split voltage (4V) supply is reqiured for a simulated split rail. This circuit uses a 741, which



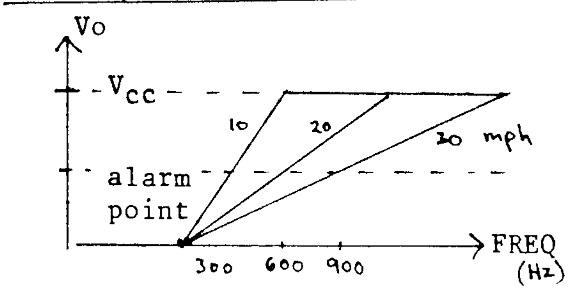
can cope with present current needs. A driver transistor can be added. The mid rail will always track the input making this circuit preferable to the usual resistor splitter (unbuffered) or twin zener methods.

3. SCHMITT TRIGGER and imput select module. The two capacitors prevent

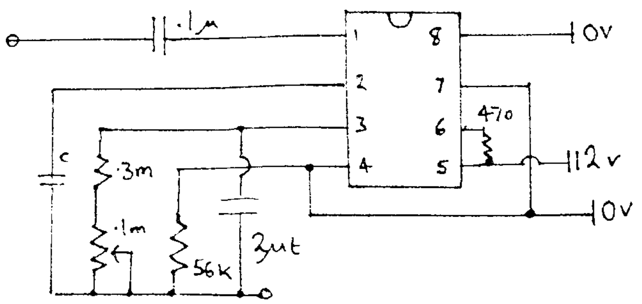


oscillation of the Schmitt. The LED allows visual indication of a signal present. The pot alters the trigger point, the resistor R varies the hysteresis. Both need to be set bearing in mind signal and noise levels.

4. FREQUENCY TO VOLTAGE CONVERTER. The 2917 tachometer is used in pref-



erence to cheaper alternatives, eg RC4151 due to better performance and ease of design. The alarm frequency is always half the full scale frequency I/P, so F/V char-

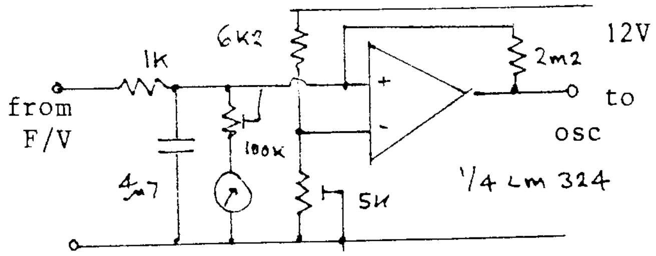


acteristics are automatically optimised. The 2uF cap smooths, not integrates.

C : 2n2 1%

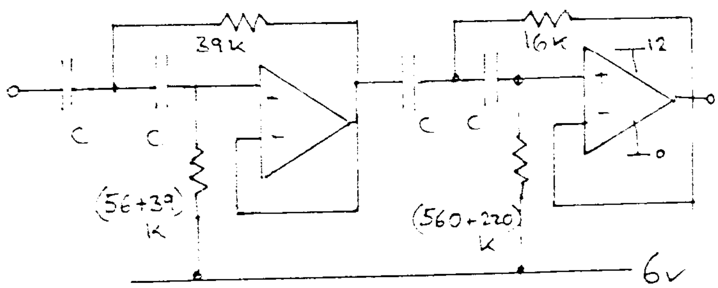
5. PHASE-LOCKED LOOP. Described in report P3. Up and down time set resistors: 2M. RC filter: 2u2 capacitor and 75K resistor, loop cap: 22nF.

6. F/V comparator. The meter should be adjusted to read the correct value (prototype calibrated in 5mph steps from 10 to 40mph). The 10K



pot adjusts the trigger point, and thus the frequency of alarm. The hysteresis is altered by adjusting the feedback resistor.

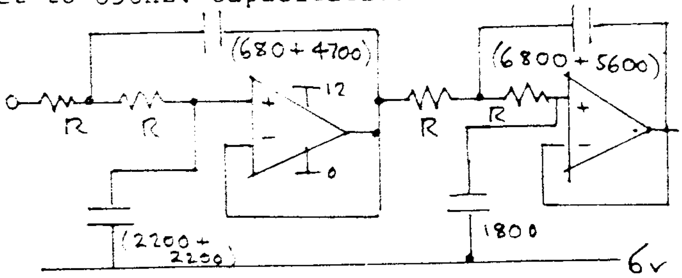
7. LOW CUT FILTER. The disigns used are all unit gain, for simplicity. Butterworth responses are used, as distortion products are not significant when fed with a



clipped signal. An alternative Chebyshev filter is available. For the given circuit, values are: C = 3n3: 400Hz
2n2: 250Hz
2n7: 320Hz

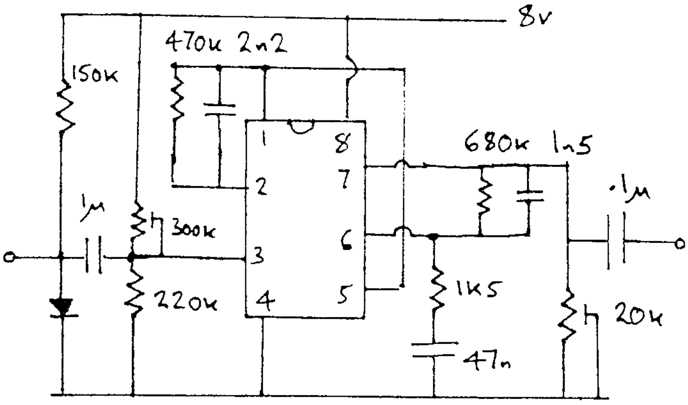
All resistors to be 2 or 1%. Filter designed using computer program described in report INT P1 (Active filter algorithm).

8. HIGH CUT FILTER. A sharp attenuation is not required. Cutoff is set to 850Hz. Capacitative feedback around a Schmitt also gives a



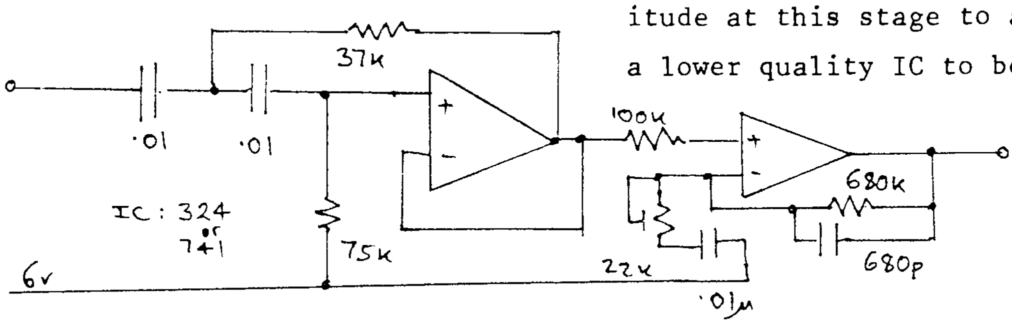
LP filter, but leaves excessive noise in the signal. R = 39K. All caps in picofarads

9. PREAMPLIFIER. This stage, in order to prevent clipping and to reduce noise, has curtailed bandwidth. Due to the amplitude of the input signals involved, selection of the IC is critical. An ICL5532 is ideal, but expensive. A good compromise is the RC4558. A table of suitable IC types and parameters appears in the appendix.



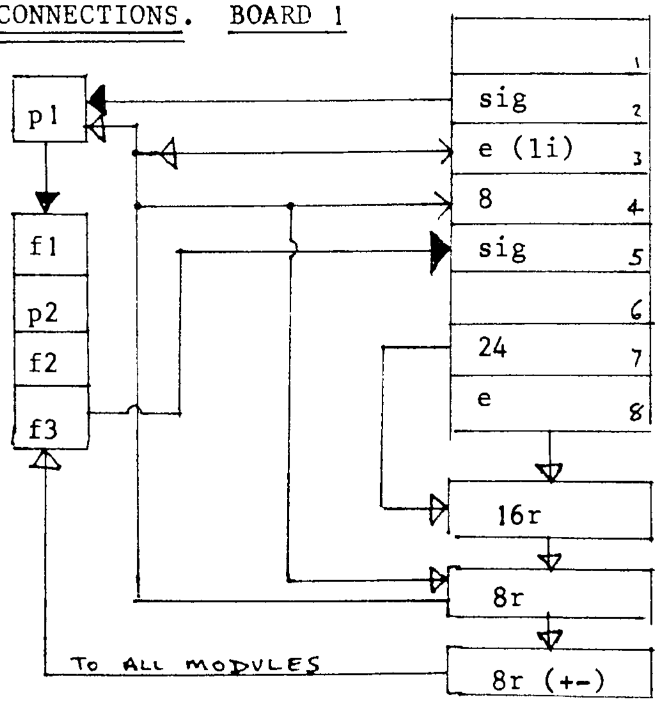
The earthing and supply layout are crucial: both returns must terminate at the central earth point. The gain is set for 3V out at 500Hz for 0.5mV in. The I/P pot allows the input bias to be set to Vcc/2, ensuring symmetric clipping. Typical signal amplitudes are approx 250 microvolts, so input wiring should be short.

10. POST- AMPLIFIER. This stage raises the signal level to that needed by the main filter section, and incorporates a low-cut section to eliminate potential causes of clipping. The signal is of sufficient amplitude at this stage to allow a lower quality IC to be used.



11. TIMING CIRCUITRY. This module is described in depth in report P7. The led indicators are described in section one of the circuitry description. The output is either a logic level alarm status signal, or a squarewave of appropriate frequency (ie above the nominal alrm frequency, as determined by the calibration of the control board).

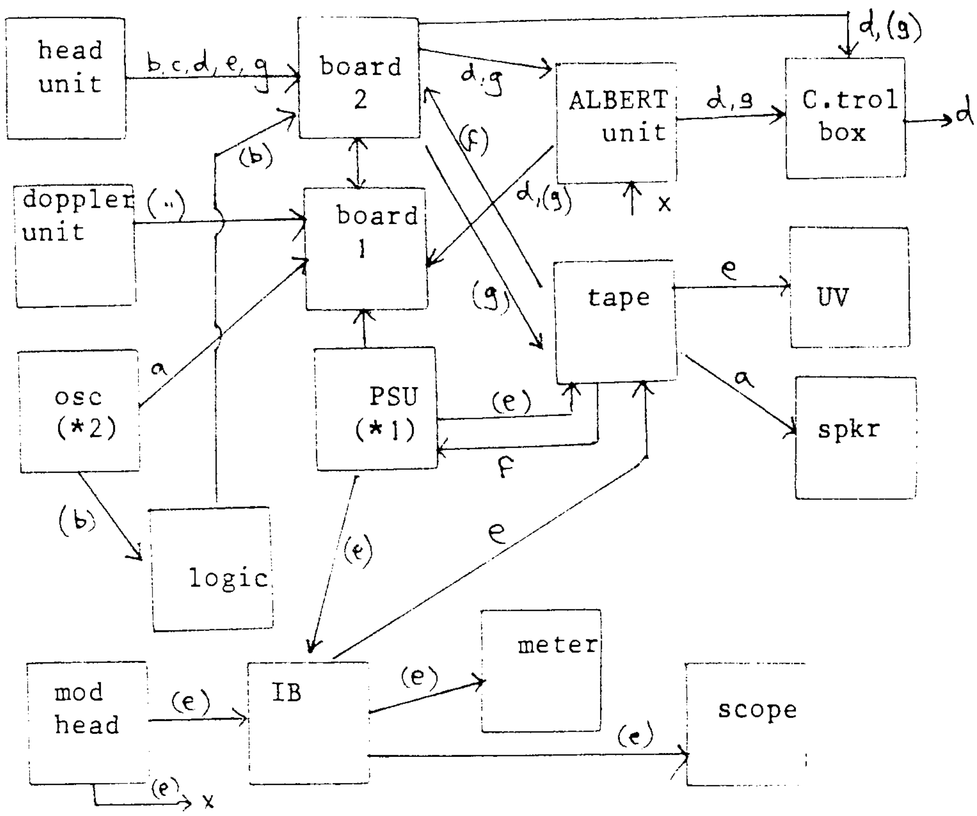
CONNECTIONS. BOARD 1



KEY:

p: preamplifier
f: filter
r: regulator
e: earth (hi I)
sig: signal
st: schmitt
c: comparator
o: oscillator
a: alarm logic
ca: cancel available
e (li) earth (low I)
pll: phase locked loop
f/v: freq to voltage

→: signal line
→: PSU line



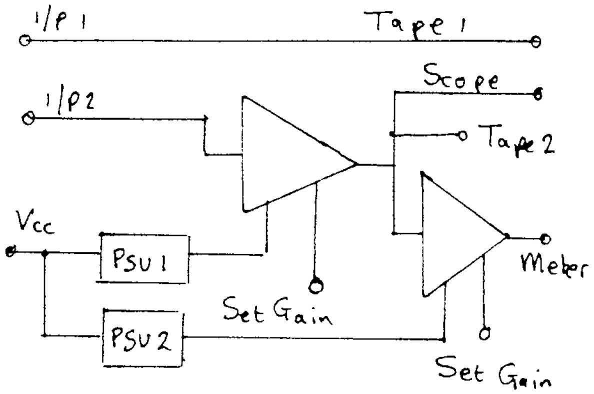
KEY
*1: internal for a,b; or external for b.
*2: internal for a,c; or external for a,d,e,f,g
a: lab development
b: module evaluation
c: validation logic test and calibration
d: road test (production: go/no go)
e: recording mode
f: playback mode
g: autocancel mode
(x): alternative connection for x

SYSTEM INTERCONNECTION DIAGRAM FOR VARIOUS MODES OF USE.

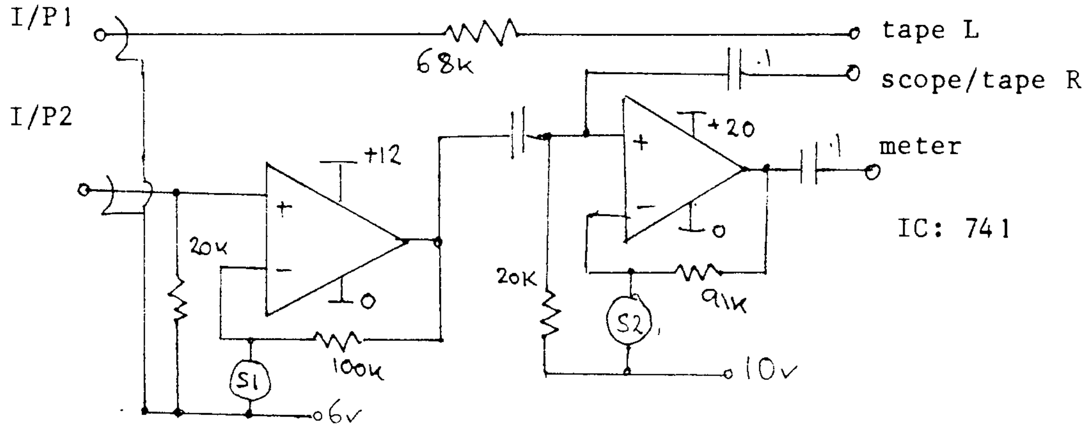
INTERFACE BOX AND MODIFIED HEAD UNIT.

The interface unit is designed to enable signals representing ground-speed to be recorded onto tape (and thence onto UV-sensitive paper), and to be measured via an oscilloscope and an analogue averaging meter. In order to facilitate this task, an existing head requires slight modification, being provided with outputs for pre- and post-filter stages and post-schmitt.
Several road tests were required to ascertain the optimal signal gain settings required for the transfer of doppler signal onto a domestic tape recorder, as this signal must not clip yet be of recordable amplitude. The meter output requires significant amplification to be readable on a 2V FSD scale. It was found that a tape input of 6V pk-pk

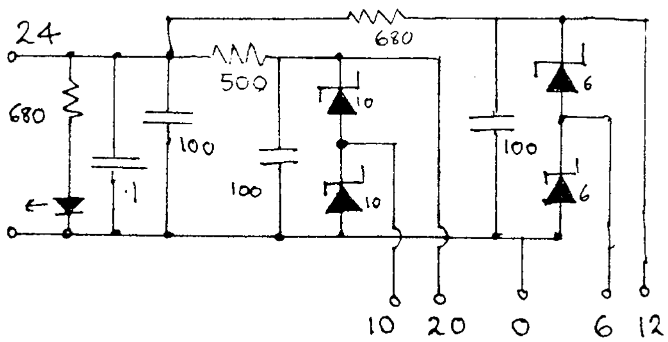
provided a suitable recording level whilst the meter drive required



a gain of ten. The 'pseudo-zero' volt line found in the head unit requires simulation in the interface unit, and complicates earthing arrangements. The full connection system is complex, requiring twenty types of connector. The diagram below indicates these connections. It can be seen that the middle section (the ' test/measurement unit') is portable, the section to the left being a permanent fixture in the truck; the section to the right being laboratory based. Thus the centre section was installed in a brief-case. This allowed true portability, and afforded protection to the contents. The full circuit diagram is thus:



IC: 741



S1: 7 way attenuator, 1,2,3,4,5,6,7 gains
S2: 5 way attenuator 1,2½,3¼,4¼,5¾, 8½ gains.

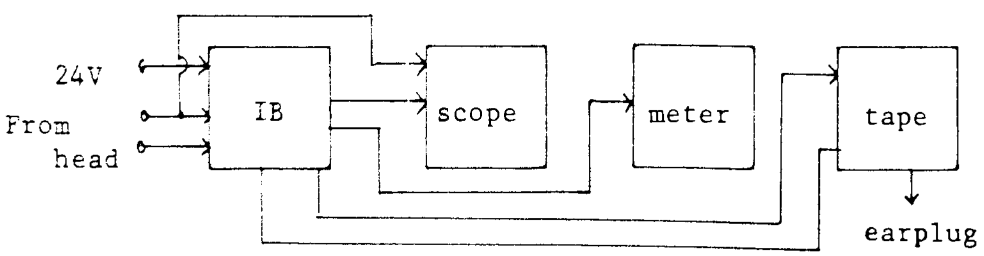
ADJUSTMENT AND TEST POINTS OF THE SIMULATOR BOARD.

Circuit part	adjustments	type
preamplifier stage 1	bias	tp
preamplifier stage 2	gain	tp
filter, low cut		
gain stage	gain	tp
low filter		
high filter		
amplifier	gain	tp
schmitt	trigger point	led
	hysteresis	
PLL	damping up	comp
	damping down	comp
F/V	alarm frequency	tp
	full scale defln.	meter
comparator	trigger point	tp
oscillator		
timer 1	timeout	tp
timer 2	timeout	tp
timer 3	timeout	tp
flip/flop and logic		leds
oscillator	frequency	
timer 4	timeout	tp
PSU 16V	voltage	tp
PSU 8V	voltage	tp,led
PSU ±8V		
PSU −12V		led

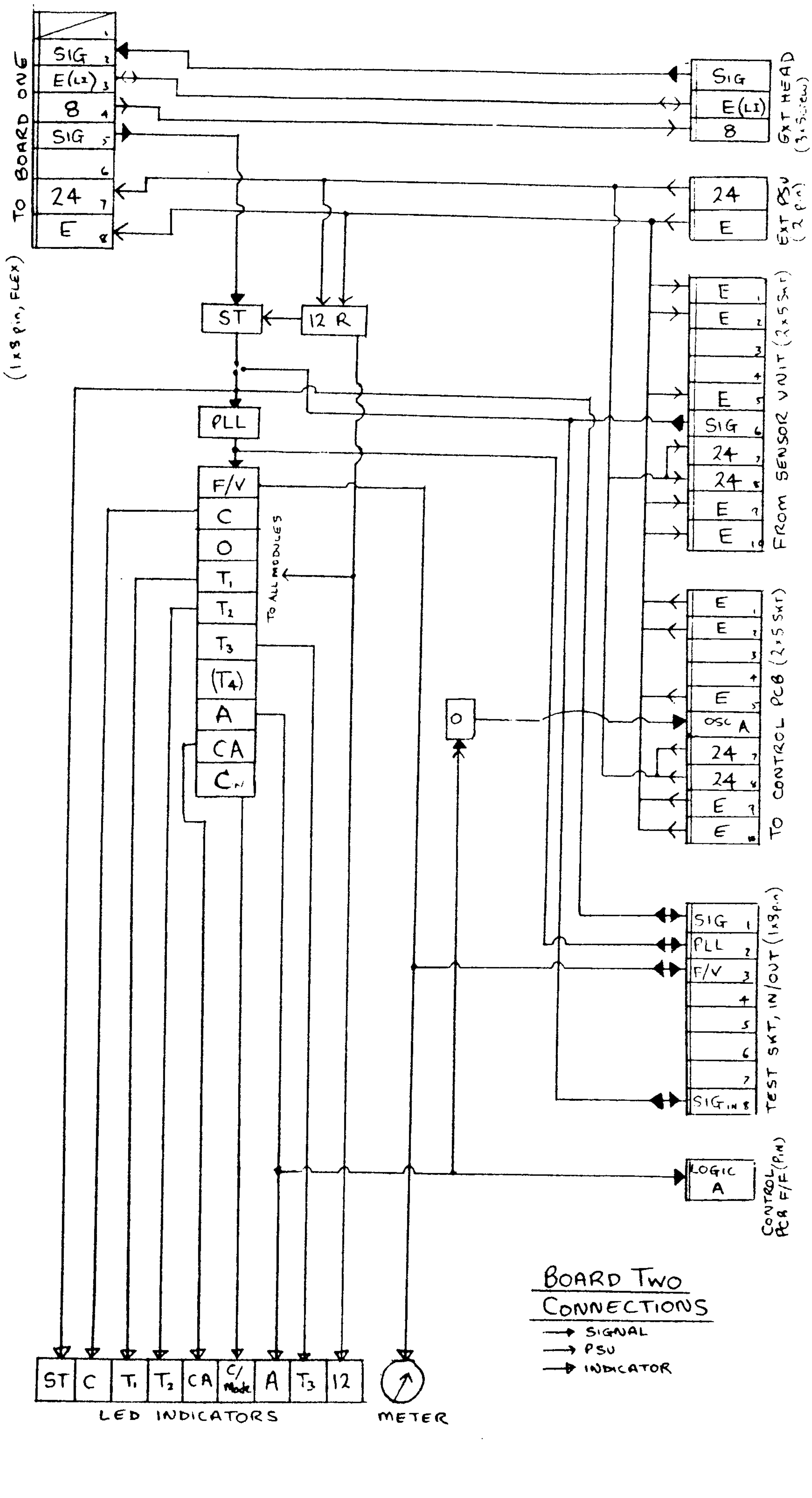
KEY: tp: test point; comp: component substitution;
led: led indication

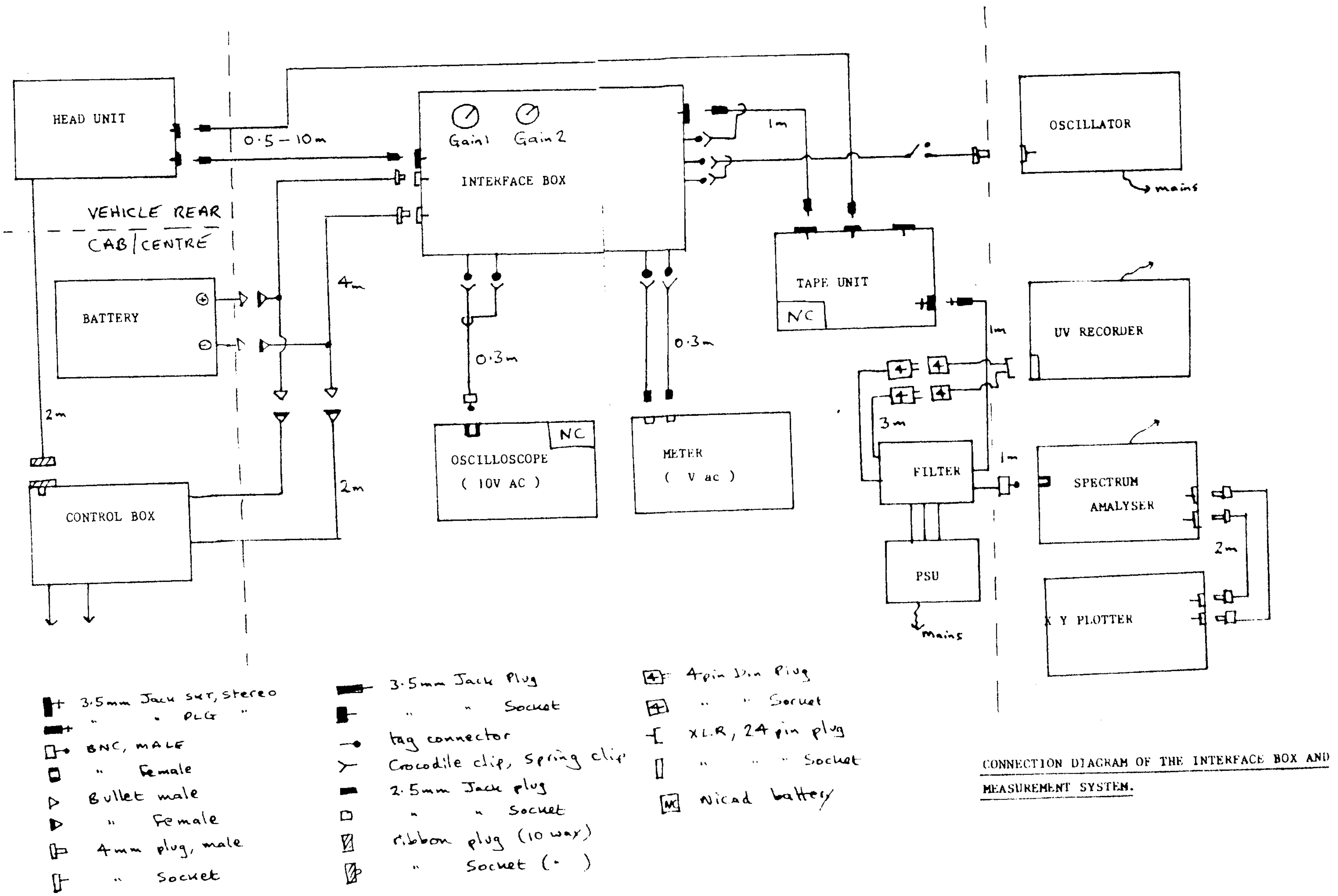
ADJUSTMENT AND TEST POINTS OF THE INTERFACE BOX AND HEAD UNIT

Circuit part	adjustment	type
radar head unit	gain	various
preamplifier	gain	tp
filter	in/out select	switch
gain 1		
gain 2	gain	tp
PSU 8V	voltage	LED
PSU 6,12V		
PSU 2 6,12V		
PSU 10,20V		



PORTABLE RECORDING UNIT: SCHEMATIC. IB: Interface Box.


TO BOARD ONE
(1×8 pin, FLEX)
SIG
E(L1)
8
SIG
24
E
EXT HEAD
EXT PSU (2 pin)
ST
12 R
PLL
F/V
C
O
T1
T2
T3
(T4)
A
CA
C/M
TO ALL MODULES
FROM SENSOR UNIT (2×5 Skt)
SIG
OSC A
TO CONTROL PCB (2×5 Skt)
PLL
F/V
SIG IN
TEST SKT, IN/OUT (1×8 pin)
LOGIC A
CONTROL PCB F/F (pin)
ST
C/Mode
12
LED INDICATORS
METER
BOARD TWO
CONNECTIONS
SIGNAL
PSU
INDICATOR

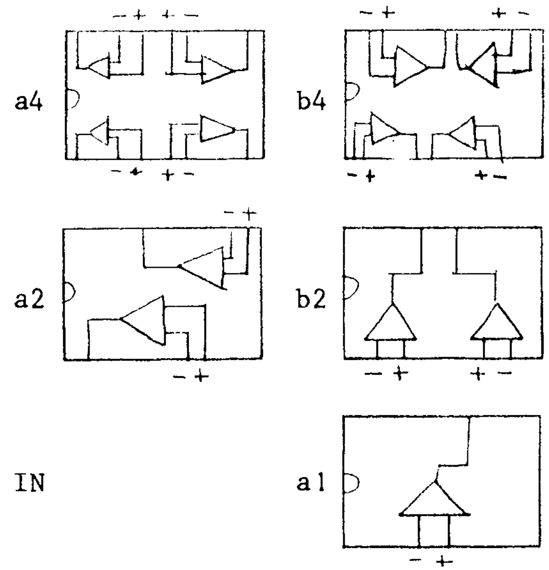


CONNECTION DIAGRAM OF THE INTERFACE BOX AND MEASUREMENT SYSTEM.

parameter		741,741N	5514	5532,34	5534	747,748	324	348	4136	4558
noise v	nv/Hz	20-50	30	4-8,3	3.5	10-30		348	10	10
offset v	mv	2-6	1-5	.5-2	.5-1	1-6	2-9	60	.5-6	.5-6
offset I	na	20-300	3	10-150,2020		20-300	5-150	1-7	5-200	5-300
bias I	na	80	3	200,500	500	80	45	4-100	40	40
BW unity gain	MHz	1	1	10	10	1	1	30	3	
supply	V	3-18	16	3-20	3-20	5-18	2-15	10-18	2-30	3-18
" rej ratio	uV/V	30	110dB	10	10	30	100dB	15	30	30
o.loop gain	dB	106		100	100	104	100	96	110	109
i/p impedance	Mohm	2	100	.4,.1	.1	2	10	2.5	5	5
cost / amp	p	33-100	65	90,125	125	33,44	15	28	16	38
pinout		a	a4	a2,a1	a1	b2,a1	a4	a4	b4	a2

		4741	081,82	084	094	3403
noise V	nv/Hz	9	25	25		
offset V	mv	.5	5	5-15	5	2
offset I	na		5pa		10pa	150
bias I	na	60	30pa	30pa	10	150
BW unity gain	MHz	3	3	3	3	3
supply	V	2-20	18	3-18	3-36	1.5-18
" rej ratio	uV/V		73dB	73	90	90
o.loop gain	dB		106	106	106	110
i/p impedance	Mohm		10e6	10e6	10e6	
cost / amp	p	24	27,25	26	90	90
pinout		a4	a1,a2	a4,b4	a4,b4	a4

PINOUT:



MAJOR PARAMETER VALUES FOR INTEGRATED CIRCUITS SUITABLE FOR INCLUSION IN THE SPEED SENSOR CIRCUIT.

SECTION 2.5

PAPER INTP12A
C. WALLACE
10.83

ALBERT: COMPETITIVE PRODUCTS AND MARKET POTENTIAL.

COMPETITIVE PRODUCTS.

There exists, at the time of writing, no direct competitor to the ALBERT safety system. Several products, however, partially fulfill the requirements of the system philosophy (sales brochure is reproduced in appendix 3.6). This report will briefly review sensor systems and modules of relevance.

The most common method of enhancing the safety of a reversing truck has been, until recently, complex mirror arrangements normally incorporating a Fresnel lens. Advances in closed-circuit television has led to trials in an off-highway environment (Johnson, 1980). Such systems are necessarily costly, and reputedly temperamental. They utilise passive displays: and merely provide the driver with a monitor screen. If he misinterprets, or fails to see, the screen, the system would allow potentially fatal accidents.

Several ultrasonic systems are available. The 'Back sensor' uses ultrasonic pulses to measure the distance from the rear of the vehicle to any target (Foreline, 1981). 'Tailmate' also uses such a system, being effectively a repackaged 'Polariod ultrasonic ranging system' as used in self-focusing cameras (Bentham 1982, EPD 1981, Elektor 1982, Polaroid). Both products are potentially useful in that readouts are provided to display the closing target distance, and the alarm point (passive, usually audible) can be set appropriately. Such products, however, do not meet off-highway applications for several reasons. OEL performed exhaustive tests in order to be able to answer customer queries and comparisons from a position of first-hand experience (Butterworth, 1/83 and 9/83). Findings included:

a) accuracy of measurement is dependent upon wind conditions and the quantity of precipitation
b) transducers are easily rendered insensitive by a covering of wet mud or ice
c) the systems are sensor only: no output/interface exists for further signal processing
d) vehicles themselves wmit much ultrasonic signal
e) mechanical construction and electrical design weaknesses.

A similar ultrasonic system for a very different application is also marketed (Sonic Tape, 1981). This hand-held device measures distance up to forty metres with an accuracy of two centimetres. It suffers, however, from the same limitations as listed above. A more sophisticated ultrasonic ranging unit is available for 'echo ranging' applications

(Sael 1982) which has a range of output types and interfaces available (including a digital signal discriminator module: details are unavailable). The high operating frequency of this unit may render it immune to vehicular ultrasonic interference.
The Torque device (Torque) links into the fuel and electrical systems of an engine and senses overrevving: the unit is designed for cars, and lathough in theory is applicable to off-highway trucks, is not adequately rugged. Extensive fuel pump and ignition modifications would also be required. The unit, being velocity linked, will not prevent overrevving in lower gears, and thus is not a complete solution to limiting engine RPM.
Few radar modules are marketed. The main contender for site motion detection is the TRW groundspeed detector (TRW, Richardson 1982). This velocity meter, designed originally for agricultural tractors, provides a digital readout. For UK operation, however, it operates on an illegan frequency (HO 14). OEL purchased such a unit for evaluation (see report INT P25): it is not as accurate or foolproof as claimed.
'Vector' is a radar motion detector for industrial environments (Craven 1983), and consists of a doppler module and amplifier only, although application notes refer to potential use as a vehicle motion detector and personnel detector. HED electronics also briefly advertised an 'anticollision radar' for cranes and plant vehicles, but details of the unit (and indeed the unit itself) seem unavailable.
Various manufacturers produce motion detectors in the form of burglar alarms, both ultrasonic and radar types are available. Being designed for static, non-harsh environments, these will not be covered further.
Several 'monitor' systems are marketed specifically for off-highway environments, but are concerned with engine monitoring, and where speed information is required, a magnetic sensor is usually utilised (Aid, Osenga 1981).
A summary of the above products is tabulated in fig 1.

ADDENDUM. Dec 1984. Details of a radar anticollision unit for off-highway equipment is announced by Lloyds British. Details are scant: 10GHz radar (CW), switchable range of 10, 50 and 100metres

MARKET POTENTIAL.

The market potential of a system such as ALBERT is difficult to assess. As a package it is unique, but certain aspects of its claimed design can be purchased from alternative sources, in many cases for far less cost. It is still informative, however, to attempt to assess the potential market, as this may well affect the decision to adapt or consolidate the existing design.

The system's full capabilities will only be realised on large off-highway dump trucks, specifically ones with retarder braking; although any vehicle could be adapted to make use of certain features. To put the size of the larger trucks in perspective, fig 3 illustrates a Terex 3319 and the miniscule comparitive dimensions of a man.

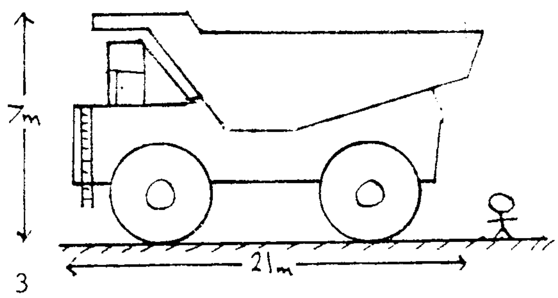


FIG 3
Comparison of a Terex 3319 and a man. The largest truck currently manufactured is approximately one-third larger.

Little information is available on potential markets for such a system: Johnson (1981) gives the present number of trucks currently employed in the US mining industry as:

35 to 100 ton: 25,000

100 to 200 ton: 10,000.

By estimating the quantities of trucks in other US industries such as large 'moving equipment' (cranes, logging, cable-laying etc) and 35 to 200 ton trucks employed in quarrying etc it is possible to arrive at a figure in excess of 100,000. Similarly the Middle East, Canada, South Africa have equally gigantic sales potential. Fig 2 illustrates a representative sample of these trucks: due to their size, visibility is poor. RTZ, for example, lose one truck per year per site on average by driver error (usually reversing over cliffs). Report INT P24 analyses truck geographical spread further for several common types. It is impossible to consider all types: twenty-three truck manufacturers traces produce over one hundred different podels (IA, 1980).

Britain has a different market: large trucks are a rarity here, a typical truck being an 85 ton capacity type. Such trucks are used due to practicalities of operation and transport: larger vehicles would usually require disassembly for transport by road, and Britain does not operate industries on such a large scale as areas of the continent and the USA. However, if the British market is not vast, it is keen. The CEGB, mining industry and coal board have all shown great interest in the system.

The smaller scale of typical British operations means certain parts of the system would require modification fo export: the overspeed sanction, for example, is set at 20mph in the UK, but would need to be moved to perhaps 35mph in the USA. Thus the overspeed is of greater relevance to the home market. The converse is true of the overrev limit system.

PRODUCT	TRANSDUCER	O/P	TYPE	COST £
Tailmate *1	US 40K	readout	range	400
Backsensor	US 40K	"	"	210
Sonic Tape	US 40K	"	"	100
SAEL Ranger	US 150K	various	"	712
Vector	MW 10.5G	logic	motion	
TRW *2	MW 24G	readout	motion	400
HED	MW		range	
Torque	*4	LED	motion	190
intruder alarms	MW 10.5G	logic	logic	50-500
ALBERT	MW 10.5G	logic, action	logic, motion	4000 *3
	MW 13G	logic	range	2500
CCTV	camera	VDU	picture	8000

notes:

*1: See Butterworth (1/83 and 9/83)

*2: See supplementary material section 7

*3: Complete safety system, excluding range radar units

*4: Electrical and mechanical linkage to engine

US: ultrasonic

MW: microwave

COMPARISON OF AVAILABLE SYSTEMS SEEN AS POTENTIAL COMPETITORS AND ALTERNATIVES TO THE ALBERT SAFETY SYSTEM.

FIG 1

TYPE	WEIGHT EMPTY	WEIGHT FULL	MAX VEL	PWR HP	DIMENSIONS H	W	L	CAP	COST £,000
Terex 3319	236	554	47	3	7	8	21	169	2500
Euclid R170	256	410	55	1.5	6	7	21	170	
Wabco 3200	161	379	40	1.8	6	7	16	124	
Terex 3311*	56	133	62	.9	5	5	11	77	
Cat 777 *	56	133	53	.9	4	5	10	77	528
Komatsu 77	85	120	58	1.1	5	6	11	70	
DJB D550	39	89	48	.5	4	4	11	54	185
Int 350B	33	78	69	.6	4	4	10	45	
Aveling RD35	30	76	50	.6	4	4	8	21	
Cortina est.	1	1	144	.04	1	2	4	2	5

NOTES:

1. Weights in 1000kg units
2. Velocity in Km/hr
3. Power in horsepower ÷1000
4. Dimensions in metres
5. Capacity in cubic metres
6. * indicates vehicles used by OEL for on-site tests

FIG 2

A COMPARISON OF SELECTED DATA ON SEVERAL LEADING OFF-HIGHWAY TRUCKS

It can be appreciated that the untapped market is vast. But this does not guarantee sales. Fig 4 illustrates a typical non-quantitative assessment of ALBERT and the speed sensor. Given the system can be made more reliable, the sales target (OEL's figure in 1981) of 2000 units annually, would seem reasonable.

FACTOR HEADING/SUBHEADING	ALBERT SYSTEM	SPEED SENSOR
1. MARKETABILITY		
- relation to existing product lines	NA *1	NA *1
- relation to distribution channels	VG *2	G *3
- quality/price relation	NA	NA
- range, options, modularity	G	VG
- efffect of sales on present product	NA	NA
2. DURABILITY		
- stability	VG	VG
- market breadth	G	A
- resistance to cyclic fluctuations	VG	VG
- exclusiveness of design	VG	VG
3. PRODUCTIVE ABILITY		
- equipment necessary	G *4	G *4
- production knowledge	P *5	A *5
- raw materials availability	P *6	P *6
4 GROWTH POTENTIAL		
- place in market	VG	VG
- expected competition	VG	VG

notes:
*1: no previous products
*2: off-highway and earthmoving equipment contacts
*3: off-highway contacts
*4: parts brought in and self-assembled
*5: skill required (poor documentation)
*6: specialised parts: long lead times

NA: not appropriate
VG: very good
G: good
A: average
P: poor

ASSESSMENT OF ALBERT SAFETY SYSTEM AND OF SPEED SENSOR MODULE AS PRODUCTS. Based on a technique by O'Meara (1961)

FIG 3

SECTION 2.6

REPORT INT P13
4.6.84
C. WALLACE

SHOCK AND VIBRATION SIMULATION: PRESENT DESIGN AND ALTERNATIVE MOUNT SYSTEMS

SECTION

1. INTENTION
2. PRESENT SITUATION
3. TESTS:
   A VIBRATOR
   B SINGLE AND MULTIPLE STRIKE
4. THE NATURE OF SHOCK-LOADING
5. MOUNTING SYSTEM MODIFICATIONS:
   A BELTING
   B FOAM
   C FOAM AND SPRINGS
   D HOSE
   E OTHER
   F NEW BRACKET
6. FIELD TRIALS
7. APPENDIXES:
   A TEST RIG DETAILS
   B FIELD TRIAL RESULTS
   C TEST RIG RESULTS
   D DESIGN DETAILS

INTENTION

This report summarises the work performed on the testing of conventional radar units for consistency of performance and longevity under conditions of shock and vibration; and considers alternative mounting arrangements. Only those mounts that could be incorporated utilising the present brackets are assessed. The progress of such units is assessed under lab conditions and on-site.

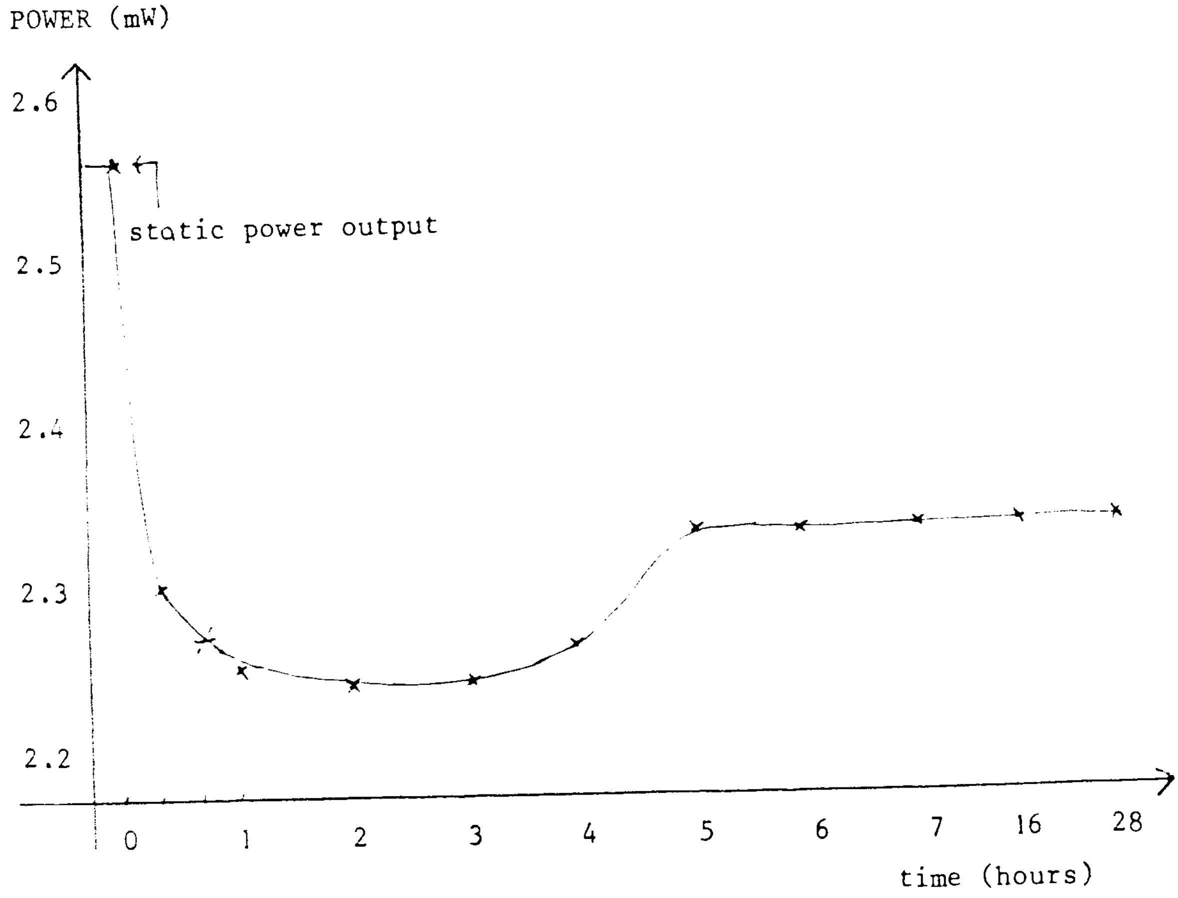
PRESENT SITUATION

There exist three head designs currently in use (termed A, B and C of which the company possess 40, 10 and 8 respectively), all utilising standard ARO heads and Metalastik antivibration mounts (type 17/1377 /1IM45). The brackets are effectively the same design; the earlier variants being smaller: the reduction in clearance allows the radar unit to strike the bracket cross-bar, causing inconsistent operation and premature unit failure. Type C, the latest, has adequate room for the mounts to flex, yet the mounts still age rapidly and fail prematurely. From site experience the average life of a set of mounts is approximately two months, and for bracket type C, three months. The speed sensor unit thus incurs severs penalties in the cost of mount replacement (£40 per head per year, and several hours per refit) and of loss of credibility from the customer's viewpoint. Little is known about the reason for mount failure: with hindsight the bracket size (considered the culprit after initial unit trials) assists longevity, but further problems exist.
The mode of failure on-site seems to follow one pattern: one of the four mounts shears, and the remaining three mounts either survive or fail almost immediately. The survival time in the former case can be surprisingly long: several weeks is not extraordinary.
It is clear that action is required to extend the life of a sensor unit on site, by either using a different mounting arrangement or by redesigning the bracket. At present, due to a lack of resources (time and money) the latter course is seen as impractical by the company. Thus, a means of ascertaining the cause of failure is needed, which should then enable alternative designs to be evaluated.
Two test arrangements were planned: a single-strike, or shock, test to simulate truck suspension 'bottoming' and/or the ARO microwave unit striking the mounting bracket; and a vibration rig to simulate (on an accelerated timescale) the typical vibration a head undergoes on-site.

VIBRATOR TEST

To test the effect of vibration on the radar head and mounting system, a test-tube shaker (kindly loaned by Mr D. Davey) was modified to carry the ARO head. The experimental arrangement is drawn in Fig 1. It can be seen that various measurements can be made whilst the tests are in progress. The tape recordings can be replayed onto a UV recorder, or via a spectrum analyser onto graph paper. The shaker displacement was set to 0.5" and to a frequency of 20Hz for all tests.

The power output against time of vibration was noted for a new ARO unit (rebuilt within the laboratory): for this test the antivibration mounts were not used. The test gave the following results:



These surprising results seem to confirm the 'old wives tale' the system fitters relate of heads needing time to 'settle-in' when first fitted to trucks: the power output drops to a low after an hour, and rises to a plateau after five hours. Upon switch-on the next day the power measured identically to this plateau. At present, the writer believes the time needed to settle the head is needed to securely bed in the aluminium waveguide into its rubber mount (both located within the ARO unit outer casing). It would be interesting to note whether there existed a corresponding settling-down of unit beamwidth or frequency. It is not uncommin, according to lab records, to receive a head measuring half the power of its noted power output at commissioning, although inadequately detailed records exist to make any specific conclusions. It would seem pertinent, however, to allow all new or rebuilt ARO units at least five hours to bed in: this could be done either in the lab on a vibrator rig, of by fitting the unit to a truck alongside an older head, the older head being connected to the system control box. A longer-term solution may involve rebuilding the units with a stiffer rubber waveguide mount, or even a stiff plastic mount: this would require significant experiment and, importantly, may lead to other unit problems (as the exact effect of the rubber waveguide mount is not known).

To simulate a ground signal, the head was covered with RAM (radar absorbtive material) so no movement can induce a doppler signal , and the head output was observed. It was immediately clear that the vibrator induced large amplitude signals into the head. The test was then repeated with a tuning fork held between the head and RAM to simulate a true signal perceived on a moving and bouncing truck. The results indicate that the vibration-induced signal swamps the true signal (which in this test is of a higher amplitude than in reality). The reasons for the vibration-induced signals are at present unclear, but the wiring or rubber wave-guide mounts were seen as probable causes. The wiring was deemed innocent after the head was rewired using several wiring topologies (balanced, unbalanced, inclusive and exclusive screen, lapped and braided sereen, thick and thin core, thick and thin outer sheath). All were equally prone to the induced signal. Gluing the waveguide to the outer case, ie bypassing the rubber mounts, made a difference, but did not eliminate the problem completely: it did allow the fundamental frequency of the induced signal to decrease, showing a residual of 200Hz (the expected signal frequency for a 20Hz vibration is 40HZ). Thus, a resonant component is most likely to blame. Upon examination of the waveguide unit, only two components have preceptible flexure: the rear-mounted PCB and the transmitting and mixer diodes. The PCB was thus glued securely in place and the test repeated. The induced signal remained. AT this time, therefore, it would seem that the waveguide is to blame. No means of rigidly fixing the diodes to the outer casing is feasible, as each requires manual tuning. This is a serious fault, as the induced signal is of high enough frequency to pass through the signal processing circuit; and may intermodulate with the true doppler return. As the vibrator used had a fixed frequency of vibration, no further tests were possible at the time.

SINGLE STRIKE TEST

This test is intended to simulate the microwave unit hitting the mounting bracket. Initially the unit was fixed to a rigid surface and surrounded by RAM: the unit was then struck by a hammer. The signal produced was different to that induced by vibration, being an 800Hz pulsetrain decaying over 60 pulselengths. Addition of the PLL circuitry into the processing electronics prevented this signal from being seen by the schmitt trigger, and hence by the control box. This is of importance, as the 800Hz frequency corresponds to a doppler signal produced at 32mph, well in excess of the required alarm speed. This result thus gives an interesting insight as to possible reasons for the seemingly inconsistent and unpredictable operation of the unit on-site.

To investigate single-strike effects further, a large solenoid was used to strike the head unit (see fig 2). The strike rate and stroke are variable, and again, facilities are available for measurement of power, and signal amplitude. The results are reproduced elsewhere in printout format, but will be reproduced here in summary. Changing the mount type produced significant differences in reading (signal amplitude averaged by meter):

standard mount: 9.5units　　units of amplitude are relative.
no mounts　: 5 units
mounts+thick foam:　7.5 units
mounts+thin foam:　8 units

It can be seen that the antivibration mounts used as standard, or indeed any non-rigid mounts, increases the amplitude of induced signal.when integrated over approximately one second. The rigid mounts, however, gave a higher instantaneous amplitude at the time of striking. As the signal processing circuitry averages over a two second period, the quoted results are the more appropriate.

Due to the limitations of the shock-producing mechanism, the quoted results, repeatable to 0.5units, were the best achievable. The rig could not produce exact plunger strokes, and even when affixed to a very solid object, the whole rig bounced violently both on strike and rebound. The strike was also non-instantaneous, requiring several fractions of a second to withdraw the plunger, by which time the microwave unit has bounced back onto the receding plunger. The stroke speed was also fixed. Thus, a new rig was designed and constructed, consisting of a large electric motor with an assymetric 'striker' or cam. Difficulty was found in keeping motor rpm constant under load, and large induced displacements were not possible. Hence a pneumatic shock test rig was constructed: as illustrated in fig 3. This unit consists of an oscillator of variable frequency and mark-space ratio, and four pneumatic valves. The operating pressure was set to 80psi and the piston stroke to 2". The results for various test samples are given elsewhere.

Four conventionally mounted heads were tested, two jolted on-beam axis and two at 40degrees (simulating the geometry on a truck). The angled head lasted only 7 minutes with unused mounts, and 7 with part-used (although visually perfect) mounts. It is possible, therefore, to assume that the rubber composition does age, be it imperceptibly. The vertical shocks produced failure in 45 minutes for part used and 100 minutes for new, although the unit only failed completely after 135 minutes. These results bear careful consideration: the vertival shock places a greater shear load on the mounts than the 40 degree shock, yet the weakness of the mounts has been accounted to the low shear tolerance of the mounts (as derived from the manufacturers literature). Further tests could not be made due to the unavailability of mounts.

The belting modifications, described in detail later, lasted for, typically 15 minutes, although one stiff type managed 95 minutes. Spring and foam construction fared well; the denser foam producing a remarkably better result. Care is needed, as it is thought this improvement due to foam type is due more to the specific frequency and stroke of the piston, rather than a general trend.

Thick tubing also fared very well; the heaviest tube lasted an astonishing 845 minutes, but unfortunately (as discussed later) did not work at all on site.

THE NATURE OF SHOCK-LOADING ON-SITE

The tests performed in the lab provided an interesting insight into anti-vibration mount design, but gave no clear insights or answers: the tubing technique lasted twenty times as long as a conventional mount on the shock tester, but failed to allow the system to operate at all on-site by (it is believed) transmitting high-frequency vibration through the head to alarm the system. This may mean that the simulation was at too low a frequency. Thus, it is crucial to attempt to link laboratory experience with site experience. Certain factors do correspond:

a) all sharp accelerations are in the vertical axis: the horizontal component is small and the head only needs holding in this plane

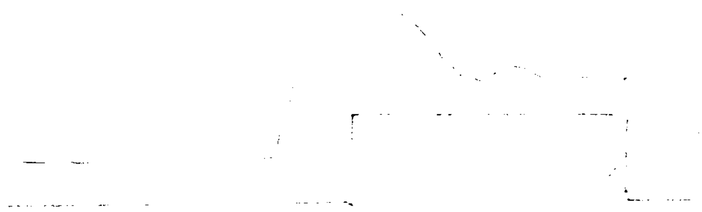
b) accelerations are greater in the upward direction, ie forcing the head downward: such accelerations are produced by hitting a bump, and landing after a bump. The downward accereration at the top of a jump and falling into a dip is little greater than 'g'.

Thus, the lab test of a step jump up or down can be said to simulate site undulations of a vertical type. Complex terrain, ie non-symmetric undulations, of the type found on site cannot be sumulated in this manner. Consider the following terrain profile:

side front

Such undulations , with the present test equipment, can be simulated only by breaking the accelerations involved into components, and testing each independently. Movement of the vehicle chassis with respect to the point of ground contact must also be ignored (suspension and tyre compression), but this is a reasonable assumption for sharp shocks and for the limited suspension travel available on such trucks.

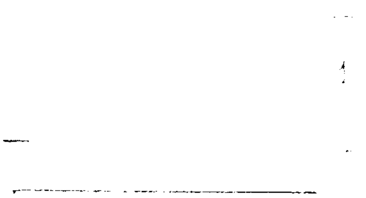
Consider a step-jump model:



: ground

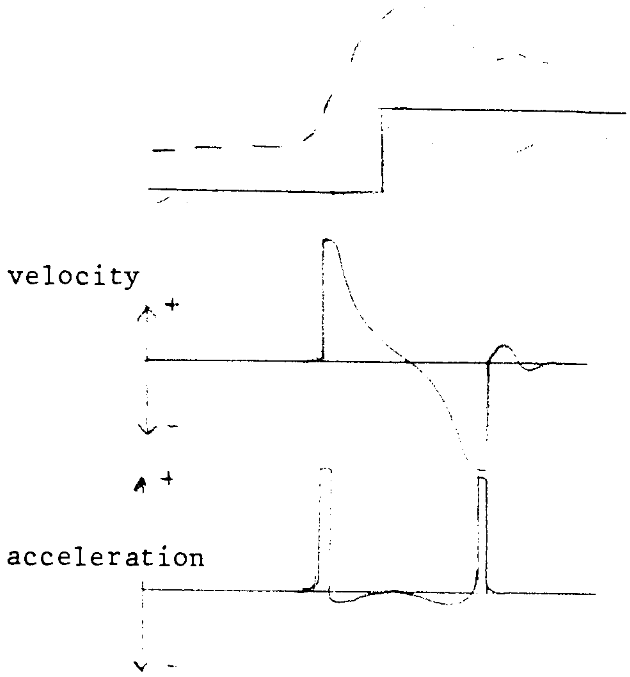
: centre of front wheel

The downward step is considered identical to thelatter section of the upward step, so only the upward step need be considered:



upward downward

Examining vertical velocity and acceleration:



derived from notes by
M. Butterworth, 11/10/83

MODIFICATIONS TO THE MOUNTING SYSTEM

So far, most tests have involved examining the performance of the conventional Metalastik mounts. The results are not inspiring, and an alternative mount system is required. Several main redesign types are feasible (for example belting, foam, springs, combinations of these), and all such types were considered.

BELTING. As the present mount system seems adequate until fauilure, and the vibrations that cause false alarms are small in amplitude, it would seem that a mounting technique that mimics the present mounts for a limited distance of travel (say 2mm which keeps the head unit within the bracket clearance) and then stiffens would seem ideal. Six belting designs were built and evaluated: these are illustrated at the end of this report. The final design has top mountings to provide downward vertical and lateral stiffness and axial movement, and bottom mountings to prevent the bottom of the head from rolling and hitting the side walls of the bracket. The results of exposing these designs to the pneumatic test rig are summarised in fig 4. The final design failed quickly when undergoing vertical shock, but lasted well (over five times longer than the Metalastik mount type) in the tilted shock. These results may be seen as an indication of the unfairness of the vertical shock test, or that the belting design is inherently weak in this mode. On-site tests to ascertain which are described in a later section.

FOAM. Foam, if one of the correct characteristics can be obtained, is a cheap and simple method of preventing the unit 'bottoming'. Typical upholstery foam fails quickly by disintegrating. Denser foam fared better, but difficulty was experienced in securing the foam permenantly in place. Best results were obtained with Declon 286 (from Boreham Industrial Services) which is silicone impregnated.. The technique did not, however, last long enough to be a serious contender.

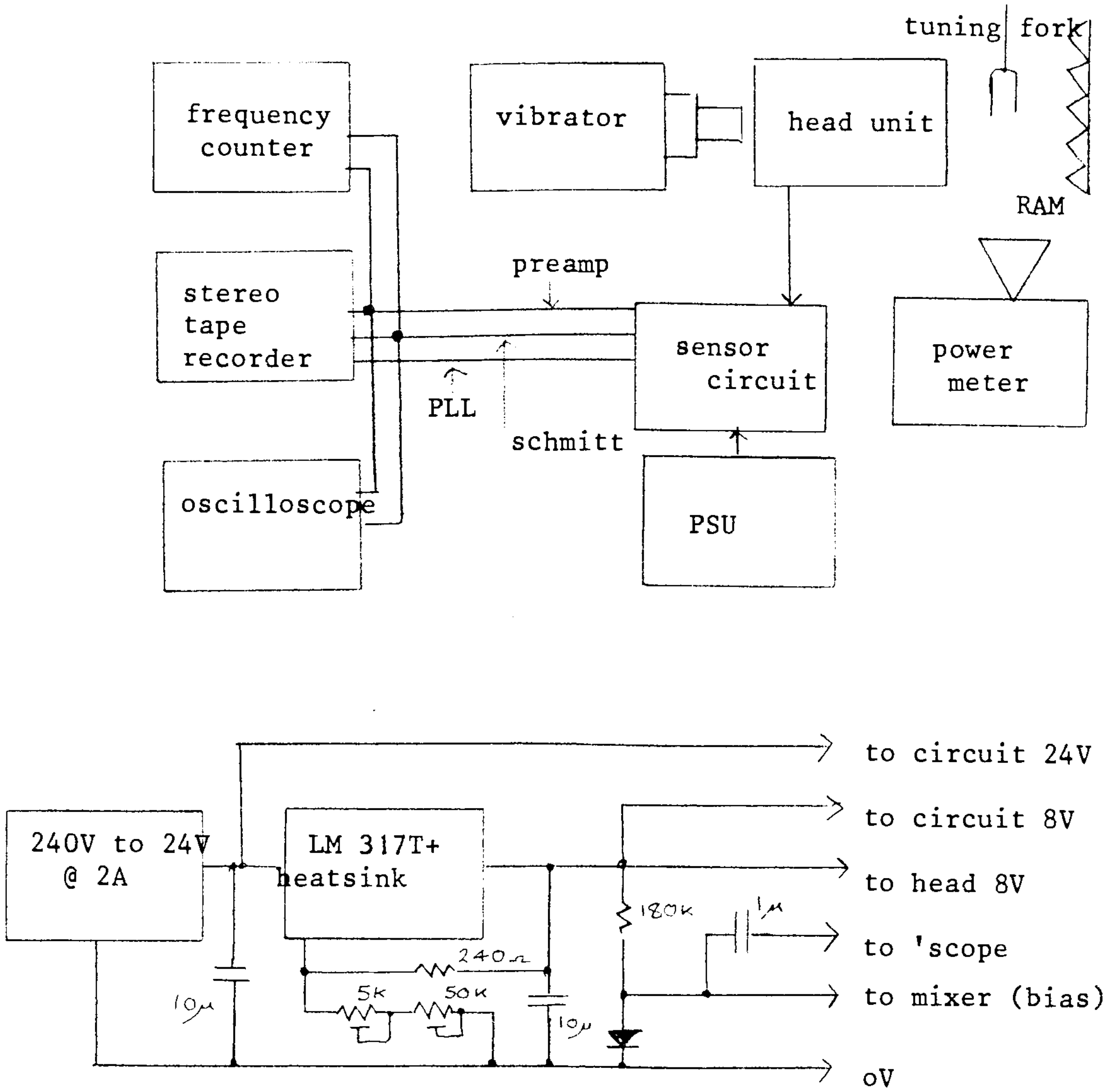
FOAM AND SPRINGS

Here the foam provides a limit on the spring travel and damps spring movement.One, two and one plus rubber feet, springs were assessed. The single spring method failed almost immediately, perhaps due to the unsuitability of the spring type. Other types, however, were not available at the time of testing. The two spring type was not completed, being difficult to construct. One spring, with the addition of soft rubber feet (usually used os instrument case feet) lasted longer, but still not long enough.. Hence four springs were tried. The increse in longevity was considerable in both modes of shock.

HOSE. Mounts were constructed out of studding and sections of rubber hose. The hose selected was stiff and ribbed, and three diameters were assessed. The results were excellent: the mounts lasted twenty times as long as Metalastik mounts, with the thicker hose giving the best results.

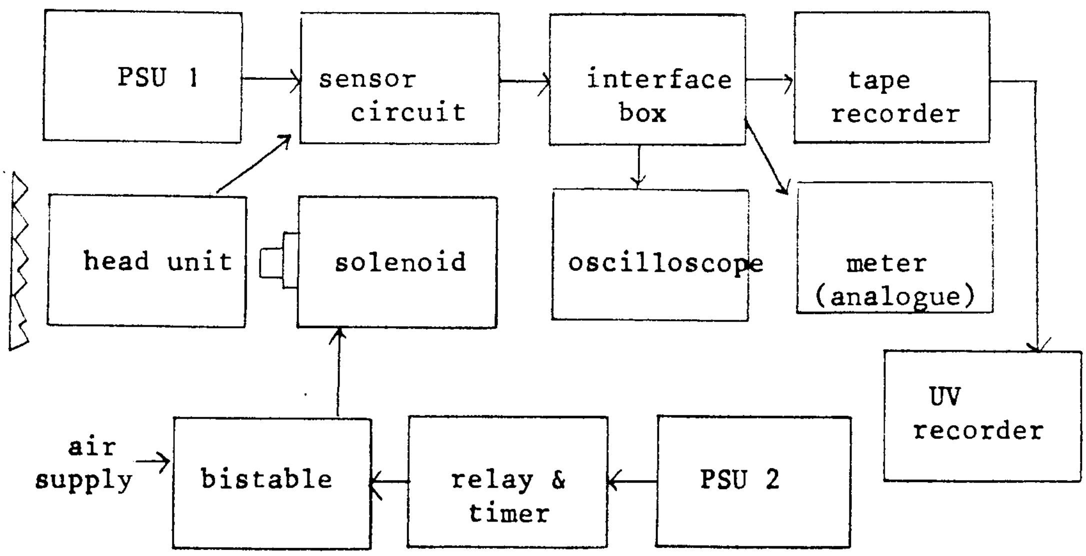
OTHER. Further modifications were tried. The Metalastik mounts used as standard have design limits of 0.6mm compression, 2mm shear. These limits are regularily exceeded, so one solution is to use these mounts, but to limit head travel. Collars consisting of ½"UNC nuts were placed over the mounts (thus permitting 1mm compression and 3mm shear), and a rubber foot mounted below the head to limit tension movement to 2mm. The results were encouraging. The unit was then modified so as to have three rubber feet, two above and one below the head, each fitting into a large rubber sleeve, thus limiting shear movement. On site, however, the simple collar produced permanent alarm, and the rubber collar prevented the unit from alarming. The designs were thus abandoned. Another design tried was the addition of an extra Metalastik mount at the rear of the bracket. This design was abandoned due to the difficulty of incorporating it into the present bracket design. Rubber buffers were tried between the mounts: the buffers did not affect the longevity of the unit on the test rig, but again, prevented the unit from functioning correctly in site conditions.

NEW BRACKET AND HOOD. The resources are not available to attempt the task of redesigning the hood unit, and the results of the shock and vibrationn rigs cast doubt on the suitability of the ARO unit as the basis of a new design. However, for completeness, one alternative design was considered. In this design, the centre of gravity of the unit is placed between the mounts, and the mounts are located vertically. A suitable mounting bracket was constructed: the mounts used were conventional Metalastik. The arrangement produced good results, and as the basis of a new design,



VIBRATOR TEST-RIG: Block-diagram and details of power supply.

FIG 1

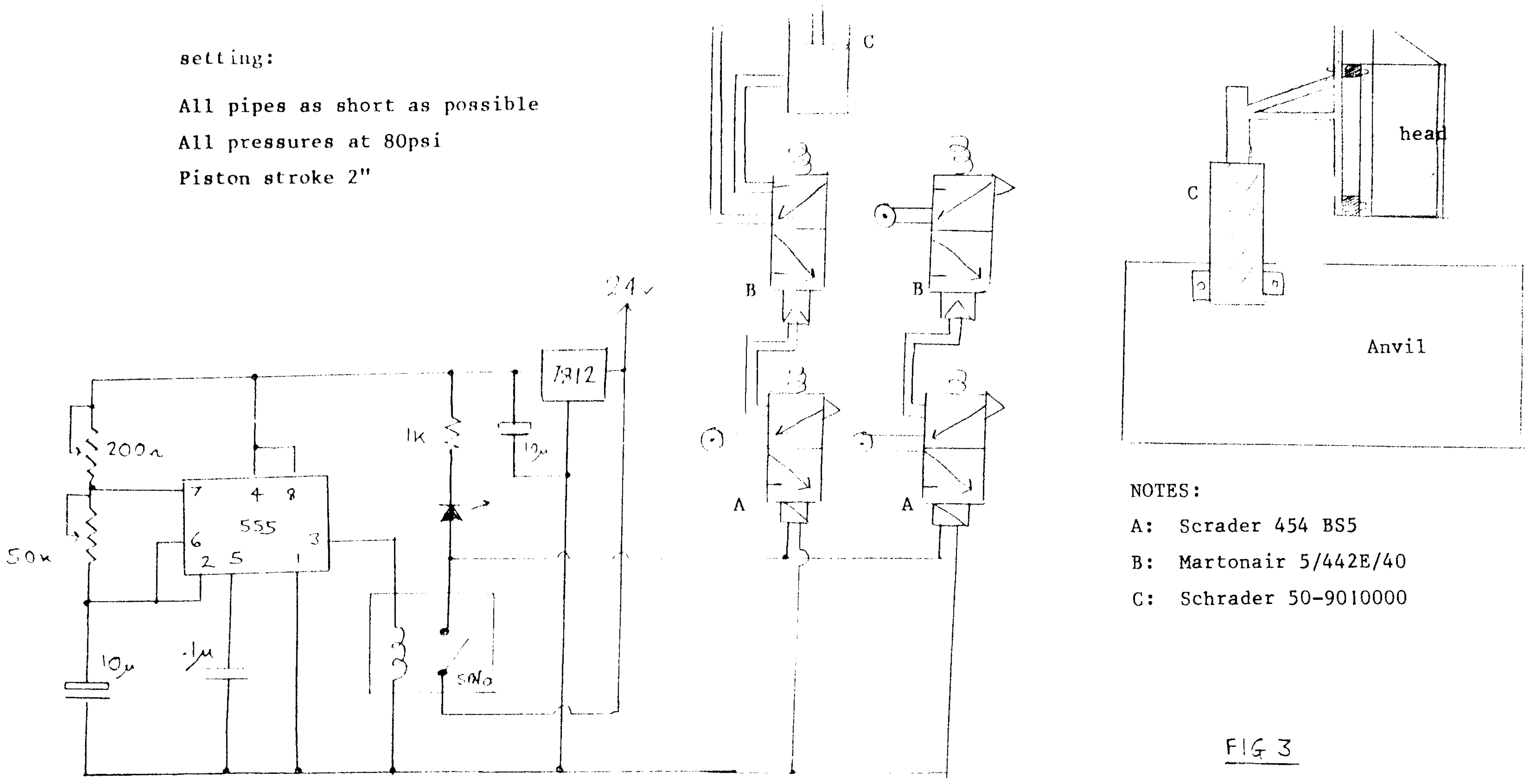


BLOCK-DIAGRAM OF THE SINGLE-SHOCK TEST-RIG. FIG 2 setting:

All pipes as short as possible

All pressures at 80psi

Piston stroke 2"



CIRCUIT AND LAYOUT FOR PNEUMATIC SHOCK TEST RIG.

NOTES:

A: Scrader 454 BS5

B: Martonair 5/442E/40

C: Schrader 50-9010000

FIG 3

looks promising, but as stated above, the basic assumption of the suitability of the ARO unit must first be confirmed.

FIELD TRIALS

The results of laboratory tests do not necessarily indicate the suitability or otherwise of a design for site use. This is well proven by the belting design whick lasted an impressive time on the shock test rig but failed in-situ. The same is true of the metal and rubber collar designs. Thus, selected designs were subjected to vehicle trials at the Butterwell site. The results are summarised at the end of this report.

Field Trial Results:

HEAD NUMBER	SENT ON	DETAILS OF UNIT	NOTES
27	29.7.83	rubber buffers	erratic alarm
27	29.7.83	metal collar	permanent alarm
27	31.8.83	rubber collar	no alarm
27	1.9.83	belting type 1	premature failure
86	2.9.83	thin tubing	erratic alarm
81	28.9.83	belting type 1	high alarm: 27mph
81	28.9.83	belting type 2	high alarm: 25mph
81	28.9.83	belting 2 and PLL	alarm OK, early fail
27	28.11.83	rubber collar,3 feet	high alarm: 30mph
51	7.11.83	belting type 3	wiring fault
51	9.11.83	belting type 3	erratic alarm
77	19.1.84	belting type 4	high alarm:26mph
71	19.1.84	belting type 4	OK
129	19.1.84	medium tube	?
45	19.1.84	thick tubing	alarm on engine idle
27	19.1.84	" "; stud	erratic alarm

type 1

type 2

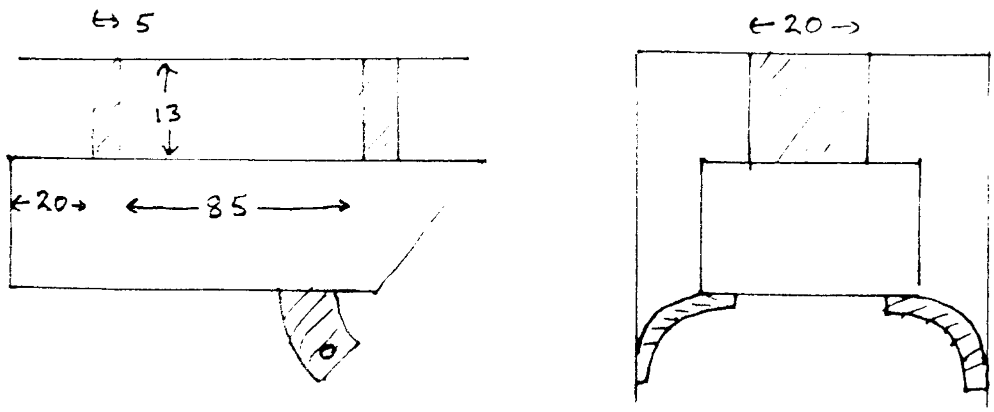
type 3

type 4

type 5

type 6

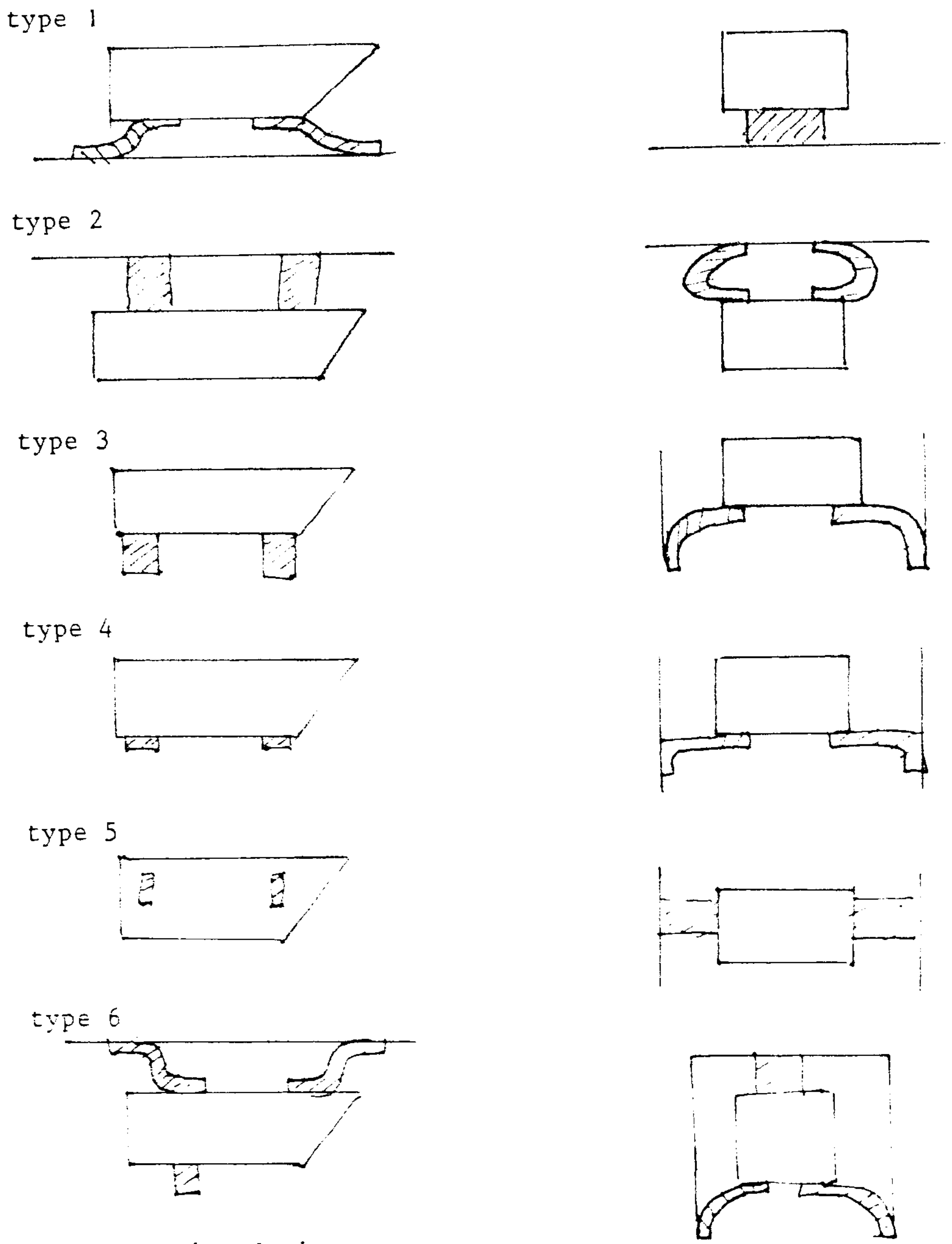
final belting design:



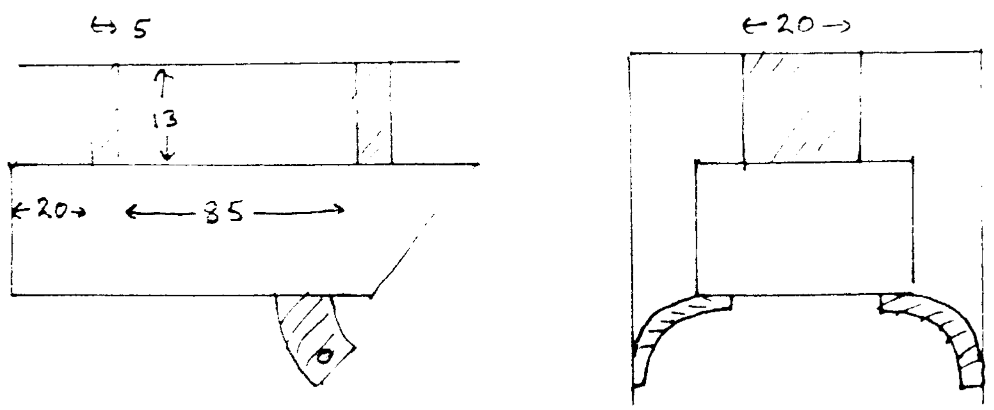
BELTING DESIGNS AND FINAL DESIGN. All belting 6mm thick.

DESIGN TYPE	SHOCK APPLIED AND TIME TO FAILURE (in minutes)			
	VERTICAL		40 DEGREE	
standard, part-used. type B	45	three sheared	7	one sheared
unused. type B	100	one mount sheared	17	one mount sheared
	135	all four sheared		
belting, type 2	5	top belt sheared	6	top sheared
	10	top and bottom broken		
belting, type 3	15	top shear, bottom split	9	top sheared
belting, type 5	15	top sheared	20	top split
belting, final design	17		95	significant movement
			110	failure
springs and foam: 4 springs	325	foam disintegrated	170	
: 4 springs, hard foam	270	spring stretch	90	spring stretch
: 4 springs, Declon	370	foam disintegrated	185	
tubing, 1½" and spring	475	220		
tubing, ½" and spring	370		70	
tubing, 2" and spring	875	tube split	125	
foam only: thin	12	disintegrated	14	
foam only: dense (Declon)	22		35	
foam and one spring	4	spring stretch	7	spring stretch
foam and two springs	-		-	
foam and one spring, rubber feet	23		18	
metal collar, Metalastik mounts	45	rubber cut through	32	
rubber collar and Metalastik mounts	40		55	
new bracket and Metalastik	185	bolts loosened	-	
belting, type four	16		14	split: head dig-in
bellting, type six (modified bracket)	21	lower belt split	24	

RESULT OF SHOCK APPLIED IN TWO AXES TO A SELECTION OF MOUNT TYPES. THE TIME TO FAILURE, AND REASON FOR FAILURE IS INDICATED.



final belting design:



BELTING DESIGNS AND FINAL DESIGN. All belting 6mm thick.

SECTION 2.7

REPORT INT P15
3.11.83
C. WALLACE

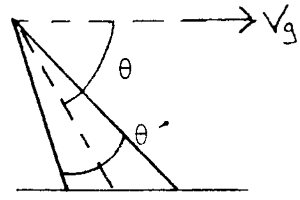
NOTES ON THE EFFECT OF BEAM GEOMETRY

SECTION

1. INTRODUCTION
2. FLUCTUATION NOISE DERIVATIONS
3. SCANNING NOISE DERIVATIONS

FLUCTUATION NOISE

For an infinitely narrow transmitted beamwidth, the returned doppler frequency, fd, is $fd = \frac{2.Vg}{\lambda}.\cos\theta$



For a finite beamwidth, θ', the received spectrum (half power points) is:

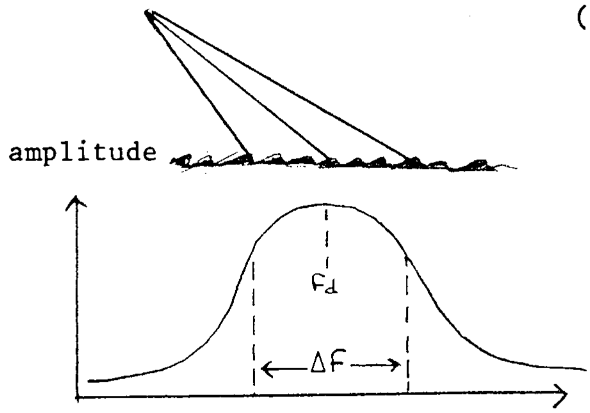
$$\Delta f = \frac{2.V}{\lambda}\left[\cos\left(\theta - \frac{\theta'}{2}\right) - c\left(\theta + \frac{\theta'}{2}\right)\right]$$

For small θ', this can be approximated. For θ' in the range 15 to 25 an error of 0.5% is introduced by the simplification:

$$\Delta f = \frac{2.V.\Delta\theta'.\sin\theta}{\lambda} \qquad \left(\Delta\theta' = \frac{\theta'.\pi}{180}\right)$$

Thus, relating Δf to amplitude and frequency:

(assuming a near-Gaussian distribution; valid for many ground types)



frequency

The standard deviation, σf, of Δf equals Δf/2. Hence $\sigma = \frac{V.\Delta\theta'.\sin\theta}{\lambda}$

For a near-normal distribution (ie for a distribution of the form $a = 1/\sigma.\exp(-fd^2/2.\sigma^2)$) the percentage area of one SD is approximately 33%, meeting the normalised curve at near 1/ 2; and the normalised deviation, σfn, is $\sigma fn = \frac{\Delta f/2}{fd} = \frac{\Delta\theta'.\tan\theta}{2}$

The correlation time, tc, equals 1/σf, so the fluctuation noise, σt, after signal smoothing over time t is: $\sigma t = \frac{\sigma f}{t/tc}$.

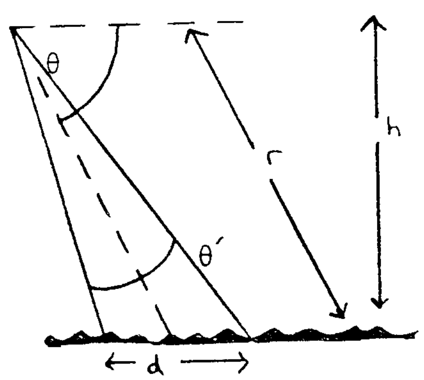
So, $\frac{\sigma f}{fd} = \frac{\sqrt{\sin\theta.\Delta\theta'\lambda}}{2.\cos\theta.\sqrt{v.t}} = K/\sqrt{vt}$. So, if S is the distance travelled in time t, $\frac{\sigma f}{fd} \propto \frac{1}{\sqrt{s}}$

SCANNING NOISE

For θ'/2 << θ, scanning time, ts, for the beam travelling distance d is 1/Vg.

So, ts = d/Vg where $d.\sin\theta \propto r.\Delta\theta'$ and $h \propto r.\sin\theta$ and $\Delta\theta' = \frac{\theta'.\pi}{180.}$

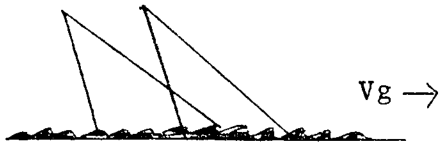
Therefore, $ts = \frac{1}{Vg}.\frac{\Delta\theta'}{\sin\theta}.\frac{h}{\sin\theta}$



so $ts = \frac{h \, . \, \Delta\Theta'}{Vg. \, Sin^2\Theta}$ and as the scanning noise, $\Delta S = 2.\sigma s$

(where $\sigma s = 1/(2.\pi.ts)$), $\Delta S = \frac{Vg. \, Sin^2\theta}{\pi.h.\Delta\theta'}$

If the return from a single point scatterer is a single pulse, the returned spectrum will mirror the pulse energy density spectrum, which is phase and amplitude modulated (due to the changing radar-to-target (scatterer) distance, and antenna pattern and terrain reflectivity changes respectively). Thus, for very narrow beamwidths, the echo spectrum is wide. For narrow beamwidths, the spectrum narrows, before broadening again due to phase modulation of the transmitted and returned signal. The process is similar for multiple scatterers.

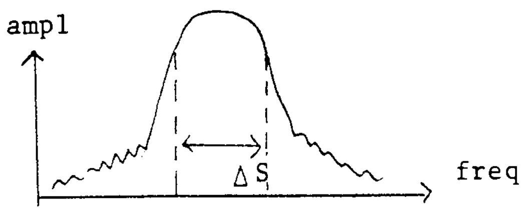


The standard deviation, σs, equals

$$\sigma s = \frac{Vg.Sin^2\theta}{2.\pi.h.\Delta\theta'}$$

and the normalised deviation, σsn, is:

$$\sigma sn = \frac{\Delta S/2}{fd} = \frac{\lambda \, Sin\theta.Tan\theta}{4.\pi.h.\Delta\theta'}$$



The ratio of σf to σs is:

$$\frac{2(\Delta\theta')^2.\pi h}{Sin\theta \;\; \lambda}$$

To illustrate how Δf and ΔS relate to fd for a given beam geometry, a computer program was written to calculate (for all $\Delta\theta'$ and θ) the values of Δf, Δs and fd. A value of h = 2m was assumed. Over 4000 values were derived and the graphs enclosed illustrate this data.

FLUCTUATION AND SCAN NOISE

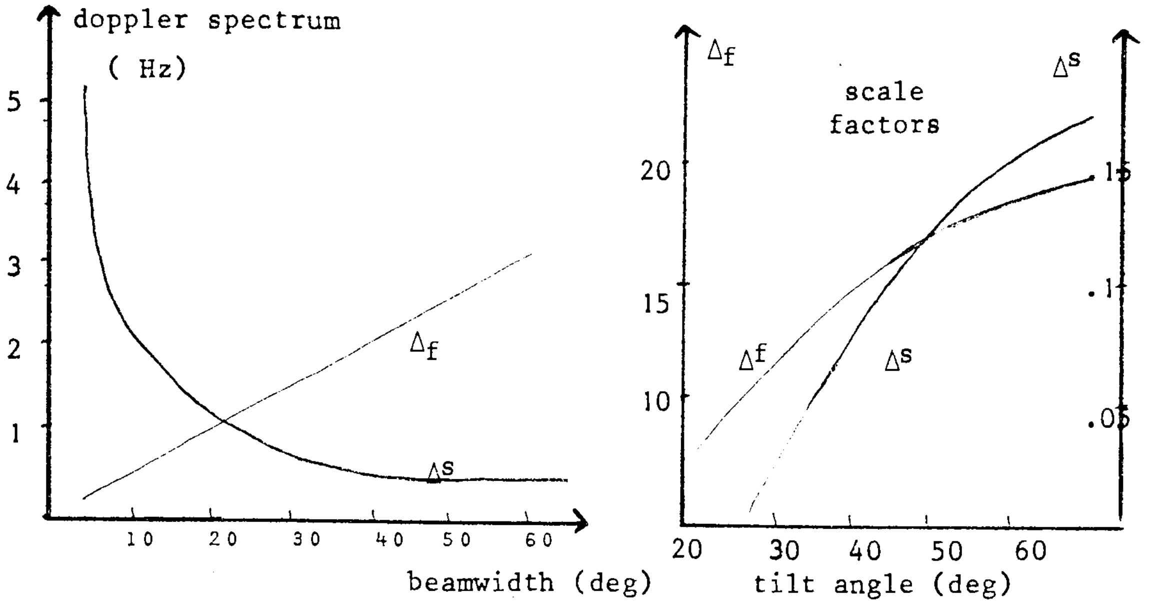
The total standard deviation (including σf and σs) is:

$$\sigma d = \sqrt{\sigma f + \sigma s}$$

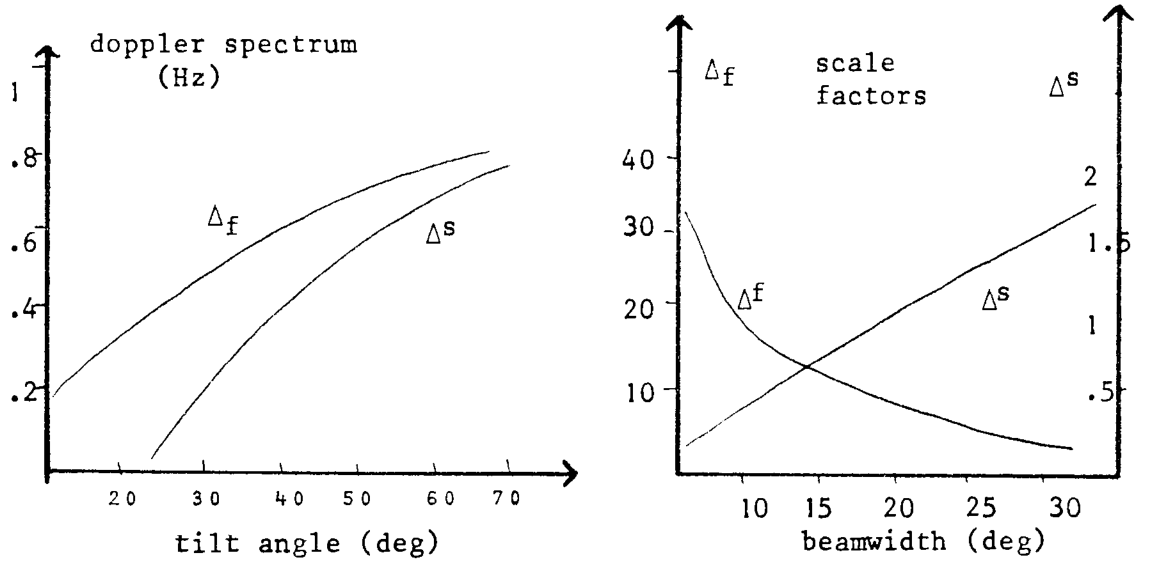
By assuming that the probability distribution of the instantaneous doppler frequency is equal to the power spectrum of the signal, the correlation time, tk, is $1/\sigma d$. For n independent samples taken over time period T, and then averaged, the resulting value has the standard deviation $\sigma n,t = \sigma d/\sqrt{N}$. The time between each sample is approximately tk, so $\sigma n,t = \sigma d/\sqrt{T/tk} = \sqrt{\sigma d/T}$

So, the normalised error is $\sigma e = \sigma n,t/fd = \frac{\sqrt{\sigma d/T}}{fd}$

Plotting $\sigma d/fd$ (normalised total standard deviation) against Θ yields:



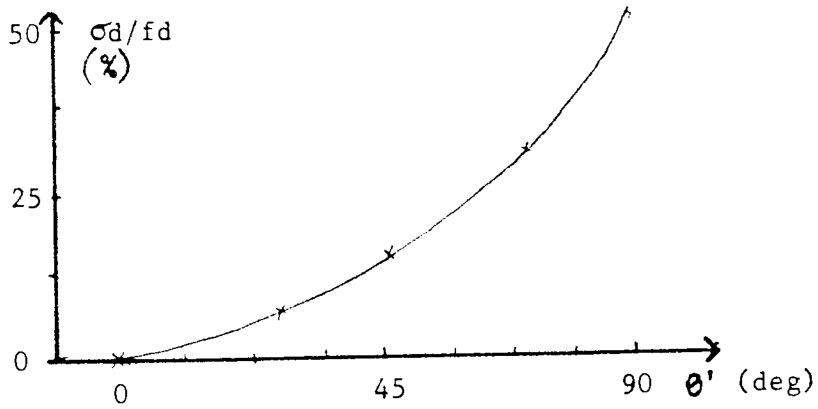
GRAPH A: DEPENDENCY OF SCANNING AND FLUCTUATION NOISE ON BEAMWIDTH FOR A GIVEN VALUE OF TILT ANGLE. For 1m/s, h = 2m.



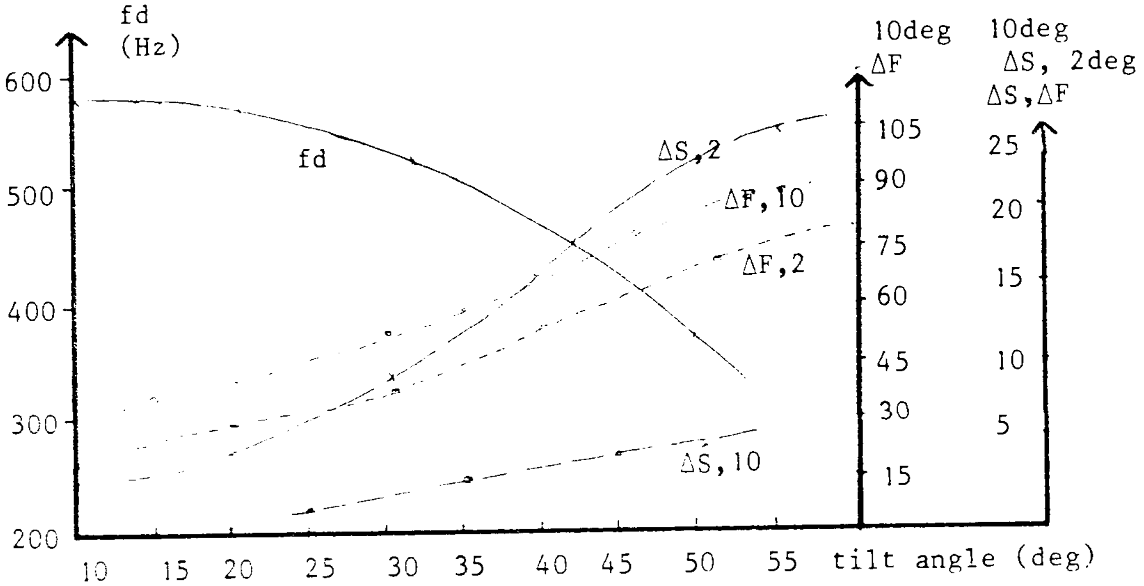
GRAPH B: DEPENDENCY OF SCANNING AND FLUCTUATION NOISE ON TILT ANGLE FOR A GIVEN VALUE OF BEAMWIDTH. For 1m/s, h=2m

EXAMPLE: for a tilt angle of 40deg and beamwidth of 10deg, from graph a, Δs = 2.0 x .08 = 0.16Hz and Δf = 0.4 x 16 = 6.4Hz. For a tilt angle of 10deg and beamwidth of 40deg, from graph b: Δf = 0.2 x 45 = 9Hz and Δs = negligible.

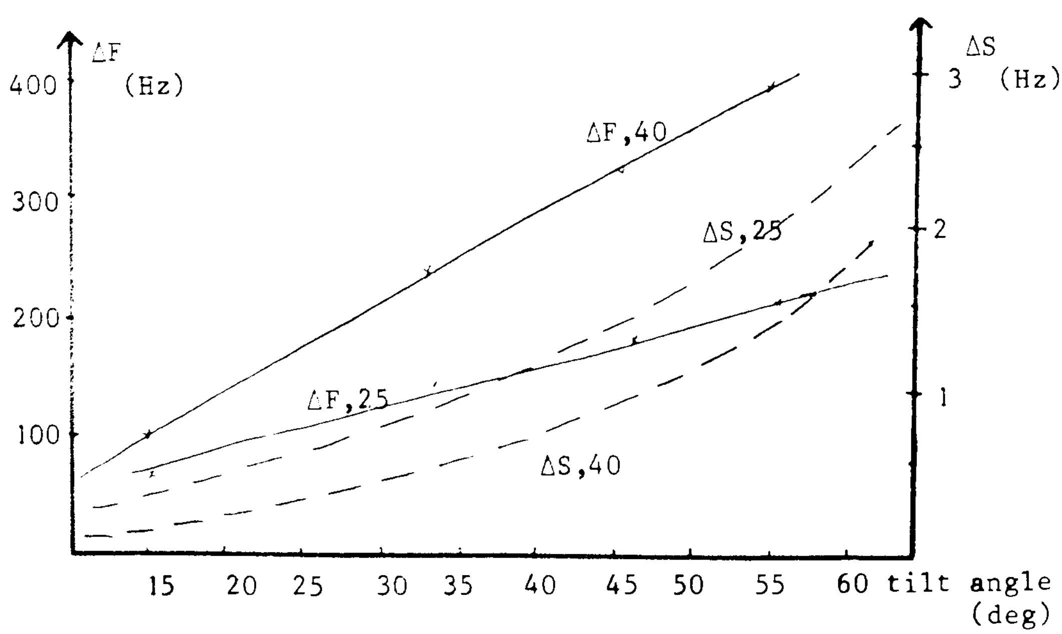
From graph a it can be seen that at low beamwidths, the scanning noise increases dramatically. However, the scale factor is low (for 40deg tilt, Δs scale is 188 times smaller that Δf scale)



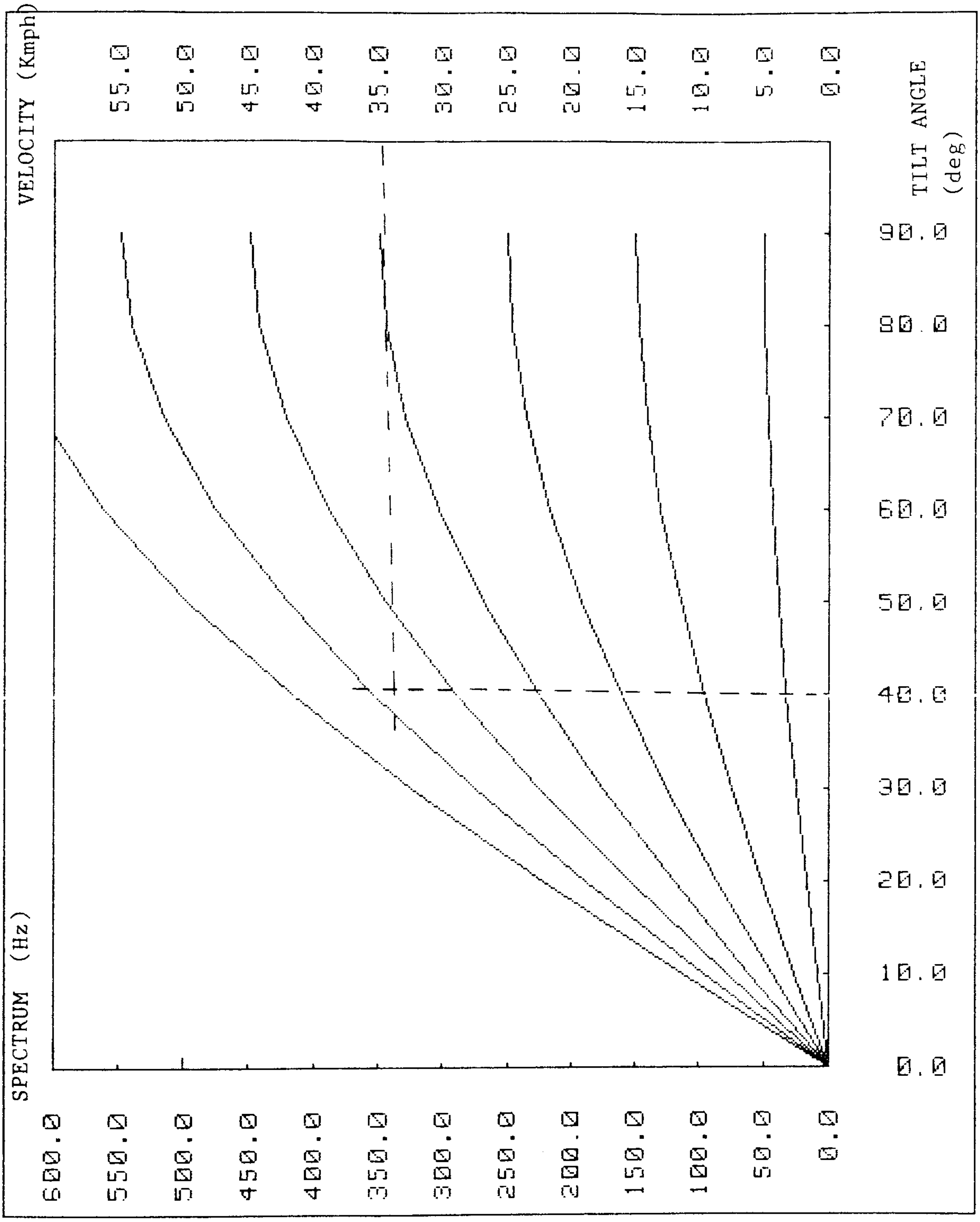
PLOT OF THE NORMAL-
ISED STANDARD DEVIA-
TION AGAINST BEAM
WIDTH.



SCANNING AND FLUCTUATION NOISE FOR A BEAMWIDTH OF 2deg & 10deg. For a velocity of 30Km/hr.



SCANNING NOISE AND FLUCTUATION NOISE FOR A BEAMWIDTH OF 25 and 40deg. For a velocity of 30Km/hr.



THE RELATIONSHIP BETWEEN TILT ANGLE, VELOCITY AND THE SPECTRUM WIDTH OF THE RECEIVED SIGNAL. Measured at the -3dB points.
Produced on an HP computer.
Dotted lines indicate the present system value of tilt angle and alarm speed.

SECTION 2.8

REPORT INT P17
2.1.84
C. WALLACE

CONFIGURABLE SPEED SENSOR.

SECTION

1. INTENTION
2. USE
3. METHOD:
   - A ANALOGUE
   - B DIGITAL
4. ARO-HORN CONVERSION
5. PRODUCTION DESIGN
6. REQUIREMENT FOR REMOTE SWITCHING
7. CIRCUIT DETAILS
8. APPENDIXES
   - A MODIFICATIONS
   - B PRACTICAL LAYOUT

INTENTION

This report covers the requirements for, the design of, and the testing of a module capable of translating frequency in a linear manner. The translation ratio is to be determined by pre-wired links, or by remote control. The module is to be used to convert new sensor design outputs to old board-compatible format.

USE

The frequency translation module (FTM) has several applications in speed sensing by doppler radar:

a) to allow different frequencies of transmission to be used with the same control board (on which the alarm frequency is fixed) by changing the ratio of frequency counts per unit of speed:

TX freq (GHz)	count/speed (Hz/mph) ratio	scaling reqd true	approx
10.6	32.0	1	1
13.5	40.5	0.79	4/5
24.0	72.7	0.44	4/9
60.0	177.8	0.18	9/50

So, for a change in TX frequency from 10.587 to 24GHz, the I/P frequency requires scaling by 4/9 in order to leave the alarm speed unaltered. This subject is covered further in report P18, specifically appendix 1.

b) to be capable of altering, by means of preset linkage, the alarm speed. This is achieved by changing the frequency perceived by the control board either by remote command or by hardwired linkage. Thus the nominal alarm speed can be altered over a range of speeds (discrete speeds only, as the FTM uses integer multiplication and division). The remote command can be sent by any appropriate means: infrared, ultrasonic, radio etc.

c) to correct for sensor module/vehicle combinations that give abnormally high or low alarm speeds. For example, a combination that consistently alarmed at 24mph (due, typically, to skewed beam geometry or an underpowered microwave unit) can be individually tuned on-site to the correct alarm speed.

d) to compensate for the difference in interpretation of different circuit designs. The PLL, for example, compensates for phase nulls to such an extent that the nominal alarm point drops by 2.5mph. Thus the FTM can be used in conjunction with such boards to allow the PCB to be utilised normally.

e) to perform the above tasks in any combination.

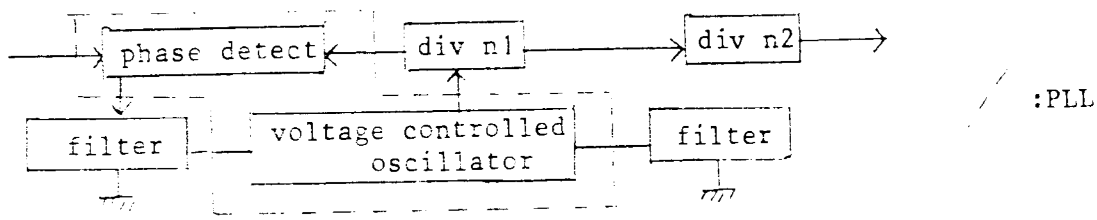
METHOD

Two means of frequency translation are available: analogue and digital. Whilst complex means are available for achieving the desired ratio change, only two cheap techniques will be considered:

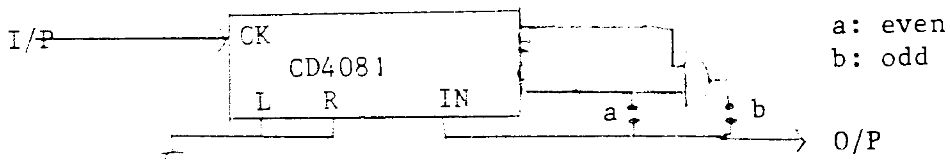
a) Analogue. This technique utilises two F/V (frequency to voltage converters) IC's, and operates by conversion of the input frequency to a proportional DC voltage which is level shifted, and reconverted to frequency. This method requires two F/C's and some thirty passive components, some of which require accurate calibration. The conversion ratios are truly linear. Such a circuit appears in appendix 4.

b) Digital. The use of digital dividers in series and in the feedback loop of a PLL (phase locked loop) achieves conversion, but only in discrete integer steps. The existing PCB two contains a PLL, so the component count totals two digital dividers. No calibration is required, and switching between ratios is achieved by hardwiring.

The digital method was selected for this design. Using a CD4046BE the FTM in block-diagram has the form:



where the dividers look thus:



Maximum and minimum frequency shifts attainable are divide and multiply by ten. For transmission frequency of 10.6GHz, and required speed range 10 to 33mph, appropriate connections can be selected (illustrated overleaf). Only those ratios required are wired; hence the circuit can divide by 4,6,8 and 10 and multiply by 4 to 10. For other TX frequencies, two dividers must be used in series. Figs 2 and 3 tabulate ratios for 18 to 24 mph, TX 10.6GHz. Fig 5 illustrates basic switch connection data.

```
10    REM        C.WALLACE 2/84     INT P17
20    REM        CALCULATOR: SPEED DIFFERENCES FOR FTM, GIVEN
      NOMINAL ALARM SPEEDS: LISTS NEW ALARM SPEEDS IN ORDER, ELI
      MINATING DUPLICATION AND OUT OF RANGE VALUES.
25    REM ****************************************************
30    PRINT "PRINTER ON LINE? (Y/N) ": INPUT P£: PRINT " TABULATE
      FACTOR DIFFERENCES FOR ALL RATIOS OR LIST SEQUENTIALLY OR
      BOTH (T/L/B)?: INPUT T£: PRINT T£:GOSUB 2000
35    PRINT " NOMINAL";A£;" (MPH);: INPUT S: PRINT S;" MPH": IF
      P£ = "Y" THEN LPRINT C£," SPEED ";S;" MPH"
40    PRINT " DIVISOR RANGE? LOW: ";:INPUT Q: PRINT Q;" HIGH ";:
      INPUT R: PRINT R;" STEP ";: INPUT U: PRINT, " MULTIPLIER
      RANGE ? LOW ";: INPUT C: PRINT C;" HIGH ";: INPUT D: PRINT
      D;" STEP ";: INPUT E: PRINT E
50    REM CALCULATE DIFFERENCES
60    FOR W = C TO D STEP E: FOR Y = Q TO R STEP U
70    LET S(1-W/Y) = T
80    IF T£ = "T" OR T£ = "B" THEN PRINT W;"/";Y,T: IF P£ = "Y"
      THEN LPRINT W;"/";Y,T
90    LET A(N) = T: LET N = N + 1
100   NEXT W: NEXT Y
110   PRINT C£
120   IF T£ = "L" OR T£ = "B" THEN GOTO 200
130   GOTO 270
190   REM SORT ROUTINE
200   PRINT " NEW";A£: IF P£ = "Y" THEN LPRINT C£,"NEW";A£
210   FOR J = 1 TO 31: FOR K = 1 TO 32-J:
220   IF A(K) LT A(K+1) THEN LET T = A(K): LET A(K) = A(K+1):
      LET A(K+1) = T
230   IF A(K) = A(K+1) THEN LET A(K) = 0
240   NEXT K: NEXT J
250   FOR N = 1 TO 31: IF A(N) GT 0 THEN GOSUB 1000
260   NEXT N
270   PRINT C£," AGAIN? (Y/N) ": INPUT R£: IF R£ = "Y" THEN CLS:
      GOTO 35
280   STOP
1000  REM TRUNCATE TO ONE DECIMAL PLACE
1005  PRINT "PRINT RANGE: LOW: ";: INPUT LL: PRINT LL," HIGH "
      ;: INPUT HH: PRINT HH: IF A(N) GT HH OR A(N) LT LL THEN
      GOTO 1050
1010  LET B = A(N) - INT A(N)
1020  IF B GT 0 THEN LET D£ = STR£B: PRINT INT A(N);D£(2 TO 3)
      : IF P£ = "Y" THEN LPRINT INT A(N);D£(2 TO 3):
1030  IF B GT 0 THEN GOTO 1050
1040  PRINT A(N): IF P£ = "Y" THEN LPRINT A(N)
1050  RETURN
2000  REM INITIALISE
2010  LET C£ = "****************"
2020  LET A£ = " ALARM SPEED "
2030  LET N = 1: DIM A(32)
2040  RETURN
```

IN THE ABOVE, LT REFERS TO 'LESS THAN', GT TO 'GREATER THAN', AND X£ IS STRING X. OPERATION TIME TYPICALLY 30 SECS FOR ONE SPEED AND DIVIDER RANGE 3 TO 10.

17	18	19	20	21	22	23	24
27.2	28.8	30.4	32	33.6	35.2	36.8	38.4
26.4	28	29.6	31.1	32.7	34.2	35.8	37.3
25.5	27	28.5	30	31.5	33	34.5	36
24.3	25.7	27.1	28.6	30	31.4	32.9	34.2
23.8	25.2	26.6	28.	29.4	30.8	32.2	33.6
22.7	24	25.3	26.7	28	29.3	30.7	32
21.3	22.5	23.8	25	26.3	27.5	28.8	30
20.4	21.6	22.8	24	25.2	26.4	27.6	28.8
19.4	20.6	21.7	22.9	24	25.1	26.3	27.4
18.9	20	21.1	22.2	23.3	24.4	25.6	26.7
17	18	19	20	21	22	23	24
15.1	16	16.9	17.8	18.7	19.6	20.4	21.3
14.6	15.4	16.2	17.1	18	18.9	19.7	20.6
13.6	14.4	15.2	16.	16.8	17.6	18.4	19.2
12.8	13.5	14.3	15	15.6	16.5	17.3	18
11.3	12	12.7	13.3	14	14.7	15.3	16
9.7	10.3	10.9	11.4	12	12.6	13.1	13.7
8.5	9	9.5	10	10.5	11	11.5	12
6.8	7.2	7.6	8	8.4	8.8	9.2	9.6
5.7	6	6.3	6.7	7	7.3	7.6	8

ALARM SPEEDS CALCULATED FOR M/N FACTOR: NOMINAL ALARM SPEED RANGE 17 TO 24MPH, MULTIPLIER M 4 TO 10 STEP 2, DIVIDER N 3 TO 10 STEP 1. SPEEDS GIVEN IN SEQUENCE.

FIG2

	nominal 23mph				nominal 24mph			
	4	6	8	10	4	6	8	10
3	-7.7	-23	-38.3	-53.7	-8	-24	-40	-56
4	0	-11.5	-23	-34.5	0	-12	-24	-36
5	4.6	-4.6	-13.8	-23	4.8	-4.8	-14.4	-24
6	7.7	0	-7.7	-15.3	8	0 -8	-16	
7	9.9	3.3	-3.3	-9.9	10.3	3.4	-3.4	-10.3
8	11.5	5.6	0	-5.8	12	6	0	-6
9	12.8	7.7	2.6	-2.6	13.3	8	2.7	-2.7
10	13.8	9.2	4.6	0	14.4	9.6	4.8	0

FIG3B

SPEED DIFFERENCES FOR NOMINAL ALARM SPEED RANGE 17 to 24mph, AND STATED MULTIPLIERS AND DIVIDERS. MULTIPLY RANGE OS 4,6,8,10; DIVIDE RANGE IS 3 to 10. EG: FOR A NOMINAL 21mph, A FACTOR OF 8/9 GIVES A NEW ALARM SPEED OF 21+2.2 = 23.2mph.

	nominal 17mph				nominal 18mph				nominal 19mph			
	4	6	8	10	4	6	8	10	4	6	8	10
3	-5.7	-17	-28.3	-39.7	-6	-18	-30	-42	-6.3	-19	-31.1	-44.3
4	0	-8.5	-17	-25.5	0	-9	-18	-27	0	-9.5	-19	-28.5
5	3.4	-3.4	-10.2	-17	3.6	-3.6	-10.8	-18	3.8	-3.8	-11.4	-19
6	5.7	0	-5.7	-11.3	6	0	-6	-12	6.3	0	-6.4	-12.7
7	7.3	2.4	-2.4	-7.3	7.7	2.6	-2.6	-7.7	8.1	2.7	-2.7	-8.1
8	8.5	4.3	0	-4.3	9	4.5	0	-4.5	9.5	4.8	0	-4.8
9	9.4	5.7	1.9	-1.9	10	6	2	-2	10.6	6.3	2.1	-2.1
10	10.2	6.8	3.4	0	10.8	7.2	3.6	0	11.4	7.6	3.8	0

	nominal 20mph				nominal 21mph				nominal 22mph			
	4	6	8	10	4	6	8	10	4	6	8	10
3	-6.3	-19	-31.7	-44.3	-6.7	-20	-33	-47	-7	-21	-35	-49
4	0	-9.5	-19	-28.5	0	-10	-20	-30	0	-10.5	-21	-31.5
5	3.8	-3.8	-11.4	-19	4	-4	-12	-20	4.2	-4.2	-12.6	-21
6	6.3	0	-6.4	-12.7	6.7	0	-6.7	-13	7	0	-7	-14
7	8.1	2.7	-2.7	-8.1	8.6	2.9	-2.9	-8.6	9	3	-3	-9
8	9.5	4.8	0	-4.8	10	5	0	-5	10.5	5.3	0	-5.3
9	10.6	6.3	2.1	-2.1	11.1	6.7	2.2	-2.2	11.7	7	2.3	-2.3
10	11.4	7.6	3.8	0	12	8	4	0	12.6	8.4	4.2	0

FIG 3B. SEE OVER FOR TITLE

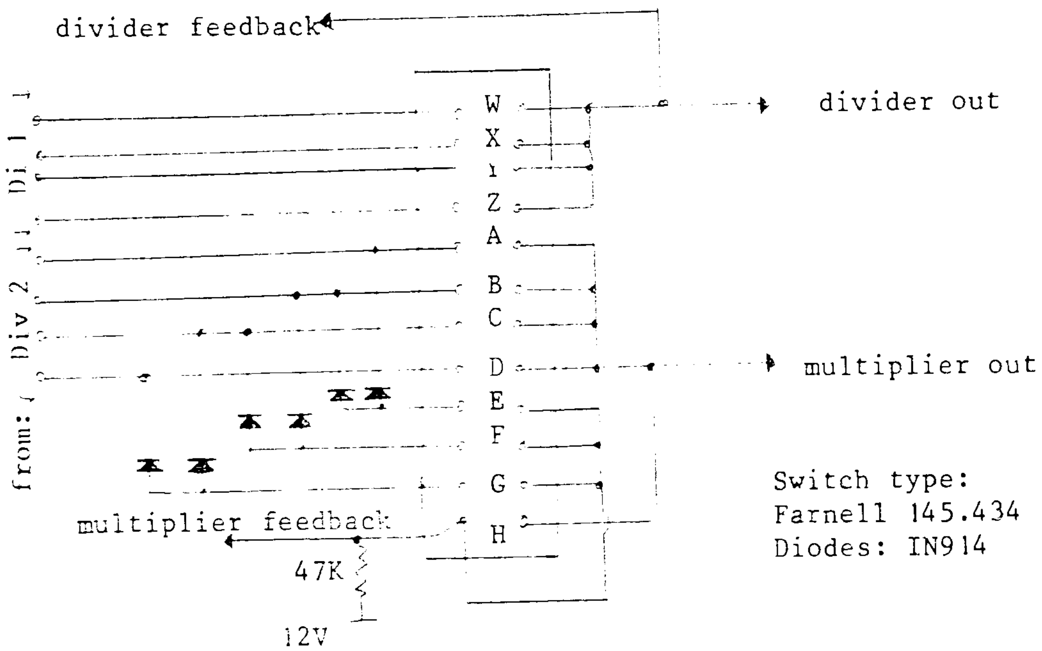
SPEED (mph)		16	17	18	19	20	21	22	23	24	25
Circuit	Ratio										
Theory	31.5	21	30	35	39	43	46	48	50	52	53
Aro+ old	26.6			11	22	28	33	37	40	43	45
Aro+ new	29.2		19	27	32	36	40	43	46	48	50

HEAD ANGLES REQUIRED FOR A GIVEN ALARM SPEED: THEORY AND PRACTICE.

The angle, is $\cos^{-1}\left(\frac{470}{\text{ratio} \times \text{alarm speed}}\right)$ (470 is the control board alarm frequency)

The ratio units are Hz/mph

FIG 4



Switch type:
Farnell 145.434
Diodes: IN914

Sw	by:
W	4
X	6
Y	8
Z	10

Divide

Sw	by:	Sw	by:
A,H	4	C,H	8
B,E	5	D,G	9
B,H	6	D,H	10
C,F	7		

Multiply

DIVIDER SWITCH POSITIONS. Divider two is wired as a multiplier.

FIG 5

FTM : PRODUCTION DESIGN

In theory a control board setting of 470hz and a tilt angle of 40 deg means an alarm speed of 19.32mph. In fact the old circuit (ARO type) alarms, typically, at 23 mph and the new pcb at 21mph. Future designs may alarm at 19.5 to 20mph, as the understanding of the factors involved in signal processing increases. Given that a FTM design for production must bear all usual considerations in mind (size, cost etc), what is the optimum horn angle ?. Several factors must be contemplated: the angle must be:

a) OK for backscatter characteristics
b) OK for vehicle geometry and physical layout
c) designed to allow selection of a wide range of speeds around 10, 25, 20 and 25mph (so the alarm speed can be fine-tuned to match vehicle gearing)

From site experiments, an angle of around 40 degrees is a good compromise, so the design must not deviate from this by more than five degrees. For a FTM ratio of w/y where w is 4,6,8 and10 and y is 3 to 10; the alteration in alarm speed is given simply by

Alteration = Alarm speed.(1-w/y)

Thus, to find the best angle, this expression must be evaluated for all w,y and s between say, 17 and 24mph. This has been done in fig 2 and fig 3aand 3b. From fig 3, the best grouping (see point c above) is a value of alteration around 0-2, 4-7 and 9-13mph (for 22, 15 and 10 mph respectively). For any one speed, the tilt angle can be calculated to obtain that speed from:

$$\text{angle} = \cos^{-1}((470/\text{speed})/31.76), \text{ in theory at least.}$$

Hence for a system that alarms at 20mph, an alarm of 22mph can be obtained by setting the tilt angle to 42.3 degrees. The appropriate table of fig 3b can now be used to ascertain the exact range of speeds available for the basic FTM circuit (that of fig 6), and for the configurable circuit (fig 7).

For the prototype horn, a ratio of 0.938 gives the correct alarm speed of 22mph. Thus, for purposes of alarm frequency correction only, fig 6 was adopted on a production basis.

ARO - to - HORN DESIGN CONVERSION

For a given roadspeed the prototype horn unit gives an output frequency approximately 7% higher than that obtained from the ARO unit and associated electronics (the reasons for this difference are explained in full in other reports, but briefly are due to the new design 'filling in' phase nulls in the received signal). Thus a FTM board is required to lower this output frequency by an appropriate amount: this ensures compatibility of radar type.

A ratio of 0.938, or 15/16 was chosen; this being performed by the circuit in figure 6. Modifications are required to the main sensor circuit board:

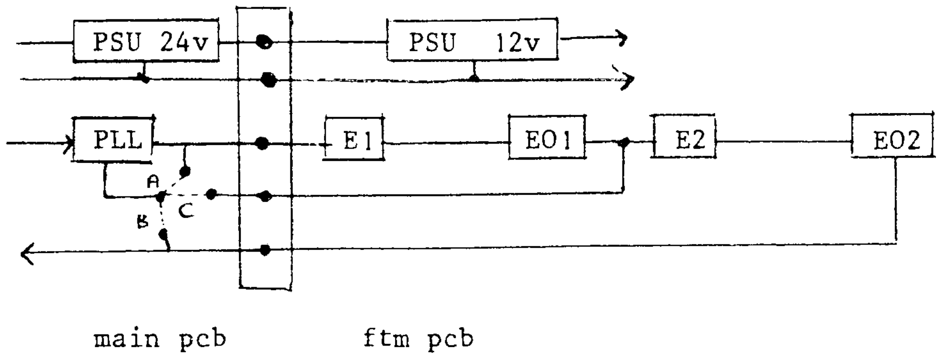
COMPONENT	OLD VALUE	NEW VALUE
R26	3m9	6m8
O/P link	yes	no
PCB FTM	no	yes
R33	47r	22r
R5	220k	75k
C3	1n	4n7
C11	22n	1n) extended range
R26	3m9	1m) FTM board only

GREATER RANGE OF ALARM OPTIONS

The previous designs give a limited range of alarm options. To assess, in the field, the suitability of likely speed options, a more comprehensive unit is required. The chosen alarm points can then be tested in-situ before the design is translated into hardware. Such a circuit appears as fig 7. At the time of writing (6/84), the exact alarm speed required by the system customers is not known (it has been assumed to be 22mph up to this point), so this unit can be used to assess site-manager and driver reactions to speed options considered marketable.

The circuit is an extension of fig 6: two switch banks are used, giving a ratio range of 16/100 to 100/16. Such a range is considered comprehensive yet the circuit will easily fit onto a small PCB using propietary switches. The range covered, in terms of factors, is 0.16 to 6.25, with 0.972 (70/72) and 1.03 (72/70) being the nearest non-unity factors to a 1/1 ratio. The exact switch positions required for a given alarm speed are tabulated overleaf for a range of speeds between 10 and 35mph.

Connections to the board, and a circuit block-diagram are as follows.



where: E = divide by even numbers in the range 4 to 10
EO = divide by even and odd numbers in the range 4 to 10

Links:

Main PCB only: link A and B

PCB with FTM : link C

REQUIREMENT FOR REMOTE SPEED SWITCHING

The ability to remotely switch alarm speeds on site is a facility easily incorporated, but is also easily misapplied. For reasons of safety it is inappropriate to sanction drivers just before a hazard: reducing the permissible vehicular speed from 20 to 10mph gives the driver only four seconds to slow down (4 seconds is the time-constant before each sanction stage of 30,60 and90% retard is applied). This, in certain circumstances, such as a muddy haul road, can be dangerous: trucks are inherently prone to skidding by virtue of their geometry, suspension and weight. An extended delay would thus have to be incorporated into the system to allow time for safe braking: this detracts from the concept of 'local hazard' beacons. Thus, the beacons are best placed in a zone system, whereby areas of haul road are permanently labelled either full or reduced speed zones. These zones could be either active or inactive: for example the reduced speed zones could be activated only in wet weather, with one speed allocated as 22mph, and the lower a safer 18mph. Or, long and safe stretches of haul road could be deemed faster speed, say 26mph alarm, the rest of the site being 20mph.

MULTIPLIER	FACTORS				ALARM SPEED	SWITCH POSITIONS					
						BANK 1			BANK 2		
.45	6	6	8	10	9.9	2	6	12	7	4	12
.46	8	4	7	10	10.12	3	5	12	10	4	
.47	6	5	8	8	10.34	2	11		7	3	12
.48	4	6	5	10	10.56	1	6	12	11	4	
.50	10	4	8	10	11.0	4	5	12	7	4	12
.51	4	9	7	10	11.22	1	9		10	4	
.52	6	7	10	8	11.44	2	10		8	3	12
.53	8	6	9	10	11.66	3	6	12	9	4	
.54	6	5	7	8	11.88	2	11		10	3	
.55	10	5	9	10	12.10	4	11		9	4	
.56	8	7	10	10	12.32	3	10		8	4	12
.57	4	10	7	10	12.54	1	8	12	4	10	
.58	4	7	6	8	12.76	1	10		6	3	12
.59	4	8	9	6	12.98	1	7	12	9	2	
.60	6	6	10	6	13.20	2	6	12	8	2	12
.63	8	5	8	8	13.86	3	11		7	3	12
.64	8	4	5	10	14.08	3	5	12	11	4	
.66	6	7	8	8	14.52	2	10		7	3	12
.67	6	8	9	8	14.74	2	7	12	9	3	
.68	6	9	10	8	14.96	2	9		8	3	12
.69	6	8	7	10	15.18	2	7	12	10	4	
.70	6	7	6	10	15.40	2	10		6	4	12
.71	8	5	7	8	15.62	3	11		10	3	
.72	6	6	5	10	15.84	2	6	12	11	4	
.75	6	7	7	8	16.50	2	10		10	3	
.76	8	4	7	6	16.72	3	5	12	10	2	
.78	6	7	9	6	17.16	2	10		9	2	
.80	8	4	10	4	17.60	3	5	12	8	1	
.83	6	10	9	8	18.26	2	8	12	9	3	
.84	6	7	5	10	18.48	2	10	11	4		
.86	6	8	7	8	18.92	2	7	12	10	3	
.88	6	7	6	8	19.36	2	10		6	3	12
.89	6	8	9	6	19.58	2	7	12	9	6	
.90	6	6	10	4	19.80	2	6	12	8	1	12
.93	4	7	5	6	20.46	1	10		11	6	
.94	6	5	4	8	20.68	2	11		5	3	12
.95	8	5	7	6	20.90	3	11		10	2	
.96	6	8	5	10	21.12	2	7	12	11	4	
.97	10	7	9	8	21.34	4	10		9	3	
1.0	4	4	4	4	22.00	1	5	12	5	1	12
1.04	8	7	9	6	22.88	3	10		9	2	
1.05	6	7	5	8	23.10	2	10		11	3	
1.07	8	4	5	6	23.54	3	5	12	11	2	
1.08	6	9	5	10	23.76	2	9		11	4	
1.09	10	7	8	8	23.98	4	10		7	3	12
1.11	10	10	9	10	24.42	4	8	12	9	4	
1.12	8	7	5	10	24.64	3	10		11	4	
1.13	6	9	8	6	24.86	2	9		7	2	12
1.14	6	8	7	6	25.08	2	7	12	10	2	
1.17	6	7	6	6	25.74	2	10		6	2	12
1.19	10	5	7	6	26.18	4	11		10	2	
1.20	6	8	5	8	26.40	2	7	12	11	3	
1.25	8	5	4	8	27.50	3	11		5	3	12
1.28	8	8	5	10	28.16	3	7	12	11	4	

MULTIPLIER	FACTORS	ALARM SPEED	SWITCH POSITIONS BANK 1	SWITCH POSITIONS BANK 2
1.29	6 9 7 6	28.38	2 9	10 2
1.30	10 7 9 6	28.60	4 10	9 2
1.31	6 7 4 8	28.82	2 10	5 3 12
1.33	6 8 6 6	29.26	2 7 12	6 2 12
1,35	6 9 5 8	29.70	2 9	11 3
1.39	10 5 9 8	30.58	4 11	9 1
1.40	4 7 5 4	30.80	1 10	11 1
1.43	8 5 7 4	31.46	3 11	10 1
1.44	8 9 5 10	31.68	3 9	11 4
1.46	10 7 6 8	32.12	4 10	6 3 12
1.48	8 10 9 6	32.56	3 8 12	9 2
1.50	6 8 8 4	33.00	2 7 12	10 1
1.52	8 8 7 6	33.44	3 7 12	10 2
1.56	8 7 9 4	34.32	3 10	9 1
1.60	8 4 5 4	35.2	3 5 12	11 1

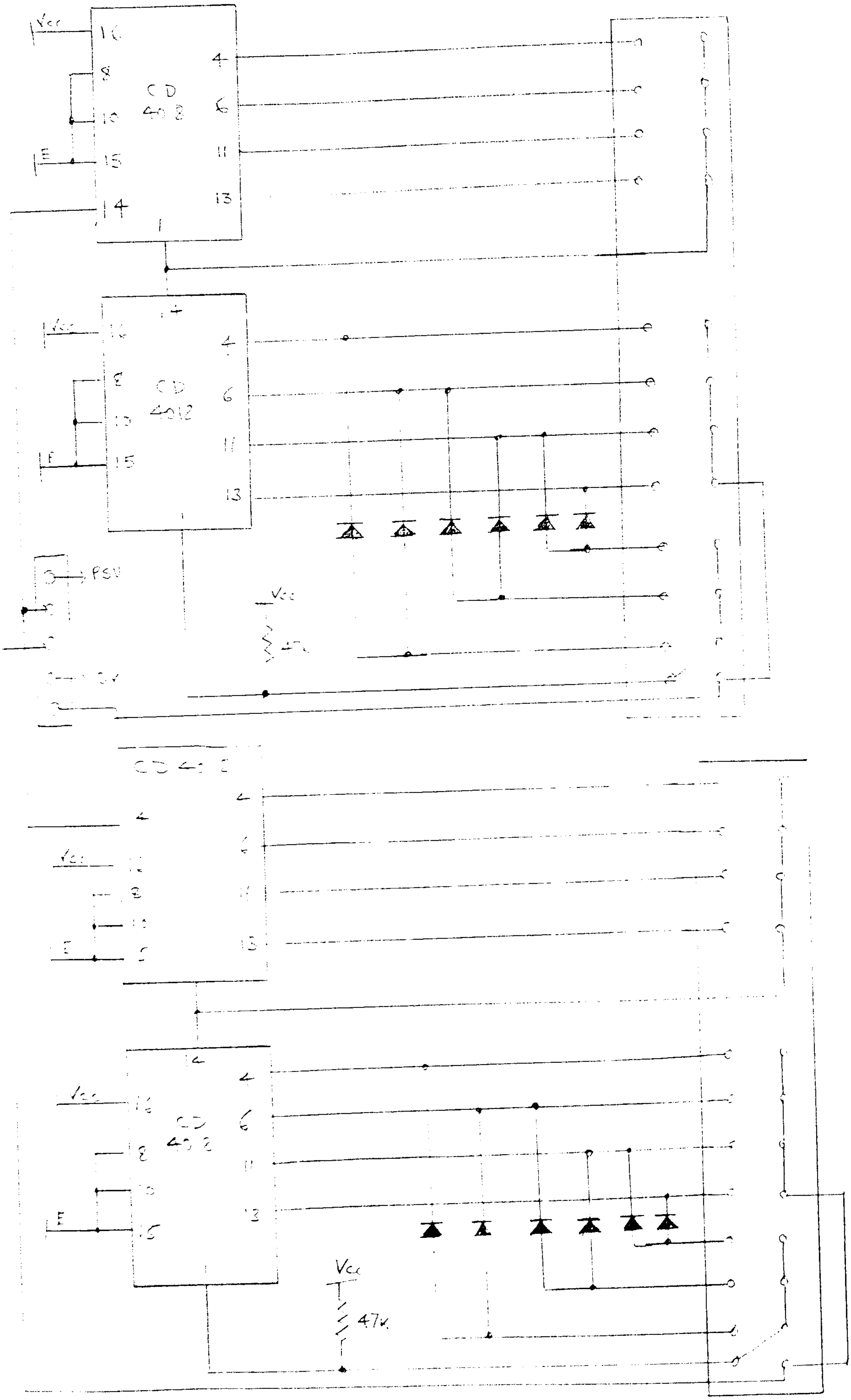
SWITCH POSITIONS REQUIRED FOR THE GIVEN REQUIRED ALARM SPEED IN THE RANGE 10 to 35mph.

MULTIPLIER	FACTORS	ALARM SPEED	SWITCH POSITIONS BANK 1	SWITCH POSITIONS BANK 2
.25	4 5 8 10	5.5	1 11	7 4 12
.30	4 6 8 10	6.6	1 6 12	7 4 12
.34	6 4 7 10	7.48	2 5 12	10 4
.38	4 6 8 8	8.36	1 6 12	7 3 12
.40	6 6 9 10	8.8	2 6 12	9 4
.42	4 5 8 6	9.24	1 11	7 2 12
.43	4 6 7 8	9.46	1 6 12	10 3
.44	8 5 9 10	9.68	3 11	9 4
1.61	10 9 7 8	35.42	4 9	10 3
1.69	6 9 4 8	37.18	2 9	5 3 12
1.71	8 9 7 6	37.62	3 9	10 2
1.75	6 7 4 6	38.50	2 10	5 2 12
1.79	10 5 7 4	39.38	4 11	10 1
1.80	4 9 5 4	39.60	1 9	11 1
1.88	6 5 4 4	41.36	2 11	5 1 12
highest and lowest ratios available:				
.16	4 4 10 10	3.52	1 5 12	8 4 12
6.2	10 10 4 4	136.4	8 4 12	1 5 12

SWITCH POSITIONS FOR SECONDARY ALARM SPEEDS OUT OF THE NOMINAL 10 to 35mph RANGE.

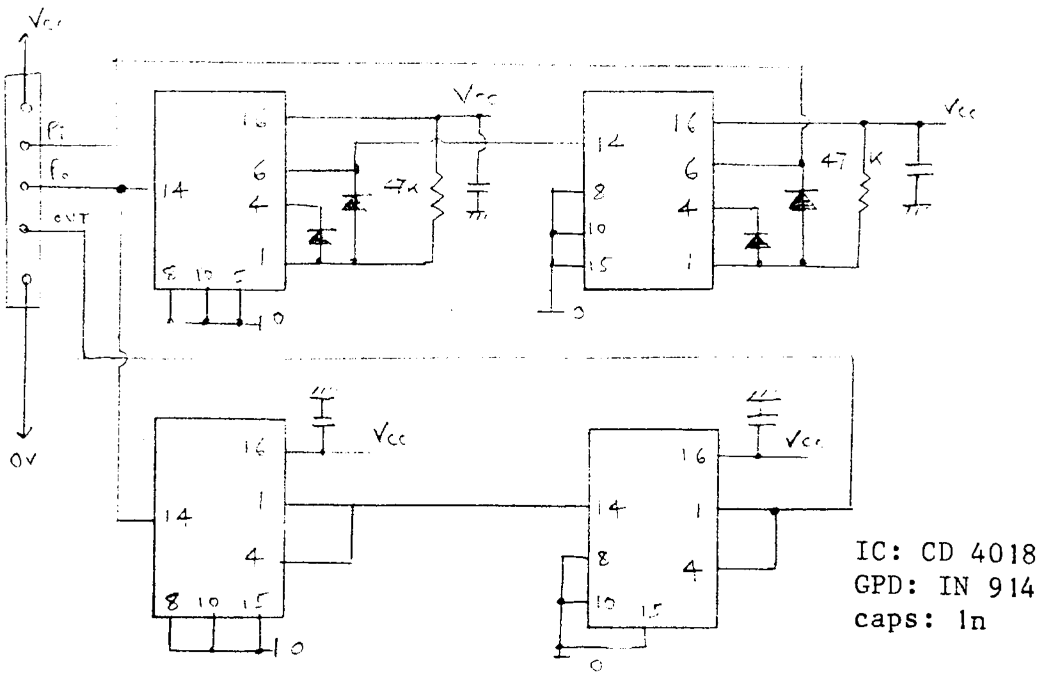
CIRCUIT DIAGRAM FOR THE FULL CONFIGURABLE SPEED SENSOR.

FIG



ALARM SPEED	GROUP			
	W	X	Y	Z
	W and:	X and:	Y and:	Z and:
9.8	G,D			
11.0	C,H			
12.6	C,F			
13.2		D,H		
14.6	B,H	G,D		
16.5		C,H		
17.6	B,E		D,H	
18.9		C,F		
22.0			G,D	D,H
24.4	A,H	B,H	C,H	G,D
25.1				
26.4		B,E		
27.5				C,H
29.3			B,H	
31.4				C,F
33.0		A,H		
35.2			B,E	
36.5				B,H

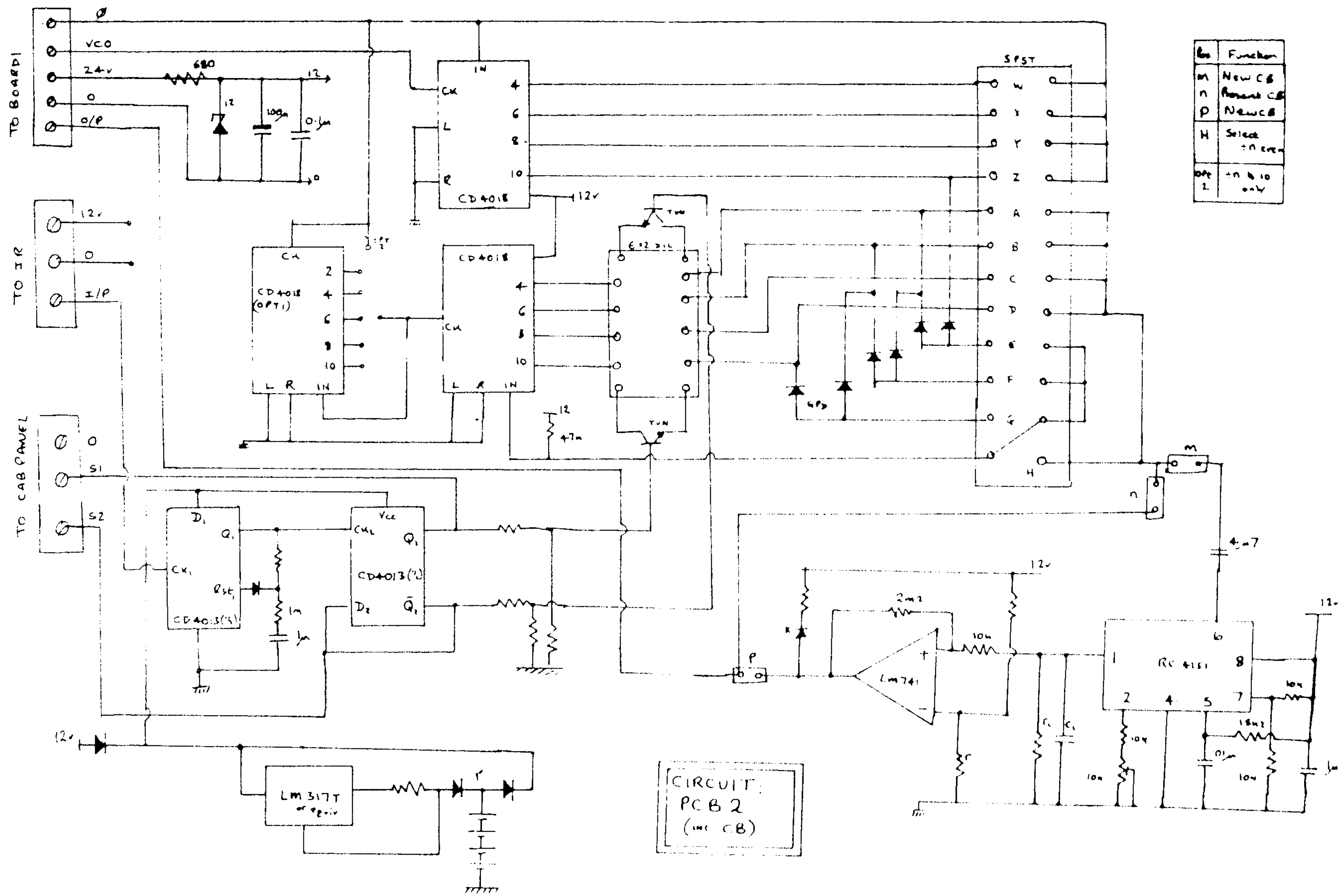
SPEED SETTINGS AND CORRESPONDING SWITCH POSITIONS. FOR REMOTE SWITCHING, SPEEDS CAN BE SELECTED BETWEEN ANY TWO SPEEDS IN ANY ONE SWITCH GROUP. Nominal 22mph alarm speed assumed.



IC: CD 4018BE
GPD: IN 914
caps: 1n

Frequency Translation Module (FTM). Ratio of 15/16 (0.938)

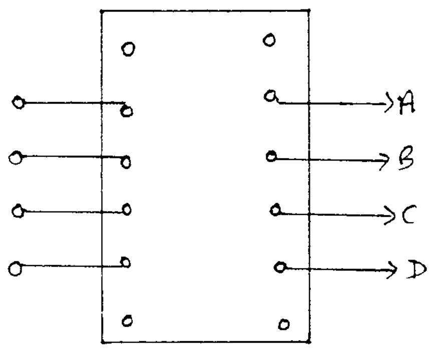
FIG 6


TO BOARD1
VCO
24v
0
O/P
680
TO IR
12v
0
I/P
TO CAB PANEL
0
S1
S2
CD4018
CD4018 (OPT1)
CD4013(½)
LM317T or equiv
LM741
RC 4151
SPST
W
X
Y
Z
A
B
C
D
E
F
G
H
12v
4n7
2m2
10k
10k
1m
47k
Sw Function
m New CB
n Present CB
p New CB
H Select ÷n even
Opt 1 ÷n & 10 only
CIRCUIT: PCB 2 (inc CB)

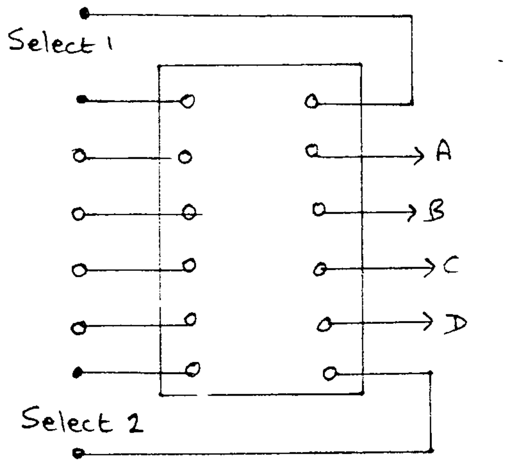
REMOTE SWITCHING

Any simple remote switching system has only two states. Thus, means must be provided to preset the frequency translation ratio for each state. This is achieved by providing a 12pin header plug which is placed in a 12pin socket. The plug connections thus determine the selected ratio by selecting which two divider lines are connected, and which is to be enables at power-up. In order to alter selected speeds, it thus is merely a matter of substituting apperoriately wired plugs.

For hardwired use:

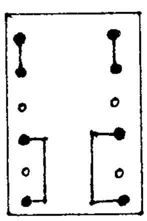


For remote switching use:

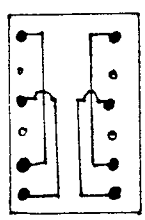


The 'select' lines are connected to the appropriate divider lines, with 'select 1' being power-up default. For example:

ratio multiply by 4 and 8, 4 on power-up:

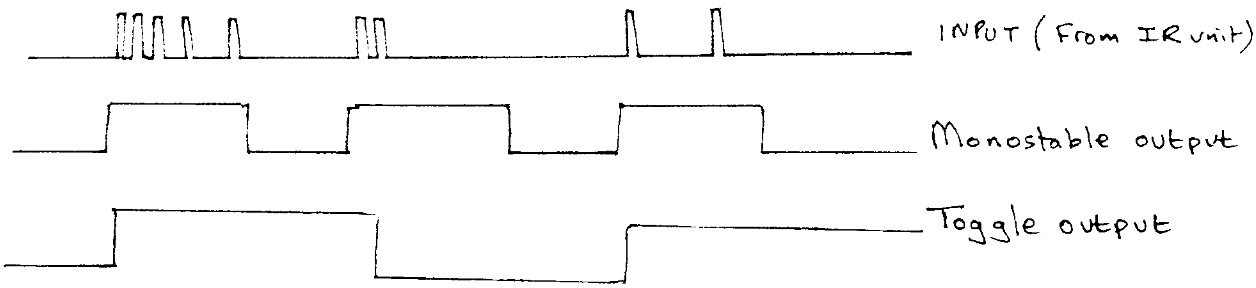


ratio multiply by 6 and 8, 6 on power-up:



Thus the speeds available are as tabulated overleaf. Selected speeds must be chosen from any one grouping. The means of switching selected alarm speeds can only, for reasons of practicality, be infrared or ultrasonic. The latter has problems in that vehicular engine noise contains significant components in the 20 to 40 kilohertz range: the range normally used (although the Polaroid units operate at 50 to 60KHZ and may be immune to such oise: if time permits, suitable development work will be carried out). For the prototype a pencil-beam reflex infrared unit was chosen.

Switching of the unit is achieved by using a prism reflector in the beam path. Thus, in a practical situation, the switching signal will consist of a sequence of irregular pulses. A monostable and toggle switch is thus required, ie

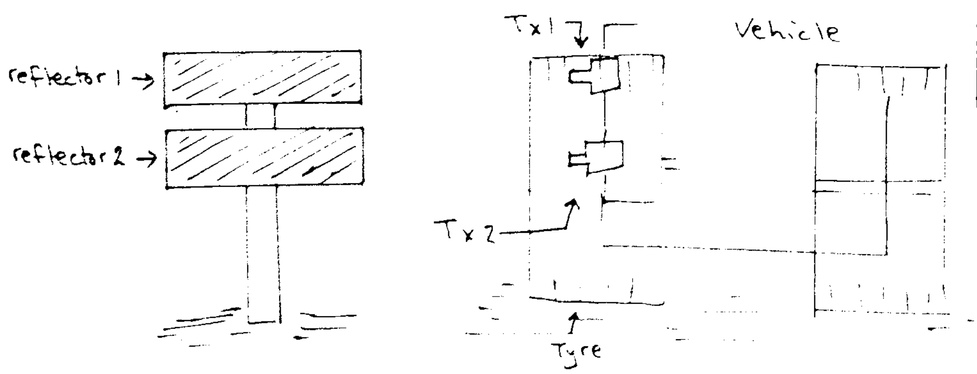


A dual 'D' flipflop suits this application well. The circuit diagram is given overleaf.

A more conceptual problem is that of switch-on reset. When power is removed from the circuit, it will reset to the indicated alarm state (normally the lower speed) as indicated by the switching arrangement. Thus, if vehicle ignition was turned off whilst the circuit was set in the higher state, the vehicle would be incorrectly sanctioned upon switch-on until it passed out of the higher limit area, through the adjacent lower area and back into a higher area (which may be the one in which the ignition was switched off). Thus a memory is required. Fortunately the toggle flipflop is the only component requiring power backup. A suitable circuit is given overleaf, along with the other components. In this diagram the components normally found on the main control board are also shown, in preparation for the design of a version two of the control board.

For remote switching between more than two preset positions, two or more transmitters can be used at each point of switching. Such a physical layout may have the form:

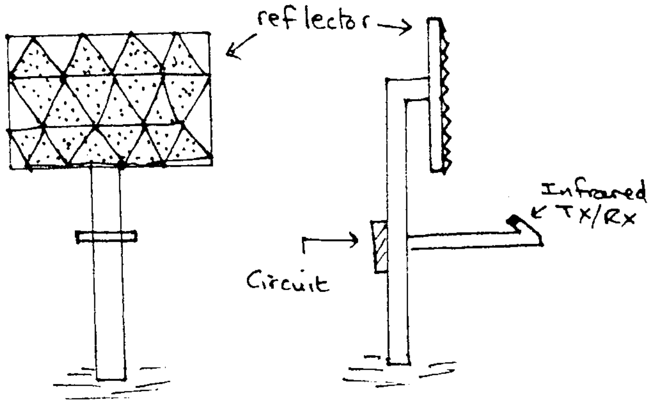
Tx_1	Tx_2	Sett
0	1	1
1	1	2
1	0	3
0	0	4



The use of more than two predetermined settings means greater complexity: the prototype thus caters for the basic binary switching only.

Details of the Infrared Unit

The response time of the IR unit selected (*1) is quoted as 50mSec. Thus for alarm speeds up to 30mph, 2.2 feet of reflector are required to ensure detection. This, then, is the minimum width for the reflector. The height is less critical: the limited suspension of off-highway vehicles means little variation in transmitter height occurs, whatever the load carried, or ground contour. Thus a height of 1.5feet is adequate. Alternative IR units (*2) have response times of 10msec, requiring smaller reflectors. It has been found that triangular reflectors used for trailers are ideal in this application, and cost only £1.60 per square foot. As thesystem is optical, it is essential to keep the transmitter and reflectors clean. Covering the prisms with glass gives a smooth surface, which has been found to be self-cleaning if left exposed to rain. For severe environmental conditions, an intermittent wiper could be powered from a lead-acid battery. A circuit that senses a dirty reflector and initiates a 'wipe' is not complex:



The logic senses when the reflector is dirty enough to prevent adequate reflection. Due to the close proximity of the sensor, it is possible to detect dirt before enough collects to stop the main transmitter functioning.

The transmitter can be placed near the vehicle petrol tank where it can then be cleaned at each fuel stop (where cab windows etc are cleaned regularily).

CIRCUIT DIAGRAM

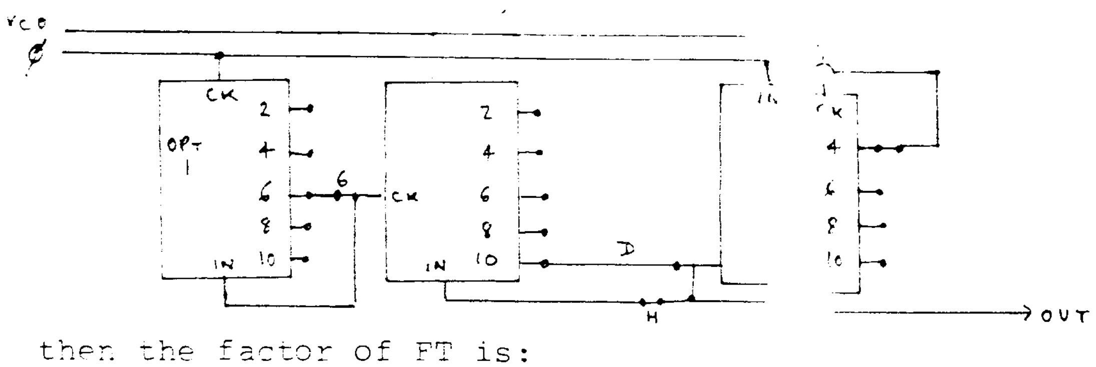
In the circuit diagram overleaf the following points should be noted:

1. The components found on the present control board are included (f/v and comparator). The FTM concept is not as necessary if such components are available, but for the foreseeable future these components will remain on the control board. Thus these components appear for completeness, and, in the event that the PCB is designed and produced on a production basis, to prevent obsolescence.

   The concept of following the f/v and comparator with an oscillator to simulate an alarm frequency was used in a previous report (INT P11A): the method is not ideal for reasons discussed in appendix 1.

   The switches m,n and p allow the appropriate topology to be selected: n made selects external components, m and p select internal ones. Obviously the former position allows the f/v and comparator components to be missed from the circuit board.

2. Two wiring options are shown: opt 1 and 2. The latter is for minor frequency translation (that can be coped-with by one set of dividers). Opt 1 allows further division to occur. If, for example, the wiring is thus:



   then the factor of FT is:

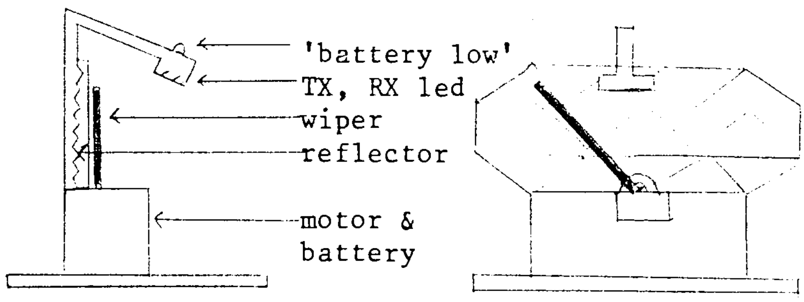
$$\times 4 : \div 6 : \div 10 = 1/15$$

3. Connections are shown for cab-panel indication of selected state (high speed zone or low speed). For a single predetermined alarm speed, the lower indication will be permenantly lit and the IP connections will be unconnected.

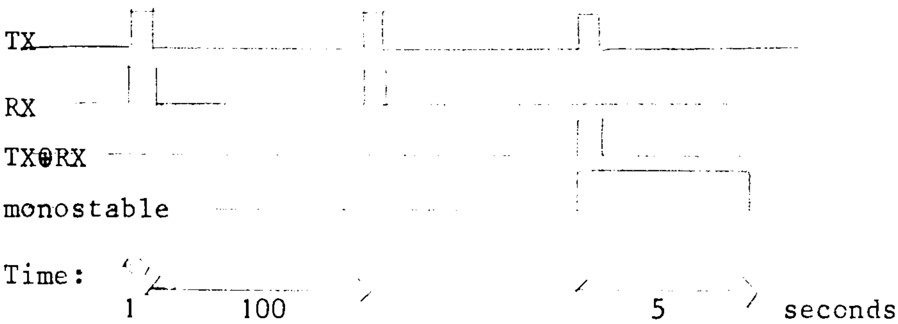
APPENDIX 1

The present circuit arrangement utilises two circuit boards, one containing circuitry to convert the radar returned signal into a rationalised squarewave pulse-train, and the other to convert the pulsetrain to ab binary alarm state. Further circuitry follows, but is of no relevance here. Hence, in order to seperate digital from analogue circuitry, and to move the second board function to the location of board one, the input to the new board two becomes a binary alarm state. It is, however, impractical to modify existing control boards in this manner: the servicing and repair of the units would present great difficulty as all units cannot be modified simultaneously, and large stocks of existing wiring looms and connections and circuit boards are held.

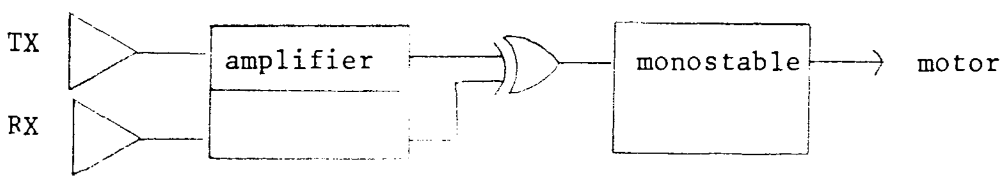
APPENDIX 2. Physical layout and timing diagram for a beacon (automatic wipe)



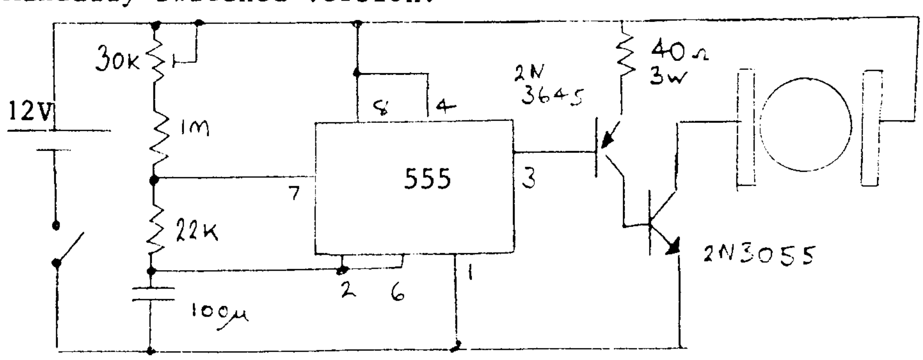
The TX and RX leds must be cleaned by hand, but are downward facing, so this need be performed infrequently.



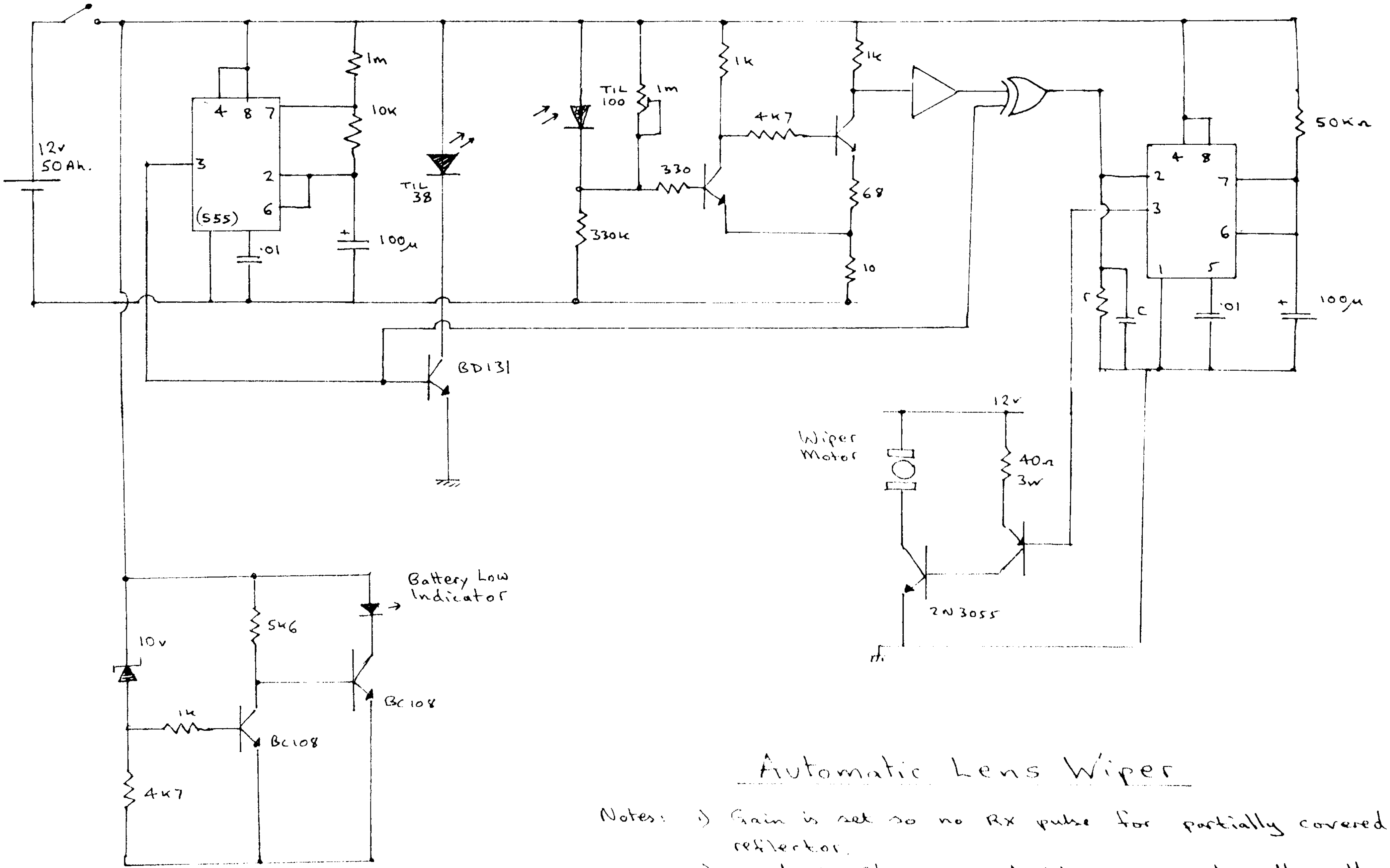
Circuit:



Manually switched version.

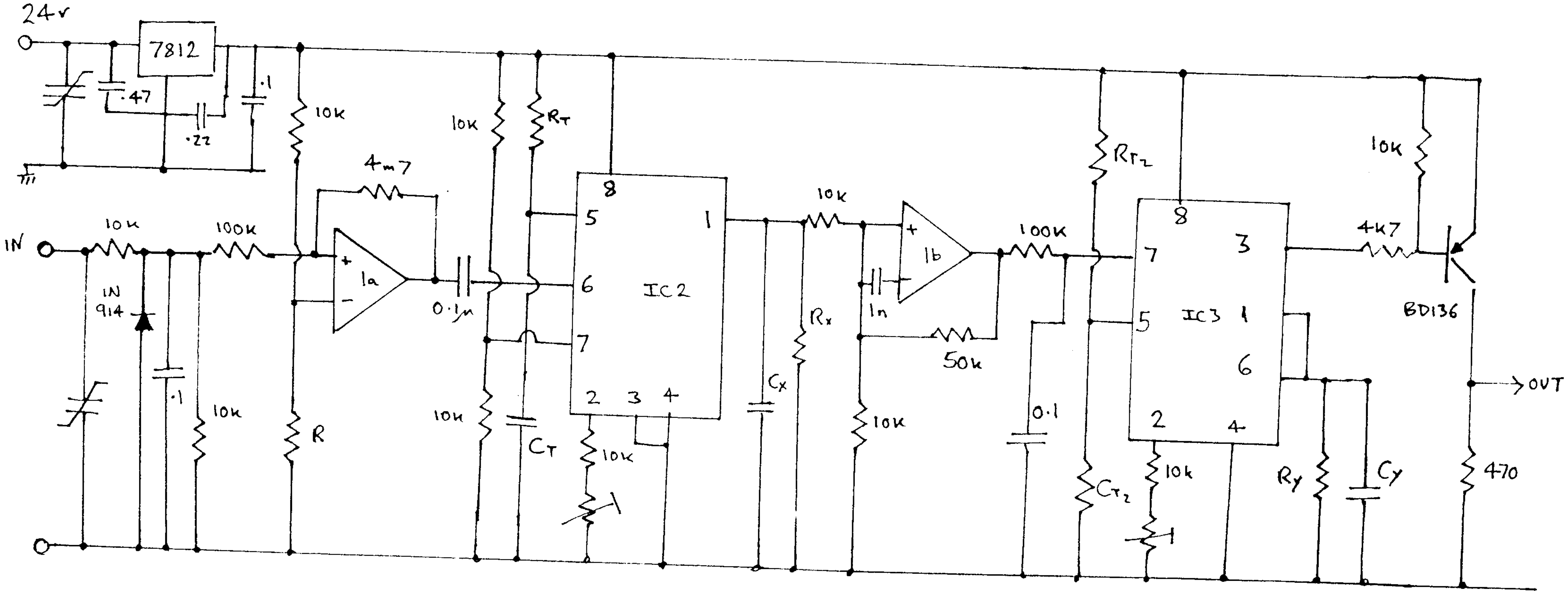


timer set to between 2 sec and 1 min. To be used only on very dry or very wet weather.



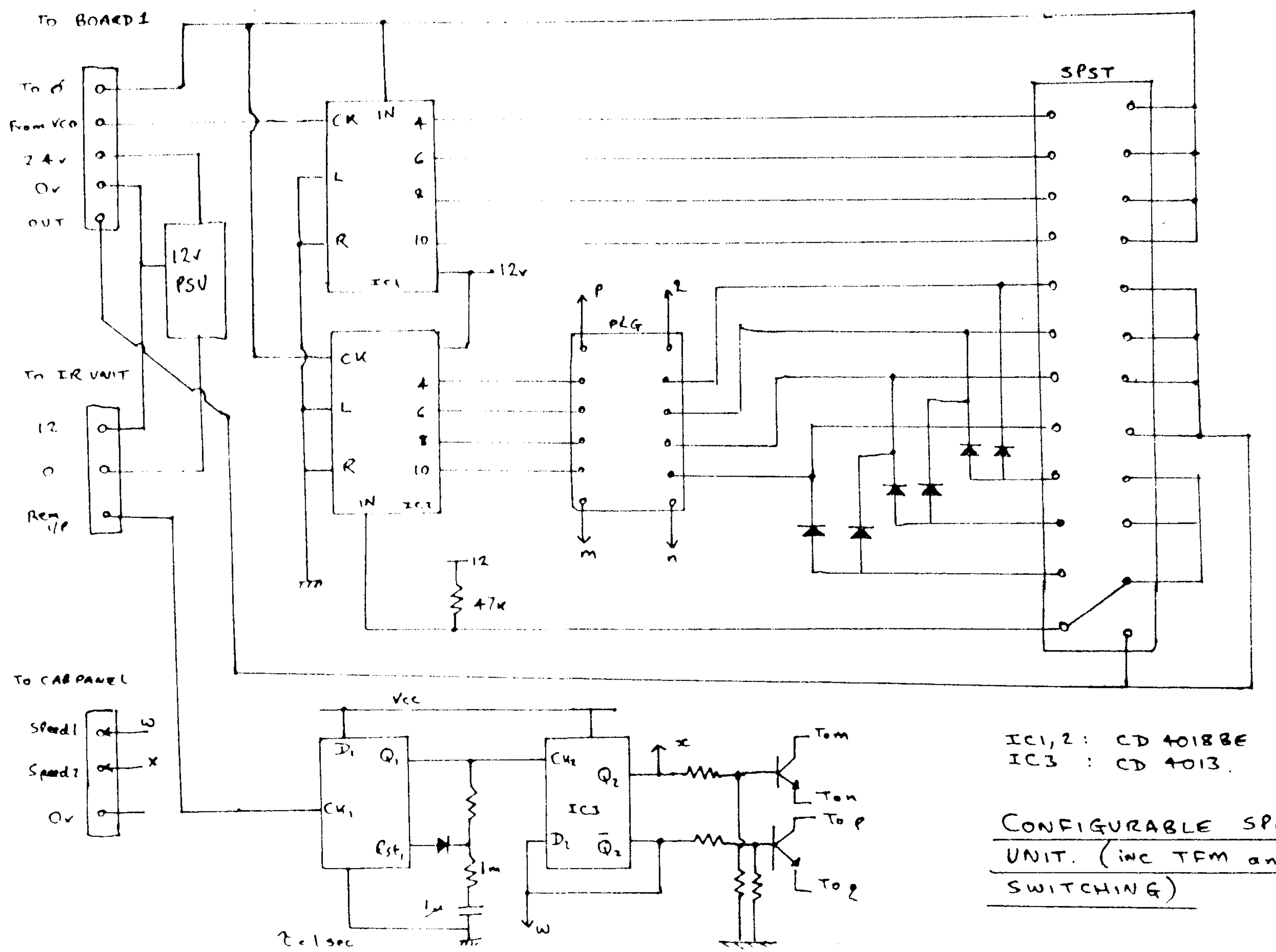
Automatic Lens Wiper

Notes: 1) Gain is set so no Rx pulse for partially covered reflector.
2) r and c slow any decision so as to allow the Rx time to 'settle'.



IC 1 : LM324 or 747 or equiv
IC 2 : RC4151
R : Set trigger level
R_T, C_T : Set F/V slope
R_X, C_X : Set integrator i/p
R_{T_2}, C_{T_2} : Set Conversion
R_Y, C_Y : Set integrator o/p

FREQUENCY CONVERSION : SEMI-ANALOGUE



IC1, 2 : CD 4018BE
IC3 : CD 4013.

CONFIGURABLE SPEED UNIT. (inc TFM and REMOTE SWITCHING)

SECTION 2.9

REPORT INT P18
12.12.83
C. WALLACE

DESIGN AND EVALUATION OF AN ALTERNATIVE SPEED SENSOR: HORN, CASE AND MOUNT.

CONTENTS

1. INTRODUCTION:
   - A INTENTION
   - B BACKGROUND
   - C METHOD SELECTED
2. DESIGN CONSIDERATIONS:
   - A BEAMWIDTH
   - B POLARISATION
   - C LENS
3. DESIGN:
   - A LENS
   - B HORN
   - C CASE AND MOUNT
   - D ANTIVIBRATION MOUNTS
   - E MICROWAVE UNITS
4. APPENDIXES:

INTRODUCTION

INTENTION

This report is intended to document and summarise the work performed on microwave antennae and horns, and unit mountings. The present unit has failings of a mechanical, microwave and geometric nature. These failings, and their effect on the speed sensor system as a whole, are covered in brief. A new microwave unit is suggested, and a preliminary assessment is reported. The prime factors in the design process are covered: notably the compromises of size/beamwidth, cost/performance and compatibility/novelty.

No mathematics is used: the equipment available for the work being inadequate to perform in any other manner than empirical experiment. To this end, the literature has been sifted in some depth to provide a theoretical background at this level.

Equipment available: Microwave power meter, HP 435A
Radar absorbing foam
Surplus microwave units

BACKGROUND

The beamwidth of a doppler radar determines the ease and accuracy of velocity measurement. For example, the fluctuation noise is proportional to the beamwidth (Wallace, P16):

$$\Delta f = \frac{2V\Delta\theta.\sin\theta}{\lambda} \qquad \Delta f \propto \theta'$$

This relation is in addition to the more obvious improvement due to increased power returns for any given radar-target range. The basic form of the radar equation is (Connor, 1972):

$$Pr = \frac{Gr.Gt.\sigma\lambda^2}{(4\pi r)^3.r^4} \qquad \text{where } \sigma = \text{ target area}$$

and $G = \frac{4\pi A}{\lambda^2}$ where A = effective aperture area.

For a doppler device, $Gt \simeq Gr \simeq G$, so $Pr/Pt = KA^2$ where $K = \frac{\sigma}{4\pi\lambda^2 r^4}$

Now K, for vehicular doppler velocity measurement, is often considered a constant, but:

1. σ is best defined as the 'radar cross-section', which is the effective target area as seen by the radar. Thus, the σ factor of a surface will depend upon the backscatter characteristics of the terrain.
2. The radar footprint has a defined area in terms of the -3dB power point of the transmitted beam. Reflections, however, are likely to occur from well out of this defined area: dependent upon the terrain backscatter characteristics and antenna beamwidth and sidelobe characteristics. A beamwidth definition at -10dB power would suffice.

3. The radar-target distance,r, is not constant: it will vary with terrain contour (large undulations), surface type (small undulations) and vehicular movement. These variations may be quite large, and as Pr/Pt $\propto$ reciprocal of the range to the fourth power, can have a significant effect on system capability.

Thus, gain and beamwidth must be maximised. This can be achieved in four possible ways:

1. Increase the transmission power. This does not increase power selectivity, and thus is not a true solution. Also the appropriate HMG regulations must be adhered-to (HO 14 and Wallace, P27)
2. Increase the effective aperture, ie increase the physical aperture dimensions by an appropriate scaling factor. This process has a limit (although in simple terms, the gain is proportional to the effective aperture): the increase in aperture can produce sidelobes of greater power density than on-axis. The optimum increase in aperture can be tabulated as follows (interpreted from Rhodes, 1948):

HORN FLARE (deg)	PLANE	HORN LENGTH FOR SIDELOBES OF POWER RATIO: (λ) 0	1/8	¼	½	¾	1
5	E	10	40				
10		4	16	45			
20		2	8	14	24		
30		1	2	4	12	14	18
40		1	2	3	7	8	10
50				3	4	5	6
5 to 50	H	minimal sidelobes....					

It can be seen that the flare angle or horn length cannot be increased indefinitely: sidelobes of 1/8 to 1/4 of the on-axis power are the maximum reasonable. Thus, the horn geometry is more critical than often stated.

3. Increase the effective gain (and decrease beamwidth) by using a lens. This topic is covered in a later section.
4. Increase the transmission frequency. This solution has drawbacks:
   a) HMG requirements stipulate 10.587 or 13.5to14GhZ only
   b) backscatter curves change, not necessarily for the better
   c) the ratio of Hz/mph changes. As the present system is calibrated for a specific ratio (31.Cos40, or 24.3), this relationship must be maintained as the control box is located remotely from the speed sensor unit. An alternative is covered in appendix 1.

<u>METHOD SELECTED</u>

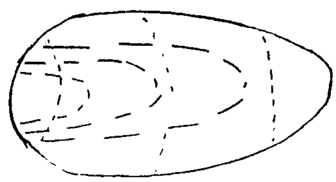
The best solution for any new design is an increase in frequency, an increase in power and an optimally designed horn and lens. This would allow a decrease in beamwidth and an increase in the predictability of ground return (and hence certainty of adequate return signal). Frequency and power modifications, however, require significant modifications, so although borne in mind, the rest of this report will concentrate in the design of a suitable horn and lens.

DESIGN CONSIDERATIONS

BEAMWIDTH

Graphical results of the effect of scanning noise and fluctuation noise, ΔS and ΔF have been presented in Wallace, P16. Briefly summarised, the smaller the beamwidth, the smaller the returned spectrum width for all angles (with the exception of 0 to 5 deg where scanning noise becomes significant). As $\Delta F \propto \theta'$, a narrow elevation beamwidth is desirable. As space for any new horn design is at a premium, the major horn design criterion is that of the largest horn size to fit within the maximum case dimensions. Thus, a beamwidth between 5 and 15 deg is a reasonable compromise, giving (for a 15 deg elev) a horn flare angle in the E plane of 30 deg, and length 6 . This will fit easily into a compact outer case. In the H plane the spectrum effect is much reduced, and a narrow beamwidth is not critical: reasons for this are presented later. The footprint width, however, must not be wider that the vehicle at, say, the -10dB point in order to eliminate signals from other passing vehicles or large reflective roadside targets. Indeed it may be reasonable to assume that within practical limits, a wide azimuthal beamwidth is at worst no disadvantage and at best an advantage. Consider the lines of equal doppler frequency within the footprint (often termed 'isodops'). Each line is such that constant velocity movement along it will produce a fixed doppler frequency. Thus, by definition, extending such a line will not increase the received spectrum. By extending the beam geometry and hence the footprint, a greater number of lines may be 'exposed', so attention must be paid to the exact footprint size and positions of isodops for any radar system geometry. A simplified set of lsodop lines will now be derived.

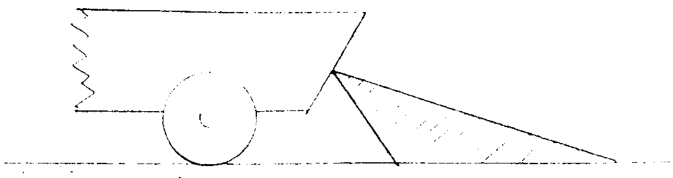
For a nominal 40 by 20 deg beamwidth (2 way -3dB power points), a section through the beam on-axis horizontally and vertically outside the Rayleigh region ($>2.d/\lambda$ where d = aperture diameter) looks thus:



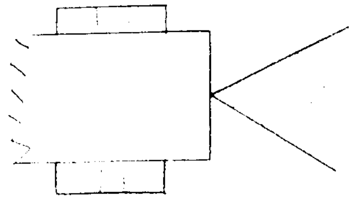
where ---- = lines of equal power

.... = lines of equal distance

The construction of isodops is rather harder. Consider the 2-D cases:

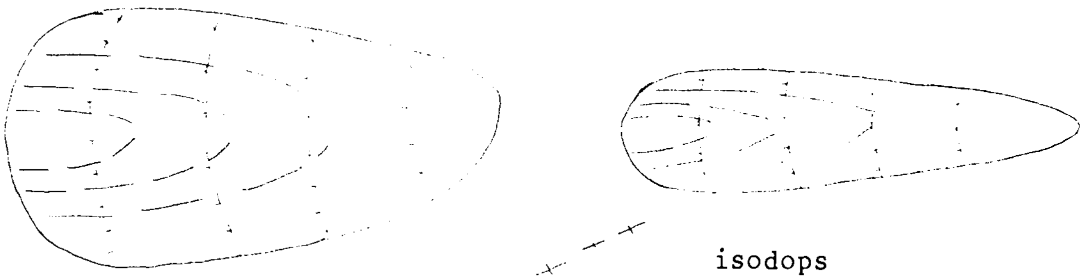


view from the side (infinitely narrow azimuthal beamwidth)



view from above (radar flat on ground)

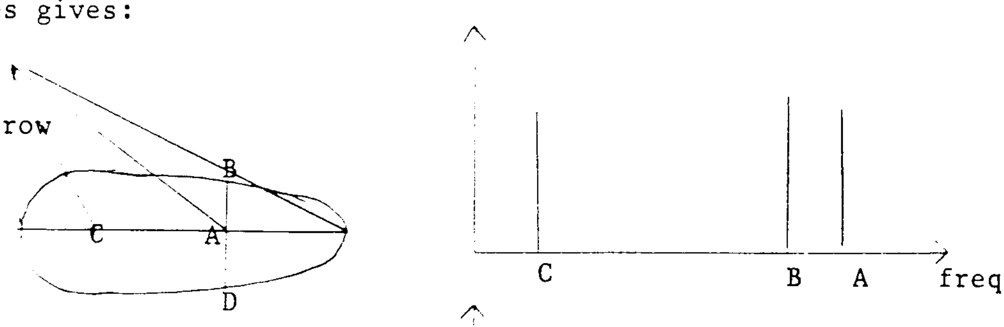
For any given beam vector, the doppler factor (32hZ/mph. Cos e.Cos h) can be calculated. By plotting a number of such points, the isodop lines can be drawn for the 3-D case. Plotting both isodops and equal power lines for both wide and narrow azimuthal angles gives:



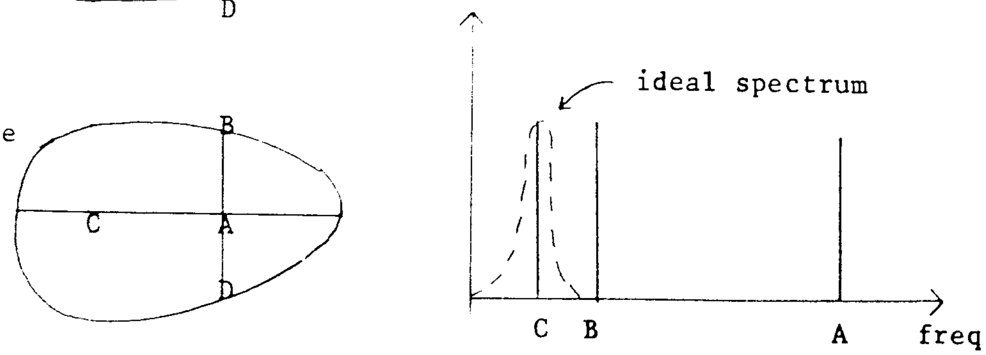
isodops

It can be seen that no benefit is derived as a result of the narrow beam-width case. It is also apparent that the max and min cos cactors for a 20 by 40 deg beamwidth and 40 deg tilt angle are: min: 20.6, max: 27.7 beamcentre: 24.5 (all on-axis). Thus, the widest portion of the footprint is far nearer the nominal beamcentre than either the inner or outer edges of the footprint. Consider the effect on the received spectrum of widening the azimuthal beamwidth: taking a cross-section through the footprint in both cases gives:

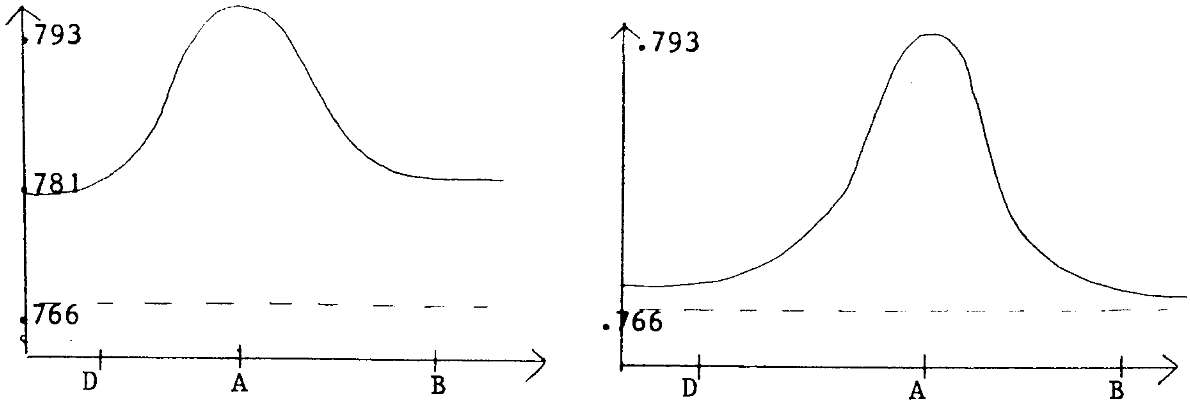
for a narrow angle



for a wide angle

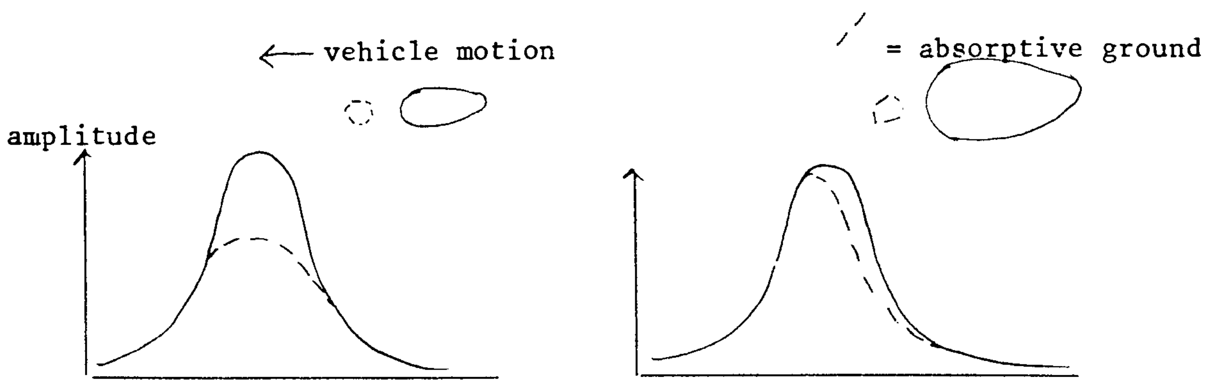


In the wide angle case, the spectrum from point B is nearer to that from point C. Thus the spectrum is less spread. Taking a section across D to B gives the following spectrums (0.766 is the nominal centre frequency and hence the r4quired frequency).



where the Y axis is $\cos\theta_e.\cos\theta_h$. It can be seen that the wide azimuthal angle gives a spectrum nearer to the required nominal frequency.

The returned signal spectrum contains components derived from interference frequencies generated by sources such as vehicular motion, vibration, finite beamwidth, terrain contour etc, in addition to the nominal doppler frequency. By accepting return from a relatively long isodop line, the interference from certain causes is reduced. For a given source of terrain interference (for example, a very wet or dry area of ground smaller than the radar footprint) the interference effect of the spectrum is reduced both in terms of frequency deviation and amplitude modulation. The system uses time-averaging to render it relatively immune to such interference effects, but certain terrain configurations can still cause misinterpretation of returned signal. A large area of very good or poor reflective ground off-axis is capable of producing a spectrum bias. Consider both a wide and a narrow azimuthal beamwidth:



narrow beam   wide beam

The narrow beam produces a large decrease in returned signal which causes a spectrum shift towards lower frequencies, the wide beam produces a small decrease in returned signal and a smaller shift.

However. There do exist practical constraints to the azimuthal beamwidth. To ensure that the beam at its widest point does not cover unwanted areas of roadside or reflect from passing vehicles, the width of the beam must be calculated. In tabular form: (calculated at the -3dB point)

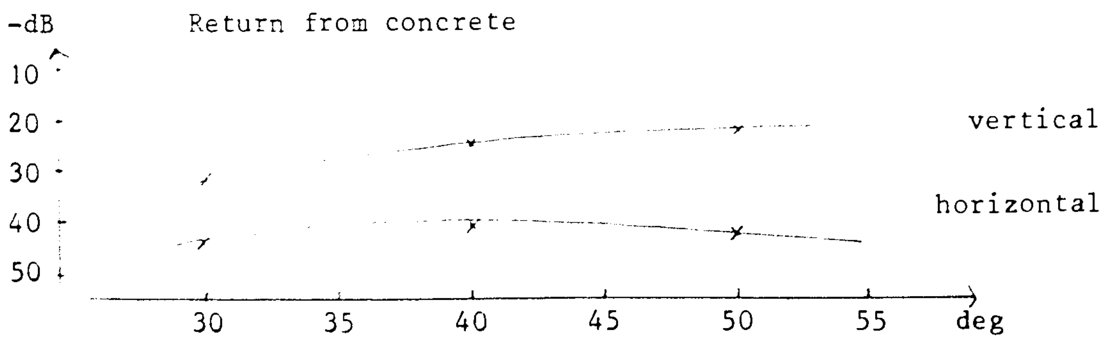
beamwidth	footprint width
10 deg	46cm
15	70
20	92
25	116
30	137
35	159
40	183
45	201
50	223
55	243

The width of a typical vehicle (Cat 777) is 4.7m. Thus the -10dB point of the beam width must lie within this width. The conversion from the tabulated -3dB values and the corresponding -10dB values depends upon the sidelobe distribution and amplitude, but assuming a factor of three, a beamwidth of 30 deg is the maximum useable. In the H plane, sidelobes are almost immeasurable and hence can be ignored.

From the horn design chart (given later) it can be seen that a horn must have greater dimension in the H plane by a factor of 1.6 over the E plane dimension for equal elevation and azimuthal beamwidths. Thus, the latter very much influences the final size of the horn, and thus of the complete sensor unit. The wider this angle, the more compact the design. Such an angle also allows the dielectric lens (covered later) to be of simpler construction by not being curved in the H plane.

POLARISATION

The literature review covering backscatter effects delves in some depth into the effects of polarisation of electromagnetic waves striking terrain (Wallace, P8). On the basis of this review, vertical polarisation has been selected since this allows the E field vector to be vertical, thus providing a statistically greater power return from terrain, due to the E vector being uniform over the horn aperture (for the H plane the field varies sinusoidally) (ref Gandhi, 1981, sect 5.6). Vertical polarisation also provides a narrower beamwidth in the elevation plane. For completeness, a typical backscatter curve will be reproduced here (ref Wallace, P4):



Thus it can be concluded that a wide azimuthal beamwidth and vertical polarisation give the best compromise for this project's horn requirements.

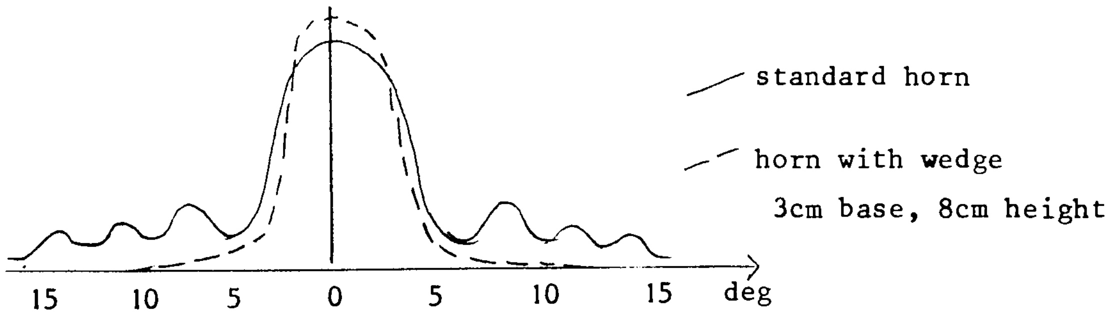
HORN AND LENS DESIGN, TEST AND EVALUATION

Much literature is available to assist in the design of microwave horns. For the purposes of this project, gain and beamwidth do not need to be accurately defined, so approximations to rigorous design equations suffice. Such simplified design criterion are tabulated averleaf. It can be seen that in general a pyramidal horn suits the project needs. The dimensions selected for the test unit are given in the appendix; and the measured performance of this unit compared with the approximate design equations looks thus:

	design intention	Terman 19	Southwark 1950	ITT &IMA 1956	MEASURED
Beamwidth E/H (deg)	15/30	18.8/33.5	20.3/28.2	18.8/35.6	14.5/29
Gain	less than 100,eg 90	36	42.8	72	70.3

No reference horn was available, so this table does not include an absolute gain measurement, but one relative to no horn being used. Taking this fact into account gives a gain nearer 80 to 85. Given the horn was constructed out of foil and cardboard, and the horn to unit mating surface was out of true by several mm (causing greater LO, swamping the required returned signal), these results are encouraging.

The horn dimensions selected allow a compact design to be realised, and the reduction in beamwidth over the ARO unit is useful. Suitable lens designs have been proposed earlier: unfortunately although one casting resin was obtained, no success was obtained casting the material into a hyperbola. A regular convex lens provided a beamwidth reduction, but was prone to surface irregularities, and would not possess the required predictability of performance. The dielectric wedge, however, worked well:



With such a wedge the horn design is indeed adequate. The second prototype was designed for a larger H plane beamwidth and smaller E plane whilst maintaining the same gain and sidelobe level. This design, however, was committed to casting. The results obtained were 12.5 by 35 degree beamwidth.

HORN SHAPE	OPTIMUM PROPERTIES	½ POWER BEAMWIDTH E PLANE	H PLANE	BEAMWIDTH NULLS E PLANE	H PLANE	GAIN
Pyramidal *1	$A = \sqrt{3.L.\lambda}$	53.b	80.a	115.b	172.a	$\frac{1}{2}.(4\pi/a.b)$
	$B = 0.81.A$ *2	50.b	65.a	$2.\ \sin^{-1} b$	$2.\sin^{-1}(3a/2)$	$10/a.b$ (*4)
	$G = 15\frac{1}{3}.L/\lambda$ *3	51.b	70.a			$7\frac{1}{2}.A.B/\lambda^2$
*5	$A = \sqrt{3.Lh.\lambda}$	(λ/d) rad	(λ/d) rad			$4.\pi/a.b$
	$B = \sqrt{2.Le.\lambda}$					
*6	$G(dB) = 10(1+\log a.b)$					
H sectoral	$A = \sqrt{3.L.\lambda}$	51.b	80.a	115.b	172.a	$0.63.(4\pi/a.b)$
E sectoral	$B = \sqrt{2.L.\lambda}$	53.b	68.a	115.b	172.a	$0.65.(4\pi/a.b)$
Conical *7	$D = \sqrt{2.8.L.\lambda}$	60.d	70.d			$0.52.(\pi/d)^2$
	$G = 20.\log(c/\lambda)$	30.d	50.d	$2.\sin^{-1}(1\frac{1}{4}.d)$	$2.\sin^{-1}(1\frac{2}{3}.d)$	$2\frac{2}{3}/d^2$

NOTES:
- *1: Southwark (1950)
- *2: Hosking (1973)
- *3: ITT
- *4: IMA
- *5 Southwark (1950) and Hull (1974)
- *6: Jasik (19)
- *7: King (1950)

A = x direction horn aperture. a = wavelength/A
B = y " " " b = " /B
D = dialmeter of " " d = " /D
L = length of "
G = gain of horn
beamwidths in degrees.

SIMPLIFIED HORN DESIGN CRITERION. Derived from standard texts (see notes, and Terman (19). For a more complex treatment, refer to Rudge et al (1983)

MANUFACTURER	REF	BAND	BW	SIZE	DIMENSIONS L	H	W	GAIN	WT	VSWR	COST	DEL
Unaworld (0494 444061)	110X	8.2-12.4	30/30	WG16	153	76	54	15		1.15		
	110XG	10-15	30/30	WG17	140	64	51	15		1.15		
	699	"	30/30	UG39/U	153	76	54	15		1.3		
	7599	"	30/30	WG17	140	64	51	15		1.3	294	16
	861	10-12	30/30	WG18	145	115	74	15		1.2	720	14
Mid Century (01 688 0203)	MC16/31	8.2-12.4	50/50	WG16	70	44	32	10			83	10
	MC31A	"	32/32	"	162	70	52	15			90	10
	MC31B	"	20/20	"	273	127	95	20			195	10
	MC17/31	10-15	50/50	WG17	64	32	25	10			83	10
	MC31A	"	32/32	"	117	53	38	15			90	10
	MC31B	"	20/20	"	193	90	67	20			195	10
Mullard (01 580 6633)	ACX01	9-11	30/30	UG135	135	76	53	16	1.2	1.2		
Microwave Assoc	86550	8-12.4	70/30	UG39U	190	178	60	12			30 (100)	10
	86551	"	25/25	"	76	89	76	17			18 (100)	10
	86554	"	70/30	"	190	178	60	12			29 (100)	10

PROPRIETARY HORN UNITS FOR NOMINAL 10 and 24gHz BAND FREQUENCIES.

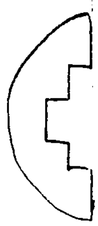
NOTES: 1. All dimensions in mm, wieghts in Kg
2. frequency in GHz: Size is waveguide reference according to RCSC
3. Cost in pounds. Figure in brackets is minimum delivery charge

MANUFACTURER AND TEL. NO.	REF	BAND (Ghz)	BW E/H	SIZE	DIMENSIONS L	H	W	GAIN (db)	WT (kg)	VSWR	COST (£ exv vat)	DEL (wks)
Microwave Assoc. (Dunst 601441)	86552	18-26.5	30/20	UG595	43	47	36	17			33 (100)	10
Flann (0208 3161)	202410	17.6-26.7	57/57	WG20				10				12
	202415	"	32/32	"				15				"
	202420	"	18/18	"	120	57	42	20	.14	1.2	100	"
Mid-Century	MC20/31	18-26.5	50/50	WG20	38	17	14	10			80	10
(01 688 0203)		"	32/32	"	67	28	21	15			90	"
	MC20/31B	"	20/20	"	111	51	38	20			190	"
Unaworld	K861	"		"	234	105	85					16
(0494 444061)	110K	"	30/30	"	70	37	30	15		1.2		"
	899	"	30/30	UG595				15		1.3	295	16
Scientific Atlanta (0462 31101)	12A-18		9/10	"	106	40	33	25	1.0		450	8
10GhZ HORNS:												
Flann (0208 3161)	162410	8.2-12.5	57/57	WG16				10		1.2	98	12
	162415	"	32/32	"				15		1.2	113	"
	162420	"	18/18	"	246	115	85	20	0.8	1.2	147	"
	172410	9.8-15	57/57	WG17				10		1.2	105	12
	172415	"	32/32	"				15		1.2	116	"
	172420	"	18/18	"	210	112	74	20	0.6	1.2	149	12
Marconi (0438 2311)	6036/4	9.4-12		WG16	153	82	78	17	0.3		49	6
Scientific Atlanta	12/8.2	8.2-12.4	12/13	UG135	356	194	144	22	2.0		405	8

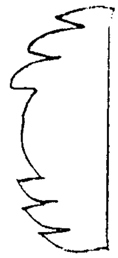
LENS / ANTENNA DESIGN

The dielectric lens is a simple and low-cost method of reducing horn beam-width and increasing gain. Types considered are full and stepped lenses, and fork and point antennas. In the former, the beam is either focused or made parallel in a manner analagous to an optical lens. Thus, the shape is easy to calculate: the calculation appears in the appendix. It can be seen that the lens shape is a hyperbola, with a maximum thickness dependent upon several factors. The zoned, or stepped, lens has a similar equation defining its shape, but is an ellipse. Whilst zoning reduces weight, complex moulding techniques must be used for manufacture. Silver (1949), Fradin (1961) and Jasik (1961) cover this technique in depth, but as the TRW unit uses a zoned lens, it is worth noting the shapes produced:

nonrefracting zoning

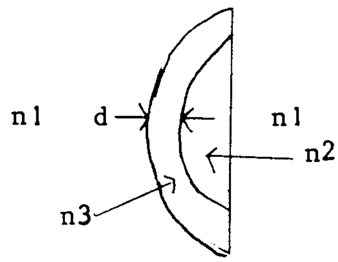


refracting zoning



Both designs are feequency-sensitive, which, whilst being adequate for unmodulated doppler radar, creates problems of accurate moulding. Both full and stepped lens types both reflect transmitted signal, and as the intended microwave unit uses direct mixing of transmitted and reflected signals to derive beat frequencies, the reflection must be considered. The reflection amplitude can be reduced by coating the inner surface with a dielectric layer ¼ thick (Marita, 1956, Jones, 1957 and Collin, 1955) such that:

$$n3 = \sqrt{n1.n2} \quad \text{and} \quad d = \frac{\lambda}{4.n2}$$



Suitable dielectric resins are available, and are tabulated. By increasing the curfature of the lens it is possible to focus the microwaves. This is is not ideal for a variable radar to target distance, and may be expected to produce results worse than for no lens, due to the widely fluctuating footprint area. A focused system is also inadvisable on grounds of satety: this is explained in Wallace, P27, but in brief, the power density of such a system can exceed safe levels of microwave radiation.

The design equations presented in the appendix allow, for an optimum maximum thickness, the required dielectric fonstant of the material can be canculated. For example, for a thickness of 3cm and aperture of 8cm, a dielectric constant of 3 is required. The table of suitable dielectric materials indicates that Stycast 1266 is ideal. Stycast 0005 and Hi-K are alternatives, but cost £130 and £160 respectively. The lens shape for Stycast 1266 appears in the appendix.: this lens is shaped in the E plane only. Reference was made earlier to impedance matching by lens coating with a material of suitable dielectric constant. For a cast lens, an alternative is ¼ wave slotting (Du, 1976). The calculations, however, are rather complex. Lazarin (1979) discusses fresnel lenses: such a design would work well, but is bulky and does not present a waterproof surface to the environment.

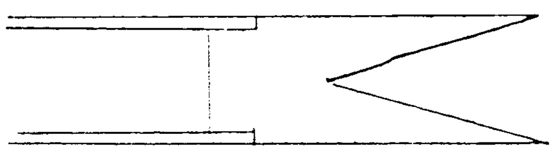
Most researchers assume the lens is used with the curved surface facing inward, thus giving a compact external dimension. Egawa (1982), however, gives results for horns with no lens, inward and outward lenses:

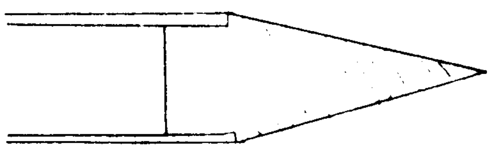
θ : E plane			θ:H plane			%error in velocity reading			gain (rel dB)		
N	L	R	N	L	R	N	L	R	N	L	R
20	20		20	20		8	6		0.4	0.4	
35	17	9	23	21	13	13	4	3	0.2	0.5	1.4
27	11	9	16	16	13	8	3	3	0.4	0.8	0.3
12	11	9	15	15	13	5	3	2	0.7	1.2	1.3

where: N= no lens, L+ lens, R= reversed lens

It can be seen that in general, outward facing lenses are preferable. Given, however, that the normal lens gives considerable improvement over a simple horn (and is more environmentally practical), this is the type selected for further evaluation.

The alternative to a lens is a dielectric aerial (as used by the ARO unit, and as described by Southwark, 1950, and Boulanger, 1970. Such an aerial was rejected on grounds of size, as a suitable 'fork' type would be over 20cm long.


Fork aerial (Boulanger, 1970)


point aerial (as ARO)

A technique not found in the standard texts is that of sidelobe reduction by use of an inward pointing wedge. This technique is cheap (as any dielectric foam will suffice), easy (as the shape is a simple wedge), and fairly effective. The major -3dB beamwidth points are not affected but the -6dB outwards points are significantly reduced in amplitude. In the absence of any textual details, the wedge shape for optimum performance was found by experiment. This shape is reported later.

PARAMETER		Stycast 0005	Hi-K	Ecostok GT22	Ecoseal W19	Stycast 1266	Ecofoam FPH 12.4	12.6	12.10
THICKNESS	(")	1/8,¼,3/8	¼,3/8,½	cast	cast	cast	cast	cast	cast
SIZE	(")	12 by 12	12 by 12						
DIEL. CONST	(e)	2.54	3 to 7	1.46	3.3	3.0	1.04	1.12	1.25
LOSS FACTOR	(*100)	.05	.2	.6	2				
WATER ABS	(%)	.05	.01	.01	.2	.2	3	1.5	.1
TEMP RANGE	(deg C)	-70 - 125	-65 - 110	-70 - 149		to 120	to 120	to 120	to 120
NOTES		adhesive £40	adhesive ECOSIL 1776			cure at room temp	room temp 4 hours		
						clear	light	medium	dense
COST	(£)	£95 for 1/8 by 12 by 12	£124 for ¼ by 12 by 12		£14/kilo	£14/kilo	£15/kilo	£15/kg	£15/kg

FEASIBLE DIELECTRIC MATERIALS FOR LENS (Manufactured products). Ref E & C.

Typical values for more common plastics can be found in Sams (1968), Keister (1968) and The supplementary report on microwave windows.

THE CASTING

Certain factors have to be considered in the production of an alloy casting. Those pertaining to the prototype harn and case design are given below

a) finish. The outside of the unit should look well-made, and the inside of the horn proper must be as smooth as is feasible. To this end, both the outside of the unit and the inside of the horn should be shot-blasted.

b) Inside of the horn. It is not known whether the horn should have a perfectly rectangular inner shape, or should have rounded corners. Propietary units are rectangular, so the prototype should follow this method. A radius of 2mm is a reasonable compromise between manufacturing ease and rectangularity.

c) The core-box should be split across the corners in order to avoid the seam along the side of the horn. The core should ideally be ceramic, although the high cost may prove a problem. The alternative is fine sand, with lacquer applications to the horn inner surface.

d) for the horn prototype a pattern built with wood is adequate. For the horn and case combined, a metal pattern should be used, to ensure longevity and accuracy.

e) Changes in section thickness must be avioded to ensure good alloy flow. Large solid sections suffer from shrinkage, possibly leading to bowed surfaces, so hollow out all such areas.

f) front face recess corners must be rounded to a large radius to allow machining.

g) The rear face of the horn must be machined to ensure good mating with the oscillator. Mounting holes, suitably tapped, should ideally be machined by the casting supplier

Suitable local casting companies were contacted for quotations for the horn assembly: Of the eleven seen,only two were suitable. For reference, the details of the companies are reproduced here:

COMPANY	TEL	AL	loff	PATT
Monkman		y	n	n
D. Harper		y	n	n
Smith & Fawcett		n		
Holcroft		n		
Hirst & Son		y	y	y
Yorks		n		
Rose & Parkins		y	y	n
Dawson		n	n	y
Frankcom		y	y	y
Hall & Botterell		y	y	n

AL: cast aluminium ?

loff: deal in small quantities

PATT: make, or arrange for patterns.

The two options; Hirst or Rose and Parkins/Dawson; were contacted for quotations. Hirst, who are also accredited to MOD DS05-24, were both cheaper and promised quicker delivery. Their quality was examined via non-selected samples, and seemed as expert as their staff who grasped the requirements quickly and correctly.

Casting Material. Several optionsare available. The conductivities of common casting materials are given overleaf. Copper is by far the best material (silver is not considered on financial grounds), but reference to the chart on 'practical considerations' shows copper to be,for HCC1 (the only copper commonly used for such castings), fairly soft. Thus, aluminium was selected. The LM25M presents a reasonable, and acceptable, compromise; being readily available, low in cost, has a fair machinability and excellent corrosion resistance.

In order to increase the conductivity of the horn inner surface, alternatives to copper were considered; namely copper spray and electroplating. The latter was proposed to several manufacturers: quantity cost would be around £2 per unit, and the **surface conductivity** would increase by 30% (Graham, 19.. and Silman, 1965) The effect of oxidation is not known: little literature exists on this topic, so gold plating was also considered. To summarise the appropriate parameters:

MATERIAL	THICKNESS (thou)	r (microhm)	NOTES
copper (MIL C 145500	class 0: 1-5 1 1 2 5 3 .02 4 .1	3.8	
silver (QQS 365)	.5	1.6	needs a 0.5thou nickel base
gold (MIL G45204)	class 1: .05 2 .1 3 .2 4 .3	2.4	needs nickel or silver base

references: Graham (19), Silman (1965), Matisoff (1982), Bogenschut (1974)

The added complexity and uncertainty of improvement in performance of any such coating was not considered worthwhile, at least for the present. The electroplating process is completely retrofittable, and will be reconsidered at a future date.

The main body casting can be constructed out of a new-generation material; plastic/metal mouldings (eg aluminium flake or stainless steel fibre are common examples) which are easy to mould, light and ensure high isolation of EMI effects. The cost at present is prohibitive, but is expected to decrease in future. (Ref: Dreger, 1983 and Transmet)

ALLOY		HARDNESS	MACHINABILITY	CORROSION RESISTANCE
AL	LM0	25	P	E
	LM4	70	G	G
	4T	105	G	G
	6	55	F	E
	25M	60	F	E
	25TE	70	F	E
	25TB7	65	F	E
	40E	105	G	E
CU	HCC1	45	F	G
	PB1	70	E	G
	PB3	70	E	G
	LB1	65	E	G
	LG2	60	E	G
	LPB1	70	E	G
	G1	75	E	G

KEY:

P: poor

F: fair

G: good

E: excellent

Hardness:
Brinell rating

CASTING ALLOYS: PRACTICAL CONSIDERATIONS

CONDUCTIVITY *1 (%)	MATERIAL	REFERENCE *2	BS REF	NOTES
105	SILVER			
100	COPPER	c101-103	2871	
96	"	SC	3839	
95	"	HCC1	1035	
75	BRONZE			
70	COPPER	C106	2871	
60	CU/NICKEL			1%Ni
57		LM0	1490	
51	"	HT9	"	
48	"	HT30	"	
43	BRASS	CZ101	2871	70%br,30%Ni
42	ALUMINIUM	HT20	1490	
39	"	LM25M	"	
37	"	LM6	"	
36	"	NT4	1471	
35	"	HT15	"	
32	"	4,4TF	1490	
30	"	LM40E	"	
26	"	NT6	1471	
25	BRASS	CZ126	2871	90%BR,10%CU
25	NICKEL			
14	COPPER	LG2	1035	
13	"	LPB1	"	
11	"	G1	"	
10	"	LB1	"	
9	"	PB1,3	"	

NOTE *1. International Electromechanical Commission rating based upon the conductivity of copper: 1.7241micro-ohms.cm at 20degrees C, referred to 100%

*2 Casting reference code: based on BS 1490 (L spec: IEE DTD)

REFERENCES: Kemp (1968), Morgan (19), BS1490 (LM and PB series), Hirst.

CONDUCTIVITY OF COMMON CASTING MATERIALS, RANKED IN ORDER, AND REFERRED TO THE CONDUCTIVITY OF PURE COPPER.

MICROWAVE UNIT SELECTION

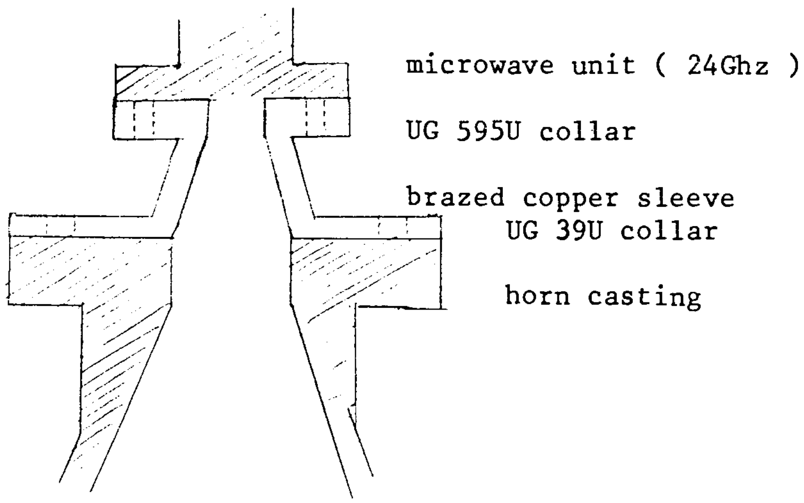
The selection of the unit is determined by the choice of redundant units available: these, with their major parameters, are tabulated overleaf. All are 10.5 or 10.6 Ghz. Mention was made in the introductory section of the benefit of an upward shift in frequency to 13Ghz (or if made legal, 24Ghz). Typical 24Ghz units are given below.

Of the available units the Mullard unit, of which the stocks are the greatest, is unsuitable on aperture termination grounds. The MA unit is small and light, but only two are held, and both failed under initial testing. The plessey unit, being somewhat more resilient to mishandling was chosen for the prototype.

24Ghz units

UNIT	MA86793	MA86859
TX (Ghz)	24.125	24.125
TX (mw)	5	5
Length (cm)	2	3.6
Termination	WG	WG
Gunn V	4.5 or 6.5	5
Gunn I (ma)	250	200

WG: UG 595U standard, ie not compatible with the horn design proposed earlier. an adaptor can, however, be constructed. A typical adaptor is drawn below.



PARAMETER		MA S6SC1 M09	PLESSEY GDHM2	IMA 5300 92	- ARO	MULLARD CL896C
Type	*0	DC	DC	SC	DIC	DIC
Temp range	deg C	-30/70	-20/55	-10/50		*10/35
Bias current	ma	120	125	150	350	165
Bias volts	V	8.5	8	8	8	7
TX power	mW	5-10	7	5	1.5	10
O/P harmonics	dBm	-35	-35			-40
Circuit noise	*6	30	25			
Mixer noise	*6	145	170		400	
Length	cm	4.17	5.73	4.6	5.5*5	4.6
Termination		WG*3	WG	WG	*7	non-std
Stocks	*4	3	20	10	0	30
Cost	*9	32/25	30/26	-/25	*8	32/-

NOTES:

*0: DC: dual cavity, SC: single, DIC: dual-independent
*3: UG 39U flange, W16 WR 90 waveguide
*4: as at mid-Nov '83, OEL
*5: excluding specialised mounting
*6; at fixed gain: comparative figure only
*7: waveguide termination; no mounting points
*8: narrow beam £43.50, wide beam ditto + £22 conversion
*9: cost in £ of one and 100
*10: max and min storage, -5/40 deg C only

SUITABLE MICROWAVE TRANSCEIVERS FOR THE X-BAND PROTOTYPE HORN.
Only easily-available units are considered.

HEAD	CURRENT *1	POWER *2	EFFICIENCY *3
Mullard	155	2.4	.075
Aro	95	1.45	.082
Plessey	150	5.4	.175
AMI	118	5.6	.241
MA sample 1	152	4.4	.140
MA sample 2	160	6.8	.204

NOTES:

*1: Total current consumed at 24V input, units are ma.
*2: Microwave output power in mW
*3: Defined as (Pwr o/P*100)/((total I-cct I)*24)
Circuit current: 47 ohm stopper resistor: 21ma
22 22
47 + PCB 2 33
Thus for 100% efficiency and 10mW o/p; 21.42ma in.
Cowley (1971) gives efficiencies for typical X band devices as an order of magnitude greater than the above.

POWER CONSUMPTION FOR GIVEN OUTPUT POWER: SIX AVAILABLE MICROWAVE UNITS.

ANTIVIBRATION PRECAUTIONS

There are two main considerations under this heading: AV mounts for the whole unit, to protect the microwave unit against certain shocks and vibration; and PCB mounting, to protect the circuit components.
At the present, the AV system is seen as a partial solution to two types of problem: extraneous frequencies produced around the required doppler signal (200 to 600Hz) and to damp shocks (0 to 100Hz). The latter are impossible to damp fully: the excursion of any AV mount would be significant, and would itself induce resonant frequencies into the measurement system. In the environment of the off-highway application, the shocks are of such severity to preclude such a 'large displacement' AV system. A limited travel mount only damps the eventual 'bottoming' of the unit onto either a rigid portion of the mount or some part of the case. To limit bottoming effects, the mounts should be made more rigid, although this prevents optimum handling of lower frequency shock. Thus, any mount system is a compromise.
For speed sensing, the overriding concern must be to eliminate interference frequencies similar to the required doppler signal: such frequencies are continuous, whilst shocks occur at intervals only. Although shocks will introduce resonance and signal modulation effects, these will not affect the spectrum peak frequency significantly, as this is time-averaged. The shocks will, of course, reduce the life of the mounts and of the microwave unit itself.
For 200 to 600Hz damplng, minimal displacement is required, and for a push-pull arrangement (4 mounts above, 4 below the unit), is easily achieved. This arrangement prevents shocks exceeding the maximum displacement rating of the mounts. The mounts also undergo minimal shear loading in this topology, in contrast to the ARO arrangement. As a design example: consider Metalastik 17/1377/1MN45 mounts used in push-pull with unit mass 3kg and isolation down to 45Hz (70% effective). In compression the load is 1.8kg, max deflection 0.65mm, actual deflection 0.22mm (for load on lower mounts of 0.5kg each, ie 3/(8/1.3). In expansion, load is 1.2kg, max defln 2.5mm, actual 1.2mm. Thus limiting compression to 0.5mm allows the unit to operate within its designed tolerance, and isolate down to 45Hz.
The PCB mount can either consist of a foam sandwich or plastic holding strips: both offer vibration protection. After extended trials it was found that either are adequate, and the latter technique is easier to implement. It also has the added advantage of better heat distribution.

CASE AND MOUNT DESIGN

The proposed horn unit differs significantly in size and weight from the ARO unit currently used. Thus, the case and antivibration mount system must be completely redesigned. Several factors must be considered:

a) serviceability: the unit should be capable of minor repair in the field, and of major repair in the workshop with a minimum of specialised facilities, tools and expertise.

b) longevity: the unit should be capable of withstanding vicious impact from all angles. Weight is not a consideration.

c) dimensions: the unit must be capable of fitting onto a vehicle using the conventional hole pattern, and locate correctly on the rear shelf. The case, preferably, will be the minimum size for the horn.

d) environmental security: the unit must be compeltely watertight, dust proof etc. The outer case must be metal (to shield EMI).

e) cost. The case is the single most expensive part of the design. The cost of casting and machining must be minimised.

f) construction: the microwave unit may require tuning: access must be provided for the tuning screw, and to the mounting stud positions.

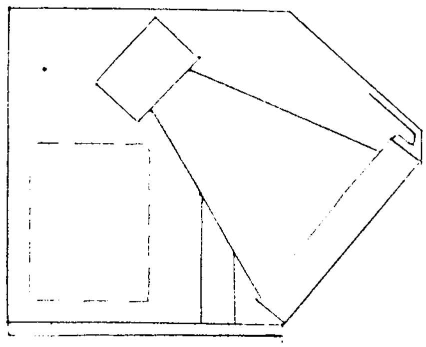
g) retrofitting of antivibration mounts of a different nature must be possible; thus the unit will suit numerous applications

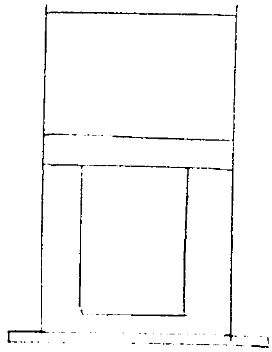
h) cleaning: the unit should not possess protrusions on the front face (dirt and grease may collect, reducing microwave effectiveness)

Several construction techniques are possible: the horn could be manufactured out of aluminium sheet, cast, even moulded plastic coated with a suitable conductive material. The case can contain the horn as one casting, or be made in seperate parts. The case can have fixed sides and removeable top, or vice versa, and so-on. In order to assess the possibility of utilising a propietary horn, all suitable manufacturers were contacted, and the relevant parameters tabulated for 13 and 24Ghz horns. None are suitable: the majority are reference horns of defined gain and beamwidth, with neither parameter matching this project's requirements.

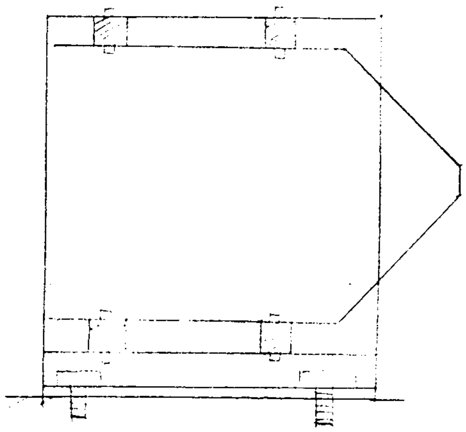
Several possible case designs were proposed: the major features of these can be found in the appendixes.

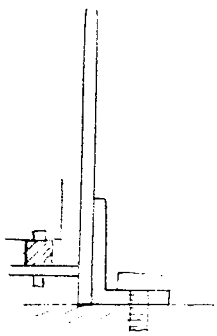
CASE DESIGNS. Several alternative designs were considered. Certain distinguishing features are noted here. Drawings are not to scale.

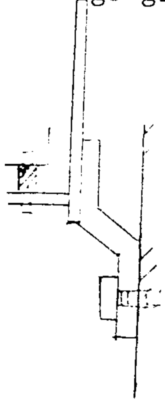




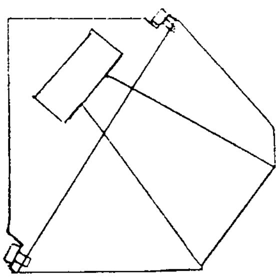
outer: one casting.
sides: aluminium
horn: cast independent.
pcb: mounted to rear.
av mounts: none, or plate type, sandwiched







av mounts top and bottom.
Adaptors for conventional or side-mounting.
outer cage gives protection



Two-piece: horn is part of the front casting. Sides can be seperate or inclusive. Gives good access to microwave unit and pcb. AV mounts can be as above.

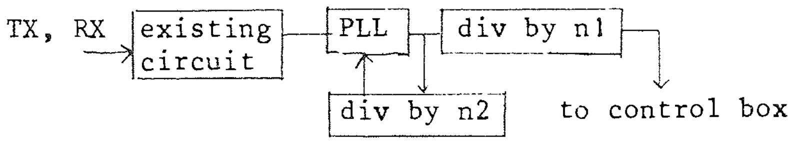
Drawing references:

ALO.203	:X band horn casting
ALC.X1.1	:prototype horn
ALC.X1.2	:prototype case: front
ALC.X1.3	:prototype case: rear and sides
ALC205.1	:production unit: horn and body casting
ALC205.2	:production unit: sides and rear casting
AL205.3a	:production unit: vehicle mount to fit existing holes
AL205.3b	: as above for 3 deg tilt brackets
AL205.3c	: as above but with new holes
AL205.3d	: as above with 3 deg tilt
AL205.4	:microwave window
AL205.5	: lens (wedge)

APPENDIXES

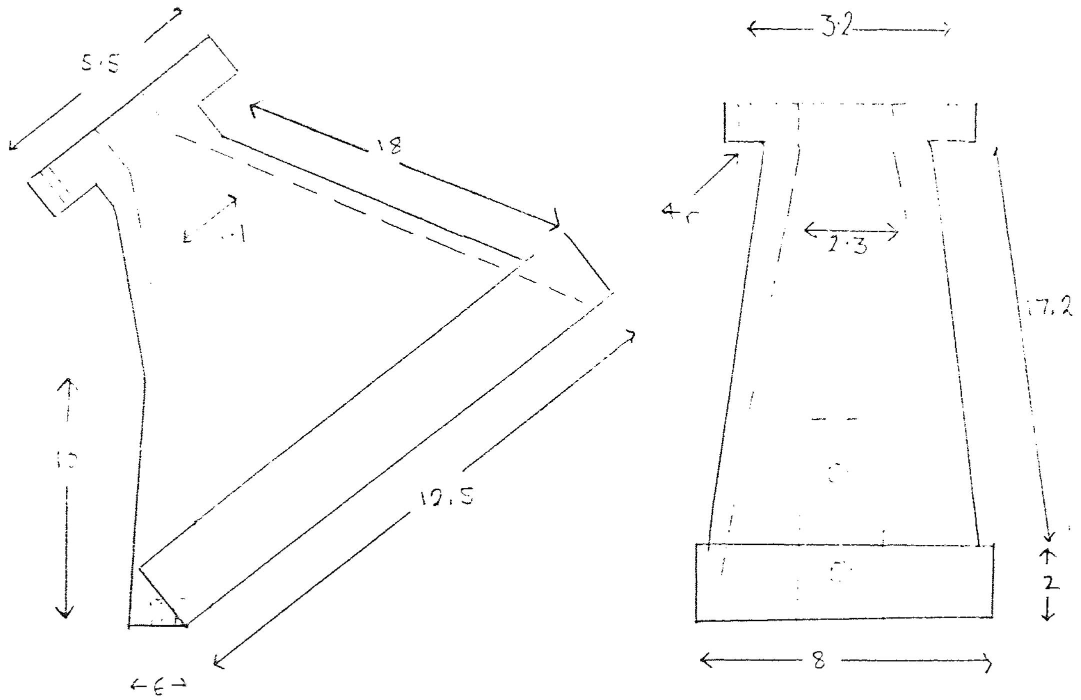
Alteration of transmission frequency but not scale factor.

The control box scale factor is set at 470Hz at 22mph at 10.587GHz TX frequency. Thus, the doppler ratio is 24.35Hz per mph for a tilt angle of 40 deg. The scale correction factor is 10.587/f G. To realise this factor, a PLL is used:

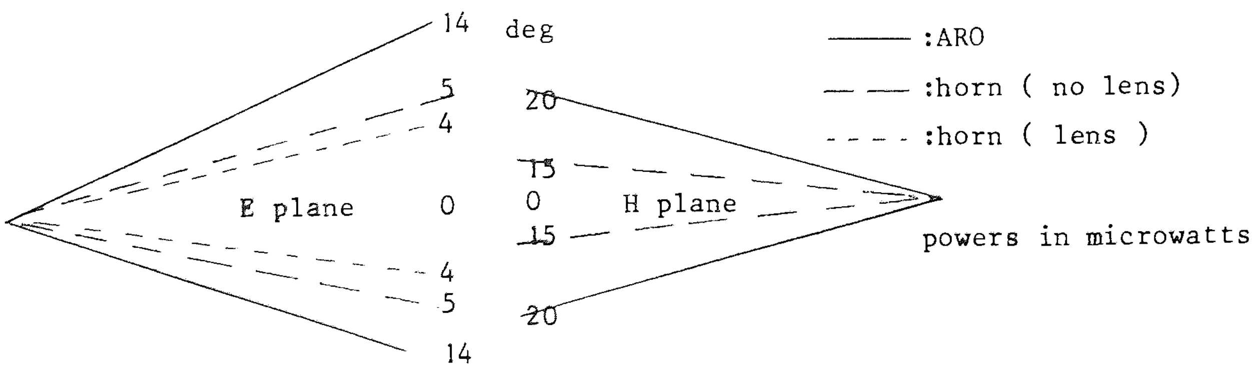


This design is covered in Wallace, P17. For 13.5Ghz, for example, K = 0.784 which is approximately 7/9. Thus n1=9, n2=7. For 24Ghz, n1=9, n2=4.

HORN DIMENSIONS: CASTING PROTOTYPE   not to scale. Flange type UG 39/U. Material: LM25. Drg ALC X1/1



BEAMWIDTH COMPARISON: ARO and prototype horn. Lines traced from polar plot paper



power/distance: ARO 4.4 @ 3m, 18 @ 1.5m. Horn 26 @ 3m, 48 @ 1.5m.

FREQ (Ghz)	WG DIM (mm)	OFFICIAL DESIGNATIONS BS&IEC	UK(RCSC)	US(EIA)	US(JAN)	COMMERCIAL DESIGNATIONS UK	DB	HP	PHILIPS(MRI)	TRG(NARDA)	NEW
8.2											I
10	23 by 10	R100	WG16	WR90	RG52	X1	G, Fa	X, M	X	X	
12.4	19by 9.5	R120	WG17	WR75							
15					RG91	Ku					J
18								N			
22	11by 4.3	R220	WG20	WR42	RG53	K2	E	K		K	
26.5		R260	WG21	WR34	RG53						K
33	8.6by 4.3				RG96	Ka					

From refs Transco, Marconi, IEEE 1976, Skolnik 1972, HMSO, Booth 1959, Harvey 1955.

<u>WAVEGUIDE DATA FOR 10.5 AND 24GHZ NOMINAL FREQUENCIES.</u>

LENS DESIGN.

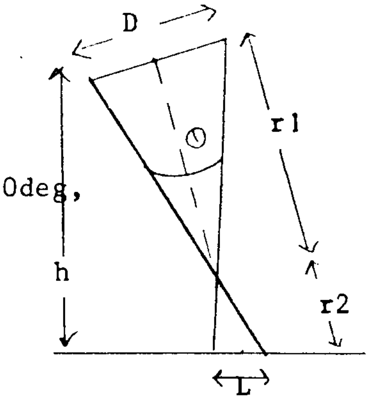
$$L1 = \frac{(n-1).L}{n.\cos\theta - 1}$$

n = refractive index
L = axial length
L1 = arbitary beam length at angle θ

$$t = \frac{-f}{n+1} + \sqrt{\left(\frac{f}{n+1}\right)^2 + \frac{(D/2)^2}{n-1}}$$

where t = maximum lens thickness
f = focal length
D = aperture diameter

(from Fradin, 1961)



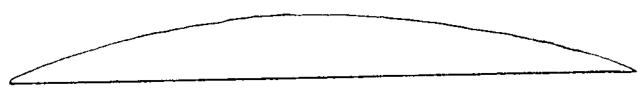
for a focused beam, $r = r1 + r2 = \frac{h}{\sin\theta}$

and D/L.Sin   = r1/r2

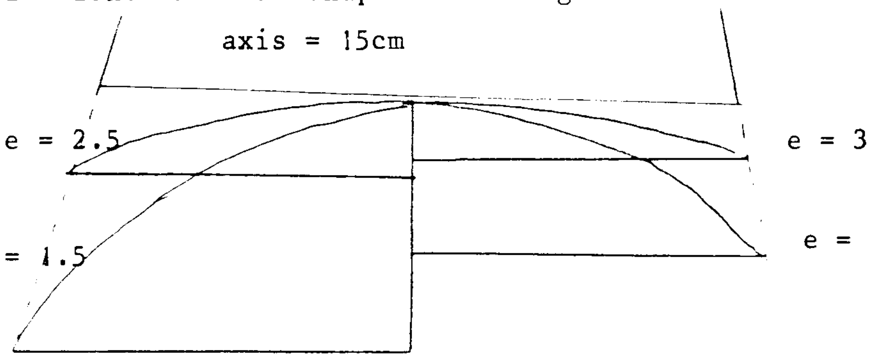
for footprint of 3cm (D=9cm, h=2m,   =40deg,

beam angle θ = 2.1 deg

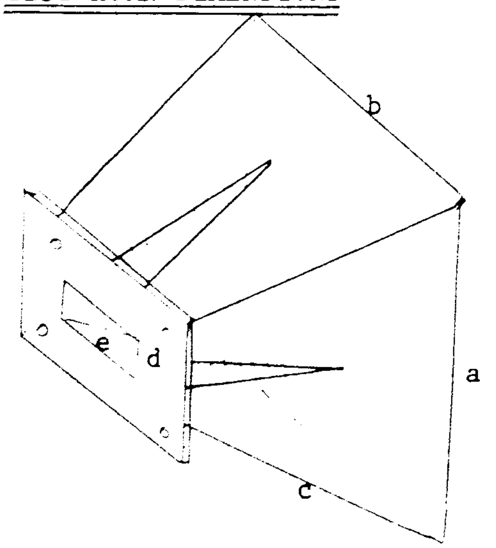
For an axial length of 15cm and aperture of 8.5 by 5.5cm, the shape for a lens of refractive index 1.73 (ie Stycast 1266) is, full size:



For the same lens the maximum thickness is 0.71cm. This lens falls within this criterion. The lens shape for a range of dielectric constants is thus:



TEST HORN DIMENSIONS



material: foil-covered card.
four strengthening ribs

dim: a 87mm
b 63mm
c 168mm
d 11mm
e 24mm

(inner angles, 30 by 22 deg ;
main axis 162mm)

SECTION 2.10

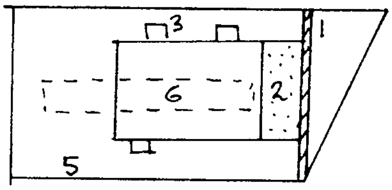
REPORT INT P19
13.12.83
C. WALLACE

AN EVALUATION OF THE ARO MICROWAVE UNIT.

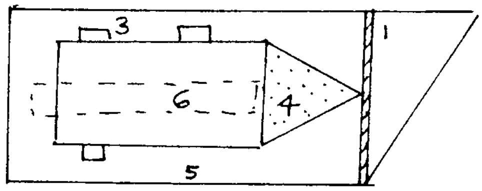
SECTION

1. BRIEF BACKGROUND
2. PRESENT ARRANGEMENT
3. EVALUATION:
   - A FAULTS AND SPECIFICATION
   - B PERFORMANCE
4. METHODS OF ALTERATION OF:
   - A BEAMWIDTH
   - B MICROPHONY/NOISE
   - C ANTIVIBRATION SYSTEM
5. CIRCUITRY

Aro Unit: Background. The ALBERT system in it's original form used a double-mixer doppler radar unit manufactures by ARO for man-detect (detection of targets immediately behind the vehicle). The microwave unit thus fulfilled the requirements of a relatively wide beamwidth and of direction sensitivity. The system was found, however, to perform unpredictably on a vibrating platform (the vibrations often being similar in frequency and greater in amplitude than the return from the objects to be detected). Thus, the microwave units were modified for another use: tip-edge detection. The required modification was the substitution of a dielectric 'lens' for the existing impedance matching stub:



original arrangement



modification

1: front face; 2: dielectric stub; 3: direction-sensing mixer;
4: dielectric horn; 5: outer casing; 6: rubber mounting strip

The success of this modification was not great (50% for Aro-modified units and 80% 'in-house'), but soon after the units were used for a different purpose: speed sensing. Thus the stocks of otherwise surplus units were gradually used up.

A typical specification for a modified unit was: power 1.3uw, beamwidth 28 elev, 42 azim. The original application used identical mounts to the present unit, but were mounted in the same plane as the shock and vibration. The mounting arrangement and electrical/mechanical parameters of the head unti will now be examined in greater detail.

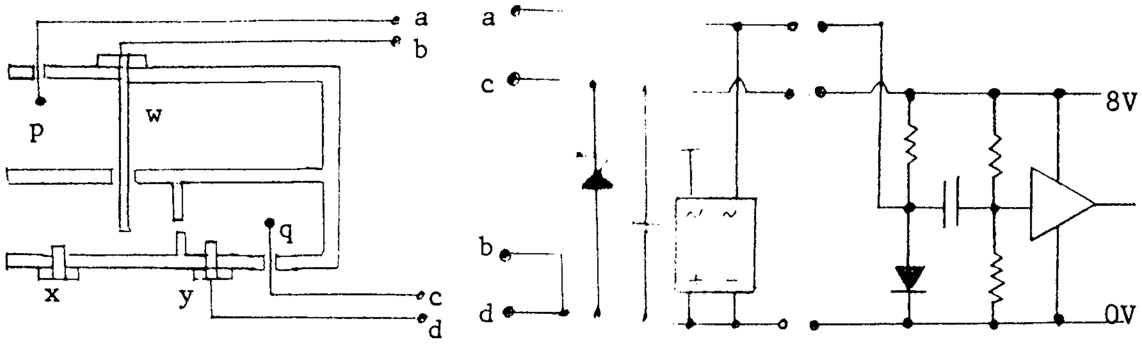
Present Arrangement. The microwave head is mounted by means of four Metalastik 17/1377/MN45 rubber studs (see fig 2). The need for these mounts and an assessment of their performance will be covered in a later report, but briefly, the application literature for the mounts stipulates the modes of correct use as shear, compression and shear/compression. Their present position allows the tensio/shear mode to affect the mounts. In order to allow adequate displacement to isolate lower frequencies, the mounts were chosen to operate in their weaker mode (for a given displacement, the loading maximums are 0.15kg shear and 0.75 in compression). The NEL report, however, (NEL) indicates two main components of shock and vibration: large amplitude low frequency and low amplitude high frequency. THe former are at such a frequency and amplitude that no mount could fully cope (see table). THe latter are at a similar frequency to the required doppler signal, and are thus

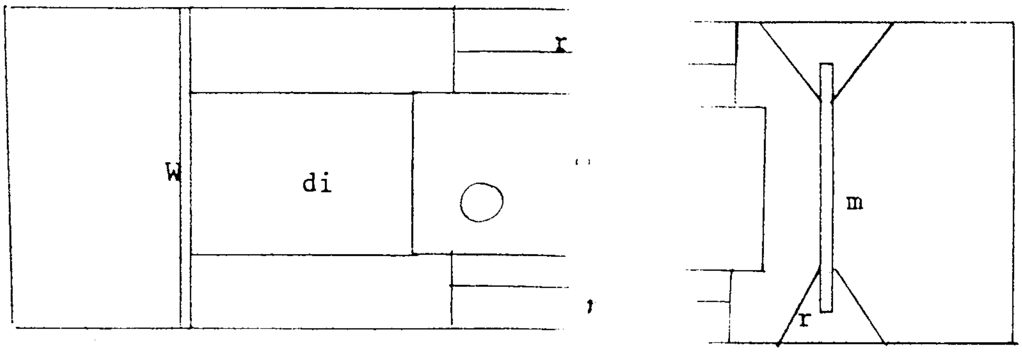
of greater immediate importance. The requirement to damp out the lower frequencies is now not the overriding concern when used for man-detect (where the lower frequency shocks were of similar frequency to the required signal), although the need for damping of shock for unit longevity remains. For 'static mass' (the actual weight of the Aro unit) and 0.5mm deflection (isolation for 45Hz and obove in shear mode) the mounts used are adequate. For severe shock, the deflection far exceeds the recommended value as the unit possesses a 'dynamic' mass in excess of the rated maximum mount load and deflection.
Thus, three steps should be taken in any new design:

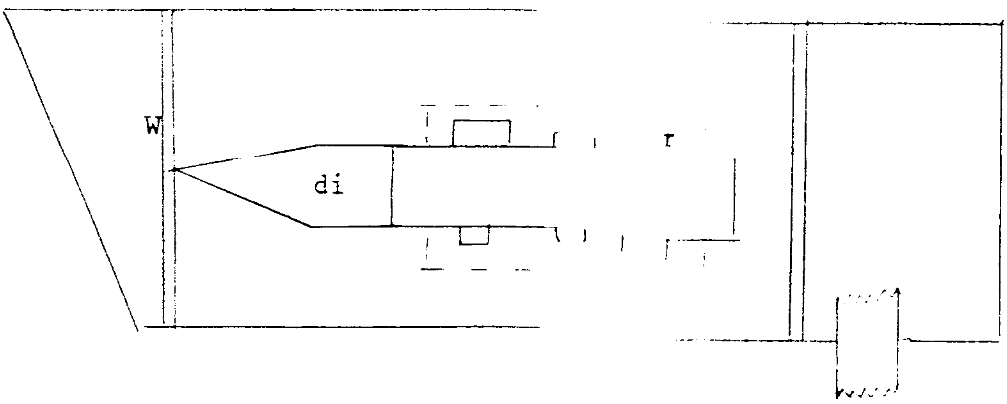
1. reduce or eliminate shear loading
2. " " tension "
3. " " large deflections.

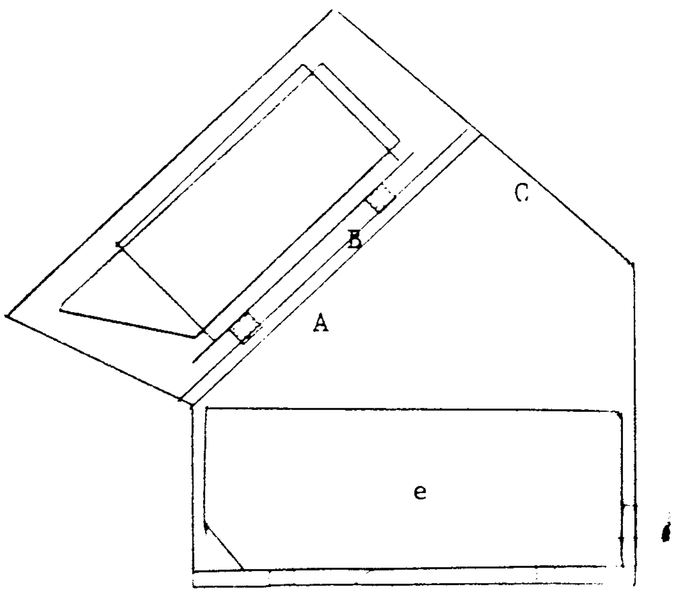
These steps can be achieved by mounting the whole unit into the vehicle chassis, which eliminates shear (apart from rare cases of vehicular sideways motion) and tension, and allows a wider range of mounts to be used due to the increased mass of the unit.
In order to assess the performance of the unit, tests were carried out on new (newly modified) units, failed units and the service records of previous failed units were consulted. The histogram of fig 3.1 plots faults as reported by the site fitters (two categories only). Faults described as 'working but incorrectly' include: incorrect alarm speed, physical damage, no led etc. The faults as found also include potting damage (a practice no longer performed). If smashed units are excluded (accident damage) and potting faults are ignored (self-inflicted) the faults fall into two groups: failure due to poor microwave units (33% of all failures) and physical weakness (39%). The extent to which malfunctioning antivibration mounts contribute to component damage and microwave unit failure will be considered later.
The power output of all 51 units was measured (taken when working, so the readings span the period of time necessary to repair malfunctioning units). Fig 4 shows that a considerable spread is found: only units between 1 and 2.5uw are found to operate well in-situ. 60% of the units fit into this category. Ten heads with powers within this band were arbitarily selected, and the operating frequencies measured: three units were found to be illegal. The output frequency can easily be altered, however, as illustrated by fig 6. As operating power is also a function of gunn voltage, this relation was examined in depth. A unit selected as 'typical' was tuned from maximum to minimum adjustment, and output power and frequency measured each ¼ turn. The mixer noise was also assessed. Results appear in fig 9: the frequency maximum appears very near the power maximum, which corresponds to the mixer noise minimum. The HMG

frequency requirements are also marked on the graph: the maxima referred to fall within the allocated band. Thus, there is an optimum tuning position for the Aro unit transceiver. Checking two arbitarily selected heads showed them not to be tuned correctly, and their measured parameters improved dramatically when tuning was performed.
The relation between power and output frequency against gunn voltage was also examined (figs 10 and 11). The test was performed for two tuning conditions: one corresponding to the lower portion of the HMG band, one to the centre of the band. For both cases the relations were approximately linear. The ability to vary the gunn voltage ofer a suitable narrow band (say 7.75 to 8.25V) would seem to be an effective and simple method of frequency tuning. This can only be performed, however, when the mixer tuning screw is correctly aligned for optimum noise and output power.
It shoud be noted that the above tests refer to power at the horn or aerial mouth. Measurements along the footprint the power are harder to perform: fig 5 illustrates this.
One means of predicting whether a microwave unit is likely to perform adequately in the field was referred-to earlier: that of checking the power output. This is certainly not foolproof, and may produce significant noise or frequency shift. In order to both attempt to provide an alternative means of assessing likely success in the field, and to provide data on why and how heads fail, the parameters of both working and failed units were measured. The gunn resistance, mixer voltage (for various connections) and frequency and power output were measured. The results are tabulated overleaf. Certain values are interesting: a low mixer to earth resistence indicates failure (in terms of 'not working properly' on a truck: the power output and transmission frequency are little affected), low gunn resistance may indicate problems, but in general, the readings are of little use. It would seem that no measurable parameter capable of measurement by the available resources is an adequate predictor of failure, or even an indicator of the means of failure.
All readings taken so far have been laboratory parameter measurements. Thus, road tests were arranged to assess other aspects of head performance. One easily variable parameter is the polarisation of the unit: by turning the head on its side so as to be vertical the difference in performance can be assessed. It can be seen from the tabulated results that the vertical orientation is significantly worse than the normal mode, requiring overspeed to generate the signal required to alarm. The average speed required to alarm is this mode was 30mph (7mph fast).









KEY:

w: LO leakage for lower cavity
x: Unit match screw
y: Iris match screw
p: Mixer diode
q: Gunn diode
r: rubber mount
m: PCB
di: dielectric
e: electronics box
A: antivibration mounts
B: mounting bracket
W: dielectric window
C: main case (hood)

THE ARO UNIT AND CIRCUITRY. The bridge is contained on the PCB (m), the op-amp is located on the main PCB in the electronics box (e)

GUNN VOLTAGE (V)	O/P FREQ (10.5xxGHz)	O/P POWER (mW)
7.99	80 - 85	1.95
7.80	77 - 82	1.80
8.20	82 - 88	1.90
7.99	80 - 88	1.98
7.83	76 - 84	1.85

VARIATION IN OUTPUT (FREQUENCY AND POWER) FOR DIFFERENT GUNN VOLTAGES. Note that returning to a similar voltage does not return repeatable frequency and power.

FIG 6

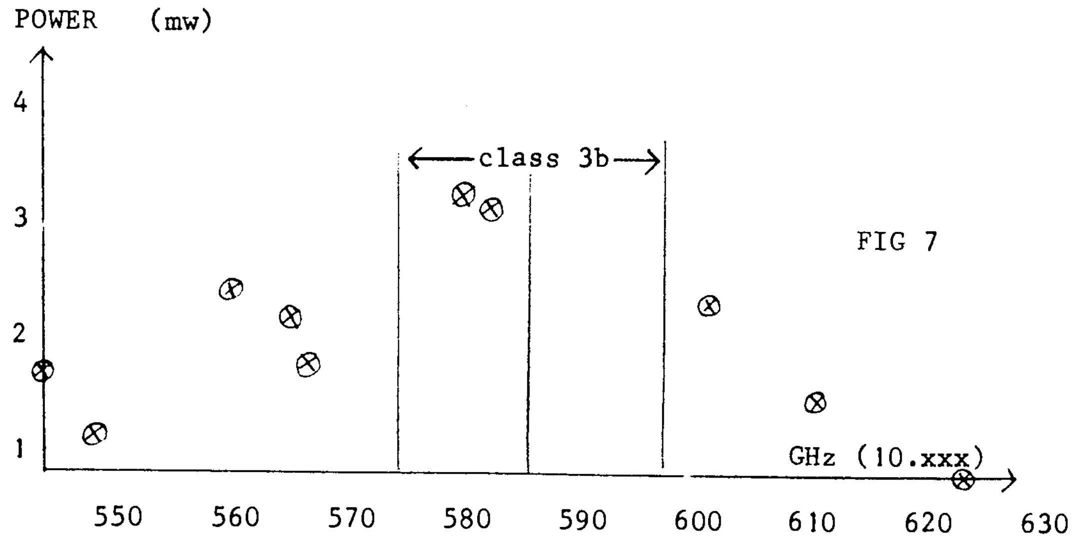
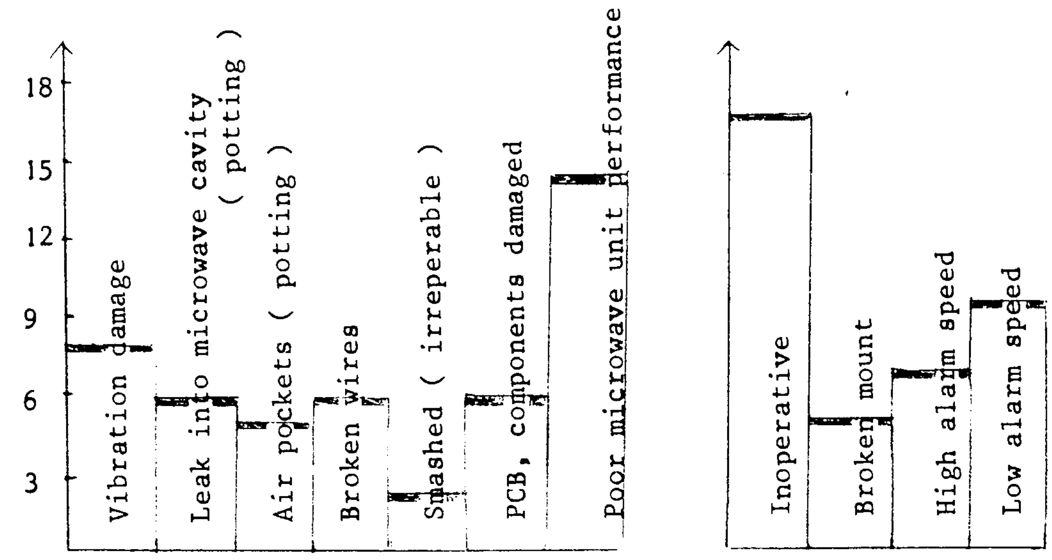


FIG 7

POWER AND FREQUENCY CURVE FOR TEN TESTED AND WORKING ARO UNITS. The lagal range (HO14) is indicated.

GENERAL TREND BETWEEN POWER, BIAS AND FREQUENCY FOR A TYPICAL GUNN DIODE. From Tsai (1970).



FAULTS AS FOUND

FAULTS AS REPORTED

FIG 3.1

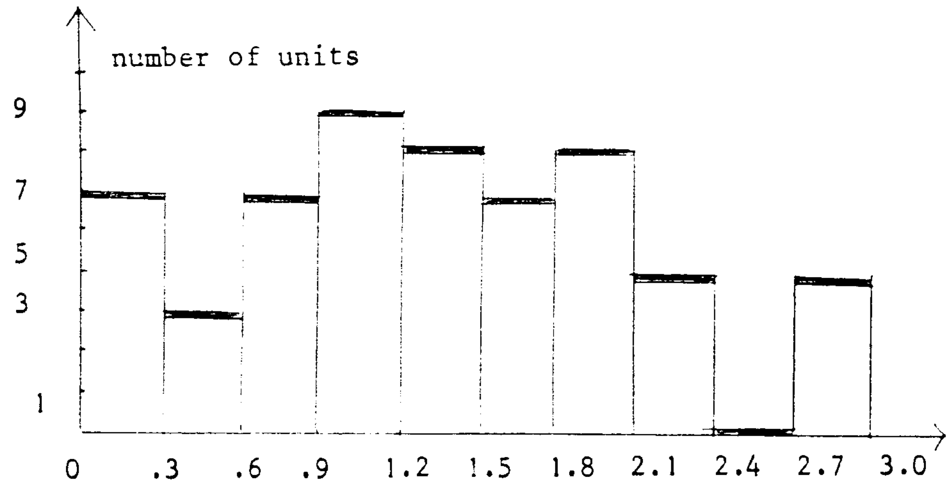


FIG 4

MICROWAVE POWER READINGS OF ARO HEAD UNITS. 51 units were tested: the readings were taken over a period of time so included are heads tested, used, broken repaired and retested. Readings accurate to 0.05microwatts, and bracketed into 0.3mw groups.

GIGAHERTZ 9 10.x to 10.y)	NUMBER	NOTES
45 - 50	2	
50 - 55		
55 - 60	7	legal range 3b (10.587 +-10m)
60 - 65	1	
65 - 70		legal range 3c (10.687 +- 10m)

FREQUENCY OUTPUT OF TEN ARBITARILY SELECTED ARO HEADS. Readings accurate to 0.01 GHz and bracketed.

DATE	QTY MANF	STOCK	HISTORY		
			FITTED	REMOVED	SCRAP
30.4.82	32	9	23		
7.5	1	8	2		
14.5		8			
21.5		8			
28.5	13	0	21		
4.6		8		8	
18.6	1	4	16	9	
26.6		4	5	1	
2.7		7			
9.7	1	1	3	5	1
16.7		4	5		
23.7		4			
30.7		6		3	
6.8	2	3	2	2	
13.8	2	3	6	1	
20.8		6			
27.8	3	11			
3.9	1	9	1		1
10.9		3		6	1
17.9		4		6	
24.9		9		1	
1.10		10		5	
8.10		8	1	2	
15.10		9	4	2	
22.10		10		2	
29.10		12		2	
5.11		11	3	2	
12.11		14	4	1	
19.11		8	8	2	
TOTALS	56	ave:7	100	60	3

SPEED SENSOR UNITS: PRODUCTION AND FITTING HISTORY. FIG 3.2

Notes: 1. at any one time, several units would be in mid-repair
2. over a longer time period, over 60% of heads are returned.
Derived from OGC (4/82) (fitters note books and production reports).

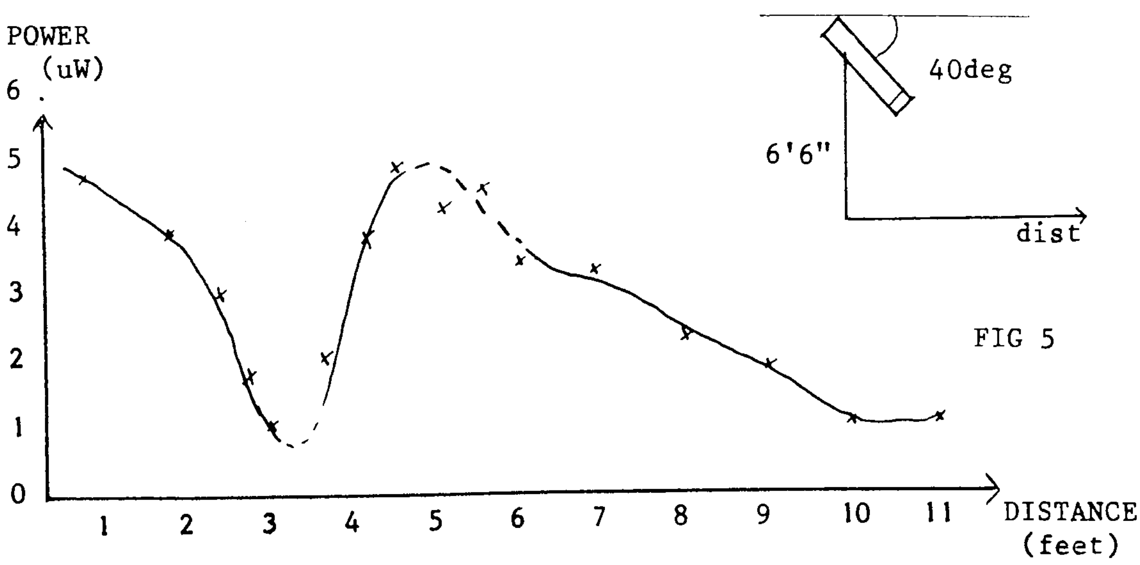
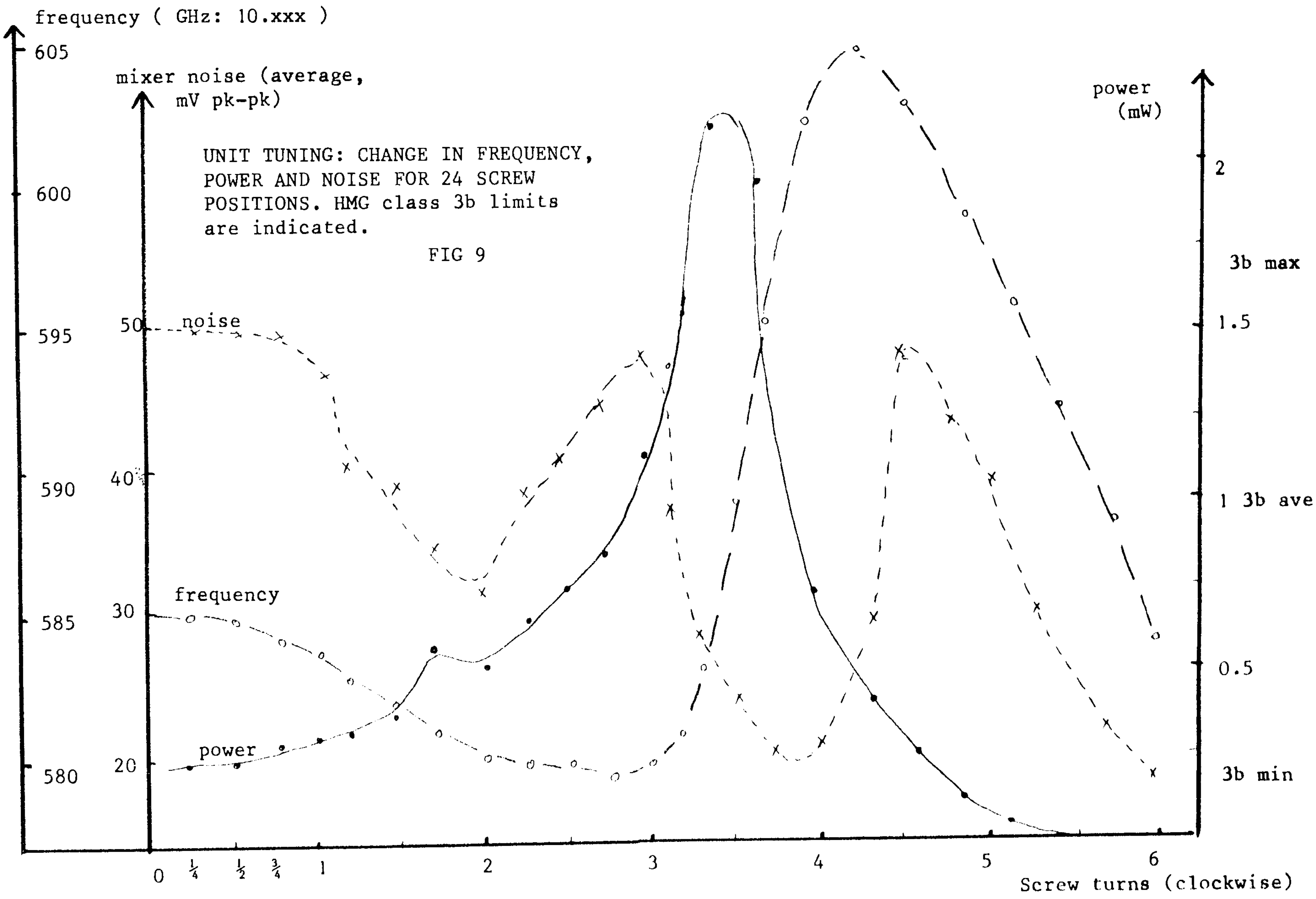


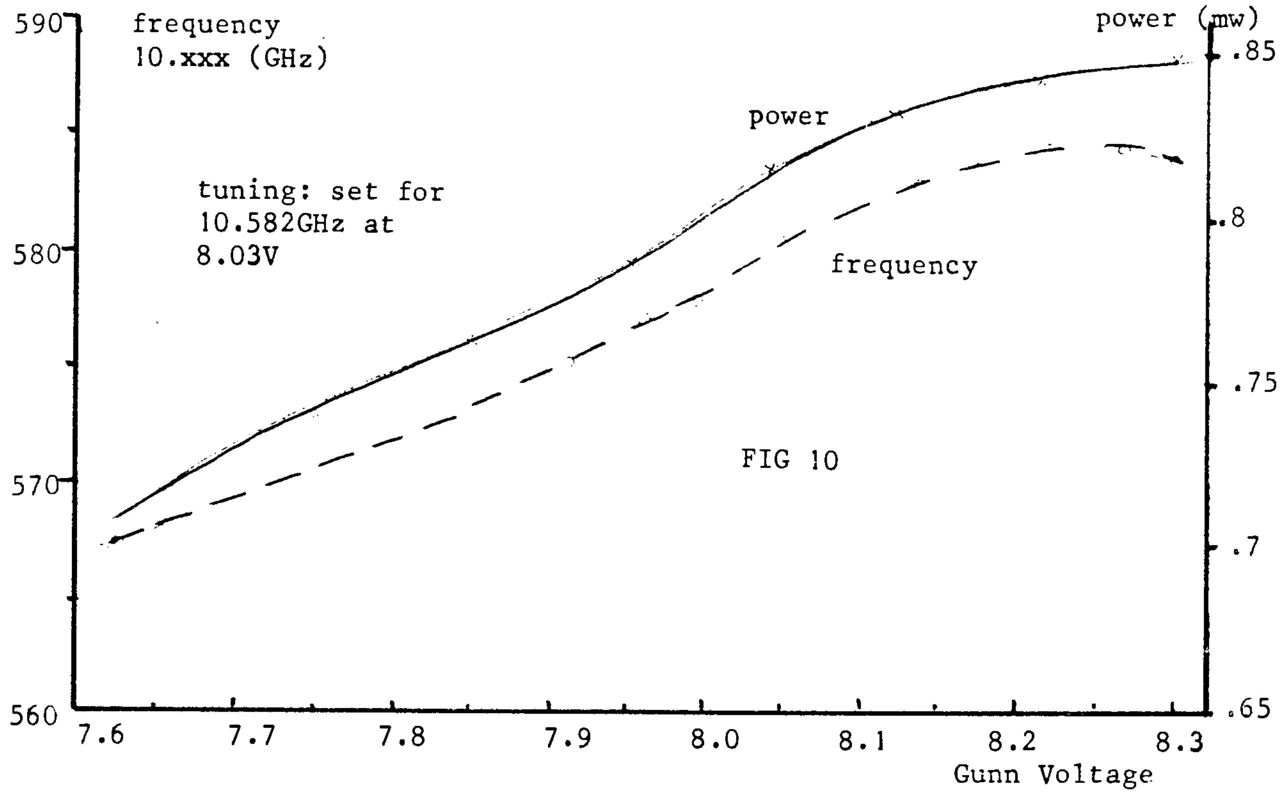
FIG 5

POWER AS MEASURED AT GROUND LEVEL, ON-AXIS, WITH THE HEAD AT THE NOMINAL TILT ANGLE AND HEIGHT.

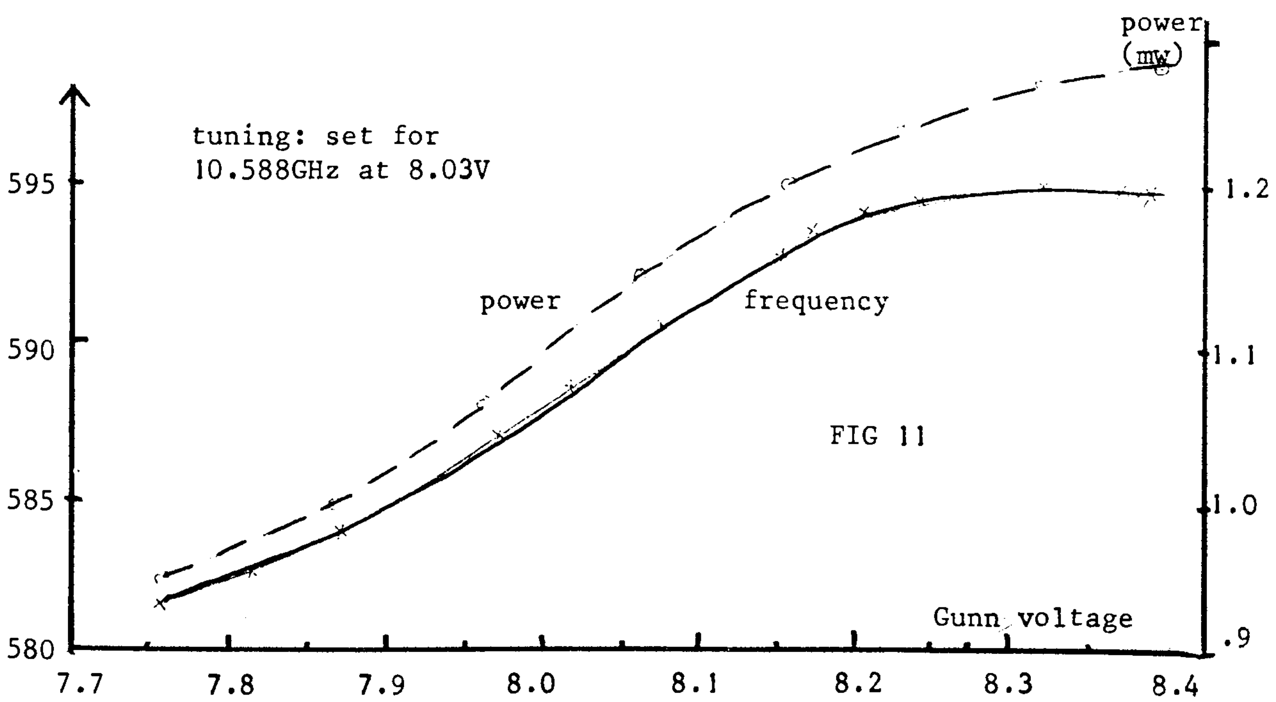


UNIT TUNING: CHANGE IN FREQUENCY, POWER AND NOISE FOR 24 SCREW POSITIONS. HMG class 3b limits are indicated.

FIG 9



PLOT OF POWER AND FREQUENCY OUTPUT FOR A RANGE OF GUNN VOLTAGES.



PLOT OF POWER AND FREQUENCY OUTPUT FOR A RANGE OF GUNN VOLTAGES.

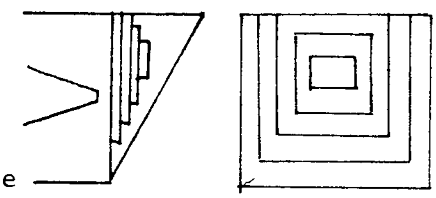
DATE	QTY MANF	STOCK	HISTORY		
			FITTED	REMOVED	SCRAP
30.4.82	32	9	23		
7.5	1	8	2		
14.5		8			
21.5		8			
28.5	13	0	21		
4.6		8		8	
18.6	1	4	16	9	
26.6		4	5	1	
2.7		7			
9.7	1	1	3	5	1
16.7		4	5		
23.7		4			
30.7		6		3	
6.8	2	3	2	2	
13.8	2	3	6	1	
20.8		6			
27.8	3	11			
3.9	1	9	1		1
10.9		3		6	1
17.9		4		6	
24.9		9		1	
1.10		10		5	
8.10		8	1	2	
15.10		9	4	2	
22.10		10		2	
29.10		12		2	
5.11		11	3	2	
12.11		14	4	1	
19.11		8	8	2	
TOTALS	56	ave: 7	100	60	3

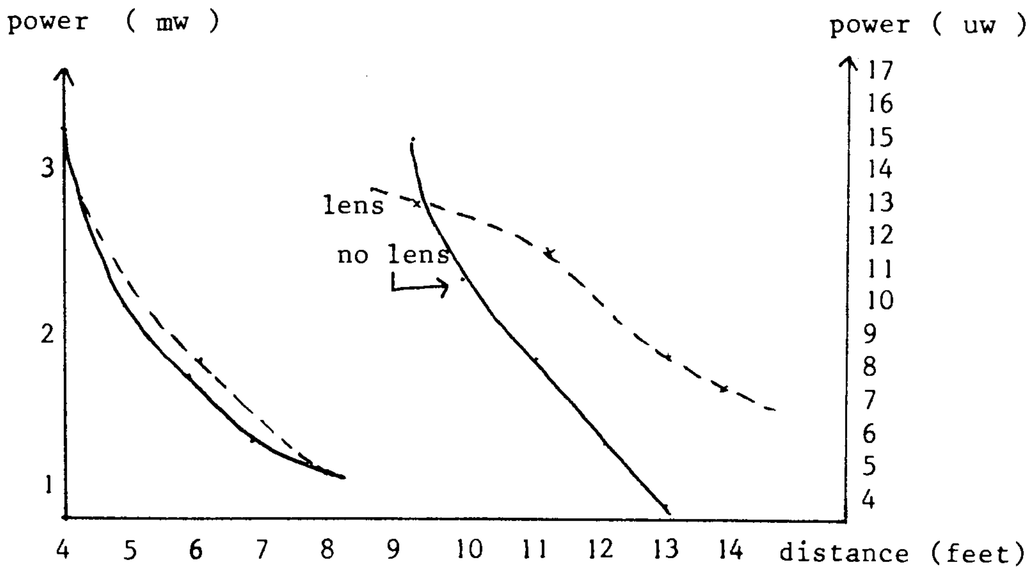
SPEED SENSOR UNITS: PRODUCTION AND FITTING HISTORY.

notes: 1. at any one time, several units would be in mid-repair

2. over a longer time period, over 60% (the figure derived from the above figures) of heads are, in fact, returned.

Methods of alteration of the Aro unit beamwidth. In order to assess the possible improvement of the standard Aro unit, several methods of beamwidth alteration were tried. The unit is effectively a waveguide terminated by a dielectric strip in the plane of transmission. It thus is prone to internal reflection and to the effect of materials placed within, or near, the beam. Three main methods of possible improvement were tried: tube extension (collimation), lens (focusing) and foam (reflection cancellation); along with several combinations of these (see fig 15). To further examine the potential of the lens solution, which would seem to be the most practical and effective solution, several lens positions and types were tried. These tests were carried out at distances of 5, 10 and 12 feet on-axis and the half-power points to either side of beam axis were measured. Thus the gain, beamwidth and skew can all be derived. From these results the design selected for further evaluation was as illustrated. This design has a narrow beamwidth, good gain and minimal skew. It is interesting to note that the unmodified head is very skewed and exceeds the nominal 25 deg beamwidth stated by the manufacturers. The plot of power on-axis in line with and without lens is:





This lens was then tried in four positions within the existing housing, and two with foam. A squared-off case was assessed, with and without various foam additions. Finally the lens was reversed, and edges for mounting added. This arrangement can be seen to give excellent beamwidth, is practical (having a flush front face and being totally enclosed within the aluminium case). The gain is lower than the optimum due to the effect of the rubber-based adhesive used to construct the lens. The collimation unit with internal foam gave a seemingly good beamwidth, but poor gain and skew characteristics.

In order to counteract the inherent skew in the Aro unit, a simpler solution is possible: foam inserts. Such a solution was exhaustively tested, and works well, although a slight power loss ensues.

After evaluation of all combinations, a final prototype waw constructed using a different Aro unit, and completely retested. The results are tabulated overleaf. It can be seen that the gain has been increased, the beamwidth reduced in both orientations, and the main axis power skew reduced slightly.

Thus the lens system has been shown to improve the Aro unit performance in terms of gain, beamwidth and skew. Other problems still exist: the wiring is prone to microphony, the unit is hard to isolate from shock and vibration and oddities of performance still remain unexamined.

To assess the effect of cable type and wiring topology on unit noise, two typical units were extensively modified, performance being noted before and after modifications: no concrete results were obtained.

Generalised conclusions can be made, however. The wiring does not significantly affect noise performance and power/frequency output. No one modification makes a significant difference, although the sum of all modifications was worth gaining. On a more practical note, heavy wiring has more chance of surviving the vicious environment of site use.

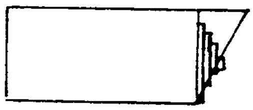
Circuitry assessment. Fig C1 illustrates the circuit of the unit: the input module is repeated five times (once for each selectable speed) and the outputs summed . Thus the total component count for this stage is: 33 resistors, 15 diodes, 10 zeners, 5 transistors, 1 IC. The design has two main failings: firstly complexity: the components occupy a large PCB area, producing a costly design in terms of PCB manufacture, component cost and assembly time. Second, and more important, the design suffers an inherent weakness of component tolerance: the zener diode used has a 5% tolerance, but the effects of this seemingly acceptable rating are catastrophic. FIg C2 illustrates the results of testing six working boards. The alarm frequency was set to be 25mph, and the required alarm frequency to produce this equivalent was measured. It can be seen that the results show inaccuracy: with a spread from 23.5 to 27.5mph, and average of 25.5 to 26.5 Thus the circuitry can only be used with zener diodes that are hand-selected (five matched diodes per PCB).

HEAD SOURCE	GUNN R	MIXER R:E-M	MIXER R:M-E	V:G	V:G/M	V:M	OUTPUT FREQ	OUTPUT PWR
working	20	300	600		.04	.2		1.3
	20	310	655		.01	.3		1.1
cw ret	20	289	660	.33	.18	.19	667	1.5
pll ref	20	310	661	.51	.5	.2		
MA unit	10	279	802	.67	.67	.04	340	5.5
faulty	20	180	180		.05	.01	568	.62
	20	163	171	.01	.01	.01	580	.95
	19	282	656	.28	.11	.05	598	.15
	19	281	662	.22	.13	.47	580	.33
	18	298	655					
	18	258	663					
	19	302	650	.2	.02	.2	606	.65
	21	186	184	.04	.03	.01		
	19	314	652	.32	.22	.19	557	.62
	19	260	639	.18	.03	.16	583	.35

NOTES: R: resistence (ohms); E: earth; M: mixer; V: voltage (-ve); G: ground. Freq:10.xxx GHz. PWR: (mw)

FIG 14

LENS CONFIGURATIONS: FIG 16:

CONFIGURATION	DIST OUT	½PWR L	½PWR R	PWR AXIS	BEAMW	REL GAIN
	5	2.4	1.0	9.8	37	1.00
	10	3.11	1.3	2.7	29	1.13
	12	4.1	1.5	2.1	26	1.4
	5	1.1	1.2	11	25	1.12
	10	1.6	1.7	2.5	17.5	1.0
	12	3.1	2.7	1.3	27	0.9
	5	2.0	0.9	9.8	30	1.0
	10	2.9	1.8	2.6	25	1.1
	12	3.0	1.7	1.7	21	1.13
	5	1.2	.1	10.1	23	1.03
	10	1.9	2.1	2.4	21	1.0
	12	2.4	1.8	1.8	19	1.2
	5	1.4	1.0	8.3	26	.85
	10	2.3	2.2	1.9	25	.8
	12	2.8	1.11	1.25	22	.8
	5	1.5	1.1	9.8	27	1.0
	10	3.0	1.10	2.4	28	1.0
	12	3.8	1.11	1.5	26	1.0

NOTES: distance out is asis distance (in feet); all powers in uw; beamwidth in degrees. Relative gain is relative to no horn. Half-power (-3dB) points described in feet and ins.

PARAMETER	HEAD TYPE					
POWER	0.6	2.3	0.74	1.2	2.3	2.2
POLARISATION *1	V	V	V	H	H	H
SIGNAL LEVEL *4 5mph	0	0	1	1.5	*2	1.3
10mph	1	1	2	2.5	6	5
20mph	2.5	2.5	3.5	5	6	6*3
ALARM SPEED mph	28	28	26	23	24	22
MOVEMENT RESPONSE (')	21	21	18	20	14	11

Notes: 1. refers to the orientation of the dielectric strip
2. rechecked. Sudden increase in signal at 9mph
3. partial clipping
4. for returns from a damp, smooth tarmac road.

PERFORMANCE OF SIX ARO HEADS SELECTED AT RANDOM. 3 WERE USED IN VERTICAL POLARISATION MODE.

FIG 12

DIELECTRIC VERTICAL			
HEAD	mph RUNS (ALARM/CANCEL)		
	1	2	3
1	27-23	27-23	27-23
2	30-25	32-25	30-25
3	27-23	28-23	28-23
4	28-24	28-24	28-24
5	34-30	40-36	35-30
ave		30	

notes: 1. partial clipping

DIELECTRIC HORIZONTAL			
SPEED	RUNS (V pk-pk)		
	1	2	3
5	1	1	0.4
10	3	3	1
20	6.5 *1	6.5	3
40	3	4	1
alarm	23	23	25 mph

ALARM/CANCEL SPEEDS OF THE HEADS USED IN FIG 12. : THREE RUNS WERE PERFORMED. Runs on tarmac, damp and smooth.

FIG 13

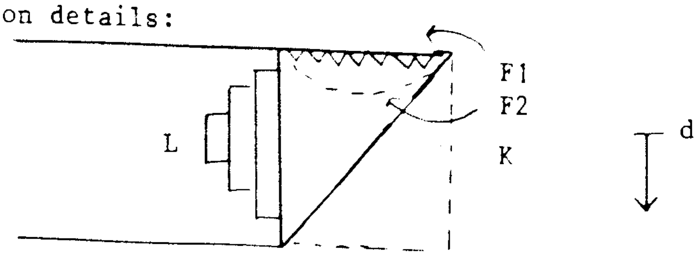
DISTANCE OFF - AXIS	MODIFICATION (powers in uW)						
	NONE	L	L,F1	L,F2	K,L	K,L,F2	F2
0	4.8	4.4	4.1	3.2	4.6	2.1	4.6
1	3.9	4.8	2.9				2.2
2	3.3	2.3	1.6	0.6	2.5		2.1
3	1.2	0.7	0.5	0.2	0.5		0.2
4	0.2	0.1			0.2		
-2	2.0		1.7	1.7	1.6		1.5
-4	0.1	0.4			0.1		0.1

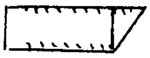
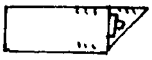
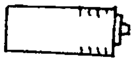
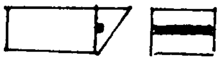
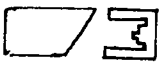
Notes: L = lens, K = tube extension (collimation),
F1 and F2 = foam (reflection cancellation)

FIG 15

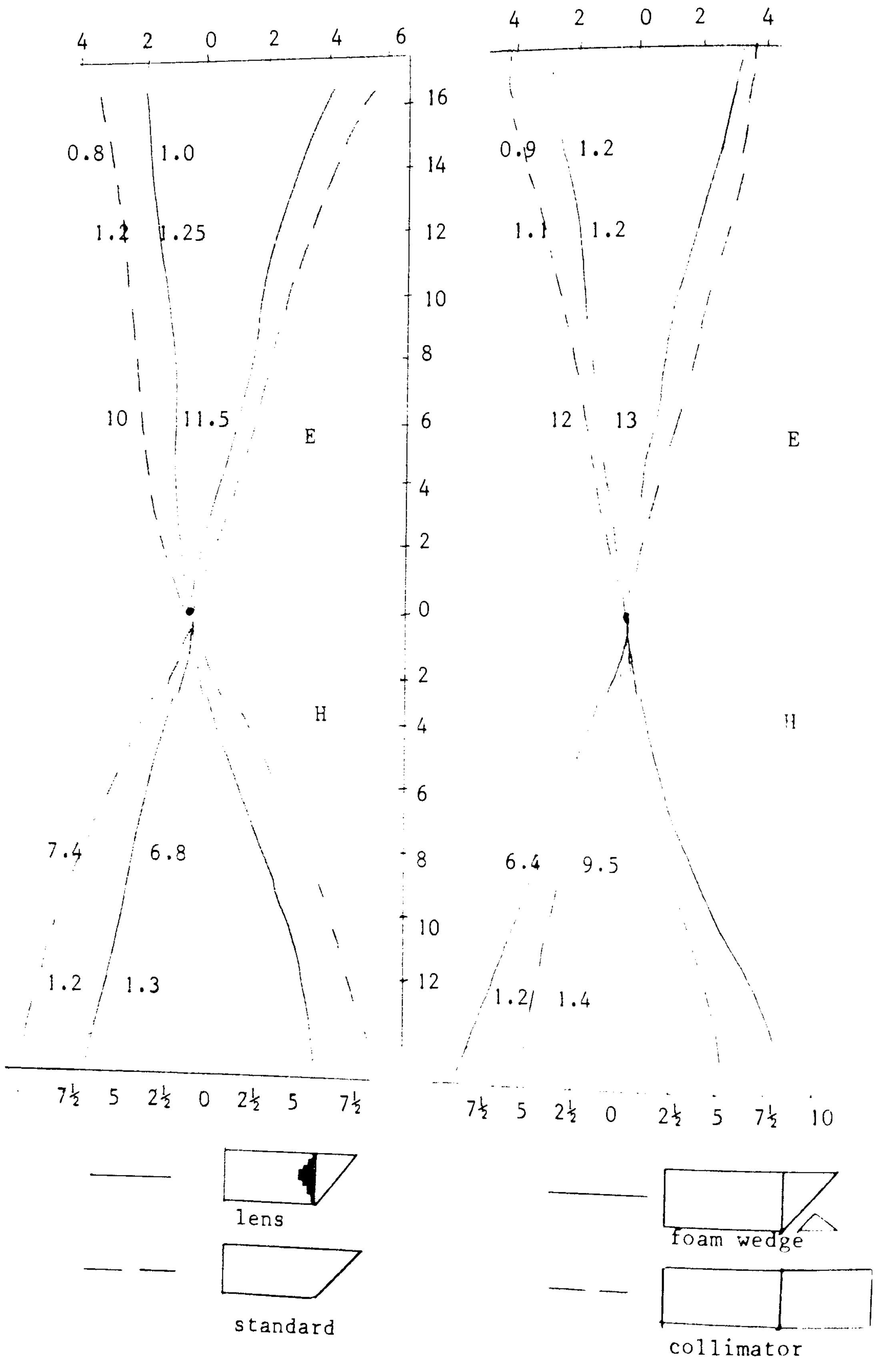
METHODS OF BEAM ALTERATION OF THE ARO UNIT: POWER MEASUREMENTS OFF-AXIS. TRANSMITTER TO MEASUREMENT DISTANCE, 7' (beam centre for 6' high 40 deg unit mount). HEIGHT ABOVE FLOOR, 4'.

Modification details:



CONFIGURATION	DIST OUT	AVERAGE L	AXIS	R	BW	NOTES
standard unit	10	1.4	2.6	3.9	28	
lens to top	7	1.2	4.7	2.1	26	
lens to bottom	10	1.3	2.7	2.3	20	
lens to bottom	10	0.8	1.9	4.9	30	2'4" skew R
lens centred	10	1.2	2.6	3.7	25	
reversed lens	10	1.7	3.3	1.8	19	power gain
foam lined	7	.8	2.4	1.4	17	
	10	.8	1.2	2.1	16	skew 1'6" R
	10	1.1	2.7	2.1	18	3mm foam
	10	1	2.4	3.8	26	foam + lens
	7	2.5	3.0	1.3	29	foam +lens/cut
	10	3.2	1.7	3	34	horiz foam
	10	1.10	1.7	2.10	27	vert foam. skew
	10	3.3	1.2	3.1	35	3 horiz foam
	10	1.4	2.6	1.6	17	offset lens rev
	7	1.2	4.8	1.2	19	sides on lens
	10	1.6	2.6	1.11	19	
	7	.8	2.4	1.4	17	cut + foam
	10	.8	1.2	2.1	16	
	7	.10	2.8	1.1	16	cut + lens + foam
	10	1.8	1.3	1.0	15	

Notes: distance out in feet (on axis); average powers in uw (axis) and L/R distances in feet and inches from axis of half power point. BW is beamwidth in degrees.

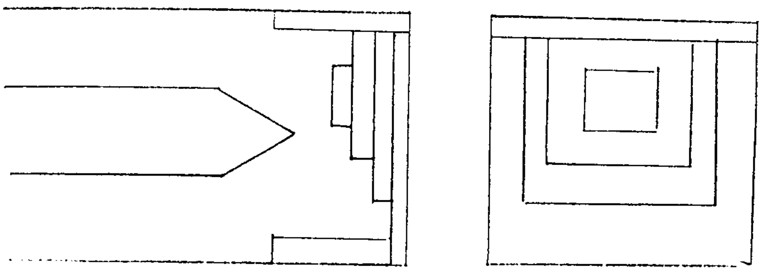


ARO UNIT BEAMWIDTH: STANDARD UNIT AND THREE MODIFICATIONS. Powers are indicated on the diagram in units of microwatts. All distances in feet. Diagrams trsced from polar plot paper for clarity.

PARAMETER	ORIGINAL	LENS UNIT	NOTES
GAIN	x1	x1.5 ave	overall figure
BEAMWIDTH: ELEV	31 deg	20 deg	
AZIM	38 deg	26 deg	(average of 3 (units
SIDELOBES		no effect	
ASYMMETRY (POWER)	3 deg	1.5 to 3deg	

DISTANCE (on axis)	ORIGINAL PWR	ORIGINAL BW	LENS UNIT PWR	LENS UNIT BW
5 feet	9.5	32.8	11.6	17.6
7			4.8	18.9
10	2.4	30.7	2.6	19.3
12			1.7	19.6
15	1.0	30.4		

NOTES: PWR: power in microwatts
BW: beamwidth in degrees

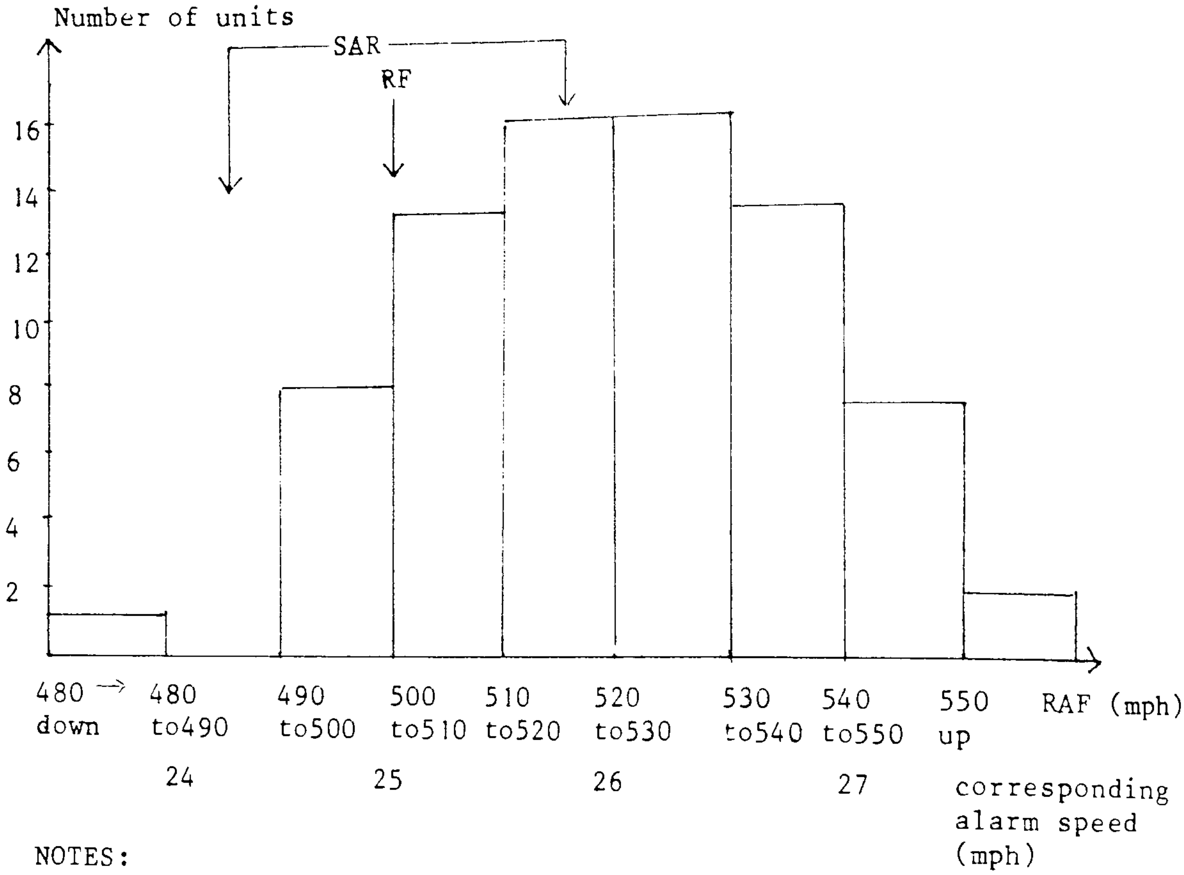


FINAL LENS PROTOTYPE DESIGN FOR ARO UNIT MODIFICATION. Comparison of performance with a standard unit

TEST	GUNN (V)	POWER (mW)	FREQ 10.x GHz	MIXER mv(pk)	STAGE O/P 1	STAGE O/P 2	NOTES
1	8.0	1.8	565-570	0.1	1.5	90	head E1
2	8.03	1.7	565-570	0.3	1.5	70	head E2
3	"	1.65	565-575	0.2	1.2	50	E2 gunn c & s to heavy c
4	"	"	"	"	1.3	150	" + TP to mixer
5	8.01	2.0	580-590	0.2	1.5	100	heavy s to mix
6	"	"	"	0.1	1.5	90	block holes in m.wave unit
7	"	"	"	0.15	1.6	75	" + 2x s to cct
8	8.0	2.05	596-610	0.2	1.5	70	test 3,5,6,7 on head E1
			microphony stage:		1	2	
9	"	"			same	good	i.pend e & s
10	"	"			same	poor	'balanced'
11	"	"			better	same	glue all c
12	"	"			worse	worse	" + cct
13	"	"			same	same	foam fill m.wave

NOTES: c: cable, s: screen, cct: circuit, e: earth

PERFORMANCE OF A STANDARD ARO UNIT UNDER WIRING AND POTTING MODIFICATIONS.

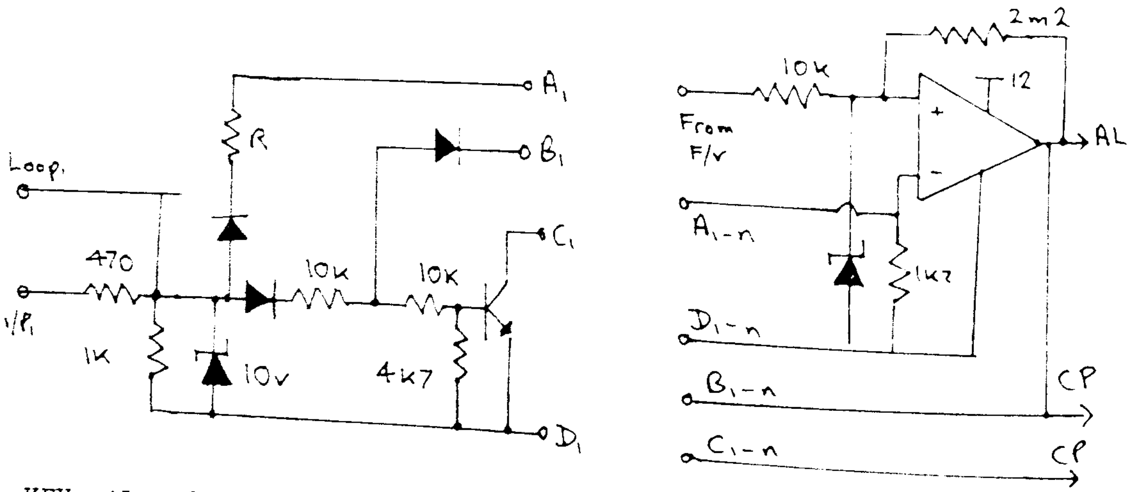


NOTES:
RF: required frequency
SAR: stated acceptable range
RAF: resultant alarm frequency (Hz)

FIG C2

The required alarm frequency (RF) was later altered on production units to 470Hz. Fron Ref OEL Z.

<u>THE EFFECT OF COMPONENT TOLERANCE ON SPEED SENSOR CALIBRATION</u>. The result of analysing the performance of 7 units is plotted.



KEY: AL: alarm line output
CP: control panel line

The I/P circuit is repeated five times. The value of R determines the frequency at which an alarm output is produced. For 5 to 25 mph the value of R is 9K1, 3K9, 2K2, 1K5 and 1K14.

FIG C1

<u>THE ORIGINAL ROADSPEED CIRCUIT: ALARM SPEED OPTION CIRCUITRY</u>. THE ERRORS PRODUCED BY THIS TOPOLOGY ARE PLOTTED IN FIG C2.

SECTION 2.11

REPORT INT P20
19.1.84
C. WALLACE

MICROWAVE WINDOWS: EFFECT OF MATERIAL AND DESIGN ON THE UNIT PERFORMANCE.

SECTION

1. INTENTION
2. REQUIREMENTS
3. MATERIALS SELECTION
4. MAX/MIN AND VSWR
5. PROTOTYPE WINDOW
6. INITIAL RESULTS AND DISCUSSION
7. PROPIETARY WINDOWS
8. CONCLUSIONS
9. APPENDIXES:
   A WINDOW MOULDING
   B NODES
   C AN GLE DERIVATION

INTENTION. This report summarises the work performed on microwave window materials. It takes the form of tabulated experimental results from which the optimum material is selected and assessed in depth.

REQUIREMENT. The front window of a microwave unit must fulfill several criteria: It must:

- be impervious to wind, weather, oil, grease and steam cleaning
- withstand minor impact
- not be prone to condensation or water droplet formation
- not reflect significant energy
- not absord significant energy
- be easily mounted at the mouth of a horn

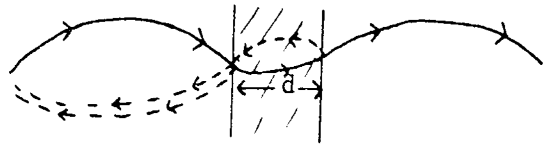
These criteria rule out all but a few categories of material: fibreglass and plastics.

TESTS. In the absence of any existing standardised test for potential window materials, a test thought suitable was conducted. Each material, many being available in several thicknesses, was placed on and near the front face of a microwave horn. Measurements of the peak-to-peak reflection signal amplitude were noted: for the front face this amplitude is a single value; near the face (spaced between 1 and 6cm away from the horn mouth) both the maximum and minimum readings were noted. Ratios of the maximum to minimum were calculated. It is thought that the lower this ratio the more suitable the material (as the ratio is an indication of the extent to which the material can reflect in and out of phase respectively with the transmitted signal: a low figure is interpreted as meaning the material does not alter the amount of reflection when moved through several wavelengths). Air thus has a ratio of unity. Care must be exercised, however, when interpreting ratios greater than seven as a metal reflector (electromagnetically, such a material should be an almost perfect reflector) gives a ratio of nine or ten; a value exceeded by certain plastics. It is thought this oddity is related to good reflectors (which conform to the laws of specular reflection) needing alignment to a fraction of a millimetre for true phase cancellation: an accuracy impossible to maintain given the available facilities (the material must be exactly parallel to the horn face, be an exact distance from it, but be capable of being moved toward and away from the horn).

EMPIRICAL METHODS OF MATERIAL SELECTION. The thickness of the window material is calculated by: $\lambda/2_{air} \cdot \eta_{air} = \lambda/2_{material} \cdot \eta_{material}$

where $\lambda/2$ air = 1.09cm and η air = unity.

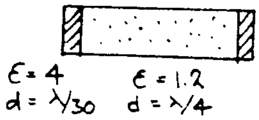
Thus, the refractive index, η, of the material must be known. This data is only known for a certain range of materials, so various thicknesses of each material were tried. The assumption of a half wavelength thick window being the optimum thickness (very thin materials are also suitable, but lack physical strength) was brone out experimentally (graph one) and is based on the principle of reflection cancellation:



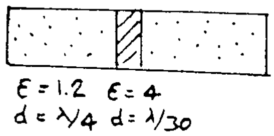
$d = \frac{n.\lambda}{2}$

The reflection from both faces of the window are thus in phase but out of phase with the transmitting wave (and of far lesser amplitude). Skolnik (1968) describes sandwich construction methods:

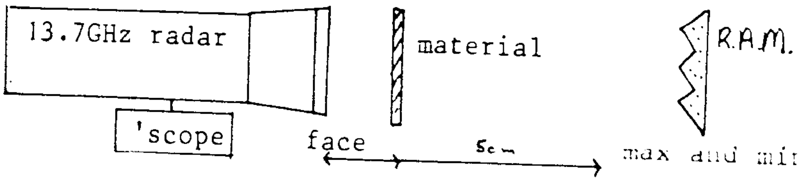
type a:



type b:



For completeness, this method of window construction was also evaluated both for three and five layer sandwiches. More complex constructions are discussed in Kay (1961) and Walton (1970). The physical layout of these tests was thus:

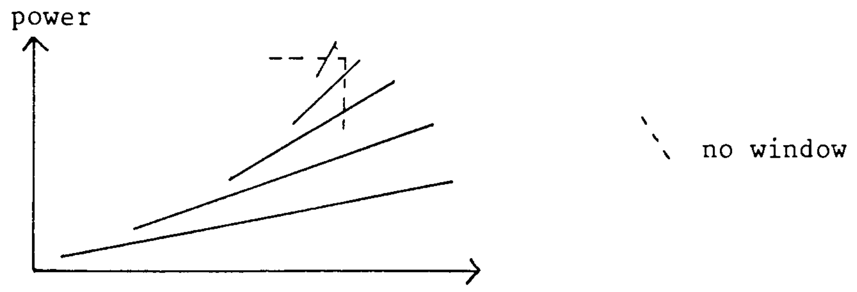


<u>MAX/MIN RATIO AND VSWR.</u> The MMR referred-to in the text can be said to approximate to the VSWR of the horn-to-window match. Walton (1970), Connor (1975) and Montgomery (1947) describe an experimental definition of VSWR as the ratio of the voltage max found in front of an adjustable matching stub to that of the voltage minimum. The window of a horn performs in a similar manner to such a stib. For a MMR or up to ten, this ratio gives meaningful results, but as in the waveguide/stub analogy, the definition becomes inaccurate above this figure. Instead, suggests Connor (1975), define VSWR = wavelength /pi times the distance from the minimum voltage to the next minimum point. The window match is critical: microwave units are factory-set for VSWR maximums of around 1.5 (MA Inc). For severe mismatches, the detector bias will shift beyond its adjustable range and a tuning screw must be added to the horn. This is not ideal: dirt on a severely mismatched window cannot be 'tuned-out' and the stub itself can cause localised mismatch. Thus the window must be selected to be transparent to the electromagnetic energy, ie have a low MMR or VSWR. Manufacturers atate a typical window thickness for an approximate match (RS3598, AMI Inc): for X band such thicknesses are less than 1mm or half a wavelength. If a significant increase in bias occurs, there is a commensurate increase in audio-frequency output for a given target, but a degraded signal-to-noise ratio. The AF increase, however, will not be a linear increase, but will vary for each module. Beyond a certain point, the

Gunn diode will be mismatched: this may 'pull' the nominal frequency of transmission. For a typical doppler module (RS3598) the bias varies as follows:

L.O coupling -(dBm)	total mixer bias (ua)	window
19	35 (dc)	none (optimum)
15	42	10-20mm expanded polystyrene
11	61	0.25mm plastic (BIP)
6	70	0.5mm plastic (BIP)

The variation of bias pull with window type was further examined by moving four window materials parallel to the horn mouth of a Plessey X band microwave unit, and measuring the transmitted power minimum and maximum, and noting a range of intermediate values. the mixer bias voltage corresponding to each power reading was also noted. the results are plotted on graph 0, and indicate a trend of a lesser gradient for a smaller voltage pull range, ie exaggerating the trend:



In order to establish the theoretical link between VSWR and percent reflected power, table 0 is reproduced. It can be seen that a VSWR of 1.5 corresponds to 3.5% power reflected.

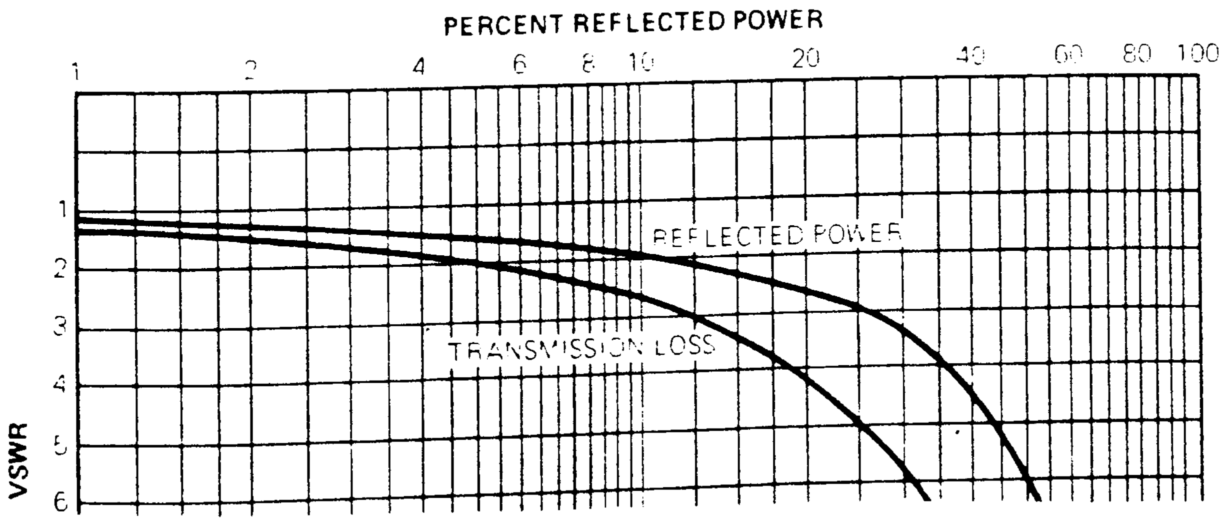
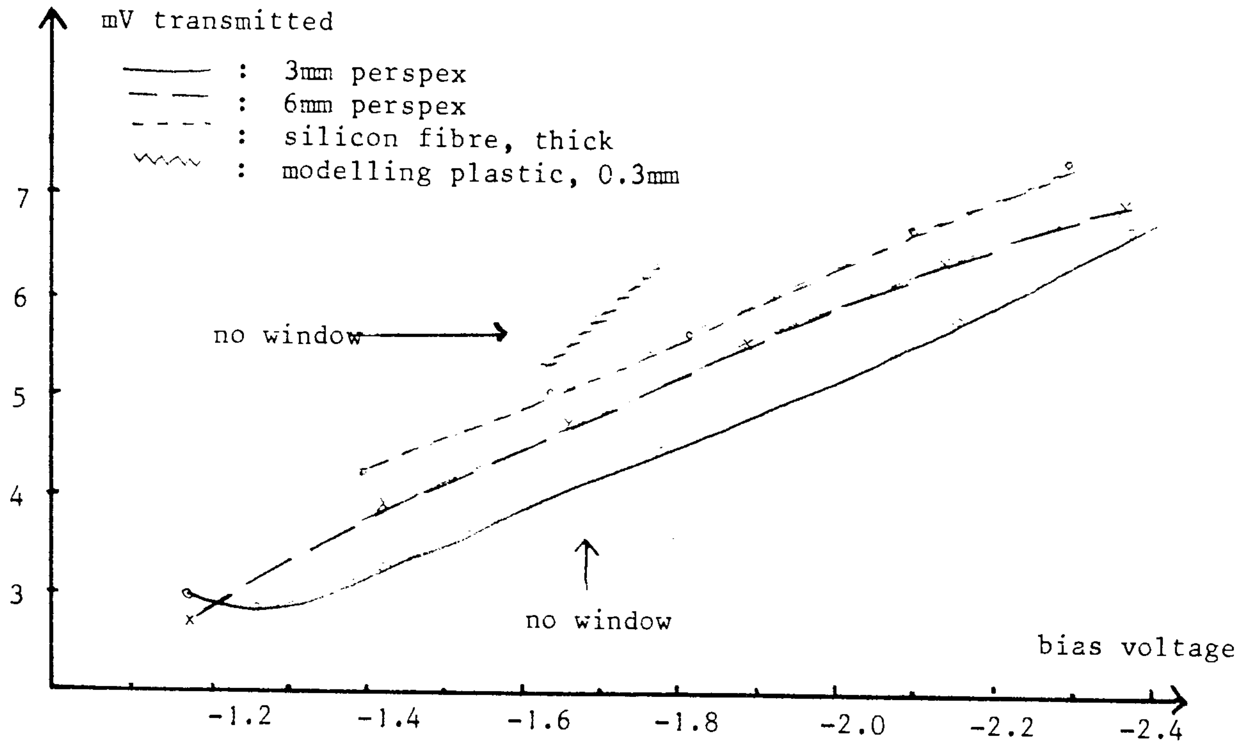
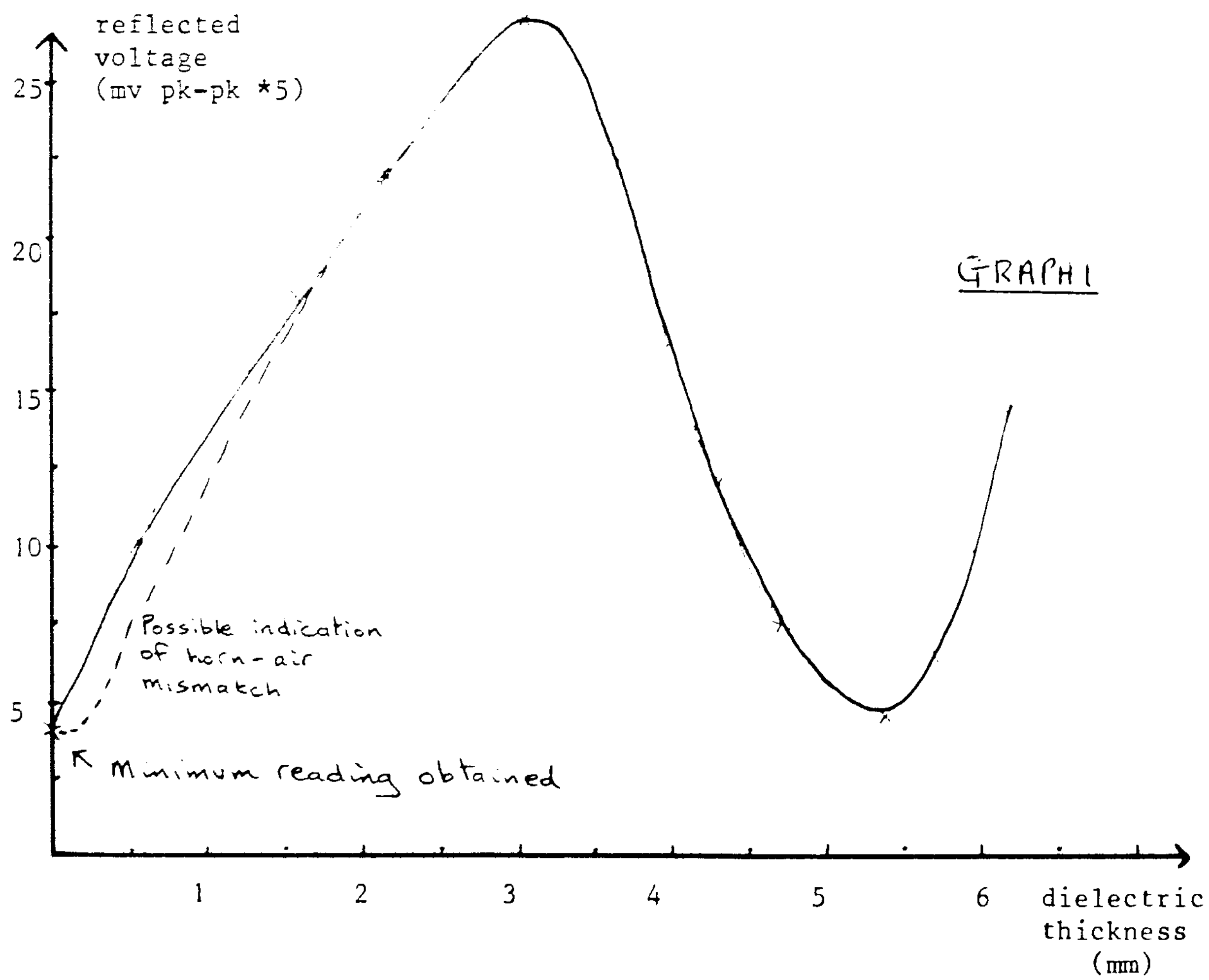


table 0.

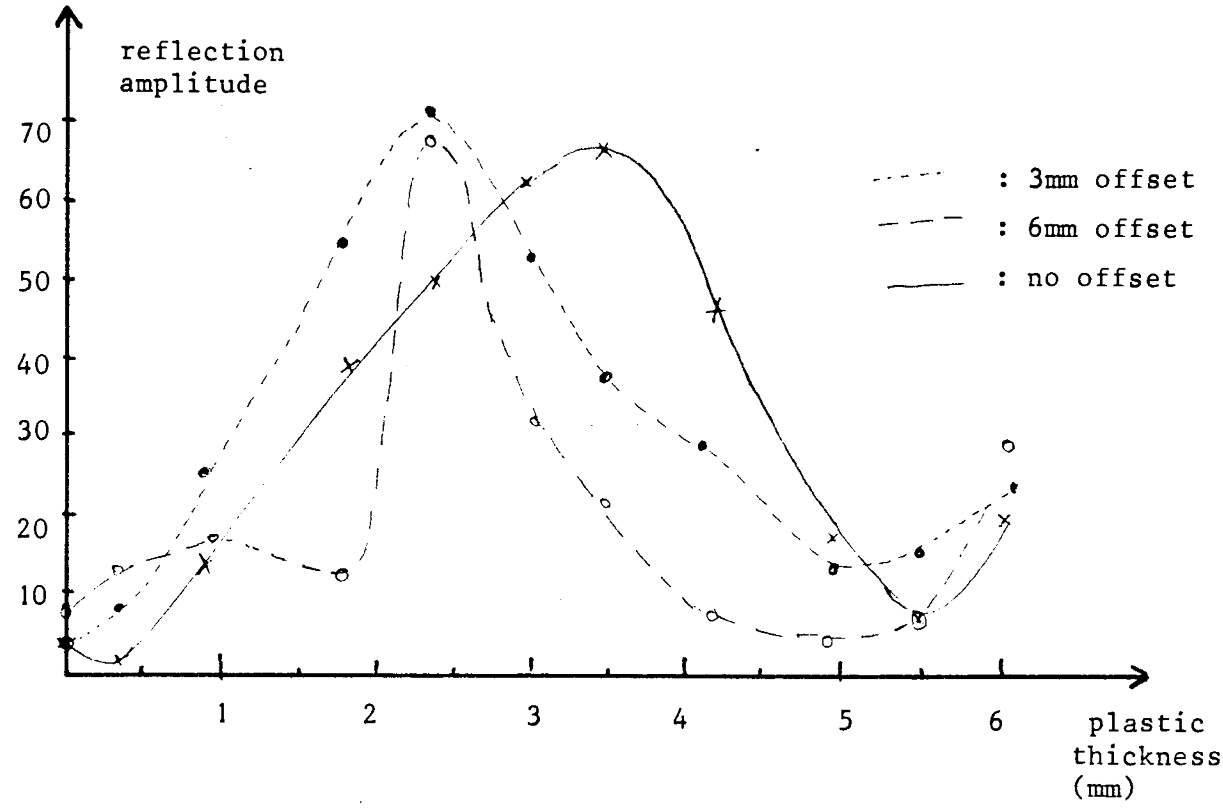


PLOT OF THE VARIATION OF BIAS VOLTAGE AND TRANSMITTED POWER FOR VARIOUS WINDOWS. The ambient condition is also indicated.

GRAPH 0

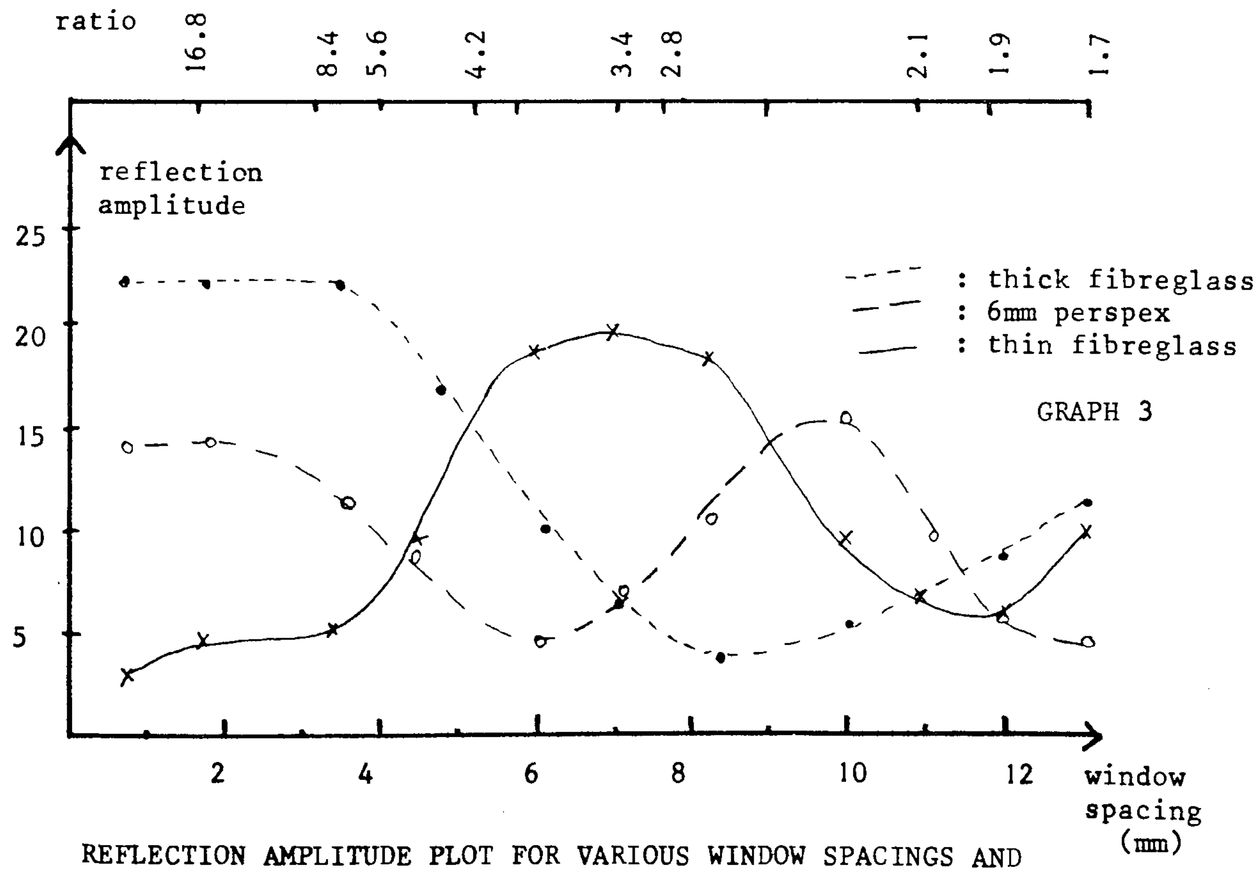


PLOT OF SIGNAL AMPLITUDE REFLECTED FROM A PLASTIC WINDOW FOR THE THICK? NESS RANGE to 6.2mm

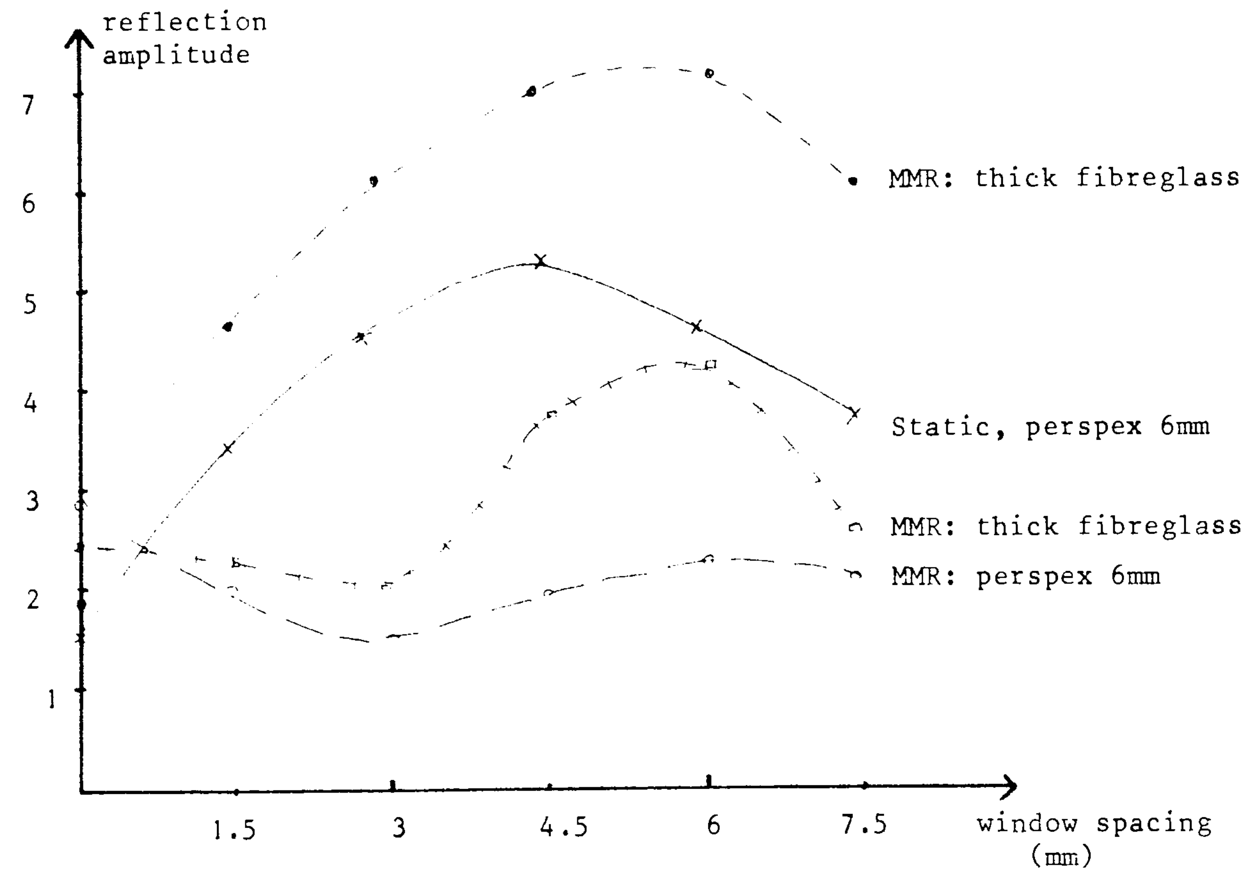


PLOT OF REFLECTION AMPLITUDES FROM A PLASTIC WINDOW PLACED THREE DISTANCES FROM THE HORN MOUTH, RESULTS FOR A RANGE OF WINDOW THICKNESSES BETWEEN 0 AND 6mm ARE PLOTTED.

GRAPH 2

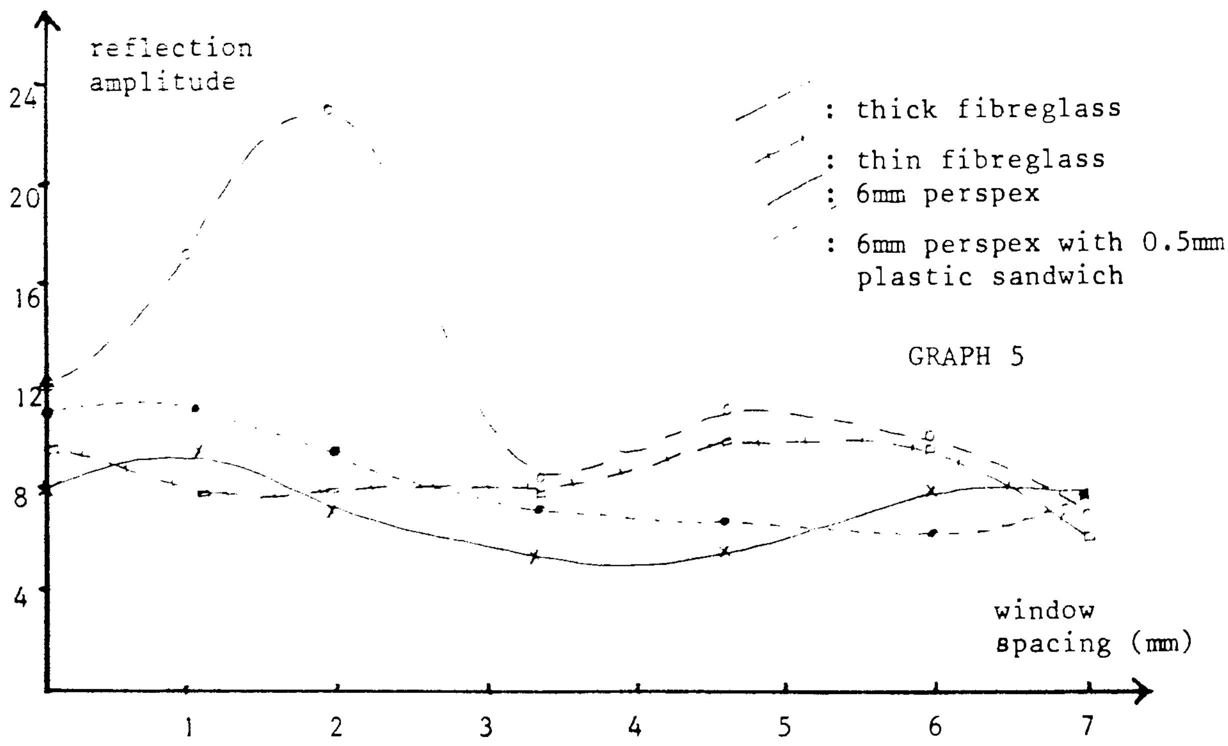


REFLECTION AMPLITUDE PLOT FOR VARIOUS WINDOW SPACINGS AND THREE WINDOW MATERIALS. The wavelength/refractive index ratio of thin fibreglass is also indicated.



REFLECTION AMPLITUDE (in terms of MMR and static) FOR TWO WINDOW MATERIALS AND SEVERAL WINDOW SPACINGS. PERFORMED BY SLIDING A WASHER ON THE E-PLANE AXIS FOR THE MMR: AND A STATIC WASHER CENTRALLY LOCATED FOR THE STATIC MEASUREMENT.

GRAPH 4a,b



GRAPH 5

REFLECTION AMPLITUDES FOR VARIOUS WINDOW MATERIALS AND SPACINGS. THE HORN WAS RETUNED (for minimal S/N) AFTER EXPERIMENT 4a,b.

PROTOTYPE WINDOW

The half-wavelength window construction provides a useful means of testing theory against practice, but the design is a compromise. For example, advantages are:

- the window can be made strong, being thick and flat; it can withstand significant impact
- materials and construction are cheap (although defined impedance materials and custom-thickness materials can be very expensive
- easily cleaned and will remain fairly clean.

Disadvantages include:

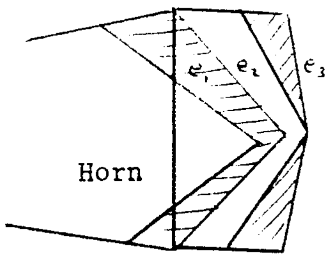
- frequency sensitive: needs very accurate machining
- side thickness 'bends' some of the beam, making the unit sensitive outside its nominal beamwidth
- for a low VSWR, the material must be of very low dielectric constant, which usually means an impractical material.

Thus, alternatives to this window type were sought. In the absence of literature on this subject, elementary physics texts were consulted, and an 'invisible' window was proposed (see appendix 3.12). This window is designed for incidence only, the design is frequency independent, and excluding the dielectric constant, can be made out of any unspecified material. To test the design, three prototypes were constructed. Design 1 worked well, but the flat top collected irt. Design three is large, but does not collect dirt. To reduce the protruberance of design 3, the inside was filled with polystyrene which reduces the required angle of incidence in proportion to the arctan of the ratio of the root of the dielectric constant. The polystyrene itself is fairly invisible to the radar. However, for e = 1.4 for this material, the incidence angle is reduced by 4 degrees. A higher dielectric constant material would then not be invisible to the radar. To overcome this problem, a sandwich technique was devised:

e_1 = 1.1 angle = 46 deg

e_2 = 1.8 = 52 deg

e_3 = 2.5 = 50 deg



For a single dielectric-air boundary, the smallest angle is tan 1, ie 45 deg. To summarise this design's performance compared to the concertina and half-wavelength slab:

PARAMETER	PYRAMIDAL	CONCERTINA	SLAB
strength	average	strong	v.strong
cost	cheap	cheap	average
dirt gathering	ok	poor	ok

ease of cleaning	OK	hard	easy
freq sensitivity	none	none	very
thickness "	none	none	very
VSWR	v.low	v.low	med
protrusion	large	small	small

INITIAL RESULTS AND DISCUSSION.

50 materials were tested (including thickness variation) in the manner previously described.

Table one lists numerous materials, and states the reflection amplitude maxima and minima. Air has an MMR of unity, and RAM of 1.3. Several interesting results were obtained: the contour of the reflecting surface contour matters more than radical changes in material composition as exemplified by the reversal of the RAM sample. Thin expanded polystyrene presented an almost invisible target; thicker samples can be seen to be critical: the perspex sheet results indicate a very significant improvement for certain material thicknesses. It is noted that for perspex, 6mm represents almost exactly a thickness of one half-wavelength. This fact is examined later. Compound windows also gave some promising results: five layer constructions giving excellent MMR's.

Graph 1 examines the relationship between material thickness and MMR using modelling plastic as a sample material; this plastic being available locally in numerous thicknesses which were combined to achieve fine increments necessary to plot an accurate graph. Materials of a half wavelength produce minimum MMR's: this minimum being the same as materials a thirtieth of a wavelength (or less) thick. Max MMR occurs at just above $\frac{1}{4}$wavelength. The discrepancy between the maximum and the exact $\frac{1}{4}$ thickness is thought to be due to the 'laminated' nature of the material: for optimum performance the material must be homogeneous to reflection, although for optimum transmission the layers are of less concern. Thick homogeneous samples were not available.

Graph 2 plots MMR for a range of plastic thicknesses offset by three distances. Max MMR corresponds to different thicknesses for different offsets. Minimum MMR remains at half-wavelength for all offsets. The greater the offset the 'peakier' the graph (teh lesser the range over which the material thickness makes a reflector). Thus for an arbitary plastic thickness, an offset can improve the possibility of a low MMR window. This phenomenon is thought to be due to the non-integer wavelength length of the horn. To delve further into this phenomenon would require much time, and thus is not examined.

Table 2 tabulates readings of reflection amplitude for a series of materials placed flush with the horn mouth. The kapton results are surprising. In general, either a half wavelength or a very thin slab is expected to provide the lowest reading. Modelling plastic exhibits the same phenomenon. A dip is apparent, however, between 0 and 1mm thick. This remains unexplained. Placing a thin plastic sheet between perspex reduces the reading far below perspex itself, but not below some thicknesses of plastic alone. The thickness of plastic alone and in a perspex sandwich do not give commensurate incremental results.

Table 3 gives values for flush, and MMR (with a retuned horn). The face and maximum readings increase with material thickness (and correspond with graph one): the minimum readings however reduce for thicker plastic. The MMR dips for thicknesses in the 1.2mm thickness range: the inverse of the measured readings. IF the MMR is calculated by taking the higher of the face or offset reading as the numerator, the results still follow the same pattern.

Table 4 lists parameters for several types of sandwich with single thickness comparisons. A polystyrent thickness of 4mm gave better results than a thickness of 4,5 or 5mm, although both are nearer the nominal ¼ wavelength. In general, air would seem to be a better filler than expanded polystyrene, although the dielectric constants of both are very similar. It is a possibility that in the case of polystyrene, the bead-type construction confuses the results.

Table 5 lists material locally available, and their parameters. Table 5B lists values for typical samples of material: data derived from materials databooks. Some materials have different dieiectric constants quoted, depending upon the source of information: thus the importance of the table of locally available materials.

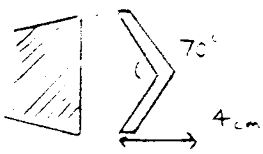
Table six lists, in order of MMR, materials with low MMR.

Graph 3 illustrates the reflection amplitude for a range of spacings and three window materials. A spacing of 12mm gives a very low amplitude for all materials. All spacings below this give divergent results. Whilst the fibreglass materials gave a peak and hump respectively at around 6 to 8mm, perspex gave a double hump.

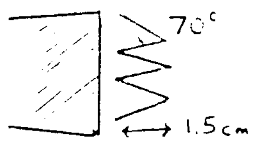
Table 7 lists the parameters thought to be important in the selection of a suitable window material. Notes on table seven now follow:

1. Test ASTM D570-63T: measure of percentage gain of water over 24 hours. Water has a high dielectric constant and significant absorption will affect window match,
2. ASTM D150-64T
3. ditto: neasure of the phase angle. A low value is required.
4. d: discolours; c: crazes; n: none
5. g: good; vg: very good
6. ASTM D256-56. Units ft.lb/inch. Nothc impact test
7. Range for colours. Clear = low MMR, opaque = high

The above notes are extracted from ASTM (1967) and MPE (1968).
Graph 5 plots refection amplitude for a range of standoffs. The spacing for minimum reflection is now 3.5mm and 8mm: results widely different from graph 3. The nulls indicated above correspond for all materials, suggesting a better horn-microwave match. This suggests that this match affects the window match significantly. The low readings correspond, approximately, to ½ and ¼ wavelength spacing or ⅓ wavelength (with respect to the dielectric and the 'free space' respectively). Graph 4a and 4b record reflection readings for a simulated point of interference on a window (rain or mud). A washer was moved on-axis: the size of the washer was 6mm diameter, corresponding to a very large reflective target. Results are plotted for perspex, and thick fibreglass. These graphs should be considered an indication of trend only: an inadequate number of points were plotted for detailed and meaningful analysis.
The similarity of the graphs is obvious, however, with minima occurring around 8mm spacing. This is the same as graph 5, suggesting that considering a homogeneous window is similar to considering a highly reflective and localised target.
An important observation is that for the same target, the window material DOES affect the severity of the mismatch. COmparing graphs 5 and 4, the material giving the highest reflection amplitude continues to do so even when grossly mismatched by a metallic target resting on the window. TEH lower section of the MMR of graphs 4a and 4b fall at a 3mm spacing: the same figure as on graph 5.
Table 9 list the power maxima and minima and respective distances from the horn mouth of a Plessey X band unit and prototype horn. These readings were derived by measuring transmission through the window rather than reflection through it. To ascertain the effect of reflection, the mixer bias was monitored. In this table, the VSWR is defined as the wavelength divided by twice the distance from a max to a min times pi; and the MMR is a ratio of received powers, and not voltages. The prototype design is given below (no.3) (and no.4)



1mm model
plastic



No further maxima or minima discernible: indicated by '5'
The experimental arrangement for this table was as shown below. The DMM is a digital multimeter; PM is a power meter (X band)
It can be seen that th prototypes give very good results in terms of VSWR and MMR, and also the lowest increase in mixer bias. The design method for these prototypes is given in appendix 3.

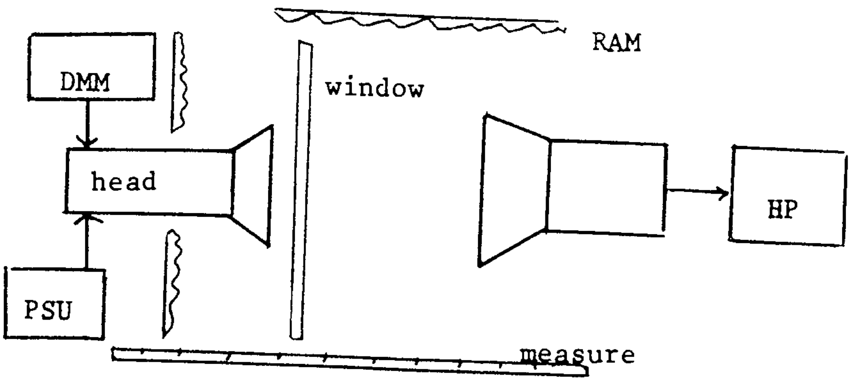


Table 10 gives the results of using the previous window materials on a Marconi unit in the usual reflection (voltage) arrangement. Again, the prototypes give excellent results, giving a VSWR almost approaching that of air. MMR was also low, and lowest for prototype 2. Type 3 was roughly constructed and is an attempt to give a window possessing the excellent characteristics of prototype 1 and 2 but that will not gather dirt. The VSWR measured with the result is very surprising: and further research will tell whether a precision designed and built window will indeed be, effectively, invisible. Table 11 gives further results for the same window types, but with the Marconi unit pointing at a distant target: prototype 3 again gives very low reflection ratio. In this instance, better than expanded polystyrene. The design of the 3rd prototype creates problems: the window protrudes 10.5cm forward of the horn. FIg 11 shows the results of attempting to flatten this shape. Only limited success was achieved.

Table 11b illustrates the transmitted power variations measured for four window displacements. Significant power variations occur (over 3:1). The next section examines plastic windows in an attempt to reduce this power variation to under 10%.

7. PROPIETARY WINDOW

In order to assess the effectiveness of propietary window materials, both accurately machined and standard (as supplied) thicknesses, a series of experiments were carried out.

A 7/32" (inches will be used here since the material is delivered measured in imperial units, and the vernier available is also calibrated in such units) slab of Micanite was obtained which was reduced in increments by sanding with aluminium oxide paper. The thickness was checked with the vernier to ensure a consistent overall thickness to within one thou. For each thickness the residual level (amount of reflected signal, in terms of voltage) was measured. The data supplied with the sample was:

Manufacturers stated thickness: 0.219 ins +- 0.015
Dielectric constant: 4

However, the measured thickness varied over the slab between 0.227 and 0.238". Upon questioning, the manufacturers also supplied the dielectric constant of typical batches: these being 4.03, 4.06, 4.16, 4.08, 3.96, 3.91 and 3.92. The frequency used for these tests was 13.65GHz, giving, for the batch average dielectric constant of 4.017, a half wavelength thickness of 0.216". Graph six illustrates the results obtained. On the graph are also marked the stated and measured sheet thicknesses, and the batch tolerance (in terms of thickness and dielectric properties). It can be seen that for minimum reflection of energy the window must be accurate to 8 thou. Combining possible errors due to batch thickness and dielectric variation gives an error (compared to the required half wavelength thickness) of up to 22 thou. Thus the material requires accurate machining for good results. The dielectric tolerance of the material is adequate, giving a possible error of only 6 thou.

The above experiment determined the voltage reflected from the window. However, the intention of this report is to ascertain a window material that interferes minimally with the transmission/reception process. Thus power loss is not necessarily of primary concern: given that the mixer bial is not pulled too far (resulting in a transmission frequency shift) then adequate results can be obtained by carefully selecting a standard thickness plastic window if certain conditions are fulfilled. For example if the batch thickness of such a material is adequately constant, transmission losses can be tolerated. A chart of nominal thickness against dielectric constant appears in graph seven. The dielectric values of seven common plastics are also indicated, but care must be taken as the colour significantly alters this value (indicated in table 5a).

Thus, grey polypropylene has a dielectric constant of 2.5, corresponding to a required thickness of 9mm. This is exactly as needed: 9mm is a stansard manufacturing thickness. The variation in thickness of the sample used was 0.01 inches, giving an adequate possible maximum and minimum effective thickness.

Five plastic windows were tried (see table twelve): all readily available, and with the exception of acetal, relatively cheap. It can be seen that two windows gave good results: grey polypropylene and grey PVC.

MATERIAL	READING (mv pk-pk)			THICKNESS	NOTES
	MAX	MIN	MAX/MIN	(mm)	
Perspex	31	1.5	20.7	3	
	3	1.2	2.5	6	
	28	1.8	15.6	9	
polystyrene	2.8	1.5	1.9	90	
	2.1	2.0	1.1	14	
ecofoam FPH	4	1.3	3.1	11	e = 1.2
	5.2	1.6	3.3	35	
	3.8	1.8	2.1	46	
silicon	26	2.2	11.8	1	e = 4.7
	8	2.2	3.6	0.2	
kapton	4	1.5	2.7	0.05	
perspex	34	4.5	7.6	4	toughened
	6.2	2.2	2.8	8	
foam	2.5	1.5	1.7	28	upholstery
RAM	1.4	1.1	1.3	100	inward pointing
	5	1.21	4.5	100	outward "
bakelite	38	3.5	10.9	3	
	35	6	5.8	6	
persopex	24	1.5	16	2	cheap
metal	75	4	18.8	2	aluminium
air	2.2	2.2	-	-	
plastic		see graph one			
compound	4.2	1.5	2.8	3/2/3	pe/pl/pe
	8	2	4	3/5/3	pe/pl/pe
	7.8	1.5	5.2	1/3/1	pl/pe/pl
	3	2.2	1.4	2/3/1/3/1	pl/pe/pl/pe/pl

MAXIMUM AND MINIMUM REFLECTED SIGNAL STRENGTH FOR A RANGE OF WINDOW MATERIALS. MAXIMA AND MINIMA WERE ONLY MEASURED BETWEEN 2 and 8cm FROM THE HORN MOUTH.

TABLE ONE

PLASTIC THICK (mm)	READING (mv pk-pk) FACE	MAX	MIN	MAX/ MIN	FACE OR MAX/MIN	% REFLECTED POWER
0.2	2	4	0.6	6.7	6.7	55
0.3	3.5	6	0.9	6.6	6.6	52
0.5	7	7.5	1.5	5	5	45
0.7	13	14	3.5	4	4	35
1.0	11	12	5	3.5	3.3	30
1.2	28	15.5	7.5	2.1	3.7	35
1.3	30	22	7	3.1	4.3	39
1.5	32	23.2	2	11.6	16	70

REFLECTION AMPLITUDES FOR A RANGE OF MODELLING PLASTIC THICKNESSES: THE FINAL COLUMN INDICATES THE PERCENTAGE REFLECTED POWER FOR THE GREATER OF THE MAX/MIN RATIOS.

TABLE THREE

MATERIAL	CONDSTRUCTION	THICKNESS (mm)	READING (mv)
Plastic		0.3	1.0
air			1.2
ecofoam	fph, medium density	40	1.2
polystyrene	expanded (dense)	60	1.3
ecofoam	fph, medium density	10	2.0
kapton	two sheets		2.2
sandwich	perspex/plastic/perspex	3/1/3	2.2
plastic	modelling	0.2	3.5
		0.5	3.6
kapton	one sheet		3.6
sandwich	perspex/plastic/perspex	3/0.7/3	5.0
		3/0.5/3	6.1
kapton	three sheets		6.2
fibreglass	thin		7.5
plastic	modelling	0.75	11
sandwich	perspex/plastic/perspex	3/0.2/3	11
		3/0.3/3	12
kapton	four sheets		14
	five sheets		22
perspex		6	22
plastic	modelling	1	22.4
fibreglass	medium		26
	thick		36
perspex		9	46
fibreglass	very thick		48
perspex		3	52

READINGS OF VOLTAGE REFLECTED FROM A RANGE OF WINDOW MATERIALS. ALL READINGS TAKEN FLUSH WITH THE HORN MOUTH. UNITS ARE mv pk-pk multiplied by five.

TABLE TWO

CONSTRUCTION				READING			
OUTER	MM	INNER	mm	FACE	NON-FACE MAX	MIN	MAX/MIN
thin si	0.2	exp poly	5	6	16	1.8	8.9
plastic	1	"	"	22	35	5	7.0
perspex	3	"	"	80	120	12	10
metal	-	-		180	200	20	10
plastic	0.2	"	"	0.5	4.5	0.5	9.0
	0.3	"	"	1.0	6.5	1.5	4.6
	0.3			1.2	1.3	0.5	2.6
	1.0	"	5	14	28	2.5	11.2
	1.0	"	4.5	12	24	1.5	16.0
	1.0		4.0	12	20	5	4.0
fibreglass	0.2	"	4.0	2	5	0.5	10.0
	0.2			11	7	1.5	4.7
	0.2	air	3	17	6	1.8	3.3
	0.2	air	6	1.2	7	1.4	5.0

REFLECTION AMPLITUDES FROM THREE-LAYER SANDWICH WINDOWS.

TABLE FOUR

MATERIAL		e	thick	notes
acetal		3.7	7.27	a,c
acrylic	clear	2.2	9.44	a,c
	opaque	2.6	8.68	c
	tinted	2.4	9,.04	c
	dense	3.2	7.83	
nylon 66		6.0	5.72	a,c
polyprop.	natural	2.0	9.90	a,c
	beige	2.2	9.44	a,c
polythene	clear	2.25	9.33	a,c
	opaque	2.3	9.23	
	dense	2.35	9.13	a,c
PTFE		2.1	9.66	b,c
PVC		3.0	8.08	a,c
polyurethane		2.5	8.85	
polyurethane foam		1.1	13.3	
" dense		2.0	9.9	
teflon		2.1	9.66	d
polystyrene		2.55	8.77	
microfibre teflon		2.4	9.04	
silicon fibreglass		4.7	6.46	

KEY:

a: £1.10 /ft sq/0.3cm
b: £4.50 /ft sq/0.3cm
c: available from local supplier in thicknesses of 3,6 9 and 12mm.
d: up to £30/ft sq/.25 cm

all e (dileectric constant) values to ASTM D150 test

TYPICAL WINDOW MATERIALS: THEIR DIELECTRIC CONSTANTS AND THICKNESS REQUIRED FOR A HALF-WAVELENGTH THICKNESS AT X BAND.

TABLE FIVE

MAX/MIN RATIO	MATERIAL AND THICKNESS	(mm)	% RELFLECTED POWER
1.0	air		0
1.1	expanded polystyrene	14	0.2
1.3	RAM		1.6
1.4	sandwich: plastic/pe/plastic	.2/3/.2	2.1
1.7	foam (upholstery)	30	5
1.9	polystyrene	90	7
2.1	ecofoam fph	46	10
2.1	plastic	1.2	10
2.5	perspex	6	15
2.7	kapton	.05	19
2.8	perspex/plastic	3/.2	20
2.8	perspex	8	20
3.0	plastic	1	25
3.1	ecofoam fph	11	26
3.3	fibreglass/air	.05/3/.05	28
3.3	ecofoam fph	35	28
3.6	silicon fibreglass	.05	31
4	plastic/perspex/plastic	1/3/1	35
4	plastic/expanded posystyrene/plastic	1/4/1	35

RATIO OF MAXIMUM AND MINIMUM REFLECTED SIGNAL AMPLITUDES FOR A RANGE OF WINDOW MATERIALS.

TABLE SIX

FACTOR	MATERIALS ABS	ACETAL	ACRYLIC	NYLON66	POLYCARB
1	.1-.8	.22	.4	1.5	.15
2	2.7-4.8	3.7	2.2-3.2	3.6-6	3
3	.7-3	.4	2-4	2-6	.9
4	g	vg		g	g
5	g	g	vg	g	g
6	3-12	2.3	.3-.5	.6-6	12-17
	PCARB *7	PTHENE *8	PTHENE *9	POLYPROP	POLYPROP *10
1	.35	.02	.01	.01	.1
2	3.4	2.3-2.4	2.3-2.4	2.2	2.6
3	1.3	.05	.03	.01	.4
4	g	vg	vg	vg	vg
5	g	g	vg	g	g
6	8-13	20	1.5-12	.5	1-5
	SIL FIBRE	PTFE	PIGID PVC	POLYESTER	CELL. ACETATE
1	.1-.2	0	.05	.1	2-7
2	3.2-4.7	2.1	3	4.2-5.8	4-5
3	.2-2	.02	.6-2	1.6	3-4
4	p	p	p	p	g
5	g	vg	g	g	
6	3-15	2.5-4	1-3	7-22	

NOTES:
1. Water absorbtion (% per 24 hours)
2. Dilelectric constant
3. Loss factor
4. Effect of surlight
5. Effect of oil
6. Impact strength
7. Filled polycarbonate
8. Low density
9. High density
10. Inert polyoropylene

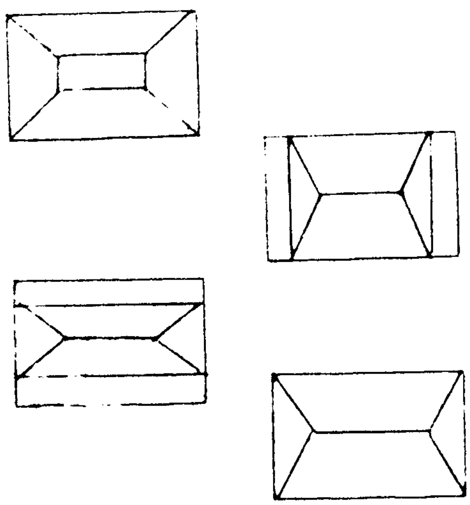
PARAMETERS OF COMMONLY AVAILABLE PLASTICS. Only those parameters and plastics suitable for microwave windows are considered. TABLE 7

Various sizes of 'snub nose' were tried: all gave poor results

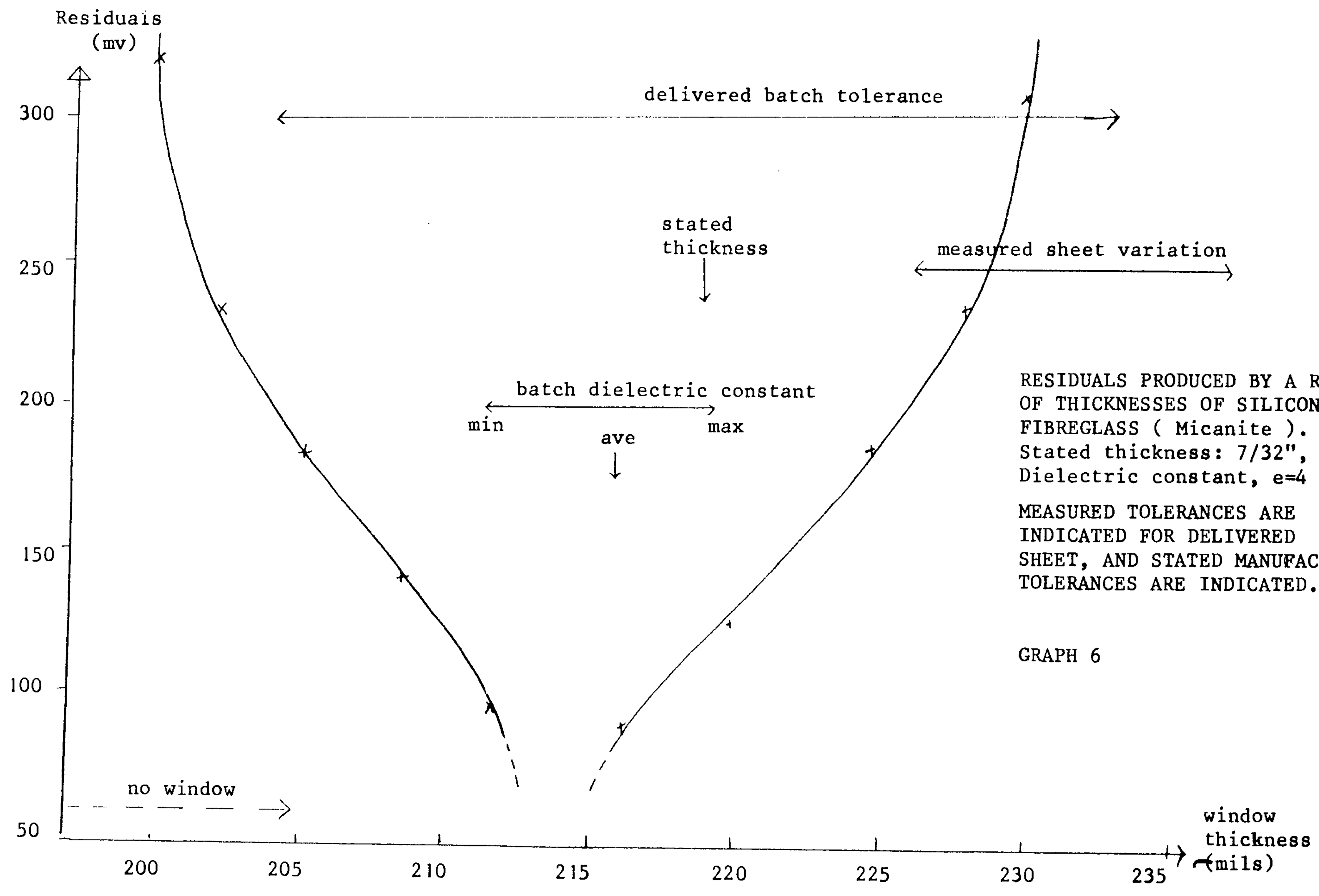
1cm wide gave no degradation in performance. Over 1cm did.

any width gave a degradation

standard prototype no. 3



BREWSTER-ANGLE 'RADOME' TYPE WINDOWS TRIED. FIG 11



RESIDUALS PRODUCED BY A RANGE OF THICKNESSES OF SILICON FIBREGLASS (Micanite). Stated thickness: 7/32", Dielectric constant, e=4

MEASURED TOLERANCES ARE INDICATED FOR DELIVERED SHEET, AND STATED MANUFACTURE TOLERANCES ARE INDICATED.

GRAPH 6

WINDOW MATERIAL	POWER/DISTANCE				BIAS @ FACE	VSWR	MMR	%BIAS INCREASE	%REFLECTED POWER
	FACE	MAX1	MIN	MAX2					
none	0.53				1.69	1	1	0	0
Sil Fibre (thin)	0.51	0.56/13	0.48/17	-/27	1.64	1.11	1.16	2.9	0.5
Sil Fibre (thik)	0.38	0.64/5	0.34/14	-/25	1.45	0.49	1.88	14.2	9
Perspex 6mm	0.34	0.6/4	0.28/11	-/21	1.16	0.63	2.14	31.3	11
Perspex 3mm	0.27	0.65/8	0.3/13	-/24	1.19	1.11	2.17	29.6	12
Plastic 1mm	0.47	0.62/8	0.43/17	-/22	1.58	0.49	1.44	6.5	3.5
Plastic 0.2mm	0.52	0.56/12	0.49/22	-/21	1.67	0.45	1.14	1.1	0.4
Polystyrene 8mm	0.53	0.53	0.53		1.68	1	1	0.5	0
Perspex S.wich 0.1mm	0.43	0.62/4	0.42/12		1.38	0.56	1.48	18.3	3.6
Prototype No 1	0.53	0.56/13	0.53/25	-/5	1.65	0.37	1.05	2.3	0.06
Prototype No 2	0.52	0.54/9	0.51/23	-/28	1.68	0.32	1.05	0.5	0.06

Notes: Power in mW, distance in mm, bias voltage in -V.

WINDOW MATERIALS AND THEIR EFFECT ON MICROWAVE UNIT BIAS AND POWER TRANSMISSION.

TESTS PERFORMED USING A PLESSEY UNIT AND PROTOTYPE HORN.

WINDOW	REFLECTION AMPLITUDE face	max	dist	min	dist	max 2	VSWR	MMR	%RP
none	45								
perspex	100	110	4	30		11	1.49	3.33	30
polystyrene	50	51	9	50				1.02	0?
sil. fiber	95	105	10	60	11	17	4.5	1.8	5.5
" thick	200	160	9	60	6	1.1	1.5	2.7	24
plastic 1mm	105	130	4	40	3	6	4.5	3.3	30
proto 2	45	48	8	35	3	11	.9	1.4	1.5
proto 2a	45	55	9	30	4	12	.9	1.9	8
proto 3	50	62	4	35	13	16	.22	1.8	4.5

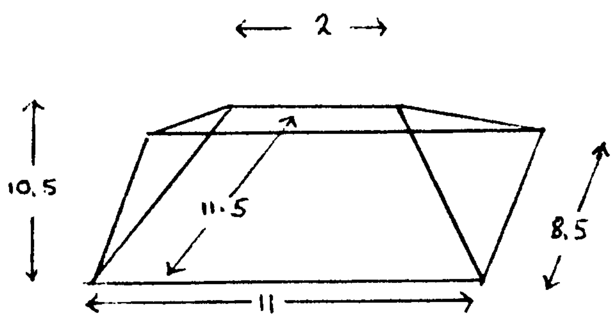
notes: distances in mm, VSWR is wavelength / (2.pi. min-to-max dist), MMR is defined earlier. RP is reflected power.

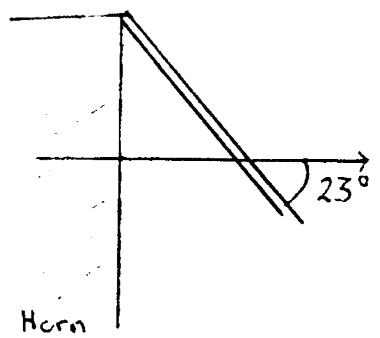
TESTS ON MARCONI UNIT: A SELECTION OF WINDOW MATERIALS THE PERCENTAGE OF POWER REFLECTED IS INDICATED. TABLE 10

WINDOW	REFLECTION AMPLITUDE face	max	min	TARGET DIST	MMR	%RF
none	9				0	0
proto 3	12	18	13	2m	1.4	2.5
sil fibre thin	80	60	16	2m	3.8	30
sil fibre thick	140	110	28	2m	4	32
perspex 6mm	85	100	16	2m	6.3	50
polyst 8cm foam	22	24	16	2m	1.5	3

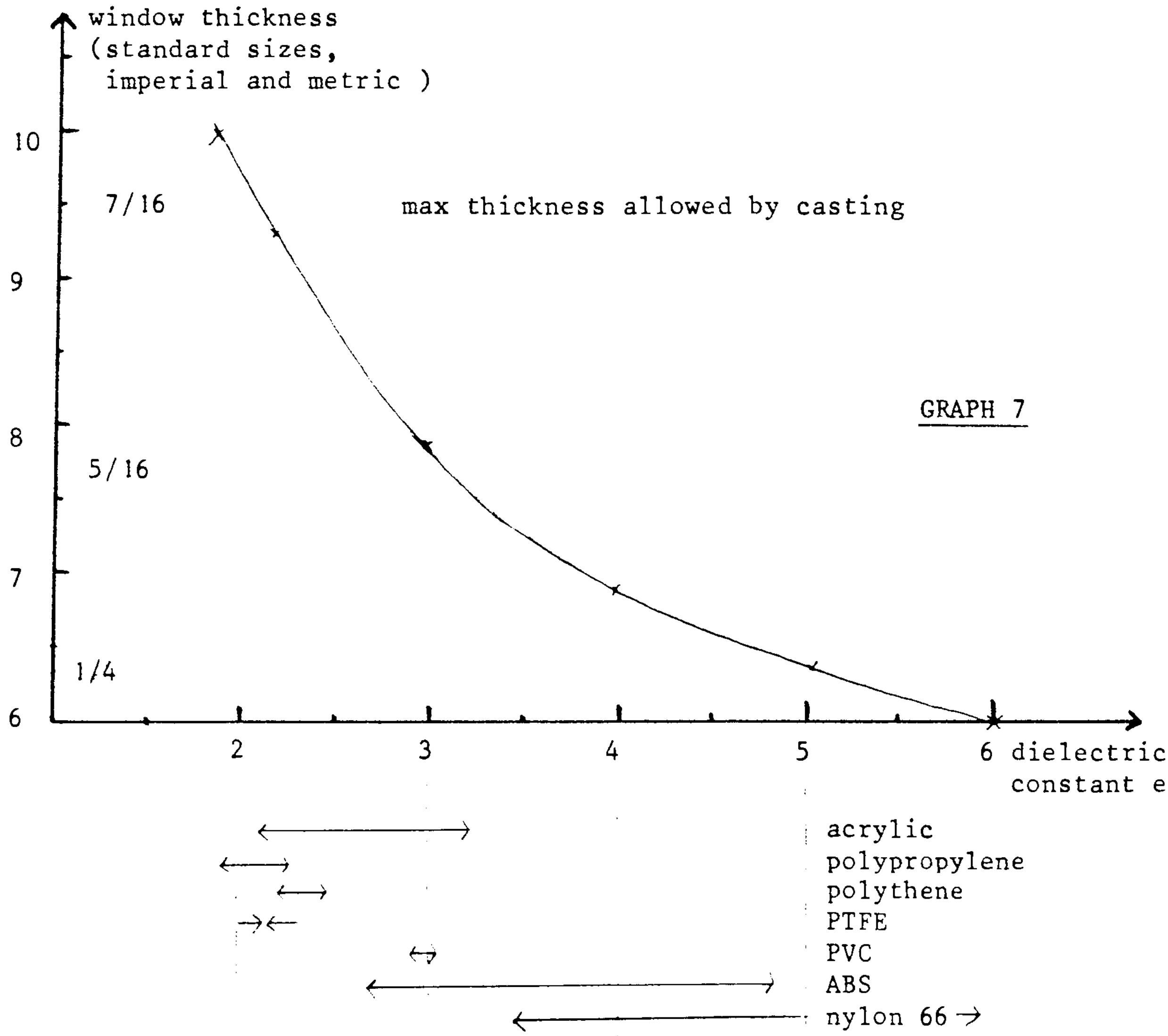
WINDOW	POWER	
one	5	
sil fibre 1mm	3.6	0
	6.2	9mm
	3.2	12mm
	6.0	17mm
mica 3/16"	2.6	0
	6.2	3mm
	2.0	5mm
	6.2	12mm

TABLE 11a and 11b: MMR AND FACE REFLECTION AMPLITUDE FOR WINDOW TYPES: MARCONI UNIT WITH A DISTANT TARGET, nad POWER TRANSMITTED THROUGH WINDOW MATERIALS, DISPLACED FROM THE FACE. TESTS PERFORMED WITH THE MARCONI UNIT.





Material: 0.7mm modelling plastic. Dimensions in cm.
PROTOTYPE 3 DESIGN. DIMENSIONS.



PLOT OF THE REQUIRED THICKNESS OF WINDOW MATERIAL FOR A HALF-WAVELENGTH PATH FOR A RANGE OF DIELECTRIC CONSTANTS. A TRANSMISSION FREQUENCY OF 10.587GHz IS ASSUMED. THE RANGE OF AVAILABLE DIELECTRIC CONSTANTS AND PLASTIC TYPES IS ALSO INDICATED.

WINDOW	THICK (mm)	POWER MAX	POWER MIN	MIX BIAS MAX	MIX BIAS MIN	MAX/MIN RATIO	% REFL POWER
none		0.6	0.6	0.41	0.41	1	0
polyprop, white	9	0.6	0.52	0.4	0.43	1.15	0.5
polyprop, grey	9	0.6	0.54	0.4	0.43	1.11	0.25
PVC, clear	8	0.42	0.54	0.33	0.46	0.28	1.1.4
PVC, grey	8	0.59	0.48	0.41	0.43	1.22	0.85
acetal	6	0.5	0.38	0.33	0.47	1.31	1.7

FINAL PRODUCTION UNIT WINDOW SELECTION. THIS TABLE CONTAINS MEASUREMENTS MADE USING CORRECTLY BUILT WINDOWS AND A AS HORN.

table 12

APPENDIX ONE.

An alternative to purchasing plastic sheets for microwave windows is to mould foam. Ecofoam FPH (E & C), for example, can be moulded directly into the horn and faced smooth (and weatherproof) by facing the mould with a smooth waxed metal. Silicon grease was found ideal. The dielectric constant for the foam is 1.2 and the shiny surface increases this to 1.5 to 1.8. This technique also assists in the prevention of condensation problems in the inner window surface. The physical strength of this solution, however, is poor, and any imperfection such as a crack will allow water to be absorbed, with disastrous results.

APPENDIX TWO.

maxima and minima are located (Yarwood, 1973) at:

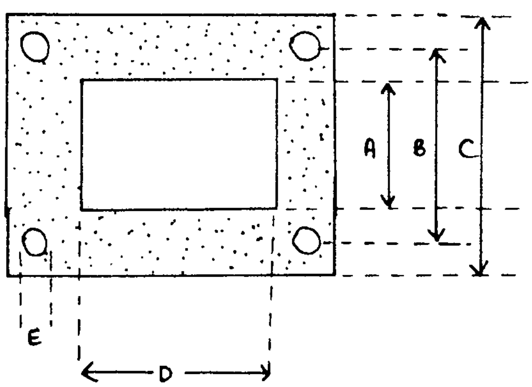
node: $(2n+1).\lambda/2$

antinode: $(2n+1).\lambda/4$ where n is 1, 2, 3, 4....

APPENDIX THREE.

Microwave unit dimensions: flange and horn.

FREQUENCY		10.6G	24G	13.5G
WAVEGUIDE		WG16WR90	WR42	
DIMENSIONS:	A	1.01	0.43	0.8
(cm)	B	3.25	1.63	2.6
	C	4.14	2.26	3.3
	D	2.29	1.06	1.55
	E	4.0	3.0	3.5
FLANGE		UG39/U	UG595/U	



SECTION 2.12

REPORT INT P21
16.1.84
C. WALLACE

ALTERNATIVE SPEED MEASUREMENT TECHNIQUES

SECTION

1. MAGNETIC TRANSDUCER:

   A DISCUSSION
   B FURTHER PROBLEMS
   C CONCLUSION
   D APPENDIXES

Magnetic Transducer. One means of measuring vehicle speed is by magnetic transducer. Truck manufacturers do recommend such units, but give basic data only (note 1). Caterpillar Tractor Co advocate (see appendix 1) certain transducers that were obtained and tested in order to establish their measurement accuracy. These results are given overleaf. For the correct output voltage, a minimum of 0.3V was required at 10mph, rising to 0.7V at 50mph. Such a voltage is difficult to generate: a problem covered later. It can be seen from the graphs that significant sample variations exist, notably in the case of the 7SM3601. In the frequency range of interest (corresponding to 15 to 30mph) the two readings deviate from each other by 4% and are up to 11% inaccurate. It is probable that other samples may well deviate further. Sample electronic speedometers were found to be more accurate: being within 1% tolerance throughtou the indicated range. However, not all governor casings have provision for such a magnetic transducer (Cat) and those that do have seemingly arbitarily fitted 3 or 6 hole idler gears. Appendix one plots serial numbers against part types: it can be seen that the fitting of such a transducer is, for practical reasons, very difficult.

For use in the 10 to 30mph range, the sensors are also scting out of their optimum frequency range (OpdenWinkel, 1983). Further problems appear when mechanical unreliability is considered. The optimum sensor to gear air gap is less than 1mm: difficult to achieve on an off-highway vehicle. In the field it is not unusual to find transducer failure and /or speedometer error in a significant proportion of trucks (see note two).

No sensor of the type considered (in fact, any system using wheel or engine revolutions as the basis for speed measurement) can deal with two sources of error: wheelspinwheelskid and tyre size variations. Wheelspin and skids are a common occurence on off-highway sites, not just in wet weather but on dry bumpy ground where the suspension characteristics allow the vehicle to leave the ground. In some wasy the problem is not serious: if enough spin occurs to alarm, the driver is either on the point of alarm whereupon a little spin tips the perceived speed over alarm speed, or the vehicle is travelling well below alarm speed and the road conditions (either wet and slippy or dry and bouncy) are bad enough to alarm. In both these cases it might be argued that the respective results are adequate, as in the former a possibly negligible error is introduced and in the latter the driver can be said to have been travelling too fast for the road conditions. This would be an oversimplification, however. THe former case will produce an alarm-cancel-alarm-cancel etc sequence as each wheel spin occurs. The latter case reduces the speed sensor to the role of a crude and inaccurate 'road condition' sensor, and sanctions the driver on conditions other than roadspeed.

Tyre size also can introduce errors that are almost impossible to compensate for. Each manufacturer and model is fitted with a different nominal tyre size: this can be compensated for by calibrating the processing circuitry for each specific application. A list of rim sizes for the more common dump truck models is given overleaf. Fourteen rim diameters are used. Within any one defined size, the ply ratings also differ, giving further diameter variations of several inches. Consulting tyre distributors in order to ascertain the exact tyre circumference pertaining to each nomimal rim size showed that standardised tyre sizes simply do not exist. Even if new tyres could be compensated-for, the wear allowance on an L^{5}T tyre indicates 10" allowable wear (for a tyre radius of 4' gives a possible velocity measurement error of up to 20%).

<u>Conclusion.</u> This discussion has considered only one transducer manufacturer. To cope with any eventuality, the serial number, make, model and tyre size of each individual truck would require noting, and an appropriate interface box would be required (note 3). Failure to account for these sources of discrepancy would introduce an unacceptable error into the measured speed.

Wheelspin cannot be compensated-for, and remains an intrinsic error. Mechanical unreliability can be minimised by careful selection of transducers and accurate installation, but the fact remains that the transducer designed for a specific model and serial number is still unreliable.

Given, therefore, the errors introduced by the undefined tyre size and wear, and the intrinsic errors of wheelspin, it is considered infeasible to use magnetic transducers to measure roadspeed to the required accuracy.

VEHICLE SERIAL NUMBER	IDLER TYPE	SPEEDO TYPE
1 to 95	6P2911	-
96 to 348	6P2911	9D8649
349 to 412	6P2911	7N1287
413 to 417	6P2911	7N6951
418 to 598	9P9266	7N6951

NOTES:

7N1287 = 7SM3601
7N6951 = 7SM3606A
(Motorola equiv)

from ref Cat 777

CROSS-REFERENCE OF CAT 777 VEHICLE SERIAL NUMBERS AND FITTED TRANSDUCER MODELS.

NOTES.

1. Caterpillar information:
   For Motorola 657772 transducer and a six hole idler gear, the Cat 777 will give 532Hz at 50mph, and the Cat 773 455Hz.
2. Based on Butterwell site fitter information
3. Interface box, possibly of the form:

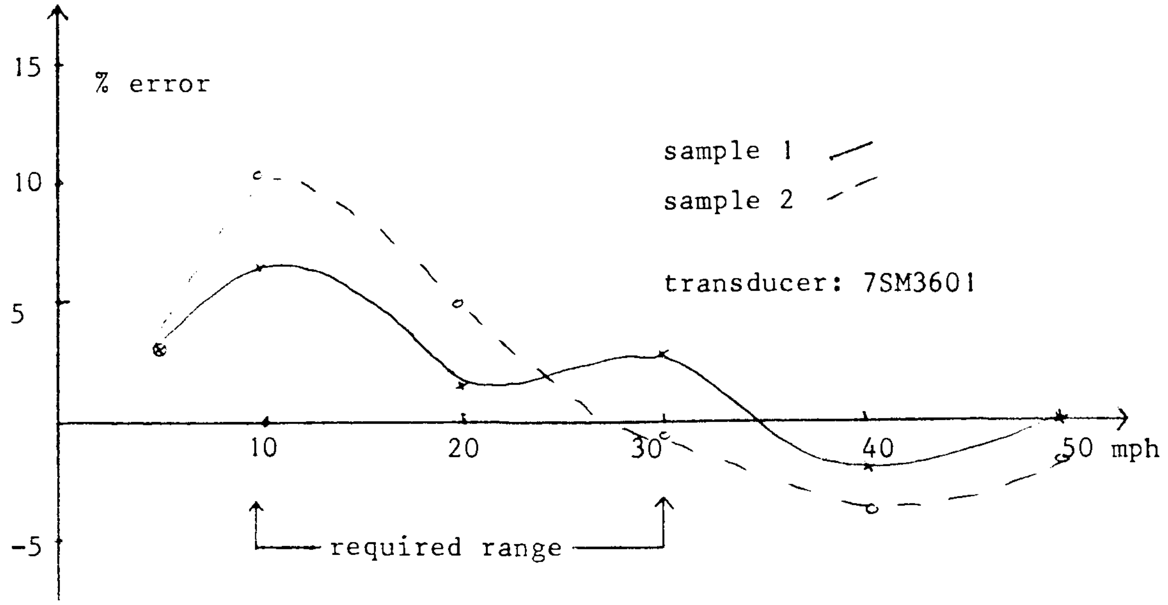
F/V → level shift → V/F

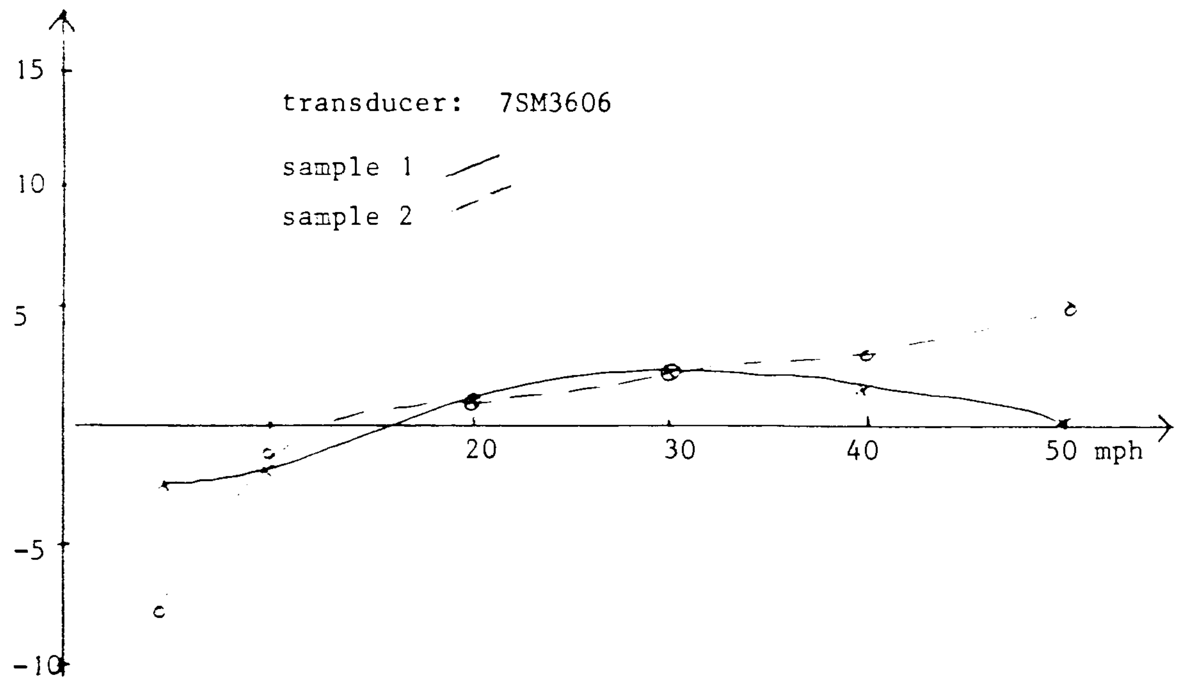
SURFACE TYPE	COEFF
concrete and asphalt	
hard dirt	0.45
smow	0.2
soft dirt	0.6
sand, dry and wet	0.2/0.4
clay loam	0.55/0.45
loose gravel dry/wet	0.35

COEFFECIENT OF TRACTION FOR TYRED VEHICLES ON A TYPICAL RANGE OF OFF-HIGHWAY SURFACES. (ref: Terex)

TYRE SIZE	COST	COST (user specified tread)
40.39	£8300	
45.45	£12200	£14300
65.45	£18500 (estimated)	£20500

EARTHMOVER AND DUMP TRUCK TYRES: COST EACH OF TYPICAL TYRES. (ref: Gyear 1980).





PERCENTAGE ERROR IN OUTPUT FOR A RANGE OF SPEEDS: TWO SAMPLES OF EACH OF TWO TRANSDUCERS (both as used on CAT 777 trucks, fitted with the ALBERT system). The plotted points are joined for guidance only: further readings are required for accurate graphical presentation.

TYRE	MAN	MODEL
10.20	d	232-D24k
11.20	v	N10
		N12
	d	232-D26
12.18	me	LK2624
12.20	m	32.240
	b	256
	me	LK2624
12.24	d	310DHLD
		310D32
	f	FC17
		FC27
14.24	f	RC20
		FC35
	e	R185
14.25	t	R17
	h	H20
15.20	ha	615
16.20	ha	620
16.25	e	R25
	k	425B
	ko	HD180-4
		HD200-2
16.28	ff	24.2
		26.2
18.22	m	32.240
18.25	t	R25
		R3305
	e	R35
	ab	RD70
		RD25
	ko	370-2
	k	442B
	h	H30
		H33
	b	545
	ff	35.4
	i	330
		350B
18.28	ab	RD25
		RD30
	c	769C
18.33	ab	RD35
		RD40GM
	c	769C
	t	R35B
	w	35C
	ff	40.4
	ko	370.2
	k	435
		445
18.36	ab	RD40CAT
21.32	c	773B
21.35	t	R50B
		330.7
	w	50
	ab	RD50
	c	773B
	e	R50
	ko	460
	ff	55.5
24.35	t	R70
		3309
	e	R75
	w	75B
	ko	680.2
24.42	c	77
24.49	e	R85
	t	3311
	w	85C
	ff	85.5
	c	777
27.49	e	R100
30.51	w	120C
	ko	1200
36.51	w	150C
		170C
		3700B
	t	T3315
	e	R170
40.57	t	3319

KEY.

c: Carerpillar
f: Foden
v: Volvo
m: MAN
ko: Komatsu
w: Wabco
me: Mercedes Benz
t: Terex
h: Heathfield
ha: Haulamatic
i: International
ab: Aveling Barford
e: Euclid
d: Deutz
b: Belaz
ff: Faun Frisch

TYRE SIZES FITTED TO COMMON DUMP TRUCKS. THE SIZES INDICATES ARE THE MANUFACTURERS RECOMMENDATIONS. THE NUMEROUS OPTIONS ARE NOT LISTED.

	7SM3601 (5.26Hz/mph)		7SM3606 (10.54Hz/mph)	
mph	1	2	1	2
5	27	27	51	49
10	56	58	103	104
20	106	110	211	211
30	160	157	322	320
40	207	202	427	431
50	263	258	527	545
40	207	202	420	431
20	107	110	211	211
10	56	58	108	109

FREQUENCIES REQUIRED TO PRODUCE VARIOUS SPEED EQUIVALENTS: VALUES GIVEN FOR TWO SAMPLES EACH OF TWO TRANSDUCER TYPES. Readings taken over two seconds. Instant readings give far greater deviations.

SPECIFICATION FOR:
GROUNDSPEED SENSOR UNIT.

Report INT P22
ISSUE 2.1
SECTION 2.13

		Approval	Mod No
1. INTRODUCTION	1.1 Intention		
	1.2 Scope of cover		
	1.3 Application		
	1.4 Requirement		
2. TECHNICAL SPECIFICATION			
	2.1 Physical		
	2.2 PSU		
	2.3 Transmitter		
	2.4 Receiver/processing		
	2.5 Output		
	2.6 Environmental		
	2.7 Housing		
	2.8 Other		
3.APPENDIXES	3.0 Notes		
Processing:	3.1.1 Scope of cover		
	3.1.2 Application		
	3.1.3 Requirement		
	3.2.1 Physical		
	3.2.2 PSU		
	3.2.3 Input		
	3.2.4 Processing		
	3.2.5 Output		
	3.2.6 Environmental		
External Specification			
	4.1 Intention		
	4.2 Scope of cover		
	4.3 Application		
	4.4 Requirements		
	4.5 Technical specification		
	4.5.1 Physical		
	4.5.2 PSU		
	4.5.3 Transmitter		
	4.5.4 Output		
	4.5.5 Environmental		

INTRODUCTION

1.1 Intention. This document is intended to summarise the technical specification required of the proposed groundspeed sensor unit. The processing circuitry is covered in the appendix

1.2 Scope of cover. The specification includes the phsical dimensions, the positioning of the unit, contents of the unit (microwave horn and transmitter, antivibration mounts, preprocessing circuitry and power supply), and the specification of these included components. Some sections include the circuit topology recommendations based upon previous experience.

1.3 Application. The groundspeed sensor unit is to be used in conjunction with an external processing unit to measure the velocity of off-highway vehicles by means of the detection of a velocity-proportional frequency signal (generated according to the principles of Doppler theory).

1.4 Requirements. The sensor must be able to respond to groundspeeds in the range 9 to 31mph. The requires signal must be isolated from noise generated by vehicular motion, finite beamwidth, irregular terrain shock and vibration; and converted to a form suitable for external processing. The output must be a CMOS-compatible logic level square-wave pulsetrain mirroring the nominal frequency of doppler return. The unit must be capable of:

a. responding correctly to speeds in the range 9-31mph (± 0.5)
b. consistent operation over compacted earth, both dusty or wet
c. consistent operation over both regular and irregular terrain contours
d. discriminating true doppler frequency from interference doppler frequencies and intermodulation
e. correct interpretation of signal trains with one-wavelength long signal nulls per ten wavelengths of input signal
f. operating in an adverse environment (mechanical & electrical)

2. TECHNICAL SPECIFICATION

2.1. Physical.

a. size. Maximum dimensions: height 25cm, width 20cm, length 30.
b. positioning. Capable of operation at a:
   1. height of 2m from the ground
   2. tilt angle of 37 to 43 degrees to the horizontal
c. mounting. Capable of being mounted onto a 25cm wide platform section, 20cm deep, of 3mm steel.

2.2 Power Supply Unit

a. Supply compatibility:
   1. range: +16 to +30V, nominal 24V
   2. surge +100 V for 1msec, +600V for 10usec
b. Supply requirements:
   1. +6, +12V at 150ma
   2. +8.ooV at 1 amp:
      a. Zout of LT 0.01ohm
      b. S/CCT protected
      c. noise LT 0.003%.Vo (rms)
      d. line regulation GT 0.01%/V

2.3. Transmitter

a. Type: continuous wave, unmodulated
b. Frequency and power: as HMG: ie 10.587G±10M at 10mW, or 13.4 to 14G ± 10M at 5mW
c. Antenna:
   1. beamwidth: elevation 5 to 15 deg, nom 10-12; azimuth 20 to 40 deg, nominal 30(*1)
   2. polarisation: vertical
   3. tilt angle: nominal 40deg
   4. gain: as HMG: max 20dB (rel: isotropic radiator)

2.4 Receiver and Processing (*2)

a. Bandwidth and amplification:

1. stage 1: 2nd order 80Hz HP, 2nd order 800Hz LP, gain 76dB. Dynamic range: GT 10:1 (*3)
2. stage 2: 4th order 120Hz HP (Bworth). Gain, X1

b. PLL response times: 1. 8ve up: 300-600Hz: 4sec
2. 8ve down: 600-300Hz: 3sec
3. centre frequency: 0Hz

c. other: no fast-acting AGC.

2.5 Output.
a. CMOS logic-level pulsetrain
b. LED indicating the presence of squarewaves
c. LED indicating the presence of power to microwave unit

2.6 Environmental.
a.operational temperature: -10 to +40deg C
b. shock: 25 of: 25 to 30g
c. vibration: as Mil Spec 202E method 201A. or 2000 sinusoidal movements at 10g peak (*4)
d. water, humidity: as SAE J1211, or no ingress under IPX5 (*5) (*7)
e. dust: 1. microwave unit: no ingress: IPX6
2. circuitry: minimal ingress IPX5

2.7 Housing
a. strength: capable of withstanding minor impact from sharp objects (gravel test as SAE J1211)
b. material: no damage due to sunlight, oil, grease, steam.

2.8 Other
a. test points to be provided at all appropriate points.

3.0 NOTES

1. Beamwidth: 2 way 3dB power points
2. From experience. For 10 to 25mph alarm points.
3. Gain 76dB produces 3vpk-pk over 100-500Hz for a 25X40deg beam at 40deg for X band for 1.3mW TX, 2way range of 20'
4. Based on OGEL/01
5. Based on IEC pub 144
6. Conversion factor depends upon TX frequency and tilt angle. For X band at nominal 40deg, is 24.5Hz/mph
7. Heavy rainfall defined as 100mm/hr

4.0 SPECIFICATION FOR EXTERNAL USE

4.1. As 1.1
4.2. As 1.2, excluding last sentence
4.3. As 1.3
4.4. As 1.4, excluding 1.4.e.
4.5.1As 2.1, excluding 2.1.b.2
4.5.2. As 2.2
4.5.3 As 2.3
4.5.4 As 2.5
4.5.5 As 2.6, 2.7 and 2.8

APPENDIX 3.1: Processing Circuitry.

3.1.1 Scope. This section covers the specification for the speed sensor processing circuitry. Circuitry for alarm samctions is not covered.

3.1.2 Application. The processing circuitry is to be used to convert the velocity-proportional pulsetrain from the head unit into a logig 'high for overspeed' status output. This circuitry must, at present, be located on the existing main control board.

3.1.3 Requirement. The circuitry must be able to correctly interpret changes in pulsetrain frequency not proportional to groundspeed, and to allow cancellation of the overspeed logic level at a lower speed than the nominal alarm speed. Thus the unit must be capable of:

a. responding correctly to pulsetrains corresponding to groundspeeds in the range 9 to 31mph with an error of 0.5mph

b. responding to changing pulsetrain frequencies in such a manner that minimal false alarms or missed valid alarms occur.

3.2.1 Physical. refer to control box specification

3.2.2 PSU. nominal supply, +12V at 500ma.

3.2.3 Input.

a. capable of operating on an input of 8 to 14V pk squarewave of mark/space ratios 15:1 to 1:15 in the frequency range corresponding to groundspeeds in the range 9 to 31mph.

b. capable of withstanding induced spikes of +100V for 1msec
+600V for 10usec

3.2.4 Processing. Assuming an F/V:

a. capable of accurate calibration of nominal alarm frequency (at present 470Hz)

b. capable of providing optimum time-constant (at present 0 to 470Hz in 2 seconds)

c. capable of providing hysteresis in the order of 10% below nominal alarm speed for cancellation of alarm logic level.

3.2.5 Output. CMOS compatible logic level: high logic for alarm state

3.2.6 Environmental. As 2.6, 2.7, 2.8.

3.3 Circuitry: external specification.

3.3.1 AS 3.1.1
3.3.2 As 3.1.2
3.3.3 As 3.1.3
3.3.4 As 3.2.2, 3.2.3b
3.3.5 As 3.2.5
3.3.6 As 3.2.6

SECTION 2.14

REPORT INT P23
C. WALLACE
ISSUE 1.3

ROADSPEED UNIT: FULL TEST SCHEDULE.

NOTES.

These tests are arranged in a 'sequential-inclusive' manner. Thus by virtue of a permanent input point, the reference point is continuously monitored ; ensuring accuracy of measurement and ease of comparison. It is important, therefore, that the tests are performed in the sequence indicated.
No burn-in test is included: the length of these tests negates the advantage of such a test.
For production batch checks, test no INT P30 should be used.
For cumulative technical data, refer to INT P30A.

CONTENTS.

1. power supply
2. preamplifier
3. filter
4. gain
5. output
6. phase-locked loop
7. microwave unit part a
8. microwave unit part b
9. sensor unit preliminary check
10. car test
11. site test
12. truck environment questionnaire

ROADSPEED UNIT TEST SCHEDULE

ISSUE 1.1
For: Aro/PcB
30.1.84.

SERIAL NO:

NAME:

PCB NO:

DATE:

HEAD NO:

STATE: BUILD/REPAIR

PROGRESS:

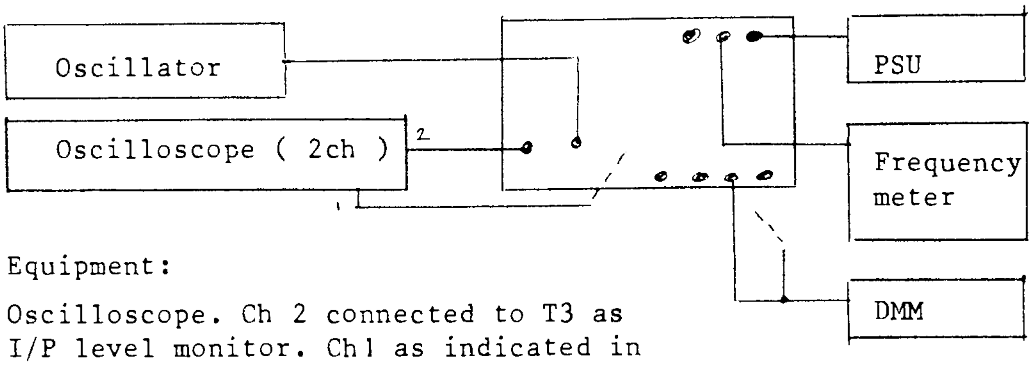
Test	Pass	Notes
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

HISTORY

Date	Change

EXPLANATORY NOTES.

1. The following schematic indicates the equipment required to complete this test schedule, and major interconnections. Electronic tests:



Equipment:

Oscilloscope. Ch 2 connected to T3 as I/P level monitor. Ch1 as indicated in schedule. Min sensitivity: 5mv/div

PSU. Variable over the range 20-28V, nominal 24V at 2A.

Oscillator. Sinewave, 0-2000Hz at 0.1mV to 1V; 20V square 100-800Hz.

Multimeter, digital. 20 and 200V DC ranges. 20V accuracy of 0.01V on 20V range. 2V DC for microwave test.

Frequency meter. 1 second gate, 0.1Hz resolution

2. Microwave unit tests require in addition:

RAM: 12 by 12" X band

Power meter. 5microwatts to 10mW. Calibrated for 10-12GHz

Counter/meter. Accurate to 1MHz at 10-11GHz

Tuning forks. Middle C and A, 490Hz (filed down C)

Vibrator. CApable of operation up to 800Hz.

3. Sensor unit tests require in addition:

Reference ALBERT system; 20mph option selected

Tape measure, 6m long

Trailer with suitable mounts, tow vehicle, two 12V batteries, leads.

4. Abbreviations used in tests:

Tn: test pin n

" ": pcb legend

O.C: open circuit

d: does not matter

g.t: greater than

V: voltage (pk-pk)

5.Tests must be carried out in the prescribed order (test 7h may precede test 7g). All alarm and cancel speeds quoted are for a wide tarmac road, dry or damp.

POWER SUPPLY TEST.

1	TEST	PASSBAND			TEST POINTS & CONDITIONS	RESULTS for I/P voltage:			OK
		MIN	NOM	MAX		20V	24V	28V	
a	PSU noise and ripple	d	5mv	10mv					
b	Gunn	7.95	8.00v	8.10	"8v". No fluctuation over 5 mins of g.t .05V				
c	Pre:split	3.9	4.0V	4.1	T2				
d	High rail	11·2	11.5v	11.8	pin 4 of IC2				
e	" noise	d	5mv	10	" " "				
f	split rail	5·6	5.7V	5·8	"K, D5"				
g	set DC I/P	23·5	24V	24·5	setting for all subsequent tests				
h	LED (red)		on		on if connected				

Equipment: 20 to 28v PSU

Oscilloscope: 5mv sens, 20ms sweep

DMM: 20v dc sens (200v dc for setting of 24 and 28v

PREAMPLIFIER TEST

2	TEST	PASSBAND			TEST POINTS AND CONDITIONS	TEST RESULTS	OK
		MIN	NOM	MAX			
a	Noise		10mv	14mv	I/P: 0.CCT O/P: T3		
b	GAIN 1	2.4	2.5 V	2.6	I/P 40mv, 500hz at T1, O/P T2	(I)	
	GAIN 2	3.6	3.7 V	3.8	I/P 500 hz to T1 so 40mv @ T2 O/P: T3	(II)	
c	CLIP POINT	62	64mv	66	I/P @ T2, 500hz, so onset of clip at T3. O/P T2	(III)	
d	Freq response	0.01	0.04V	0.05	I/P 500hz at T1 so 2V at T3. Change freq to: V measured at T3 20Hz		
		0.05	0.15	0.18	50		
		0.25	0.55	0.65	100		
		1.3	1.4	1.5	200		
		1.6	1.75	1.9	300		
		1.9	2.0	2.1	500		
		1.7	1.8	1.9	700		
		1.3	1.6	1.7	1000		
		0.4	0.75	0.8	2000		

Equipment: 24V PSU
Oscillator: sinewave
Oscilloscope

OVERALL GAIN = $\frac{I * II}{1.68} * 1000$ typ 5150 to 5850

I/P CLIP LEVEL = $\frac{III * 40}{I * 1000}$ typ 1 to 1.2 mv

Gain:	
Clip:	

FILTER STAGE TEST

3	TEST	PASSBAND MIN	NOM	MAX	TEST POINTS AND CONDITIONS	TEST RESULTS	OK
a	Noise		10mv	15mv	I/P: 0.CCT O/P: T4		
b	Clip point				I/P: set at T1 (500hz) so voltage at T3 is: b) just clipping, measure @ T4		
c	Freq resp	0.01	0.07	0.1	c) 2V (500hz): change I/P freq to: 100hz V Measured at T4		
		0.05	0.45	0.5	150		
		0.7	0.8	0.9	180		
		1.1	1.2	1.3	200		
		2.0	2.1	2.2	300		
		2.0	2.1	2.2	500		
		1.9	2.0	2.1	700		
		1.1	1.5	1.7	1000		

Equipment: 24V PSU
Oscillator: sinewave
Oscilloscope

GAIN STAGE TEST

4	TEST	PASSBAND			TEST POINTS AND CONDITIONS	RESULTS	OK
		MIN	NOM	MAX			
a	Noise		0.5V	0.7V	I/P: O.CCT O/P: T5		
b	Freq Resp				I/P set at T1 (500hz) so V at T3 is 0.25V. Change freq to: (measure at T5)	square	
		0.9	1.0	1.1	100		
		2.1	2.2	2.3	150		
		4.1	4.2	4.3	180		
		6.0	6.1	6.2	200		
		10SQ	10SQ	10SQ	300		
		10SQ	10SQ	10SQ	500		
		9	9	10SQ	700		
		7	8	8.5	1000		
		3.8	4.0	4.2	2000		

Equipment: 24V PSU
Oscillator: sine
Oscilloscope

OUTPUT STAGE TEST

5	TEST	PASSBAND			TEST POINTS AND CONDITIONS	TEST RESULTS		OK
		MIN	NOM	MAX				
a	Amplitude	9	10V	11	I/P: set so 2V @500hz at T3. O/P: T6			
b	M:S ratio		1:1		I/P as above: I/P freq 300hz			
			1.5:1		500			
			2:1		700			
c	Sensitivity	LOW 220	230	240	I/P: set so 0·25V at 500hz at T3: measure at T6	LOW	HIGH	
		HIGH 730	740	750				
		LOW 170	190	210	as above, but 0.4V			
		HIGH 1100	1300	1600				
d	LED		ON		Test LED ON for LOW level at T6			

Equipment: 24V PSU

Oscillator: sinewave

Oscilloscope

PHASE LOCKED LOOP STAGE TEST

6	TEST	PASSBAND			TEST POINTS AND CONDITIONS	TEST RESULTS			OK
		MIN	NOM	MAX					
a	amplitude	9	10V	11	I/P: set at T1 so T3 measures 2V at 500hz. Measure at "OUT"				
b	Rise time	2	2	3	Switch oscillator from 0 to 800hz				
c	Fall time	5	6.5	8	Switch oscillator from 800 to 0 hz				
d	Sweep		No Jump		Sweep 100 to 1000hz, over 10 sec approx. Check for smooth freq change	SMOOTH/JUMPS AT: hz			
e	Slip				Measure freq over 10 sec and note max, min ; freq:	MAX	MIN	DIFFERENCE	
			3hz	5	300				
			3	5	500				
			3	5	700				

Equipment: 24V PSU

Oscillator: sinewave

Oscilloscope

Frequency meter: 1 sec gate, 0.1 hz resolution

MICROWAVE UNIT TEST SCHEDULE (Part a)

7	TEST	PASSBAND			TEST POINTS AND CONDITIONS	TEST RESULTS		OK
		MIN	NOM	MAX				
a	GUNN VOLTAGE	AS TEST 1b ± 0.05v			HEAD CONNECTED, O/P @ "8V"	TEST 1b	TEST 7a	
b	NOISE OUTPUT	0.3	0.5v	0.7	RAM IN FRONT OF HORN. O/P @ T4			
c	MIXER BIAS	-1.5	-1.0v	-0.5	MEASURE AT T1			
d	OUTPUT PWR	1.0	1.2mw	3.0	HORN MOUTH TO HORN MOUTH			
		0.15	0.2mw	0.4	ON-AXIS AT 0.5m.			
e	FREQUENCY	XXX:- 0.577	0.587	0.597	10.XXX.			
f	WAVEFORM PURITY	2	4v	6	TUNING FORK 25cm FROM HORN ON AXIS. CHECK SINEWAVE PURITY AND AMPLITUDE MAXIMA AT T4	SINE/BREAKUP/CLIP AMPLITUDE:		
CONT..								

EQUIPMENT:

24V PSU
REFERENCE SENSOR PCB
X BAND RADAR ABSORBTIVE MATERIAL (RAM)
DMM
OSCILLOSCOPE
POWER METER
RF FREQUENCY METER
TUNING FORKS
RULER

EXTRA EQUIPMENT FOR TEST 7g and h:

10m tape measure
TROLLEY
VIBRATOR
FREQUENCY COUNTER
SQUAREWAVE OSCILLATOR

NOTES:

*1: USE RAM TO RESET POWER METER AFTER EACH READING

*2: HEAD AND POWER METER SHOULD BE AT LEAST 1m FROM THE GROUND

*3: MONITOR EITHER WITH A FREQ COUNTER OR AN OSCILLOSCOPE AT T1 AND T5

MICROWAVE UNIT TEST SCHEDULE (PART B)

7	TEST	PASSBAND			PASSBAND			TEST POINTS AND CONDITIONS	RESULTS		OK
		MIN	NOM	MAX	MIN	NOM	MAX				
g	BEAMWIDTH	ELEVATION ANGLE			AZIMUTH ANGLE			MEASURE DISTANCE FROM AXIS TO ½ POWER POINT. NOTE *1 and *2. dist out:	DIST/ANGLE ELEV	DIST/ANGLE AZIM	
		9	12	12	29	32	35	1.5m			
		9	12	13	29	32	35	CALC ANGLE (*4) 2.5m			
		9	12	13	28	32	34	4m			
		11	12	14	27	32	34	5.5m			
h	SENSITIVITY	MIN			MAX			PLACE VIBRATOR ON-AXIS FED BY 20V SQ. SWEEP OVER 150 TO 550HZ & NOTE RANGE OVER WHICH CORRECT SQUAREWAVES ARE PRODUCED (*3). DIST OUT:	MIN	MAX	
		200	230	280	510	550	580	5cm			
		225	260	310	515	525	530	10cm			
		250	280	340	490	500	545	20cm			

NOTES (CONT): *4: $\theta = 2 \times \tan^{-1}(L/D)$, L = ONE WAY WIDTH, D = DISTANCE OUT

SENSOR UNIT TEST SCHEDULE: PRELIMINARY CHECK

8	TEST	PASSBAND			TEST PROCEDURE	TEST RESULTS	OK
		MIN	NOM	MAX			
a	FREQUENCY				HOLD TUNING FORKS 20cm FROM HORN MOUTH. NOTE TIME TO ALARM.		
			NONE		FREQ 440HZ		
		2.5	3.0	3.5	490HZ		
		2.5	3.0	3.5	540HZ		
b	SENSITIVITY				MOUNT UNIT ON TRAILER. WALK BACK ON-AXIS: NOTE RANGE OVER WHICK LED RESPONDS CORRECTLY (*1).		
			LED OFF		NO TARGET		
		4.5	5.0	6.0	MIN DIST		
		7.0	8.0	8.5	MAX DIST		

*1: LED SHOULD FLICKER FOR MOVEMENT OVER AROUND 5MPH, IE TO VIGOROUS HAND-WAVING.

CAR TEST SCHEDULE

9	TEST	PASSBAND			TEST PROCEDURE	RESULTS				OK
		MIN	NOM	MAX		RUN 1	RUN 2	RUN 3	AVERAGE	
a	Slow accel, Smooth	20 19	21 19	21/22 20	SLOW ACCEL UNTIL ALARM, SLOW DECEL UNTIL CANCEL. NOTE ALARM AND CANCEL.				(I)	
b	Fast accel, Smooth	22 18	23 17	24 16	DITTO FOR FAST ACCEL AND DECEL.					
c	Consist-ency		NO ALARM		HOLD SPEED 1MPH BELOW 'I' FOR 10SEC. CHECK NO ALARM.					
d	Slow accel, Rough	20 19	21/22 20	22/23 20/21	ROUGH GROUND TEST: AS FOR SLOW ACCEL ABOVE					

SITE TEST SCHEDULE

10	TEST	PASSBAND			TEST PROCEDURE	TEST RESULTS				OK
		MIN	NOM	MAX		RUN 1	RUN 2	RUN 3	AVERAGE	
a	Preliminary Check		NONE		TUNING FORK HELD 20cm FROM HEAD. CHECK DELAY TO ALARM (CAB PANEL). a) 440HZ					
		2.5	4.0	4.5	b) 490 Hz					
		2.5	4SEC	4.5	c) 540 Hz					
b	Site Test	21.5	22.0	22.5	HAUL ROAD: NOTE ALARM & CANCEL SPEEDS					
		21.5	22.0	23.5						
c		21.0	22.0	23.0	SITE ROAD: NOTE ALARM & CANCEL SPEEDS					
		21.0	22.0	23.0						

NB : Fill in environment Sheet whilst performing tests 9b, 9c

SITE TEST: ENVIRONMENT SHEET.

a. TEMPERATURE

HOT	WARM OR COOL	COLD	FREEZING

b. WEATHER

DRY	MIST or DRIZZLE	RAIN

c. TERRAIN

DRY	DAMP	WET
DUSTY		MUDDY
		SNOW OR ICE

d. VEHICLE/RIDE

SMOOTH	SMALL BUMPS	LARGE BUMPS
	FEW	FEW
	MANY	MANY

DATE	
FITTER	
UNIT SER.NO.	
VEHICLE NO.	
REMARKS:	

NOTE: CIRCLE ALL APRROPRIATE BOXES FOR THE CONDITIONS APPLICABLE.WHEN THE VEHICLE TEST SCHEDULE IS PERFORMED. THUS AT LEAST ONE BOX OF EACH BLOCK MUST BE COMPLETED, AND IF CONDITIONS VARY OR CHANGE OVER THE TEST RUN, NOTE ALL CONDITIONS MET.

SECTION 2.15

REPORT INT P24 & 33
12.3.84
C. WALLACE

THE OFF-HIGHWAY VEHICLE AS AN ENVIRONMENT FOR THE SPEED SENSOR.

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INTRODUCTION

The general environment within which the off-highway vehicle must operate is harsh. Combinations of conditions are met that are unique in the field of applied electronics (although military electronics environmental specifications are similar): conditions that determine very quickly whether a piece of electronic equipment is adequately designed and built. It is of importance, therefore, to understand the effects of such conditions of the speed sensor and associated componentry, and briefly establish likely causes of these effects, and to review the accepted techniques of environmental testing.
This review categorises the off-highway environment according to four distinct, yet interrelated, sections:

a) mechanical, including shock and vibration considerations, and a brief review of vehicular geometry
b) electrical: power supply, interference, EMI
c) climate: temperature, humidity and their effect upon the electronic components and performance
d) terrain: categorisation of contour, surface type etc.

It is acknowledged that sections will interweave: the terrain profile has a prime effect on the success with which the anti-shock precautions protect the unit, and the climate will certainly influence the terrain type. But in the interests of clarity, the sections are dealt with seperately. Further, the relative importance of each category for, possibly, a range of vehicles carrying from ten to two hundred and eighty tons is not discussed. Environments covering all potential marketing areas of the world are examined, and designs for each environmental extreme recommended. Indeed, it might be argued that the largest market for the ALBERT system is the truck manufacturer, who could then offer the system as standard or optional equipment. Thus, the worldwide distribution of the trucks of two typical manufacturers is examined in terms of truck payload, geographical distribution and climatic distribution (suitable climatic categories are first defined).

Relevant literature (papers, conference proceedings, magazine articles, books, datasheets, military and civil standards and reports) has in each case been thoroughly searched, not often with success. It is thought that this lack of information results mainly from the fact that electronic circuitry (and certainly radar equipment) is not fitted to such trucks either as standard or optional equipment; indeed such equipment is unavailable. Much information, however, is available pertaining to related (but for this project, inapplicable) topics such as comparisons of suspension types, vehicular geometry, farm tractor behaviour on ploughed fields, vibration tolerance of drivers etc.

Sifting the relevant data consumed the majority of time spent preparing this report. The final document, however, should serve both as a tool for the design of the sensor, and as the basis of a discussion document for future environmental testing of future products. To the end of the this section, the findings are grouped together in such a manner as to produce the basis of a design specification: a comprehensive environmental test procedure. Component value changes corresponding to each of the climatic categories are also given, along with an assessment of the effects of several standard test assumptions on the MTBF (mean time between failure).

THE EFFECT OF CLIMATE

The speed sensor system must be capable of correct operation (accurate and consistent) in extremes of temperature, humidity, water and salt spray, dust and mud buildup. Even in the UK on one given site, the climatic conditions provide a challenging environment for the componentry: temperature ranges of -15 to +32 degrees and humidity from 30 to 90%RH are not uncommon. High windspeeds are a feature of much of the UK, as are heavy downpours. And these conditions exclude the thermal contribution of the truck itself: the skip is usually internally warmed by exhaust gases, and areas nearby reach elevated temperatures (up to a remarkable 160 degrees near the vehicle exhaust, 64 deg at the vehicle body centre, and 75 along the chassis beam (Davey, 1983). Other potential sales areas worldwide (for now considered to be the USA and South Africa: this topic will be expanded upon later) have their own peculiarities: each unique climatic environment requires special consideration; and the system must tolerate them all.

There exists the marketing possibility of providing the ALBERT system directly to truck manufacturers as standard or optional equipment. The system must thus operate in all likely destinations for such trucks however extreme the climate. Kockums, for example, manufacture a model of truck noted for its advanced electronic and electrical features now operating in forty-nine countries, from the arctic to teh equator. Such trucks, boast their manufaturers, operate at -40 to +50 deg, at altitudes of 4000 metres, and 60 metres underground. Another major manufacturer, International, operate plant 120 hours per week on the La Grande river project, where temperature variations of -48 to +46 degrees occur.

It may be considered unlikely that the sensor and associated componentry would meet such temperatures: it is easy to make a point by selectively quoting extreme usage examples. Thus, two manufacturers with whom negotiations over the fitting of ALBERT have already taken place were selected to provide detailed information on the worldwide distribution of their off-highway trucks. Appendix 1A tabulates this information: locations vary from near-arctic (N Sweden, Canada) through tropical (N Giunea) to desert (Liberia). All continents and environmental groupings are encountered. Indeed, the major proportion of trucks are located in areas of climatic extreme. Of the 2405 trucks located, only 5 were based in the UK. Appendix OD lists truck types and quantities according to the environmental groupings defined in appendix OB. It can be seen that approximately one-third of the distribution is located in the temperate or maritime category. However, the figures assume that regions of high seasonal variation are considered on an average of that variation: thus the groupings are over-generous. By considering regions of great variation in terms of that variation, only one-tenth of the vehicles would still fall into the category of an 'easy environment' climatically speaking. It is the corrected figure above that reflects the true climatic stress that the sensor unit must undergo: 91% of the off-highway trucks are located in hostile climatic environments.

Temperature.

Thermal design is of great importance for regions of use where the ambient temperature variation is significant and/or where the performance and longevity of the unit might be compromised due to internal heating, cooling, or temperature cycling. On a typical British open-cast site the temperature range met by electronic equipment may range from -20 to +35 deg (values taking into account chill factor and direct solar radiation: both important factors for equipment encased in metal and mounted in an exposed position on the truck).

Several components in the standard sensor system are rated 'commercial' (nominally 0 to 80 deg operation temperature range typically) and substitution for the more tolerant industrial temperature range or military rating components can be costly: appendix 4 compares integrated circuit rating categories and prices for the main circuit board of the sensor unit. Simple substitution for the semiconductor components of this board alone would cost up to £1.97, £20.81 and £22.19 for commercial, industrial and military ratings respectively. Thus, if at all practicable, the internal temperature of the circuit casing must be accurately controlled to within the 'commercial' rating whatever the external temperature. To this end, the basic sensor design utilises internal heat generated by allowing a 'stopper' resistor (low value high wattage resistor in series with the supply line) to run warm: this heat is retained by packing the circuitarea with foam. However, for elevated ambient temperatures this arrangement is inadequate as the resistor will continue to provide heat. To combat this deawback it is proposed that five component lists are maintained, each containing appropriate integrated circuit and component temperature ratings, and selected stopper resistor values. Such recommendations are listed in appendix 11, but in brief look thus: for cold: a large heater resistor, possible secondary heater, industrial rating components, selected microwave unit; for temperate: small heater, commercial range components; for hot: very small heater, or cutout circuit, industrial or military components and a selected microwave unit.

Difficulty arises in regions of large seasonal or even diurnal temperature variations: appendix OA catalogues high and low average monthly temperatures (most fall within a range of 15deg), whilst appendix OC lists temperature extremes of those areas likely to be destinations for the sensor unit. Means of dealing with such extremes will be dealt with later.

In general, the lower the temperature (within the components stated range) the greater the reliability of the component and the more stable the performance of the circuit. Abnormal cooling, heating or temperature cycling may lead to a change in component value (temporary or permanent), shortened operating life and even catastrophic failure. The effect of system components operating outside their stated range is exemplified by the experiences of OEL at the S Wales opencast site: the connecting cables used were found to require continuous replacement. Upon examination these cables were found to conform to an inadequate specification (see app 5). Clearly the cable presently utilised is unsuitable as its power rating is referred to use at room temperature and its limited temperature rating is bound to be exceeded due to proximity to hot chassis parts, steam cleaning etc. Night air temperatures may also drop below the cable minimum temperature rating.

Thus the balance between ambient air temperature, solar radiation, chill factor, internal heat generation and dissipation, and optimum operating temperature is a difficult one to optimise. Bar-Cohen (1980) states that any temperature cycling in excess of ± 15 degrees reduces the reliability of electronic components almost independint of the influence of the nominal temperature level. This is illustrated in appendix 4.

Chill factor and solar radiation

Two further factors to be considered in unit desing are heating due to solar radiation and cooling due to wind chill. Solar radiation (based on the accepted value of approx 2cal/cm sq/sec and 15% surface reflection) will heat one square foot of metal by 60 deg in still air and 15deg in a moderate air flow. In the UK the maximum surface temperature of equipment exposed to the sun, assuming solar radiation of 25% of the above value (simulating medium cloud cover) and an ambient temperature of 20 deg, will be around 24 deg. This increase must be considered. In areas of high ambient temperature this effect can be catastrophic: in desert areas, 50 deg ambient can increase the surface temperature of metal to 80 deg. Fortunately in such areas the radiation effect has maximum heating after the air temperature peak (around midday), so such high heating of surfaces is relatively uncommon.

The chill factor is far less quantifiable, and little information could be found relating to it, although a widely accepted estimate would seem to be a cooling rate of 1 deg/mph windspeed (see app OC). Trucks are usually used on sites fully open to the elements: freezing fog and high chilling winds are commonplace, taking the metal casing and circuitry inside well below the ambient air temperature. Such low temperatures must be considered: microwave transceivers have difficulty operating below -10 deg, and as described earlier, commercial ICs are rated only down to 0 deg. All component values will alter (none used have a zero temperature coefficient) although unlike excessively high temperatures, the component lifetime will not be reduced and the change is value will usually be temporary (the exception being electrolytic capacitors which often fail at -20 deg). Whilst, for temperatures around zero, the heating provided by the power dissipation from the components may provide an adequate circuit temperature, problems occur at lower temperatures. Most heat is generated by the stopper resistor, but only when the high current required by the gunn diode is drawn. If the temperature is low enough to prevent the microwave unit from 'starting' (the diode needs a high current surge to commence oscillating), no current will be drawn and the stopper resistor will not warm. Localised heating of this type has associated problems: Bar-Cohen (1980) reports that by decreasing 'hot spots' on a PCB, the nearby components will double their MTBF.

Appendix 3 tabulates the alternative temperature ratings for ICs used in the speed sensor, and appendix 6A lists the effect of temperature on the other componentry. App 6C deals with PCB type, 7B with the range of permissible operating temperatures for available microwave unit types. All such data must be carefully interpreted: the temperature ranges quoted are long-term extremes: rapid cycling within the stated range may cause component value shift greater than that predicted by examining its temperature coefficient, and may induce premature failure.

Humidity

Ranges from 0.1 to 32g/m^3 have been recorded. It is not known at present how well 100%RH air passes microwave energy: the literature on the topic refers mainly to long distance attenuation in rain cloud. This problem, however, will be examined is detail later. Another more quantifiable problem introduced by humidity is that of condensation: this must not be allowed to form in the microwave transceiver or horn. The idea of filling the horn with an inert gas has appeal, but a more practical solution is the use of a low-loss low dielectric constant fuam (Ecofoam FPH, for example, has an e of 1.12). The foam, however will not prevent condensation forming in the waveguide cavity of the transceiver. Report INT P18 covers the foam filling of horns.

CATEGORISATION OF TERRAIN

The range of surface types upon which large off-highway trucks aperate is wide. Any one site may incorporate several distinct terrain categories, and the surface is constantly changing: to quote Ballard:

> "Frequently surfaces will deform after the passage of just one machine, require constant maintenance and rarely receive it. Ground materials vary from the softest silt to hardest rock

which may degenerate into a dust bowl or quagmire...."

Ballard (1975)

It is important that the probable range of terrain types upon which the truck must operate are identified: to this end a brief review of terrain evaluation techniques was performed. This data can then be used as a basis for the section dealing with shock and vibration. It should be noted that we are dealing here with terrain profiles (ie macroscopic contour) as opposed to 'roughness' which is covered in report INT P8.

Copious literature exists on the topic: Beckett (1969) provides an illuminating review, but the majority of researchers rely upon a macro-view of the terrain for purposes of geological surveys. Much work is reported on the analysis and synthesis of ground areas by examination of terrain features and a categorisation based upon recurrent patterns of sub-features. Such a method was proposed by Beckett (1975) who defined the basic feature unit as a 'facet' (being the smallest reasonably homogeneous area of categorisation). This technique, however, does not lend itself easily to off-highway terrain due to the practical limit on the size of a single facet. The AMC programme (Rula, 1971) identified the need for a system of classification that would assist in the fields of design and operation of off-highway combat vehicles. Of interest to the writers project is the 'terrain database' section of the report which describes the technique of defining terrain as a mosaic of patches, each with a reference number; the number corresponding to a predefined list of terrain features. Since no limit exists on the number of different patches, the ground areas can be made very small.

Heal (1964), Wenderborn (1966) and Bogdanoff (1966) attacked the problem oc profile classification by using a technique based on spectral density (defined in terms of the mean-square amplitude per unit bandwidth). Thus for a given wavelength, say one metre, the overall roughness of the terrain is characterised by the area under the spectral density curve. Appendix 2A examines this method further. Van Deusen (1967) proposed a means of off-highway terrain evaluation and analysis specifically intended to gather data in a form suitable for computer processing. Rula (1973) expanded the 'patch' concept, and divided each patch into factors, these factors being grouped into three categories (listed in app 2B). With modifications, these factors can form the basis of terrain categorisation suitable for this project. But, like any evaluation technique, terrain mapping becomes complex when the defined features change with weather or physical alteration: the use of a haul road will change the very features of that haul road. Indeed, the factors labelled 'obstacles' will usually be earth and/or rock shed from a truck load, or earth piled along the haul road from a scraper (in constant use to clear and level the haul roads).

The need for terrain categorisation is exemplified experimentally by the variation in performance of the existing sensor unit over different types of terrain. Alarm frequencies corresponding to velocities of 22±3mph have been noted on working units. Appendix 2C lists the wide range of coefficients of traction met on a typical site: such terrain variations test every aspect of vehicle and electronic circuitry design. It is thought, empirically, that the lower coefficient of traction surfaces provide lesser shock and vibration effects.

Examination of experimental data derived from this project is, of course, crucial. Such an examination is performed in the section dealing with graphical and plotted results.

SHOCK AND VIBRATION

One of the most severe tests for electronic equipment is shock and vibration. Shock, for this projects purposes, is aptly defined by Crede (1957):

"Shock is a transient condition where the equilibrium of a system is disrupted by a sudden applied force or by a sudden change in direction or magnitude of a velocity vector"

Vibration can be considered the 'continuous' analogue of this, caused by the repetitive (although not necessarily constant magnitude) application of a force. The off-highway terrain profile of a typical site is not the only factor to contribute to the resultant effect on on-board equipment: many such factors, some unquantifiable, contribute. For example:

a) terrain surface contour: smooth undulations, flat or small protuberances (regular or irregular)

b) terrain roughness: potholes, craters, rocks, ground slippage, dropped load, moved earth (from scrapers) etc

c) vehicle tyre effectiveness: pressure, sidewall elasticity, tread depth, tyre width and diameter

d) vehicle suspension: travel amplitude, stiffness, smoothness of travel, bottoming characteristics

e)vehicle condition: skip locking, transmission jerk, engine vibration, gearbox vibration

f) stage of braking, retarder and gears

g) vehicle load: mass, distribution, stability, consistency
h) location of equipment: vehicle geometry, C of G

Thus the behaviour of such a truck when hitting an obstacle is difficult to predict. It would be expected that literature would exist on this topic if only for purposes of military vehicle design and operation, but little could be traced. Maclaurin (1975) describes how large off-highway vehicles, being fitted with minimal suspension undergo large lightly damped resonant vibrations when travelling at speed (at, and above, 20mph) producing 'wheel hop' and loss of vehicle controllability. Whilst this is ceratinly true, no paper can be traced that examines the shock produced by such wheel hop. For purposes of useful comparison, literature regarding shock and vibration on other modes of transport was reviewed: this information is tabulated in app 7A. This data is indirectly relevant: several factors are common between off-highway trucks and listed transport types: ships, for example, undergo constant and relatively undamped vibration; a rocket or missile undergoes shocks of a similar nature to an off-highway truck. but it would be misleading to compare too closely, and this lack of data prevents the normal antishock and antivibration design procedure and analysis from being applied.

In contrast however, much data exists on the effects of shock and vibration on electronic components and subassemblies. Matisoff (1982) states that vibration failures are four times as frequent as shock failure is such equipment; many components being able to stand shock of 75g yet fail under 2g of sustained vibration. he continues to give the typical failure point of such equipment as 5g up to 2KHz of vibration and 50g for 6ms of shock. Resistors and capacitors can withstand 15g of vibration (assuming correct mounting: this being the single most important factor in electronic reliability).

The relationship between equipment reliability, longevity and vehicle geometry is a variable that must be quantified for each installation type. Specifically, the positioning of the corcuitry with respect to the vehicular centre of gravity is crucial for three reasons: it determines the likely amplitude of travel of the equipment (to this extent the present position on or behind the rear axle is not ideal). Second, the radar characteristics of the sensor are impaired by the introduction of low frequency, high amplitude modulation (covered in another report); and thitd, the laden/unladen weight distributions determine the position of equipment with respect to ground. The angle of radar beam axis to the ground will change according to this distribution (tabulated in app 2D for eight typical trucks). It can be seen that the percentage of weight on the rear axle can be, for one truck, 67% laden and 49% unladen: hence the equipment mounting bracket may tilt; the exact amount dependent upon make, weight and weight distribution of the vehicle and load. Unit placement at, or near, the C of G will reduce the amplitude of the effect of shock, but will not stabilise such tilt. It is worthy of note that a typical suspension has only 16cm of travel from static (3% of truck height) or a travel from C of G of 6deg). In practice this travel is used as a loading impact absorber: the suspension settles low when loaded, making the truck effectively 'suspensionless' (the tyres then being the main shock absorber).

The effect of various categories of shock and vibration, temperature cycling and electronic equipment reliability is illustrated in app 8a to 8g. Care must be taken when relating such results to the sensor unit, so a means was sought to categorise such tests into groups of severity, and to then relate the groups to the components contained within the sensor unit. A method is available: the US Department of Defense reliability method achieves both aims (MIL H 217C, MIL STD 756, RADC TR72), and has been adapted for this project's use in app 8e. It is assumed that the category best describing an off-highway vehicle is Ns or Nu to Ml, or for lower speed smooth terrain, Gm to Ns. Thus component reliability can now be related to specific modes of use, and by inspection the sensor components are 23 to 40 times more unreliable than the circuit used in a laboratory test (excluding microwave components) for the Ml test. Not surprisingly the general trend of the data indicates increasing unreliability as environmental severity worsens. App 8F calculates sensor MTBF for the pertinent environmental security categories.

Shock Mounts

It is tempting to categorise truck motion as a series of vertical shock superimposed upon horizontal motion. Certainly travelling in such a vehicle is an experience: the overriding impression left in one's aching limbs is of violent vertical shocks, continuous vibration and intermittent sideways 'lunges'. However, the vehicle, especially when laden, posesses significant inertia, and given the pneumatic tyres, it is reasonable to assume that potentially violent impact will be 'smoothed out'. So does the truck undergo violent shock? Available literature (app 7, for example) is sparse. Thus a series of assumptions must be made. First, that shock capable of reducing the lifetime of electronic equipment does exist, second, that this shock is intermittent. The third, and most contentious, assumption is the magnitude and direction of the shock: a figure of 25g max is the vertical direction is assumed (simultaneously with the less important lateral shock of 4g). Shock mounts have a problem: whilst they modify shock pulses (replace hf vehicle-borne with lf equipment-borne) and filter hf transient vibrations (thus protecting equipment which has a relatively high natural frequency), they are designed so the natural frequency (nf) of the mounted equipment is higher than any vibration to whick it is subjected. If any part of the equpipment has a low nf, the mounts may increase the destructiveness of shocks by resonance amplification.

Vibration Mounts

Normally such mounts have an nf substantially lower than the frequency of the vibration to be isolated. For 4-point mounting there exists 6 matural modes of vibration and 6 nf. Care must be taken to prevent operating frequencies matching any of these nfs. Given this mount type using resilient isolators, each degree of freedom will have an nf in translation or rotation. If subject to vibration, 6 possible frequencies may resonate: all forcing frequencies must not coincide with mount resonant points (best if all nf are close together). Hence the AV measure effectiveness is dependent upon the extent of knowledge of the forcing amplitude and frequency spectrum: the very data that remains undocumented.

Mean Time Between Failure

To assess the effect of shock and vibration on the sensor, the MTBF was calculated for several test conditions: AGREE Nos 1 to 3 and DoD tests (conditions covered in app 8A and 8E respectively) and the MTBF results appear in app 8G and 8F respectively. App 8B tabulates the relative frequency of fault occurrences in electronic circuitry as investigated by the US Navy. Shock and vibration are the second most important factor, temperature sensitivity being sixth.

The relevant MIL series tests pertinent to the above re given in app 8C, the BS9000 (CEC) tests for components of the sensor in 8D.

ELECTRICAL

The electrical environment of an off-highway truck is harsh: compounding the usual automotive problems of line fluctuations, severe direct and induced spiking occurs due to the close proximity of high current solenoids and unscreened cable. Such solenoid switching is common: trucks utilise an electronic gearbox, so suppression must be included ineach boxed electronic assembly at the point of cable entry. The casing must also be constructed out of a suitable screening material. Appendix 9a compares suitable suppressor devices and appendix 12 allows calculation of attenuation of RF energy through the enclosure walls (it can be seen that even for a reasonably thin metal enclosure, the case acts almost as a faraday cage for all but the highest frequencies). However, all digital integrated circuits must be fitted with local decoupling capacitors

The problem of high-energy spiking is difficult to quantify: early problems encountered included PCB tracks burning out, and random logic switching (both of which were cured by suppressors, and high power resistors in series with truck feed lines, which are used by the safety system as logic lines).

To provide protection against load dump conditions, a resistor is used in the supply line to the roadspeed unit (previously referred to as a 'stopper resistor'), together with a high value electrolytic and a small value disc capacitor. Six volts is dropped across this resistor when a standard 47 ohm value is used (appendix 9a recommends alternative values: these will alter this voltage drop). To ensure a perfectly smoothed Gunn voltage, a second precision regulator is used, and the analogue circuitry utilises a split zener regulator. These measures, for typical conditions of use, are adequate. Anomalies do still exist: spikes capable of operating the schmitt trigger have been observed whilst the vehicle changes gear, for example. Such interference will generally only exist as one pulse per gear change: a small error compared to the 470Hertz alarm frequency.

Some researchers consider power supply isolation crucial: Thoburn (1983) recommends both a low DC cutoff VDR and a zener regulator (the former to absorb the bulk of the transient energy, the latter to precisely define the peak voltage transmitted). Appendix 9b lists the electrical supply parameters: the supply can be seen as a nominal DC voltage inter--sperced with multi-sourced high voltage transients. Such factors as battery condition, load demand etc result in an actual battery voltage different from the nominal. In order to establish the longer term supply fluctuations on a typical truck, a suitable recording system was devised (detailed in app 9C). The technique is crude so only slow variations can be examined. The results appear in app 16.

In addition to the above sources of interfreence (all 'long-term' effects), the truck electrical environment includes EM effects. Molyneux-Child (1984) states that:

> "all equipment containing electronic circuitry in which electrical lignals are changing, are potential radiators of EMI. Such interference is also generated by atmospheric activity..."

Hence the sensor unit must be adequately shielded to prevent both malfunction due to external interference, and radiation. The UK regulations governing EMI are unclear: the USA are more specific as the FCC docket 20780 (of which part 15/J is now law) states that all equipment must pass the included EMI tests. Tests ANSI 80 and SAE J1113A are also available (the FCC rules are utilised in the EEC, but Germany uses VDE 0875/6.77 and DIN 57-875). The sensor must pass such tests if export is to be considered.

Appendix 12 gives data to calculate, for an enclosure, the EM attenuation (several writers, eg Schaffner, 1980 state the weakest point to be joins, notably hinged; so the unit design must bear this in mind). Fogg (1983) states that RF and EMI will be induced into unscreened cables by alternator switching, radio, static, wipers, solenoids and natural phenomena (eg lightning). Greneker (1980) also writes that CB radio can cause interference of such severity that the signal is detected by the mixer diode, producing modulation effects that would interfere with system accuracy.

The FCC tests can be simplified thus: emission (conducted and radiated) and susceptibility (conducted and radiated). The environmental specification givel later deals with radiated energy only.

Further research into the field of vehicular supply problems appears in the literature review, part three (including tabular lists of major researchers and contributions).

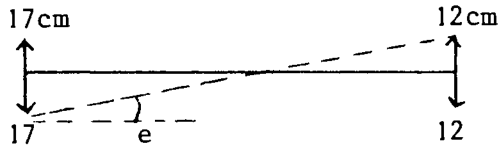
Truck and terrain effects on speed measurement accuracy,

This section examines the effects of suspension bounce, terrain contour and obstacles on the measurement of groundspeed using doppler radar. The literature review deals with theoretical findings of major researchers in this field: this section refers specifically to truck-borne radar on typical haul roads.

All speed errors are referred to a nominal alarm speed of 19.2mph (control box setting of 470hz; assuming the doppler/velocity relation of 32hz/mph, ie a true transmitted 10.587Ghz; and a nominal tilt angle of 40deg). The truck dimensions and suspension geometry assumed are that of a Cat 777 85 ton payload truck, as used for site trials.

1.Suspension: bounce

Off-highway truck suspensions have limited travel, and are extremely 'stiff'. Thus the effect described below refers to a laden truck; unladen, the suspension movement is negligible, and the effect on speed measurement becomes similar to that covered later for obstacles. Taking the extreme case of suspension travel front and rear, and including 2cm of pneumatic tyre 'give':



$e = \pm 2.8^\circ$

This can change the required alarm speed by

$$\frac{f}{r}\left(\frac{1}{\cos t} - \frac{1}{\cos(t \pm e)}\right)$$

f: alarm frequency (hz) = 470
r: velocity/frequency ratio (hz/mph) = 32
t: tilt angle (deg) = 40
e: tilt angle error (deg)

Thus a change of +0.85 or -0.73mph from the nominal 19.2mph can be experienced. Such movement will rarely occur and, even if it does, the effect for a properly distributed load will be instantaneous in effect.

For a more reasonable suspension extension, consider half-extension of the rear absorber only: the effect reduces to +0.17 or -0.17mph.

2. Suspension: laden/unladen

From fitter experience, the truck suspension settles at the most by 2cm when fully laden, effectively equally front and rear. In consequence the effective tilt angle will not alter by any significant degree, and the mean radar-target path length will not perceivably alter by the lowering of effective radar height by this distance. Indeed, the mounting brackets welded to the rear of the trucks specifically to house the system are not located to this accuracy.

3 Platform height accuracy

The rear platform positioning was measured on a random sample basis: the height variation from the nominal 1.8m of four trucks were +4,+1,-3 and-8cm.
The height does not directly affect speed accuracy, but can produce two causes of inaccuracy:

a) scanning noise variations (spectrum width)

b) radar-target distance variations (amplitude).

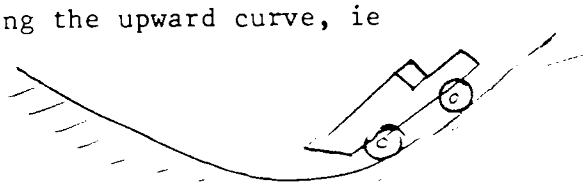
Only spectrum deviations due to scanning noise will be covered here.

As $dS = \frac{v.\sin^2\theta}{h.d\theta.\pi}$ ie $dS \propto 1/h$

the range of dS for the sample varies from 0.58 to 0.54, giving, for a mean value of 0.56, errors of +3.6 and -3.6% respectively.

4. Terrain

The extreme case of terrain geometry affecting radar parameters is, in the interests of simplicity, considered to be a steeply concave section with the vehicle approaching the upward curve, ie

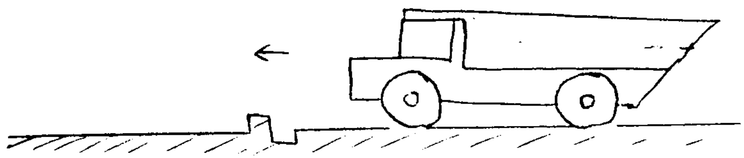


It is at this position that the effective radar tilt angle is affected to the greatest degree. The corrolary: the convex section is not considered as the truck velocity will be greatest at the lower point of the concave section. Trucks slow considerably when ascending, and would usually reach a hill brow in second gear at perhaps six mph. From site experience, the steepest haul road slope found was 1:5, and for a concave section, 1:7 approximately.
The latter figure will alter the effective tilt angle at the lower point of the dip by 16.4 deg, changing the required truck velocity for system alarm to 16.0mph. Commensurate with this change is the spectrum centre shift due to the movement of the ground-radar distance at either side of teh beam axis. Such a shift is difficult to quantify..
For a long slope, only the change in gradient need be considered, so the above effect will occur for, perhaps, two seconds. Nevertheless, this time is a significant length: for a truck travelling downwards at just below alarm speed the circuit (which averages the processed ground return signal by averaging) will have an integration time of only fractions of a second. The two second alteration of effective tilt angle will thus have a very real effect of system accuracy. Such slopes, after all, are the very areas where speeding is likely, and where drivers need sanctioning.

4. Obstacles

The effect of a truck striking a pot-hole or object (eg a rock) is difficult to quantify. Report P13 (Evaluation of alternative radar mounts and lab shock test rig) describes the shock effects of a truck striking such an obstacle but in geometry terms the effect is rather less severe. The additional tilt effect is similar to that covered under the 'bounce' heading; and similarily the teffect is transitory.
An obstacle affecting one side of the vehicle will certainly affect the instantaneous azimuthal tilt angle, but again the effect in negligible.

As an example consider a rather contrived obstacle:



Assuming the front wheel is thrown into the air by 12cm and the rear suspension 'bottoms', the maximum velocity error is -1.76mph, and for the rear, +1.12mph. Although this deviation is instantaneous, wallowing (very low frequency oscillation of the truck chassis with respect to the ground plane) may follow. Site experience though, would seem to indicate near-critical damping, and the wallow amplitude diminishes rapidly. The averaging effect of the F/V control board does not allow such a transitory inaccuracy of measurement to adversely affect the velocity reading. If several such obstacles are negotiated in succession, the net effect in crude terms will be the average error, ie -0.64 mph. In practice such a succession of obstacles would never be negotiated at speed, and rarely at low speed.
The result of 'corrugated' road surfaces is covered in another section of this report, although the work reviewed is in terms of accelerations produced only.

5. Vibration

Truck vibration produces a doppler signal due to the relative movement of the radar with respect to the ground (stationary or moving). The mode of vibration is duifficult to assess but would seem to incorporate motion in all three axes. Variations in tilt angle are, however, negligible, so the effect on system accuracy is that of additive 'noise' (which, in the case of a moving truck, may intermodulate with the true doppler return).

6. Summary.

CAUSE	ERROR		
	MPH +	MPH −	dS %
Max diagonal extension of suspesion	0.85	0.73	
Half rear extension	0.17	0.17	
12cm front rise	0	1.76	
12cm rear rise	1.12	0	
12cm average rise		0.64	
platform height (*1)	*2	*2	7.2
vibration	*3	*3	
concave dip: 1:7		3.17	

Notes:

*1: random sample of four trucs

*2: dependent upon terrain typeand conditions: general trend is for increased platform height to produce nward spectrum skew, thus giving a higher alarm speed.

*3: unquantifiable, but the pereived doppler signal will be the sum of the true and vibration-induced ignals.

TOTAL ENVIRONMENT

It is clear that several environmental factors are unquantifiable: for example the condition of a vehicle's suspension; but, in general, limits can be placed on the extremes of environmental factors met for a given set of circumstances. This section will attempt to categorise such factors and reccommend suitable action.
An assumption made throughout this report is that all environments likely to be met (inclusing possible future sales) should be covered. Thus, reccommendations will cover British and overseas locations and conditions.

It is of interest and of use to review the environmental test procedures of similar products. In the absence of off-highway literature, auto-motive requirements were examined, and table 1 tabulates the findings and assumptions of the major contributors to the topic. The test requirements cover both climate (temperature, humidity, special require-ments), mechanical (shock, vibration) and electrical (psu variation, transients, emi etc) parameters. It should be noted that the specifi-cation refers specifically to automotive tests (with the exception of Tsuha, 1982) and cannot be directly applied to truck use, and certainly not to off-highway vehicular use.
Thus, in the absence of any suitable specification on which to base the speed sensor environmental design specification, intelligent assumptions must be made. Therefore, based on previous findings in this report, appendix 11 and 13 catalogue design modifications and specifications for specific environmental circumstances.. The factors covered follow Cluley (1974) who lists:

PSU: supply range
long-term fluctuations
transients
EMI

Environment: operational temperature
shock, vibration
humidity, water

but the parameter list is extended to cover component selection, specific modifications (stopper resistor cutout, heater etc, foam filling, circuit gain, component specification).
Whilst extreme climatic conditions warrant extreme measures, the more average climate patterns give surprising results: a typical open-cast site in northern Britain, for example, puts a greater strain on the sensor circuitry than does a similar site in, say, Cyprus. For whilst components used in the unit are rated to cope with higher temperatures than those met

in Cyprus, they are outside their rating with the lower temperatures met in the UK.

At present the unit is mounted, fortuitously, on a bracket above the rear axle, which, some time after the engine has been running, warms to a moderate temperature. The drawbacks of this mounting position have been discussed in a previous report (and briefly covered in the section dealing with shock and vibration) and it's continued use therefore cannot be assumed.

SYSTEM RELIABILITY

Previous sections have covered an assessment of the likely MTBF of the sensor system: appendix 8f gives seven values dependent upon the DOD environmental severity groupings, and appendix 8g calculates the MTBF for three AGREE standards, and for constant temperature. These results are tabulated overleaf for comparison and convenience. It is relevant, however, at some point in this report, to briefly consider the methodology behind reliability calculation. The points listed below correspond to MIL 217C and the MIL 756 recommendations

Procedure:

1. Define the purpose of the equipment and required modes of operation,
2. Define the anticipated environment for each mode of operation,
3. Define the functional and physical boundaries,
4. Define the conditions that constitute 'incorrect operation' or failure,
5. Calculate appropriately.

Thus, by referring to earlier sections of the report for likely environ--mental conditions, and calculating failure probabilities for each condition, the basic requirements of system reliability prediction have been met.

WRITER	DATE	SHOCK (qty/g)	VIBRATION (g/Hz)	Temp (C) -/+	Hmidty (%/deg)	PSU (-/+)	TRANS ±V/msec	EMI	OTHER
GRIMES	1974	-/33	8/10-55	40/113	0-100	4/2	200/2		no dust
STEINBERG	1973		7/2-60	*1		4/3	100/5		
BABA	1978	5/1500	2/5-66	40/85		5/3	600/.01		no dirt, RFI
WEINSTEIN	1977		5/10-60*3	40/80		3/3	SAE		
TSUHA	1982	25"25	*4	40/85	SAE J1211	3/2	*4	FCC*5	48 hrs salt spray
HYLTIN	1973		4/9-900	40/85*6	80/65 98/38		100/.5	*8	water: 15min/20deg salt: 96 hrs

KEY: *1:temp cycling: -40/+80; thermal shock ditto.
*4:mathematically defined
*6:thermal shock, +5 to +85 deg
*8:+-40V at 70MHz for 120 usec

*3: max 30g for 10msec
*5: susceptibility @ 10GHz: 50V/m
*7: nominal 12V. Double for truck PSU

ENVIRONMENTAL TEST REQUIREMENTS FOR ELECTRONIC EQUIPMENT IN THE AUTOMOTIVE ENVIRONMENT: MAJOR WRITERS.

	CT	AGREE			DoD						
		1	2	3	Gb	Gf	Gm	Ns	Nv	Aut	M1
PCB only	89	12.8	0.8	0.4	90.4	34.3	13	24.5	7.2	7.5	4.2
PCB & transceiver	67	6.6	0.73	0.3	44.5	42	8.9	19.3	5.7	6.6	2.6

Notes: 1. Dept of Defense abbreviations explained in app 8E: calculations in app 8F
2. AGREE and CT tests explained in app 8A, calculations in app 8G
3. All numbers are years of MTBF

TABLE 1

SUMMARY OF THE MTBF RESULTS FOR THE SPEED SENSOR COMPONENTS FOR CT, AGREE AND DOD ENVIRONMENTAL TESTS.

ENVIRONMENTAL FACTORS

The intention of this section is to outline, briefly, suitable environmental tests for the speed sensor unit. Table 1 illustrates the environment (in terms of shock, vibration, temperature, humidity and electrical parameters etc) as assumed by the major researchers in the field. No indication is given of the method of testing as this information is generally not part of the literature pertaining to such tests. Appendix 10 quotes extracts from the basic design specification for the sensor unit, but again, does not go into detailed test procedures.
As a preliminary step it is of use to concisely review the main factors needing quantification for any test procedure pertaining to electrical equipment fitted to off-highway vehicles. Whilst this list is not compre--hensive, it provides a useful document for the basis of discussion; and provides the basic structure for the complete environmental specification.

1. TEMPERATURE.

a) Main FActors:
- climatic environment in terms of diurnal and seasonal variations (average and peak)
- climatic category in terms of geographical location
- internal heat sources and sinks (component dissipation, metal casing, heatsinks etc)
- external heat sources and sinks (solar radiation, chill factor, exhaust heat, metal case and chassis etc)

b) Test should deal with the effect of
- extremes, both upper and lower
- slow cycling (thermal cycling)
- rapid cycling (thermal shock)
- repetitive rapid cycling (thermal stress)

On:
- short-term performance
- long-term reliability

2. HUMIDITY.

a) Main factors:
- ambient, max, min average: diurnal and seasonal variations,
- climatic category
- internal effects due to temperature cycling

b) - upper extremes (90% RH)
- temperature cycling
- effect of condensation on performance

3. WATER.

a) - efficiency of unit join sealing (wathertightness)

b) - salt spray
- water spray (pressurised)
- immersion
- steam cleaning

4. DUST AND GRAVEL

a) - efficiency of unit joins
- effect of minor impact

b) - gravel impact
- ingress of dust, dirt, sand etc

5. PRESSURE

a) - efficiency of unit joins

b) - effect on humidity test
- effect on heat transfer (by convection)

6. SHOCK AND VIBRATION

a) - terrain category: surface roughness, surface contour, surface material, wetness
- truck type, condition, load, geometry
- antishock and antivibration measures

b) - sudden impact
- continuous vibration
- simultaneous shock and vibration
- effect on unit seals
- effect on unit performance
- long and short-term shock and vibration

7. POWER SUPPLY

a) steady state: nominal voltage variations: amx and min
- transients: load dump, inductive switching, electrical noise (common ground return, engine-generated, accessory generated), EMI (susceptibility, emmission)

b) - long-term fluctuations
- short-term interfrernce
- interference generation
- effect of temperature and changing nominal supply voltage

8. OTHER

- effect of steam cleaning
- effect of oil and grease

ENVIRONMENTAL TEST PROCEDURE.

The following represents a comprehensive test procedure suitable, in general, for any electronic componentry fitted to off-highway equipment, and specifically for the speed sensor unit. Where possible the document is self-contained, though obviously cannot delve into the exact means by which these tests ought to be carried out. Hence appropriate test procedures (eg SAE, MIL etc) are referred-to.
The tests assume a climatic grouping emulating the UK, although alternative test values are indicated where appropriate.
In addition to measurable or visible alterations in the unit under test completion, other indications of likely (or imminent) failure may be present on a working unit. Thus note should be made of the more visible effects:

- component failure: mechanical and electrical
- joint or connector failure: seperation, dry joint
- joint or connector failure
- external damage

and the more subtle failure indicators:

- component value changes: temporary and permanent
- PCB cracking, delaminating
- component discolouring
- ingress of moisture, dirt, dust
- intermittent or inaccurate unit performance.

TEST SUMMARY SHEET:

TEST	PERFORMED	PASSED
Temperature: max		
min		
cycle		
humidity		
salt		
splash		
immersion test 1		
test 2		
dust		
gravel		
pressure		
vibration: test 1		
test 2		
shock		
other: oil		
grease		
cleaning		
thermal & electrical		
electrical: steady state		
transients		
noise		
emi susc		
emi emmiss		

Abbreviations used:

S: salt
I: immersion
G: sand, dust, gravel
O: oil
RH: relative himidity

F: frost
SP: splash test
SD: sand and dust test
slew: change in temp (deg/min)

DOCUMENTS CITED:

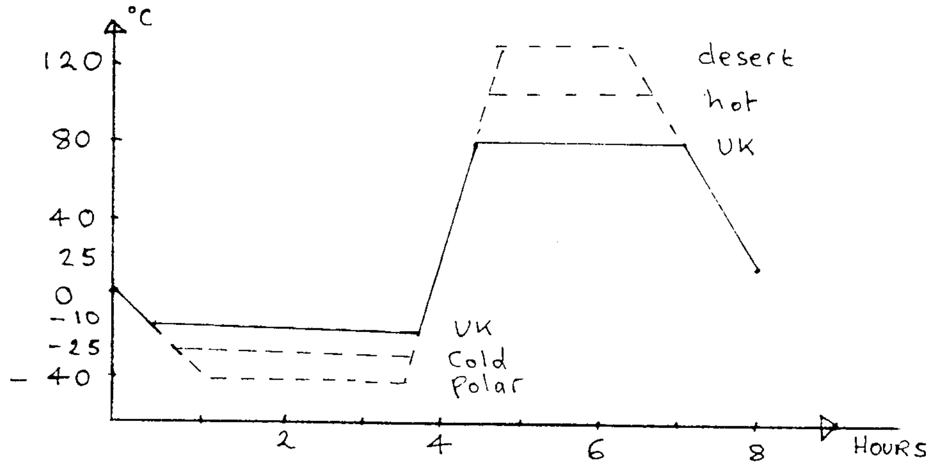
This list includes document titles only, not sections or sub-sections. These are listed fully in the reference list.

SAE J1211; J726B; J400
MS 202E; 810B
ASTM B117-3
IEC 68-2
FCC 15F

1. TEMPERATURE.

maximum: 85° for 48hours if average ambient at or below 30
121° " " " " above 30
minimum: -40° " " " low ambient at or below -20
-10° " " " " " above -20

cycling:

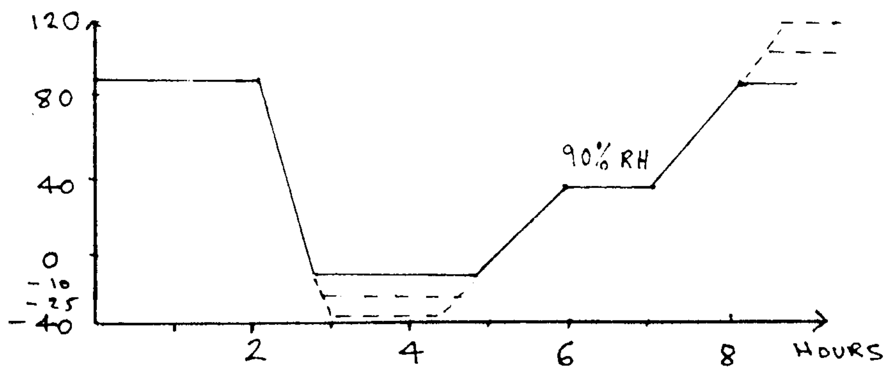


The above is based on SAE J1211 section 4.1 and MIL STD 202E/102A. This test also simulates thermal shock (introduced by the 6 /min change), which is found to be most severe if operation is intermit--tent in low temperature environments. Shock causes, typically, wire brittling and breaking, broken solder joints and component leads. Thermal stress can be assessed by repetition of this test.

2. HUMIDITY

Produced partially as an effect of cyclic thermal stress (conden--sation and evaporation cycles), and partially as a climatic effect.

Soak test:
'Soak' a non-operating unit for 10 days at 95% RH and 38°C (for maritime and temperate categories, 80% RH and 35°C)
Cycle test:



The above is based on SAE J1211 section 4.2 and MIL STD 202E/103B and 106D, and MIL STD 810B/507 part 1.

3. SALT

Spray with water containing 5% salt at 35 C for 24 hours. Wash with clear water, dry with compressed air, and test.

Based on ASTM B117-73

4. SPLASH

Spray water at 18°C at the rate of 0.25cm/minute at 45 degrees above and below the unit. Dry. Test. It is reccommended this test is first performed with a non-powered unit to prevent it being a test-to-destruct.

5. IMMERSION

1. Immerse unit in water at 18°C for 5 minutes. Cool to just below zero. Warm, dry and retest. For polar environment, cool to -20°.
2. Stringent test: perform shock and vibration test on unit whilst immersed in water.

6. DUST

Spray dust conforming to SAE J726B at a density of 0.88g/metre cubed for 24 hours. Based on SAE J1211 section 4.5 and MIL STD 202E/110A.

7. GRAVEL

Bombard gravel of 0.96 to 1.6 cm diameter (nominal 1.3cm) at 35cm under a pressure of 500 KPa (approx 70psi) at a rate of 30 stones per second. Bases on SAE J400

8. PRESSURE

No change in results of temperature cycling test for an atmospheric pressure range of 10psi to 15psi (corresponding t o operational altitudes of 3000m and -200m).

9. VIBRATION

a) Location of resonant points: apply a 1-1000 Hz sweep at a constant acceleration of 8g. Performed in each of the three planes. Based on MIL STD 202E/201A, 202E and 204C. MIL STD 202E/214 deals with random vibration. See also IEC 68-2-6

b) apply 10g over 10 to 60Hz for 48 hours
apply 4g over 0 to 100 Hz for 96 hours.
Based on Grimes (1974) and NEL (1982)

10. SHOCK

Preliminary transit shock test: drop unit from 122cm onto a 5cm plywood base backed by concrete. Repeat for each face and corner. Operational shock test: 25 of 30g shocks. Based on IEC 68.2.29
Based on MIL SPEC 202E/203B and 213B, and SAE J1211 section 4.8

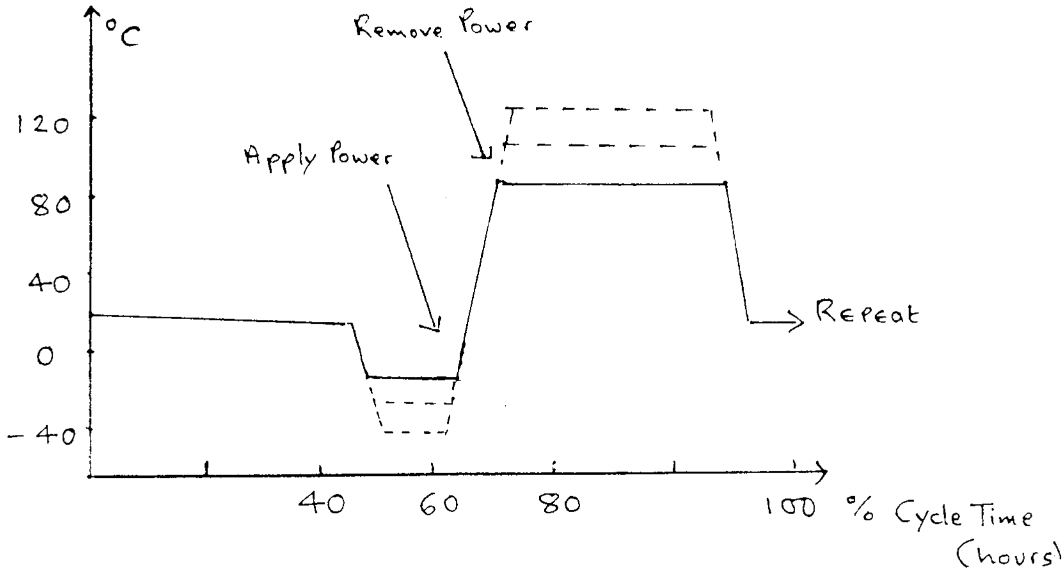
11. OTHER

The unit should not produce an adverse effect on performance when exposed to oils or grease.

Steam cleaning: no effect on performance when nozzle applied at 20cm for 1 second per cleaning area along all joins of the unit.

12. COMBINED TESTS

Thermal and electrical. This test can be destructive: the number of cycles completed should thus be noted. Apply the stated supply voltage. Test also with maximum and minimum nominal supply voltages.



13. ELECTRICAL

a) Steady state.

Unit should operate consistently from supplies of 18 to 30 volts over a range -10 to 30 degrees. The unit should not malfunction with a short-term voltage of 100v applied.

b) Transients

TYPE	MAX AMPLITUDE	CHARACTERISTIC
load dump	120	106 . exp(-t/0.188) + 14
inductive switching	-250	-300. exp(-t/0.001) + 14
alternator field decay	-100	-90. exp(-t/0.033)
mutual coupling	215	+ 200 exp(-t/0.001) + 14

c) Noise

TYPE	AMPLITUDE	DURATION	RATE	NOTES
accessory	1.5V		50-10KHz	14 + 3. Sin 2πft
ignition	3	10-15usec	as engine speed	
misfire	75	100usec	" " "	
transceiver	20mV			

d) Simplified electrical:

long term fluctuations: +-8V continuous

+- 30V for 1 second

short term fluctuation: +-200V for 2 milliseconds

+- 600V for 5 microseconds

Note: if long harnesses, unshielded conductors or common ground return impedances form part of the system, electrical tests must simulate the worst effects generated by any such layout. Thus, for poor layouts, the above tests must be modified accordingly.

14. EMI

1. Emission.

Emmission of the fundamental at 10.525GHz: 250mv/m at 30m

spuriae: maximum of 15microvolts/m at $\lambda/2\pi$ distance

harmonics : 2.5 microvolts/m at 30m

non-harmonic spuriae: 50dB down on fundamental.

2. Susceptibility

Up to 10GHz: 50v/m or greater tolerance.

Recommended test bands:

10K - 25M
25M - 50M
50M - 150M
150M - 175M
175M - 445M
445M - 520M
520M - 800M
800M - 875M
875M - 1000M

The above based on FCC part 15 subpart F 1971, and Tsuha (1982)

SUMMARY OF THE ENVIRONMENTAL CONDITIONS FOR SIX EQUIPMENT LOCATIONS.

LOCATION	TEMP lo	hi	slew	HUMIDITY hi	@ temp	F	S	I	G	O
semi-enclosed hot	-40	600	7	95	38	y	y	sp	sd	y
warm	-40	121	7	95	38	y	y	sp	sd	y
chassis isolated	-40	84		98	30	y	y	y	y	y
warm	-40	121		80	66	y	y	y	y	y
exterior	-40	113		95	38	y	y	y	y	y

Mechanical condition: see SAE J1211 section 5

Electrical condition: see SAE J1211 section 4 and previous specification.

LOCATION	SITE	RAINFALL (mm) MAX	MIN	TEMPERATURE ('C) MAX	MIN
UK N	FORT WILLIAM	250	100	16	4
UK S	LONDON	60	40	16	2
S.ARABIA	HELIPOPOLIS	1	0	30	12
S.ARABIA	ADEN	5	2	34	25
W AFRICA	LAGOS	460	40	28	26
S AFRICA	CAPETOWN	85	15	20	9
INDIA	CALCUTTA	325	5	31	20
EAST	HONGKONG	390	25	30	15
CANADA	DAWSON	30	20	16	-30
USA NW	SEATTLE	130	20	20	5
USA NE	N.YORK	105	70	25	0
USA SW	SAN DIEGO	60	0	22	14
USA SE	TAMPA	225	40	28	19
S AMERICA	RIO	125	30	25	20
AUSTRALIA	DARWIN	375	10	32	28
NORWAY	BERGEN	228	100	16	0

HIGHEST AND LOWEST AVERAGE MONTHLY TEMPERATURES AND RAINFALL FOR LIKELY OFF-HIGHWAY EQUIPMENT LOCATIONS.

DERIVED FROM PHILIPS ATLAS, ED 80, 1983. APPENDIX 0a

THIS TABLE IS DIVIDED INTO AREAS OF SIMILAR CLIMATE PATTERNS: ONLY THOSE FACTORS LIKELY TO HAVE A BEARING ON THE RELIABILITY OF ELEC--TRONIC CIRCUITRY IS COVERED. ALL TEMPERATURES IN 'C, HUMIDITY IS RELATIVE HUMIDITY. DERIVED FROM DUMMER AND GRIFFIN (1966), PHILIPS WORLD ATLAS (1983), ANDERSON (1975), HOLFORD (1983)

1. TEMPERATE : NO SEVERE EFFECT: EXTREMES A RARITY

2. MARITIME: (EG WEST USA, UK). AVERAGE CLIMATE, MEAN ANNUAL TEMPER--ATURE 21 TO 29DEG, PEAKS UP TO 38. HUMIDITY 45 to 55%

3. TROPICAL: a) INLAND: HIGH RAINFALL, DAY TEMPERATURE UP TO 45, EARLY AM AND PM. HUMIDITY 80% DAY, 90 TO 100% EARLY PM.
   b) COASTAL: 100% HUMIDITY, HIGH SALT CONTENT

4. DESERT: AIR TEMP 60 DAY to -10 EVE. IN DIRECT SUN, 75 ON METALLIC SURFACES. HUMIDITY 3 TO 10%. DUST PARTICLE SIZE 0.005 to 0.02mm, SAND 0.4mm; SAND CLOUD DENSITY TYPICALLY 300 PARTICLES/CM SQUARE/ HOUR.

5. POLAR/ARCTIC: DAY TEMP TO -40, SOMETIMES -55 (LOWEST RECORDED -70DEG). SEASONAL VARIATION CAN BE -55 TO +35. SWEDEN TYP +35 SUMMER, -35 WINTER.

CLIMATE (AVERAGE AND EXTREMES) OF MAIN WORLD GROUPINGS.

APPENDIX 0b.

This appendix tabulates climatic data (extremes, mean and peak) of areas in which the sensor unit might be expected to operate is sold overseas: thus only those areas listed in appendix 1a appear below. Where possible, UK figures are given. Data derived from refs listed in app 0b. All temperatures is deg centigrade.

1. Temperature. Peak: instantaneous, in shade; mean: yearly.

high				low			
peak		mean		peak		mean	
Libya	58	Ethiopia	35	USSR	-60	Canada	-54
Calif	57	UK	12	Canada	-58	UK	6.4
UK	37			UK	-28		

High peak (no shade): california, 98. Extreme variations: seasonal, USSR (-70 - 37); diurnal, California (-49 - 56).

2. Rainfall. Peak: over 24 hours; instant: over 1 min. Values in mm.

peak		mean		instant	
S.E Africa	1870	Hawaii	11450	Guadeloupe	39
UK	280	UK	4390	UK	8

3. Sunshine. Max: E. Sahara: 97%; UK, 78%

4. Windspeed. Max: USA, 371 Km/hr; UK, 231 Knm/hr. Wind chill factor average for 0 deg and 40% RH: 1deg/mpg.

APPENDIX 0C: CLIMATIC EXTREMES IN AREAS OF OFF-HIGHWAY TRUCK OPERATION, IN UK AND ABROAD.

Climatic region	vehicle location	load tonnage		tot %
		36-100	over 100	
1.temperate, maritime	UK, Belgium, E & N Mid USA.	349	356	29
2.hot	Spain, Greece, Mexico, S.Africa S. USA	341	83	18
3.V hot desert	N, W, E Africa Australia	170	31	8
4.cold	NE USA, USSR, E,M Canada, China, Yugoslavia, Roumania	245	289	22
5.Polar,arctic	Norway, Sweden N Canada	207	96	13
6.tropical	Philipines, Brazil Chile, Peru, N Guinea	123	128	10

Notes: for wide seasonal variations, the average is quoted. Thus, for example, Norway appears only once, although summer temperature may fall into the temperate category. These figures were derived from the references of app 0b, geographical locations as used in app 1a.

OFF-HIGHWAY TRUCK DISTRIBUTION ACCORDING TO CLIMATIC CATEGORY: LISTED FOR MEDIUM AND HIGH LOAD CAPACITY. APPENDIX 1B

LOCATION	EUCLID R100	EUCLID 170	UNIT RIG TRUCKS 36	85	100	120	180 200	TOTAL
EUROPE N NORWAY	16	15	19					50
N SWEDEN			9	9				18
E UK. BELGIUM	5		5		6			16
E ROUMANIA			8			1		9
M YUGOSLAVIA		29			5	60	37	131
SW SPAIN					17			17
S GREECE							8	8
USA M WYOMING	16	31			61		97	205
E KENTUCKEY	3	11	88					102
N DAKOTA			72	101	8		6	87
N MINNESOTA			1	36	130		25	192
OTHER	64	57						121
CANADA NW ALBERTA				17				17
NW BRIT.COLUMB.			14	75	64		65	218
E NEWFOUNDLAND			27	20		3		50
E QUBEC	5	1	4	24	62	4	30	130
M ONTARIO	1				19			20
S.AMERICA SW CHILE		10	8	6	28		68	120
W PERU			8		36			44
E BRAZIL			13	16				29
N MEXICO			30	8	19		31	88
AFRICA NW MOROCCO					59			59
M ZAIRE				8	74			82
NW SENEGAL							2	2
W LIBERIA		5		4	8	10		27
S S.AFROCA		11		12	152		6	181
S ZAMBIA					63		8	71
AUSTRALIA SW PERTH		14	12					26
SE N.S WALES			5					
USSR							112	112
CHINA		10						10
PHILLIPINES/NEW GUINEA	8	50						58

GEOGRAPHICAL LOCATION AND TYPE OF TRUCKS SUPPLIED BY EUCLID AND UNIT RIG TOTAL NUMBER OF TRUCKS ACCOUNTED: 2405 (SIZE RANGE 36 - 200) TON CAPACITY).

SOURCES:
1. EUCLID INC, CLEVELAND. UNIT OWNERSHIP DATA, APRIL 1981
2. UNIT RIG CUSTOMER LIST AND SHIPPING DATA. JUNE 1981
3. PHILIPS WORLD ATLAS, ED 80, 1983.

NOTES: COMPASS DIRECTION REFERS TO CONTINENT.
COUNTRY GROUPINGS DO NOT CORRESPOND TO THOSE USED FOR CATEGORISATION OF CLIMATE GROUPINGS IN THE DESIGN MODIFICATION SECTION OF REPORT P24.

App 1a

NB appendix 2A is located after app 9C for compactness)

CLIMATIC REGION	LOCATION OF VEHICLES	LOAD TONNAGE 36-100	over 100	TOT %
TEMPERATE, MARITIME:	UK, BELGIUM, USA (EAST, NORTH, MID)	349	356	29
HOT:	SPAIN, GREECE, MEXICO, S.AFRICA, USA (SOUTH)	341	83	18
V. HOT, DESERT:	AFRICA (NORTH, WEST, EAST) AUSTRALIA	170	31	8
TROPICAL:	PHILLIPINES, NEW GUINEA, BRAZIL, CHILE, PERU	123	128	10
COLD:	USA (NE), USSR, CHINA, YUGOSLAVIA, CANADA (EAST, MID), ROUMANIA	245	289	22
POLAR/ARCTIC:	NORWAY, SWEDEN, CANADA (NORTH)	207	96	13

NOTE: FOR WIDE SEASONAL VARIATIONS, THE AVERAGE WAS TAKEN. THUS, FOR EXAMPLE, NORWAY APPEARS ONLY ONCE ALTHOUGH SUMMER TEMPERATURES MAY FALL INTO TEMPERATE CATEGORY.

DERIVATION: GENERAL GROUPINGS AS USED IN APPENDIX 0b
GEOGRAPHICAL LOCATIONS AS USED IN APPENDIX 1a

OFF-HIGHWAY TRUCK DISTRIBUTION ACCORDING TO CLIMATIC CATEGORIES, LISTED IN MEDIUM AND HIGH LOAD CAPACITY.

APPENDIX 1b

	CAT 777	CAT 769	TEREX 3311	EUC R100	EUC R85	TEREX R70	EUC R170	INT
DIM L	9.8	7.8	10.4	10.5	9.3	10.6	11.9	9.2
DIM H	4.9	4.0	4.8	5.4	5.0	4.7	5.7	4.1
DIM W	4.8	3.6	4.8	5.4	4.9	4.3	6.4	4.1
W: E_F	55.6	26.8	55.0	67.0	51.2	47.9	85.3	32.6
W: LR	67.0	67.0	67.0	66.0	67.0	71.0	67.0	51.0
W: ER	49.0	51.0	49.0	52.0	54.0	55.0	51.0	70.0
ST: F	0.32	0.24	0.24					
ST: R	0.16	0.19	0.17					
S: O	6(*1)	8(*1)	7	8			8(*2)	
GRS 2		13	12	13	10			
3	17	16	17	13				
4	13	22	21	23	17			
5	17	30	27	30	23			
6	24	42	36	41	32		28	42
7	34						34	

KEY: *1: nitrogen suspension; W: weight (X by 1000Kg)
*2: liquid suspension. L: laden
E: empty R: rear, F: front
ST: suspension travel to bottoming (cm)
SO: suspension oscillation (± deg)

SUSPENSION CHARACTERISTICS, WEIGHT DISTRIBUTION AND GEAR CHANGEOVER POINTS FOR LADEN AND UNLADEN TRUCKS. APPENDIX 2D

CATEGORY	FACTORS
surface composition	wetness (3 classes) strength (11 ") (see ref D.Def 1962) type (5 ")
surface geometry	slope (in %) roughness (RMS microprofile: statistical) obstacles: random/regular distribution spacing height, depth approach angle length, width

CATEGORISATION OF GROUND TYPE FOR VEHICULAR MOBILITY ASSESSMENT
Derived from Rula (1973). APPENDIX 2B

SURFACE	RR	CofT
concrete and asphalt	1.5	0.9
dirt: hard / soft	2 / 8	0.45 / 0.6
snow	4.5	0.2
sand: dry / wet	10 / 10	0.2 / 0.4
soft mud, rutted track	16	
clay loam: dry / wet		0.55 / 0.45

ROLLING RESISTANCE AND COEFFICIENT OF TRACTION FOR SURFACES OFTEN MET ON OFF-HIGHWAY APPLICATIONS. APPENDIX 2C

(note that clay loam CofT decreases for wet conditions and soft dirt has a higher CofT than hard.)

PROTOTYPE COMPONENT	COMMERCIAL TYPE	INDUSTRIAL TYPE	MILITARY TYPE
LM 324	LM324 (51) LM324I (110) LM324A (505) LM324J (190) LM324AJ (1155) TEMP RANGE : 0-70°	LM224 LM224J (255) LM224AJ (1811) LM2902J *1 (422) LM2902N *1 (128) -25 TO 85°	LM124J (375) LM124JBS (1010) LM124AJ (1873) LM124AJBS (2450) LM124AJ3 (2559) LM124F (252) LM124J3 (750) (JBS: *2) -55 TO 125°
RC4558	RC4558P (90) MC4558P (82) RC4558D (151) RM4558 (90) RC4558JG (124) TEMP RANGE 0 TO 70°		RM4558JG -55 TO +125°
LM317T	LM317H (420) LM317K (578) LM317MP (71) LM317T (110) TEMP RANGE 0 To 125°	LM217H (1686) *3 LM217K (1873) -25 TO +150°	LM117H (2436) *4 LM117K (2653)*5 LM117HBS (1550) LM117KBS (2025) LM117H3 (2551) LM117K3 (2702) -55 TO +150°
CD4046BE	CD4046AE (280) CD4046BCN (129) CD4046BF (259) *7 CD4046BE (46) *8 TEMP RANGE -40 TO 85°	CD4046AD (1462) CD4046BF (426) CD4046BD (1467) CD4046BF3 (817) CD4046BD3 (2116) CD4046BMJ (1093) CD4046BCJ (143) *6 MC14046BAL (394) RANGE -55 TO 125°	
CD4018BE	CD4018BE (46) CD4018BCN (85)	CD4018BCJ (169)	CD4018BMJ (827) *9

SEMICONDUCTORS USED ON THE SPEED SENSOR MAIN PCB: ALTERNATIVE VARIANTS FOR TEMPERATURE RANGE SELECTION, AND PRICES (IN PENCE). KEY TO TABLE APPEARS OVERLEAF.

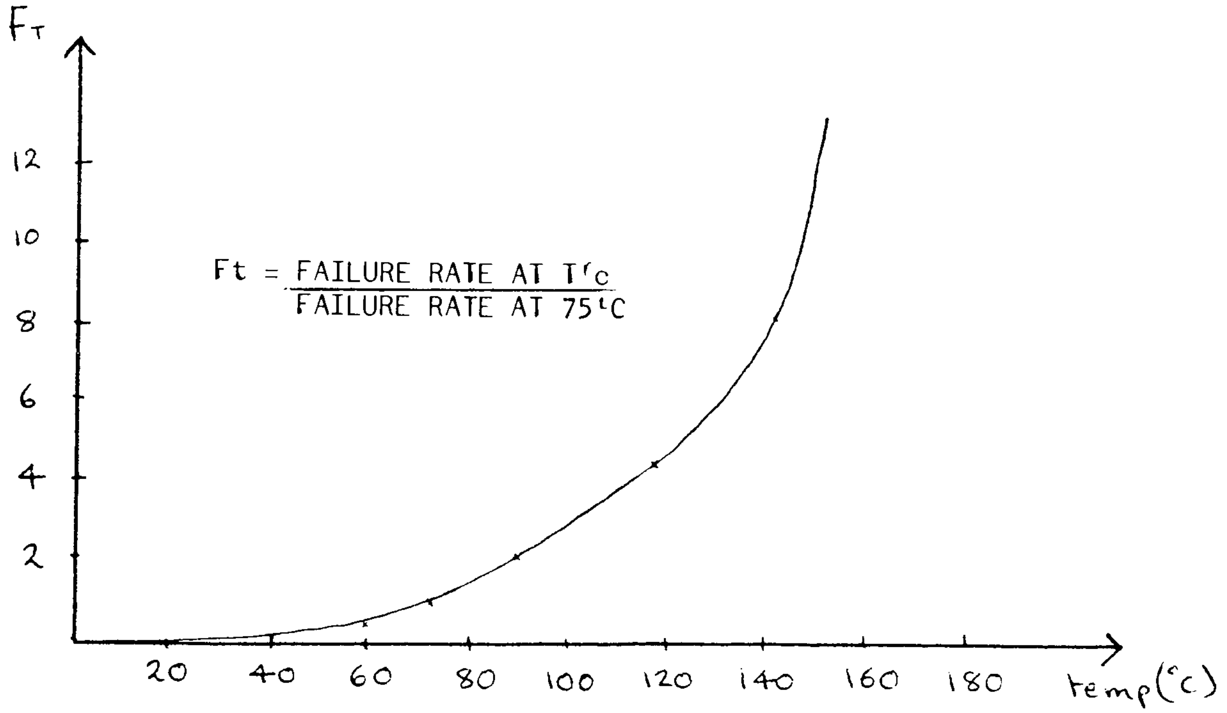
APPENDIX 3

KEY TO ALTERNATIVE SEMICONDUCTOR TABLE.

NOTES:
*1 TEMP RANGE -40 TO 85
*2 TO BS9460-F0139
*3 TO 39 CASE (½AMP)
*4 TO BS9430-F0114
*5 TO BS9430-F0119
*6 TO BS9490-F009
*7,*8 ALTERNATIVE SOURCES
*9 TO BS9490-F3032

MIL SPEC 883:
-55 TO 125 SPEC,
125 BURN IN FOR
3 HOURS.

ABBREVIATIONS:
BS: TO BRITISH STANDARD
E,P: PLASTIC PACKAGE
D: CERAMIC
JG: GLASS MOUNTED CERAMIC
A: UPRATED PERFORMANCE
J: CERAMIC CASE (NSC)
F: " " (SIG)
L: " " (MOTOROLA)
3: TO MIL SPEC 883 (SEE BELOW)
H: TO5 CASE: 2AMP
M: T0202 (½AMP)
T: T0220 (1.5AMP)
BF: FLAT PACK CERAMIC



THERMAL ACCELERATION FACTOR, Ft, GRAPH. FROM BAR-COHEN (1980)

APPENDIX 4

APPENDIX 5

PARAMETER		PRESENT	ALTERNATIVE CABLES					
STRAND NO./THICK	/mm	16/0.2	32/0.2	24/0.2	256/0.05	19/0.16	7/0.2	30/.25
CURRENT	A	3	6	14	6	6	6	22
TEMP RANGE	°C	0 85 (*2)	0 85	0 85	-100 300	-55 200(*3)	-55 200	-20 70
OUTSIDE DIAM	mm	1.6	2.58	2.8		1.35	0.95	
TO SPEC		BS4808/2	BS4804/2	BS6231		MILW1687E	BSG210	BS 6231/4BK
		DS61-12/6/2	DS61-12/6/2				DS61-12/8	
							MILW 16878E	
COST	p/m	3.36	5.2	6.3	51	38.3	22	7.3
TYPE		CONNECTION	SWITCHGEAR (*4)	SWICHGEAR	SILICON	PTFE	PTFE	SWITCHGEAR

SYSTEM CABLE TYPES: EXAMPLE OF CABLE UTILISED AT PRESENT AND POSSIBLE ALTERNATIVES. CABLE IS EXPOSED AND PRONE TO AN EXTENDED TEMPERATURE RANGE.

NOTES:

1. BS 6231/4BK: operating temperature -20 to 70 degrees
2. Nominal operating temperature: 25 deg
3. MIL W16878: to -70 deg
4. BS 6231 data resume:
   - a) to tolerate 85+-2 deg for 1000 hours
   - b) fire resistance to BS 4066 part 1 and BS 6141
   - c) for this project, specify AK (-15 to +70)
BK (-20 to +70)
CK (-15 to +85)
   - d) physical strength to BS 6746

APPENDIX 5

	RESISTOR 0.4W	RESISTOR 2.5W	CAPACITOR ELECT	TANT	POLY	ZENAMIC	DIODE BZX	LED
TEMPERATURE RANGE °C	-55 155		-25 85	-55 85	-55 100	-20 +60 (*2)	0 85	
MAXIMUM TEMPERATURE		350	*1	*1		110	*4	125 (*3)
TEMP COEFF (ppm/°C)	+-100	+-200		-15% @ -55 +15% @ 55	+330	0.07%/ C	1.5mV/ C	

NOTES: *1. RIPPLE CURRENT HALVED AT 76°C
*2. DERATE 2%/°C ABOVE 60°C
*3. " 1.5%/°C " 25°C
*4. " 80% AT 150°C

EFFECT OF TEMPERATURE ON SPEED SENSOR PCB COMPONENTS: PASSIVE COMPONENTS

APPENDIX 6a.

RADAR UNIT	TEMP RANGE	STABILITY (MHZ/°C)
MA 86501	-30 70	0.3
PLESSEY GDHM2	-20 55	N/A
IMA 5300 92	-10 50	0.3
MULLARD CL8960	0 40 (*5)	-0.3
ARO	?	?

EFFECT OF TEMPERATURE ON RADAR UNITS (Manufacturers Data)

APPENDIX 6b

NOTE: *5. ABS MAX STORAGE RANGE: -10 to 70

PCB PARAMETER	POLY	GLASS/EPOXY	TEFLON	KAPTON
MAX TEMP (ABS)	149	300	274	300
MAX CONTINUOUS	130	150	200	150
LOW TEMP	-50	-20	-85	-50
WATER ABSORB (*6)	0.8	0.5	0.01	3

EFFECT OF TEMPERATURE ON PCB MATERIALS. APPENDIX 6c

NOTE. *6. IN % PER 24 HOURS.

VOLTAGE REGULATOR

	LM217	LM317		
LOAD REGULATION % OF Vo	-0.3	-0.3	-0.4	-0.4
ADJ CURRENT MICRO A	45	50	57	58
DROPOUT VOLT V	2	1.8	1.6	1.5
REF VOLT V	1.246	1.249	1.236	1.232
TEMP	-25	0	125	150

OPERATIONAL AMPLIFIER (QUAD)

	LM124	LM324	
SUPPLY CURRENT Ama	0.5	0.7	
O/P CURRENT Ama	50	40	28
I/P " ma	35	38	32
TEMP	-55	0	125

OPERATIONAL AMPLIFIER (DUAL)

	RM4558	RC4558		
O/P GAIN (DB)	100	100	100	100
I/P OFFSET V	7.5	7.5	6	7.5
SUPPLY I ma	7.5	6.6	5.6	5
TEMP	-25	0	25	100

PLL

	4046
TEMP STABILITY	0.08%/ C

EFFECT OF TEMPERATURE ON INTEGRATED CURCUITS USED ON THE SPEED SENSOR CIRCUIT. APPENDIX 6d

time (hours)	heated		cooled	
	alarm	cancel	alarm	cancel
0	473	468	479	483
0.5	476	477	483	485
1	477	479	484	486
3	479	483	485	486

EFFECT OF TEMPERATURE ON THE LINEARITY OF THE CONTROL BOX ALARM AND CANCEL FREQUENCIES. APPENDIX 6e

	REF	NF *6	3 degrees C		17°		35°		58°		67°	
			F	P *1	F	P	F	P	F	P	F	P
PLESSEY	8	587+-10	584	0.86	(576)	1.3	(575)	1.2	(567)	1.15		
	11		591	1.05	588	1.45	583	1.25	(575)	1.05		
	L		594	1.05	585	1.35	579	1.15	(570)	0.85	(568)	0.65
IMI	8	687+-10	688	1.35	686	1.45	683	1.5	(674)	1.45	*4	
	12		(721)	1.55	(703)	1.8	(704)	1.56	695	1.45		
	9		629	1.14	695	1.25	686	0.95	680	0.85		
MA	L	525+-10	529	2.05	524	1.95	520	2.05	518	1.5	(516)	0 *2
	P				340*3	0.7	310					

NOTES:

1. POWER: MEASURED WITH NO TERMINATING LOAD: RELATIVE MEASUREMENT ONLY
2. DEVICE SIFFERED PERMANENT FAILURE
3. DEVICE MALCUNCTION. RECOVERED AFTER SWITCH-OFF
4. 67° EXCEEDS THE MANUFACTURERS STATED RANGE
5. BRACKETS INDICATE OUT OF HOME OFFICE TOLERANCE.
6. NF IS NOMINAL OPERATING FREQUENCY: 10.xxx GHZ

temperature test for operating frequency and power of three types of microwave unit.

APPENDIX 6F

Speed	surface A						surface B					
	rear			C of G			rear			C of G		
	a	b	c	a	b	c	a	b	c	a	b	c
10	2.5	2.7	2.2	2.0	1.7	1.2	19	11	14	17	8.4	10
20	3.6	2.5	2.8	3.1	2.4		2.4					
15	9	4.2	5.4	4.0	3.9	2.0	6.8	5.2	3.9	6.0	3.6	3.7
25	3.3	3.0	2.7	3.0	2.9		2.8					
30	4.5	3.2	3.3	5.2	2.2		2.9					
	surface C						surface D					
	rear			C of G			rear			C of G		
	a	b	c	a	b	c	a	b	c	a	b	c
10	12	5.9	6.6	8.8	3.8	3.4	14	7.2	7.6	7.1	5.0	9.7
15	17	7.2	12	7.1	4.0	5.4	17	9.5	13	6.7	3.3	4.5

Key: Surface A: 5cm protruberance per 30cm
B: 5cm 60
C: random, D: random

a = X plane
b = Y plane
c = Z plane

TRUCK VIBRATIONS (in g) FOR FOUR SURFACES. MEASUREMENTS IN THREE PLANES AND TWO POSITIONS.

APPENDIX 7B

Transport	Shock (g)	vibration freq (Hz)	ampl (g)	reccom. aV freq
ship	38	10-15	2.4	25-30 AV
aircraft (passenger)	5	50	5-7	100-500
aircraft (military)		150	12	
rocket/missile	100	2000	40	100-400
helicopter		3-500	½-4	40-2000
truck 2ton	30			
truck 70ton	*1			
truck 2.5 ton	*2	5-55		
car	4,7*3	5-25	1	

Notes: *1: see app 8C. *2: see app 8B. *3: Grimes (1974)
Refs: Grimes (1973), Cluley (1974), Crede (1957), Dummer & Griffin (1966), NEL (1982)

SHOCK AND VIBRATION MET IN VARIOUS MODES OF TRANSPORT.

APPENDIX 7A

FAULT	FREQ
inadequate electronic design	32
poor design/manufacture control	16
poor shock performance	12
poor vibration performance	10
poor assembly	8
poor mounting of PCB components	5
components used in excess of rate	5
temp extreme performance poor	5
overcomplex circuitry	3

Derived from US Navy Electronics Lab equipment analysis.

Only those faults pertinent to the speed sensor are listed.

RELATIVE FREQUENCY OF OCCURENCE OF FAULTS ON ELECTRONIC EQUIPMENT.

APPENDIX 8B

SPEC	ISSUED BY	COVERS
MIL C 172C	DOD	VIBRATION MOUNTS FOR ELECTRONIC EQUIPMENT
MIL S 4446	USAF	METHOD AND APPARATUS FOR VARIABLE DURATION SHOCK TESTING
MIL T 4807	USAF	VIBRATION AND SHOCK TESTS FOR ELECTRONIC EQUIPMENT
MIL E 4970	USAF	ENVIRONMENTAL TESTING OF EQUIPMENT
MIL G 9412	USAF	ENGINEERING AND PROCUREMENT DATA FOR GROUND EQUIPMENT
MIL T 5422E	ASG	ENVIRONMENTAL TESTING OF ELECTRONIC EQUIPMENT FOR AIRCRAFT
MIL E 5400D	ASG	GENERAL SPEC FOR ELECTRONIC EQUIPMENT
MIL P 9024B	USAF	SPECIFICATIONS AND GENERAL DESIGN REQUIRE--MENTS FOR PACKAGING OF MISSILE SYSTEMS
MIL E 5272C	ASG	GENERAL SPECIFICATION FOR ENVIRONMENTAL TESTING OF AERONAUTICAL ELECTRONIC SYSTEMS

MILITARY SPECIFICATIONS FOR SHOCK AND VIBRATION EFFECTS AND TESTING ON ELECTRONIC EQUIPMENT. FROM MATISOFF, 1982. APPENDIX 8C

SPECIFICATION	
9301	GENERAL PURPOSE DIODES
9305	VOLTAGE REGULATOR DIODES
9330	GENERIC: DIODES
9400	INTEGRATED CIRCUITS
9490	DIGITAL LOGIC
9491	ANALOGUE
9073 -F002,5	TANTALUM CAPACITORS
9074 -N002	POLYSTYRENE "
9076 -F0034	POLYESTER, POLYCARBONATE CAPACITORS
9078 -F0009	ELECTROLYTIC CAPACITORS
9075 -F013,14	CERAMIC CAPACITORS
9110	RESISTORS (FIXED)
CECC 40101019	RESISTORS (LOW POWER)
CECC 40201002	VITREOUS RESISTORS

BRITISH STANDARD SERIES 9000 SPECIFICATIONS FOR ELECTRONIC COMPONENTS USED IN THE SPEED SENSOR CIRCUIT.

APPENDIX 8d

Component	Number	Failure rate (%/1000Hr)			
		1	2	3	CT
Diode	7	.005	.01	.06	.12
resistor ¼w	31	.003	.005	.735	.3
resistor 2w	2	.02	3.3	1.95	.02
cap (elect)	3	.05	3.2	3.33	.4
cap (tant)	6	.04	.04	.05	.4
cap (other)	10	.001	.06	.08	.02
IC	4	.04	.04	.06	.12
sdr joint	188	.0006	.0008	.0008	.006
IC skt	3	.08	.08	.09	?

Notes: Defining MTBF as K.(100/ N.F) where N = no. of components and F = failure rate in %/K hours, and expressing it in terms of the boards working life (3 shifts 6 days/week: 7200 hours/year)
The MTBF for:

Agree test schedule 1: 12.8 years MTBF
" " " 2: 0.8 " "
" " " 3: 0.4 " "
Constant temp test: 89 years "

The failure rate of certain components does not, in practice, correspond well with Agree tests 2 and 3: no record exists of a ¼w res failure, whilst capacitors do so regularily. In practice, results similar to test 1 seen most realistic.
Agree test parameters are listed in appendix 8A.

CALCULATION OF THE MEAN TIME BETWEEN FAILURE USING FOUR TEST SCHEDULES FOR THE NEW SPEED SENSOR BOARD (main PCB only)

APPENDIX 8C

Device	Vdc	Voltage			Ipk	E(j)	cost	manf
		Min	Nom	Max				
MAV33M1B	26	29.5	33	36.5	40	0.15	37	GE
ZV27ZA4	22	23	27	31.1	1000	5	80	GE
ZV33ZA1	26	29	33	36.5	250	1.2	73	GE
Z7L220	19	23		31	200	3	34	IR
Z7L330	23	28		38	200	3	34	IR
Z7L390	27	33		45	200	6	34	IR
Z10L330	23	28		38	500	18	45	IR
Z10L390	27	33		45	500	24	45	IR
Z15L390	27	33		45	1000	30	61	IR
BZW70-11	21				20	400w	75	M
BZW70-12	23				20	400w	75	M
BZW70-13	26				20	400w	75	M
BZW70-15	26				10	400w	75	M
ZP1027	30	20		40	125	0.4	28	L
ZP2027	30	20		60	125	1.8	47	L
ZP3037	30	20		60	125	6.5	71	L
ZV33ZA5	26	30	33	36.5	1000	6	80	GE

Notes: GE: General Electric; IR: International Rectifier; M: Mullard; L: Lucas; E: energy absorption (in 1 msec) ; I: peak current capacity.
Cost in pence as atmid 1983

APPENDIX 9A

SUPPRESSION DIODES SUITABLE FOR A 24V NOMINAL LINE PROTECTION ON TRUCKS

COMPONENT CLASS	MIL SPEC NO.	Gb	Gf	Gm	Ns	Nv	Aut	Ml
S.CONDUCTOR: CMOS	M 38510	.2	1	4	4	5	4.2	10
S.CONDUCTOR: LINEAR	M 38510	.2	1	3	3	3	4	10
RESISTOR: FIXED	R 10509	1	2	4	2	11	8.5	18
RESISTOR: W.WOUND	R 26	1	2	5	2	11	8.5	30
CAPACITOR: PLASTIC	C 18312	1	2	4	4	9	10	20
CAPACITOR: TANTALUM	C 3965	1	2	9	6	14	14	30
CAPACITOR: ELECT.	C 62	1	2	12	6	20	21	40
DIODE: GENERAL	S 19500	1	5	25	10	25	20	40
DIODE: ZENER	S 19500	1	5	30	15	30	20	40
M.WAVE DET, MIX	S 19500	1	10	50	15	50	40	200
LED	S 19500	1	2	4	4	5	4	10
PCB	Y 55110	1	2	4	4	10	10	20
SOLDER JOINT	-	1	1	3	1	3	4	7

KEY:

DEPT OF DEFENCE CATEGORY	ABBREV	INCLUDES
GROUND, BENIGN	Gb	VERY LITTLE ENVIRONMENTAL STRESS, OPTIMUM OPERATION AND MAINTENANCE.
GROUND, FIXED	Gf	LITTLE ENVIRONMENTAL STRESS,, LESS THAN IDEAL MAINTENANCE
GROUND, MOBILE	Gm	SEVERE STRESS (VIBRATION AND SHOCK). NON-UNIFORM MAINTENANCE.
NAVAL, SHELTERED	Ns	AS Gf BUT OCCASIONAL HIGH SHOCK AND VIBRATION
NAVAL, UNSHELTERED	Nu	AS Ns BUT REPETITIVE HIGH SHOCK AND VIBRATION
AIRBORNE, UNINHABITED	Aut	VERY HIGH VIBRATION AND TEMPERATURE CYCLING, EXPOSED TO OIL, EXHAUST FUMES ETC. LITTLE MAINTENANCE
MISSILE LAUNCH	Ml	VERY SEVERE SHOCK AND VIBRATION.

REFERENCES:
1. MIL HDBK 217C 1979 (DERIVATION FROM 300 PAGES)
2. RADC TR 72 1972
3. MIL STD 756

US DEPT OF DEFENCE ELECTRONIC EQUIPMENT ENVIRONMENTAL SEVERITY CATEGORIES, AND RELIABILITY FACTORS RELATING TO THESE CATE--GORIES. FACTORS ARE GIVEN FOR EACH COMPONENT CLASS USED IN THE SPEED SENSOR. MIL SPEC REFERENCES ARE ALSO GIVEN.

	N	CT	Gb			Gf			Gm			Ns			Nv		
			F	F*Ct	W	F	F×Ct	W	F	F×Ct	W	F	F×Ct	W	F	F×Ct	W
DIODE *1	7	.12	1	.12	.84	5	.6	4.2	30	3.6	25.2	15	1.8	12.6	30	3.6	25.2
RES ¼W	31	.3	1	.3	9.3	2	.6	18.6	4	1.2	37.2	2	.6	18.6	11	3.3	102.3
RES 2W	2	.02	1	.02	.04	2	.04	.08	5	1	2	2	.04	.08	11	.22	.44
C: ELEC	3	.4	1	.4	1.2	2	2.4	2.4	12	4.8	14.4	6	2.4	7.2	20	8	24
C: TANT	6	.4	1	.4	2.4	2	.8	4.8	9	3.6	21.6	6	2.4	14.4	14	5.6	33.6
C: OTHER	10	.02	1	.02	.2	2	.04	.4	4	.08	.8	4	.08	.8	9	.18	1.8
IC *2	4	.12	.2	.06	.24	1	.12	.48	4	.48	1.92	4	.48	1.92	5	.6	2.4
SOLD. J.	188	.006	1	.006	1.13	1	.006	1.13	3	.018	3.38	1	.006	1.13	3	.018	3.4
ΣFNG		.156			.1559			.321			1.066			.567			1.931
MTBF *3		642			651			312			94			176			52
MWAVE	2	5	1	5	1	10	5	10	50	25	50	15	7.5	15	50	25	50
ΣFNG		.206			.312			.331			1.566			.717			2.431
MTBF		485			321			302			64			139			41

CALCULATION OF THE MTBF FOR THE SPEED SENSOR CIRCUIT (PCB AND PCB WITH MICROWAVE TRANSCEIVER) FOR THE RELEVANT D.O.D ENVIRONMENTAL CATEGORIES. TABLE IS CONTINUED OVERLEAF.

NOTES:

0. CT IS THE FAILURE RATE AT CONSTANT TEMPERATURE AND NO VIBRATION. FIGURE IS *100, AND IN UNITS OF PERCENT PER 1000 HOURS.
1. DIODE FAILURE RATE IS THE LOWER OF THE FIGURES FOR THE VARIOUS TYPES OF DIODE EMPLOYED IN THE CIRCUIT.
2. AS POINT 2 BUT LOWER FIGURE FOR LINEAR AND DIGITAL IC TYPES.
3. IN UNITS OF 1000 HOURS

APPENDIX 8F (Page 1)

	N	AUT F	AUT F.Ct	AUT W	M1 F	M1 F.Ct	M1 W
Diode	7	20	2.4	16.8	40	4.8	33.6
Res ¼w	31	8.5	2.8	86.8	18	5.4	168
Res 2w	2	8.5	0.2	0.4	30	0.6	1.2
Cap: elect	3	21	8.4	25.4	40	16	48
Cap: tant	6	14	5.6	33.6	30	12	60
Cap: other	10	10	0.2	2.1	20	0.4	0.4
IC	4	4.2	0.5	2	10	1.2	4.8
sold. J.							
sum FNG				1.72			3.27
MTBF				54			31
Mwave	2	40	20	40	200	100	200
sum FNG				2.11			5.27
MTBF				47			19

Notes. MTBF (weeks) is (100.K/ Ct.Gx.N).(H/52) where
H: shift hours per year (est 7200)
N: no. of components
Ct: failure rate in percent per K hours at constant temperature and no shock
Gx: reliability factor (see appendix 9E)

APPENDIX 8F (part 2)

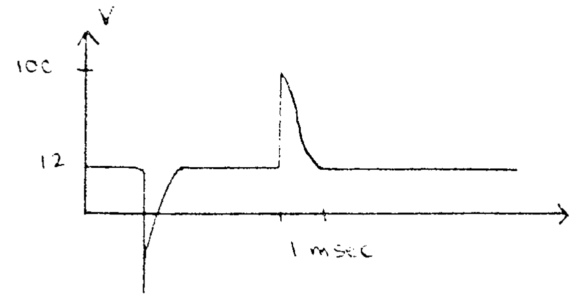
CONDITION	PLANE: FREQ (hz) AND ACCEL (ms^{-1})					
	X		Y		Z	
	F	A	F	A	F	A
Tickover	80	9	80	4.5	80	5
			160	2.5		
25mph. On head	5	16	5	8	5	8
	60	8			60	2.5
Reverse. No AV	150	7.5	150	6.5	100	6
	90	1.9	2	6	2	5
		Vel(ins/s)				
20mph On chassis	1	14	1	16	1	9
	3	9	3	6	3	4
	60	3			60	1.5
25mph On chassis	1	70	1	60	2	38
	3	50			3	50

LOCATION AND VALUE OF MAIN PEAKS IN SPECTRUM OF ACCELERATION AND VELOCITY FOR AN OFF-HIGHWAY VEHICLE (Nel, 1982)

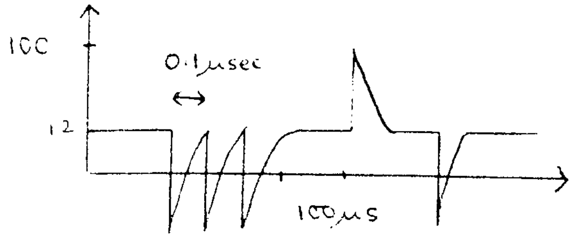
Parameter	1	2	3	4	5
temp (deg C)	25±5	40±5	-54, +55	-65, +71	50±5
vibration ("/Hz)	-	.01@25	-	-	.01@20
cycling (hrs)	3hrs cyc	3	3	3	3
I/P voltage	nom	max±2%	max±2%	max±2%	nom

AGREE TEST PROCEDURES: TESTS ONE TO FIVE.

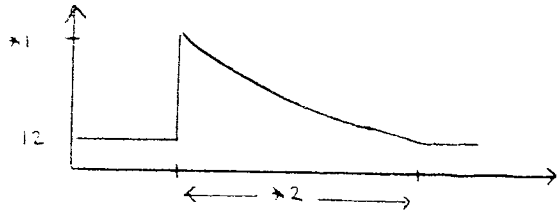
APPENDIX 8A



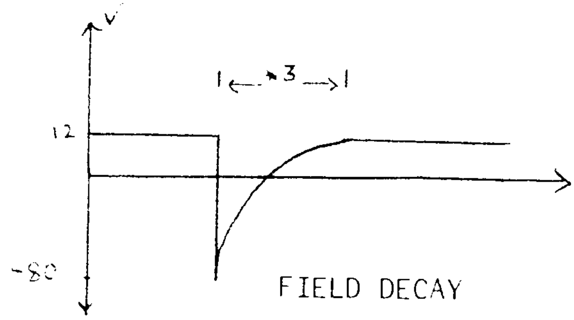
LINE TRANSIENTS: SLOW, LOW VOLTAGE



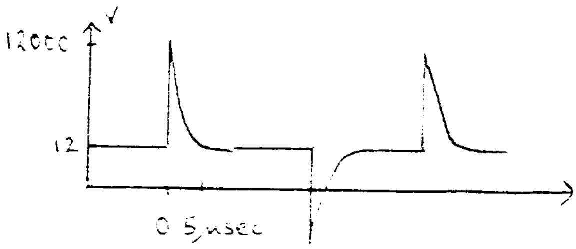
FAST, LOW VOLTAGE



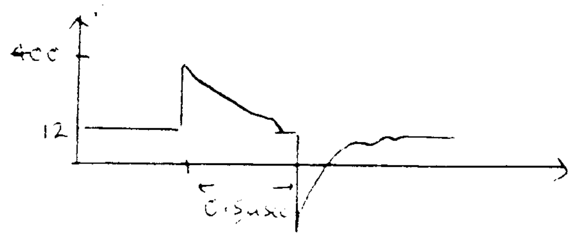
LOAD DUMP



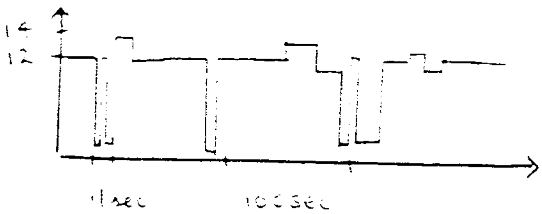
FIELD DECAY



ELECTROSTATIC DISCHARGE



LINE TRANSIENT: FAST, HIGH VOLTAGE



LONG-TERM FLUCTUATION

NOTES:

*1, *2: GIBBONS (1983) V = 1000V, TIME = 1 SECOND

: MENNITI (1980) V = 90V, TIME = 300MICROSECONDS

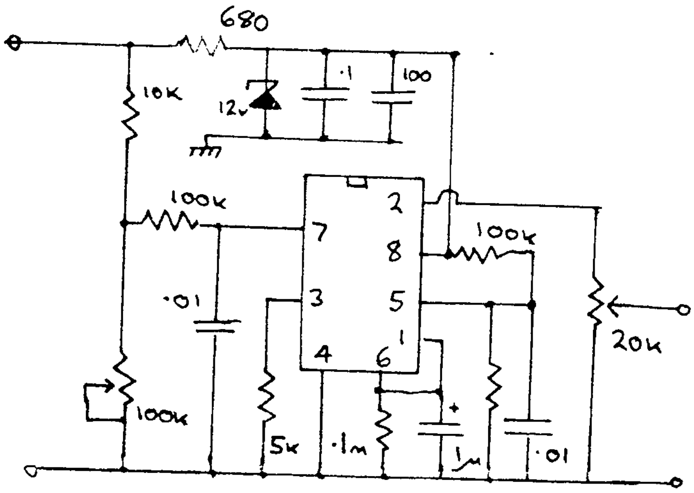
*3 : GIBBONS (1983) TIME = 150MILLISECONDS

: MENNITI (1980) TIME = 150MICROSECONDS.

INTERFERENCE APPEARING ON VEHICULAR SUPPLY LINE. VOLTAGES FOR AUTO--MOBILE SUPPLY.

FROM GIBBONS (1983), BLACKMORE (1983), MENNITI (1980), MORGAN (1973), AND SAE J1211/4.11

APPENDIX 9b



to tape recorder ch1 (ch2: voice)

IC: RC4151
set for 24V in
gives 2400Hz out
response time: .2s

CIRCUIT DIAGRAM OF SUPPLY LINE MONITOR: Voltage of vehicle is converted into a recorded frequency (1 volt = 100 Hz)

APPENDIX 9C

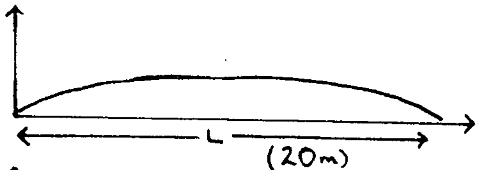
APPENDIX 10 (Extracts from Sensor specification): see paper INT P22 in the Supplementary Material.

The following is based upon a technique described by Maclaurin (1975) and proposed by Heal (1964) and Bogdanoff (1966):

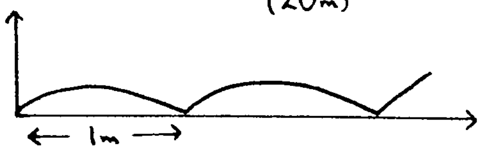
Let n = number of ground peaks per metre; c = roughness coefficient; v = vehicle speed.
Define $S(n) = c/n^2$ (from Van Deusen, 1965) Where S(n) is the mean square amplitude per unit bandwidth of the ground peaks
Now as f = n.v then
$S(f) = S(n)/v = c.v/f^2$
In terms of the mean square input amplitude, z^2; integrate over frequency range of interest:
$z^2 = \int_{f_1}^{f_2} c.v/f^2\,df$ so $z = \sqrt{c.v/(f2 - f1)}$
At higher frequencies, this converges to $\sqrt{c.v/f}$ (Ryba, 1973, states this as $z = \sqrt{c.v/f.q}$ where q = damping)
So $z = \sqrt{c/n}$

For example (assume S(n) = 1

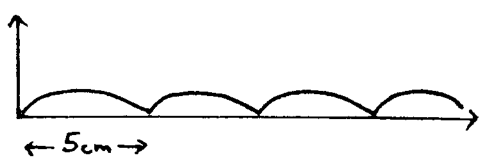
Case 1: n = 0.05, L = 20m; so c = 0.0025 and z = 0.22



Case 2: n = 1, L = 1m; so c = 1 and z = 1



Case 3: n = 20, L = 0.05 so c = 400, z = 4.5



TERRAIN PROFILE CLASSIFICATION. Derived from above refs.

APPENDIX 2A

APPENDIX 11

RECOMMENDATIONS FOR SPECIFIC DESIGN MODIFICATIONS FOR CLIMATIC/ENVIRON?
-MENTAL GROUPINGS. VALUES GIVEN AS: SUMMER/WINTER/ALL YEAR.

1. UK OR EQUIVALENT.

a) PSU. : TO ACCEPT SUPPLY VOLTAGES IN THE RANGE 18-27/16-27/17-27
: TO ACCEPT TRANSIENTS OF +-100V OF 1SEC DURATION
: " " " " +-600V OF 10MICROSECONDS
: INTERNAL HEATING BY STOPPER RESISTOR OF 10/47/22 OHMS

b) ENV : OPERATIONAL TEMPERATURE RANGE 0-70/-20-85/-10-70
: SHOCK: 25 OF 25 TO 30g
: VIBRATION. AS MS202E/201A
: HUMIDITY. NO INGRESS TO 60%
: WATER. " " UNDER VERY HEAVY RAIN

c) MWAVE : FREQ/POWER. 10.587G+-10M at 10mW
13.5 TO 14G+-10M AT 5mW
: RX 1st STAGE GAIN 76DB
: COMPONENTS.COMMERCIAL RATING (IF HEATER FITTED),
INDUSTRIAL IC RATING

2. USA AND SOUTH AFRICA

a) PSU. : AS UK BUT INTERNAL HEATER:
S.AFRICA AND NW USA: 10/47/22
NE : 10/47/15
SE : 5/5/5
SW : 10/10/10

b) ENV. :OPERATIONAL TEMPERATURE RANGE:
S.AFRICA AND NW : AS UK
NE : -25 25
SE : 0 85
SW : 0 110
: SHOCK AND VIBRATION: AS UK
: HUMIDITY: NO INGRESS TO 50%
: WATER: NO INGRESS UNDER HEAVY RAIN

c) MWAVE : EMI: AS FCC PART 15
: FREQ/POWER: AS UK PLUS 24.2GHZ AT 10mW
: RX 1ST STAGE GAIN 76DB-78dB (SE USA 80DB)
: COMPONENTS. AS UK BUT SE: INDUSTRIAL SPEC IC'S, PLESSEY
OR MA OSCILLATOR.

3. S.ARABIA, S.AMERICA, INDIA, AUSTRALIA

a) PSU. : AS UK BUT 2 TO & OHM STOPPER RESISTOR. OPTIONAL STOPPER
CUTOUT CIRCUIT (APPENDIX 18)

b) ENV. : OPERATIONAL TEMPERATURE RANGE: 0-125DEG
: STORAGE TEMPERATURE RANGE: -20 125DEG
: SHOCK AND VIBRATION: AS UK
: HUMIDITY AND WATER INGRESS: N/A
: DUST. NO INGRESS FOR 300p/cc/HR.

c) MWAVE : FREQ, POWER, EMI. AS USA
: RX GAIN 83DB (86 IN SAND AREAS)
: COMPONENTS. MILITARY SPEC (INCLUDING PCB AND CABLES).
MA OSCILLATOR WITH HEATSINK. STOPPER RESISTOR CUTOUT.

4. SCANDINAVIA, CANADA ETC.

a) PSU. : AS UK BUT TO ACCEPT SHORT TERM VOLTAGES UP TO 40V
: STOPPER RESISTOR: 10/68/NOT AVAILABLE

b) ENV : OPERATIONAL TEMPERATURE. -25 TO 85
: STORAGE TEMPERATURE -55 TO 85

C) MWAVE :POWER, FREQ, EMI. AS USA
: COMPONENTS. MILITARY SPEC THROUGHOUT. MA OSCILLATOR AND HEATER TO BE USED (SEE APPENDIX 18). CASE: NO WATER TRAPS. HORN: DIELECTRIC FOAM FILLED.

5 TROPICAL AREAS

a) PSU : AS S.ARABIA
b) ENV : OPERATIONAL TEMPERATURE RANGE 0 TO 85
: HUMIDITY: NO INGRESS TO 100%
: WATER: NO INGRESS IN TORRENTIAL DOWNPOUR
c) MWAVE : AS USA
: COMPONENTS. FOAM-FILLED HORN. STOPPER RESISTOR CUTOUT CIRCUIT. COMPONENT VARNISH/POTTING APPLICATION

APPENDIX 12

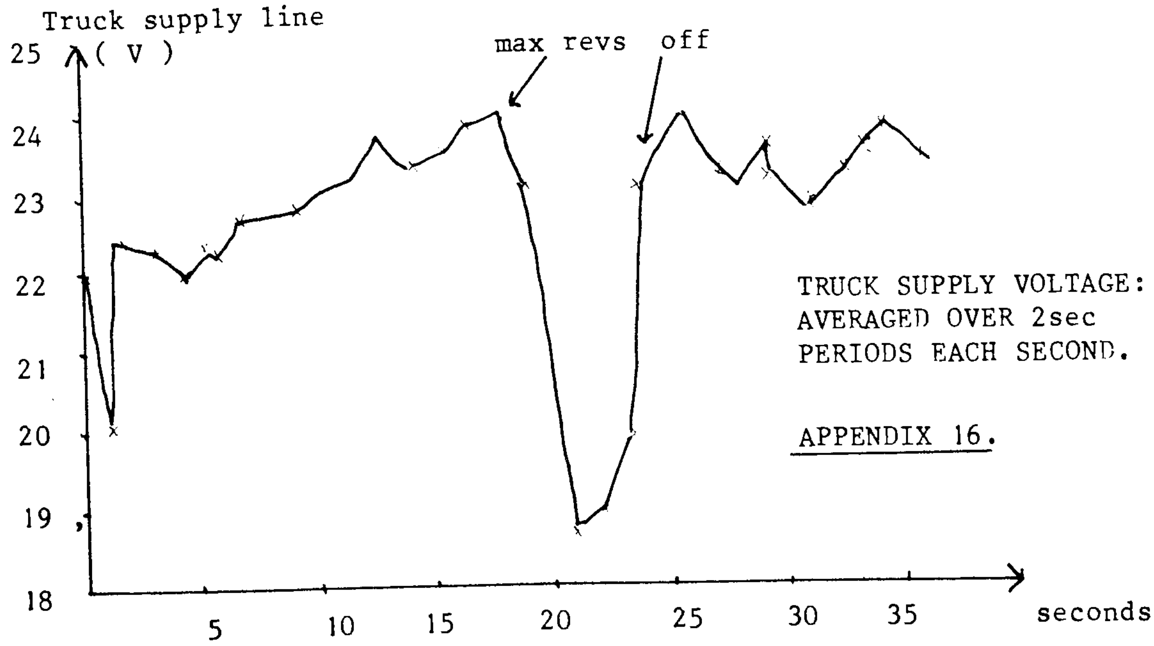
WALL MATERIAL	G	U
COPPER	1.0	1.0
ALUMINIUM	0.61	1.0
IRON	0.17	1000
STEEL	0.1	1000
STAINLESS STEEL	0.02	1000

WHERE G = RELATIVE CONDUCTIVITY
U = " MAGNETIC PERMEABILITY
F = FREQUENCY (MHZ)
T = WALL THICKNESS (MILS)
A = ATTENUATION (DB)

$$A = 3.3*T*\sqrt{U*F*G}$$

EXAMPLES: FOR 100DB ATTENUATION USING ALUMINIUM THE REQUIRED THICKNESS IS 12.2MILS (GAUGE 30/28 *1)
FOR 100DB USING STAINLESS STEEL, THICKNESS IS 2.1 MILS (GAUGE 46/40 *1)
NOTE: *1: IN SWG OR BG/AWG.

REFERENCES: BRITISH STANDARD BS3737 (1964), BARHAM (1968), MATISOFF (1982)



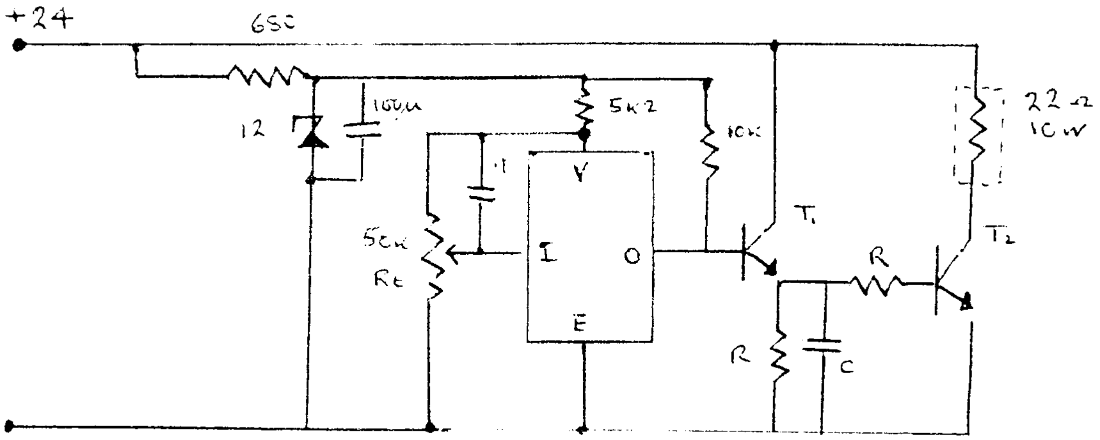
TRUCK SUPPLY VOLTAGE: AVERAGED OVER 2sec PERIODS EACH SECOND.

APPENDIX 16.

APPENDIX 13

HEATER/COOLER CIRCUIT.

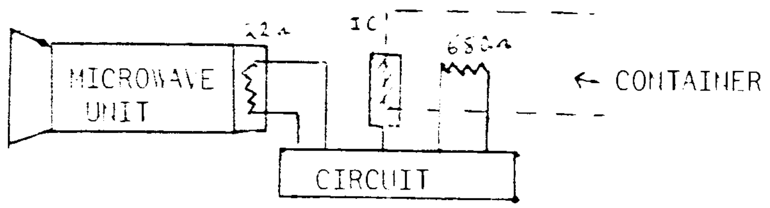
IN ADDITION TO THE STOPPER RESISTOR, FURTHER HEATING IS REQUIRED FOR AMBIENT TEMPERATURES BELOW ZERO DEGREES CENTIGRADE. THE SECONDARY HEATING CIRCUIT PROVIDES SUCH HEATING IN THE FORM OF A HIGH-DISSIPATION RESISTOR AND TEMPERATURE SENSOR. THE POTENTIOMETER CAN BE ADJUSTED TO ENABLE SWITCHING OF THE HEATER AT ANY TEMPERATURE FROM -25 TO 85 DEG--REES. CURRENT CONSUMPTION IS APPROXIMATELY ONE AMP, AND THE 24V SUPPLY LEAD FROM THE CONTROL BOARD MUST BE UPGRADED TO CARRY THIS EXTRA LOAD.



SET R,C FOR SMOOTH SWITCHING
SET Rt FOR SWITCHING TEMPERATURE.

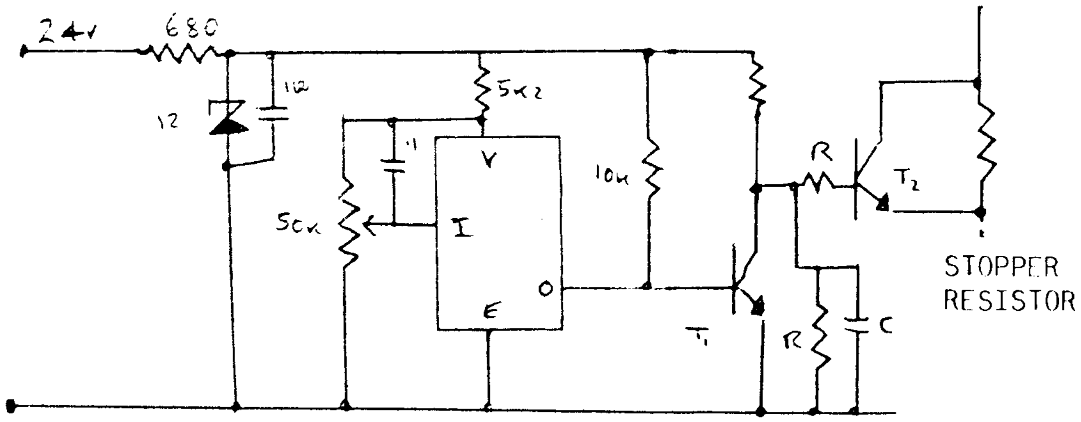
IC: LM3911. T1: 2N3053
T2: 2N3055

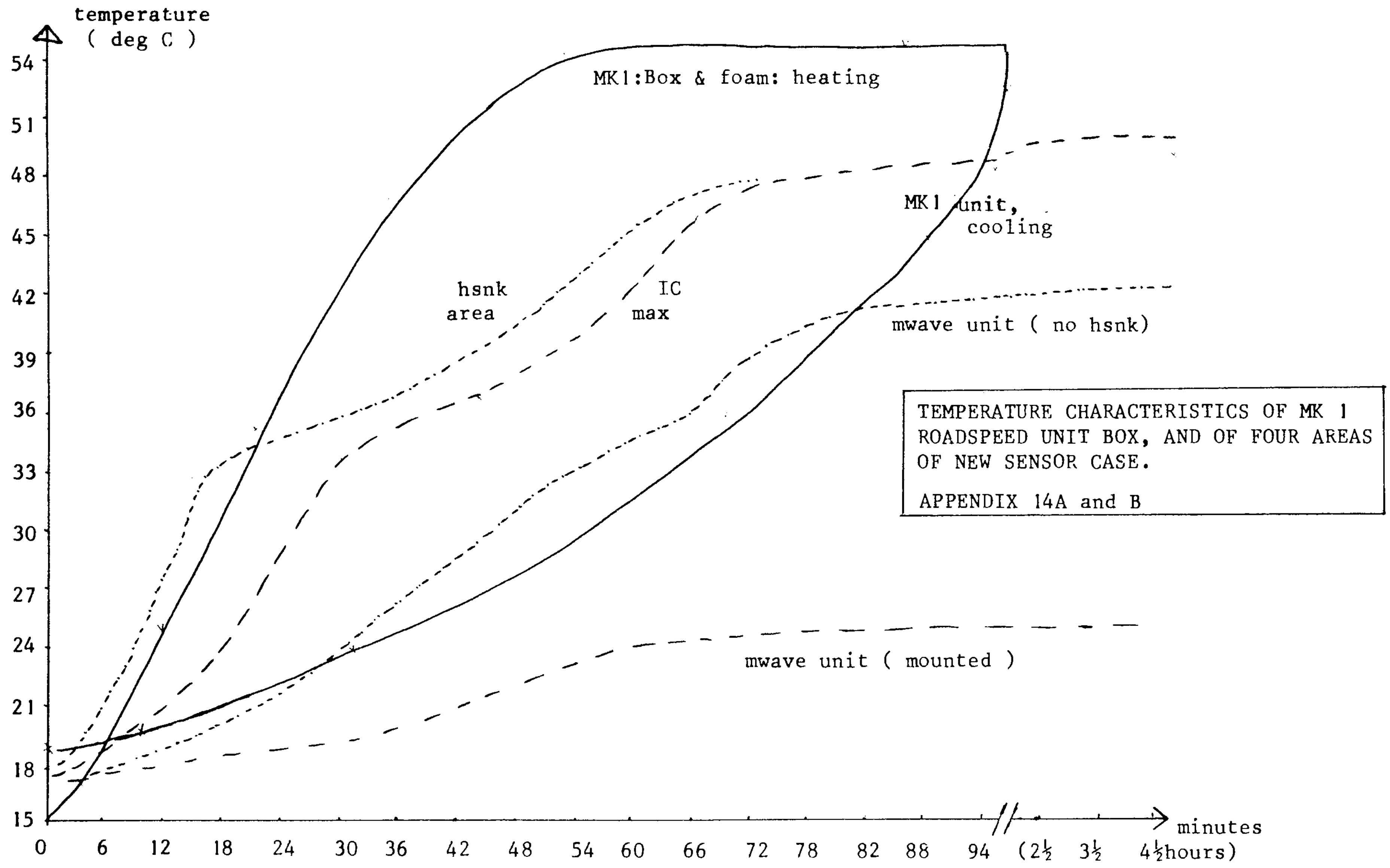
THE PHYSICAL LAYOUT OF THE CIRCUIT IS IMPORTANT AND IS INDICATED BELOW:



STOPPER RESISTOR CUTOUT CIRCUIT.

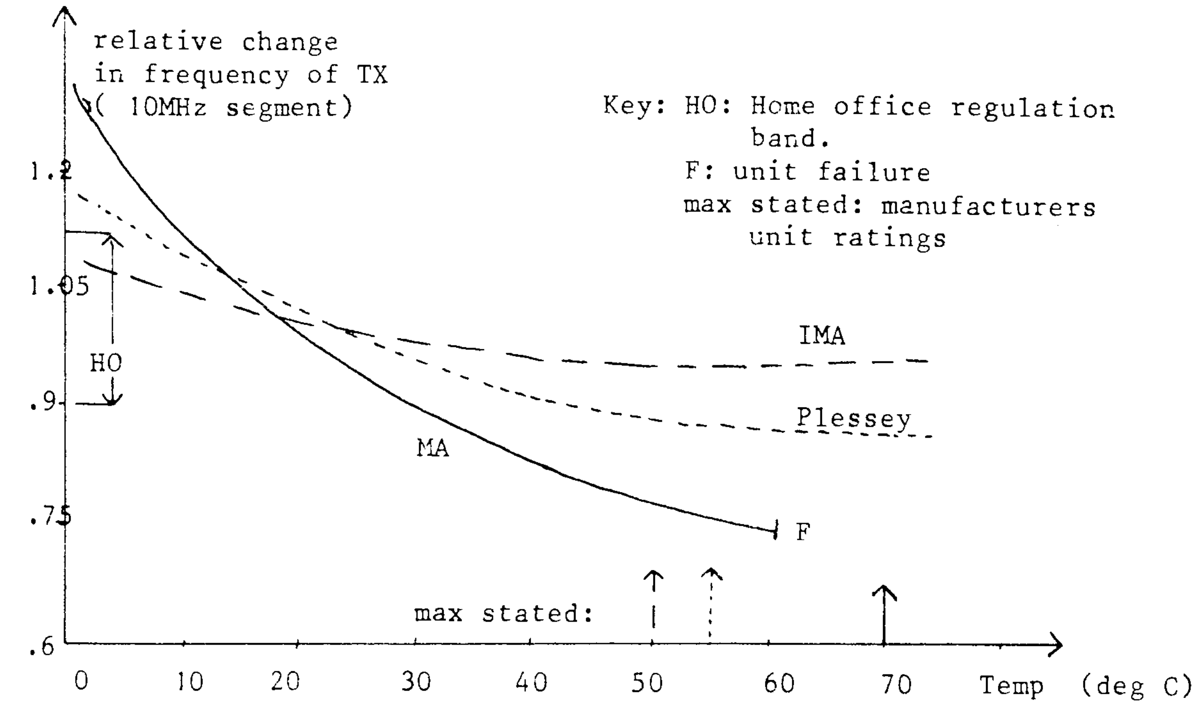
FOR HIGH AMBIENT TEMPERATURES THE STOPPER RESISTOR VALUE IS BEST REDUCED (SEE APPENDIX 11). HOWEVER, TO PROVIDE A DEGREE OF SUPPLY SMOOTHING, OF CIRCUIT PROTECTION IN THE EVENT OF A SHORT-CIRCUIT, AND OF LIMITED HEATING WHEN COOL, A RESISTOR SHORTING CIRCUIT IS RECOMMENDED. AT A PRESET TEMPERATURE THE STOPPER RESISTOR IS EFFECTIVELY REMOVED FROM THE CIRCUIT, THUS REMOVING A SOURCE OF INTERNALLY GENERATED HEAT.





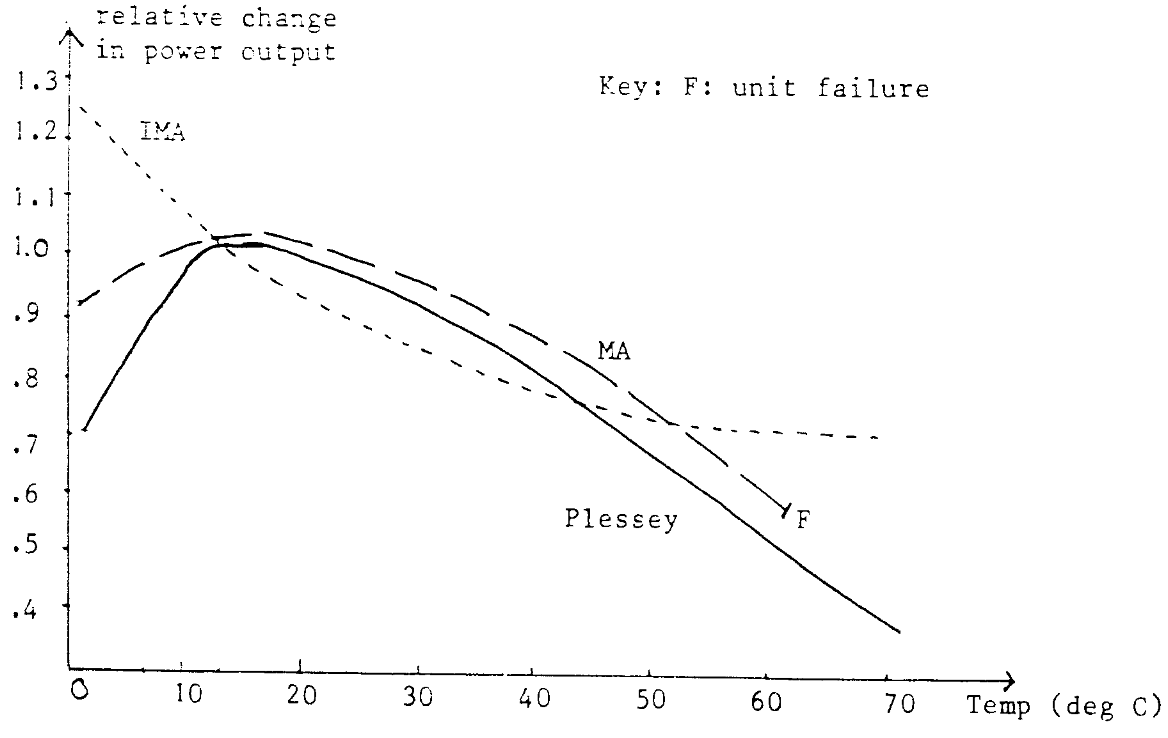
TEMPERATURE CHARACTERISTICS OF MK 1 ROADSPEED UNIT BOX, AND OF FOUR AREAS OF NEW SENSOR CASE.

APPENDIX 14A and B



AVERAGE TRANSMISSION FREQUENCY OF THREE TYPES OF MICROWAVE TRANSCEIVER FOR A RANGE OF TEMPERATURES. Plotted as relative change.

APPENDIX 15A



AVERAGE POWER OUTPUT FOR THREE TYPES OF MICROWAVE TRANSCEIVER FOR A RANGE OF TEMPERATURES. Plotted as relative change.

APPENDIX 15B

UNIT TEMPERATURE CHARACTERISTICS.

To ascertain the performance of the casing arrangement of the MK1 box under extremes of temperature, three experiments were performed:

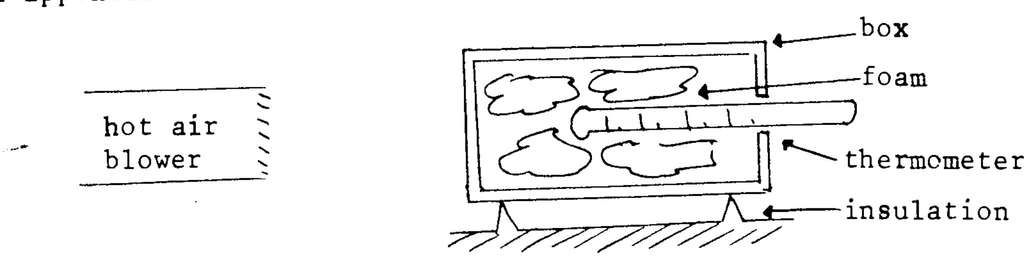
1. Characteristics under external heating. Air of a known temperature was gently blown toward one side of the case. The temperature rise against time was noted. The results are given in appendix 14A.
Time to stabilisation upon heating was 50 mins and on cooling was 75 ins. The max stabilised temperature was 53 deg, and the rate of heating was 0.66 deg/min, and of cooling was 0.44deg/min. The air temperature at the box position was 75 deg.
Thus the effective insulation value is 22 deg (inc reratiation).

2. Characteristics under internal heating. The sensor circuit was connected as if for normal operation (both with and without the horn connected) and the temperature rise monitored near the PCB proper and near the supply heatsink and stopper resistor. The microwave unit was monitored with and without horn connected. Results are given in appendix 14B. The time to stabilisation of the PCB was 270 mins, of the microwave unit was 90 mins (no horn) and 75 mins (with horn). The max temperature reached was 51 deg for the PCB, 42 deg fo the microwave unit (no horn), 28 deg (with horn). The rate of heating of the PCB was .13deg/min, the microwave unit with h horn was 0.15deg/min and no horn: 0.28deg/min. The stopper resistor with heavy foam packing max was 142 deg on surface after 3 hours.

3. Characteristics under internal cooling. Facilities unavailable.

DISCUSSION.

The graphs offer an interesting insight into 'dynamic' performances of various aspects of the sensor unit. By assuming a very reasonable applied heating of 35 deg (see earlier environmental data) the internal temperature can easily reach 60 deg. For desert climate (40 deg air, 10 deg solar radiation) the internal temperature may rise to 70 deg with localised heatspots at 150 deg. The microwave heating was unexpected: this may well explain why the units work at ambient temperatures well below their rated minimum. However, the horn unit acts as a copious capacity heatsink in normal use for the new design.
On order to establish the effect of temperature on microwave transceivers likely to be used in future products, the transmission frequency and power output was monitored over a range of temperatures for three makes of unit. The results appear in appendix 15A and B. The averabe result is plotted relative to the ambient result (17 deg). The MA units (two of which were available) performed badly: one failed permanently at 67 deg (within the unit stated rating), and the other operated incorrectly. These units were expected to perform very well: they are highly regarded within the industry, and are not cheap. For elevated temperatures, only one unit of each type was used for testing to prevent loss of too many units. The results appear in appendix 7f.



SECTION 2.16

REPORT INT P25
3.4.84
C. WALLACE

AN ASSESSMENT OF THE TRW GROUNDSPEED RADAR.

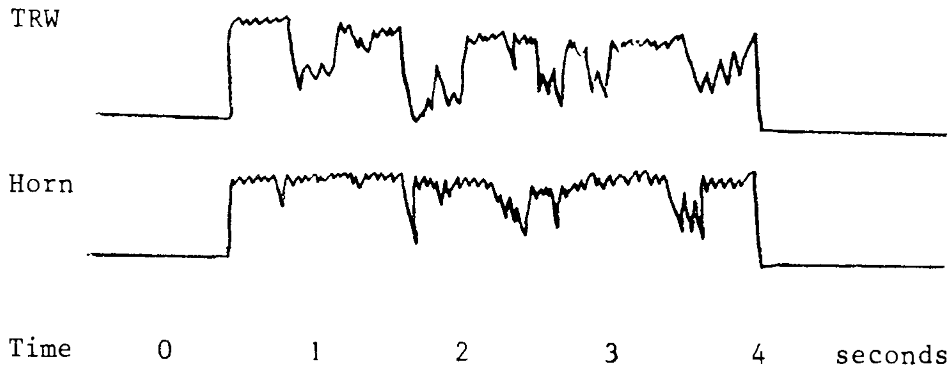
This report is intended to summarise the evaluation of the TRW agricultural groundspeed sensor. The TRW unit is designed to measure and indicate the speed of agricultural vehicles. It thus consists of a microwave unit environmentally sealed and a display unit intended to be positioned in the tractor cab. No speed limit sensing is included, and hence no overspeed sanctions can be taken.

To assess the performance of the unit, trials were conducted on a typical production unit, and a full laboratory test series was also undertaken (Davey 1983 and the author's lab notes). The results are not repeated here: this report is concerned only with the practical application of the unit. The device did, however, cope with a range of electrical tests designed to simulate the effects of mounting the unit on an off-highway truck.

In order to assess the ability of the unit to measure and display vehicle speed correctly, two test runs were performed: the first on a Cat 777 and the second on a Cat 276. For both tests the weather was dry and the road surface was rutted, compacted mud with smooth patches. No load was carried. The results of these runs are tabulated in table 4. It can be seen that the unit read the vehicle speed within ten percent up to a speed of twenty miles per hour, but over this speed the unit badly misread the true speed. On run two the reading broke up over rougher ground at a lower speed, at one point misreading a speed of fifteen mph. The signal form the head unit, when examined on an oscilloscope, was seen to 'snake' (indicative of inadequate filtering of low frequency interference signals) and on rutted ground the preamplifier signal dropped to 0.2 volts peak to peak. The antivibration and shock protection mounts successfully isolated engine vibration (as no output pulses were generated with the vehicle stationary and engine running).

When laden the unit measured velocities up to twenty mph adequately. The 'snake' worsened, and for higher speeds, the basic preamplifier signal was modulated by a low frequency component with an amplitude some six times greater.

To assess the contribution of the beamshape (namely the footprint area) to the above effects, the unit was used over dry and wet surfaces the latter being composed of puddles. The test was performed for a range of tilt angles. Table one summarises the results: a significant deterioration in performance over puddles is apparent, ant the performance suffered over compacted earth when compared to tarmac. This is not as theory would predict. A further test illustrates the susceptibility of the unit to terrain type and contour: the plot of frequency tracking for the unit campared to a prototype horn sensor looks thus:

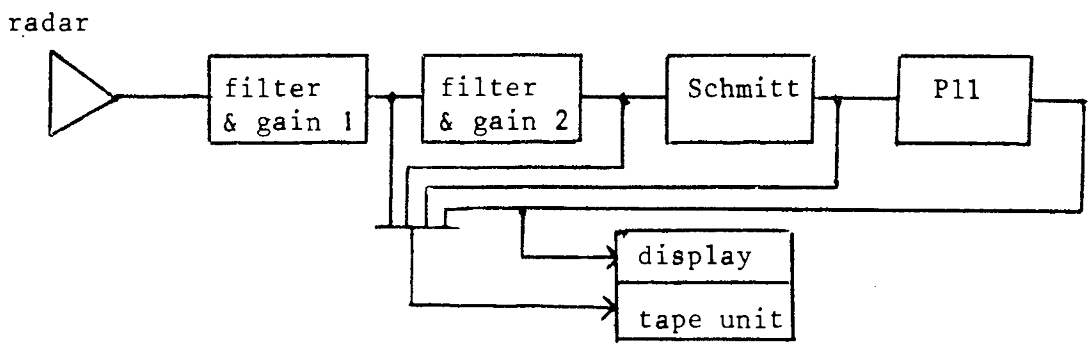


(the actual results obtained appear under the section dealing with ground return results).

The TRW unit would thus seem to have too small a footprint, notably in the azimuthal plane, which leads to a swamping of the beam by such obstacles as puddles, or terrain contour (which accounts for the frequency track trace breakup as indicated above).

Further tests were carried out at Otley on main roads: the results are summarised in table two: the unit under-read by approximately ten percent and that speeds of five to fifty mph were adequately tracked within this error.

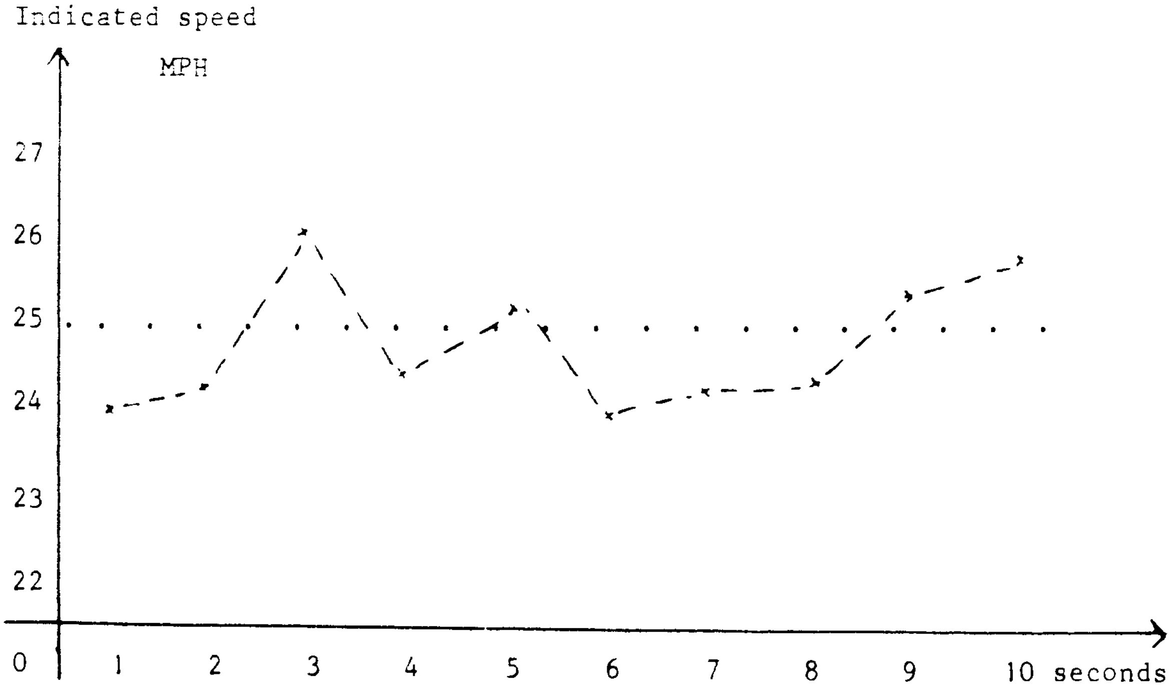
These findings were reported to TRW, who provided a 'modified unit'. No details of the modifications were provided but an internal examination suggests the filter passband was increased in frequency (thus filtering lower frequencies). Hence, further tests were conducted at the Butterwell opencast site. For this sequence the unit was dissected and test cables attached thus:



TILT ANGLE	COMPACTED EARTH						TARMAC	
	DRY				WET/PUDDLES		DRY, SMOOTH	
	CLIP	PRECLIP			CLIP	AVE	CLIP	AVE
		MAX	MIN	AVE				
15		25	0	15		0		20
20		40	5	35		0	y	30
25		65	25	45		10	y	35
30	y	80	35	60		15	y	40
35	y	90	35	65	y	20	y	45
40	y	100	30	70	y	20	y	40
45	y	105	20	70	y	15	y	40

Effect of dry and wet ground for a range of tilt angles. The run over wet ground was selected to have a significant number of puddles in the radar footprint. All signal levels are in millivolts peak to peak as measures at the output of the second stage amplifier.

TABLE ONE



Modified TRW unit: indicated speed for a nominal 25mph speed. Terrain: dry, smooth compacted earth.

GRAPH ONE

The indicated speed was accurate to plus or minus one mph at fifteen and twenty mph for typical ground, and around two mph at twenty mph on rough ground and twenty-five mph on smooth ground. The speed inaccuracy took the form of fairly sudden jumps in indicated speed. A ten second sample recording is plotted in graph one.

Thus, the unit is much improved since modification, but still inaccurate. Spectra, waveforms and frequency track plots are provided under the section dealing with ground data processing.

The unit as delivered (a standard production unit) was incapable of performing adequately in the off-highway environment. The TRW modified unit behaved in a consistent, but inaccurate, manner. Both suffered from being oversensitive to terrain contour and surface obstacles: it is thought the effect is due to the small radar footprint, which is incapable of averaging the ground profile, as the footprint area is smaller than a typical puddle or a typical off-highway tyre print or even smaller than a boulder. TRW rely on an electronic averaging technique, but it is clear that this technique is incapable of correctly interpreting the badly corrupted received signal. To requote the old adage: garbage in: garbage out.

CAR SPEED (mph)	SMOOTH TARMAC		PITTED TARMAC		rough minus smooth (mph)	%ERROR smooth/ rough
	TRW speed (mph)	Signal (mv)	TRW speed (mph)	Signal (mv)		
0	0	0	0	0	0	0/0
5	4.7	2-3	4.7	3	0	6/6
10	8.7	2-3	9.6	3	0.9	13/4
20	18.1	2-3	18.7	3.2	0.6	9½/6½
30	27.5	2	28.5	2.5	1	8/5
40	34.1	1.6	36	2.2	1.9	15/10
50	-	-	46.2	1.5	-	-/7½

ACCURACY OF TRW UNIT: Indicated speed versus car indicated speed for wet roads. Car speedometer accuracy estimated to be within 0.5mph: stated results are averages of four runs. TABLE TWO

	TRUCK SPEED SPEED (mph)	INDICATED RPM/GEAR	TRW INDICATED SPEED (mph)	GROUND CONDITIONS	TRW ERROR	% ERROR
Run 1: CAT 777	9	1700	9.7	wet, rutted	+0.7	7.8
	12	1750	12.4	"	+0.4	3.3
	15	1950	14.6	"	-0.4	2.7
	20	2200	7 - 19	"	-13,-1	5 to 65
	15	2200	15.4	smooth, damp	+0.4	2.6
	10	2000	10.6	smooth, wet	+0.6	6
	15	2200/4	11 - 15.4	wet, rutted	-4 to .4	21 to 3
	15	2300/4	16	"	+1	6.6
	15	2300/4	16	"	+1	6.6
	15	2300/4	16	"	+1	6 to 6.6
Run 2: CAT 276	20	2200/5	20 - 21	"	+1	5
	23	/6	22 - 23	" (alarmed)	-1 - 0	4.3
	16	/6	16	wet, rutted	0	0
	20	/6	20	"	0	0.5
	20	/6	4 - 10	v. rutted	-10 to -16	50 to 80
	20	/6	4 - 14	"	-6 to -16	30 to 80

Site: Butterwell opencast: trucks unladen. TABLE FOUR.

TRUCK INDICATED SPEED VERSUS INDICATED SPEED FOR TWO RUNS.

SOURCE	TRW indicated speed (mph)	Hz equivalent	% error
Tuning fork: 440Hz	7.6 - 7.8	433 - 445	0
Tuning fork: 600Hz	10.1 - 10.3	576 - 587	3.8 - 1.9
440 and 600Hz forks	7.8 - 9.1	445 - 519	13 - 26
Man swaying	1.7	97	/
Man swaying and 440Hz	2.4 - 2.6	137 - 148	68
Man walking	3.1	177	/
Man walking and 440Hz	3.1 - 3.3	177 - 188	57 - 60

PERFORMANCE OF TRW UNIT GIVEN SIMPLE AND COMPLEX TARGETS. Where possible, amplitudes of signal (as seen at the preamplifier output) were matched. No clipping of input signal occurred. TABLE THREE

SECTION 2.17

REPORT INT P26
8.4.84
C. WALLACE

TERRAIN RETURN SIGNALS AND METHOD OF TABULATING AND PROCESSING GROUND RETURN DATA.

SECTION

PART ONE.

1. NEED FOR MEASUREMENT
2. FACTORS AFFECTING THE QUALITY OF THE SIGNAL
3. DATA RECORDING
4. CALIBRATION
5. MEASUREMENT OF SUBSURFACE MOISTURE

PART TWO

1. INTRODUCTION
2. METHOD OF PROCESSING: SUMMARY
3. METHOD OF PROCESSING: DETAIL
4. TABULATION OF RESULTS

INTRODUCTION. This report is intended to summarise reasons for the need for quantifiable data on speed sensor radar signals. In the literature review on backscatter, it was stated that the basic problem of interpreting terrain returns (excluding vibration and vehicle bounce etc) is that of determining the backscatter coefficient. Two techniques can be used to ascertain this data: both possessing serious drawbacks:

a) measure σ for all types of terrain. It is impossible to measure all types of terrain, all angles of incidence in all climatic conditions, and even if this were achieved, there is no unique way of predicting which of the measurements would apply to a new terrain sample.

b) calculate σ theoretically. This procedure would be of little use; firstly because theory is of little value on practical applications unless validated by experiment; secondly because there would still be no means of associating a given type of terrain and radar geometry with a particular theoretical model.

Ideally, both approaches would be considered together: terrain samples being classified into categories for which a suitable theoretical model exists. Such categories may be chosen:

a) intuitively, based on the subjective appearance of the terrain

b) experimentally, based on observed characteristics of the signal

c) theoretically, based on the particular model selected.

This report will deal with the intuitive and experimental methodologies.

FACTORS AFFECTING THE QUALITY OF THE RETURNED SIGNAL. Whilst the backscatter coefficient, σ, is important in determining that adequate signal is present for correct processing, the quality of signal is crucial, and is determined by five main factors:

1. tilt angle (also relevant for backscatter coefficient data)
2. signal beamwidth (in terms of the 2way 3dB power points)
3. signal beamwidth (in terms of ¼, 1/8 and 1/16 power points)
4. signal beamwidth (in terms of ratio between elevation and azimuth, and radar height; ie the footprint area and geometry)
5. ground type (see below)

and the quality of the processing is determined by:

1. system gain
2. system bandwidth
3. system dynamic range and signal to noise ratio

the major ground parameters being:

1. terrain contour (irregularity wavelength)
2. surface type (material and microscopic contour)
3. surface conditions (wet, dry etc)

the major vehicle parameters being:

1. vibration and shock of supporting structure (platform)
2. suspension characteristics under dynamic loading
3. vehicle velocity

Clearly no data recording system could cope with all the above: the experimental regime carried out for the purposes of this project is, therefore, a compromise. Thus the recording system deals with:

1. radar tilt angle
2. radar type and beamwidth
3. terrain surface, material, contour and ground wetness

and measures, specifically:

1. alarm speed
2. signal nulls (of the preamplifier, squarewave pulsetrain and phase-locked loop train)
3. signal amplitude
4. signal consistency (of the factors as in '2')

From this data the following is calculated for each recording made:

1. mean frequency
2. standard deviation
3. coefficient of variation
4. mode
5. skew
6. symmetry
7. kurtosis
8. nulls
9. signal amplitude
10. signal consistency

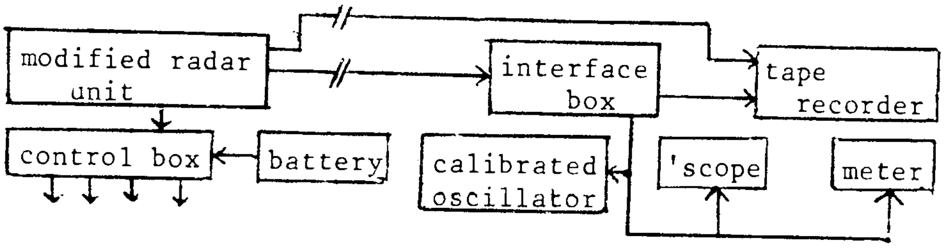
and these calculations are repeated for normalised data (definition of the above terms appears in a seperate section delaing with the method of data processing).

Hence, the intention of these experiments is to gather data on radar return for a given radar type, vehicle speed, geometry and ground type. This information should yield data on the optimal design of processing circuitry, radar placement and type. For example the optimum tilt angle, typical dynamic range and return amplitude etc can be ascertained, as can required filter characteristics and gain settings etc. It may also allow the selection of an appropriate model (be it simplified) to assist in the prediction of return for any given surface.

<u>DATA RECORDING.</u> The equipment available did not include a data recorder of any sort. Thus, a domestic cassette recorder was tried, and found to be satisfactory. In order to optimise recordings, several volts pk-pk level are required, so an interface box was constructed (details given elsewhere). Briefly, this allows calibrated gain of the ground signal so that the amplitude of the signal is large, but does not clip. An oscilloscope output is provided to monitor the signal to ensure no clipping, even of an instantaneous nature, occurred. A calibrated meter output is also provided, giving averaged amplitude readings.

The signal is derived from a modified speed sensor unit (a sample of the last batch to be made by OEL) with outputs being taken

from the post-filter, and schmitt trigger points. Hence the signal is already low filtered to a significant extent (some 30dB/8ve from 200 Hz downward). This factor is important, as the majority of the signal derived from the radar falls within this filtered band.
Location of the equipment presents problems in the truck environment: ten metres of screened cable is required to link the radar unit to the interface box located in the cab. For ease of use, the interface box, oscilloscope, meter and tape recorder were mounted in a large briefcase. Calibrated data recording tape was used throughout, although it is thought that the recording machine itself was the limiting factor. Fig 1 of the data recording results illustrates the frequency response of the recording system and the radar bandwidth.
In block-diagram the system looked thus:



Calibration.

The interface box posesses a calibration input, which can be used th check internal gain settings and frequency response by connecting the internal oscillator. The gain settings for tape recorder and radar unit direct output are preset. By feeding known signals into the system, the o/p can be checked. For testing the system as a whole, a tuning fork of known frequency is held in front of the radar horn. This technique of calibration is examined for suitability in supplementary material chapter four.

The intrinsic noise of the system can be determined merely by pointing the radar skyward: this must be performed distant from buildings as fluorescent lights interfere with the readings. Typical noise figures are a factor of one hundred down on typical signal levels.

The frequency response of the recording system is ascertained by connecting an oscillator to the interface box, recording signals at ceratin pitches and amplitudes, and measuring the ultraviolet trace (UV) output amplitude. The sensor electronics response is measured by replacing the doppler transceiver with an oscillator and observing the amplitude of output against frequency. The recording system response is, effectively, flat over the sensor passband: this is illustrated in Fig 1. Meter calibration is performed by noting the meter reading for a range of frequency and amplitude inputs: these too appear on Fig 1. All actual readings are corrected by the inverse of these responses.

It should be noted that the cassette units used for these experiments are fitted with automatic gain control (AGC). This enables the unit to set its own optimal gain level, thus ensuring good quality recordings. The penalty for this facility is that the method prevents any derivation of signal amplitude from the recordings. The AGC response was measured to be approximately 0.25 seconds: hence nulls and peaks at instantaneous points within the data are not affected.

MEASUREMENT OF SUBSURFACE MOISTURE

It is already known that x-band microwaves have the ability to penetrate terrain to a significant depth (refer to literature review on ground models and backscatter experiments). Hence in order to assess the effect of water on the surface of terrain and of moisture under the surface, a hygrometer was constructed. The intention was to use this instrument to derive an average value for subsurface moisture for each radar run made, and to correlate this information with data derived form the recordings of the signal return. By repeating the recording process on the same length of terrain in different weather conditions, a correlation between subsurface moisture and backscatter should be apparent.

The hygrometer consisted of a copper shield, calibrated in cm, and an aluminium inner conductor connected either to an internal or to a more accurate external meter. A range-doubling switch was incorporated. By pushing the hygrometer into the ground one centimetre at a time, and noting the reading, a moisture profile can be setablished. It should be noted that the reading must be performed speedily to prevent moisture collecting around the probe tip, and that the readings are of one localised point: the procedure must be repeated locally, and an average taken. Also, the indicated readings are purely relative: 0 indicated fairly dry, 20 indicates very wet.

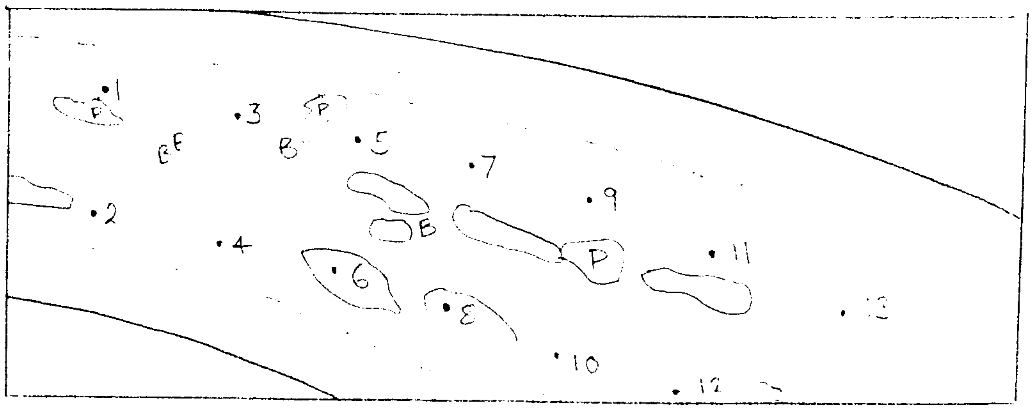
Hence a map can be constructed, indicating the variation in moisture for given ground depths along the radar footprint path. Fig 2 illustrates the hygrometer construction, and Fig 3 a typical map.

Whilst the meter worked well in trials, it proved of disappointingly little use for the majority of tests. One reason is that all tests performed near the laboratory were on asphalt: totally imperveous to the probe; another was site access at Butterwell is limited, and site rules forbid walking on haul roads for any reason. Thus the use of the meter was abandoned.

TERRAIN SUBSURFACE MOISTURE MAP

LOCATION: Old railway cutting, Otley
WEATHER: damp
RADAR TYPE: Aro, calibrated

DATE: 6.4.83
SCALE: 1:60
REF: C1



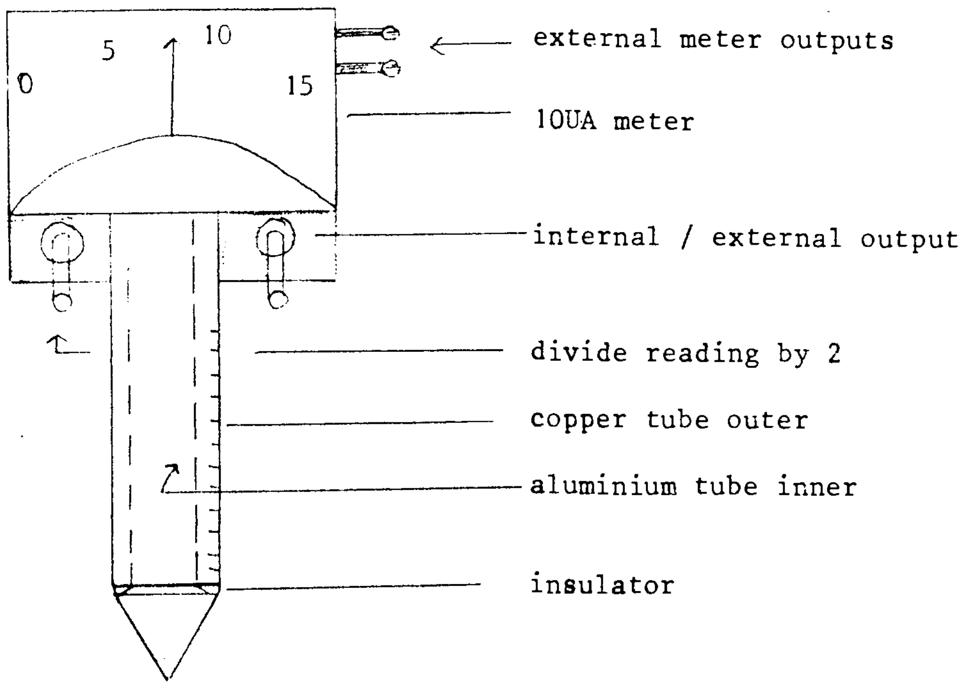
RESULTS:

SEGMENT	DEPTH (cm)					
	0	2	4	6	8	10
1	6	8	8	8	8	8
2	6	8	8	8	8	8
3	6	8	10	10	10	8
4	6	10	10	12	12	12
5	10	12	13	13	14	14
6	14	16	16	20	22	23
7	10	15	16	18	18	22

SEGMENT	DEPTH (cm)					
	0	2	4	6	8	10
8	10	14	16	16	16	16
9	7	10	12	12	12	14
10	6	7	7	8	8	10
11	6	7	7	8	8	6
12	6	7	7	7	7	7
13	8	8	7	7	7	8

KEY: 0 = dry, 30 = wet.
◌ = pot-hole, P = puddle, B = boulder, - - = footprint

FIG 3



HYGROMETER CONSTRUCTION

FIG 2

MEANS OF PROCESSING GROUND RETURN DATA.

This section deals with the processing, comparison and interpretation of ground return data. This data falls into three main categories:

a) waveforms from the preamplifier, squarewave pulsetrain and PLL
b) spectra
c) frequency tracking.

WAVEFORM RECORDINGS

1. Count the number of nulls per quantity of true wavelengths for:

   a) the preamplifier
   b) the squarewave pulsetrain (Schmitt)
   c) the phase-locked loop (PLL)

2. Count the proportion of time that the waveform is centred around the nominal alarm frequency for a, b and c above.

SPECTRUM PROCESSING

1. The spectrum trace is 'smoothed' by drawing a best-fit line through all peaks and dips,
2. The smoothed curve is converted into histogram format,
3. The following are calculated:

   a) Mean
   b) Mode and modified mode
   c) Standard deviation
   d) Skew
   e) Coefficient of variance
   f) Symmetry
   g) Kurtosis

4. Repeat step 3 for a corrected 'normal' curve
5. Repeat step 3 for theoretical values where possible
6. Compare values obtained by methods 3,4 and 5

FREQUENCY TRACKING

1. Assess the proportion of time over which the signal is within the passband (30 or 100Hz) and at the upper limit of the track
2. Repeat step 1 for the half-way point of the track

DETAILED PROCESSING EXPLANATION. The above method of processing will now be expanded, and terms explained.

Spectra. To quantify such curves, the method adopted follows Spencer et al (1977) who state that $N(\mu,\sigma^2)$ uniquely identifies a normal curve. However, this assumes a fully symmetric curve, so a means must be sought of categorising and quantifying curve types. The parameters used are skew, kurtosis and variation coefficients.

The spectrum portion of greatest importance for long-term operation of the sensor is the main peak at, or near, the alarm frequency. Whilst secondary peaks are of relevance for design and assessment work (and are analysed by using the data as recorded), their removal provides an insight into exactly how the central spectrum behaves. Hence, secondary peaks are removed for calculating corrected data parameters. This is not a drastic measure: the frequency count derived from the incoming system will be, in the time domain, near the peak value of the spectrum (in the frequency domain) for much of the time: this point is illustrated later in the 'signal consistency' data analysis section. Also, the corrected data does not take account of spuriae due to intermodulation and interference etc. In addition to this correction method, the mode is also calculated in two ways: these are described later.

Skew. The usual technique of quantifying skew by examining the third moment about the mean, ie (Spencer, 1977, sect 12.5)

$$\gamma = \frac{\mu_3}{\sigma^3} = \left[\frac{\sum_i f_i(x_i - \mu)}{\sigma}\right]^3$$

is overcomplex. This report will use Pearson's measure (Yule and Kendall, 19):

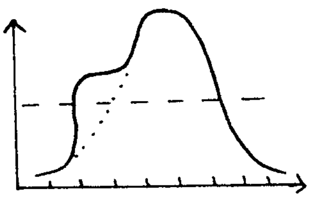
$$Sk = \frac{(\text{mean} - \text{mode})}{\sigma}$$

Where appropriate the equivalent (and often easier) definition of:

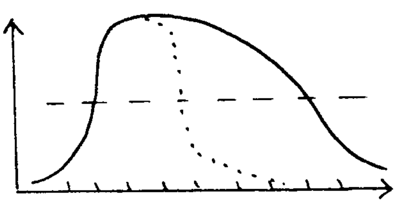
$$Sk = \frac{3(\text{mean} - \text{median})}{\sigma}$$

is used.

Symmetry. This is a crude assessment of the symmetry of the curve sides, and is effectively a measure of the difference between standard and normalised spectra shapes. Thus, the symmetry, SY, is defined as the deviation in value between the true spectrum and the corrected spectrum; the latter being obtained by making the true spectrum symmetrical about the centre with respect to the inner curve; and measured at half the maximum ordinate value. It may be a similar, or different, value for standard and corrected curves. For example:



SY = −2



SY = +3

Mean. The accepted definition of $\bar{x} = \frac{\sum f_i Y_i}{\sum f_i}$ will change for standard and normalised data.

Mode. The frequency corresponding to the spectrum peak. For unimodal spectra, the value for standard and normalised data will be identical. For bimodal the frequency nearer the theoretical frequency is taken.

Standard Deviation. To best utilise the data, the definition used is:

$$SD^2 = \frac{1}{n-1}\sum_{i=1}^{r} f_i (x_i - \mu)^2$$

where n = sample size, r = no. of classes of data, f = frequency.

notes: a) (n-1) is used as the sample size is small
b) it is noted that converting continuous data into, effectively, a histogram, is inaccurate. Sheppard's correction is intended to deal with this problem and involves reducing the sample variance by c/12 where c is the sample size. The correction is not used for the bulk of the data.

Putting the above definition into a more useful form (Sprent, 1977) gives:

$$SD^2 = \frac{1}{\Sigma f - 1}\left(\Sigma f y^2 - \frac{1}{\Sigma f}(\Sigma f . y)^2\right)$$

Kurtosis. To establish the 'humpiness' of the spectra, the coefficient of kurtosis is usually used: $\beta = \mu_4/\mu_2^2 = \Sigma P(x-\mu)^4/(\Sigma P(x-\mu)^2)^2$

This definition is overcomplex: this report uses the visual identities of: B < 0: let B = -1 platykurtic (humped)
B = 0: B = 0 mesokurtic (rounded)
B > 0: B = 1 leptokurtic (flattened)

Variation. As the mean spectrum frequency may deviate from the theoretical value (calculated from the vehicle speed and tilt angle), a means of usefully comparing similar data distributions is the coefficient of variation (Efficker, 1981) where $CV = \sigma.100/\mu$.

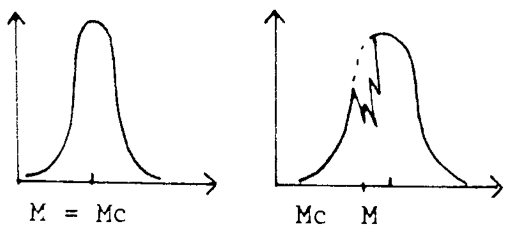
Change of origin. All spectra are plotted from zero hertz upward, but up to 50Hz the plots are unreliable due to mains interference in the record/playback system and switch-on transients of the plotter. Thus the axis transformation used is:

$$Y = (m - 50)/c$$

where m = mid-range value, c = class interval

A value of c = 100 is used throughout. The summation of frequencies is then performed excluding the frequency corresponding to m = 50.

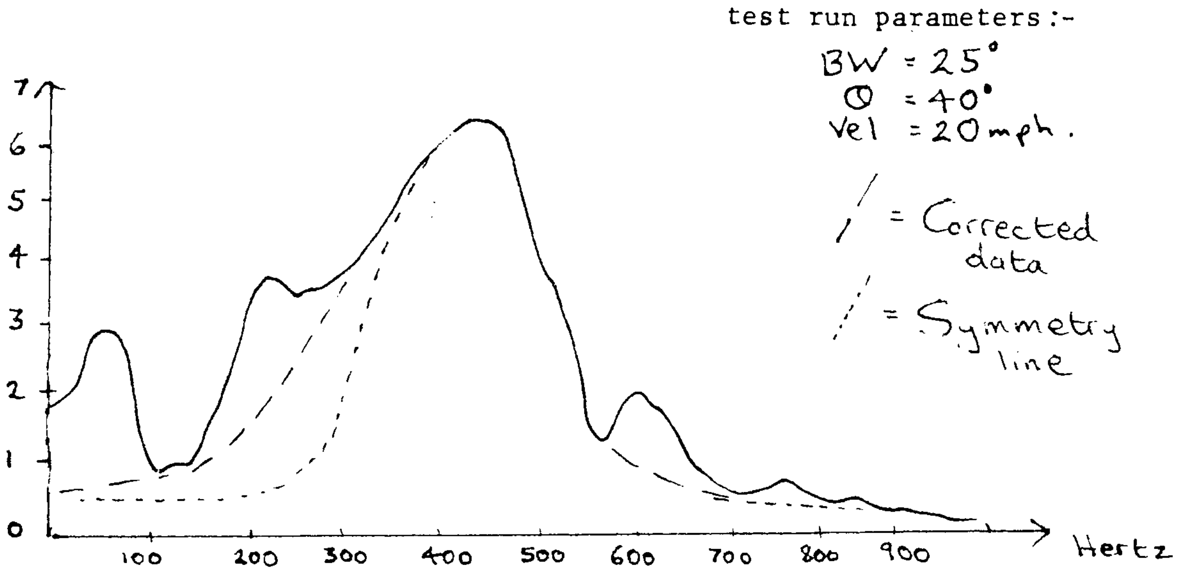
Corrected mode. In some circumstances the true mode will not represent the 'spectrum' mode. For example:



Hence the corrected mode is defined as the mode of a 'rounded' spectrum at its peak point.

EXAMPLE

To clarify the above definitions, a simplified example will now be illustrated:



Let Y = (m - 50) / 100. Constructing a table of y value versus frequency gives:

range	mid value	f	y	fy	fy^2
0 - 100	50	-	0		
100 - 200	150	4	1	4	4
200 - 300	250	3	2	6	12
300 - 400	350	5	3	15	45
400 - 500	450	6	4	24	96
500 - 600	550	5	5	25	125
600 - 700	650	3	6	18	108
700 - 800	750	1	7	7	49
800 - 900	850	1	8	8	64
sum:		28		107	503

Hence, $\bar{x}$ = 107/28 = 3.8 so: μ = 3.8*100+50 = 430hz

SD = 1/27(503-107 /28) = 3.48 so σ = 190hz

mode = 470hz. CV = σ/m *100 = 190/470 * 100 = 40.4

skew =((mean - mode)/σ)/100 = -21.1

SY = -200; B = -1.

And, by the same process for the normalised curve (see dotted line on spectrum), the results are also calculated. The theoretical values are also calculated:

$$f = 2.V\cos\phi/\lambda = 490hz \text{ and } SD = V.\Delta\phi\sin\phi/\lambda = 90.1hz$$

The above results are now tabulated But first, the other sources of information will be explained.

WAVEFORM ANALYSIS

Nulls

The percentage of nulls in the returned signal gives a useful measure of signal consistency and accuracy. A high proportion of nulls may indicate:

a) preamplifier output: -too wide a gain
-wide beamwidth causing intermodulation
-patches of ground with a low reflection coefficient

b) squarewave o/p: - too great a hysteresis

Thus, the number of nulls per true count is calculated and tabulated wherever possible for all data recordings. This is converted into a percentage:

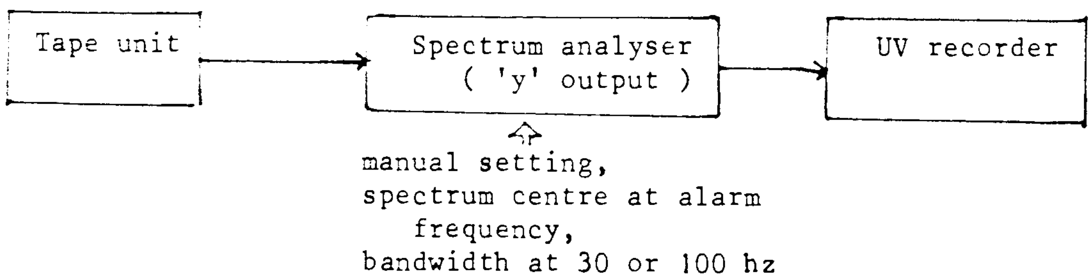
$$\text{nulls} = \frac{\text{no. of nulls per w wavelengths}}{w} * 100$$

Signal Consistency

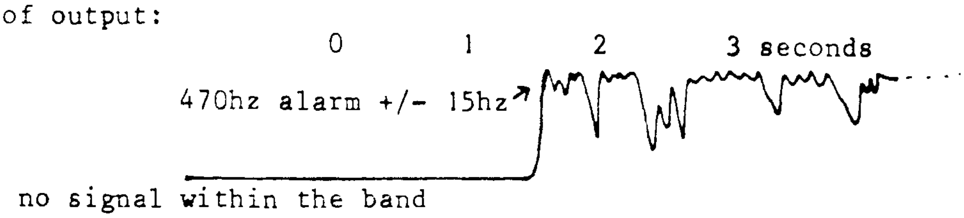
This is defined as the theoretical number of zero-crossings (or squarewave pulses) divided into the measured number for a reasonably long data sample expressed as a percentage. Values can be expressed relative to an assumed 40 degree tilt angle, or to that actually used.

FREQUENCY TRACKING

TThis is a measure of the proportion of time the signal falls within defined bandwidths above and below the nominal centre frequency. The equipment, in block diagram, to achieve this measurement is as below:



Example of output:



TABULATION OF RESULTS.

Each data segment appears in four main tables:

1. definition of radar type, tape reference, transport used and terrain information. The alarm speed (if appropriate) is also noted.
2. data recording results: nulls, amplitude of signal, consistency and frequency tracking.
3. statistics of the spectrum, the corrected spectrum and theoretical calculations.
4. comparisons of the three result fields (1 to 3 above).

Further tables then compare different data segments.

The symbols and abbreviations used are:

Main Symbols:

U = mean

S = standard deviation

V = coefficient of variation

K = skew

Y = symmetry

M = mode

B = kurtosis

Subscripts:

c = corrected data

t = theoretical value

EXAMPLE

The calculations made earlier will now be placed in an example set of tables. Those columns blank are filled with typical results.

All speeds are entered in units of mph: this corresponds with vehicle speedometer markings, and with the geometry of the original speed sensor unit.(intended to work at 25, then 20 then 22 mph).

TABLE 1

RUN	REF	MAKE	TILT	RADAR TRANSPORT					TERRAIN TYPE			
				BW	TYPE	SPEED	ALARM	SURFACE	MATERIAL	CONTOUR	LOCATION	WEATHER
1	Aro 3	Aro	40	25/40	trail	20	23	dusty	tarmac	flat	b.Pool Rd	dry

TABLE 2

RUN	NULLS			SIGNAL AMPL.	FREQ TRACKING						SIGNAL CONSISTENCY			
	PREAMP	SCHMITT	PLL		PRE		SCHMITT		PLL		PREAMP	SCHMITT	PLL	SCH @40'
					FULL	HALF	FULL	HALF	FULL	HALF				
1	26	28	-	3	30	41	35	40	58	72	78	72	-	67

TABLE 3

RUN	TRUE CURVE							CORRECTED CURVE						THEORY		
	U	S	V	K	Y	M	B	Uc	Sc	Vc	Kc	Yc	Mc	Bc	Ut	St
1	430	190	40.4	-20	-200	470	-1	458	170	36	-7.1	-100	470	-1	490	90

TABLE 4

RUN	SKEW	SYMM	MEAN			STD DEV			MODE			
			Ut-U	Ut-Uc	Uc-U	S-St	Sc-St	S-Sc	M-U	M-Uc	Ut-M	M-Mc
1	20	-100	60	32	28	100	80	20	40	22	20	0

EXAMPLE TABLES FOR THE COLLATION AND COMPARISON OF TERRAIN RETURN DATA. Each table contains data on

every run (run 1 in the above example). Table 1 is the definition of radar type, tape ref and terrain information. Table 2 are the data recording results; table 3 the statistics of the spectrum, and 4 the comparisons of the tables. All speeds are in mph.

ABBREVIATIONS:

U: mean
S: standard deviation
V: coeff of variation
K: skew
Y: symmetry
M: mode
B: kurtosis
c: corrected data
t: theoretical value
40': 40 degree tilt angle

SECTION 2.18

REPORT INT P27
7.4.84
C. WALLACE

MICROWAVE RADIATION: CONFORMANCE TO LEGISLATION AND SAFETY LEVELS

SECTION

1. INTRODUCTION
2. DEFINITIONS
3. LEGAL REQUIREMENTS
4. COMMENTS
5. CONCLUSIONS

Introduction

An assessment of the appropriate legislation governing the use of microwave devices is crucial: specifically to ensure that the end-product is a saleable item, but also to assist in the design process.
Microwave lenses and horns of several designs were considered during the design phase of the speed sensor, and numerous microwave units assessed. In order to establish if any combinations exceed the safety legislation, the means by which such danger is assessed must be examined.

Definitions

A general expression for the power density of a radar system (for uniform illumination and a parallel beam) is:

power density = power radiated/aperture area

Uniform illumination is a simplification: Michaelson (1972) adopts a factor of two to allow for increased power density at a horn or lens centre. So, for a circular aperture:

$$P = 2 . P_{tx} / \pi . r^2 \quad mW/cm$$

For clarity, the writer adopted the letter 'd' to indicate an abbreviation for the units of power density, ie $[d] = [mw.cm^{-2}]$ To assess typical density figures, consider a 10mw transmitted power system and a 9 by 5 cm aperture (as used in one prototype). The density, P, is 0.44d. For a focused lens, however, assuming a footprint of 2cm, the value is 5d, over ten times greater. For no lens, the power equals that of the parallel beam at the horn face, and diminishes outward. For a beamwidth of 15 degrees and a radar-target distance of 2m, the power density at ground level is 0.007d: almost negligible.
To assess the danger of the lens system, which clearly presents the worst risk, the appropriate recommendations and legal requirements pertaining to such radar systems will now be reviewed.

Legal Requirements

In the absence of detailed British regulations on microwave safety levels (the HMSO (1960) cover the topic by referring to recommendations from the Medical Research Council, who in turn refer to the American Standard Institution), this brief resume will deal with American and Russinn standards. ANSI (1966) stipulate a maximum exposure of 10d for 6 minutes or more, and 1d.hour within any 6 minute period (USASI 1966, OSHS 1971, Lindsay 1975).

Munford (1967), however, states that 1d (and not 10d) should be used as a safe level if conditions are averagely humid; and that the effect of 4d on skin is perceptible as a rise in skin temperature. The stated power density meeded for permanent damage varies considerably between researchers. One common figure is that of 100d, whereupon eye opacities and cataracts are likely to result (Michaelson, 1972 refs 251 to 261).

The ACGIH (Michaelson 1972, ref 41) states that for 8 hours in any 24, up to 10d is permissible. Russian standards, however, are far more stringent: 0.01d average over eight hours and 0.1d for up to two hours; peaks of 1d for 15 minutes are permissible once each eight hour period (USSR, 1976).

Power output limitations are more clear-cut: absolute limits are placed on output: for X band, 10mW is the present maximum (Ho 14) with the maximun antenna gain stipulated as 20dB relative to an isotropic radiator.. These requirements are identical to those currently enforced in the USA. Alternative methods of expressing maximum ratings for equipment includes field strength maxima: the FCC (FCC 82) advocate 25mv/m at 30m in FCC part 15 (relating to equipment sold without end-user licensing: parts 89 and 91 cover licensed equipment). Conversion from power output and field strength is approximately:

Field strength, $E = 0.18\sqrt{G.P}\ \mu V.m^{-1}$ where G = antenna gain
P = power output

Comments

The above data will now be applied to the makes of microwave unit,and horn /lens designs, used. The present unit, the Aro, at the horn opening posesses a power density of 1.6d. This power is clearly in excess of the Soviet requirements of long-term exposure and of peak exposure, but comfortably below ANSI recommendations. The focused lens, however, according to the literature, possesses a power density capable of generating a perce-ptible skin temperature rise; and is half the maximum working-day dose. This is clearly not ideal: if a factor of four is introduced into the def-inition of P to allow for the lens having a significant power concentration in the centre of the lens (the previously assumed factor of two was a standard agreed over fifteen years ago: many writers have since called for a reduction on permissible levels), then the focused lens at a transmission power of 10mW exceeds the ANSI safety level. This lens would also exceed the Russian standard by a factor of 1000.

To put this discussion in context it should be stressed that situations of potential danger are likely to be rare indeed: only two circ-umstances are seen by the writer as being worthy of note: first, simul-taneous unit testing, and second, extended tests. The former may be a danger as the summed effect of all units may exceed safe recommendations; the second (usually involving standing in front of the unit, such as for 'walk-in' trials to ascertain beamwidth patterns) due to the eye-level height of the unit, and the prolonged times involved. In the case of the speed sensor, the unit points groundward at such an angle that no real danger is present for a truck-mounted unit.

If either the Aro or any alternative units are to be used with power applied but no horn mounted, these units must be kept at some dist-ance form personnel. The Plessey transceiver, for example, will produce a near-field density of 5d. The distinction between near-field and far-field is difficult, but essential. The ANSI and GOST recommendations all relate to far-field effects (Schwan, 1972) as the near-field effect is difficult to assess. Wacher (1971) proposes a technique of measurement that is rather complex: it is surely simpler to take basic preventative action.

Conclusion

It is recommended that:

1. Power is applied only to correctly mounted horn systems and not to transceivers in isolation.

2. Testing of transceivers, horns and lenses should be performed with due regard to a) time of exposure
   b) nearness of units
   c) power of units
   d) number of units

3. Focused lens systems should be tested and used only when the dangers are fully quantified.

It should be noted that:

1. The transceiver, horn and lens system must conform to the appropriate legislation

2. Whilst a perceptible temperature rise can be produced by a surprisingly small power density, any lens system contemplated with normal vehicular doppler transceivers will not produce densities capable of direct measurable damage in the short-term.

SECTION 2.19

REPORT INT P28
23.4.84
C. WALLACE

STAND-ALONE SENSOR AND SANCTION SYSTEM

SECTION

1. INTRODUCTION
2. NEED FOR AN ALTERNATIVE SYSTEM
3. BASIC SYSTEM DESCRIPTION
4. OPTIONS
5. COSTINGS
6. APPENDIXES:
   A OPTIONS
   B CONSTRUCTION EXAMPLE
   C ALARM COUNTER

INTRODUCTION

The intention of this report is to examine the feasibility of a stand-alone speed sensor and sanction system. The basic requirements are discussed, options available are described, and costings calculated.

NEED

As developed, the speed sensor unit was intended for use with the ALBERT safety system: hence the unit relies upon components of this system in order to operate. The full system is illustrated in fig 1: it can be seen that the speed sensor transceiver and circuitry comprises only a small section of the total number of units required in order to operate the sensor. Sections of this total system are costly: table 1 indicates the total manufacture cost of the system (including the retarder sequence logic and interfaces). Whilst the speed sensor is sold at £200 as an option on the basic ALBERT configuration, at which proce it represents excellent value, this total cost is prohibititively exorbitant if only speed sensing (or speed sensing and, for example, non-retarder functions).is required. As the system stands, therefore, the cost would dissuade potential customers in the stand-alone speed sensor market.

This report records an attempt to design a stand-alone sensor and sanction unit for under £150, allowing a reasonable profit to be made within the projected selling proce of three hundred pounds.

The concept of the stand-alone system is appealing: the sanctions imposed at present are harsh, and in the event of malfunction, can be dangerous. At present if a driver exceeds the preset alarm speed, a low-volume bleeper sounds, and four seconds later the first of the three retarder stages engages. By pushing the cancel button, the alarm is cancelled as long as the truck speed has dropped adequately. If the sensor fails (which has happened on a prototype test), and the system believes it sees a permanent alarm state, the truck will be stopped and can only be moved by disabling the entire safety system. If this happens on-site, an a hill with slippery ground conditions, a potential hazard is created: and even at best, site production on the blocked haul road is halted.

Consider now the replacement of the retarder sequence with a three-stage sounder: stage one being quiet, two being noisy and three being intolerably loud. The driver would thus have to endure irritatingly loud wailing as the penalty for overspeeding. And in the event of an emergency or malfunction, the truck is not disabled, and remains driveable at and above the alarm speed.

A further feature of the audible sanction is that the third sounder stage can use an external klaxon: the driver will most certainly be aware of its activation, as will nearby personnel. Thus the driver is effectively exposed in public of speeding. And, of course, nearby personnel and drivers are warned. The debate concerning alarm auto-cancel or driver cancel is now easily resolved: whilst the driver is required to manually cancel the retarder sequency in the conventional design (to prevent him simply placing a foot hard on the accelerator and allowing the system to automatically regulate his speed), this is no longer required. He cannot use the system as a 'cruise control' without undergoing the alarm sounder. Thus the control logic of the present system is, to a large extent, made obsolete.

BASIC SYSTEM

The sensor unit would require an on-board f/v, comparator and timers (all located at present on the main control board). The drivers for the sounders are internal to the sounder units, although one transistor is used as a buffer. In block-diagram the system looks as in fig 2. The components of PCB 3 will now be examined in detail. A suitable circuit is illustrated in fig 3 and 4 (componentry, sounder connections and power supply unit respectively), although the required functions can be realised in several alternative ways. Briefly, the system operates in the following manner. The squarewave pulsetrain is converted into a dc voltage proportional to the input frequency. This is then compared to the comparator alarm level and if higher, the comparator output switches. This initiates the first sounder, which emets a low frequency tone, and triggers the first timer. This, after 2.5 seconds, changes the low pitch to a louder high pitch; which, in turn, triggers the second timer. This, after five seconds, triggers the second sounder, of high volume and high pitch. If the squarewave frequency drops to below alarm speed (or a little lower due to the comparator hysteresis), the sequence is instantly cancelled. Fig 5 illustrates the timing sequence.

The power supply and the interface between the sensor unit and the f/v, are both transient protected as this cable run is approximately eight metres: long enough for significant induced interference.

The output sequence, in summary,is tabulated in fig 0.

ALARM STATE	TIME FROM ALARM (seconds)	FREQUENCY (hertz)	SOUND LEVEL (dBA @1m)
no alarm	-	0	0
alarm	immediate	800	65
"	after 2.5 sec	3400	70
"	after 7.5 sec	3200, 5hz pulse	93 *1
alarm cancel	-	0	0

note *1: alternative sounder provides up to 113dBA

SUMMARY OF THE SOUNDER SEQUENCE. FIG 0

OPTIONS

The simplest option has already been mentioned: that of a very high volume sounder mounted on the outside of the cab. The 113dBA produced would be more than audible within the cab, and for some distance around the truck. It is also possible to adapt the system to display the truck speed. Such a speedometer would ensure that the driver had the information to drive at just below alarm speed: the mechanical speedometer fitted as standard is unreliable and inaccurate (most mechanical speedometers fitted to such trucks possess electrical circuitry to convert a magnetic sensor to a conventional 'dial' reading. The sensor is incapable of accuracy in the off-highway environment and a typical speedometer, if working at all, will jump violently between speed, being accurate to only +- 25%). A speedometer taking a signal from the radar output would only give a meaningful reading above 5mph, which is adequate, and would be accurate to around 4%. Several readout formats are possible: for example, large seven-segment LED displays, a bargraph or discrete LED stages, ar an analogue meter type. Suitable options are illustrated in appendix 1, and a typical construction example in appendix 2.

It would be a potentially useful facility to incorporate into the unit some means of tallying the number of overspeeds. This information cannot be collected over an extended period of time in order to identify guilty drivers as each truck is used on three consecutive shifts. This information can be useful in other ways:

a) to check on the quantity of overspeeds per truck per shift (if a foreman is willing to check the counters; assumedly on a random basis)

b) to assist in the identification of general statistics of truck behaviour over an extended period of time. This would lead to useful information on the savings the speed sensor gives in probable engine and tyre wear.

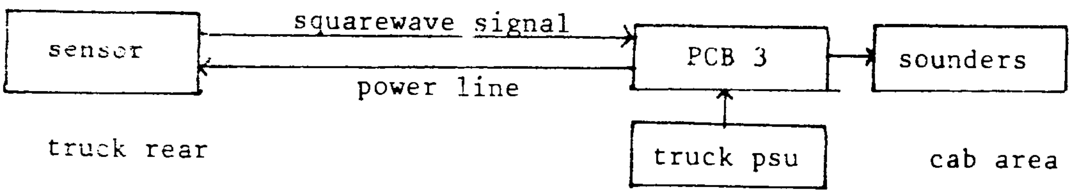
Both these aims can be easily achieved by a cheap and simple circuit illustrated in appendix 3. This design has the benefit of being totally tamper-proof.

Further useful information would be a count of operative time. Such a unit would be required to maintain an accurate tally of hours of truck operation. This data could be used as:

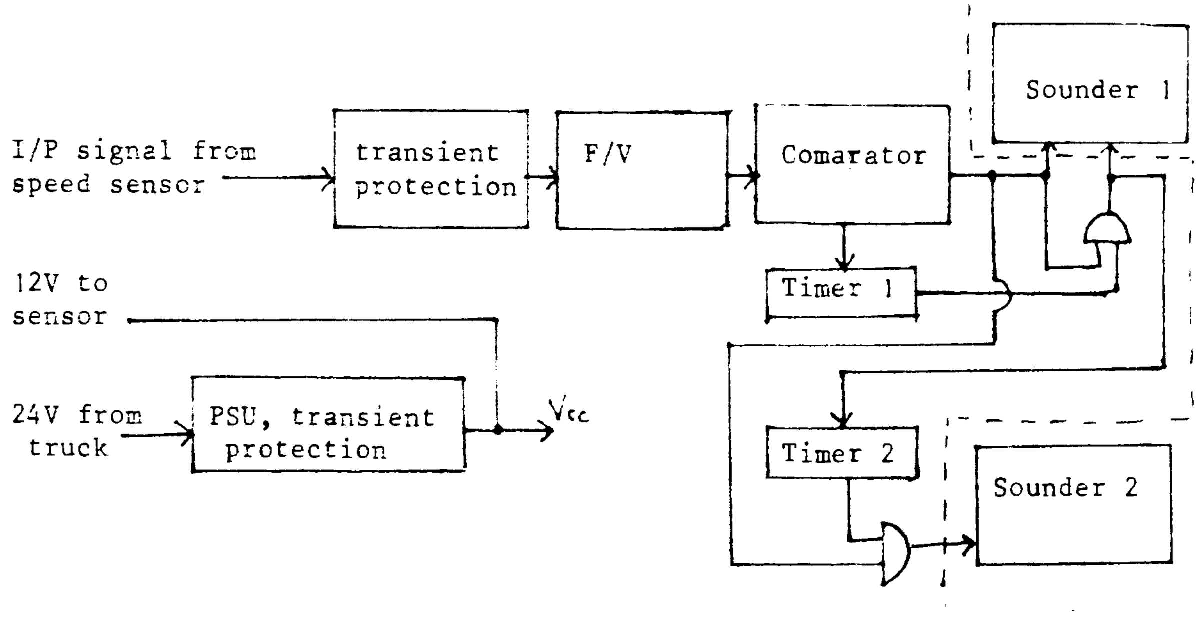
a) a true indicator of MTBF (by collating data on the number of hours of operation to a mechanical or electrical failure of any one, or all, of the safety system modules.)
b) an aid to arranging preventative maintenance (by servicing the units prior to the calculated MTBF).

Suitable circuits are illustrated in appendix 4.

FIG1

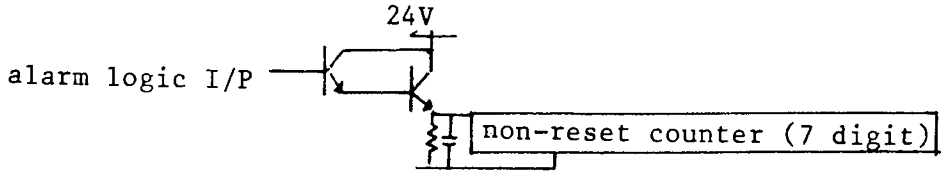


where PCB 3 contains:



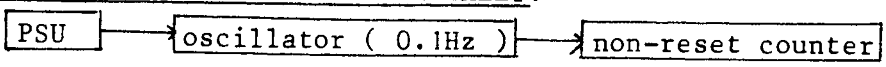
BASIC SYSTEM IN BLOCK-DIAGRAM. FIG 2

APPENDIX 3: ALARM COUNTER.

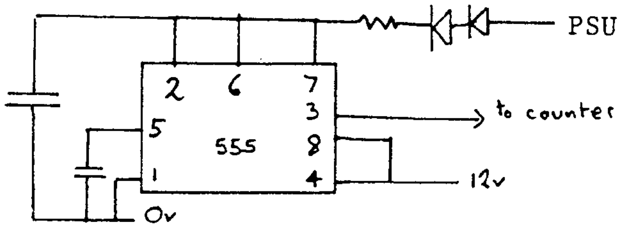


the RC network prevents spur iae triggering the counter. Typical counter is the RS 259 741 @ £6 each.

APPENDIX 4: HOURS OF OPERATION TALLY.

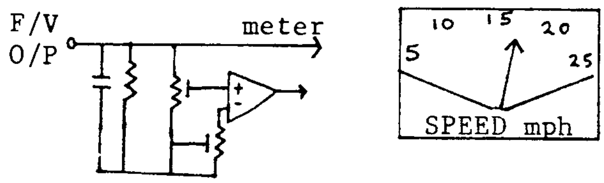


for truck operation three shifts per year, the total count is 8.3 million. Counter resets at 9.9 million. Typical oscillator circuit:

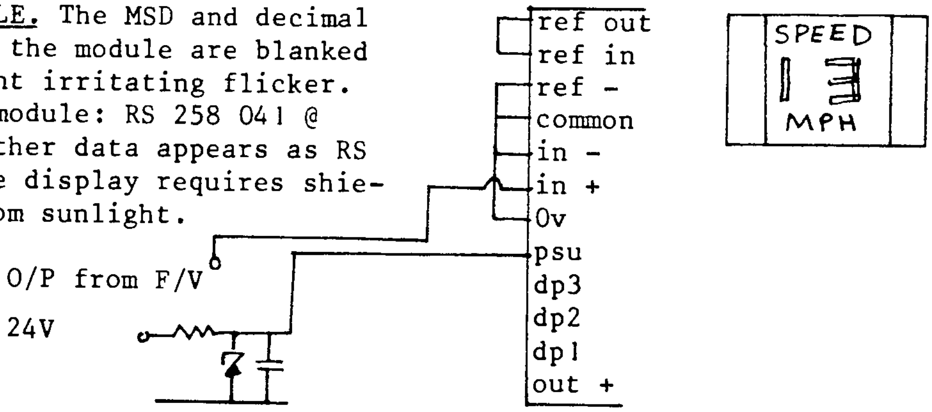


OPTIONS.

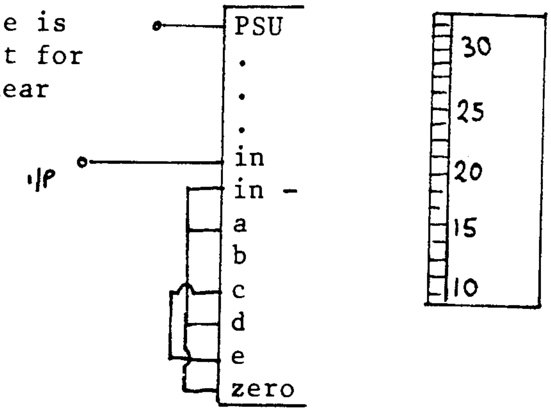
1. METER. The meter is blanked out below 5mph and above 30mph. A typical meter is the RS 259 662 @ £15 (large display).



2. LCD MODULE. The MSD and decimal point of the module are blanked to prevent irritating flicker. Typical module: RS 258 041 @ £20. Further data appears as RS 5106. The display requires shielding from sunlight.

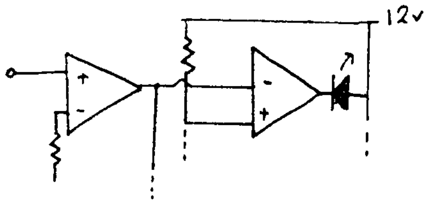


3. BARGRAPH. Suitable bar module is the RS 258 855 @ £20. COnnect for a solid bar display with linear spacing between leds.



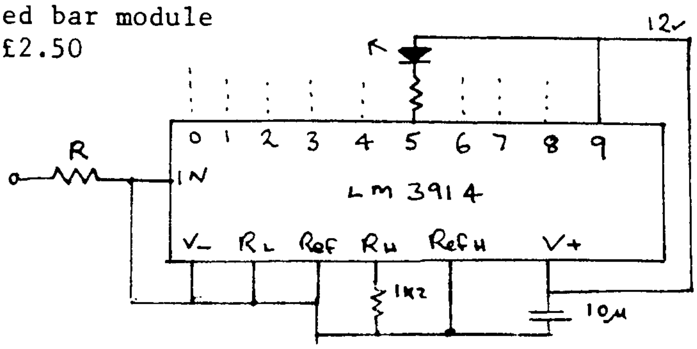
4. DISCRETE LED. This design allows the designer to specify the mph indicatıon of each led by alteration of the voltage trip point of the comparators. The IC used is LM 324 (3 req for 11 stages).

Generalised format of circuit is as illustrated.



An alternative design can be constructed utilising the LM 3914 IC (See Marston, 1981). A suitable led bar module is the RS 588 027 @ £2.50

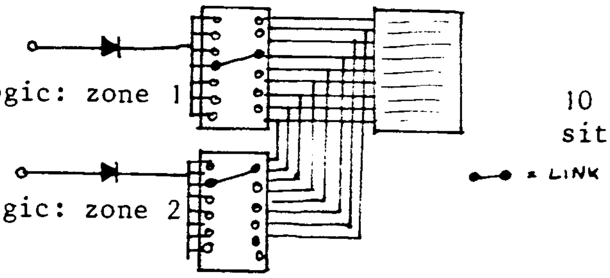
$$FSD = 1.2\left(1 + \frac{R}{10m\Omega}\right)$$



CONSTRUCTIONAL EXAMPLE OF THE LED DISPLAY.

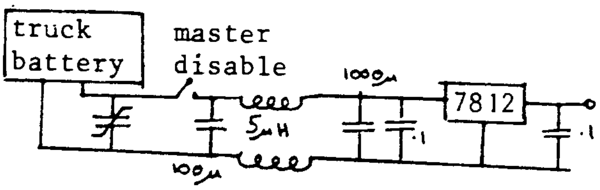
The construction details shown indicate the ergonomic design of a suitable display. The sounders and PCB are housed within the unit.

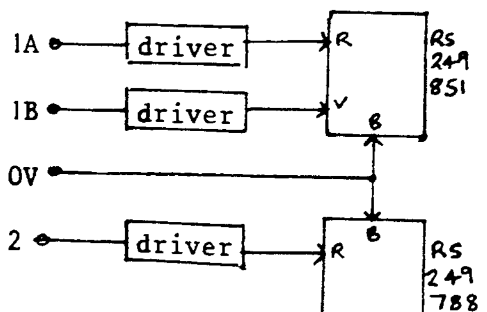
Notes: The sounders are mounted so as to be rear-facing: this ensures they cannot easily be quietened by blocking the case aperture with a rag or tape. Preliminary warning light illuminates with the 29mph led for a nominal 20mph alarm speed. This light is a high-intensity unit. The unit is mounted immediately in front of the driver at the top of the fascia (near eye-level). Right-hand markers illustrate the current alarm speed setting. For only one speed option, the led can be permenently illuminated. DIL linkages are used to program the leds for a zonal system, which a site fitter can alter. For a system with changeable alarm speeds but not zonal, a rotary switch would suffice.



10 segment led indicating site speed setting.

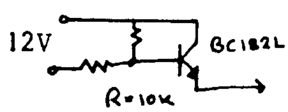
SOUNDER DRIVERS AND PSU. MOUNTED ON PCB 3. FIG 4



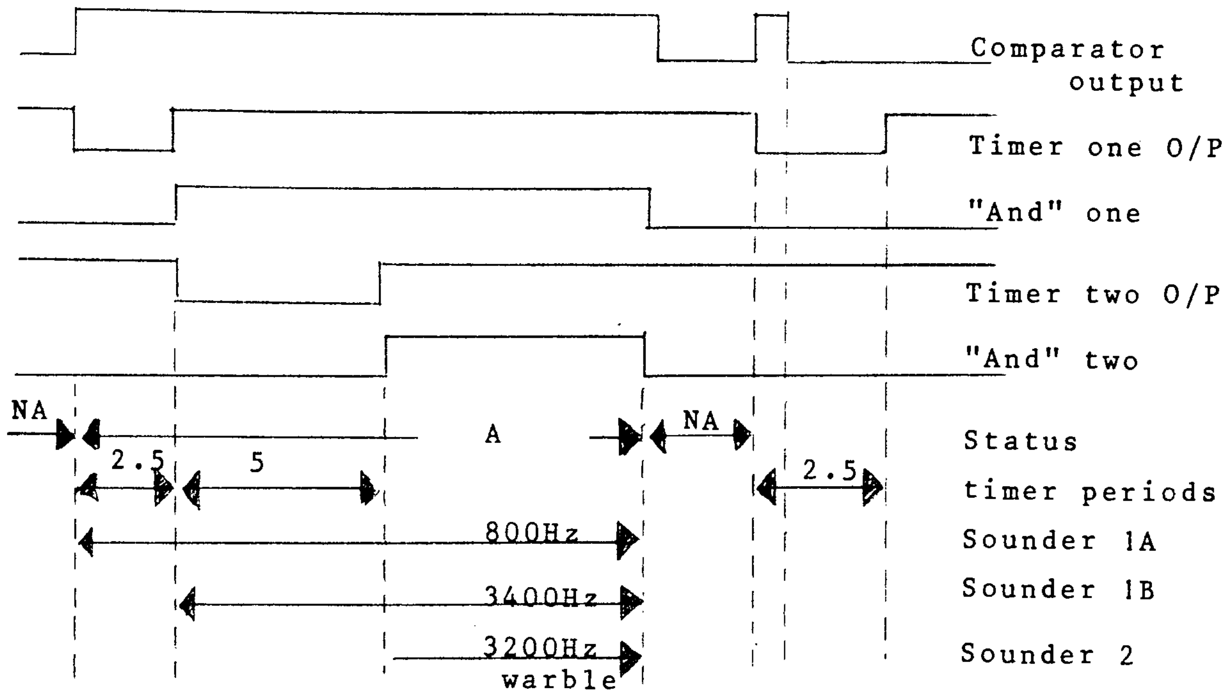


where:

driver =



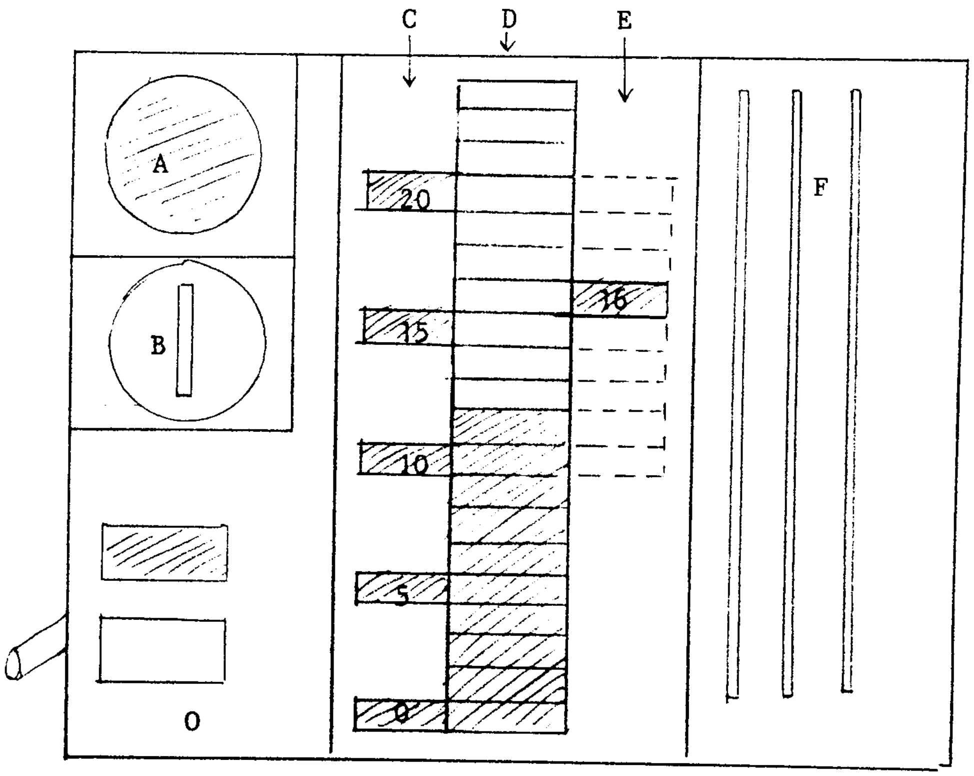
NOTES: sounder 2 equivalent is RS 248 404 (100dBA) or RS 249 930 (113dBA).



KEY: NA= no alarm. A = alarm.

FIG 5

TIMING DIAGRAM FOR PCB 3. Sounder outputs are indicated.



KEY: A: 'CAUTION' light
B: Master disable key
C: speed markers (LED)
D: Indicated speed (LED)
E: Site alarm speed (LED)
F: sounder slots (front & rear)
O: (option): cancel available indicator and button

EXAMPLE OF A CAB PANEL UTILISING LED BARGRAPH DISPLAT FORMAT.

UNIT	COST £ (*1)
Horn assembly	70.00
Cab panel	60.30
Brake box	145.08
Control box	93.63
Cables	32.95
Mounting brackets	80.00
Air loom	11.10
Pneumatic fittings	42.00
Suppression kit (*2)	50.20
TOT:	585.26

NOTES:

*1: from Butterworth (1984)
*2: for Terex vehicles only

COST OF SPEED SENSOR UNIT ONLY (INCLUDING SYSTEM COMPONENTS REQUIRED TO PERMIT FULL OPERATION OF RETARDER SEQUENCE.)

TABLE 1

UNIT		COST £
Horn assy:	case	27.00
	microwave unit	26.00
	PCB	3.00
	components	6.00
Logic (PCB 3)	case	3.00
	PCB	2.00
	components (*1)	5.52
Sounders, keyswitch		15.82
Cable, connectors etc		8.00
	TOT	95.34
	TOT (*2)	56.97
options:	cheapest speedo	3.50
	external sounder	2.75
	TOT	104.59
	TOT (*2)	62.72

NOTES:

*1: see table 1. Assumes no stock
*2: total assuming present stocks of unused (and unuseable) components.

UNIT COSTING (including and excluding present component stocks) OF STAND-ALONE SPEED SENSOR AND AUDIBLE/VISUAL SANCTION.

TABLE 2

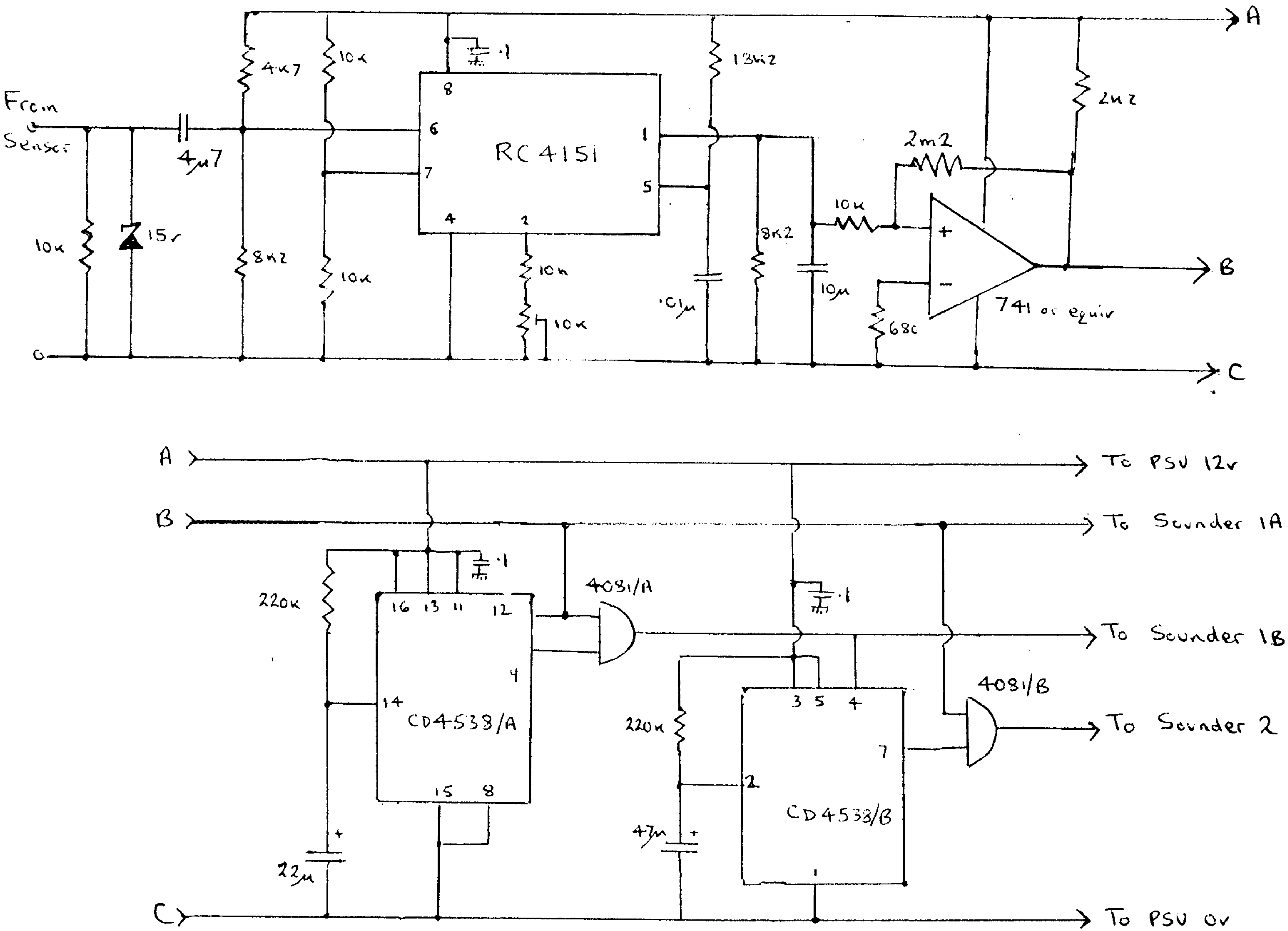


FIG 6

ANALOGUE AND DIGITAL CIRCUITRY OF PCB 3. THE PSU AND DRIVERS ALSO APPEAR ON THIS PCB.

COMPONENT COSTINGS. ADDITIONAL COMPONENTRY REQUIRED OVER BASIC SPEED SENSOR MODULE.

COMPONENT			*1	QTY/ PCB	COST EACH	*2	*3	RS stock no.
PCB	IC	RC4151	50	1	.60	.45	.60	
		CD4538	925	1	.78	0	.78	
		CD4081	1000	1	.19	0	.19	
		LM741	0	1	.22	.22	.22	
		LM7812	600	1	.45	0	.45	
		SKT	0	4	.10	.40	.40	
	RES	1% 0.2w	0	20	.02	.40	.40	
	CAP	25V elect	1824	5	.08	0	.40	
		63V elect	700	2	.25	0	.50	
		decoupl	4500	5	.03	0	.15	
		Zenamic 30V	414	1	.58	0	.58	
	TRAN	BC 182L	16500	3	.10	0	.30	
	ZENER	15V	1600	1	.07	0	.07	
	OTHER	choke	20	2	.24	.45	.48	
		PCB	0	1	2.00	2.00	2.00	
EXT.								
	KEYSWITCH		300	1	3.50	3.50	3.50	
	SOUNDER 1		160	1	5.22	0	5.22	
	SOUNDER 2		0	1	7.10	7.10	7.10	
OPTIONS								
	SOUNDER 2 LOUD		0	1	+2.75			RS 248 404
	or SOUNDER 2 V.LOUD		0	1	+18.40			RS 249 930
	METER		0	1	+60.00			RS 259 662
	or BRAGRAPH		0	1	+40.00			RS 258 855
	or LCR o/P		0	1	+20.00			RS 258 041
	or LED, discrete		0	1	+3.50			
	or LED, IC, 10		0	1	+8.00			
	or LED, IC, 20		0	1	+16.00			

TOTALS.

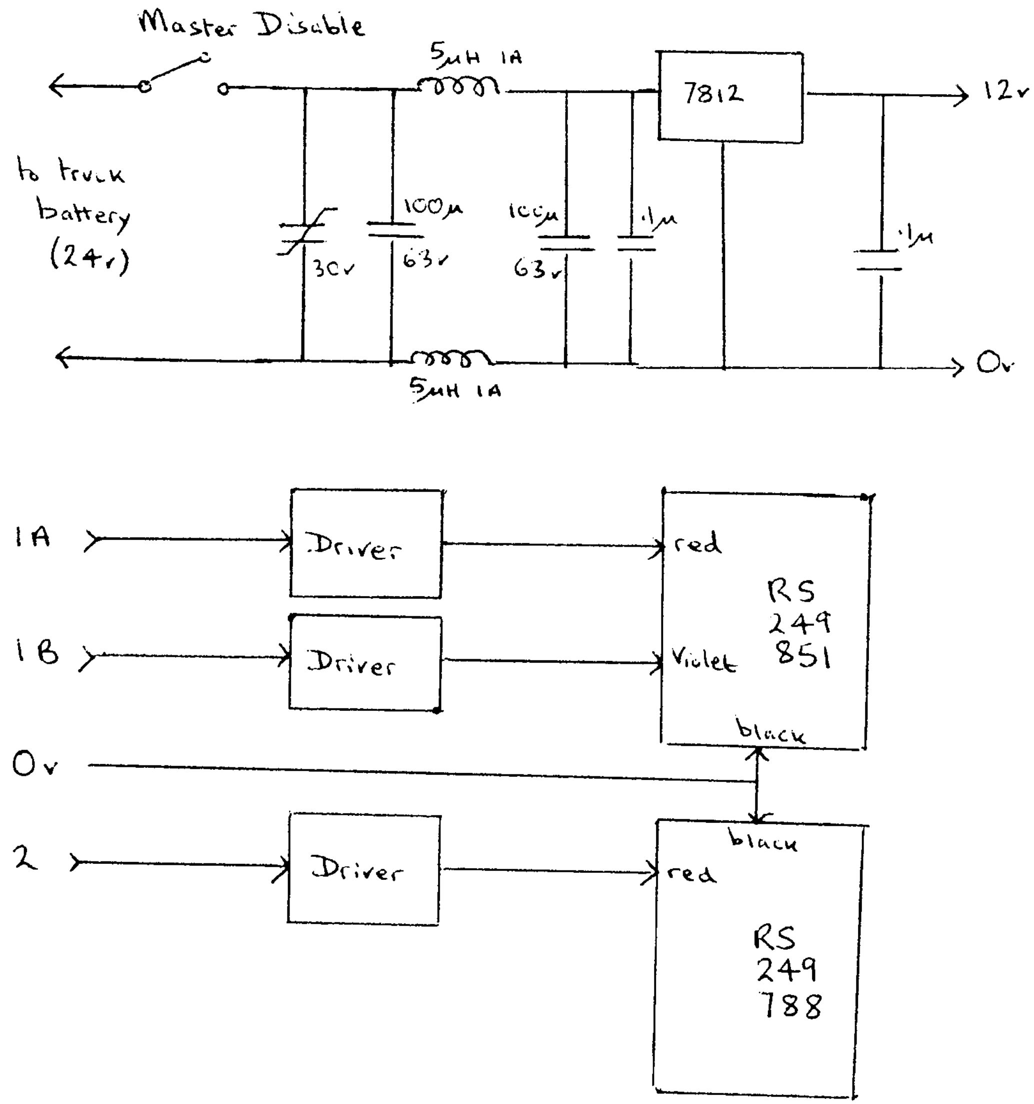
PCB	total cost:	£7.52
	cost exc stock:	£3.87
EXT	total cost:	£15.82
	cost exc stock:	£12.32
TOTAL COST:	tot:	£23.34
	exc stk:	£16.

NOTES:

*1: OEL stock as at 4/84

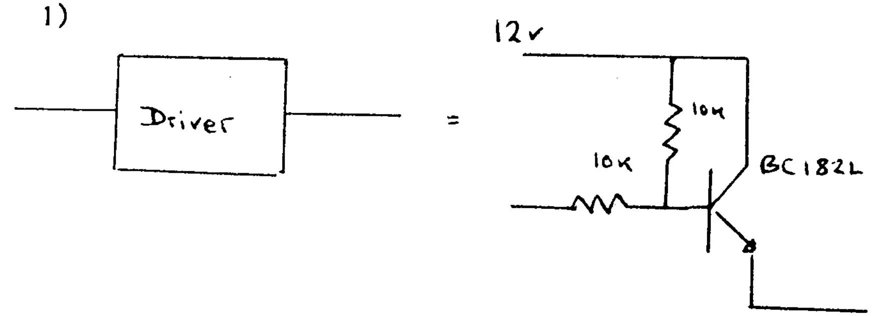
*2 total cost excl stock items

*3 total cost of all items



NOTES:

1)



2) Sounder two can be replaced by:

louder output: RS 248 404 (100dBA)

very lout: RS 249 930 (113dBA)

3) Master Disable. It is suggested this is a keyswitch.

CIRCUIT DIGRAM FOR PSU AND DRIVER STAGES. these components are mounted on PCB 3.

FIG 7

SECTION 2.20

REPORT INT P30

PRODUCTION UNIT TEST SCHEDULE.

NOTES. THE SCHEDULE OVERLEAF SUFFICES FOR BRIEF GO/NO GO TESTS. FOR CUMULATIVE PERFORMANCE DATA USE P30A BELOW. FOR A FULL ANALYSIS, REFER TO FULL TEST SCHEDULE P23.

RESUME.

measuring point	parameter	typ value	result	OK?
premaplifier	gain	74.5		
	atten @ 100Hz	9.8		
	atten @ 1KHz	1.4		
filter	gain	0.4		
	atten @ 100Hz	29.5		
	atten @ 1KHz	2.9		
gain stage	gain	14.5		

notes: typical values in dB.

PRODUCTION TEST SCHEDULE: Speed Sensor

This schedule pertains to standard boards ref ALC 104, Issue 1, only. For variants and fault-finding schedules, refer to test schedule Issue 1.3 (Int P23). Perform WITHOUT fluorescent lighting present.

BOARD SER NO:	ISSUE:	PCB ONE NO:	PCB TWO NO:
PCB TYPE: aro/horn/dev/b1/b2	TESTER	TEST DATE:	PASSED

STAGE	TEST	INPUT	OUTPUT	TYPICAL VALUES			TOL	MEASURED	OK
PSU	gunn volts	24V at 2A.	'v'	8.0			0.1v		
	green led		led	on					
	filter		K, D5 & D6	5.5	11.0		0.4v		
PREAMP	stage 1	40mv @ T1. .1/.2/1khz	T2	1.2	2.6	2.0	0.2v		
	stage 1 horn	" "	T2	.27	.6	.44	0.1v		
	stage 2	" T2 "	T3	1.2	3.8	3.0	0.25v		
FILTER	freq **resp**	2v @ T3 .1/.1/.5khz	T4	.2	1.4	2.3	.1/.2v		
SCHMITT	o/p hz sweep	.8v @ T4, sweep	T6	170	1600		20/200		
	red led	" "	led	on (off otherwise)					
PLL	resp. time	" 250-500hz	'out'	2	4		.5/1		
UNIT	noise	head connected	T3	80			10mv		
	strike	vibration	'out'	none					
	tune fork b1	440hz @ 30cm	T6	440			0hz		
	" " b2		T6	412			2hz		

BEACON SYSTEMS

SECTION

1. INTRODUCTION
2. APPROACHES:
   - A) BASIC ULTRASONIC
   - B) CODED ULTRASONIC
   - C) BASIC INFRARED
   - D) CODED INFRARED
   - E) LOGIC CODED INFRARED
3. COMMERCIAL DESIGN

INTENTION & INTRODUCTION

This report briefly summarises the work performed on beacon systems, both for zonal speed selection systems, and alarm disable.

Several approaches were assessed: infrared (both continuous, pulsed and coded) and ultrasonic transducers were used. In the absence of information on appropriate dedicated integrated circuits, most circuitry was designed and built from first principles. The two final systems, selected as commercially viable, are described in some depth at the end of this report.

APPROACHES

1. Basic Ultrasonic.

Both 23 and 40KHz ultrasonic transducers were tried in a straightforward 'on-for-changeover' configuration, whereby the vehicle would sense the presence of the transmitted frequency, and the present state of the alarm frequency comparator would 'flip' to a second preset value; and upon detecting further beacons, flip back. Although considerable time was spent on this concept, which with hindsight proved useful for gathering relevant information, the designs failed for the simple reason that too much ambient noise contains such ultrasonic frequencies. For example:

air brakes: detected at	15metres
metal striking stone:	8
pneumatic drill:	12
diesel engine:	4
air brake release:	22

2. Coded Ultrasonic

In an attempt to distinguisdh between noise and signal, a coded configuration was tried. In order to utilise to best advantage any existing remote-control devices, the Plessey ML928/9 series (Plessey) was used. Briefly, this superimposes a pulse-width modulated signal on a carrier frequency. (Circuit details appear in ETI 79a,b; 82a, b). For a transmission window of ten metres at 35km/hr, 15 frames can be passed. Thr receiver requires two consecutive valid pulse sequences before action. A discrete component preamplifier was used in front of the IC receiver in order to reduce circuit noise. One receiver was incorporated, although for expansion to sixteen codes, two can be used in parallel. The output is directly transferred to CMOS switches which control the alarm frequency (and as an option, the filter frequency of turnover, and gain). The transmitter is placed three metres from the point at which the vehicle passes, thus utilising the sidelobes of the transducer to widen the transmitted beamwidth. This system worked well in the laboratory and on car tests, but on site trials, transmitted code sequences were often missed due to spurious noise (a 40khz noiseburst only one millisecond long would cause the receiver to throw away the last valid received code). Isolating the receiver from ambient noise, by encasing it in a foam-lined 'funnel', improved the system performance, but in general the unit did not prove reliable. Substitution of the transducers to 60Khz types (P.Elect, Elektor) improved matters considerably, but still not enough to provide the basis of a commercial design. Further complications occur with this system with regard to dirt on the transducers: a self-cleaning unit would require incorporation as coded transmission requires steep rise-time signals.

3. Basic Infrared

This system utilises a simple infrared light emitting diode and receiver. Reception of the transmitted frequency of light activates a latch, and this is passed on to the processing electronics, which changes the alarm frequency. Home-made circuits were assessed, but a batch of supposedly identical IR TX/RX pairs gave widely different performance characteristics, resulting in ranges of 3m to 5m and beamwidths of 10 to 30degrees. Thus, a commercial unit was purchased (Sunx, RS 3560). Due to the narrow beamwidth of this unit (a 'retroreflective' type) several reflectors were joined to provide a large pyramidal reflection surface. The system performed well, responding without fault at up to 9m. The unit also proved impossible to fool with sunlight (direct, indirect, filtered with colour, polarised vertically and horizontally etc). However, dirt on the inbuilt lens significantly reduced range, and a lens cleaning facility must be built into any commercial design.

4. Coded Infrared

The IC types used for ultrasonics were tried with home-designed IR transmitters. This design worked well at short range (1 to 2m) but failed at longer distances. This was considered unfortunate, as this design in all other respects is ideal; being cheap, simple, foolproof, and capable of transmitting sixteen codes (but receiving only eight). Ultra-powerful IR TX/RX LEDs were tried: these improved the range but at the expense of beamwidth (at 3m the working beamwidth was 3 to 5 degrees only).

5. Logic coded Ultrasonic

Ths system uses the assumption that noise contains both 23 and 40kHz components. The receiver senses both 23 and 40khz seperately, and will alarm only if 40khz is present in isolation, ie

40khz	23khz	output	typical ambient conditions
yes	yes	none	noise present
no	no	none	no noise or signal
yes	no	alarm	signal present
no	yes	none	noise present

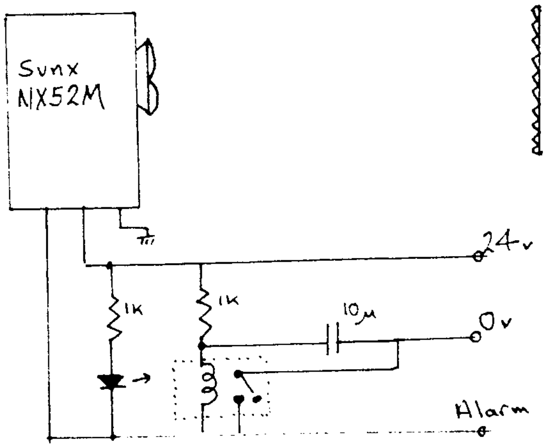
A time delay is also used which delays alarm output for two seconds to ensure that the reception of 40khz in isolation was not an 'instantaneous' specific frequency noise burst.. The transmitter is of the 40khz type, with additional driver transistors, and a 'low battery' alarm. Due to the non-coded transmission format, a range of 15m was achieved, with a beamwidth of 45deg. This system performed well both in the lab, on a car and on site. Indeed, with a clean transducer (dirt reduces effectiveness slightly) the performance was faultless as long as isolation from the truck was achieved. This was performed by placing the receivers in foam-lined funnels which worked for all but certain trucks that seemed to possess a different 'noise signature'. For these trucks, the 60Khz transducers were used. At the time of writing, no problems have been reported due to high windspeed, although this is seen as a potential problem.

COMMERCIAL DESIGN

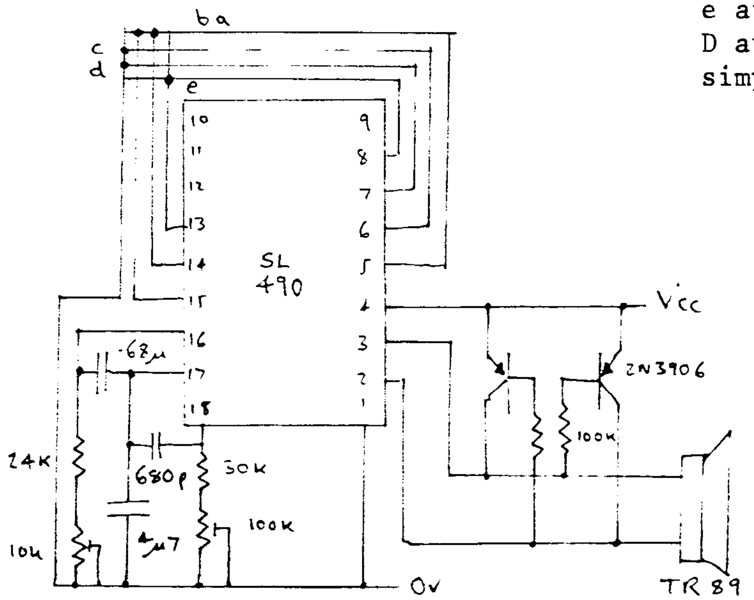
The designs most suitable for commercial use are the retroreflective infrared system and the logic ultrasonic system. Both, however, meet the original design requirements only partially: they are both capable of transmitting or not transmitting. No further information can be encoded. The zonal beacon system must thus be limited in scope. One method of improving this situation is to use both methods simultaneously: ie

IR	US	action
yes	no	15mph alarm
no	yes	20mph alarm
yes	yes	25mph alarm

Both systems require a clean transducer: in both cases a 'window wiper' arrangement can be incorporated, although this will provide a drain in the beacon battery supply. For no wiper, the battery would last over 1000 hrs; with wiper, perhaps 200hours, or 12 working days. However, batteries are easily interchanged, and power supplies are often available due to the preponderance of site lighting.

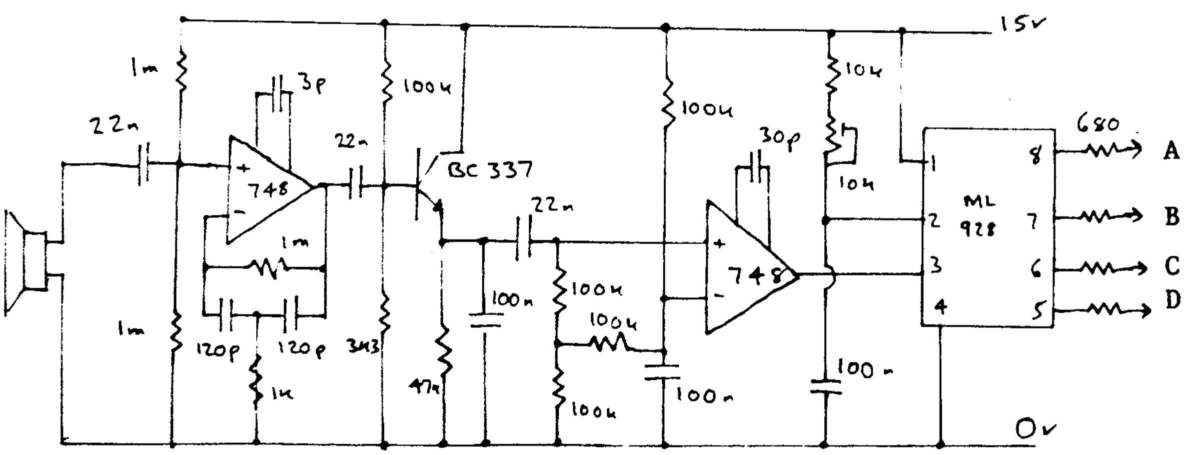


BASIC IR SYSTEM. The Sunx transceiver incorporates both receiver and transmitter, and requires pyramidal reflectors to operate.

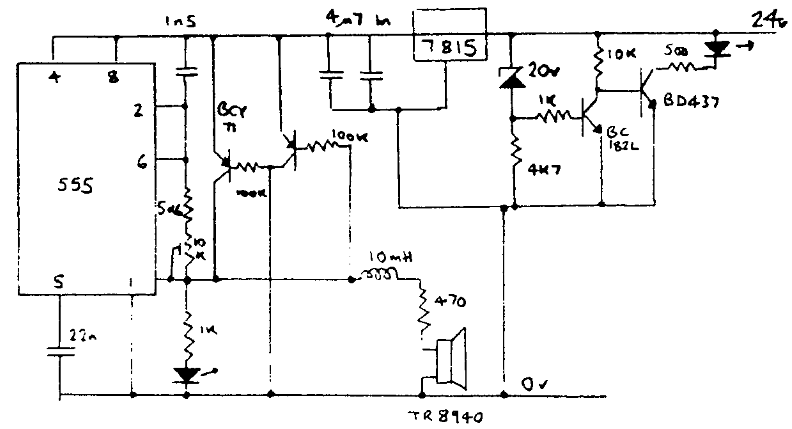


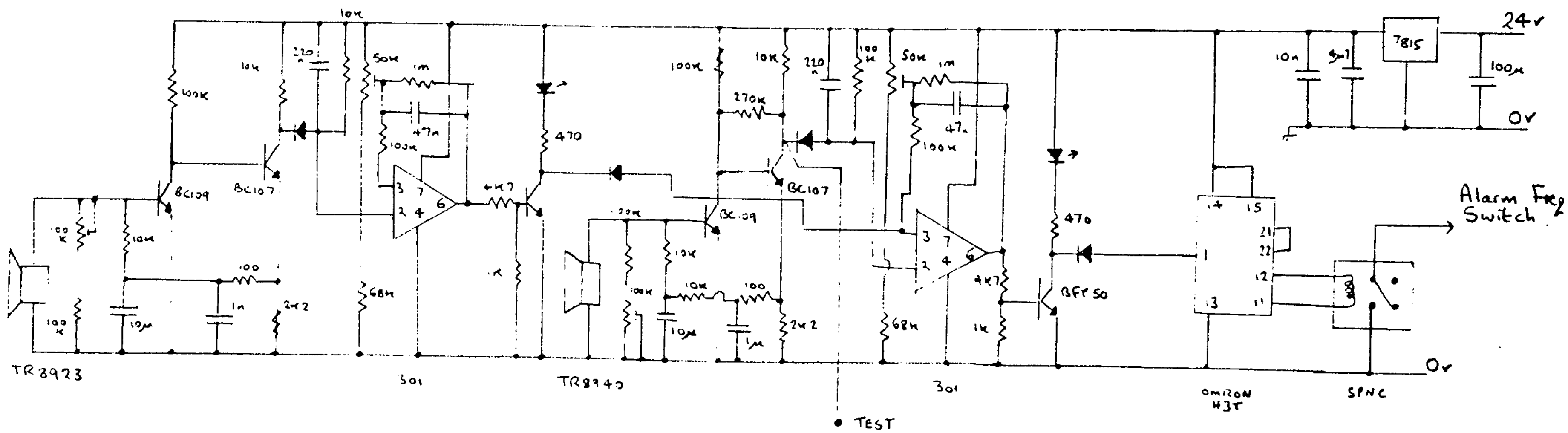
CODED SYSTEM (IR and Usonic). a to e are latching switches. Outputs A to D are coded outputs, but are used as simple logic levels (see logic chart).

Switch	out DCBA	alarm mph
a	0010	15
b	0001	10
c	0100	20
d	1000	25
e	1111	test
-	0000	disable



ULTRASONIC
BEACON SYSTEM
DRG 008-322A
Drn C Wallace 23.11.82





SECTION THREE

APPENDIXES

APPENDIXES.

3.0 Speed sensor unit: component and supplier listings
3.1 Index of tape recordings
3.2 Index of main drawings (production and prototype)
3.3 Project chronology: resume
3.4 Off-Highway truck contractors and manufacturers
3.5 Component selection, an example (from report P2)
3.6 A. ALBERT sales brochure
B. Control box: schematic diagram
3.7 A. production of Doppler frequencies by microwave
B. Doppler microwave transceiver configurations
3.8 A. generalised transducer system block-diagram
B. Assessment of radar configurations for velocity measurement applications
3.9 A. Unit calibration accuracy: tuning forks
B. Error in velocity measurement due to variations in transmission frequency
3.10. Frequency to voltage conversion errors
3.11. Useful addresses and contacts
3.12. Invisible window constructions (Bewster angle)
3.13. OEL development priorities in Dec 1982
3.14. Resume off the work performed on the Aro circuitry:
A. General findings
B. Modøifications assessed
3.15. Company reply

COMPONENT LISTING: SPEED SENSOR UNIT.

Program: Title: Complist
Pages: 4
Disc : Elect-file-one
Update: 30.5.84

ABBREVIATIONS:

SUP: supplier

F	Farnell	0532 636311
R	Rapid electronics	0206 36412
C	Marco	06286 4422
S	Radio Spares	01 250 3131
K	RTK engineering	0423 58253
B	Crickewood electronics	01 452 0161
L	Hustlers Engineering	0532 503166
A	Amphenol	0227 264411
H	Hirst and Son	0422 201666
P	Plessey Microwave	0327 51871
T	Sandalloy Engineering	0532 436661
N	North Eastern Rubber Co	0632 590000
E	Emerson and Cumming Ltd	01561 1798
M	Maplin Electronics	0702 552911
O	Ogden Group (stock item)	
D	Crofton Electronics	

MANF: manufacturer

Du Dubilier — U Mullard (&BZY)
Si Signetics — W Wima
O Molex — Ra Raytheon
I International Rectifier
Rp Redpoint — M Multicore
B BDF Tesa 0908 615577
C Critchley — H Hellermann
MA Microwave Associates, Dunstable 601441
IMI IMI Inc

APP: application: a = aro unit only; n = not aro unit; 2 = board one and two; 1 = board one only

N: notes: see notes at end of component listing
DEL: delivery time in days. s = stock item
QTY: quantity required per complete unit

Component abbrev:

t	tantalum	r	radial
a	axial	e	polyethylene 10%
p	polypropylene 2%	m	metal oxide 1%
v	vitreous 4watt	R	red
G	green	u	microfarad

APPENDIX 3.0: COMPONENT LISTING FOR SPEED SENSOR.

COMPONENT	SUPPL	REFERENCE	NUMBER	AP	NB	DEL	QTY	COST	of:	TOT
	CODE	Order code	Manf					1	100	
RESISTORS										
220k m	F	MR25.220k	MVMR25			s	2	.03	.03	.06
180k m	F	MR25.180k	MVMR25			s	1	.03	.03	.03
100k m	F	MR25.100k	MVMR25			s	4	.03	.03	.12
2k2 m	F	MR25.2k2	MVMR25			s	2	.03	.03	.06
1k m	F	MR25.1k	MVMR25			s	3	.03	.03	.03
10k m	F	MR25.10k	MVMR25			s	3	.03	.03	.09
75k m	F	MR25.75k	MVMR25			s	2	.03	.03	.06
22k m	F	MR25.22k	MVMR25			s	1	.03	.03	.03
62k m	F	MR25.62k	MVMR25			s	1	.03	.03	.03
82k m	F	MR25.82k	MVMR25			s	1	.03	.03	.03
12k m	F	MR25.12k	MVMR25			s	2	.03	.03	.06
560k m	F	MR25.560k	MVMR25			s	1	.03	.03	.03
680k m	F	MR25.680k	MVMR25			s	1	.03	.03	.03
240 m	F	MR25.240r	MVMR25			s	1	.03	.03	.03
1m m	F	MR25.1m	MVMR25			s	1	.03	.03	.03
1k2 m	F	MR25.1k2	MVMR25		6	s	1	.03	.03	.03
91r m	F	MR25.91r	MVMR25		6	s	1	.03	.03	.03
3m9 m	R	3m9 .4w		1		s	1	.03	.03	.03
6m8 m	F	MR25.6m8	MVMR25	2		s	1	.03	.03	.03
220k m	F	MR25.220k	MVMR25	a		s	1	.03	.03	.03
47k m	F	MR25.47k	MVMR25	n		s	1	.03	.03	.03
47r v	F	104.223	VTM.kh	a		s	1	.15	.14	.14
22r v	F	104.221	VTM.kh	n		s	1	.15	.14	.14
680 v	F	104.230	VTM.kh		1	s	1	.15	.14	.14
CAPACITORS										
1u 35v t.r	F	100.900	Du.SH		2	s	3	.12	.09	.27
10u 10v t.r	F	100.869	Du.SH		3,6	s	2	.19	.13	.26
1n e	F	146.072	Du.mmp			s	3	.07	.06	.18
1n e	F	146.072	Du.mmp	a		s	1	.07	.06	.06
1n p	F	143.697	W.FKP2	n	4	s	1	.17	.11	.11
470u 16v r	B		Du.ceb			s	2	.14	.11	.22
470u 35v a	F	143.662	Du.cea			s	1	.23	.18	.18
22n e	F	146.077	Du.mmp			s	4	.08	.06	.24
22n e	F	146.077	Du.mmp	1		s	1	.08	.06	.06
.22u t	F	100.896	Du.sh			s	1	.11	.08	.08
4n7 e	F	146.075	Du.mmp	2		s	1	.07	.05	.05
zen 27v	F	Z15L390	I(IR)			s	1	.61	.46	.46
4n7 disc	F	630.02472				s	1	.08	.04	.04
ACTIVE										
LM317T	R	LM317T	N		5	s	1	.90	.65	.65
RC4558	R	4558	RA			s	1	.40	.23	.23
LM324N	R	324	N			s	1	.30	.30	.30
CD4046BE	R	4046	N			s	1	.40	.40	.40
3v9 zen .4w	R	3v9z.400	BZY888			s	1	.06	.03	.03
5v6 zen .4w	R	5v6z.400	BZY88			s	2	.06	.03	.06
Led red 5mm	R	5mm R		a/n		s	1	.07	.04	.04
Led yell5mm	R	5mm Y		a/n		s	1	.08	.05	.05
clip	R	5mmclip		a/n		s	2	.03	.01	.02
Led/case R	M	QY.48c		n	7	s	1	.38	.30	.30

Led/case G	M	QY.49D		n	7	s	1	.38	.30	.30
IN914	F	IN914	U			s	1	.02	.02	.02

H WARE

H.sink lge	F	170.073	Rp220			s	1	.30	.15	.15
H.sink smll	F	170.070	Rp220			s	1	.25	.20	.20
wshr. 220	F	170.649(10)				s	1	.07	.06	.06
IC skt 8	R	IC8				s	1	.06	.04	.04
IC skt 14	R	IC14				s	1	.08	.06	.06
IC skt 16	R	IC16				s	1	.09	.06	.06
Pins. s.s	R	0.1ss (50)	Vero				19			.05
Clip adh	S	543923(50)		n			4	.02	.02	.08
Cable scr	F	140.458(100)		n				.09	.09	.09
Cable 4w	F	140.467(50)		n				.14	.14	.14
Cable tie	F	TY.523M	Tyrap			s	4	.04	.03	.12
nut m2.5	F	101.331(100)				s	1			.01
boltm2.5/6	F	101.443(100)				s	1			.01
PCB	C	ALC104	C		10	1	1	2.59	1.50	1.50
solder	F	D622(178m)	M			s	1m	.04	.02	.02
link wire	F	TCW16(.5kg)				s	7cm	.12	.10	.10
foam		4,3,1		n		7		.15	.12	.12

BOARD TWO

CD4018BE	R	4018	Si	2		s	4	.45	.30	1.20
100u 16v r	F	100.814	Du.ceb	2		s	1	.07	.07	.07
680r .5w	F	MR25.680	UMR25	2		s	1	.03	.03	.03
12v zen .5w	R	12vz.400	BZY88	2		s	1	.06	.03	.03
IN914	F	IN914		2		s	1	.03		.02
47k r	F	MR25.47k	UMR25	2		s	1	.03	.03	.03
1n disc	F	629.06102	U.629K	2		s	1	.05	.03	.03
PCB	CW	CW1		2		8	1	1.00	.70	.70
solder	F	D622(178m)	M	2		s	.3m	.02	.01	.01
link wire	F	TCW16(.5kg)		2		s	7cm	.01	.01	.01
foam		3*1.5*1		2n		7		.10	.08	.08

CASE

Plug	A	3109	A	n		42	1	3.89	2.70	2.70
skt	A	3111	A	n		42	1	3.56	2.35	2.35
stud 2"	F	101.244(12")		n		s	8	.05	.03	.24
stud 2"	F	101.244(12")		n2		s	4	.05	.03	.12
holder		ALC205?7		n		s	1			
holder		ALC205/7		2n		s	1			
locknut 4ba	F	101.185(100)		n		s	12			.03
locknut 4ba	F	101.185(100)		2n		s	8			.02
gasket	N	7/16,1/8	N	n		21	3'	.08	.06	.06
gasket	B	3mm,1/8	B	n		s	1'	.03	.02	.02
p.clip	F	146.173	C15	n		s	1	.02	.01	.01
sleeve	F	H15	H	n		s	.1m	.08	.04	.04
shrnk.sleev	F	143.722		n		s	.1m	.06	.04	.04
tyrap	F	TY523m	T	n		s	4	.04	.03	.12
bolt m5/12ck	F	101.305/12(100)		n		s	20	.01	.005	.10
bolt m5/12	F	101.341/12(100)		n		s	4	.01		.02
bolt m5/40	F	101. /40(100)		n		s	4	.04	.03	.12
bolt m12/30	O			n		s	4	.03	.02	.08
bolt m5/40csk	F	101.491/40(100)		n		s	4	.04	.03	.12

bolt m6/20	F	101.627/20(100)		n		s	4	.02	.01	.04
bolt m10/20	O			n		s	4	.02	.02	.08
nut m10	0			n		s	4	.02	.01	.04
lokwash m10	O			n		s	4	.01		.02
window	T	AL205/4		n	12	7	1	3.50	1.35	1.35
lens	E	AL205/5		n		1	1	.50	.20	.20
casting;body	H	AL205/1a		n		6	1	28.5	23.0	23.0
casting;rear	H	AL205/1b		n	3	6	1	8.65	5.50	5.50
unit side	L	AL205/2		n		2	2	6.45	4.30	8.60
unit bracket	L	AL205/3 or 3b		n	11	2	2	2.20	1.60	3.20
oscill X	P	GDHM2/587	P	n	8	56	1	50.0	27.0	27.0

<u>:ALTERNATIVES</u>

1.	680r	F	MR25.680	MVR25			2	.03	.03	.06
2.	1u 35v r	F	143.236			s	3	.06	.05	.15
3.	10u35v r	F	143.242			s	2	.07	.06	.12
4.	1n 10%	F	146.072			s	1	.07	.06	.10
5.	7808	M	Remove 240r, 190r,10k			s	1	.47	.35	.35
7.	5mm leds and clip					s	2	.07	.04	.08
8.	osc.x	IMI	5300-92	IMI	n	12	1	42.0	26.0	26.0
	MA86501-09			MA	n	10	1	43.0	25.0	25.0
9.	Alternative		FE44		n	s	1	.40	.30	.30
			FE43		n	s	1	.70	.59	.59
			RPC2 12P35		n	s	1	.74	.56	.56
			RPC212 RB3P		n	s	1	.43	.32	.32
			NC 3MP and		n	s	1	.95	.69	.69
			NC 3FC		n	s	1	1.47	1.06	1.06
10.	PCB	alternative suppliers:		RTK Eng		28	1	4.80	3.00	3.0
				EAP		4		4.80	3.00	3.00
				Beter		4		7.00	5.00	5.00
11.	bracket. For new mount holes refer to DRG AL205/2/b									
12	window.	alternative supp:		Polyform		24		4.50	3.00	3.00
				Sandalloy		4		3.50	1.35	1.35

INDEX OF TAPE RECORDINGS. APPENDIX 3.1

M indicates a mono recording. All others are stereo. (two channel)

TAPE	DATE	NO. OF RECORDINGS	SUBJECT AND CONDITIONS
T1S1	15.8.83	31M	Aro unit roof-mounted on smooth tarmac: tilt angles from 25 to 55 deg. Readings taken at 10, 15, 20, 25 and 30mph. Wet.
T1S2	15.8.83	40M	Continuation of tape T1S1: rough cobbles tarmac and wet road.
1A	16.9.83	35	Pool road, dry. Tilt angles from 25 to 55 deg, for each of 10, 15, 20, 25, 30 mph. Aro unit, roof-mounted.
TRA	26.9.83	14	Aro unit, roof-mounted, on rough tarmac, cobbles and unmade track for 35, 40, 45 and 50 deg tilt. Dry, dusty ground; and very wet.
R2	27.9.83	11	Aro unit, 20mph. A range of surfaces (20 different tarmac roads, 2 concrete, 2 cobbled). Weather dry.
R1	27.9.83	26	Aro unit, 20mph. Comparison of old circuit and PLL addition. Tests on potholed road, cobbles and tarmac. Weather dry.
2AB	23.9.83	23	Butterwell site: Aro unit. Speeds of 10 to 25mph, and sample site runs. Laden and unladen. Dry weather.
RdB	6.10.83	12	Aro unit, 20mph on a range of surfaces: tarmac (wet, dry), unmade road, concrete track. Very dry, dusty.
IN1	10.11.83	18	Aro unit: output at preamp, schmitt and PLL stages for various tuning fork targets, head mounts and applied vibration amplitudes. Head struck with sharp and blunt objects.
2A1	18.11.83	8	Aro unit output for a tuning fork target. System mounted on a vibrator. PLL, preamp and schmitt outputs recorded.
TRW1A	19.12.83	12	TRW unit, roof-mounted, on a range of surfaces (4 tarmac, rough & smooth, and unmade road) at 10, 15, 20 mph in damp, wet and very wet conditions.

ARO	19.12.83	6	Aro unit, roof-mounted on tarmac road, snow-covered ground (newly fallen and slushy)
TR1	21.12.83	7	Aro unit on trailer, 15 & 20 mph. Rough & smooth tarmac. Very wet & muddy.
XP1/1	29.2.84	6	Horn prototype on trailer: no AV mounts. Dry & wet surfaces, rough and smooth tar-mac & unmade road. 10, 15, 20 mph.
XP1/2	2.3.84	14	Horn proto, roof-mount: with & without AV mounts. Smooth & rough tarmac, with & without PLL. Dry & wet surfaces.
SUSP/RD	5.3.84	3	Proto horn on trailer: extended tarmac runs: no AV, light and heavy AV. Dry.
XP2/1	16.3.84	8	Horn proto (casting) on trailer: with and without AV, smooth & rough tarmac, rough track. Dry.
PSU	21.3.84	4	Voltage/frequency converter recording of truck PSU. Typical Butterwell site runs.
TRW	21.3.84	8	TRW unit (modified), Butterwell. 15mph & typical runs, laden & unladen.
BWH1/1	21.3.84	5	Butterwell, proto horn with & without AV, Laden & unladen, Muddy. 15, 20mph.
BWH1/2	21.3.84	5	Butterwell, Aro unit with AV. Laden and unladen. 20mph and tyipical site runs.
XP2/1	11.6.84	8	Production proto on trailer: tarmac (smooth & fairly rough). Dry surface.
XP2/2	11.6.84	5	Prodn proto: intrinsic noise and striking with heavy object (with & without tuning fork as target)
XP3	14.6.84	8	Aro and horn production proto: roof & trailer mounted: smooth and potholed tarmac for PLL, schmitt and preamp outputs. Dry.
XP4	15.6.84	8	Aro and horn production proto: roof & trailer-mounted. Smooth and rough tarmac, wet surface.
PP1	17.7.84	19	Production prototype at Butterwell. Per, schmitt and PLL outputs with variable gain stage and PLL response time. Very dry.

Total number of recordings: 617

Total number of tapes: 26

MAIN DRAWINGS INDEX. minor variants are not included (eg SS 2 - 5 and 8 - 10.) AL and ALC series are production drawings.

APPENDIX 3.2

DRAWING	DATE	TITLE
D0a	9.8.82	S.S circuit (discrete PSU, MF10 filter)
D0b	24.8.82	ditto, including PCB 2 (f/v etc)
D0c		ditto, including AGC
D1	4.10.82	S.S autocancel circuit and connections
D2	30.10.82	S.S circuit (3 stage low, 2 stage high filter)
D3a	22.11.82	S.S with production filter
D3b	22.11.82	PCB 2 (f/v, oscillator, PSU)
D4a	13.1.83	S.S + test pins (preamp and oscillator)
D4b		PSU, f/v and test pins) (used with D4a)
D4c		Filtes (used with D4a)
RC1	11.3.83	Ultrasonic TX, RX, interface
RC2	24.3.83	infrared TX, RX and interfavce
D5a	21.4.83	PLL, f/v, logic for simulator (used with D5b)
D5b	21.4.83	Simulator logic board
D5c	21.4.83	(as D5b with LED indicators and revised sockets)
D5d	4.5.83	S.S preproduction (4 low, 2 high filters)
DR1	12.5.83	S.S with validation logic
DR2	2.9.83	S.S no. 6
Dr3	12.9.83	S.S no. 7
D6a	28.9.83	S.S no. 11 (plug-in boards)
D6b	28.9.83	S.S PCB2 (used with D6a)
D7	4.10.83	S.S no. 12 (inc PCB 2)
D8a	17.10.83	S.S board 2 (production PCB V1)
D8b	20.10.83	S.S board 1 (production PCB V2)
D9	24.10.83	S.S mark 2 board 1 PCB V3
ALC.104.1	26.10.83	S.S type 2 board 1 PCB and component list
ALC.104.2	26.10.83	S.S type 2 board outline
ALO.203	12.12.83	S.S X band horn
ALC.X1.1	12.1.84	Prototype horn
ALC.X1.2	24.1.84	prototype case (part 1)
ALC.X1.3	24.1.84	prototype case (part 2)
AL.205.1	9.3.84	S.S production unit: horn and body casting
AL.205.2	13.3.84	S.S production unit: end and sides
AL.205.3a	9.4.84	S.S production unit: vehicle mount (existing)
AL.205.3b		" " " " (" + tilt)
AL.205.3c		" " " " (new hole)
AL.205.3d		" " " " (" + tilt)
AL.205.4	20.4.84	microwave window
AL.205.5	24.4.84	microwave lens
AL.205.6	17.5.84	wiring loom
AL.205.7	17.5.84	foam/bakelite
AL105	11.4.84	Frequency translation module: 15/16 PCB
D10		FTM (fully configurable)
D11		FTM including f/v etc (Production PCB 2)

PROJECT CHRONOLOGY

APPENDIX 3.3

Only events relating specifically to the progress of the project are covered.

Abbreviations:

M: meeting	SS speed sensor	BW beamwidth
FV freq/volt	P production	w week
D: design	proto:prototype	Bwell: Buttewell
RD: redesign	veh: vehicle/vehicular	
SL: Mr Love	GJ: MrJones	DD: MrDavey
DH Dr Hickson	KW Dr Waterhouse	KF Prof Foster
AJC: Dr Cochran		

2.11.81	M:DH,SL re: 'Veh Information Management' as proj title
18.2.82	Proj redef: 'Low cost signal discriminators'
9.3.82	Visit Bowburn
24.2.82	M:SL re: case study on doppler radar
16.4.82	M:SL re: SS history & development
18.5.82	M:GJ,KW,DH re:proj mech. aspects. M:GJ,KF,CW re: facilities
20.5.82	Proj title change to SS specifically
22.6.82	M:GJ,KW,DH,SL re SS
29.6.82	M:DD re SS failings
5.7.82	D road test rig
14.7.82	M:SL re rolling road, check out present SS PCB. NEL report out
16.7.82	SS problems: suspect BW
21.7.82	M:SL re SS (F/V, clipping, noise,BW)
26.7.82	RD lo and hi filters
2.8.82	RD SS cct
9.8.82	Build modular SS unit. Try AGC, limiter etc
18.8.82	Unit OK. Examine 'scope O/P on road. RD filters
23.8.82	Modify SS cct to 'production compatible'
25.8.82	Try switched filter(MF10),low noise preamp,DC atten,autocancel
1.9.82	Measure road return. RD hi filter
8.9.82	RD head earthing. Write computer program for filters
23.9.82	D switched filters (S&K+ CMOS switch). Try AF151,MF10
24.9.82	Extended road tests; concrete,tarmac,cobbles,potholes etc
28.9.82	M:SL re beacon, zonal speed
4.10.82	D on/off beacon
29.10.82	Build final p.proto beacon; IR and Usonic.
30.10.82	M:SL,DD re Aro mount failure, problems with wet/dry surfaces
5.11.82	Modify beacon. Check Aro service history
7.11.82	Visit Bwell. Measure performance of Aro units
9.11.82	D temperature sensor, heater and cooler
17.11.82	D SS for plug-in test skt, RD filters (cheby)
23.11.82	M:SL re SS unit including F/V and alarm osc
25.11.82	Assess TRW unit, bench and car
2.12.82	SS proto works OK
3.12.82	Build test rig (electronic tuning fork)
13.12.82	M:DD re Aro beacon and elect tuning fork
14.12.83	Look at Aro history, analyse
16.12.82	M:SL re Aro v TRW v my cct; circuit 'proving tests'
21.12.82	Cct tests using 2 osc, osc + gaps etc
22.12.82	M:SL,DD re SS potting, wiring, mounts,TRW
4.1.83	Buy IR unit. Try. Works OK
6.1.83	Compare preamp IC types. Build 3 vero ccts

12.1.83	M:GJ re offer of data recorder
18.1.83	Examine theory of spectrum effects.M:Sl re piezo v intermod
20.1.83	BWell test. Fail. OK in lab. Osc fault
21.1.83	M:Aro re vibratin & head failure
22.1.83	RD preamp (distributed).
4.2.83	Hire power meter. Examine Aro beamwidth
15.2.83	Try lens on Aro to reduce elev angle
18.2.83	Disect TRW unit
22.2.83	COmpare Aro and Aro+lens on car test
23.2.83	Decide on PLL in cct.
24.2.83	M:DD re PLL and failsafe measures
25.2.83	Ponder validation systems: triple delay,CFAR,maj vote, window
27.2.83	Decide and design val logic window
1.3.83	M:SL,DD re PLL pro and con. Build CMOS PLL
3.3.83	RD PLL up/down response times
7.3.83	UV recorder obtained
8.3.83	Build 'inline' PLL cct. Fit to road trial. Adj Response times
11.3.83	build val logic
17.3.83	test val logic in car
18.3.83	M:GJ re aro mounts,NEL report, vehicle osc
22.3.83	RD val logic
27.3.83	Try PLL and Val logic on potholed terrain. Compare with theory
6.4.83	Examine tip-edge detect. RD cct
11.4.83	Make groundspeed readings/plots/spectra
12.4.83	D simulator board incl val logic
14.4.83	Look at tip edge horns; compare BW with theory. Examine theory
21.4.83	PLL inline at BWell. OK
29.4.83	RD SS cct for simplicity
4.5.83	Further SS mods
10.5.83	M:SL,GJ,AJC re ground return study, terrain categorisation
13.5.83	Build PCB incl PLL. Test on road
17.5.83	Build hygrometer. Design terrain assessment sched. Try. Mod.
13.7.83	Build Interface Box
18.7.83	Try Interface Box. Calibrate.
18.8.83	M:Sl,DD re data recording (mono),truck bounce,BW,PLL,meter
26.8.83	Stereo recorder and analogue meter bought. Readings taken
31.8.83	Build 6 PCBs; fit on site. RD cct
8.9.83	Enquire re PCB manf cost. D PCB board 2
15.9.83	Access to spectrum analyser. Get site results
19.9.83	Compare theory alarm v measured v measured with PLL
20.9.83	BWell: data racordings as 19.9.83
23.9.83	BWell further data (wet/dry terrain)
29.9.83	D SS horn.
6.10.83	Try IR switch. OK. No aro units for SS.
11.10.83	M:SL re new aro mounts, new horn, on-site speed select
12.10.83	D configurable SS (PCB2,3). Build and test
14.10.83	BWell. Problems, traced to control box. D SS horn
20.10.83	M:DD re PCB design: layout,components,cable termination
4.11.83	No SS boards or mounts left. Order PCBs
10.11.83	Vibration and shock tests. Examine Aro unit in detail
29.11.83	M:SL re trailer, TRW, casting quotes
1.12.83	Compare Aro with Plessey, MA and IMA
2.12.83	New TRW arrived. Try
20.12.83	Trailer built and tested with TRW, Aro.
21.12.83	Horn prpto made (card/foil). Test on car
4.1.84	PCBs arrive

6.1.84	Examine front face materials
20.1.84	M:SL,DD re TRW, new PCB, Test spec and schedule, lack of heads
21.1.84	Examine propietary horns
24.1.84	Final horn drawing. Test schedule written
25.1.84	New PCB tried on-site.OK
27.1.84	Component changes on PCB: reduce cost
30.1.84	Site report: alarms at 20mph. D PCB 2 (15/16 div)
1.2.84	Build 4 proto PCB 2
2.2.84	M:AJC re SS progress
7.2.84	3 horns ordered
10.2.84	D, build 24V line monitor
17.2.84	Proto horn unit case built. Mwave window materials assessed
29.2.84	PCB 2 and horns arrive. Measure BW. Test on road
1.3.84	Build lens. D Horn casting. RD horn case dimensions
5.3.84	Try proto horn with/without suspension. Casting too dear
8.3.84	RD casting
21.3.84	Try proto horn at BWell with/no suspension
23.3.84	Value engineer casting design
26.3.84	Documents (SAE,FCC,MS,BS) arrive. Assess
29.3.84	Compare purchase & run cost of horn v Aro SS.
4.4.84	Order casting
11.4.84	Further PCB 1 ordered
18.4.84	Horn brackets designed. Sample Prodn windows ordered
19.4.84	Sides of case ordered
2.5.84	Sides arrive. Wrong. Return
11.5.84	Final window selection. Order. Select gasket etc
17.5.84	Windows arrive.
7.6.84	Castings arrive. Build one unit
11.6.84	Lab and road test unit
14.6.84	Road and BWell test unit. Fault. Build other units
22.6.84	RD wiring.
25.6.84	RD bracket, plug
29.6.84	RD bracket (tilting). Site test: OK
5.7.84	Site problem: not SS unit. Make recordings
9.7.84	Rebuild all horn units.
17.7.84	Commence full field trials at Butterwell
28.9.84	Completion of OEL sponsorship
4.10.84	Build next ten PCBs

APPENDIX 3.13

OEL DEVELOPMENT PRIORITIES. As listed in Dec 1982 (OEL 82)

1. Development of roadspeed
2. Development of beacon system for zonal roadspeed alteration
3. Review of engine RPM control (interface box requirements)
4. Review suppression systems and specific truck requirements
5. Preparation of up-to-date circuit diagrams, user and driver manuals; and a comprehensive library of drawings for all fittings and accessories for all truck types
6. Evaluation of Dlalton (JMS) scanners
7. Development of test equipment for production and fitting

NOTES: only those tasks pertinent to the speed sensor are listed.
the list is not in order of importance.

MANUFACTURER	PAYLOAD	TEL	TELEX
Vlvo BM	25	0787 237751	98309
Aveling Barford	23-45	0476 65551	
Terex UK	15-318	0698 732121	77141
Blackwood Hodge		0604 61111	31476
Euclid (INC)	16-154	Ohio 441177	
Euclid (UK)		07072 62333	
Euclid (trucks)		092681 3096	311362
Caterpillar	32-77	07535 68121	
Komatsu	18-120	0527 27711	339657
Kockum (MD)	16-40	0628 239944	
Kockum (UK)		0742 26311	54119
Wabco (INT)	32-218	0101309 672700	
Wabco (UK)		03272 5621	311436
International	33-45	01572 7434	8813731
DJB		0783 863333	53361
Belaz (UMO)	13-43	4626 714111	825247
Heathfield	18-30	07072 62333	22796
Haulamatic	17-20	03043 5012	377356
Caledonian		0236 20111	
Bowmaker		05435 2551	338523
Deutz	14-22	06065 4411	669022
Man		01995 3131	934140
Frisch	22-77	0783 44521	261718
Foden	15-32	09367 3244	36553

DUMP TRUCK MANUFACTURERS. Payload is in units of 1000kg.

CONTRACTOR	CONTACT	TEL
Budge	AF Budge	0777 703781
Cambro	H Camm	0246 862679
Costain	G Henderson	01928 4979
Crouch	Mr Finch	0733 222341
Dowse	N Allinson	0704 862664
French	L Payne	0767 40111
Merriman	Mr Hughes	0533 696363
Taylor Woodrow	R Vince	01578 2366
Miller Mining	R Taylor	0924 407811
Rorke	T Nolan	0226 5541
Shephard & Hill	P Harris	0895 36471
Mcerlain	D Mcerlain	0629 4295
Northern Strip	Mr Mcinnes	0742 445481
Simms	B Burke	0602 412345
Gleeson	P Moran	01 648 6271
Currall Lewis	G Schreider	0438 3477
Douglas	Mr McCaron	021 356 6021
Lemand	M Udake	062 983 2501
Loumont	Mr Walker	0632 446511
Roberts McGregor	T Cluer	061 790 0411
Fairclough	A Angus	0532 645081
Murphy	Mr Gillette	0533 696111
Wimpey	J Pillington	01 748 2000

DUMP TRUCK CONTRACTORS IN BRITAIN.

APPENDIX 3.5

COMPONENT SELECTION: AN EXAMPLE.

capacitor type	P	P	P	C	M	Pc	Pe	Pp	
tolerance	5	2.5	1	10	1	10	10	5	%
temp coeff	n	n		p	n	p	p		
cost	8	29	29	39	20	12	16	17	p
range	1-7	2-6	2-6	5-7	1-6	5-8	6-8	4-6	

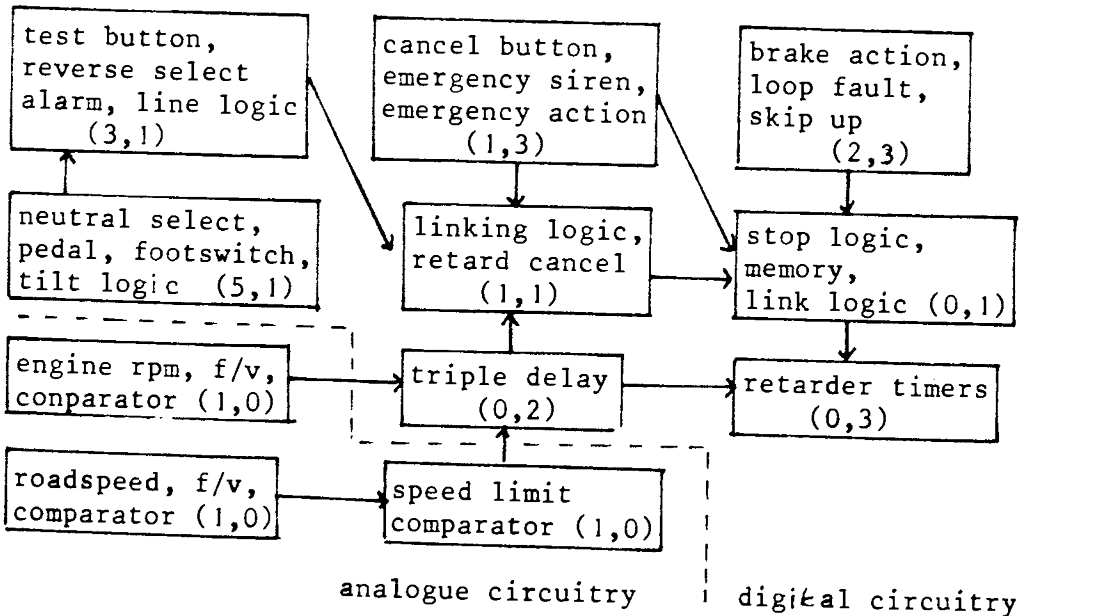
Key: range: 1=2.7pf; 2=10pf; 3=22pf; 4=200pf; 5=1nf; 6=10nf 7=0.1uf; 8=1uf.
type : P=polystyrene; C=ceramic; M=mica; Pc=polycarbonate; Pe=polyester; Pp=polypropylene

resistor type	Mo	Mf	Tg	Cf	
temp coeff	250	100	100	500	ppm/deg c
noise	.1	.4	.1	1	uv/v
range/series	10-1M W24	10-1M E24	1-1M E12	10-1M E12	
cost	3.5	3.3	4.3	1.8	p

Key: type: Mo=metal oxide; Mf=metal film; Tg= thick glaze; Cf=carbon film

APPENDIX 3.6B

ALBERT CONTROL BOX SCHEMATIC

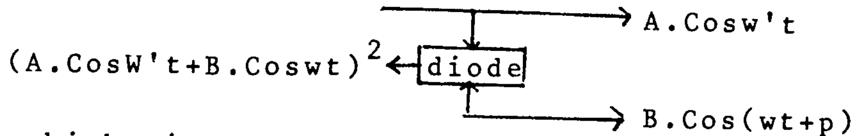


(x,y): x is no. of I/P types, y is no. of O/P types. Total no. of I/P and O/P connections is over 130, with 215 connection pins.

APPENDIX 3.7

A. PRODUCTION OF DOPPLER FREQUENCIES BY MICROWAVE RADAR.

For a CW radar system, assume a transmission of A.Coswt and return of B.Cos(wt+p). Using a diode as a square-law device , ie



which gives

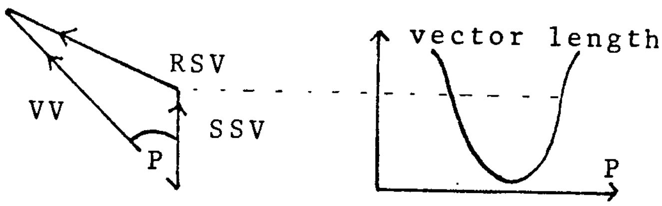
$$A^2 Cos^2 w't + B^2 Cos^2 Wt + 2AB.Cosw't.Coswt$$

The last term equals

$$AB(Cos(w'-w)t+Cos(w'+w)t)$$

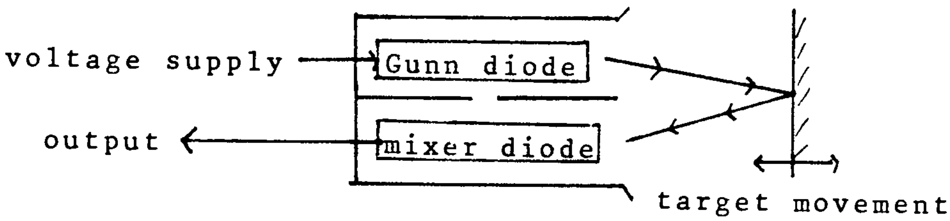
Now Wd=w'-w, so the mixer output is

AB.CosWd.t and is identical for phasor B rotating clockwise or anticlockwise. If the transmitted signal at source is considered as a phase-reference, the return signal vector is added thus:



where:
RSV=return signal
SSV=source signal
VV=true velocity

Assuming that RSV has a phase displacement P relative to SSV, then as the target moves, RSV rotates once per wavelength change of the round-trip distance, producing VV. For steady state target movement, VV is a sinusoidal function.
To achieve vector summation, a percentage of the local oscillator power is leaked from the Gunn diode to the mixer diode. The output is thus dependent upon the frequency and phase differences of the source and reflected waves



Further details can be found in Berger (1957) and Merriman (1974). A more lengthy treatment is provided by Gill (1965). Mathematical treatments can be found in Levanon (1980), Gupta (1977) and Kelly (1961)

B. DOPPLER MICROWAVE CONFIGURATIONS

There exist five main configurations for non-pulsed, non frequency modulated radars. This type of radar bears a resemblance to the superheterodyne principle, using a zero intermediate frequency (homodyne) with the local oscillator being replaced by a leakage signal from the transmitter. The configurations are:

1. Monostatic: single unit using a single TX frequency
2. Bistatic: two units in unison, physically separated with beams pointing to a common point

3. Janus: two units working in unison with beams pointing forwards and backwards
4. Diplex: one unit using two (for triplex, three etc) TX frequencies in alternation
5. Binaural: three units, seperated physically, one central transmitter and two outer receivers.

For velocity measurement, monostatic or janus configurations are usually used, the former where cost is at a premium, the latter where the effect of platform tilt must be eliminated. The radar can have numerous physical configurations, but low cost units are usually in one of three formats:

1. Single cavity: TX and RX in the same cavity
2. DIL cavity: TX and RX in separate cavities, TX located behind the RX cavity
3. Dual cavity: TX and RX in separate cavities, alongside.

For the purposed of this project, these three types are interchangeable, but the dual cavity type is difficult to match to a horn throat. The single cavity type is usually more expensive, but has the possible advantage of separate tuning screws for the Gunn and mixer diodes.

APPENDIX 3.9 B

ERROR IN VELOCITY MEASUREMENT DUE TO A VARIATION IN TRANSMISSION FREQUENCY.

Empirically, a change in TX frequency of df % produces an error in the measurement of velocity of dVm %.

Assume the standard (non-relativistic) doppler frequency formula:

$$f = \frac{2.V}{\lambda} \cos\theta$$

let θ = tilt angle = 90
f= doppler frequency = K.Vm,
where Vm = measured velocity

$$\text{so, } Vm \pm dVm = \frac{2.V}{K.c}(f \pm df)$$

$$dVm = \frac{2.V.df}{K.c} \quad \ldots\ldots\ldots \text{ i}$$

now as $K = \frac{2.f.V}{c.Vm}$ and V = Vm for a correctly working unit

then $K = 2.f/c = 2/\lambda$ ii

substitute ii into i:

$dVm = df.V/f$ so, for v = Vm, dVm/Vm = df/f .

Thus the error in velocity measurement is the product of vehicular speed and the fractional change in transmission frequency.

RADAR TYPE		S	A	E	P	RS	P	R	D
monostatic:	continuous wave	5	1	0	5		5	4	5
	frequency modulated	4	1	0	4				
	pulse	3	5	3	4				
bistatic	continuous wave	5	1	3	4	5	0	3	5
	frequency modulated	4	1	3	3				5
	pulse	3	4	4	3				
janus	continuous wave	4	5	4	2				
phase eval.	continuous wave	5	1	3	1				
	frequency modulated	1	1	3	0				
	pulse	3	4	4	1				
freq mod + circulator						4		4	2
+ serial coupler						3		4	2

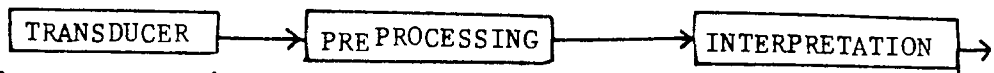
Derived from Dull (1978) and Grimes (1973)

Key: S = ease of obtaining velocity data
A = accuracy of measurement of velocity
E = effect of environment, terrain etc on unit
P = cost
RS = receiver sensitivity
R = reliability
D = design risk, overall

Where: 0 is poor and 5 is excellent.

appendix 3.8B

ASSESSMENT OF RADAR CONFIGURATIONS FOR VELOCITY MEASUREMENT



Radar: monostatic
bistatic
Janus
CW
FMCW
pulse
Ultrasonics
Light/laser
Camera
Magnetic transducer
Shaft encoder

Filter: analogue
digital
tracking
bandwidth
slope
Gain: noise
overload
AGC

active/passive
software:
(convolution,
correlation,
FFT
trend)
hardware: analogue
digital

Generalised block-diagram of a Transducer system. Such a diagram applies to both precision military and simple commercial units.

APPENDIX 3.8A

APPENDIX 3.9A: TUNING FORK CALIBRATION ACCURACY

This appendix assesses the accuracy and practicality of calibrating Doppler velocity meters by the use of tuning forks of known frequencies.
The easist method of testing a velocity meter in-situ or in the laboratory is by the utilisation of a target vibrating at a measurably accurate and repeatable frequency. But does a tuning fork provide such a target? Whilst a simple fork test is certainly adequate for a working/not working type of test, it is inadequate, for instance, for accurate frequency testing and calibration. The speed sensor must alarm at approximately one percent accuracy (at least, in laboratory tests).
To test a unit with a nominal alarm frequency of 470Hz, the usual procedure would be to use two forks, one of 465Hz and one of 475Hz, to indicate 'under' and 'over' alarm states respectively.
The National Bureau of Standards conducted controlled tests on tuning forks, and assessed variations of temperature, moisture and physical damage in order to ascertain the frequency stability of such forks (Allen,1976). No notable variation was found. Courts in the USA also usually rule that tuning forks retain their frequency of oscillation accurately enough for the police to calibrate thier radar velocity measurement equiment (Case,1966). Ishii (1965) confirms this view by reporting that most police use tuning forks for test and calibration, and that manufacturers of these units recommend this procedure.
The use of forks is not as straightforward as the above references would seem to suggest: the fork must present an amplitude of return that neither saturates (clips) the circuitry, nor nulls significantly. Thus the optimum fork-to-radar distance must be ascertained, and adhered-to for all tests. Fisher (1980) stresses that tuning forks present an amplitude-modulated (as opposed to a true frequency derived) calibration signal. It is important that the 'narrow' edge of the fork faces the radar, thus providing a true relative movement.
The writer has demonstrated that, bearing in mind the above points, a radar system sees a tuning fork of a given frequency as accurately as if the transceiver were replaced by an electrically matched oscillator of the same frequency.
Thus, if several precautions are observed, the technique of utilising tuning forks provides a very cheap, simple and accurate method of testing and calibrating Doppler velocity measuring radar.

For the ALBERT sensor system, the following system should be adopted:

UNIT	FORK FREQUENCY (Hz)	REQUIRED RESULT: alarm ?
ARO standard unit	440	no
	490	yes
Horn standard unit	440	no
	490	no
	520	yes
ARO unit with AL104 PCB	As for Horn standard unit	
Aro unit with retuned control board freq	*1	*2

NOTES: *1: add 23Hz for each mph increase in alarm speed
*2: add 20Hz: alarm required. Subtract 20Hz: no alarm required.

APPENDIX 3.9A:

MICROWAVE TRANSCEIVER SELECTION CRITERION: FREQUENCY STABILITY.

The microwave transceiver selection criterion must include long and short-term frequency stability. Hence the effect of each stability type on the accuracy of speed sensor measurement will now be briefly reviewed.

Brady (1959) investigated the effect of short-term fluctuations, and found them significant: this source of error is commonly produced in the USA courts as defence evidence (Carosell, 1964). However, courts now generally accept that a 'typical' gunn diode transceiver is accurate enough for police radar speedometer evidence (usually implying a consistency of reading of 1% or less) (Greneker 1980 refs 1 to 9), although these cases do not refer to the stability of frequency with temperature and other such effects. No literature dealing with the effect of temperature and humidity on stability can be traced, although the influence on long-term parameters is examined in this thesis under the section dealing with the 'off-highway environment'.

Few papers deal specifically with continuous-wave doppler systems: Kelley (1961) for instance, in a well-known paper derives velocity error equations for pulsed radar, and deals mainly with signal-to-noise effects. Craig et al (1962) examines errors due to such effects in a superficial manner for CW systems, and Mayer (1964) and Feurstein (1964) discuss many cases of velocity error but pay little heed to transmission frequency deviations. Cowley (1971) and Fisher (1980) both deal with the result of AM noise, and state this as the limiting factor in short-term transmitter frequency stablility and of receiver sensitivity. Acker (1975) also finds AM noise a source of transmission frequency fluctuation, as is, to a lesser extent, FM noise.

Bushnell (1958) deals with longer-term frequency stability, and derives a proportionality between the received frequency variance and spectral density of the system noise. However, for the purposes of this project, only a generalised understanding of the effect of frequency fluctuations is needed. Ishii (1965) states that the fractional change in transmission frequency is directly proportional to the error in doppler velocity measurement. Although this relation may be empirically obvious, it is an important fact: the writer's derivation of this appears in app. 3.9B.

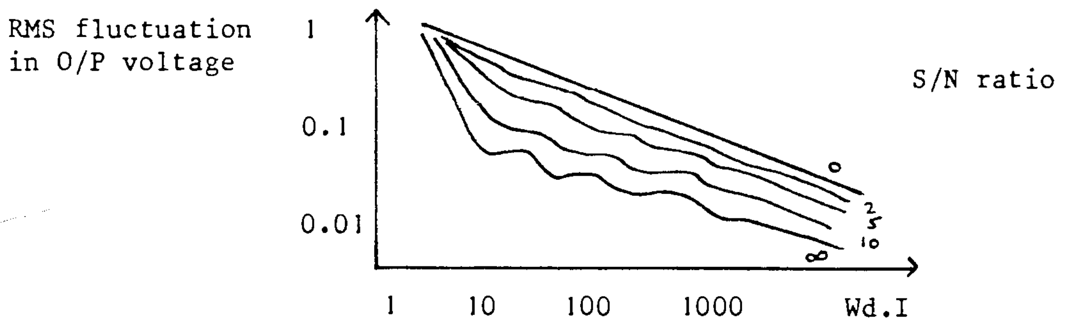
APPENDIX 3.10.

FREQUENCY TO VOLTAGE CONVERSION.

Adrian (1972) and Wilmhurst (1971) both state that:

$$e = \sqrt{\frac{Wd}{Wd^2 . I}}$$ where e: error measurement
I: integration time

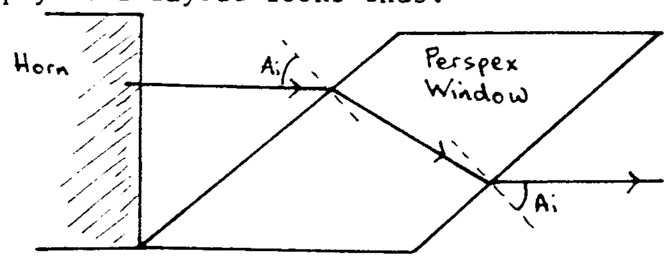
This expression assumes no input noise. For a full treatment, refer to Ehrman (1964) and Schultheiss (1954). Of use is a graph presented by Adrian (1972) who shows, for a filter of bandwidth 8.Wd centred at the doppler frequency:



APPENDIX 3.12

THE 'INVISIBLE' WINDOW.

As $n2/n1 = \tan Ai$ where n: refractive index
Ai: incidence angle,
(derived from Snell's law by removing the reflective component)
By placing a window at angle Ai, internal reflections are (at least in theory) cancelled.
A typical design would assume n1 = air = 1; n2 = perspex = 1.58, giving Ai = 58 degrees.
Hence the physical layout looks thus:



APPENDIX 3.11

USEFUL CONTACTS (ADMINISTRATIVE AND COMMERCIAL)

Pages removed due to Confidentiality reasons

APPENDIX 3.14.

PART A. RESUME OF FINDINGS OF THE ARO CIRCUITRY ASSESSMENT

1. The incoming signal is inadequately filtered; the premaplifier introduces significant noise; and the bandwidth and gain of this stage varies considerably between samples. A typical specification is 300uV sensitivity (for squarewave output) and a 4mV clip point; both measured at 500Hz.

2. The gain setting and lack of overload margin allows the input signal to clip, producing frequency multiplication at the schmitt trigger stage.

3. The low-cut filter uses low-tolerance components: the cutoff frequency and slope varies between samples (minimum and maximum measured values: centre frequency 300 and 550Hz, gain at 500Hz between 3 and 8dB, final slope between 3 and 6dB/8ve).

4. The power supply runs too warm, often resulting in component failure

5. The speed select circuitry uses zener diodes to set a reference voltage: the error introduced is too great, giving up to 15% deviation from the correct alarm frequency setting.

PART B: RESUME OF WORK PERFORMED IN ASSESSING POSSIBLE MODIFICATIONS TO THE ARO CIRCUITRY.

1. Alternative F/V circuits: the LM3214 was preferred due to the lower number of external components, ease of calibration, and the non-reset mode of operation.

2. High cut filters of 6, 12, 24dB/8ve at 600, 800 and 1000Hz, all Butterworth. The signal looked cleaner on an oscilloscope but no perceptible improvement in site performance. in-band noise still triggered the Schmitt erroneously.

3. The use of CMOS switches and resistors to optimise preamplifier gain in predefined steps. The result did not warrant the increased complexity.

4. The alteration of integration time of the F/V: reduction after an alarm to assist a 'cancel available' state, reverting back upon cancel. In some circumstances a small benefit, in others detrimental.

5. Power supply. 78 series IC types were found to be noisy. Discrete versions were fine but bulky (two pass transistors and one op-amp gave the best performance of 8+-0.1V from 12 to 36V with immeasurable noise). Split op-amp rail was given larger capacitors. Two regulators in series (LM and a transistor) gave good performance, but bulky. best compromise felt to the a single LM3 series with tantalum capacitors.

6. Changes in low-cut filter. Butteworth and Chebyshev (24, 30, 36, and 30, 45, 55 db/8ve respectively) at 400, 350, 300, 200, 150

Hz. components of 20, 10, 5, 2.5, 1% tried; gains of 1, 2 and 10 used. Chebyshev passband ripple adequate at 0.5dB, but introduced severe frequency multiplication if ovedriven at cutoff point.

7. Type of filter: op-amp (Sallen and Key), clock-driven (MF 10) and resistor tuning (AF150, 151) tried. The latter used DIL plug-in resistors. AF and MF types have adjustable gains. All types performed similarily. Op-amp type costs least.

8. Preamplifier IC selection: all major types assessed. Much improvement with low-noise types, eg NE5534, RC4558, LM382, or with TL70 series.

9. Circuit configuration: distributed gain stages of 2, 3, 4 and 6 stages. Good filter performance, but very noisy.

10. Compressor at input. Feedback diodes gave poor performance. DC attenuator (IC) worked in lab but badly on road trials due to amplification of intrinsic noise during signal nulls and on low amplitude return terrain. Increasing the integration time also increases the response time to valid input signal.

11. Auto/manual cancel option added, including TTL/CMOS converter

12. Gain and cutoff point of the preamplifier: providing an independent regulated supply. Gain/bandwidth a compromise.

13. Board earthing. Single central earth, high and low current returns, screened earths, resistive (high) earth. Earth plane PCB. Noise from other sources dominates all but hi/lo current earth layouts.

14. Temperature stabilisation for the discrete PSU, and overheating shutoff for fault conditions.

15. Component layout: minature preamplifier near microwave unit, screened PSU section, short leads, separation of i/p and o/p cables.

16. Zero-crossing detector. Reference level set by diodes, resistor divider, by average of signal level. Zener tolerances found to be too wide. Signal derived can give good results, but can be fooled.

17. Buffer stage before filter; gain stage before filter. Chebyshev damping improved, but still distorts on overload.

18. Parallel tuned filters (400, 430, 460, 490, 520Hz) and peak detect and tracking circuitry. Prone to error in complex signals. Would need complex preprocessing circuitry (software?).

19. Low noise, high tolerance resistors and capacitors in the preamplifier. Electrolytic, tantalum and polypropylene caps; metal oxide, metal film resistors tried. Best caps for PSU: tantalum.

20. Curent limit at supply input, series and shunt electronic; fuse. Bulky and unnecessary.