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SUMMARY

This Memorandum summarises the principles found relevant to the successful operation of OMEGA and VLF installations in aircraft. It includes a list of interference field strengths found in various RAE aircraft, the considerations to be taken into account in the choice of aerial type and site, installation problems and their relation to receiver design. An indication is given of the direction that receiver design might take to eliminate the need for skin-mapping.

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1 INTRODUCTION

A previous Memorandum[1] covered, in the main, the disturbances which affect OMEGA signals on their way to the receiving aerial. The story is now continued to cover problems encountered when installing OMEGA in RAE aircraft; these problems have led to a comprehensive survey of the factors involved. Most of the work described in this Memorandum is applicable to reception at VLF in general.

The greater part of this work is summarised in Table 1, which compares in a systematic way the signal and interference levels found at an aircraft skin. This is essential information for the design of receivers, and its implications are discussed. It was found in practice, and implied by these figures, that current receiver design is barely adequate for many aircraft and quite hopeless for some, particularly helicopters, but calculation suggests that other approaches should be quite successful. Most experience at RAE has been with Comet, BAC 1-11, and Wessex aircraft, and successful installations have been achieved in all three.

2 THE VLF FIELDS AT THE AIRCRAFT SKIN

2.1 General

The figures presented in Table 1 are gathered in part from measurements on RAE aircraft, and partly from reports of others' experiences where sufficient detail was presented to allow conversion to the absolute units used here. Note particularly the distinction drawn between electric and magnetic components of the field. Magnetic interference is often quoted in volt/metre, being calculated as though it were the magnetic component of an electromagnetic wave in free space. This is not the case at the surface of an aircraft, and the actual electric field associated with the interference source is considerably less than such a figure would suggest. In Table 1, all such figures have been re-expressed in tesla (= 10^4 gauss). Another distinction evident in Table 1 is between broad-band noise (in $\mu V\ m^{-1}\ Hz^{-\frac{1}{2}}$) and single-frequency noise (in $\mu V\ m^{-1}$). The former figures have been reduced to the units used here from the various idiosyncratic units of the various sources (*eg* dB above 1 pT in 50 Hz) by dividing by the square root of the bandwidth. When made comparable in this way, the agreement of the information from various sources is quite good.

There is some difficulty in deciding on the definition of the E-field figures given in Table 1. As section 3 shows, the effect of the aircraft is to modify considerably any electric field in its neighbourhood, while many of the noise figures were measured away from an aircraft, or by comparison with an OMEGA transmission. The modification is different when the aircraft is or is not in contact with the ground, but the changes between these two conditions are similar for internally generated noise, external noise, or signal. Accordingly it seems more convenient, though less rigorous, to quote equivalent free-field values (even when the effect is truly local on the aircraft skin) and to estimate the signal and noise arriving at the receiver from the effective height of the entire aircraft-and-aerial system. The changes in received signal during and after take-off are more conveniently assimilated in this way.

2.2 OMEGA signal strengths

The OMEGA signal is a sequence of bursts of carrier, one from each transmitter, of around 1 s duration and with a repetition period of 10 s. Consequently, its frequency spectrum contains a continuous carrier and a sequence of sidebands as in Fig 1, which is for 1 s bursts. The navigational information (*ie* the phase) is contained in the carrier, which carries $\frac{1}{10}$ of the average power, while the sidebands are for separation and identification of the stations. An attempt to measure the width of these spectrum lines by scanning the received signal with a narrow-band filter showed them to be narrower than 0.002 Hz, the filter bandwidth. Although the signal at Farnborough was dominated by nearby Norway, which possibly receives less short-term phase modulation from the ionosphere than longer-path signals, this does offer some information on the spectral density of the OMEGA signal. This is important because no noise with comparable density at the same frequencies can be prevented from corrupting the signal by any form of linear filtering.

The more usual field strength figures given in Table 1 are the peak values during the bursts as observed in free space unperturbed by an aircraft. The strongest field quoted is the field at the shortest distance (~1000 km) from the transmitter at which mode interference effects are assumed acceptable: if they were tolerable at shorter ranges this figure would be revised upwards. The lowest field is set by current receiver performance, and how this arises is shown in section 4.3. Although the range of usable OMEGA signals is thus only about 20 dB, world-wide coverage can still be obtained (apart from certain trouble areas) as charts such as Fig 2* indicate, provided local noise conditions are compatible.

The field is propagated between the earth and ionosphere, which act as a spherical shell waveguide[2]. Basically the electric field is vertical near the ground, and the magnetic field is horizontal everywhere. Wavefronts near the ground are thus vertical planes, although low ground conductivity will cause

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* Prepared for RAE by Decca Navigator Co Ltd

curvature of the wavefront. That this should have no effect on the line-of-position is shown in Fig 3. The variation of field strength over normal aircraft operating heights is of no operational significance.

2.3 Atmospheric noise

The background geophysical noise is at its highest around the OMEGA band (actual maximum about 5 kHz - Ref 3) and consists of noise from distant lightning discharges, with more local discharges showing as less frequency large impulses. Like OMEGA, this noise can propagate for great distances along the earth-ionosphere waveguide. Contributions from the magnetosphere are also observed[4]. The ratio of electric and magnetic components for all these is about the free-space value.

2.4 Precipitation static

A contribution to the E-field noise is caused by discharge from the aircraft of charge collected by impact with rain or ice crystals. This causes intense broad-band interference, and normally affects other aircraft equipment such as communications. The generation can be reduced by improved bonding together of parts of the aircraft (to maintain high capacitive loading on the discharge points) and by specially designed dischargers (which discharge at a lower voltage and are inductively decoupled from the aircraft).

These precautions cannot, of course, alleviate the effects of discharge from the aerial itself (or its insulating coating). It helps to mount the aerial in a position where impact is minimised, and suppressed plate aerials (*ie* flush with the aircraft skin) are found to be particularly free from precipitation-static (p-static) for this reason.

The currents involved are small (~10 mA, Ref 5) so the magnetic component is negligible. Some cases of interference with reception on a ferrite loop (H-field) aerial have been reported[6] but it seems likely that this was due to electrostatic breakthrough in electrically imbalanced loops[7].

The high ratio of electric to magnetic fields has prompted the US Federal Aviation Administration (FAA) to attempt a current-sinking approach to reducing p-static[8]. The aerial is shorted to re-radiate a field cancelling both OMEGA and the static: on removing the short, OMEGA recovers more quickly, because of its lower impedance. The attempt was not successful. Other approaches include using two aerials and cancelling the common noise components.

2.5 HF transmissions

The HF transmitter of an aircraft can produce several kW, and at such frequencies that the whole structure of the aircraft is involved in radiating it. High voltages are used, so discharges from the aircraft, and between poorly bonded parts of the aircraft, can be produced. The effect is similar to that of p-static, only of a uniform high intensity. In RAEs experience, there is no effect on an OMEGA loop aerial, so the magnetic component is negligible.

2.6 Electrical machinery

RAE has measured electrical noise in a variety of aircraft, including a Buccaneer, Canberra, BAC 1-11, two Comets, two Wessex and a Sea King, and in all cases the magnetic fields were much more significant than the electric field (indeed the latter were hard to measure). Throughout this time there has been a slow development of the field sensing probes used, but it is possible to compare the results. Broadly, as might be expected, aircraft display noisy areas with electrical machinery or wiring close behind the skin, and quiet areas far from machinery. Mapping of the skin is often performed for this reason, and some aspects of this process are discussed in section 6. The main difference between various aircraft types seems to result simply from the fact that in smaller aircraft, particularly helicopters, it is impossible to get far from machinery. Typical fields in a noisy area are shown in Table 1.

RAEs measurements were taken with a swept tunable receiver so distinction could be drawn between the narrow-band interference, mainly harmonics of the 400 Hz power supplies, and broad-band interference, presumably caused by contacts breaking, brushes sparking etc. Fig 13f is a particularly good illustration where for the first part of the scan an actuator was operating behind the panel (a promising-looking aerial site on the BAC 1-11) but stopped part way across, enabling direct comparison to be made.

2.7 VLF transmitters

The field strengths of VLF transmitters close to the aircraft can easily exceed the other interference sources so far discussed. For example, about 250 mV/m can be expected at 10 km from the 80 kW 16 kHz GBR transmitter. Fortunately, this interference is frequency stable, and receivers can be designed to reject it. Incidentally, the high power continuous transmissions from VLF communications stations make their reception much easier than OMEGA's, and much less difficulty is encountered in aerial installations. However, navaids using these stations cannot be certified as primary navaids, as the stations are not subject to regulations protecting such usage. Typical VLF communication station field strengths might be 25 mV/m at 100 km or 100 μV/m at 10000 km[9].

3 AERIAL SITING AND THE EFFECT OF THE AIRCRAFT ON THE OMEGA FIELD

3.1 Electrostatic field

3.1.1 Aerial principles

An electrostatic aerial consists fundamentally of two conductors, each terminating as many field lines as possible of the incident field, with the capacitance between them as small as possible. The voltage between the conductors is then fed to the receiver. One of these conductors is usually the body of the aircraft, and the other a wire, whip, blade or plate mounted on the skin. A consideration in choosing the type of aerial is the likelihood of encountering p-static. The plate, which is generally suppressed to appear continuous with the skin, collects less charge from the impact of rain or ice, and produces less noise. The penalty is greater difficulty in installation. The aircraft, an equally important component of the system, may also have arrangements to reduce discharges, as section 2.7 described.

The efficiency of an electrostatic aerial is measured by its 'effective height', *ie* the length by which the field strength (in volt/metre) must be multiplied to give the voltage at the aerial terminals. An amplifier is generally installed as close to the aerial as possible to keep the capacitance low between aerial and aircraft skin (see, however, the Appendix). If this has unity voltage gain the effective height as defined and calculated in the Appendix, may be expected to be a few centimetres for a blade or plate. However, this is the value to be taken to calculate the response to the field local to the aerial, whereas the total system of aerial and aircraft must be examined to get the response to the OMEGA field. If the aerial is sufficiently smaller than the aircraft to see a uniform local field, calculation of the effective height of the aerial/aircraft system can proceed in two stages. First the effective height of the aerial to its local field can be estimated as in the Appendix, and then a field plot will enable the local field to be found as a function of the undisturbed field.

Fig 4a shows the form of the field around an aircraft body in good electrical contact with the ground, while Fig 4b shows the field for the aircraft in the same position relative to the ground but with the contact broken. The lines in Fig 4a&b are cross-sections of planes of equal potential, so their spacing is inversely proportional to field strength. The field for an aircraft far from the ground will be similar to Fig 4b, and it can be seen that the surface field increases with vertical distance away from the electrical centre. There is no reason why internally generated interference, which is small anyway, should vary in this way on a smooth fuselage, so siting the aerial as high or low as possible is advantageous. However, the tips of tail fins and similar projections may enhance noise, and are liable to suffer more if precipitation static occurs.

3.1.2 Directional effects

The electric component of the OMEGA field is vertical near the ground and so contains no information on the direction of propagation. In attempting to infer such effects from the radiation pattern of an inclined dipole, as drawn for example in Ref 10, one should remember that the polarisation is different. The vertical component of the radiation from an inclined dipole is omnidirectional.

However, changes in the aircraft attitude can change the ratio of the unperturbed field to the local field at the aerial, with a danger of signal loss. This is particularly likely if the aerial is mounted at one of the extremities of the aircraft, not very far from the electrical centre plane (the upper aerial site in Fig 6 showed this very well).

3.1.3 Effects on take-off

When the aircraft is on the ground, the field is modified towards the situation in Fig 4a to an extent depending on the ground conductivity and the contact resistance of the aircraft with the ground. The effect is to enhance the signal seen by an aerial on top of the aircraft, and to reduce the signal seen by one underneath. If contact is particularly good, the field on the lower surface is reversed in direction as Fig 4a shows. The resulting 180° phase shift in all VLF signals at the moment contact with the ground is broken has given trouble with the ONTRAC system in small helicopters[11] since it relies on individual phase measurements of signals at several frequencies. OMEGA used in the hyperbolic mode is potentially less susceptible to this effect, as it relies on phase differences.

This redistribution of field around the aircraft with ground contact will also apply to much of the internally generated electric interference, small as it is. This is because the OMEGA component of the surface electric field anywhere reasonably far from the electric centre plane is dominated by the surface charges induced by the incident field, and surface charges behave in much the same way whether induced by OMEGA or an internal source. In effect the ground becomes a further radiator of the interference, cancelling that beneath the aircraft and enhancing that above. The effect on signal-to-noise ratio would thus be expected to be minimal.

RAE has made some measurements of these effects in a Wessex helicopter. Two aerial positions, shown in Fig 5, were tried. When the aerial was in the upper position, the Norway signal level at one of the receiver test points dropped from 500 mV to 300 mV when the ground generator was detached after engine-start, and then to less than 100 mV at take-off (see the photographs in Fig 7). This last value varied noticeably with aircraft pitch and bank angle. Clearly this aerial site is close to the in-flight electrically central plane. With the aerial in the lower site, the Norway signal at the same point fell from 1.2 V to 1.0 V at take-off. There was no way to observe phase changes in either of these tests. In all cases the noise levels seen at the test point also changed in rough proportion to the signals.

3.1.4 Rotor modulation

As the rotor blades of a helicopter move relative to the fuselage, they might be expected to amplitude-modulate the local field at the aerial. No sign of this was observed on any of the Wessex experiments.

3.1.5 Helicopters and cables

In the early stages of flying OMEGA in helicopters, the aerial would be a long metal cable trailing beneath the aircraft. Although dangerous, this always guaranteed good reception. The points made so far in this Memorandum should make it clear that it was unnecessary to attach the cable to the receiver aerial socket: such a cable would enhance the field at any site on the aircraft. However the effect of lowering a cable (for any purpose) must be taken into account in siting the aerial. In particular, a low site will experience the electrical centre's moving through and past it as the cable is lowered, with an accompanying signal fade and return with inverted phase.

3.2 Magnetic field

3.2.1 Aerial principles

A magnetic loop aerial consists of several hundred turns of wire on a ferrite block. The voltage across the coil depends only on the magnetic induction passing through the coil, so the aircraft plays a rather less intimate part in the operation than in the case of the electric aerial. The 'effective height' for a loop is taken as the length which multiplies the electric component of a free-space wave to give the voltage at the aerial terminals when the aerial is

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Appendix

looking at the magnetic component. As the fields received on an aircraft are in the main not free-space, a more rational parameter would be the effective area, which would multiply the angular frequency by the magnetic induction to give the voltage across the coil. The effective area of a loop or the effective height of an electric aerial are fundamentally independent of frequency, while the effective height of a loop is proportional to frequency. At VLF the effective height of a loop is less than 1 mm (effective area of order 1 m^2). The figures of several centimeters quoted by manufacturers for their aerial systems include the gain of a pre-amplifier.

A practical complication for the loop is the stray capacitance in the winding which produces resonance. This resonance may be encouraged and adjusted to the required frequency if only a narrow-band is required, but in any case it limits the upper frequency for a given loop, as does the fall in permeability[12] of ferrites with increasing frequency.

3.2.2 Directional effects

Because the OMEGA magnetic field is horizontal, a loop aerial is directional. A magnetic aerial system consequently consists normally of two perpendicular loops. The usual way of operating is to select whichever loop is expected to give the stronger signal by calculation from the aircraft heading and position by computer. The same computer will also make allowance for the 180° phase difference seen by the aerial for reciprocal directions. A different approach is to shift the phase of the signal from one of the loops by 90° over the whole band of interest, without changing the amplitude, and adding this to the signal from the other loop. The resultant is a signal with amplitude independent (in a perfect system) of the transmitter bearing, and a phase shift equal to the bearing. For hyperbolic navigation, it is then necessary to correct the LOP values by an angle equal to the difference in transmitter bearings (and independent of heading). If the 3.4 kHz OMEGA pattern is being used[1] even this correction may be unnecessary, as it should be the same for both 10.2 and 13.6kHz signals.

3.2.3 Skin currents

Reception of the magnetic component of the OMEGA field will be modified by currents induced in the aircraft skin by the field. These currents themselves produce a field which may couple to the aerial. The aerial is mounted to see the tangential component of the field, so coupling to nearby currents is minimised. The extent of the field modification is reasonably small as may be judged from the distortion of the polar diagram (Fig 8) of a loop mounted on the rear cargo hatch of a Comet. These measurements were taken in flight, using GBR (16 kHz) as a signal source. Phase variations would have been more interesting, but were not available.

Because the permeability of the ground is not radically different from that of air, there is little difference in the loop aerial performance when the aircraft is on the ground, unless it happens to be parked in, over or near large metal structures, when the signal may become weakened.

4 CURRENT RECEIVER PRACTICE

4.1 RAE Comet installation

The experimental installation used by RAE in two Comet aircraft contained fundamentally the functions which a practical airborne receiver would be expected to provide, so this will now be described.

The aerial was a pair of crossed loops on ferrite blocks mounted in a fibreglass dome under the tail (Fig 9). Amplifiers next to the loops fed cables to the main equipment.

The first item of the main installation encountered by the signals from the loops was the aerial switching unit, which connected either loop to the receiver under computer control. It also generated an omnidirectional signal for use during synchronisation by adding the loop outputs in quadrature (section 3.2.2). The receiver is entirely typical of current design philosophy, and is dealt with in greater detail later. It was a superhet, reducing each OMEGA frequency to an IF of 1 kHz. A monitor scope was added to the receiver outputs, which were also interfaced to a computer.

The computer was a 4k word 12-bit machine (Sperry 1412). As well as the receiver, it was interfaced to the aircraft's magnetic compass system and the Doppler/TANS system which provided a measure of the velocity in N-S and E-W directions. A teleprinter and control-display unit (CDU) were used for input and output: the teleprinter was for experimental recording and control of the computer.

The functions of the computer were:

(a) Initialisation, starting at switch-on.

(i) Selecting the OMNI aerial input, the computer measured the amplitude of the 13.6 kHz signal (chosen because it was expected to be the strongest) in

200 50 ms intervals (total 10 s), repeating and accumulating the measurements for 2 min. It then correlated this with the known OMEGA pattern and identified the signals. If the strength of the signals was low, it sometimes required several attempts.

(ii) Meanwhile it accepted inputs of time, date and initial position.

(iii) Velocity data from the TANS was used to dead-reckon position.

(b) Navigation mode, initiated by instructing the computer which lines of position to use. Use of A, B, C and D at 10.2 kHz only was possible because of program limitations.

(i) The bearings of the transmitters A, B, C and D were calculated and, using information from the compass, the loops were selected to give the best signal in each segment. Allowance was also made for the $\pm 180^{\circ}$ phase difference between signals from fore and aft or port and starboard.

(ii) The computer measured the times of zero-crossing of the 10.2kHz signal and calculated a mean phase and standard deviation for each of the four signals.

(iii) Using the heading and speed inputs already mentioned, it calculated smoothed values for the received phases incorporating measurements over the last 64, 128 or 256 s according to the program used.

(iv) On the basis of the measurements of zero-crossing standard deviation, it decided whether the selected signals were strong enough to use. It also checked that the spacing of the selected lines of position was not excessively large owing to poor disposition of the transmitters around the receiver. If either of these tests failed, the system reverted to dead reckoning from the TANS input.

(v) A prediction of the diurnal variation in propagation delay was calculated from a mathematical model for each of the selected signals.

(vi) The corrected station pair phase differences were calculated from these figures and the line-of-position numbers obtained, keeping track of any lane boundary crossings. These figures were converted into latitude and longitude.

(vii) Position was displayed on the CDU and teleprinter.

4.2 ESRO trials

The equipment was flown on two trials, organised by ESRO (now ESA) for experiments involving the ATS 6 satellite. The first was based on Atlantic City, NJ, from 28 August 1974 to 4 October 1974 and the second based on Lajes, Azores, from 20 February 1975 to 27 March 1975.

Because of the higher signal environment, increasing experience of the operators, and most of all the continuous use of the monitor oscilloscope, it became possible in the Azores trial to analyse to some extent the effects which were causing periods of signal loss leading to navigation in the Dead Reckoning mode.

The first major effect to be isolated was interference from the other aircraft electrical systems, which appeared on the monitor oscilloscope as a strong coherent signal swamping the receiver output. As the frequency of this signal was not correct (up to ~5 Hz away from 1 kHz), the standard deviation of the zero-crossings from the values a correct frequency would give was high, and the computer would go into DR.

The occurrence of the noise was found to be associated with the synchronisation of the engines. Each engine drove a generator whose output was rectified and dumped into a 28V battery. Other systems were then driven from the battery, some via rotary converters and inverters. Beats between the generators were audible on the intercom, and these correlated to some extent with the interference to the OMEGA signals. The trouble tended to be worse towards the end of a flight when the reduced fuel loading made a different engine speed appropriate, and would often disappear for a while if the engines were re-synchronised. The pilots were very co-operative in doing this once the trouble was recognised (not very practical except under experimental circumstances), but it became less effective after various servicings and an engine replacement.

The noise entered the OMEGA system by at least two routes. A sudden high amplitude part could be removed by disconnecting the inputs from the loop pre-amplifiers, sometimes just one or the other, sometimes both. The most likely cause of this is coupling between the aerials and skin currents. Another lower amplitude but more persistent component could not be so removed. The oscilloscope showed about 200mV ripple at around 100 Hz on the 28V receiver supply under good reception conditions and no apparent disturbance on other supplies, and no change was obvious when interference occurred. No facilities were available for a fuller investigation.

The second major effect was first noted on 7 March 1975, when timed east-west paths were being flown. On turning downwind, the aircraft reduced airspeed, tilting the nose up by 4 or 5°. Both signal and noise seen on the monitor were strongly attenuated, so that only the Norway signal remained visible, and the system promptly entered DR. On later flights in the Azores, (27000 ft, clear weather) deliberate tests of reduced speed produced the effect reliably, but a flight over the Bristol Channel on 3 April 1975 (30000 ft, heavy overcast), designed to detect directional dependence of the effect, was quite inconclusive as the phenomenon could not be convincingly reproduced.

Some other minor observations were interesting:

(a) The need for rate-aiding was amply demonstrated on 12 March when on landing, the OMEGA showed a position almost exactly 1° to the east, with no error in latitude (placing us fortunately on the next island). Subsequent investigation revealed that the navigator, mistrusting his TANS, had unplugged it for a few minutes, at which time four lane slips occurred in quick succession, just accounting for the error.

(b) In turbulence there was an immediate loss of signal. The pilots' reaction to turbulence is to reduce speed so the nose-up effect would account for this, but ONTRAC, another VLF navigation system being tested and connected to an HF wire on top of the aircraft, also saw the loss in turbulence, but was unaffected by the nose rising on other occasions.

(c) HF breakthrough was never seen to affect the OMEGA, though it could be clearly heard on the intercom. The OMEGA aerial could hardly be better positioned relative to the HF wire. Also, no effects which could be described as precipitation static were observed.

An analysis of the periods of DR was given in Ref 1.

4.3 Discussion of causes of signal loss

In retrospect, many of the instances of signal loss on these flights can be explained in terms of receiver design. The principle things that happen to the signal are summarised in Fig 10. The major feature is the successive stages of clipping of the signal followed by narrowing of the bandwidth. The philosophy behind this approach[13,14] is that, if the noise is impulsive, a wide bandwidth enables spikes of interference to be clipped off, with a consequent improvement in signal-to-noise ratio. The noise will be impulsive only if it is predominantly atmospheric, and Table 1 showed that, unless exceptional care is taken in aerial siting, the atmospheric noise will be a minor contribution for the bandwidth involved. In those cases where the design principles of specific commercial OMEGA systems have been available to RAE, allowance was found to have been made only for the atmospheric noise in the design.

When a clipper acts on a noisy signal, for the periods when the clipper is acting both signal and noise are suppressed. For impulsive noise this may not reduce the signal too severely, but when the interference is a sine wave harmonic from the power systems, or precipitation static of high amplitude, the clipper is acting virtually the whole time, and the signal vanishes.

If the noise is atmospheric, its value from Table 1 will be around $10\,\mu V/m\,Hz^{\frac{1}{2}}$. The final bandwidth of this and many other receivers was around 10 Hz, so the noise at the aerial which reaches the detector is around 30 μV/m. The final limiter of a receiver must be the first one to limit, otherwise it will not limit at all, so the 10Hz bandwidth signal in all these receivers is amplitude limited, either by explicit circuitry, or in the form of a phase detector which, by separating phase from amplitude, must have the effect of a limiter. For a signal to survive the clipper, the signal-to-noise ratio has to be above about unity, so this derives the figure of 25 μV/m given in Table 1 and quoted in several receiver specifications, for the smallest usable OMEGA signal. This limit depends on the receiver design philosophy.

The failure of the system to tolerate power harmonics in the Azores trial obviously arose at what is effectively a further limiting process at the zero-crossing detector.

A clue to the effect where both signal and noise disappeared was given by a fault which occurred in the receiver which detuned the local oscillator. Now only noise appeared at the output, except when Norway, a strong local signal, was transmitting. The Norway signal itself did not appear at the output, but the noise disappeared. Clearly the Norway signal lay within the 200Hz band of the early amplifiers and was operating the first limiter to remove the noise, but was outside the 10Hz band of the final amplifier and so could not itself reach the output. It is suggested that a coherent interference source produced by specific engine conditions was producing this effect in the Azores flights.

It has been found, on a different OMEGA receiver, that occasionally it was beneficial to insert an attenuator in the aerial lead, to reduce the limiting. When effects as unnatural as this can happen, it seems clear that receiver design has taken a wrong turning.

5 DESIGN PROPOSALS TO ALLEVIATE NOISE PROBLEMS

This section will examine the implications of greatly reducing the bandwidth of an OMEGA receiver, and eliminating the two limiting processes shown in Fig 10. The target bandwidths will be those which enable operation in particularly noisy conditions with no particular care being taken over aerial installation. For broad-band noise the improvement caused by reduction in bandwidth will be proportional to the square root of the factor of reduction, while the narrow-band noise, since it is unstable in frequency over periods of minutes, will be reduced proportionally to the bandwidth. Taking the broad-band noise first:

(i) For an electric field aerial the most severe conditions are those of precipitation static. From Table 1, the receiver must accept no more than 25 μV/m of noise from a source of 300 $\mu V/m\ Hz^{\frac{1}{2}}$ to allow reception of the weakest stations for comparable coverage with current practice. This requires a bandwidth of 0.007 Hz (150 s).

(ii) For a magnetic field aerial, the receiver sees $\sim 0.5\ pT/Hz^{\frac{1}{2}}$ and selects no more than 0.08 pT, implying a bandwidth of 0.003 Hz (400 s).

Two difficulties arise from such a bandwidth reduction. The first is the loss of the synchronisation information, and the other is the lag in phase of the filters when the receiver is moving. Of course the latter is already a problem with current receivers, as they contain a final filter of the same bandwidth here proposed. The often-quoted objection that bandwidth reduction promotes ringing does not bear close examination: bandwidth reduction always improves signal/noise ratio.

If synchronisation has been achieved, the simple scheme of Fig 11a should be suitable. Bandwidth should be reduced as much as possible as early as possible to reduce the chance of inadvertent limiting by exceptionally strong interference, but must not be reduced below about 10 Hz before the signal is split into independent channels, one for each transmitter. The effect of bandwidth reduction below 10 Hz on an OMEGA signal is shown in Fig 12: too narrow a bandwidth can mix the signals in the various segments if they have not already been separated. The type of filter suggested for the final bandwidth reduction is a commutating filter[15,16], which consists of a number of capacitors (four or more) switched sequentially across the input. Very narrow bandwidths are easy to obtain, and the accuracy and stability depend not on the components but on the switching frequency source. Such a filter made the measurements mentioned in section 2.2.

When it is necessary to synchronise in the presence of severe noise, *eg* whenever a loop aerial is being used, it is usual to regard a bandwidth of at least 5 Hz as necessary for the OMEGA format to be preserved. This gives a noise tolerance, assuming one moderately strong signal of 100 μV/m, of about 50 μV/m Hz$^{\frac{1}{2}}$ for an electric aerial (rare on the ground) or 0.3 pT/Hz$^{\frac{1}{2}}$ for a magnetic aerial (almost inevitable without a successful skin mapping procedure). However, this ignores the fact that the OMEGA signal has a 10 s period, and hence requires an indefinitely small bandwidth, provided it is separated into a number of equal bands situated one on each side-band and one on the carrier. Some recognition of this is given by the signal integration in the synchronisation procedure described in section 4.1, but the gain is largely nullified by the limiting performed in the detector before the integration is performed.

The most direct way would be to situate narrow filters on each of the carrier and side-bands at each frequency, but to locate the bursts adequately, at least 10 side-bands are required. Further, if it is intended to measure the phase from the filtered signal in formatted form, the 10 balancing side-bands are needed to preserve the phase. This means a lot of filters, and of course each one lets in noise, so all have to be correspondingly narrower.

More practical might be the scheme of Fig 11b. A commutating filter has the advantage of selecting a harmonically related series of frequencies so such a filter, with an adequate number of capacitors and a fundamental frequency of $\frac{1}{10}$ Hz, can tune all the side-bands if the OMEGA signal is down-converted to zero frequency. Fig 11b also contains circuitry for up-conversion back to the original frequency, so that direct comparison is possible between filtered and unfiltered signals. In practice the reconversion will be unnecessary, as the two filters of Fig 11b merely hold a running average of the phase and quadrature components of the received signal throughout the 10 s period, from which LOP values are directly calculable. Indeed they are more likely to be implemented by computer store locations than by capacitors. This view of the system shows that the number of capacitors, or locations, will be around 100 per filter.

Finally, examining the response of such a receiver as Fig 11a to narrow-band interference in more detail, it can first be seen that there will be no response until the unwanted sinewave comes within 5 Hz of the OMEGA frequency. This means with random frequency drift an immediate reduction in duration of the problem by 20 or more times (reducing the problem in the Azores flight for example from 3½ h to 10 min out of 98 h flying). Suppose, however, that a particularly stable power harmonic settled in the 10Hz bandwidth before the segment gate. The switching spreads this into a comb of frequencies, just like the OMEGA (Fig 1) with 100 mHz spacing and $\frac{1}{10}$ the amplitude. Since we are postulating bandwidths of around 5 mHz for the tracking system, this may well lie between the comb frequencies for most of the time, and the problem is even further alleviated.

6 SKIN MAPPING

It is often necessary, when using receivers that employ wide-band limiters, and particularly when using a loop aerial, to measure the noise levels at the aircraft skin to find the quietest place to install the aerial. There is, of course, no guarantee that a suitable site can be found, particularly on small aircraft. The sort of results to be expected have already been mentioned in Table 1 and section 2.6. However, there are some further points to note when skin mapping is done with aerial installation in mind.

(i) The three components of the magnetic field can be quite independent, as Fig 13a-c indicate. It is a common technique to use the ribs of the airframe as reference points, and measure the normal component of the field there. In fact, the aerial will be installed between ribs, and the tangential components are what matter.

(ii) The aerial modifies the local field, so a probe as much like the aerial as possible should be used. A loop probe, for example, should have a ferrite core, not an air core. There is particular difficulty with an electrostatic probe such as described in the Appendix in ensuring that contact with the aircraft is adequate, and that trailing feeders are not influencing the local field. Fig 13d&e compare the responses of a blade aerial and a plate-type probe at its base. The extra interference on the probe could be attributed to poor contact.

(iii) The measurements are being made on the ground, and for the electric field the situation will change radically on take-off. It is best to estimate the noise against the known amplitude of an OMEGA transmission (from, for example, coverage maps like Fig 2) as the ratio will not change greatly on take-off.

(iv) Results vary from aircraft to aircraft of the same type, and during the aircraft's lifetime. The situation may well degrade owing to corrosion etc.

6.1 Equipment used for mapping the magnetic field

The best probe to use for measuring the field would be an OMEGA aerial. Since one was not available initially, RAE used a loop probe designed for the

RE01 test in MIL-STD-461A. This responds to the magnetic field normal to the aircraft's skin over the frequency range 20 Hz to 50 kHz. The plane of the loop is spaced 7 cm from the skin of the aircraft by a low dielectric spacer. The sensitivity was quite inadequate.

As the magnetic OMEGA aerial responds to the tangential component of the field with respect to the plane of the loop, and thus the aircraft's skin, a ferrite probe was made to measure this component. It consists of 1000 turns on a 15 cm (6 in) ferrite core with an inductance measured as 237 mH. The input impedance of the measuring receiver was selected as 10 kΩ to avoid excessive mismatch. This probe gave us 20 dB greater sensitivity than the original loop.

For most of the aircraft surveyed, the measuring receiver was an Electrometrics EMC-10E, which is tunable over the frequency range 20 Hz to 50 kHz. This has since been replaced with a Singer NM-7 receiver which has greater sensitivity and a short term memory enabling the relative strength of the OMEGA signal to be measured.

The maximum sensitivity obtainable at present, using the ferrite probe and the NM-7 is -12 dB with respect to 1 pT.

6.2 Test technique

Those areas of the aircraft which were unsuitable for practical reasons were eliminated. The aircraft ribs in the areas of interest were identified and numbered. An x-y recorder was connected to the measuring receiver to enable an automatic plot of interference to be made in the frequency range 9-14 kHz. With all practicable electronics and electrical loads energised, powered from the aircraft's own generators, the probe was placed against the aircraft's skin, either directly over a rib when using the loop probe, or between two ribs when using the ferrite probe. The interference levels were recorded using measurement bandwidths of 5 Hz and 50 Hz to aid identification of the type of interference (narrow-band or broad-band, coherent or incoherent).

The results from each location could then be compared and the most favourable site from an interference aspect determined.

6.3 Electric field interference

A probe developed to measure this with an effective height of 12 mm is described in the Appendix. Calibration was performed (for this and the magnetic probes) in a calibrated waveguide. Care is necessary to prevent the probe's distorting the field it is intended to measure, by the presence of trailing cables or the high-dielectric operator. An example of the probe's output is given in Fig 13d.

7 POWER SUPPLIES AND RECEIVER INSTALLATION

7.1 Standards and specifications limiting aircraft electrical interference

A possible source of interference to an OMEGA installation is electrical noise on the power supplies, produced either by the generating system or by other equipment sharing the same supply. In principle, maximum permissible levels are laid down in specifications of which many can be applied to aircraft. However, the two most important of these are BS 3G100 and MIL-STD-461A.

The current British standard is BS 3G100. This is divided into several parts covering all environmental tests. The two sections of most interest are Part 3 - characteristics of aircraft electrical systems - which defines the required performance of the electrical generation systems, and Part 4, section 2, which covers electromagnetic interference of electrical equipment at radio and audio frequencies. This standard is applied to both civil and military aircraft.

The only protection given by the standard in the OMEGA operating band is in Part 3, which specifies the allowable harmonic content from the aircraft's generating systems. Part 4 does not limit interference below 50 kHz.

The equivalent American Standard is MIL-STD-461A, a joint military standard for the US Army, Navy and Air Force. This limits narrow-band interference down to 30 Hz (*eg* generator harmonics) and broad-band interference down to 20 kHz.

7.2 Aircraft electrical power supply interference

The electrical generation system of an aircraft produces electrical interference across the OMEGA operating band. On an aircraft where the prime generation system is dc this can be typically broad-band noise from the brushes of the dc generator or narrow-band harmonics of the ripple frequency of the rectifier units. On an aircraft with an ac prime generation system, harmonics of the fundamental power frequency (400 Hz) are present on the busbar as well as interference from transformer rectifier units. In both cases, interference from static or rotary inverters is present. Interference from static inverters is a mixture of narrow-band and broad-band noise.

7.3 Electrical equipment interference

From on board electrical equipment, a major source of interference in the OMEGA band is the internal power supply. Switching mode type power supplies can be especially troublesome if their switching frequency is in or below the OMEGA frequency band.

Another source, increasingly present, is electronic strobe anti-collision or navigational lamps. In these a capacitor is charged from a frequency varying oscillator and then discharged through a gas discharge tube. Two forms of interference result: broad-band transients occurring at discharge (usually once per second) and narrow-band frequency varying signals from the oscillator. Both these occur in the OMEGA frequency band and great care must be taken to ensure the OMEGA installation is kept well segregated from these, especially from the lead connecting the strobe's power supply to the lamp head as this is the main source of radiated interference.

Further information on interference from equipment can again be found in Ref 17.

7.4 Earth loops and installation problems

Some of the troubles which can beset an OMEGA installation through careless power supply arrangements are indicated in Fig 14. A connection to the airframe from the aerial pre-amplifier is essential for an electrical aerial (as section 3.1.1 makes clear), and if dc supplies are used this opens a return path for noisy currents to the generating system, which can very easily enter the OMEGA signal path. Such supplies were used in the early RAE Comet installation (section 4.1) and a great deal of time was spent ensuring balanced aerial feeders and earthing and unearthing aerial feeder screens, equipment cases and pre-amplifier power returns to arrive at an arrangement with least interference (section 4.2). In the Wessex installation (section 3.1.3) the dc supplies were so noisy that the receiver (a model intended for marine operation from a ship's dc supplies or batteries) could not even generate the format switching. To combat this, an inverter was used to drive a laboratory-type stabilised power supply, in turn driving the receiver's battery input. As well as removing supply noise, this arrangement breaks the earth loop apparent in Fig 14 by inserting a transformer, and so keeps current from other equipment out of the system. The result in the Wessex was an installation completely tolerant of earthing of the receiver case or aerial feeder screen (as long as one connection was made at the blade to the airframe) and able to use unbalanced aerial feeder cable.

Use of a transformer in this way to avoid connection of signal ground to any supply lead seems an elementary precaution to take in any VLF or other sensitive installation, particularly as most aircraft now generate ac primary supplies.

8 CONCLUSIONS

The success of an OMEGA installation in an aircraft depends on three things:

(a) The quality of the power supplies.

(b) The quality of the aerial installation.

(c) The receiver design.

It appears that further developments in (c) (a once-only task) could greatly alleviate the dependence on (b), which requires individual attention to each aircraft. In particular the wide-bandwidth limiter approach seems inappropriate to the noise environment involved, and improved performance should be obtained with narrow-band non-limiting receivers. The following are recommended:

(a) Use an electrostatic aerial, particularly in small aircraft.

(b) Site the aerial as far above or below the aircraft electrical centre as practical, bearing in mind that this moves relative to the aircraft on take-off. For non-hyperbolic systems, above the centre is preferred because of possible phase inversion on take-off at lower sites.

(c) As a non-limiting type of receiver does not seem to be available, choose one with as narrow a bandwidth as possible (10 Hz) at the final limiter, and arrange the gain of the whole system (remembering that it changes at take-off) so that atmospheric noise does not operate the limiter. Immunity to precipitation static will then be as good as can be expected with this receiver type. If the resulting performance is not acceptable, resort to a loop aerial and skin-mapping may be necessary, but is not a guaranteed remedy. In this case, immunity to power harmonics can be maximised by avoiding limiting in the same way.

(d) Use an ac power supply, and allow no connection between signal ground (the airframe) and supply line through the receiver. This applies equally to any synchro inputs or outputs.

Appendix

AN E-FIELD SKIN MAPPING PROBE

An E-field probe with an effective height of 12 mm is described here, and the principles are equally applicable to the design of aircraft aerials.

If two parallel plates of area A are placed in an alternating electric field E, the current flowing in the capacitance between them is

$$I = j\omega\varepsilon_0 AE \quad .$$

If this capacitance is C, the voltage between the plates will be

$$V = \frac{I}{j\omega C} = \frac{\varepsilon_0 A}{C} E \quad .$$

Hence the effective height of this arrangement used as an aerial is $\varepsilon_0 A/C$. To keep C low, it is usual in a plate aerial to make the spacing between the plates several centimetres. In the RAE probe, however, a bootstrapped plane is introduced between the plates to reduce C, enabling the plates to be brought to a separation of 4 mm. The circuit is shown in Fig 15, and includes a resistor R to reduce the bandwidth to 100 kHz. The formula for the effective height of this arrangement is

$$h = \frac{\varepsilon_0 A}{C_3 + C_1 \dfrac{j\omega C_2 R}{1 + j\omega C_2 R}} \quad .$$

C_1 is around 1.5 nF, but the amplifier reduces this in practice to about 20 pF. Similar treatment might be given to the feeder to an aerial pre-amplifier for any electric aerial, reducing the constraint on feeder length.

Table 1

TYPICAL FIELD STRENGTHS

	E-field	B-field
OMEGA carrier spectral density, minimum usable strength*	$>50\ \mu$V/m Hz$^{\frac{1}{2}}$	>0.2 pT/Hz$^{\frac{1}{2}}$
Strongest usable OMEGA signal (just outside mode interference zone)	200 μV/m	0.7 pT
Minimum usable OMEGA signal*	25 μV/m	0.08 pT
16 kHz field 10 km from GBR transmitter	250 mV/m	900 pT
16 kHz field at 10000 km from GBR	100 μV/m	0.35 pT
Average atmospheric noise	10 μV/m Hz$^{\frac{1}{2}}$	0.03 pT/Hz$^{\frac{1}{2}}$
Precipitation static	300 μV/m Hz$^{\frac{1}{2}}$	<0.1 pT
Broadband background on BAC 1-11 skin with operating actuator behind		4 pT/Hz$^{\frac{1}{2}}$
Broadband interference on BAC 1-11 skin 3 ft from anti-collision light during discharge		20 pT/Hz$^{\frac{1}{2}}$
Broadband noise on Wessex skin with all electrical systems running	$<50\ \mu$V/m Hz$^{\frac{1}{2}}$	1.5 pT/Hz$^{\frac{1}{2}}$ average 5 pT/Hz$^{\frac{1}{2}}$ at upper aerial site (Fig 5)
Power harmonics on Wessex and BAC 1-11 skin		10-70 pT

* Minimum as defined in section 4.3

REFERENCES

No.	Author	Title, etc
1	H.G. Hill J. Kilvington W.R. Turner	The performance of OMEGA and other VLF navigation systems in aircraft. RAE Technical Memorandum Rad-Nav 19 (1975)
2	J.R. Wait	Introduction to the theory of VLF propagation. Proc IRE, 50, 1624-1647 (1962)
3	F. Lied	High frequency radio communications with emphasis on polar problems. AGARDograph 104 (1967)
4	D.L. Jones R.M. Gallet J.M. Watts D.N. Frazer	An atlas of whistlers and VLF emissions: a survey of VLF spectra from Boulder, Colorado. Nat Bur Standards Technical Note 166 (1963)
5	D.A. Granville-George B.G. Smith	An information study of noise in aircraft communication systems between 2 and 400 MHz. Smith Associates Technical Report TR 123 (1975)
6	F.C. Sakran, Jr P.B. Burch	Flight tests of two airborne OMEGA navigation systems. Navigation, 21, 194 (1974)
7	K. Ikrath	The susceptibilities of electrical and magnetic antennas to precipitation static noise (experiments in an electrostatic wind tunnel). US Army Electronics Command Report ECOM 4319 (1975)
8	O.J. Baltzer	Investigation of 'antenna dumping' as a means of reducing precipitation static interference in airborne OMEGA. FAA Report FAA-RD-72-1 (1972)
9	A.D. Watt R.D. Croghan	Comparison of observed VLF attenuation rates and excitation factors with theory. Radio Science, 68D, 1 (1964)
10	J.V.N. Granger J.T. Bolljahn	Aircraft antennas. Proc IRE, 43. 533-550 (1955)

REFERENCES (concluded)

No.	Author	Title, etc
11	S. Broadbent	Ontrac airborne. Flight International, p 59-60, 10 July 1975
12	C.D. Owens	A survey of properties and applications of ferrites below microwave frequencies. Proc IRE, 44, 1234 (1956)
13	D. MacTaggart	Design and performance of CMA-719 computerised airborne OMEGA receiver. Proceedings of the First OMEGA Symposium, Institute of Navigation, 63-74 (1971)
14	R.L. Eisenberg A.F. Thornhill M.F. Williams	Development and flight testing of pre-production OMEGA aircraft receivers and antennas. *Ibid*, p 144
15	G.C. Temes S.K. Mitra	Modern filter theory and design. Wiley (1973)
16	V.B. Mitchell	50 Hz power line signal suppression using a multi-stage boxcar detector. J. Atmos and Terr Phys, 37, No.2, 325 (1975)
17	-	Guide to electromagnetic compatibility in aircraft systems. AvP118. UK Ministry of Defence (1976)

Fig 1

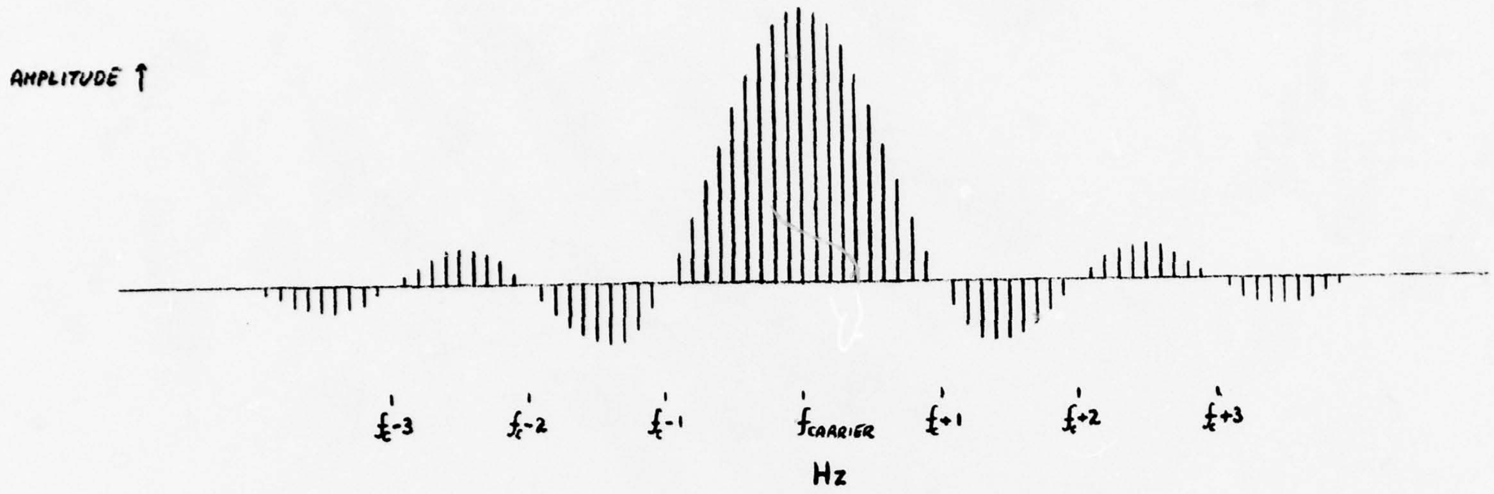


Fig 1 Calculated spectrum of an OMEGA signal

Fig 2

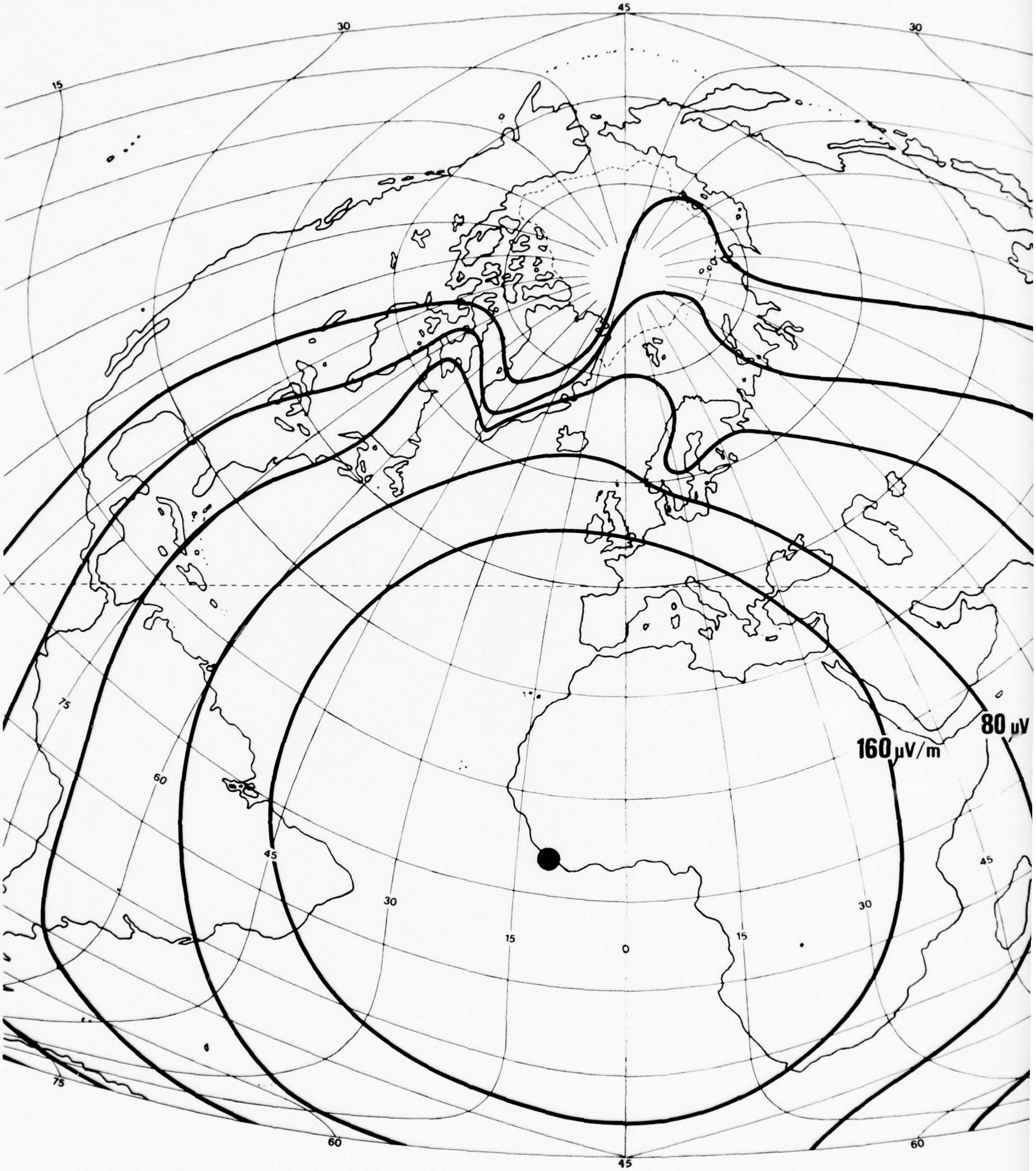


Fig 2 Signal strengths from the Libe

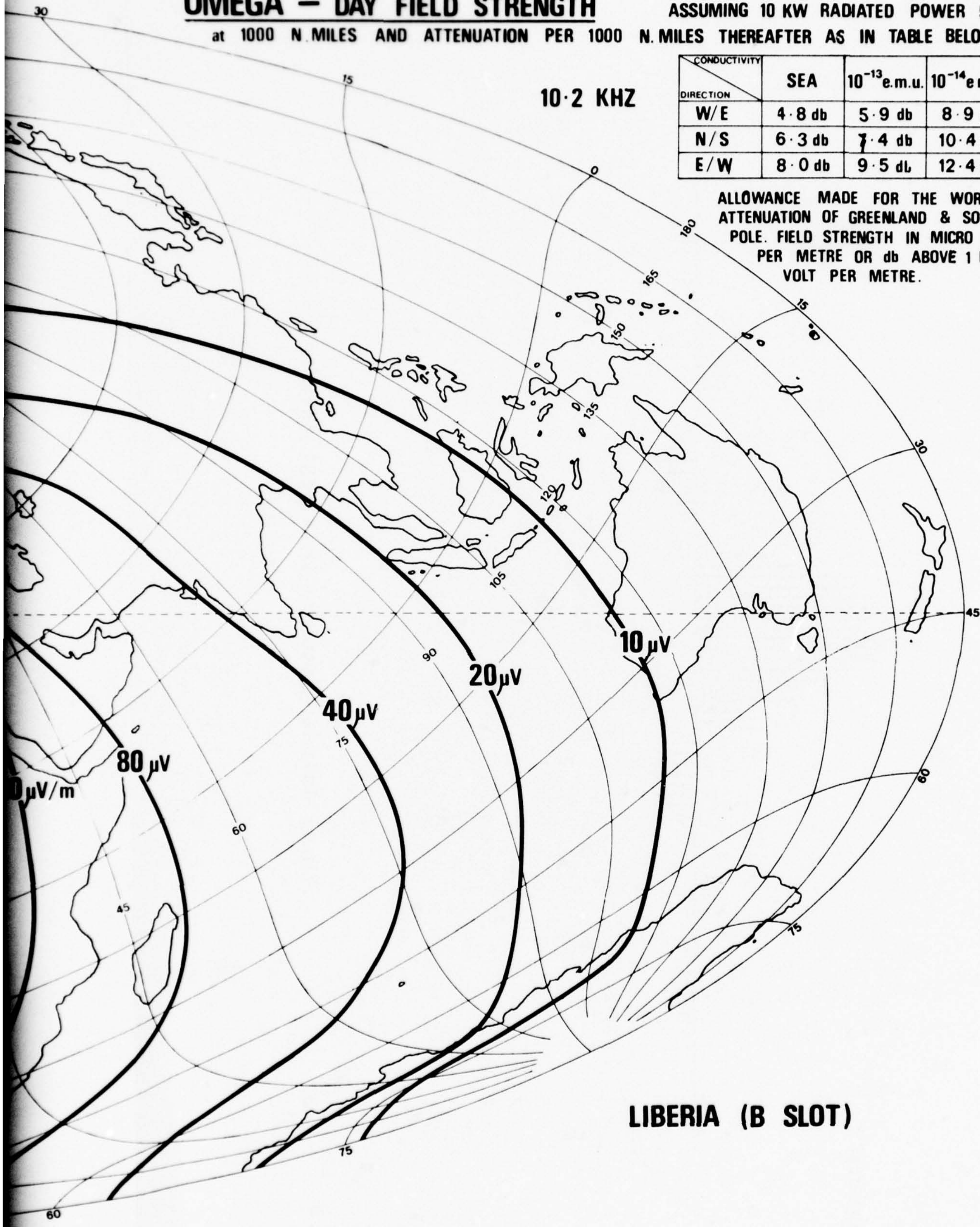
OMEGA — DAY FIELD STRENGTH

ASSUMING 10 KW RADIATED POWER 55 db at 1000 N. MILES AND ATTENUATION PER 1000 N. MILES THEREAFTER AS IN TABLE BELOW

10·2 KHZ

CONDUCTIVITY / DIRECTION	SEA	10^{-13} e.m.u.	10^{-14} e.m.u.
W/E	4·8 db	5·9 db	8·9 db
N/S	6·3 db	7·4 db	10·4 db
E/W	8·0 db	9·5 db	12·4 db

ALLOWANCE MADE FOR THE WORSE ATTENUATION OF GREENLAND & SOUTH POLE. FIELD STRENGTH IN MICRO VOLTS PER METRE OR db ABOVE 1 MICRO VOLT PER METRE.



s from the Liberia transmitter

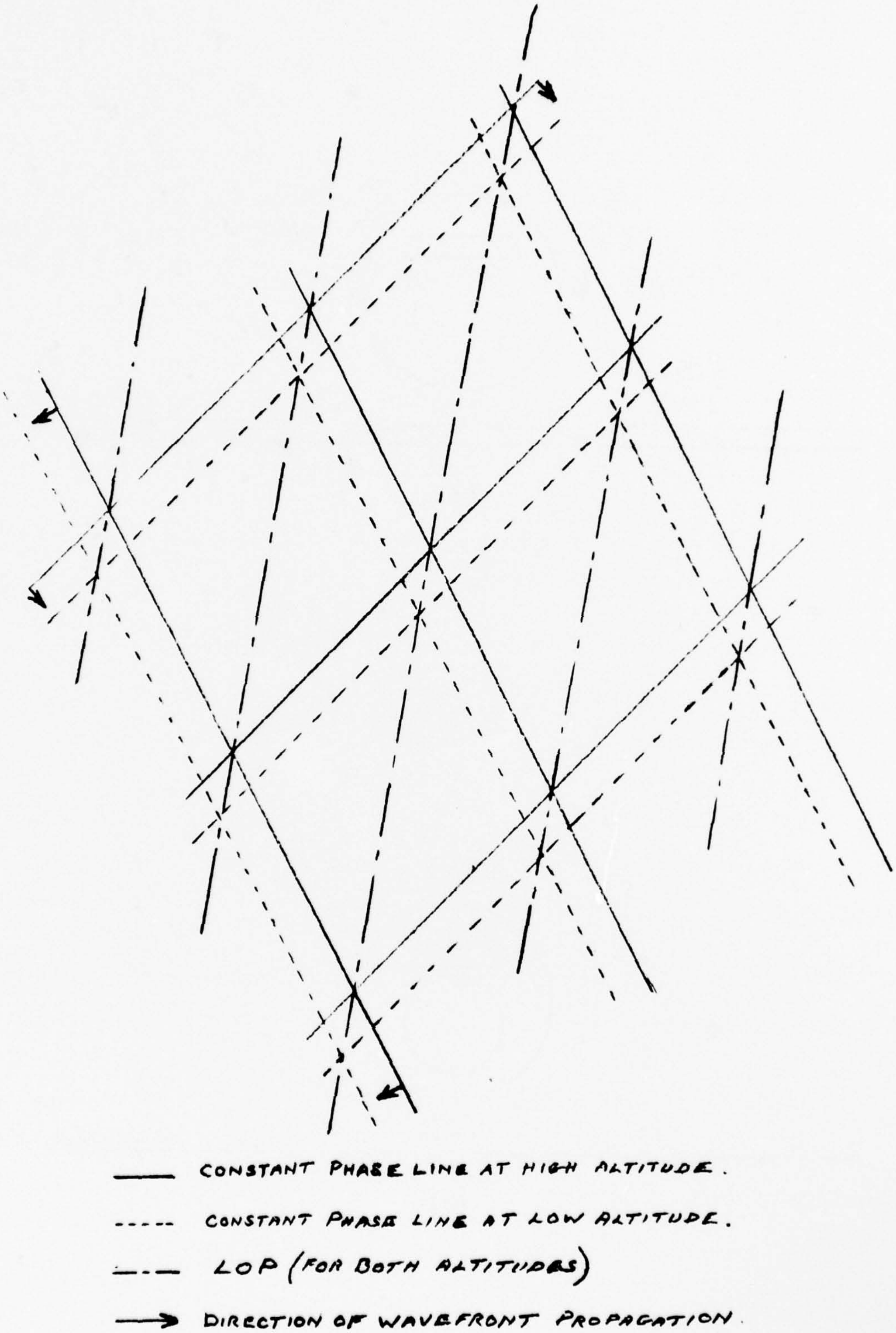
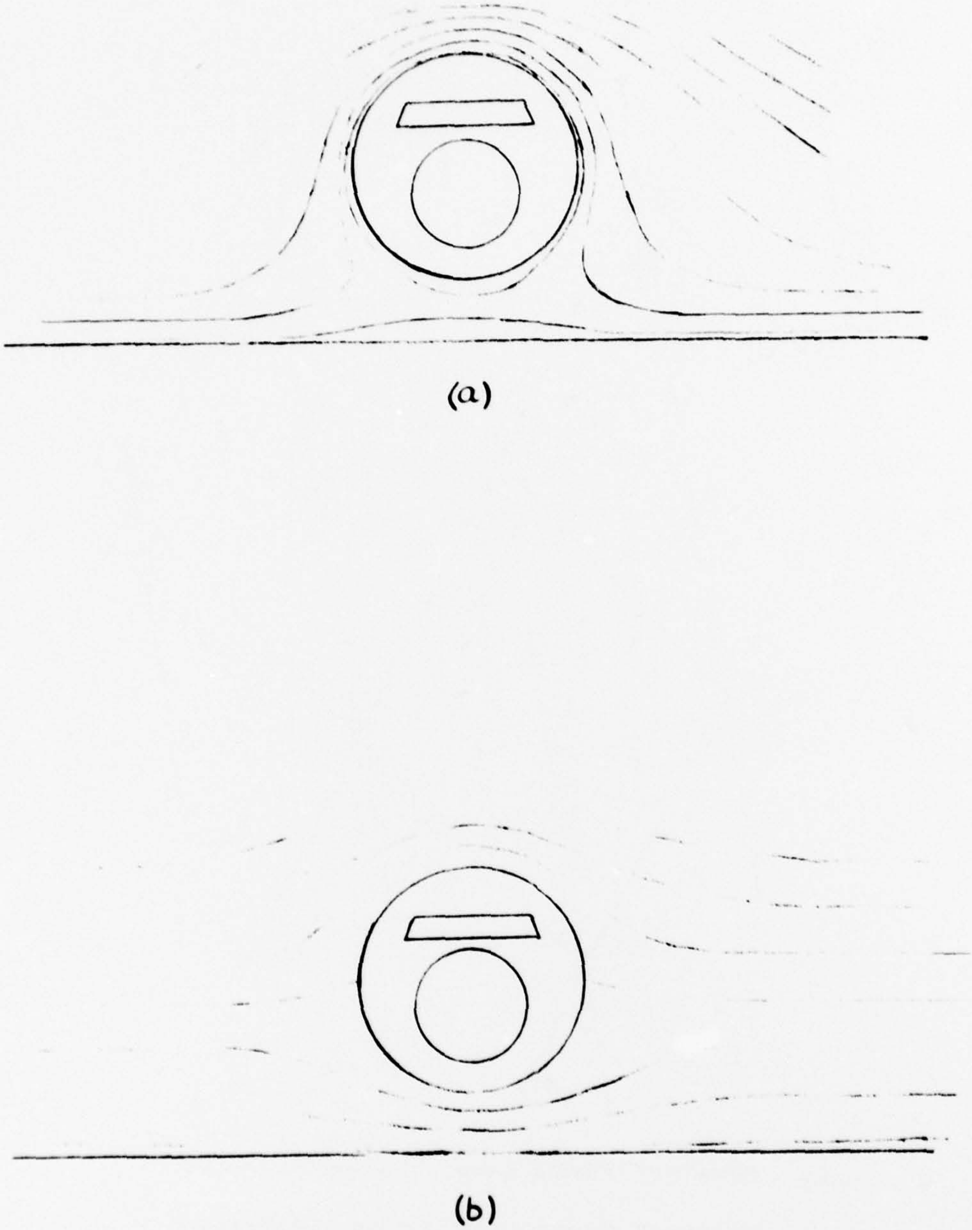


Fig 3 Effect of wavefront curvature



(a)

(b)

Fig 4 Equipotential surfaces round an aircraft

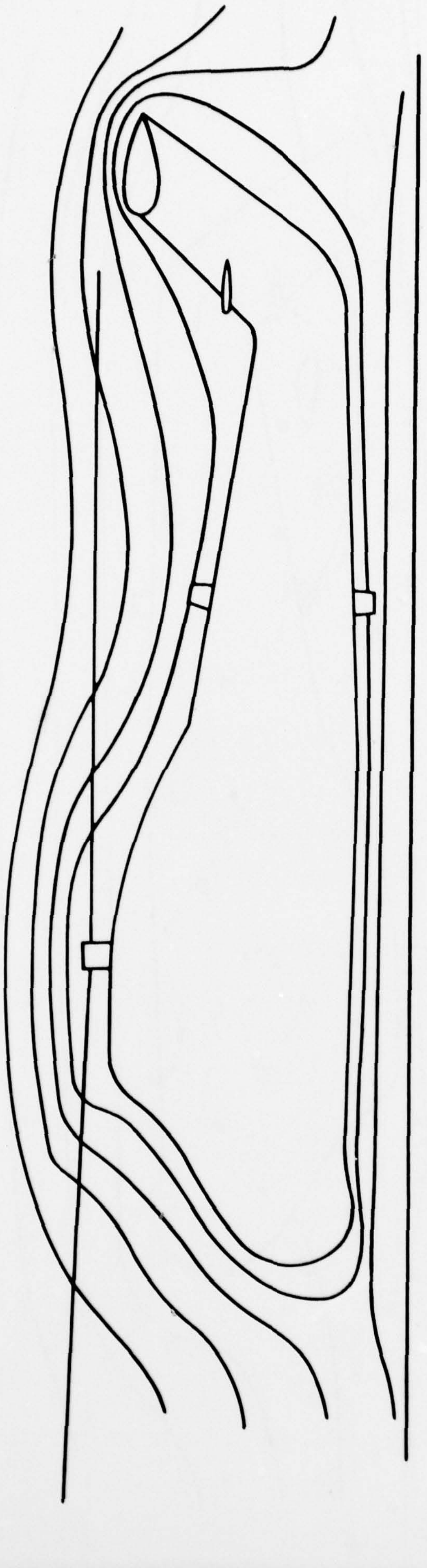


Fig 5 Equipotential surfaces round a helicopter on the ground

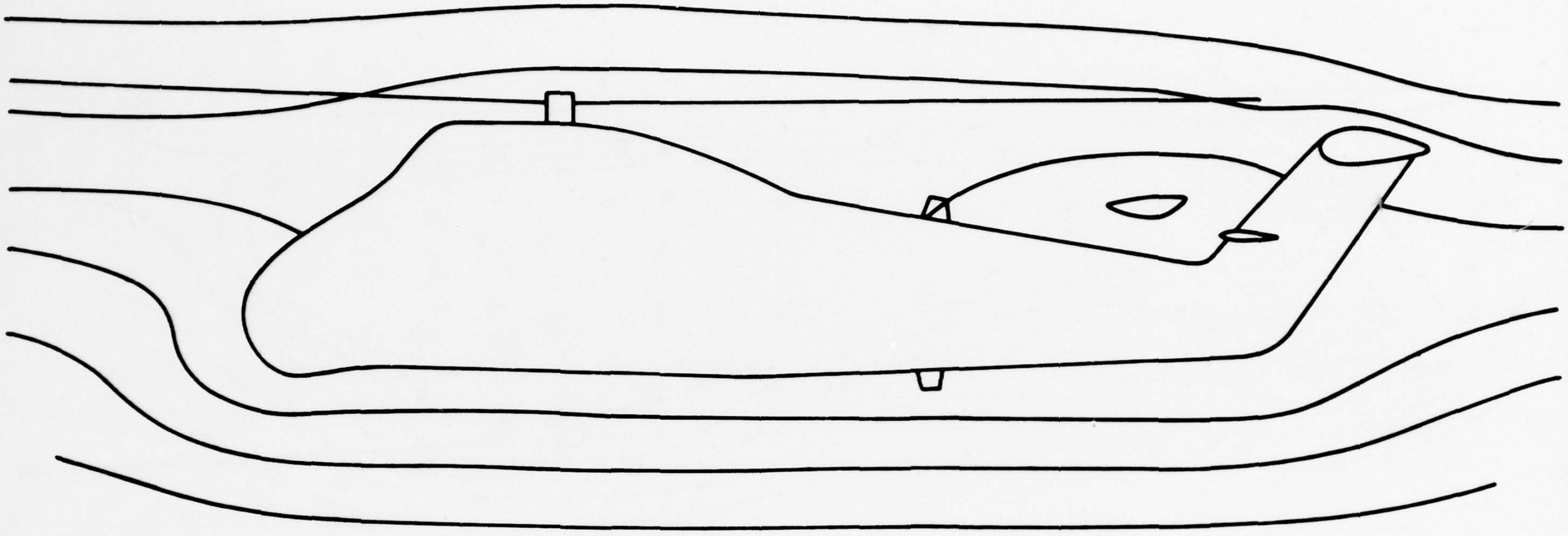
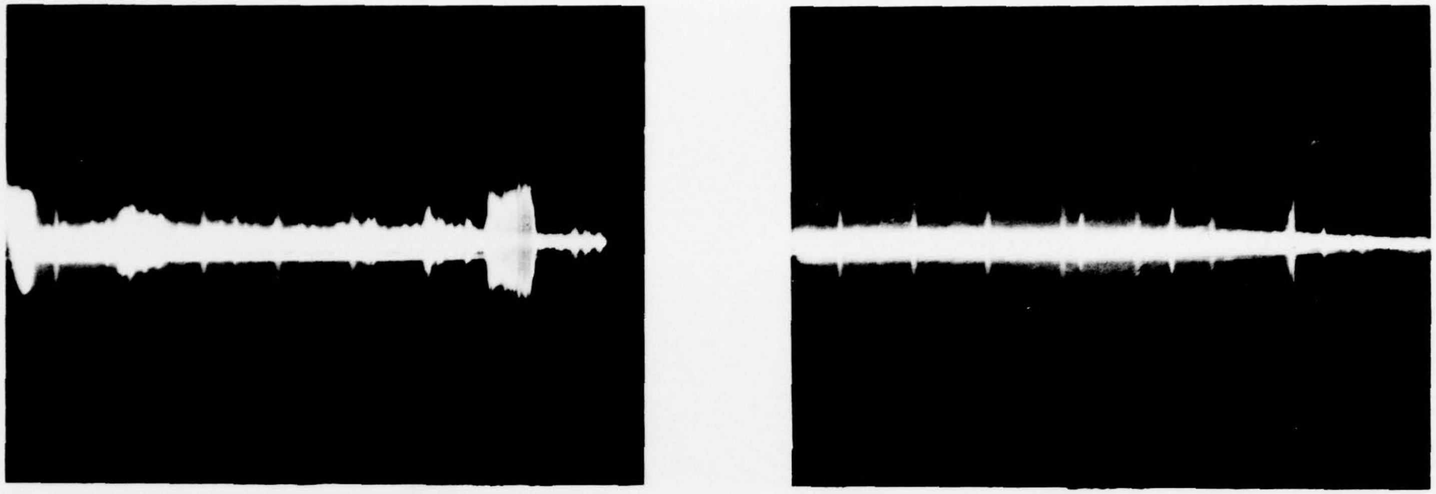
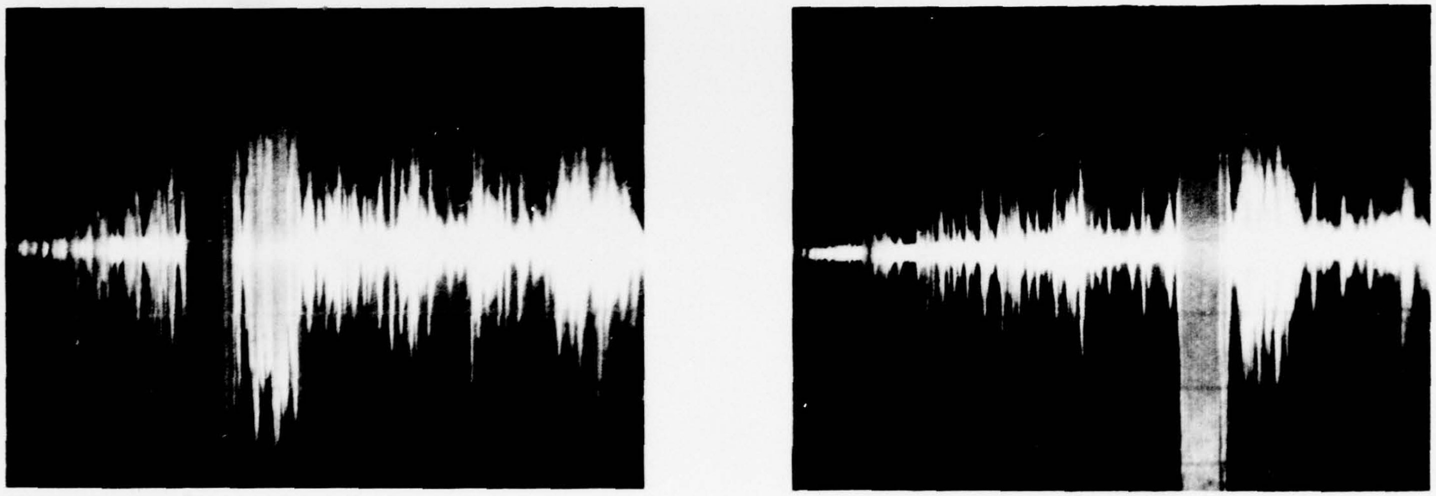


Fig 6 Equipotential surfaces round an airborne helicopter



Upper aerial aircraft on ground

Upper aerial aircraft airborne



Lower aerial aircraft on ground

Lower aerial aircraft airborne

Fig 7 Received Omega signals in a helicopter

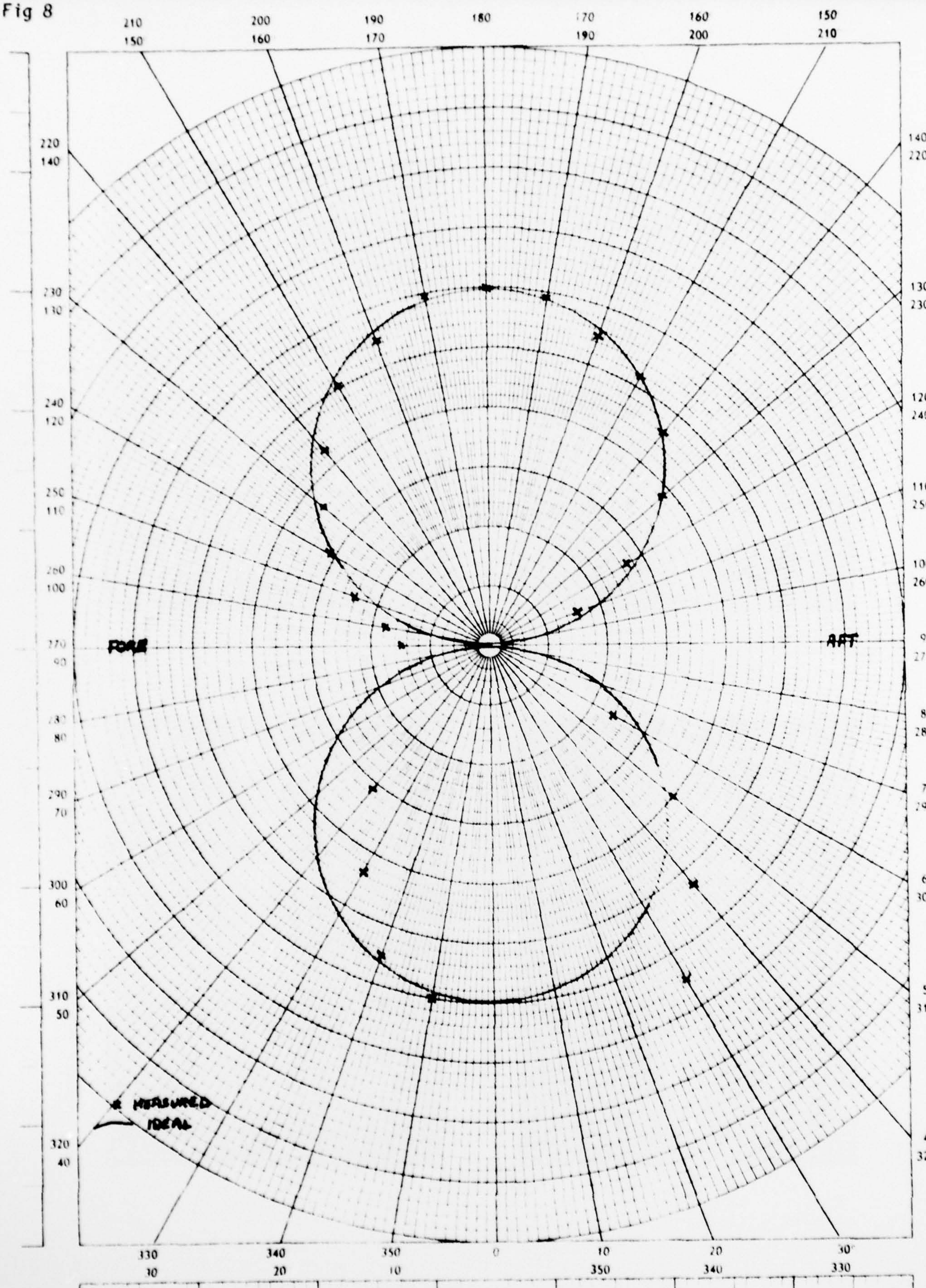


Fig 8 VLF loop polar diagram on Comet

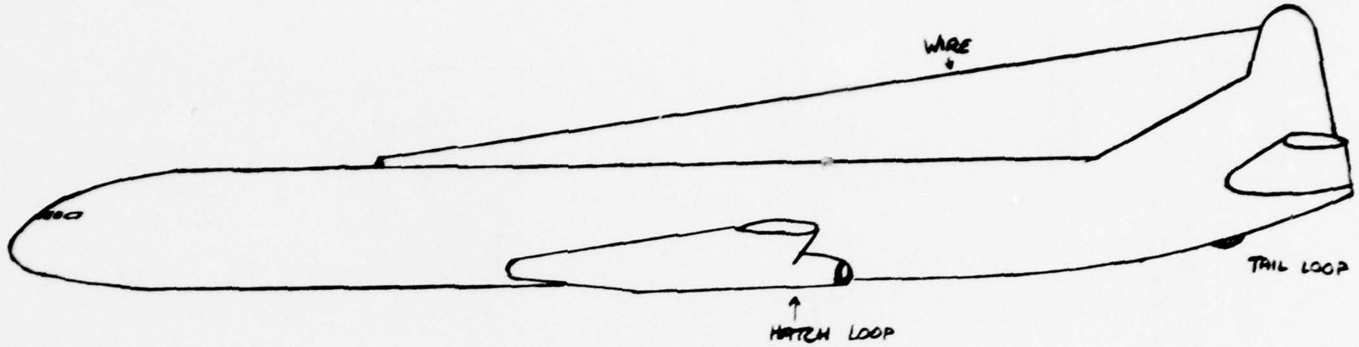


Fig 9 Comet aerial sites

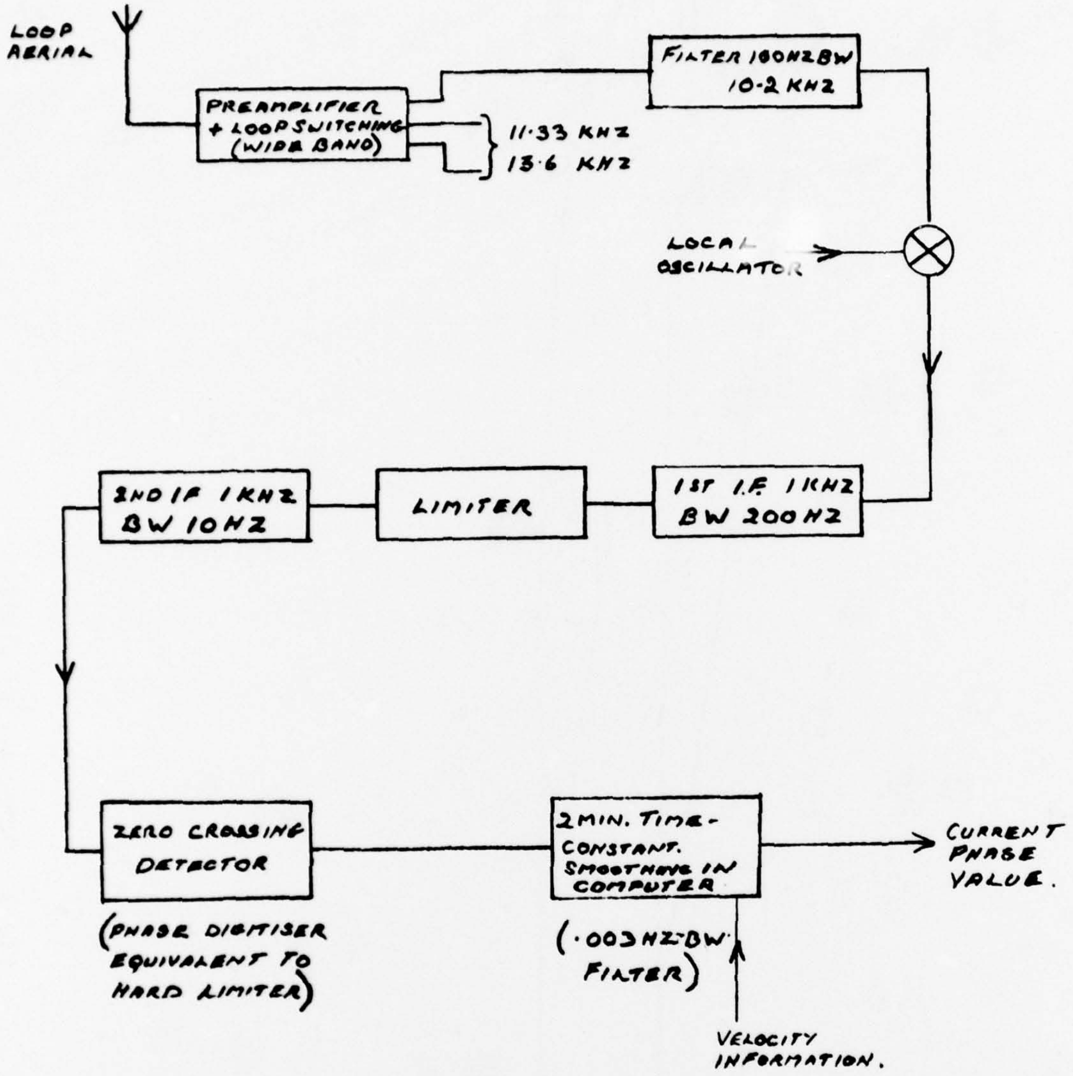


Fig 10 Signal processing in the Comet installation

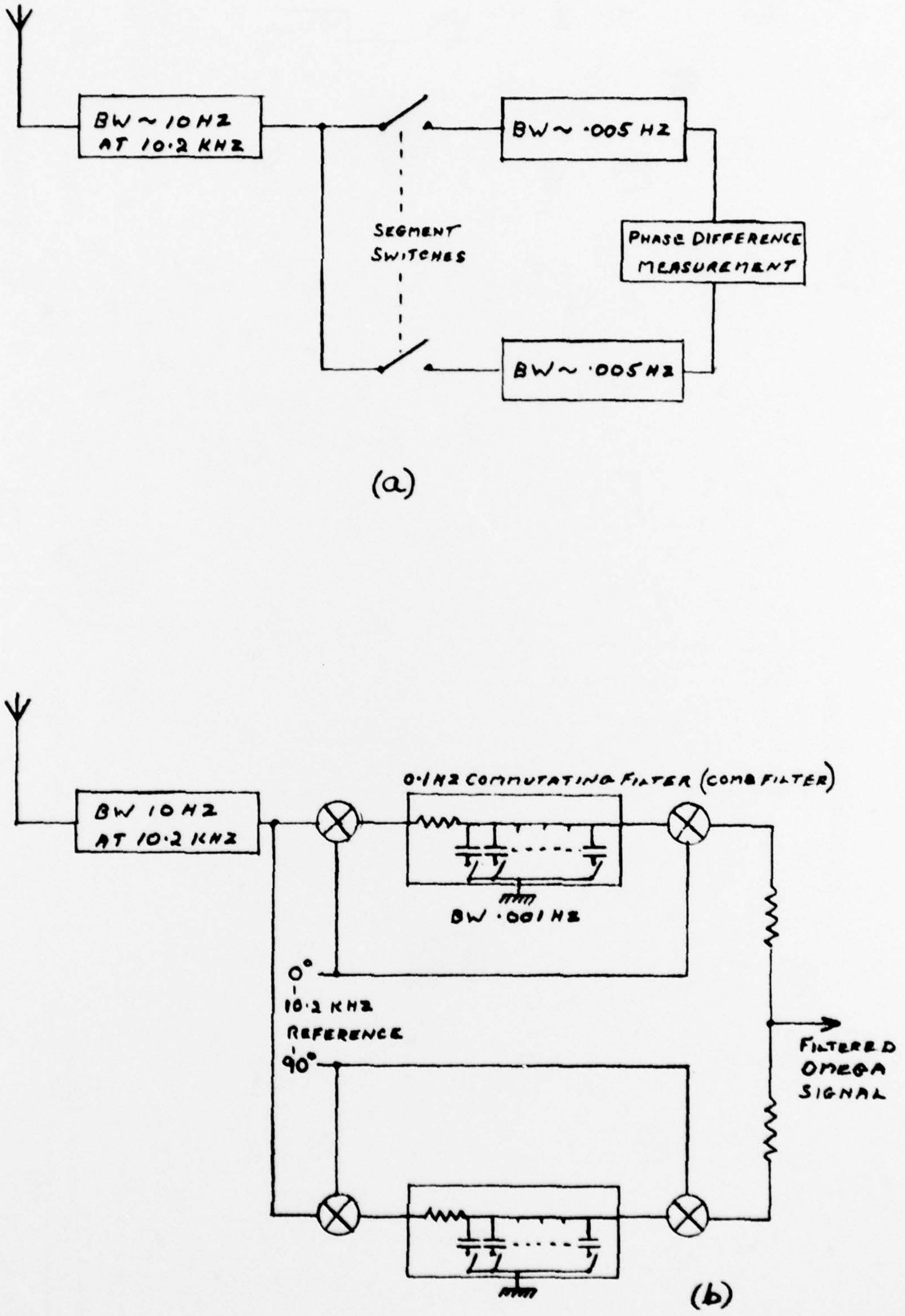


Fig 11 Narrow-band OMEGA receivers

Fig 12

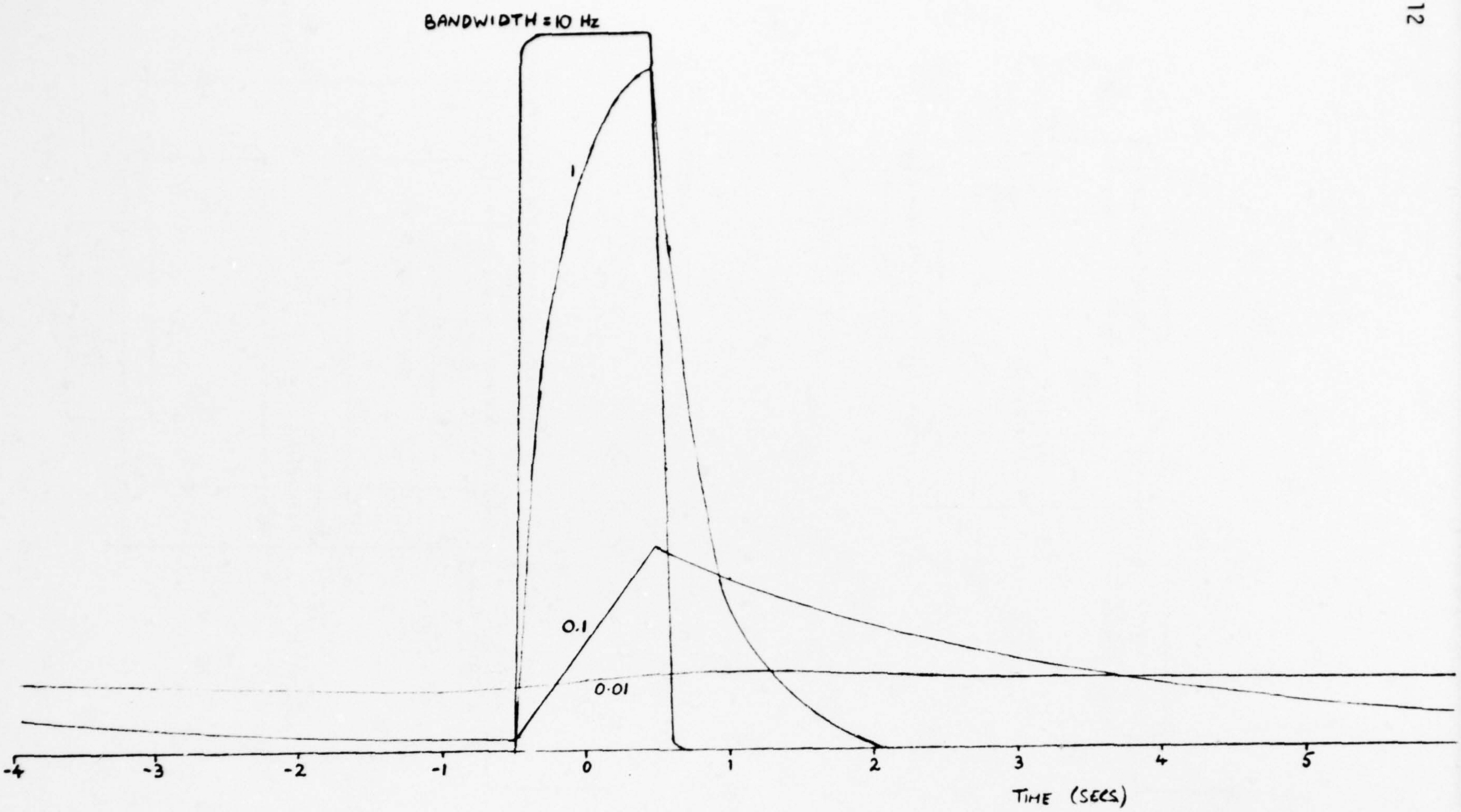
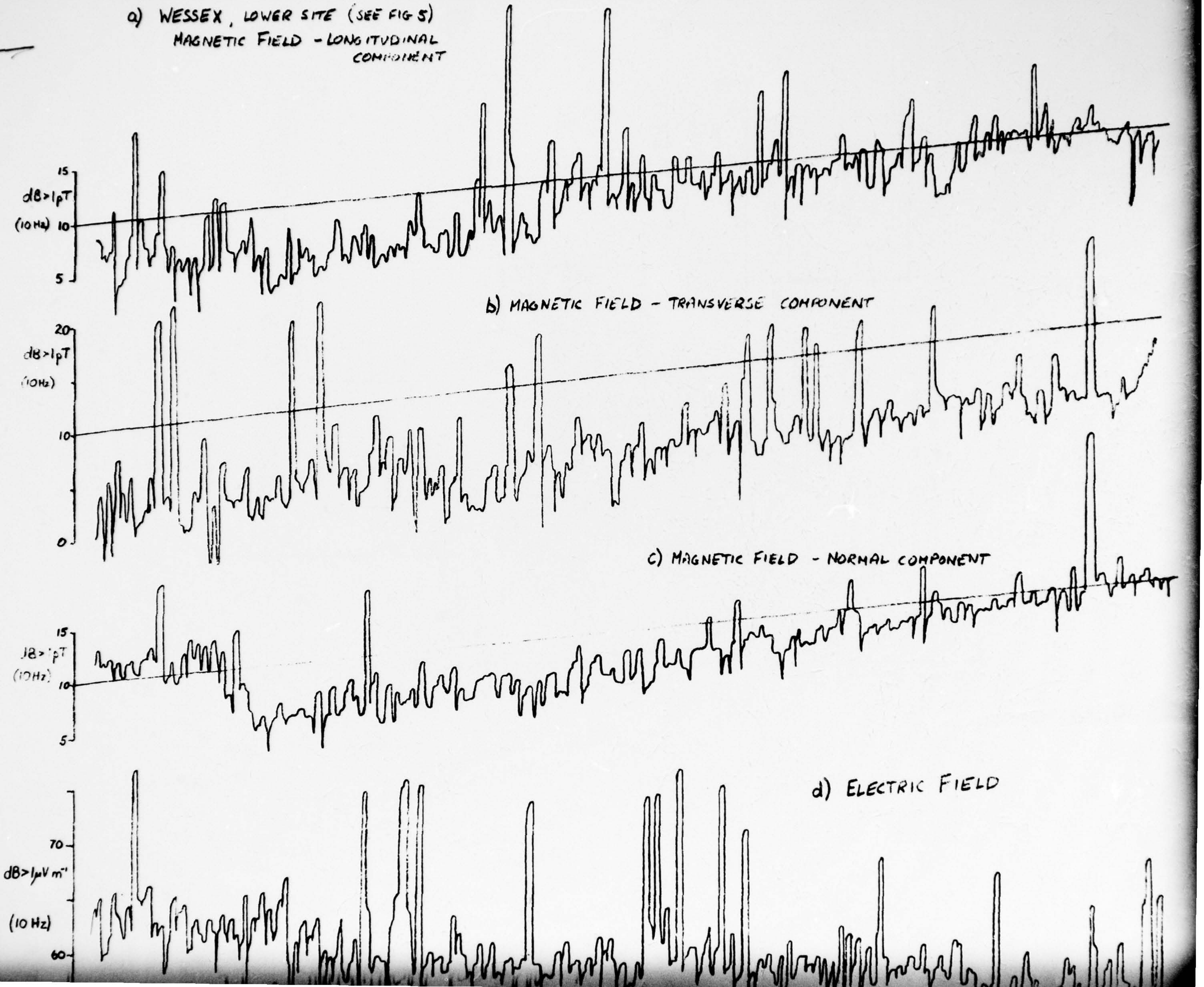


Fig 12 Effect of reducing bandwidth on OMEGA format


a) WESSEX, LOWER SITE (SEE FIG 5)
MAGNETIC FIELD - LONGITUDINAL COMPONENT
15
dB>1pT
(10 Hz) 10
5
b) MAGNETIC FIELD - TRANSVERSE COMPONENT
20
dB>1pT
(10Hz)
10
0
c) MAGNETIC FIELD - NORMAL COMPONENT
15
dB>1pT
(10Hz)
10
5
d) ELECTRIC FIELD
70
dB>1μV m⁻¹
(10 Hz)
60

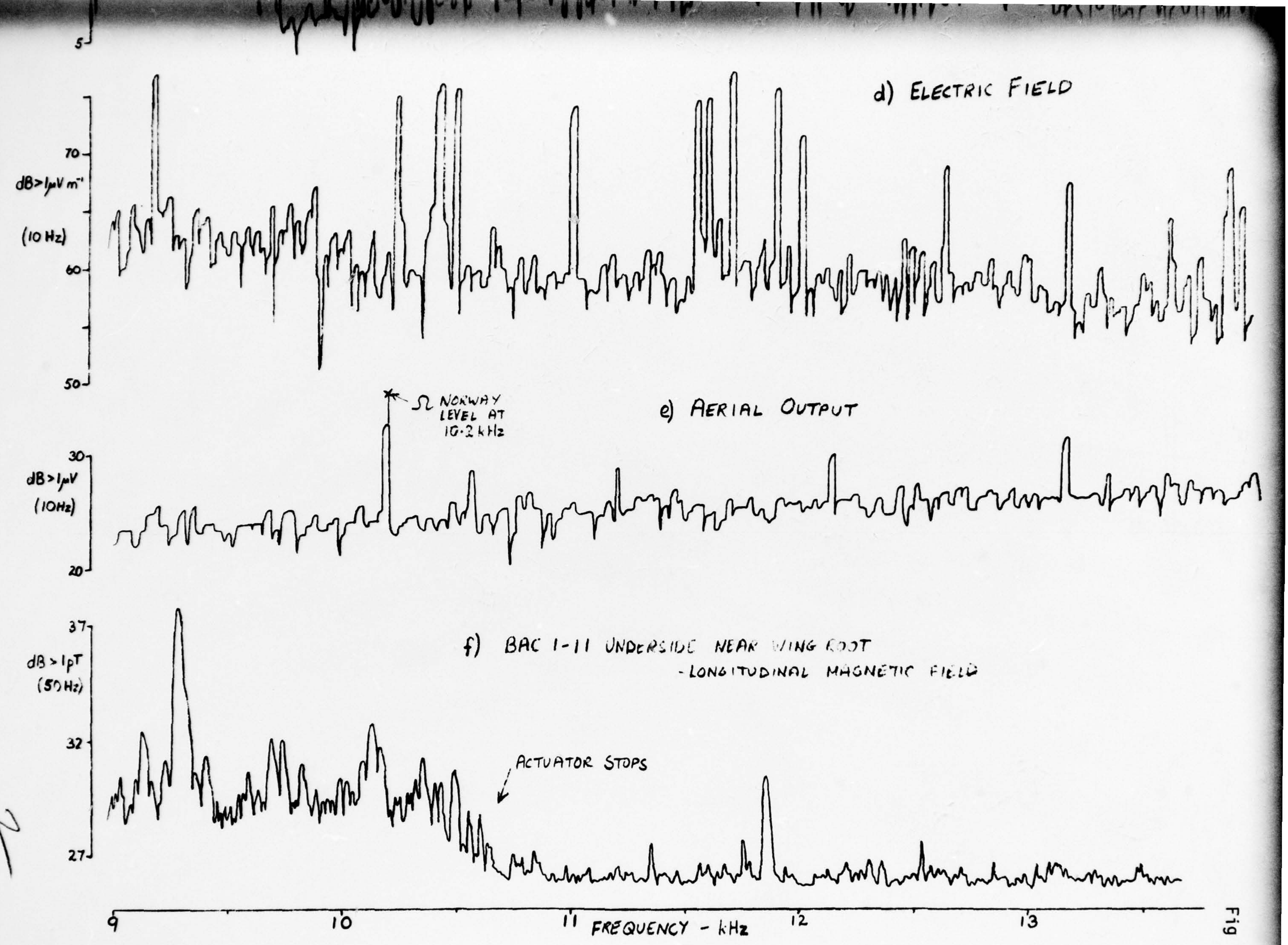


Fig 13 Noise spectra on aircraft skins: (a)-(e) Wessex helicopter, (f) BAC 1-11

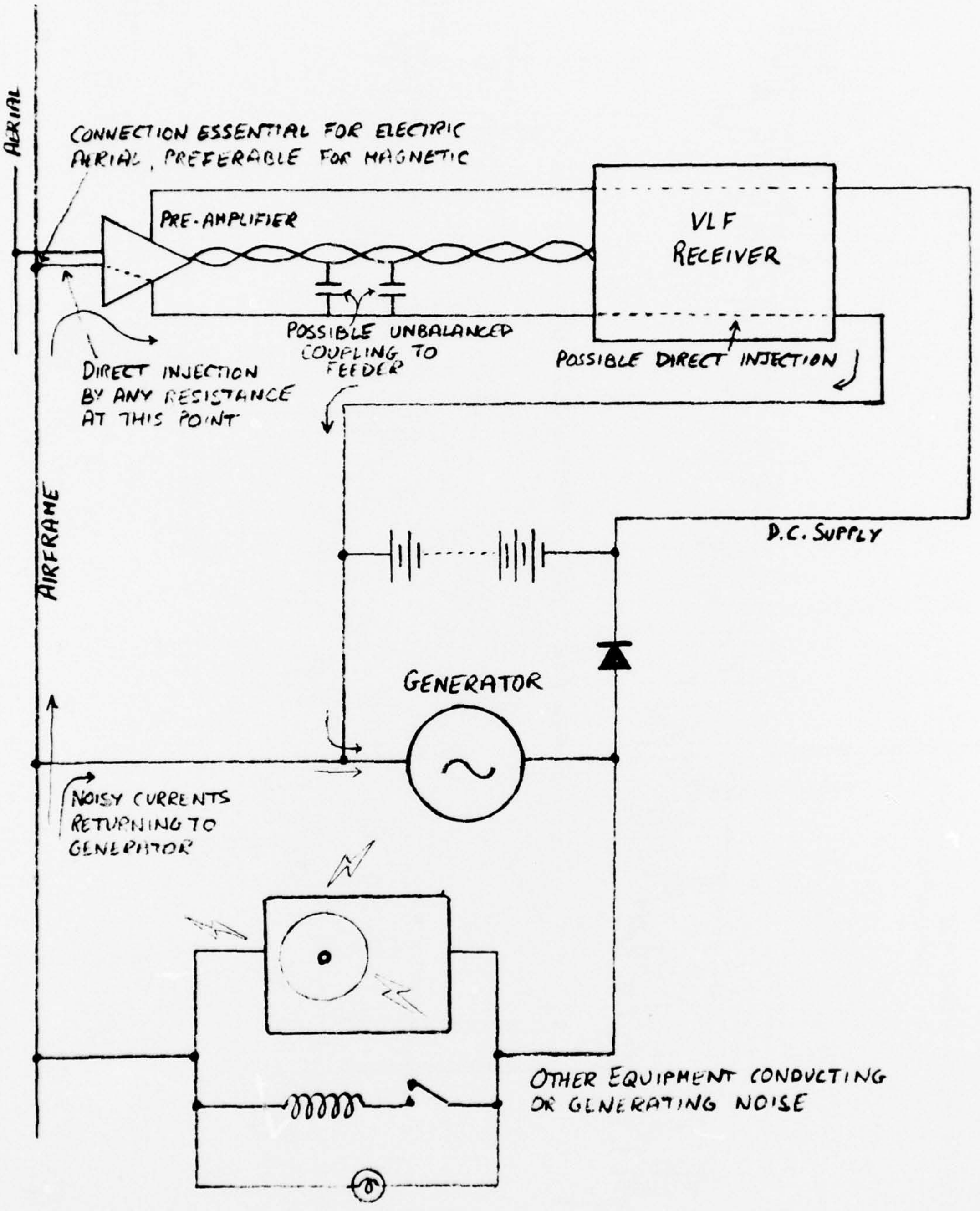


Fig 14 Interference injection into a VLF receiver

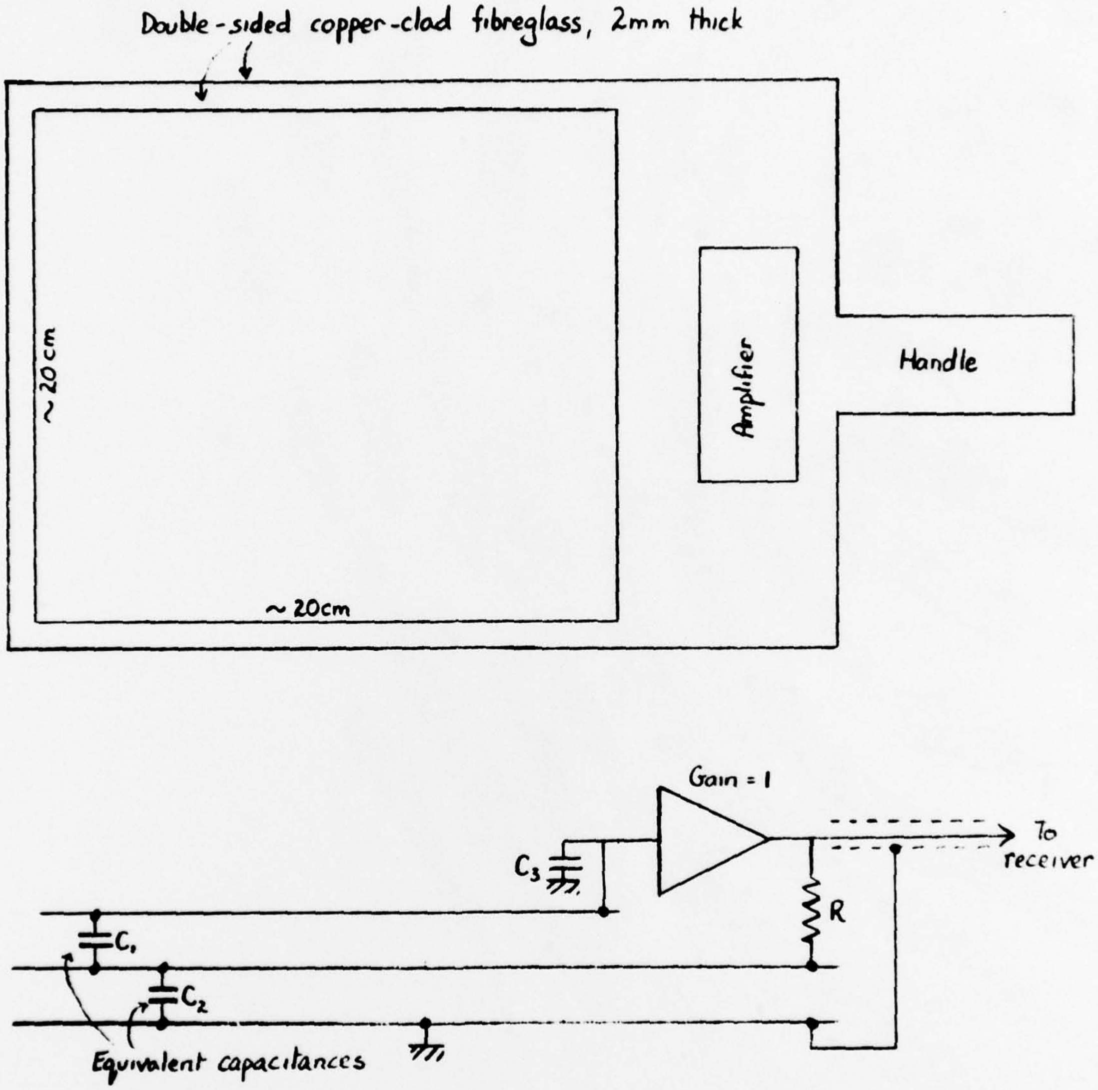


Fig 15 An E-field sensor

REPORT DOCUMENTATION PAGE

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Navigation. OMEGA. VLF

17. Abstract

This Memorandum summarises the principles found relevant to the successful operation of OMEGA and VLF installations in aircraft. It includes a list of interference field strengths found in various RAE aircraft, the considerations to be taken into account in the choice of aerial type and site, installation problems and their relation to receiver design. An indication is given of the direction that receiver design might take to eliminate the need for skin-mapping.

RAE Form A143