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ROYAL SIGNALS AND RADAR ESTABLISHMENT,
CHRISTCHURCH.

# Effects of trees and foliage on the propagation of UHF satellite signals

by

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# (6) EFFECTS OF TREES AND FOLIAGE ON THE PROPAGATION OF UHF SATELLITE SIGNALS

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(10) M. J. DOWNEY

ABSTRACT

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The Report describes measurements of the extra attenuation of UHF satellite signals due to siting of the receiver equipment within woods in Southern England. The results are summarised as probability distributions. At 254 MHz the average loss was 8 dB. The effects due to undergrowth and soil surface were minimal.

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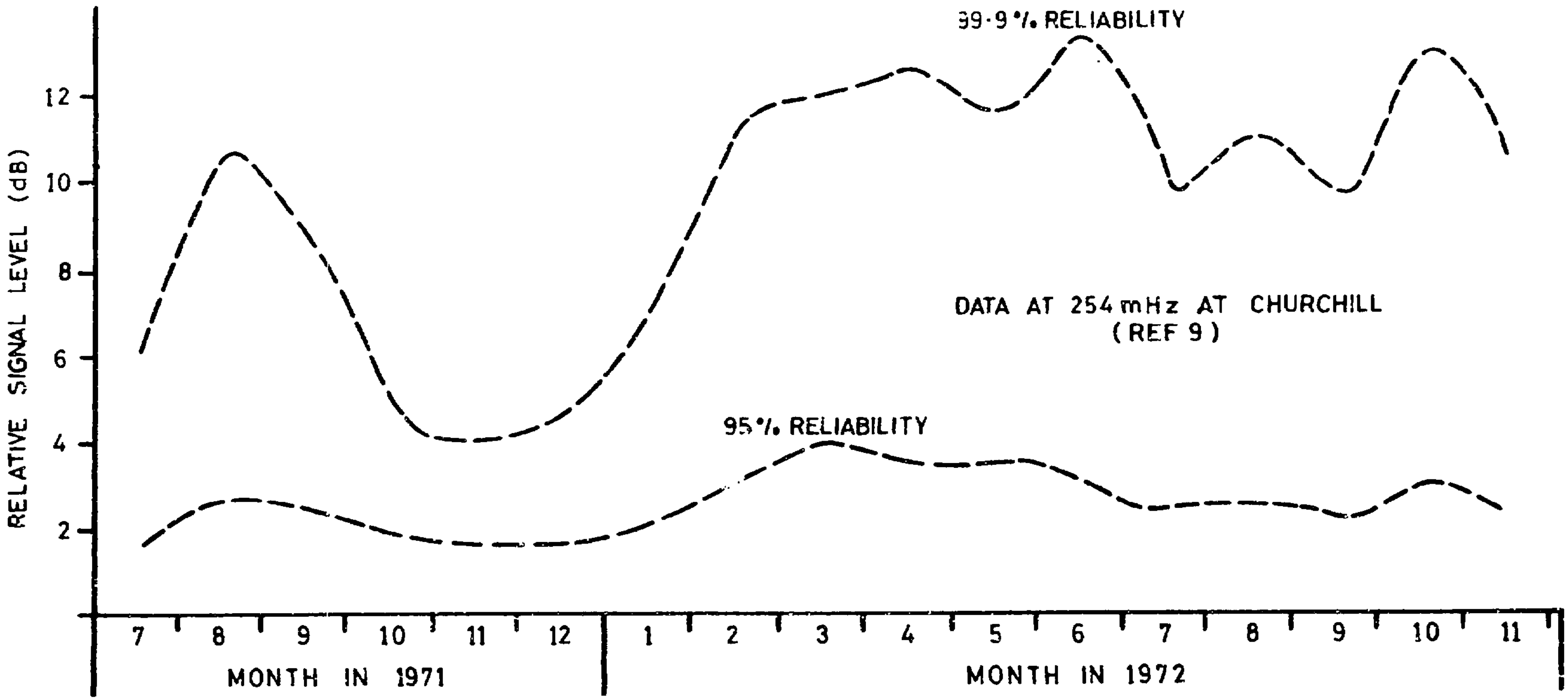


FIG. 1 IONOSPHERIC FADING MARGINS FOR 95 % AND 99·9 % PROPAGATION RELIABILITY

## 1. INTRODUCTION

The use of UHF for satellite communications has the particular attraction in that it allows the employment of simpler ground equipment. However one disadvantage of UHF is that multipath and scintillation effects are greater than those encountered at higher frequencies.

The use of small UHF sets for satellite communications is now feasible. In order to achieve an optimum equipment design there must be knowledge of all the possible signal losses that can occur. This paper reviews the various types of losses and describes some experiments carried out to measure the effects of trees and multipath on UHF signals from the MARISAT and LES 6 UHF satellites.

## 2. UHF SIGNAL LOSSES

A satellite signal strength (C) at a ground station may be expressed as

$$C = L_T \left[ P_T \; G_T \; G_R \right] \quad G_{MPG} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 1$$

where $P_T$ = transmitted power

$G_T$ = satellite antenna gain

$G_R$ = ground station antenna gain

$L_T$ = total losses in system

$G_{MPG}$ = multipath gain

The total loss $L_T$ may be broken down as follows (assuming no polarisation loss)

$$L_T = L_S \cdot L_A \cdot L_{EXR} \cdot L_F \cdot L_O \cdot L_{SCT} \cdot L_{T/R} \cdot L_{MPL} \qquad \ldots\ldots\ldots\ldots\ldots \; 2$$

where $L_S$ = free space loss

$L_A$ = atmospheric loss

$L_{EXR}$ = excess rain loss

$L_F$ = foliage loss

$L_O$ = obstacle loss

$L_{SCT}$ = scintillation loss

$L_{T/R}$ = pointing loss

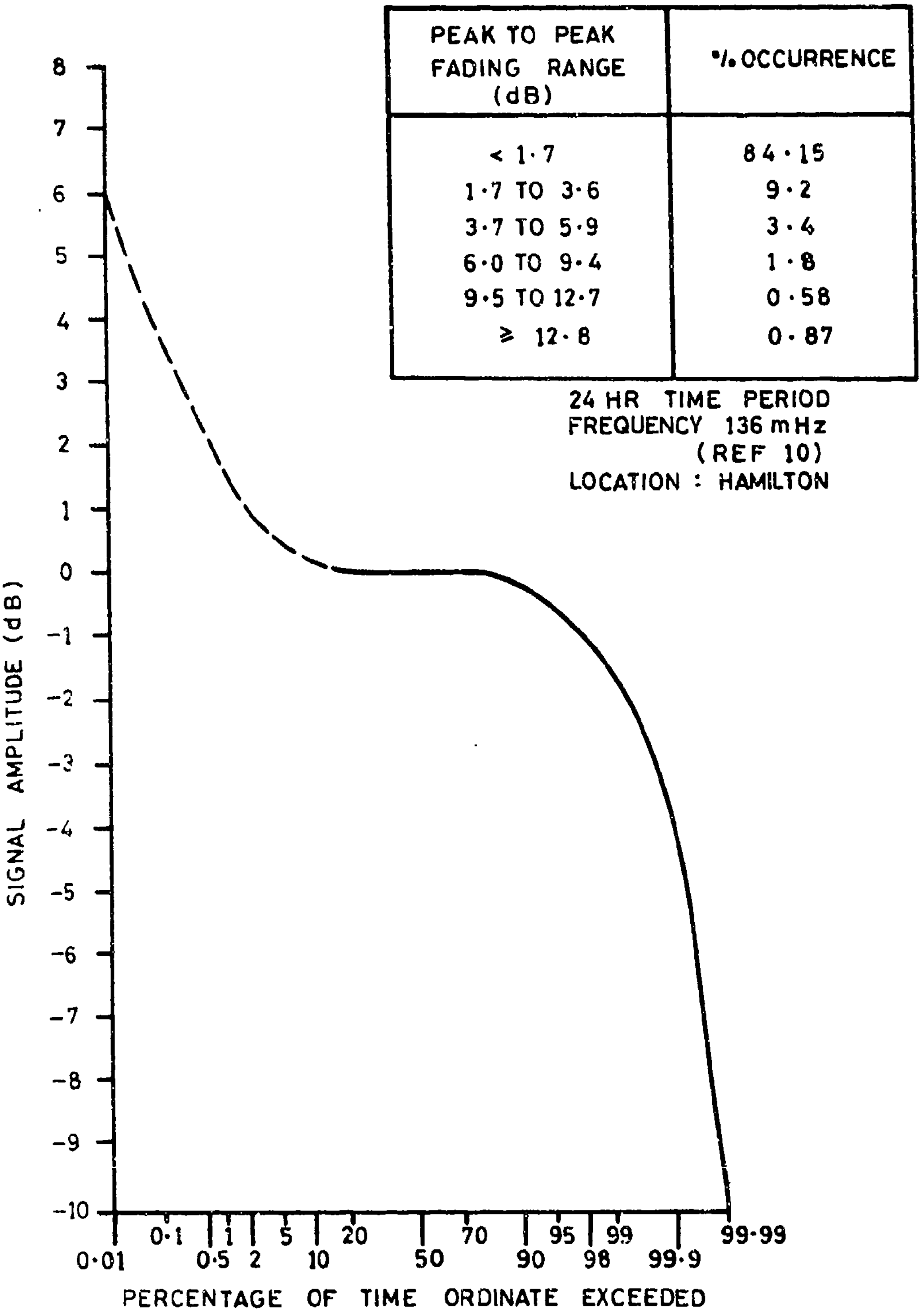
$L_{MPL}$ = multipath loss

The free space loss ($L_S$) increases linearly with increasing frequency as follows

$$L_S \text{ (db)} = 32.44 + 20 \log f + 20 \log d$$

where f = satellite frequency (MHz) and d = distance to satellite (km)

The atmospheric losses ($L_A$), which include fog, rain, oxygen, ozone, etc, vary in a complicated manner as a function of frequency. The main effect occurs above 5 GHz[1] and losses at UHF can be ignored. Ducting, inversions and other conditions which depart from the "standard" CCIR atmosphere can lead to losses (or gains) at UHF as shown by Kitchen et al[2] and MacDonald[3]. These are discussed by Burrows[4]: although the atmosphere extends to some 400 miles above the Earth's surface, the ducting and inversions occur in the atmosphere part which extends to 8 miles, so signals from satellites are not expected to be influenced by this phenomena except perhaps at very low angles of elevation.



| PEAK TO PEAK FADING RANGE (dB) | % OCCURRENCE |
|---|---|
| < 1·7 | 84·15 |
| 1·7 TO 3·6 | 9·2 |
| 3·7 TO 5·9 | 3·4 |
| 6·0 TO 9·4 | 1·8 |
| 9·5 TO 12·7 | 0·58 |
| ≥ 12·8 | 0·87 |

24 HR TIME PERIOD
FREQUENCY 136 mHz
(REF 10)
LOCATION : HAMILTON

FIG. 2 CUMULATIVE DISTRIBUTIONS FOR 2 YEARS OF ATS DATA

Significant losses due to rain occurs mainly in the 3 - 100 GHz range[5 and 6]. For excessive rain (say 100 mm/Hr), the loss is only 0.5 db/km at 3 GHz and becomes negligible for the lower UHF region. The pointing loss ($L_{T/R}$) can also be ignored at UHF.

The remaining four losses : [foliage ($L_F$), obstacles ($L_O$), scintillation ($L_{SCT}$) and multipath ($L_{MPL}$)] can each be considerable at UHF and are considered separately in the following sections.

## 3. HISTORICAL REVIEW

### 3.1 Scintillation Losses

A considerable amount of work has been carried out in recent years on scintillation effects, this being mainly due to the increased interest in satellite communications. Ionospheric scintillation is usually a result of changes in the F region of the ionosphere at attitudes of between 300 to 600 kilometres. A summary of the main conclusions reached is as follows:

a. Scintillation fading decreases with increasing frequency (f). Most authors quote a square law depedent but recent work[7] shows a variation according to $f^{-3/2}$, particularly in weak scintillation areas over the UHF range. Some experimental work shows that in the equatorial region at night time, 30 db fading is regularly noted at 130 MHz with little change at 250 MHz. In the 4 to 6 GHz range, the fading is 4 to 8 db whilst at 8 GHz the change is 1 db peak to peak.

b. The effects of scintillation are normally discussed in terms of geographical areas namely the equatorial belt located ± 20° around the magnetic equator, the polar cap above latitude 65° and the mid latitude belt. The effects in mid - latitudes are of prime interest for European operations.

A comparison of measurements made in Resolute Bay (74°N)with those made in Ottawa (46°N) during the same period, indicates that the duration of fading is less at mid latitudes. Attempts have been made[9] to link reliability of communication with scintillation frequency. Fig 1 gives some data showing such relationship for Churchill (58°N latitude). To assist engineers designing satellite systems, two years of data obtained at Hamilton (43° N) has been analysed and described in[10]. Fading margins obtained are reproduced in Fig 2.

Ionospheric phenomena are associated with geomagnetic rather than geographic latitude so that when relating data obtained in North America to European areas, there is need to make a correction of approximately 10° in latitude. Thus, data obtained at Hamilton (43°N geographic latitude approximately) could be considered relevant to, say, London (52° N latitude approximately). It can be seen therefore from Fig 2, that scintillation in mid and Southern European areas does not appear to be a major problem.

c. Studies on elevation-angle dependence show that up to 70 degrees at least, the intensity of scintillation is comparable at all angles[11].

d. The amount of scintillation depends on Sunspot activity. There appears to be little work done on longitude depedence. A number of papers on scintillation effects has been issued by the European Test Co-ordination Centre (ETCC)[12].

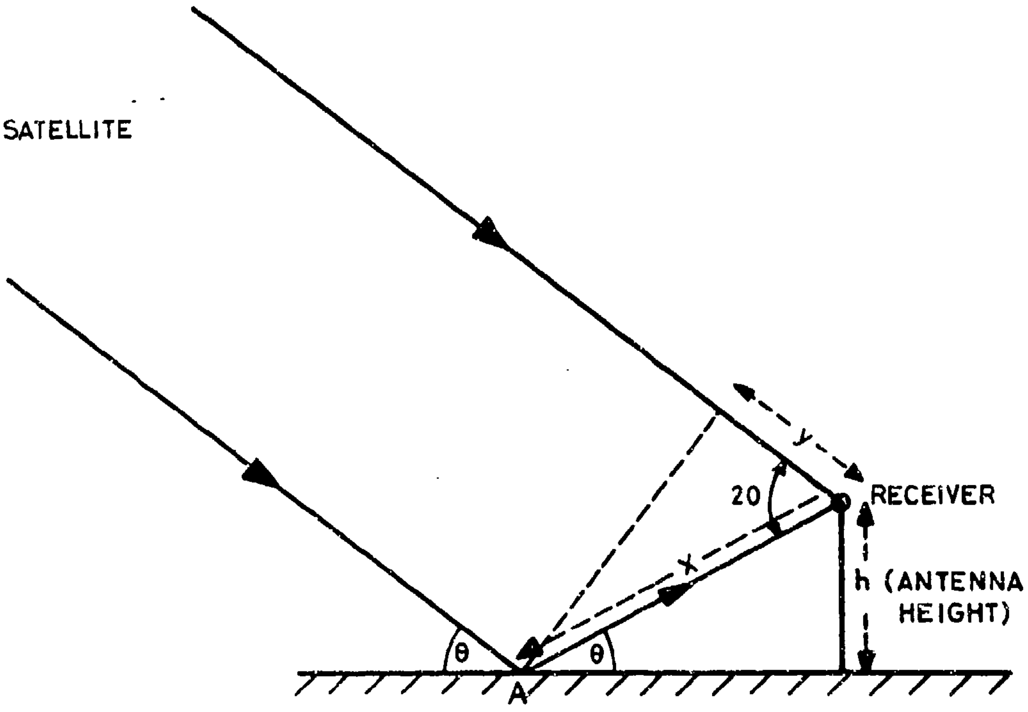
THE TOTAL FIELD AT THE RECEIVER

$$= E_d \left[ 1 + |R| e^{j(\phi - \psi)} \right]$$

WHERE $R$ = REFLECTION COEFFICIENT AT A

$\psi$ = CHANGE IN REFLECTED RAY PHASE ANGLE DUE TO PATH DIFFERENCE

$\phi$ = CHANGE IN PHASE ANGLE DUE TO REFLECTION AT THE POINT



PATH DIFFERENCE $= x - y = h / \sin\theta - x \text{ LOG } 2\theta$

$= 2h \sin\theta$

PHASE DIFFERENCE $= 2\pi / \lambda \, (2h \sin\theta) = \pi$ (MAX)

WHEN $4h \sin\theta / \lambda = 1$

i.e. WHEN $h = \lambda / 4 \sin\theta$

FIG.3 INCIDENT PLUS REFLECTED SIGNAL FROM A SATELLITE

## 3.2 Multipath Losses

In mathematical treatments, three types of waves are defined namely ground, space and sky waves. For satellite communications neither the ground wave (sometimes called "surface wave") nor the sky wave (sometimes called "ionspheric wave") play a significant role. Satellite transmissions take place by means of the space wave which can be broken into two components namely, the "direct wave" (no contact with the ground) and the "reflected wave".

### 3.2.1 Space Wave

A detailed derivation of free space propagation can be found in the literature dating back to 1910. Theoretical expressions for the resultant field obtained by the combination of the direct and reflected wave have also been given by numerous authors[13,14,15].

### 3.2.2 Direct and Reflected Waves from Satellites

For satellites, particularly at geo-stationary heights, the distance between the transmitter and receiver is so great that all waves from the satellite in the vicinity of the receiver can be considered parallel, as shown in Fig 3.

Thus, if the antenna height is fixed, then moving the antenna from one location to another should not change the amplitude of the received signal, assuming ground conditions do not vary. However, a series of maxima and minima will be found if the antenna height is varied. As shown in Fig 3, the maximum strength should be found when

$$h = \lambda/4 \text{ Sin } \theta$$

assuming 180° reversal on reflection, which occurs when the wave is horizontally polarised (see following section). For vertical polarisation this formula gives the minimum strength except at low angles of incidence where the precise nature of the ground reflectivity affects the results.

When circular polarisation is reflected, it changes hand so that a perfect circularly polarised antenna should not see the reflected ray for small angles of incidence and hence there should not be a change of signal strength with antenna height. However, for larger angles of incidence, a change of signal with height is to be expected, as shown later.

### 3.2.3 Reflection Coefficients

The amount of reflected signal received by an antenna is dependent upon

a. the polarisation of the incident and reflected wave

b. the angle of incidence of incident and reflected wave

and c. the reflection coefficient of the surface which in turn is related to the permittivity and conductivity of the medium. The reflection coefficients ($R_V$ and $R_H$) can be calculated as shown in Appendix A.

### 3.2.4 Properties of the Earth's Surface

Typical values for the relative permittivity and conductivity of the Earth's surface are given in the following table. These parameters vary with frequency but the values given are those obtained from measurements made in the UHF region.

| DESCRIPTION | $\varepsilon_r$ | $\delta$ (mho/m) | REF |
|---|---|---|---|
| Sea water | 81 | 4.5 | 29 |
| Fresh water | 80 | 0.01 | 29 |
| Moist soil | 15-30 | 0.005-0.01 | 5 |
| Pastoral, low hills<br>Rich soil | 20 | 0.01 | 29 |
| Pastoral, medium<br>Hills, forestation | 13 | 0.005 | 29 |
| Rocky soil, flat sandy | 10 | 0.002 | 29 |
| Dry soil | 4 | .001-0.01 | 5 |
| Cities, industrial | 5 | 0.001 | 29 |

Measurement techniques for obtaining ground dielectric constants are described in 16 .
The following values have been quoted(17) for trees:

Thin forest $\varepsilon_p = 1.01$ $\delta = 10^{-5}$ (mho/m)

Thick forest $\varepsilon_p = 1.5$ $\delta = 10^{-3}$ (" ")

### 3.2.5 Rough Surfaces

Diffraction effects produced by hilly terrain and obstacles are treated later. When a receiving antenna is situated in the vicinity of rough or undulating terrain (eg rocky beach, side of undulating hill, etc) a mathematical prediction of the total field can be complicated. The Rayleigh criterion is usually used to define roughness which states that the surface may be regarded rough if the variations of the surface are such as to cause variations in the path length of more than one eighth of a wavelength. Thus, for an angle of incidence $\theta$ this means

$$2 H \sin \theta < \lambda/8$$

Where H is the average height of the roughness. For roughness height greater than $\lambda$ /16 Sin O, the laws of specular reflection no longer apply and the reflections must then be considered diffuse.

## 3.3 Obstacle Losses

Obstacles are defined as objects which are opaque to UHF waves. (Buildings and trees which are somewhat transparent are considered in section 3.4). Obstacles include mountains and hills and in many cases these can be regarded theoretically as knife edges or edges with a parabolic section.[18 19] The effect of a knife edge cutting the Fresnel zones is shown in Fig 4.[13] The loss due to diffraction across a knife edge has been calculated by numerous authors and has been given in the form of a nemograph.[1 20]

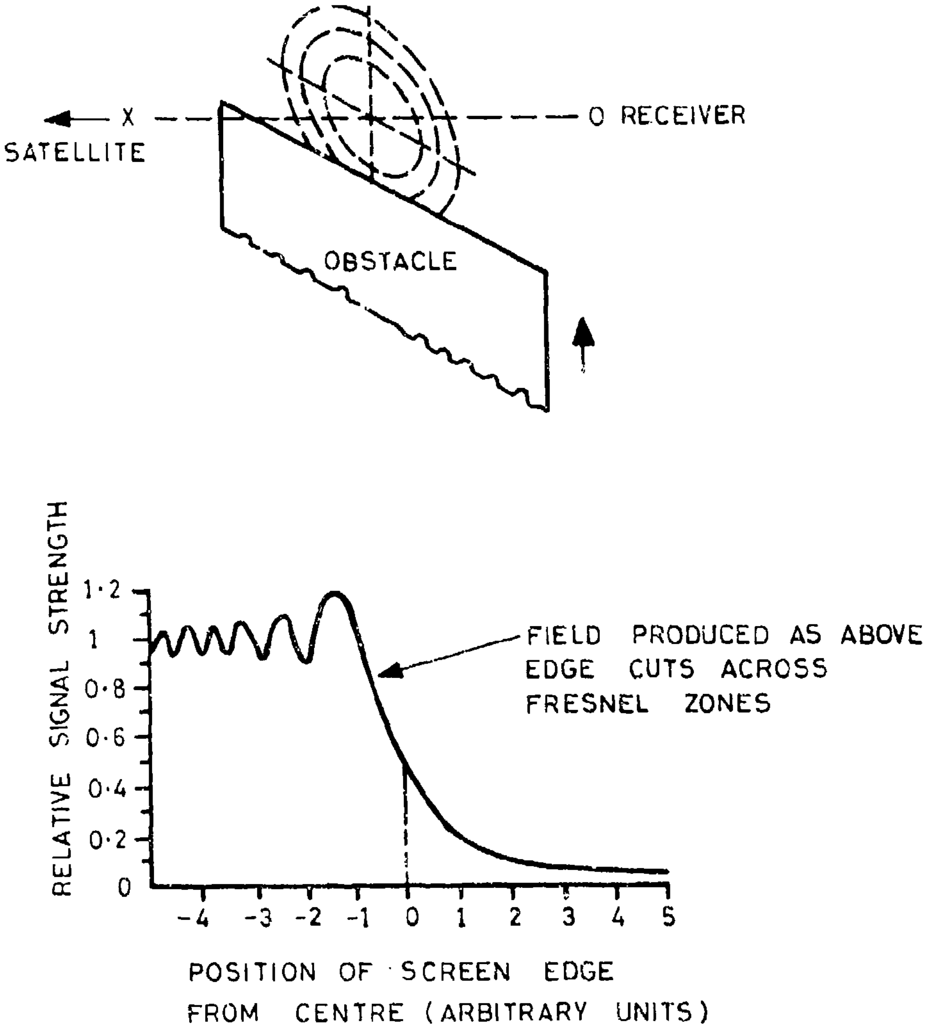


FIG. 4 STRAIGHT EDGE DIFFRACTION EFFECTS

From Fig 4 it can be seen that when a ray path from a transmitter to a receiver grazes the knife edge obstacle then half of the signal is lost. Thus, the amount of loss will depend on the radii of the Fresnel zones. If the distance between the transmitter and receiver is d, the $N^{th}$ Fresnel zone clearance distance ($r_N$) at a distance $d_1$ from the end of the path is

$$r_N = \left[ \frac{N\lambda d_1 \quad (d - d_1)}{d} \right]^{\frac{1}{2}}$$

When $d_1$ is small compared to d, then

$$r_N = (N\lambda d_1)^{\frac{1}{2}}$$

As shown later, the radius of the first Fresnel zone at UHF is comparable with the diameter of trees.

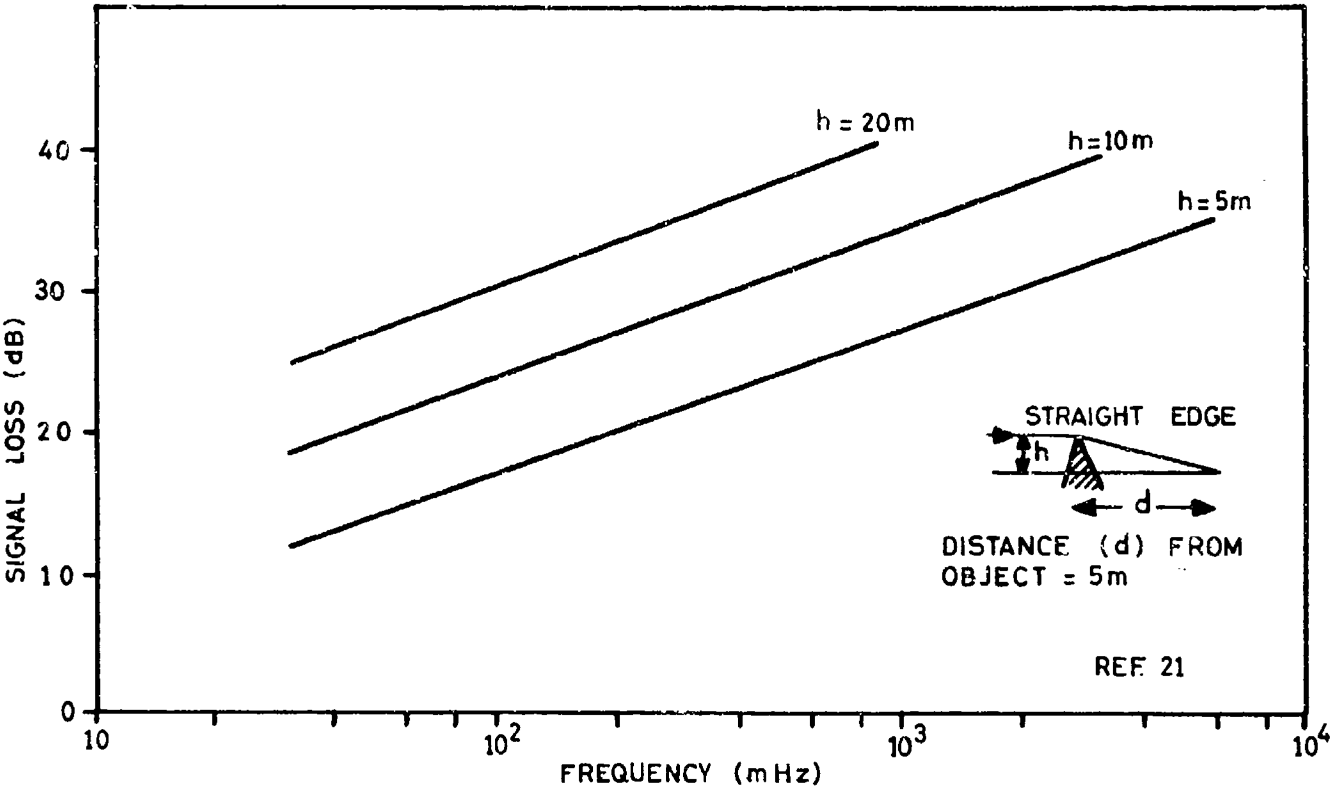


FIG. 5 DIFFRACTION LOSSES AT A STRAIGHT EDGE

Using Fresnel theory, some diffraction losses have been calculated[21] and are shown in Fig 5 for diffraction around a sharp edge.

### 3.4 Tree Losses

Because trees and buildings may be transparent to radio waves the field in the shadow of such obstacles cannot be calculated using the same assumptions as for diffraction beyond hills. It has been shown experimentally[20] that the field observed in New York City has a median value about 25 db below the value expected over a plane earth in the frequency range 40-450 Mc/s. Although some data exists for ground to ground measurements there appears to be little data from satellite experiments.

A number of authors [22 to 26] have attempted to measure the loss for transmission through trees. The loss here depends on frequency and polarisation. For example, at 30 Mc/s the loss may be 3 db for vertical polarisation and negligible for horizontal polarisation. However, at 100 Mc/s it may be 10 db for vertical and 3 db for horizontal. As frequency increases, the effect of polarisation becomes less, and at about 500 Mc/s the loss is independent of polarisation[5].

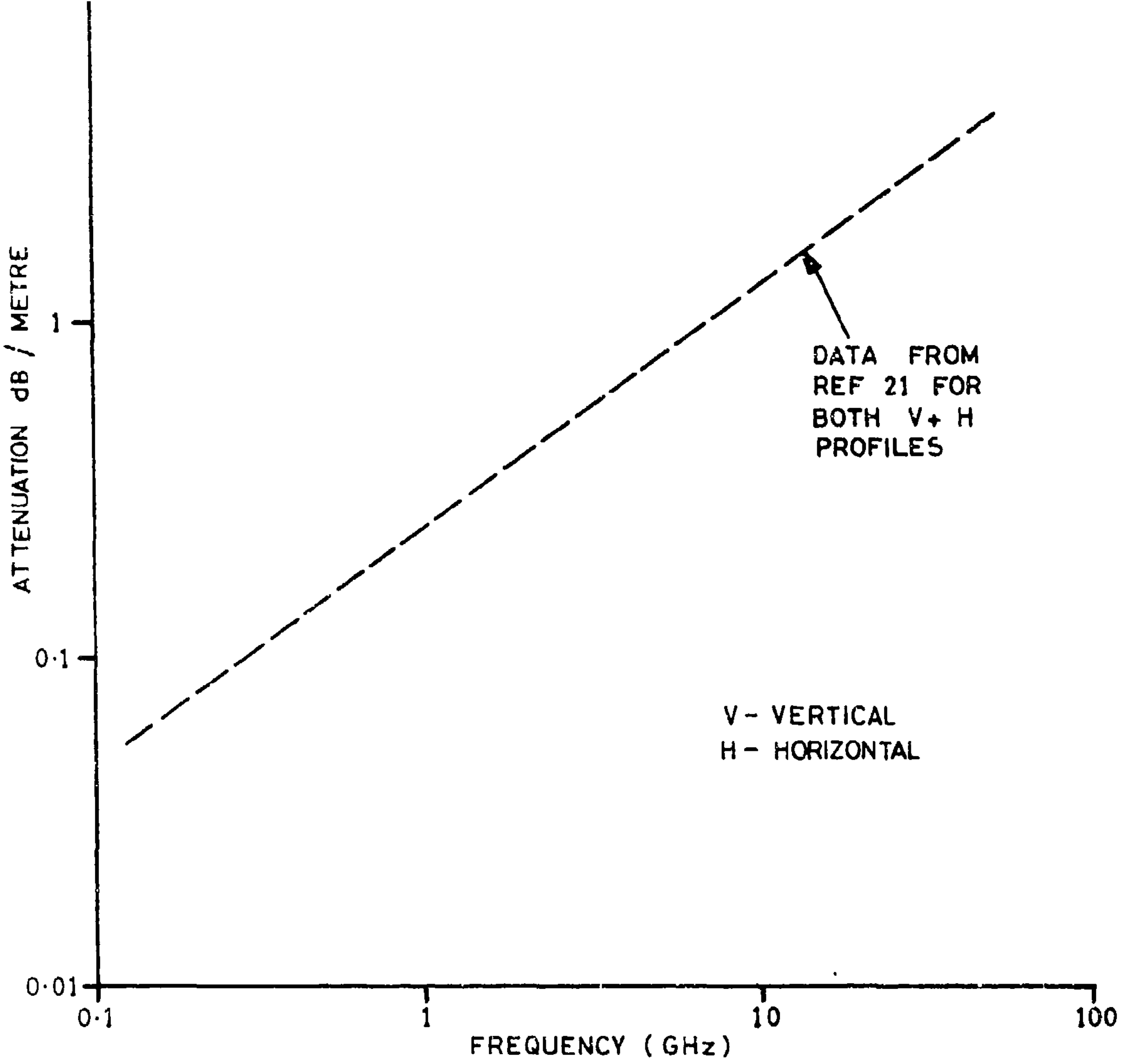


FIG.6 ATTENUATION VERSUS FREQUENCY IN TREES

Attempts have been made to measure the rate of attenuation in woods with trees in leaf[21] as shown in Fig 6. At say 200 MHz, the approximate rate of attenuation is given as 0.08 db/m.

Recently, a comprehensive theoretical study has been made of the propagation of radio waves for communication paths that may lie partly within a forest and partly in the air region outside the vegetation[27]. It is shown that depending on frequency, on distance and on the positions of transmitter and receiver, the prominent field along the mixed path may be a refracted wave or a lateral wave, ie a wave travelling along tree tops. For satellite communication, it would appear that only the refracted wave concept applies but again no significant data using satellites is available.

## 4. DESIGN OF EXPERIMENT

The first objective was to build a mobile receiving station to operate with a satellite transmitting a constant UHF signal. The LES 6 satellite was chosen but unfortunately this satellite was switched off in the middle of the trials and the equipment then had to be modified to operate with another satellite, namely MARISAT. Because the MARISAT UHF signal was not constant, a second stationary receiving station had to be built to monitor the open signal and thus establish a reference for all signals received using the mobile station.

### 4.1 LES 6 Satellite

The initial satellite chosen was LES 6 which although launched in September 1968 was considered to be constant and reliable. The beacon transmission was used and, according to information available at that time, had the following characteristics:

Frequency 254.15 MHz
200/sec biphase modulation of carrier
Right hand circular polarised antenna
Antenna gain (satellite equator) 8.4 db
Antenna 3 db beamwidth 54°

The beacon power (EIRP) was calculated from data available for the period 1971 to 1974 and extrapolated to January 1976 (date of trials) to yield an average 3.2W. The satellite was synchronous at 38° West on the equator giving a look angle of 226° azimuth and 21° elevation from RSRE Christchurch.

It was known that the beacon signal was affected by

a. a spin related ripple in the radiated power due to the fact that one of the solar cell panels was defective and

b. a ripple caused by switching from one antenna segment to the next; there are 16 switching points per satellite rotation. A typical example of the recorded signal is given in Fig 7 and from this the spin rate of the satellite can be calculated.

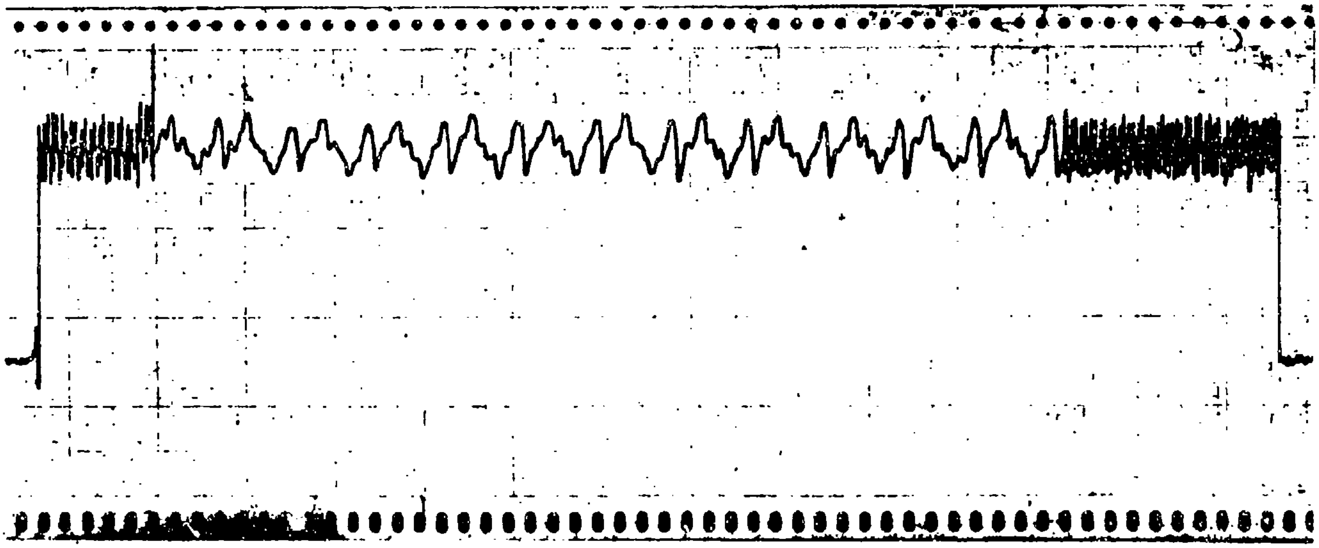


FIG. 7 LES 6 SATELLITE SIGNAL (CHART SPEEDS 1" AND 8" / MIN)

The signal to noise ratio for free space was calculated to be 44 db/Hz, assuming a ground station antenna gain of 6 db and an effective temperature of 300° K.

## 4.2 MARISAT Satellite

MARISAT (also known as GAPFILLER) was launched in Feb 1976 and placed very close to LES 6. As a result the LES 6 transmissions were switched off. The beacon frequency on MARISAT is in the SHF range but fortunately one of the narrow band channels from the UHF communication repeater was found to give a reasonably constant signal so that these studies could continue. The Marisat published characteristics for the UHF repeater are as follows.

| | | | |
|---|---|---|---|
| Frequency (transmit) | 248-260 MHz | | |
| Channel bandwidth (1 dB) | 480 kHz | 24 kHz | 24 kHz |
| Saturation EIRP (edge of coverage) | 28 dBW | 23 dBW | 23 dBW |

The theoretical signal to noise ratio for free space for the narrow channel used was calculated 62 dB/Hz approx.

## 4.3 Theoretical Considerations

The MARISAT frequency used was close to the LES 6 frequency. The calculations given in this section are for 254 MHz only.

### 4.3.1 Maximum Signal Strength

As shown in Fig 3, the signal strength of the receiver depends upon the phase angle change and path difference associated with the reflected ray. For small angles of reflection, the reflection coefficient is 1 and the phase of the reflection coefficient is $-\pi$ (see following section) for both horizontal and vertical polarisation.

For angles of incidence of 21° (satellite angles above) and hard soil, the Brewster angle occurs about this angle so that the vertical reflection coefficient is small. Hence for circular polarisation (satellite polarisation above), the reflected ray is mainly horizontally polarised and the received signal will go through a series of maxima and minima with change in antenna heigth. The first maxima for the UHF satellites used should occur when

$$h_1 = \frac{118 \text{ cm}}{4.\text{Sin } 21} = 82 \text{ cm approx}$$

The angle of incidence is the same as the elevation angle and thus assumes an antenna mounted on horizontal terrain.

### 4.3.2 Reflection Coefficents

In order to understand multipath effects more fully, it is necessary to determine the horizontal reflection coefficient ($R_h$) and the vertical reflection coefficient ($R_V$) for the LES 6 frequency and for the type of terrain being used for this experiment.

Properties of typical Earth surface for this experiment were taken from section 3.2.4 as

$$\varepsilon_1 = 15 \qquad \delta = 10^{-2} \text{ mhos/metre}$$

From the equations in section 3.2.3 the coefficients $R_H$ and $R_V$ were calculated for f = 254 MHz as detailed in Appendix A. The results are plotted in Fig 8. It should be noted that for the

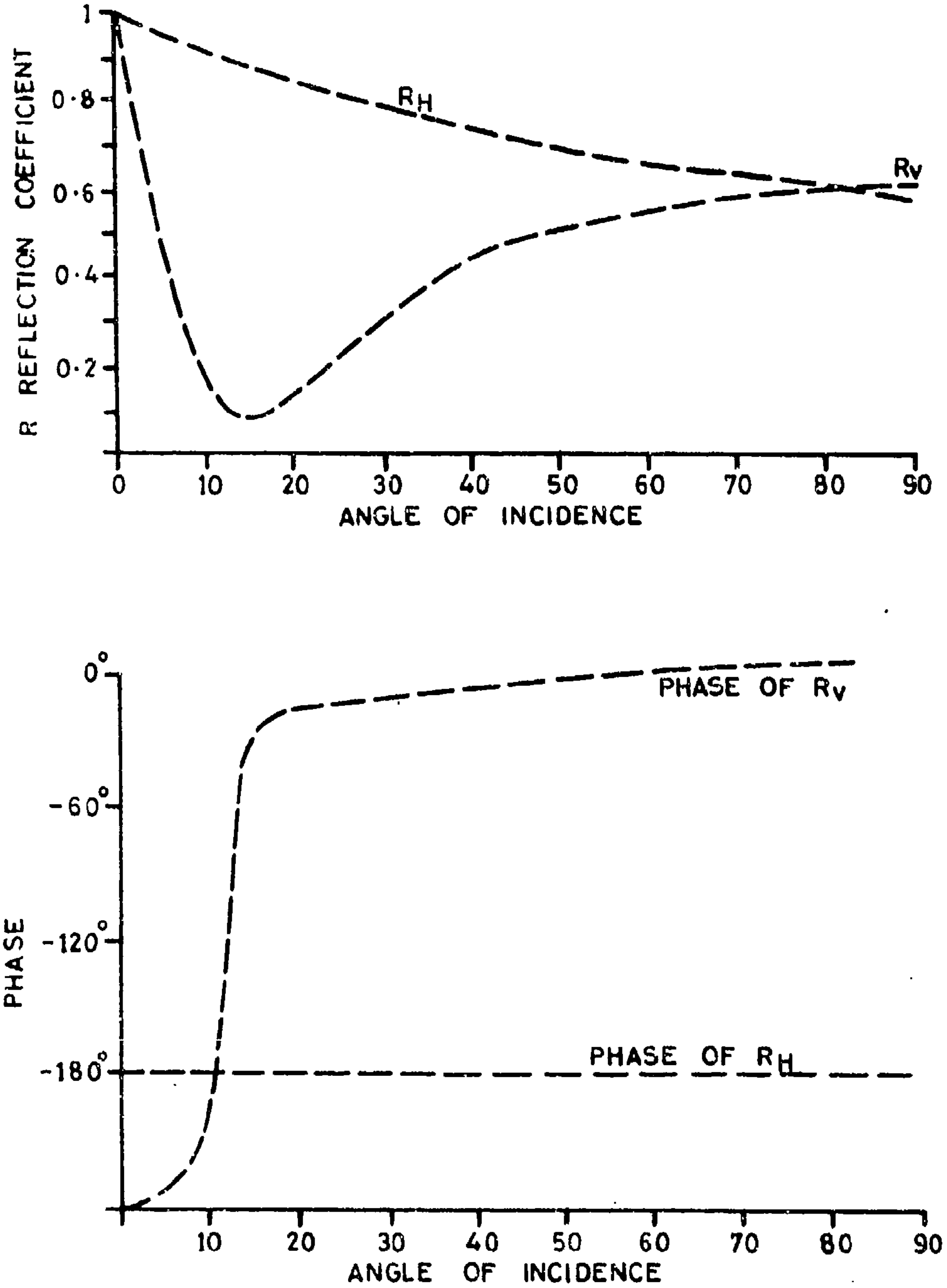


FIG 8 REFLECTION COEFFICIENT VERSUS ANGLE OF INCIDENCE

angle (21°), coefficients are as follows:

| | Reflection Coefficient | Phase |
|---|---|---|
| Horizontal Component | 0.84 | $-180^{\circ}$ |
| Vertical Component | 0.13 | $-12^{\circ}$ |

### 4.3.3 Rough Surfaces

The criterion for roughness was given in section 3.2.5. For the elevation angle of $21^{\circ}$ and frequency 254 MHz, the average height was calculated to be

$$H < \frac{118}{2 \times 8 \times \text{Sin } 21^{\circ}} = 20.6 \text{ cm}$$

Thus, in order to ensure specular reflection, the average height of the ground surrounding the antenna must be less than 20.6 cm.

Since both direct and indirect rays are originally parallel, then for an antenna height adjusted for maximum signal (ie at 82 cm) and the surrounding terrain horizontal, the reflected ray would originate from the ground at a distance

$$X = \frac{82}{\tan 21} = 213.6 \text{ cm}$$

### 4.3.4 Obstacles and Trees

In section 3.3, Fresnel's theory was used to give losses as a function of obstacle height and distance from the obstacle. The geometry was as shown in Fig 5. For an obstacle perpendicular to a flat terrain and a satellite which has an elevation angle $\theta$, the loss can be calculated from

$$E_o/_{E_d} = 0.36 \, h_N \, (f/_d)^{\frac{1}{2}} \quad \text{(see Fig 5)}$$

where $E_o$ is the field without the obstacle and $E_d$ is the field with the obstacle and where h is now $= h \cos \theta - d \,\text{Sin}\, \theta$

If a forest could be considered opaque, then for trees 20 m high and an antenna placed 5 m behind trees, the diffraction loss for $0 = 21^{\circ}$ would be

$$0.36 \times 16.88 \left( \frac{254}{5} \right)^{\frac{1}{2}} = 32.73 \text{ dB}$$

As shown later no loss of any such magnitude was actually measured.

The kind of forest being considered here can be described as having patches of dense forestation intermingled with clearings so that when the antenna is pointing at the satellite, the forest does not present itself as a uniform medium. Thus, each location in the forest can be considered unique. From section 3.3, the radii of the first 3 Fresnel zones, at the frequency considered here, are 1.09, 1.54 and 1.88 metres. Thus, a tree of 1 metre or 0.5 metre diameter has a significant diffraction effect.

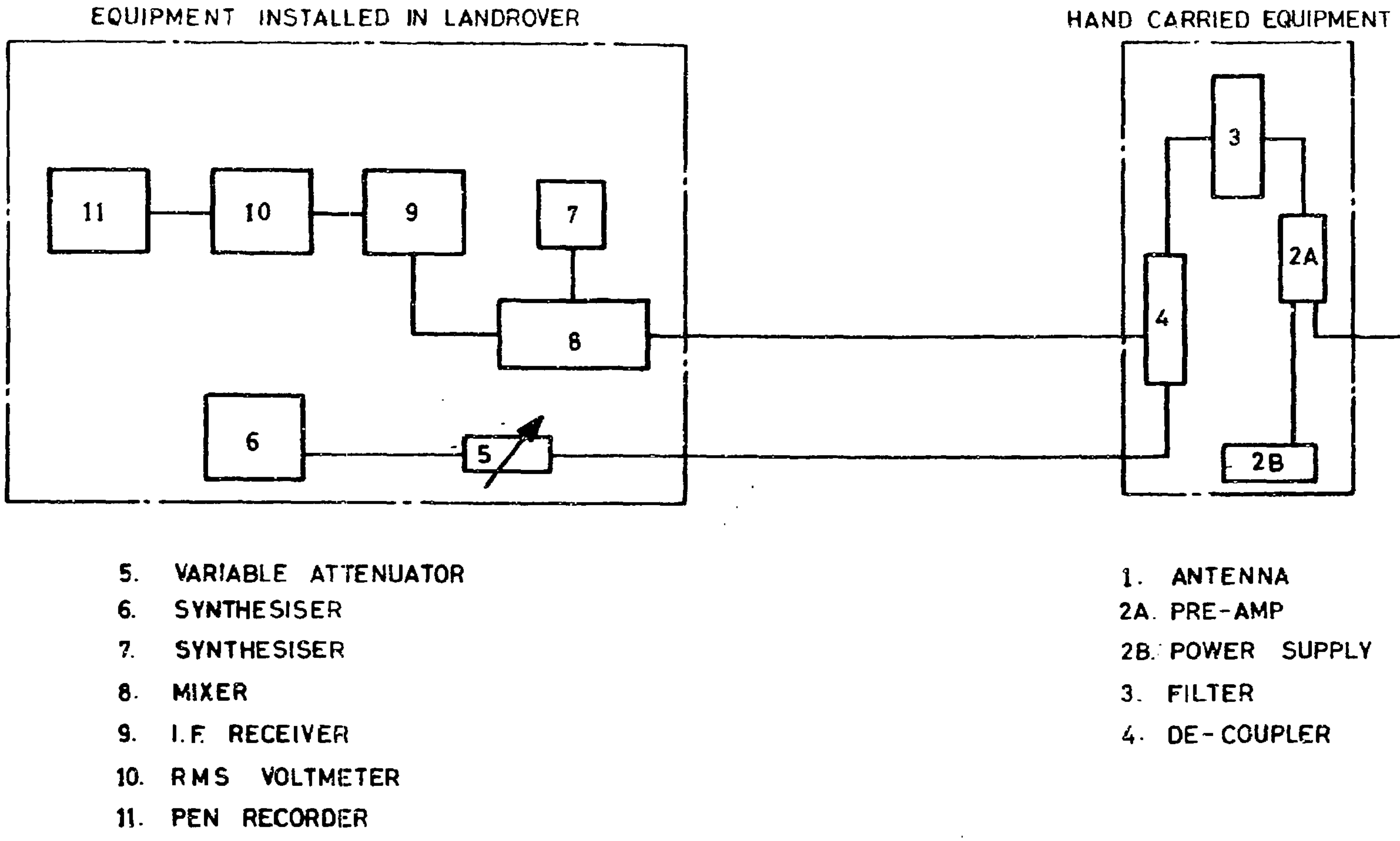


FIG.9 SCHEMATIC OF RECEIVING STATION EQUIPMENT

## 5. EQUIPMENT DESCRIPTION

The main aim of the experiment was to measure the attenuation of UHF satellite signals passing through woodland to a ground based receiver. Thus, the measuring equipment had to be mobile and as far as possible light and compact. These conditions were partly satisfied by putting it into a Land Rover which was connected to a light-weight antenna and preamplifier by means of a long cable, thus enabling continuous recordings to be made as the antenna was placed in typical combat locations.

### 5.1 Land Rover Equipment

The equipment is listed and is connected as described in Fig 9. The synthesiser (No 6) and attenuator (No 5) were used for calibration. The synthesiser was first checked to ensure that frequency and power emitted were known, then with the known variable attenuation inserted, the signal from the antenna could be calibrated by switching from antenna signal to known signal.

The measuring equipment was conventional: the incoming signal was amplified and fed to a mixer which was also being fed by a synthesiser, the frequency difference usually being set at 18 MHz. The signal from the mixer was then fed to a receiver, an RMS voltmeter and a chart recorder. The signal to noise ratio of the system was 28 dB.

A similar receiving station was assembled at the home base (RSRE Christchurch) to enable the satellite signal in open terrain to be continuously recorded.

### 5.2 Antenna and Portable Equipment

In order to keep the length of cables between antenna and pre amplifier as short as possible, the decoupler, filter and preamplifier were mounted on a portable board. The gain of the preamplifier was 36 dB with a noise figure of 2.2 dB at the frequency concerned. The filter used was a tubular bandpass type with an insertion loss of 2 dB at the 254 MHz centre frequency and a 3 db relative bandwidth from 246.5 to 261.5 MHz. The antenna had to be light and compact and able to receive right-hand circularly polarised radiation from LES 6 and MARISAT. Since the elevation angle was about 20°, and knowing the phase and reflection characteristics given in Fig 8, it was decided to compare a horizontal dipole attenna with a helical antenna and also with a four element crossed Yagi. The calculations are given in Appendix B where the total gain for a number of commercially available antennas are compared.

Experimental work was carried out on the efficiencies of different types of antenna. A helix was designed and made to give a gain of 6 dB approx. For the frequencies being used here, the relevant dimensions were (a) diameter = 38 cm, (b) pitch = 26 cm and (c) backplane = 95 cm. With 3½ turns, the antenna proved to be too cumbersome to operate in the field environment, despite the use of a removable backplane and other modifications.

There are two sets of dimensions given in the literature for crossed Yagi antenna design; one of these giving considerably shorter distances between Driver, Reflector and Director than the normally-used figures. Because of the interest in a light and compact antenna work was done with these short dimensional crossed Yagi's (also with a 3 element single plane horizontal Yagi) for circular polarisation response. However, this proved time consuming owing to the criticality of balancing and matching and was temporarily abandoned.

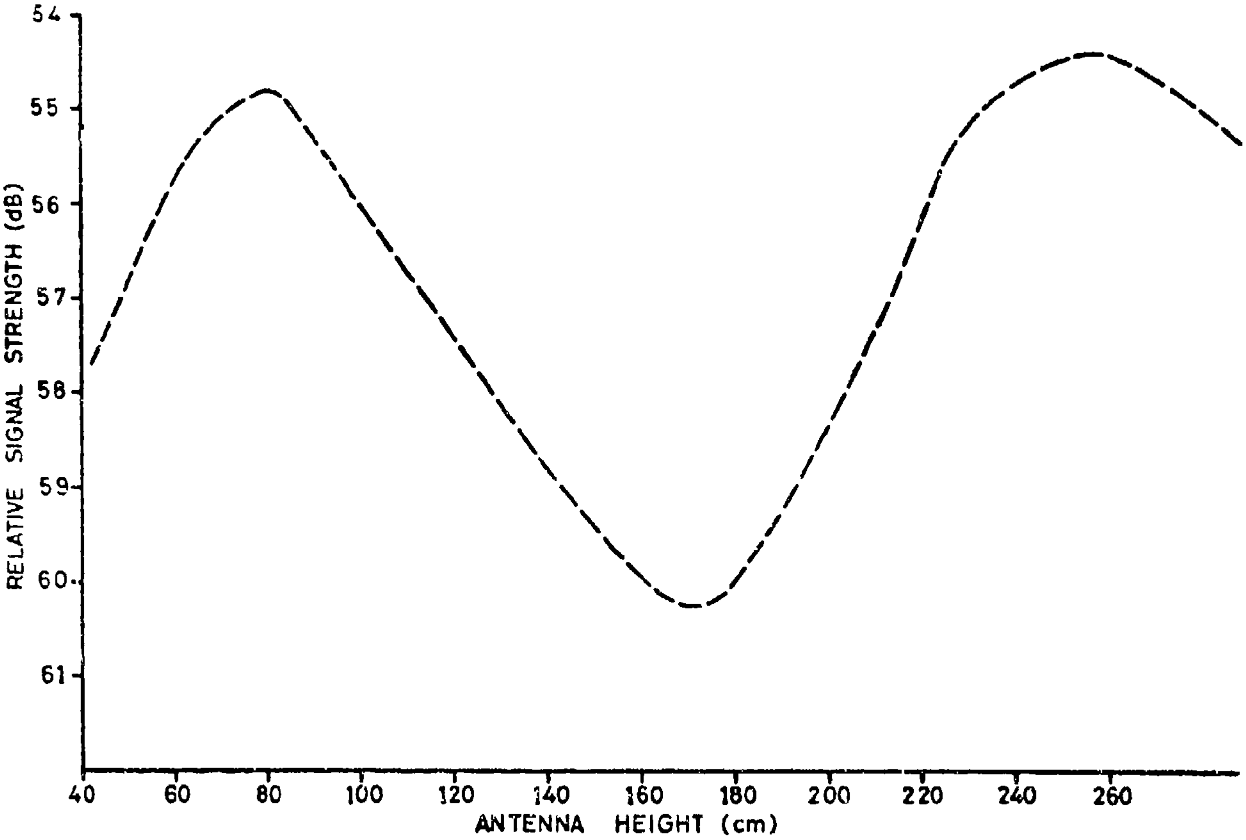


FIG. 10 CHANGE IN SIGNAL STRENGTH WITH ANTENNA HEIGHT

The antenna eventually used in the field was a light-weight four element crossed Yagi which gave a 7 dB gain and had the following dimensions:-

| DISTANCES (cm) | LENGTHS (cm) |
|---|---|
| Reflector to Driver = 29.5 | REFLECTOR = 61 |
| Driver to 1st Director = 24 | DRIVER = 50 |
| 1st Director to 2nd Director = 23.5 | 1ST DIRECTOR = 47.5 |
|  | 2ND DIRECTOR = 47.5 |

The antenna was matched to a 50Ω feed and the polarisation was right hand circular to within 1½ dB.

## 6. EXPERIMENTAL RESULTS

Two separate trials were carried out in woodlands. The first was in January 1976, using LES 6, when preliminary data was obtained but not as much as was intended because of the shut-down of LES 6. The second was in July/August 1976 using MARISAT. Both trials are described below.

### 6.1 Effect of Antenna Position and Height

To obtain a signal which could be used as a standard and against which all data obtained in the field (forest) could be compared, the antenna was situated in the open on a flat tarmac surface at sea level with the antenna pointing out over the sea towards the satellite. By rotating the antenna in azimuth and elevation a maximum signal was recorded for a given height. The signal was then measured for different antenna heights and the results plotted as shown in Fig 10. In this Figure the difference between maximum and minimum is about 6 dB and it can be seen that the first maximum occurs at a height of 82 cm, which is a useful height from the point of view of an equipment operator. Throughout the trials the test antenna was mainly kept at this height, apart from some special studies to examine the effect of height with surface. One antenna was moved to different positions on the flat open surface and then later moved to an adjacent flat roof where it was employed to continuously receive a reference signal. The variation in signal for all these positions was less than 1 dB.

### 6.2 Effect of Ground Surface

It had been intended to carry out a detailed study of the effect of different types of surfaces on the total signal received. However climatic conditions in the UK were unusual in that the ground was firm in January (little rain in previous weeks) and extremely hard in July (little rain in previous months). Large flat areas were chosen which allowed measurements to be made on a) concrete b) tarmac c) sandy soil d) grass e) surfaces covered in fern and also other vegetation up to the height of the antenna and f) marsh land. Also in August, when the ground was extremely hard, the effect of a 12 cm layer of water was examined. The maximum difference between all measurements, with numerous measurements on each surface, was found to be less than 1.5 dB.

### 6.3 Scintillation Effects

Because two stations were receiving simultaneously, any variation in satellite signal could be eliminated. However, a secondary aim of the experiment was to look for scintillation effects. Continuous measurements made from 0800 to 1800 hours on week days during the period 2 to 27 August 1976 appeared to indicate that scintillation was taking place frequently but that the amount of variation was similar to or occasionally slightly greater than the amount of ripple on the satellite signal, namely 1 dB. However on two occasions two very distinct scintillation phenomena occurred, when there was considerable variation. On 5 August scintillation lasted one hour commencing at 1400 BST with a maximum to minimum variation of 10 dB. On 23 August intense phenomena was again noticed commencing at 1215 to 1400 BST with a very worst maximum to minimum variation of 12 dB. This is shown in Fig 11. Attempts to correlate this phenomenon with other measurements being made by Aberystwyth University and NRC, Slough failed because neither of these scintillation observation posts happened to be carrying out satellite measurements at that time. However, Aberystwyth University[28] was monitoring a number of radio stations in France and Spain on 23 August and was able to verify that considerable scintillation phenomena (Sporadic E) occurred at this time in mid latitudes.

### 6.4 Forest Data

Because of the time of year, it was necessary to choose sites of coniferous trees, such as Spruce, Pine and Fir trees. It was not possible to find a site where the trees were planted to a regular pattern or where the trees were equally spaced apart. Four sites were chosen where the trees were approximately 15 in (33 cm) in diameter and between 3 and 12 metres apart. The average height of the trees was approximately 20 metres with foliage extending down to within 2 metres of the ground. The ground was firm, dry and flat. Thus typically, an observer standing on the ground could see through the trees near the ground for some distance but looking upwards could only see small patches of sky in places; the remainder being a canopy of foliage.

Some 20 discrete measurements of satellite signal strength (adjusting antenna heighth to give maximum signal) were made at each of the four sites. An arbitrary position within the wood was chosen and the 20 measurements around this were made usually in a grid pattern, covering an area of approximately 15 metres x 30 metres. The amount of attenuation

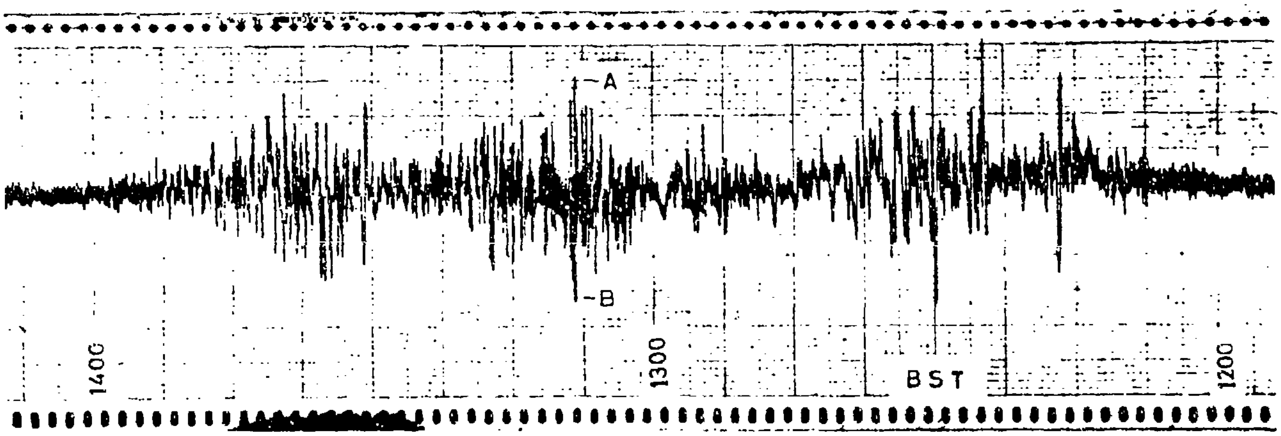


FIG.11 OBSERVED SCINTILLATION ON MARISAT SATELLITE SIGNAL (A-B = 12dB)

pattern or relationship between the data at each location. The data appeared to exhibit a sinusoidal pattern both in the direction of the satellite and in a line at a right angle to the direction of the spacecraft but the distance between peaks varied according to direction and site.

As mentioned earlier it was not possible to complete this experiment because of the switch-off of LES 6. However although there is insufficient data to allow confident statistical statements to be made, some conclusions can be drawn from the data plotted in Fig 12. The mean of the curve is calculated to be approx 8 dB and the analysis was taken further by plotting the density function against attenuation, using 2 dB intervals Fig 13 and then finding the probability of any particular value of attenuation being exceeded as shown in Fig 14. For example, Fig 14 indicates that the probability of 10 dB being exceeded is 0.2, for any random site selection in the measured forest.

Since neither the LES 6 or MARISAT EIRP was known accurately, it was not possible to calculate the expected free space signal strength at the antenna and so convert the measured data into absolute signal strength. All data given are relative to the maximum signal obtained in the open at the RSRE, Christchurch base station. However, from Fig 10 it is estimated that the data given in Figs 12 to 17 can be converted to measurements with respect to free space by subtracting 2 db.

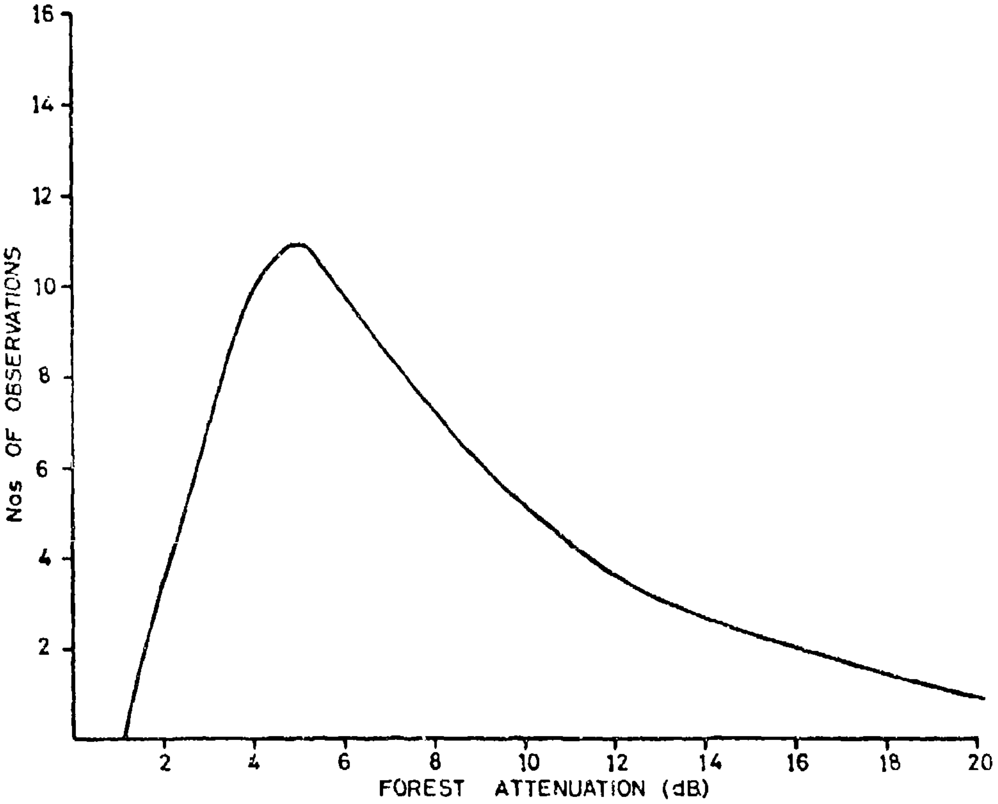


FIG. 12 OBSERVED ATTENUATION DISTRIBUTION

## 6.5 Forest Data, July/August 1976

Attempts were made to assess the effects of gorse, heather and fern landscapes on signal strength. A large flat dry area was chosen consisting of a dense mixture of fern, gorse and heather bushes some 2 metres tall in places. From measurements taken it was shown that the effect of fern 90 cms high, thus hiding the Yagi antenna, was very small, the signal variation being less than 1 dB. Even when surrounded by thick gorse bushes 2 metres tall the signal loss was never greater than 3 dB except in 2 out of 50 readings where a 5 dB loss was recorded in the middle of a very large gorse bush. Forest data was obtained in experiments similar to those described for January 1976.

Some 11 locations were examined and about 40 signal-strength measurements made in each location. The locations were woods which mainly consisted of fir trees; each place being different from the other in regard to the height of trees (9 metres to 15 metres) diameter (22 cm to 37 cm) and distance between trees (2 metres to 10 metres average). Two of the locations consisted of oak trees (20 metres high and 40 cm diameter approx), the difference between the two being the average distance apart of the trees namely, 3.6 m and 5.5m. The remaining locations were a mixture of firs, oaks, rhododendron bushes and thick undergrowth. In all woods the same type of phenomena was encountered as previously described, namely a series of maxima and minima in signal strength. A comparison of average attenuation for each location showed that all results agreed to within 3 dB. There was insufficient statistical data for each location to enable useful statistical comparison between locations to be made. The data was generally similar for all locations (ie random up and down values mainly in the range 2 to 10 dB) no significant correlation with tree diameter, height, distance apart etc could be distinguished. It was noted that each wood exhibited "hole" phenomena ie positions where the loss was considerably greater than usual for the region. In a number of "hole" locations, this loss was as much as 20 dB.

The variation in signal strength in the vicinity of all holes was measured and the detailed pattern at each hole was found to be different. An example of the sort of variation found is given in Fig 15(b): it can be seen that the signal attenuation increased from 5 to 20 dB in a distance of 1 metre.

As mentioned earlier, the signal strength went through a series of maxima and minima when measured in a line at right angles to the direction of the satellite. An example is given in Fig 15(a).

Because each location appeared much the same regarding attenuation phenomena, it was decided to combine the data for all locations. First atypical data was removed (eg values obtained in the close vicinity of a hole) then the observed density distribution was plotted as a function of attenuation (Fig 16). the probability of any particular loss being exceeded was derived as shown in Fig 17.

## 7. DISCUSSION OF RESULTS

A first point of interest was the change in signal strength with antenna height. In section 4.3.1 it was shown that the first maxima for the UHF satellites used should occur at an antenna height of 82 cm. Fig 10 confirms this.

The ground was dry during both the January and July trials, although moist underneath in January. It was shown that fern, bushes and other vegetation on top of the ground (even above antenna height) did not significantly influence the total signal received, hence it was of interest to discuss how different ground conductivities would influence the signal. From the data in section 3.2.4 and in section 4.3.2 and assuming that the horizontal polarisation component is the dominant reflected ray, then a calculation following those in Appendix A, indicate that very little difference in total received signal strength should be observed for the various types of earth encountered. This appears to agree with practice: no significant difference was observed for different surfaces, even between boggy and sandy surfaces.

The data obtained suggest that the observed losses were due to both foliage effects and diffraction effects but that diffraction played the major role. Diffraction effects were expected as discussed in sections 3.3 and 4.3.4. Losses of the order of 30 dB from diffraction could be expected in a 20 metre high forest assuming the forest was opaque. The observed periodic maxima and minima in signal level reveal the presence of diffraction affects. Thus, in practice it was not possible to determine the influence of foliage "on its own" and it was not possible to make direct comparison with "foliage" data published by other authors.

The average loss for the January and July trials (8 dB approx) could be expressed as loss per metre. Assuming a satellite angle of 21°(and thus a maximum path length of 36 metres for an average tree height of 13.5 metres) the loss per metre was 0.22 dB/metre. This compares with the value of 0.08 dB/metre given in reference 21.

Another way of looking at the summaries of results, Figs 14 and 17, is to consider the average number of antenna sitings necessary in order that the loss is not greater than a specified value. For example if the loss is not to exceed 15 dB, the number is one. Other values are as follows:

| Margin (dB) | Average Nos. of Antenna Siting Attempts |
|---|---|
| 15 | 1 |
| 7 | 2 |
| 5.5 | 3 |
| 2 | 50 |

In practice it appears that with an acceptable loss (6-8 dB), no more than two attempts would normally have to be made.

## 8. CONCLUSIONS

a. Measurements have been made of UHF signal attenuation due to siting of receiver equipment in wooded locations in Southern England. The results are summarised as probability distributions.

b. The average loss was 8dB. There was a .97 probability that loss would not exceed 13 dB, however occasionally 'hole' locations were discovered where the loss was up to 20 dB.

c. Moving 1-2 metres to the side of a 'hole' resulted in signal attenuation returning to the normal values. In general, for an 'acceptable' loss of 7-8 dB, only two attempts at siting an aerial should be necessary and if three attempts are acceptable, then the loss can be assumed 5.5 dB.

d. The loss appeared to be mainly due to diffraction phenomena. The effects of bushes, fern, tall grass and other undergrowth are minimal.

e. The effects of different surfaces (tarmac, soil, boggy ground etc), are minimal, at least for the incident angles (20° deg) examined in this study. For frequencies in the region of 250 MHz, the antenna heights should be about 80 cm to receive maximum signal strength.

f. All tests were performed on dry days. Useful further work would be to perform repeat measurements with all foliage very wet.

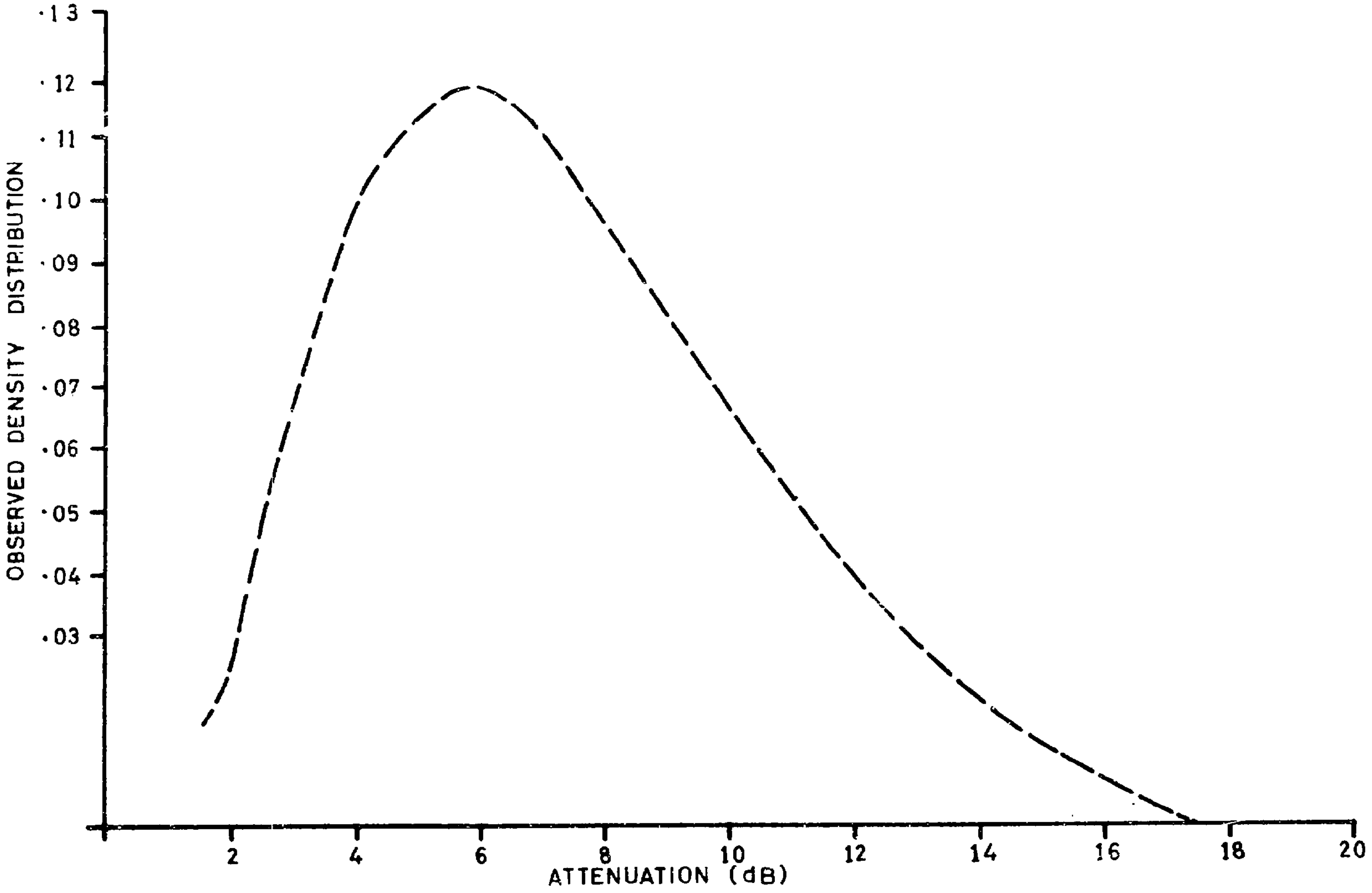


FIG. 13 ATTENUATION DENSITY DISTRIBUTION FROM 1st TRIAL WITH LES 6

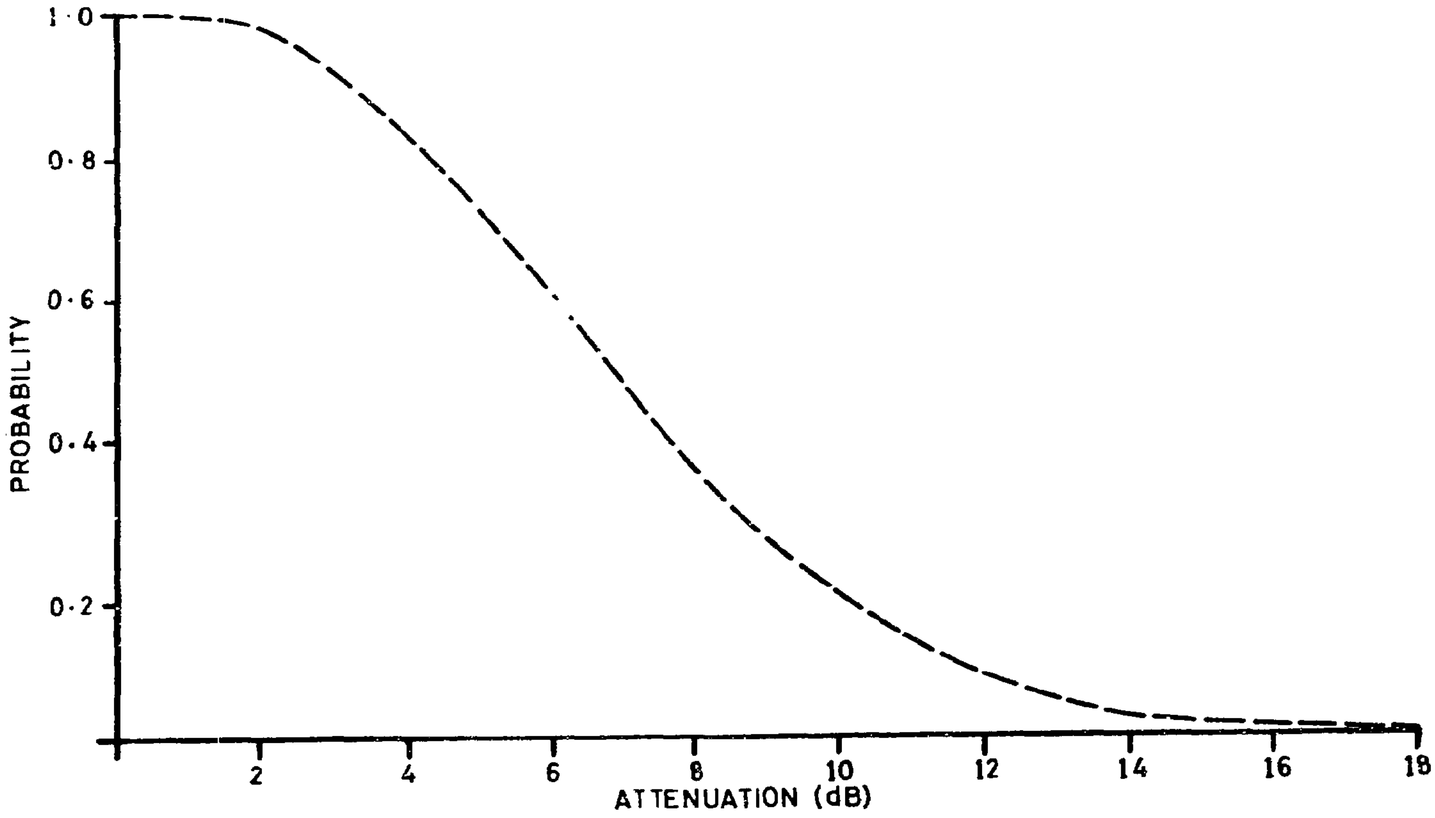
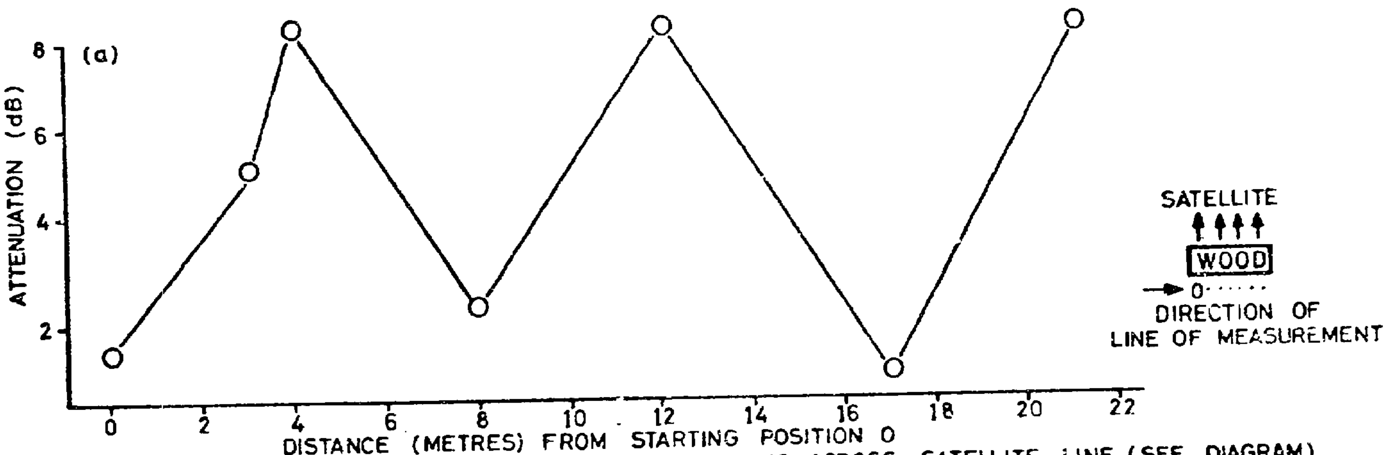
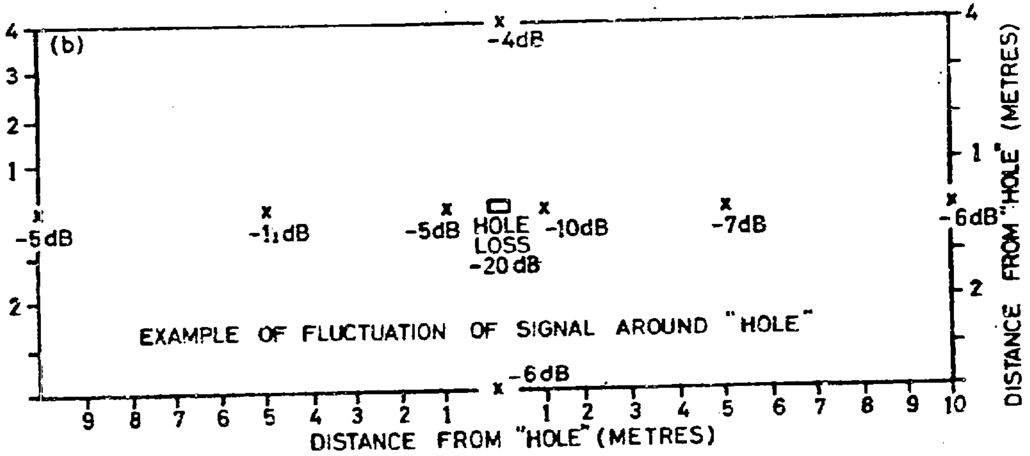


FIG. 14 CUMULATIVE DISTRIBUTION FROM 1st TRIAL

SIGNAL LOSSES FOR VARIOUS LOCATIONS



EXAMPLE OF FLUCTUATION OF SIGNAL WHEN MOVING ACROSS SATELLITE LINE (SEE DIAGRAM)



EXAMPLE OF FLUCTUATION OF SIGNAL AROUND "HOLE"

FIG. 15 SIGNAL LOSSES FOR VARIOUS LOCATIONS

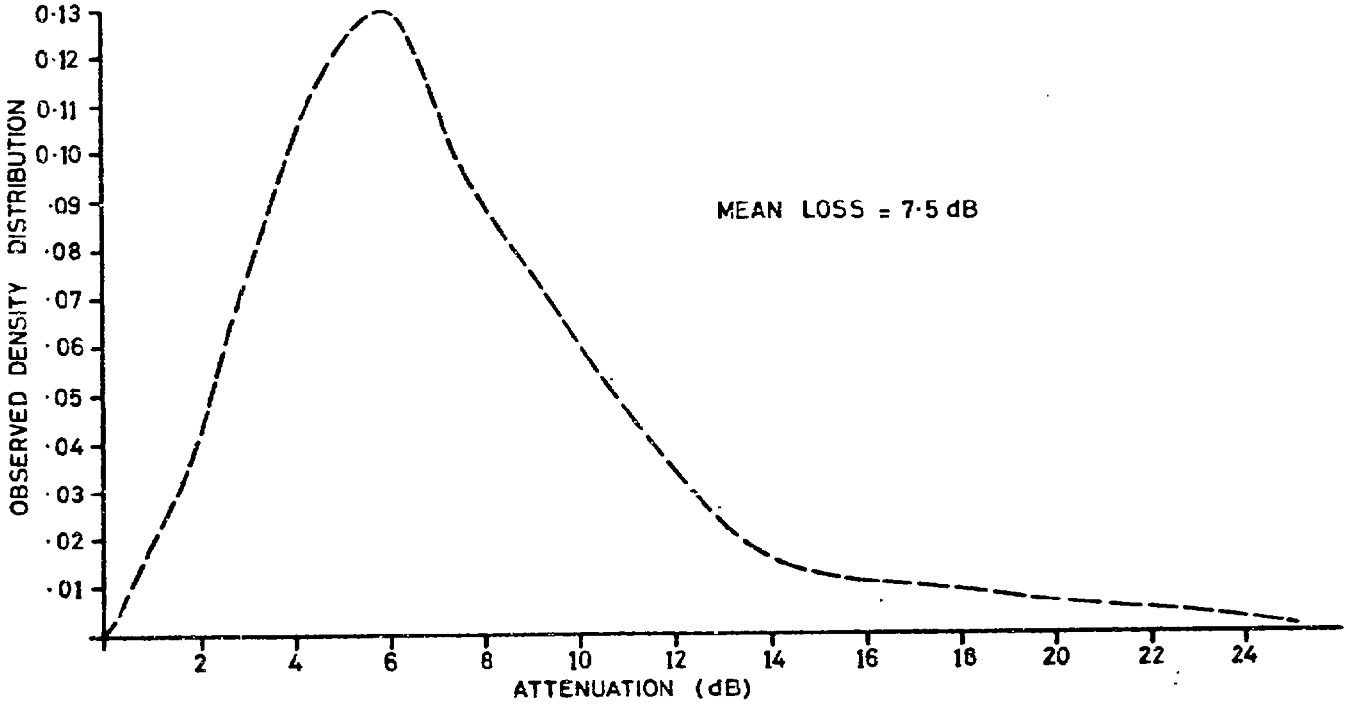


FIG. 16 ATTENUATION DENSITY DISTRIBUTION FROM 2nd TRIAL WITH MARISAT

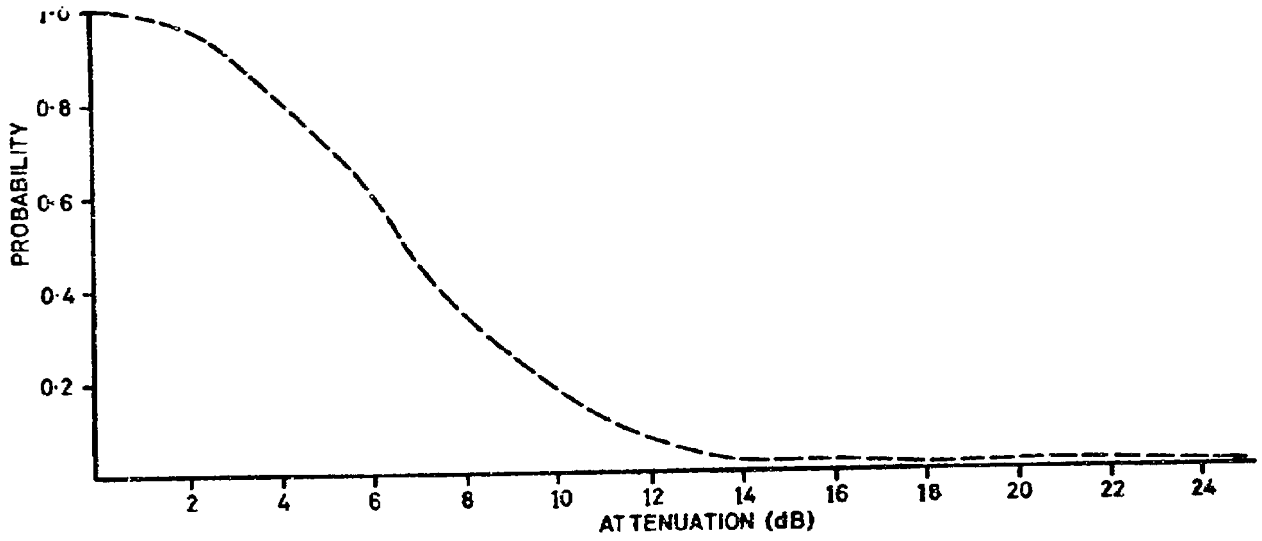


FIG. 17 CUMULATIVE DISTRIBUTION FROM 2nd TRIAL

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# APPENDIX A

## CALCULATION OF HORIZONTAL ($R_H$) AND VERTICAL ($R_V$) REFLECTION COEFFICIENTS AND CORRESPONDING PHASE CHANGES AS A FUNCTION OF ANGLE OF INCIDENCE.

$$R_V = E_R/E_I = |R_V| e^{j(\phi-\Psi)_V} = \frac{\eta^2 \sin\theta - \sqrt{\eta^2 - \cos^2\theta}}{\eta^2 \sin\theta + \sqrt{\eta^2 - \cos^2\theta}}$$

$$R_H = E_R/E_I = |R_H| e^{j(\phi-\Psi)_H} = \frac{\sin\theta - \sqrt{\eta^2 - \cos^2\theta}}{\sin\theta + \sqrt{\eta^2 - \cos^2\theta}}$$

where $E_R/E_I$ is the ratio of reflected to incident field strengths where $(\phi-\Psi)$ is the total phase difference between direct and reflected wave and $\eta$ is the refractive index of the medium. (13)

Consider the boundary between air (considered as free space) and a plane earth surface and let $\epsilon_p$ and $\epsilon_v$ be the respective permittivities. Then

$$\epsilon_v = \epsilon + \delta/_{jw}$$ where $\epsilon$ is the absolute permittivity and $\delta$ the conductivity.

Since the relative permittivity ($\epsilon_r$) is defined as

$$\epsilon_r = \epsilon/\epsilon_p$$

then

$$\eta^2 = \epsilon_V/\epsilon_p = \epsilon_r - j\ \delta/\omega\,\epsilon_p \simeq \epsilon_p - j\,1.8 \times 10^3\ \delta/f$$

Assume typical values $\epsilon_r = 15$, $\delta = 10^{-2}$ mho/metre, then for f = 254 MHz

$\therefore(\epsilon_r - j\delta/w\epsilon_p) = 15 - 0.7\ j$

Consider 10° angle of incidence so that $\sin\theta = 0.1736$, $\cos\theta = 0.9848$ and $\cos^2\theta = 0.97$

$$\therefore R_V = \frac{2.6-0.12j-(14.03-0.7j)^{\frac{1}{2}}}{2.6-0.12j+(14.03-0.7j)^{\frac{1}{2}}}$$

$$(14.03-0.7j)^{\frac{1}{2}} = \pm\ [3.7-j0]$$

$$\therefore R_V = \frac{-1.1-0.12j}{6.3-0.12j} \quad \text{or} \quad \frac{6.6-0.12j}{-1.1-0.12j}$$

$$\therefore |R_V| = 0.17$$

$$\tan\theta = \tan + 0.109 - \tan - 0.019 = +6^\circ\ 12'-0^\circ 6'$$

$$\therefore \text{lag} = 174^\circ$$

Similarly

$|R_H| = 0.912$ and Phase = 180°

Coefficients for other angle of incidences have been calculated and are as follow (f = 254 MHz)

| Angle of Incidence | 10° | 20° | 30° | 40° | 50° |
|---|---|---|---|---|---|
| $R_V$<br>Phase of $R_V$ | 0.17<br>-174° | 0.13<br>-12° | 0.3<br>-10° | 0.43<br>- 8° | 0.5<br>- 6° |
| $R_h$<br>Phase of $R_h$ | 0.91<br>-180° | 0.84<br>-180° | 0.78<br>-180° | 0.72<br>-180° | 0.66<br>-180° |

## A COMPARISON OF PERFORMANCE OF 30° AND 60° HELIX WITH DIPOLE AND 4 ELEMENT YAGI

For MARISAT and LES 6 satellites the angle of incidence for the direct ray striking an antenna situated on horizontal ground was 20° approximately. From Fig 3 it can be seen that the reflected ray will strike the antenna at 40° approx. If the antenna height is adjusted to give the maximum signal, then from Fig 9 we can assume that the phase change of the vertical equipment is zero and the phase change of the horizontal component is 180°.

### Consider (1) Horizontal Dipole for 20° incident ray

Direct ray = 1 volt (assume)
Indirect ray = 0.87 volts (from Fig 9)
Total H compt = 1.87 volts
Gain due to direct and indirect ray = + 5.4 dB

### Consider (2) 4 Element Yagi for 20° incident ray

Horizontal compt: Direct ray = 1 volt (assume)
Indirect ray = 1 x 0.87 x 0.4 (where 0.4 is the voltage ratio at 40° taken from the radiation pattern for this antenna)

Total H compt = 1.348 volts

Vertical compt: Direct ray = 1 volt (assume)
Indirect ray = 1 x 0.14 x 0.4 (where 0.14 is taken from Fig 9)

Total V compt = 1.056 volts

∴ Total average H + V compt = 2.404/2 = 1.202 volts

∴ Gain due to direct and indirect ray = + 1.6 dB

### Consider (3) Helical Antenna (30° Beamwidth) for 20° incident ray

Horizontal compt: Direct ray = 1 volt (assume)
Indirect ray = 1 x 0.87 x 0.31 (from Fig 9 and Radiation Pattern)

Total H compt = 1.27 volts

Vertical compt: Direct ray = 1 volt (assume)
Indirect ray = 1 x 0.14 x 0.31
Total V compt = 1.043 volts

∴ Total average H + V compt = 2.313/2 = 1.156 volts

∴ Gain due to direct and indirect ray = + 1.26 dB

As **above** but using 0.5 instead of 0.51 for voltage ratio from radiation pattern.

∴ Gain due to direct and indirect ray = + 1.94 dB

A comparison of Total Gains at $20^\circ$ incidence is as follows:-

| Gain | Dipole | Crossed Yagi 4 Elements | Helix ($30^\circ$) 11 Turns 2 m Long | Helix ($60^\circ$) 3 Turns 60 cm Long |
|---|---|---|---|---|
| 1 w.r.t circular polarised isotropic Aerial and relative to free space | -1.0 dB | 12.2 dB | 16 dB | 10.2 dB |
| 2 Gain due to direct and indirect ray | 5.4 dB | 1.6 dB | 1.3 dB | 1.9 dB |
| 3 TOTAL GAIN | 4.4 dB | 13.8 dB | 17.3 dB | 12.1 dB |

MOD(PE), RSRE(C)

Report No. 77017

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by M J Downey

### ABSTRACT

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7a. Title in Foreign Language (in the case of translations)

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7b. Presented at (for conference papers). Title, place and date of conference

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| 8. Author 1, Surname, initials | 9a Author 2 | 9b Authors 3, 4... | 10. Date | pp | ref |
| Downey M J | - | - | 5.1977 | 33 | 29 |
| 11. Contract Number | 12. Period | 13. Project | 14. Other References | | |
| - | - | - | | | |

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