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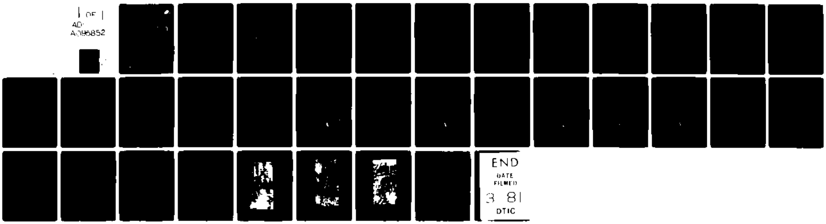

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A PRACTICAL GUIDE TO THE DESIGN AND CONSTRUCTION OF A SINGLE WIRE BEVERAGE ANTENNA

by

H. L. Spong

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6 A PRACTICAL GUIDE TO THE DESIGN AND CONSTRUCTION OF A SINGLE WIRE BEVERAGE ANTENNA.

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10 H. L. Spong

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SUMMARY

This Memorandum has been written to fill a need for practical advice on the design, construction and operation of a simple, single element, Beverage antenna.

Theoretical results are presented which show the performance likely to result from using differing antenna heights, lengths and wire sizes and from operating with different ground conductivities.

The assessment of performance and conclusions are based upon practical experience by the author in using this type of antenna.

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1 INTRODUCTION

The Beverage travelling wave antenna which was first used in America in 1922[1] for the reception of European VLF transmissions consisted of a horizontal wire, 12 km in length, supported approximately 10 m above the ground and terminated at one end by a resistor, the other end being connected to a receiver by an impedance matching transformer.

Over the years the BBC and the British Post Office have used Beverage antennas for the reception of signals in the MF and HF bands. In order to receive the MF signals, antennas of approximately 2 km in length and 4-5 m high were used whereas for HF, smaller antennas approximately 300m long and 1-2m high were found to be satisfactory.

A further development of the HF Beverage which exploits its directional qualities has been the implementation of a circular array for direction finding purposes[2].

In recent years, SRDE at Christchurch, in collaboration with Imperial College, London have constructed a phased receiving array for testing with a 50-baud HF data transmission circuit between Cyprus and the UK[3].

Radio and Navigation Department, RAE has evaluated a number of Beverage antennas at their Cobbett Hill receiving station and have also had experience in erecting and operating such antennas in both Cyprus and Gibraltar during communication trials with a Buccaneer aircraft flying in Germany[4].

A more efficient design of Beverage antenna, utilising up to four parallel elements, which allow it to be used for transmission as well as reception purposes has been investigated in recent years by a number of agencies.

An example of this work, by the Canadian Communications Research Centre, has resulted in a feasible design[5].

This Memorandum which deals exclusively with a single wire receiving antenna has been written to provide the user with basic guide-lines in the choice of design and to give practical advice on the antenna construction. The theoretical information presented, is based upon calculations performed by running the computer programmes 'BEVAZ' (giving azimuthal data) and 'BEVEL' (giving elevation data) on the main RAE 1906S computer.

The results show the effect at two frequencies of varying the main parameters of antenna height, antenna length, wire size and ground conductivity.

2 THEORETICAL CONSIDERATIONS

The Beverage antenna when employed as a single element is pointed directly towards the transmitting station and principally receives vertically polarised waves. The incident wave-front on the antenna undergoes a tilt (Fig 1a) which in the case of a ground-wave is caused by ground losses or in the case of a space wave by the angle at which the wave is reflected by the ionosphere.

The forward tilt of the wave-front produces an electric vector Ex (Fig 1b) which is parallel to the wire and thus as the wave sweeps along the length of the wire, this component of the electric field induces a current into the wire which is continually enhanced by the sweep.

For this reason the Beverage is sometimes known as a travelling wave antenna.

It follows that the magnitude of the vector Ex is a function of the wave-tilt angle δ , therefore the greater the tilt (ie more lossy the ground) the greater the induced current.

Induced currents will flow however in both directions; those flowing toward the receiver will be summed and detected as signal, those flowing away from the receiving end will be absorbed in the terminating resistor.

The antenna can be considered as a matched transmission line having a characteristic impedance Zo . The terminating resistor should be selected to equal the characteristic impedance at the centre of the operating frequency band or at a particular frequency if fixed frequency working is used: similarly a matching transformer (unbalanced to unbalanced) should also be selected to match the antenna impedance to the receiver input impedance.

It is not intended in this Memorandum to deal with the mathematics of design or operation which are quite complex and are adequately covered elsewhere[6].

It has been shown[7] that a single wire antenna, although exhibiting a gain at say 10 MHz of -5 dBi does have a directivity of approximately +15 dB. Also since gain = efficiency x directivity then the antenna has an efficiency of only about 1%.

3 COMPUTER PROGRAMMES

Two computer programmes have been written in FORTRAN by the author called 'BEVAZ' and 'BEVEL'. As already mentioned these programmes deal with azimuthal and elevation patterns respectively and are based upon flow charts, prepared by the Southwest Research Institute[6], for single and radial elements only. Parallel elements are not catered for.

The programmes are stored on the main RAE 1906S computer and can be edited prior to running to take into account desired changes in parameters, principally antenna height, length, wire size, ground conductivity, frequency, number of elements, angular element spacing, signal arrival angles and signal polarisation.

The programmes contain a plotting routine which allows the patterns to be printed out in cartesian coordinates on a line printer. Superimposed on each printout are details of the antenna, frequency, characteristic impedance, wave-tilt angle and attenuation constants. Other data can be printed simply by making changes to the programmes.

4 THEORETICAL PATTERNS

Theoretical patterns have been reproduced in Figs 2 to 9 and have been drawn to illustrate the performance of the antenna at two typical operating frequencies, namely 3 MHz and 13 MHz.

The azimuthal patterns which are calculated at 0° elevation angle and the elevation patterns at 0° azimuthal angle have been normalised at the maximum of their main lobes with their theoretical absolute gain being marked on each diagram. In every case the ground permitivity (E_r) has been taken as 12.0.

Fig 10 which depicts the azimuthal and elevation pattern of a typical omnidirectional antenna is included for comparison purposes.

The effect of raising the height of the antenna is illustrated in Figs 2 and 3, changing the length of the antenna in Figs 4 and 5, varying the wire size in Figs 6 and 7 and having different soil conductivity in Figs 8 and 9.

Theoretical graphs of absolute gain extracted from other literature[7] are shown in Fig 11.

Examination of the azimuthal patterns at 3 MHz shows that changes of wire size or ground conductivity have a negligible effect on the directivity/gain, pattern shape, beamwidth or side lobes. By doubling the height of the wire from 1-2 m there is a slight increase in beamwidth and a reduction in the side-lobe level.

Lengthening the antenna wire is comparable to using a higher frequency on a short wire, ie the directivity is increased, a narrower beamwidth is obtained but the side lobes become more prominent.

Typical values of azimuthal characteristics at 3 MHz for a 1m high, 100m long Beverage antenna are:-

Beamwidth at -3dB points	=	60°
Gain	=	-10 dBi
Side lobe level relative to main lobe	=	-18 dB

Considering the elevation patterns at 3 MHz, again the patterns are independent of wire size or conductivity. Raising the height of the wire however does raise the take-off angle by a few degrees and moves the angle of the side-lobes correspondingly.

By increasing the length of the wire a much narrower vertical beamwidth can be achieved with a lower take-off angle. The number of side-lobes and their levels are however increased and their angular position reduced. Typical elevation characteristics at 3 MHz are:-

Beamwidth at -3dB points	=	54°
Take-off angle	=	35°
Major side-lobe level relative to main lobe	=	-9 dB

Operating at 13 MHz shows an increase in gain of 6 dB over the value at 3 MHz, wire size and conductivity still having negligible effect. By doubling the height of the wire to 2 m gives a further increase in gain of 3 dB and a reduction in the side-lobe level.

Lengthening the antenna does tend to reduce the gain slightly, narrows the beamwidth by about 6° and shows a tendency at this frequency for at least 3 side-lobes to appear.

Typical values for azimuthal characteristics at 13 MHz for a 1m high, 100m long antenna are:-

Beamwidth at -3dB points	=	34°
Gain	=	-3.5 dBi
Side-lobe level relative to main lobe	=	-11 dB

The elevation patterns at 13 MHz are shown to be mainly independent of wire size, conductivity and height. The major effect, as has already been seen at 3 MHz, is caused by lengthening the wire, which marginally reduces the beamwidth and decreases the angle at which the side-lobes start to appear. One observation is that there are many more lobes with the longer wire but are not so pronounced.

Typical characteristic values for an elevation pattern at 13 MHz for a 100m long, 1m high Beverage are:-

Beamwidth at the -3dB point	=	20^{o}
Take-off angle	=	16^{o}
Major side-lobe level relative to main lobe	=	-6 dB

Tables 1 and 2 summarise the performance of the antenna with the varying parameters outlined above. Direct comparison of the patterns in Figs 2 to 9 with the omni-directional antenna pattern in Fig 10, highlights the advantages in terms of directivity and low angle performance attainable with a Beverage antenna.

Figs 12, 13 and 14 show how the antenna characteristic impedance varies resulting from changes in conductivity, height or wire size.

It is noticeable that the reactive component of the characteristic impedance is always capacitive and becomes less capacitive as the frequency is increased.

For a given wire size it can be seen (Fig 12) that the impedance of the antenna increases as it is raised above ground (cf increasing the spacing of a pair of open wire transmission lines).

Considering a fixed height above ground the impedance increases as the wire size decreases. This again is comparable to an open wire transmission line.

If however the height and wire size are maintained constant (Fig 14) then the impedance increases as the conductivity decreases. However, as with a correctly matched transmission line the characteristic impedance is unaffected by its length.

5 DESIGN PARAMETERS

Ideally for good directivity and low angle performance the antenna length should be at least 3 wavelengths at the lowest operating frequency, however this parameter may be limited by the ground area available.

The height of the antenna is chosen mainly on the basis of available pole size and ease of construction although the question of gain (Fig 11) may be a deciding factor.

The size of wire can be selected from any stock available, however the thinner the wire the more supports (poles) will be necessary and the greater the susceptibility to damage. The thicker the wire the more expensive the material if a special purchase has to be made. Generally speaking the antenna performance required must be balanced against available ground area, cost of materials and ease of construction and maintenance.

The user, having selected with the aid of the computer programmes a particular performance requirement and having decided upon length, height and wire size, it remains only to determine the necessary characteristic impedance and acquire a suitable matching transformer to suit the receiver impedance.

The terminating resistor can be manufactured locally and experience has shown that for an antenna height of 1 m, a number of $\frac{1}{2}$W carbon resistors can be soldered together in series making a resistive chain spanning the 1 m approximately.

6 ANTENNA CONSTRUCTION

Fig 15 shows in schematic form the construction of a typical single wire Beverage antenna. The single conductor of say 12 SWG is supported about every 10 m by either wooden posts with insulators or, for cheapness, inserted into slots cut in plastic tube as depicted in the photographs (Figs 16 and 17).

The two end posts are fixed or guyed back to maintain a satisfactory tension on the wire. At the base of each end post a good earthing facility is required. This can take the form of a number of earth stakes driven into the ground or better still a square metre of copper sheet, buried a few feet below the surface.

The terminating resistor connected between the antenna wire and earth should be protected from the weather by covering with plastic sleeving.

At the receiving end the primary of the matching transformer is connected between the antenna wire and earth while the secondary is connected by co-axial cable to the receiving system.

Because of the low efficiency of the antenna (1%) and hence low sensitivity, it is advantageous to immediately follow the antenna by a low noise, high gain (20 dB), wide band pre-amplifier and then route the output via a co-axial cable to the receiver.

It is pointed out that the height of the antenna is a mean height and that it is not necessary to accurately level the site. Antennas have been shown to operate when the wire has drooped between posts and the antenna has tended to follow the terrain. However everything should be done within reason to make a neat, sound mechanical and electrical installation in order to realise the required performance.

Fig 16 is a photograph of a typical Beverage antenna showing the matching transformer and Fig 17 shows the connection of the terminating resistor. Fig 18 is included to show a close-up of the matching transformer.

7 ASSESSMENT OF PERFORMANCE

Experience has been gained in the use of single wire Beverage antennas for receiving HF transmissions from either ground transmitters or aircraft.

Trials have shown that the directivity and low angle performance are advantageous in excluding off-beam noise or interference, often outperforming on a signal to noise basis, omni-directional antennas by as much as 20 dB (see Tables 3 and 4). Experience has shown that it is not unusual for the Beverage antenna to have equivalent performance to a more expensive, more sophisticated directional antenna.

Inclusion of the pre-amplifier under weak signal conditions improves the system gain and produces an antenna superior to an omni-directional antenna and again equivalent to larger more costly arrays.

A disadvantage compared with other antenna systems is that with increasing frequency there is an increase in the number of vertical lobes. Although the majority are greater than 10 dB below the level of the main lobe there is a possibility that unwanted, high angle signals may be received.

It would perhaps be a feasible proposition to steer the nulls between the vertical lobes onto these unwanted transmissions or to cancel out other propagating modes emanating from the wanted transmission. Evidence has shown that the back to front ratio is generally good being about 20 dB or better.

Some very rudimentary measurements have been made to characterise the Cobbett Hill Beverage antenna by using suspended standard radiators beneath a helicopter. Whilst initial results were encouraging insufficient results were obtained to report on. It is hoped to complete this task eventually.

8 CONCLUSIONS

The Beverage antenna for use on the HF band is a low cost, low profile antenna requiring a small area and having excellent directivity (particularly in azimuth) and good low angle performance. Under certain conditions it is capable of performing as well as large directional arrays and will usually outperform an omni-directional antenna.

A major advantage of the Beverage antenna is that it is very easily maintained, accidental damage can be readily and rapidly repaired.

The design parameters can be easily obtained with the aid of the computer programmes and from readily available materials an antenna can be rapidly constructed.

It is possible to increase the directivity by adding more elements either in parallel or on a radial basis, the computer programmes 'BEVAZ' and 'BEVEL' catering only for the latter.

There is great latitude in the parameters to meet a particular performance requirement and unlike other vertically polarised antennas large ground screens are not required to achieve good low angle performance.

Because of the low efficiency it is recommended that a low noise, wide band, pre-amplifier be used immediately after the matching transformer.

A directional array can be made from Beverage antennas by switching between a number of elements set up on different bearings.

Table 1

AZIMUTH DETAIL

Fixed parameters	Variable parameters	Freq MHz	Absolute power gain dBi	Beamwidth -3 dB points	Side lobe level rel to main lobe	Angle of side lobe max	Remarks
L = 100 m 12 SWG σ = 0.01 S	H = 1.0 m	3.0	-10	64°	-18 dB	$120^{\circ}/240^{\circ}$	Patterns practically identical
	H = 2.0 m	3.0	-10	68°	-20 dB	-	
H = 1.0 m 12 SWG σ = 0.01 S	L = 100 m	3.0	-10	64°	-18 dB	$120^{\circ}/240^{\circ}$	Narrower pattern with longer antenna cf higher freq on 100 m antenna
	L = 300 m	3.0	-8.5	40°	-16 dB	$50^{\circ}/310^{\circ}$	
H = 1.0 m 12 SWG L = 100 m	σ = 0.01 S	3.0	-10	64°	-18 dB	$120^{\circ}/240^{\circ}$	Patterns practically identical. Power gain unaffected by conductivity
	σ = 0.005 S	3.0	-10	64°	-18 dB	$120^{\circ}/240^{\circ}$	
H = 1.0 m σ = 0.01 S L = 100 m	12 SWG	3.0	-10	64°	-18 dB	$120^{\circ}/240^{\circ}$	Pattern marginally narrower beyond -3 dB points with thinner wire
	16 SWG	3.0	-10	64°	-18 dB	$120^{\circ}/240^{\circ}$	
L = 100 m 12 SWG σ = 0.01 S	H = 1.0 m	13.0	-3.5	34°	-11 dB	$40^{\circ}/320^{\circ}$	Pattern slightly narrower at greater wire height. Also side lobes slightly lower
	H = 2.0 m	13.0	-0.5	32°	-13 dB	$40^{\circ}/320^{\circ}$	
H = 1.0 m 12 SWG σ = 0.01 S	L = 100 m	13.0	-3.5	34°	-11 dB	$40^{\circ}/320^{\circ}$	No defined side lobe but pattern starting to develop at least three at this frequency
	L = 300 m	13.0	-4.5	28°	-	-	
H = 1.0 m 12 SWG L = 100 m	σ = 0.01 S	13.0	-3.5	34°	-11 dB	$40^{\circ}/320^{\circ}$	Patterns narrower with less conductivity. Side lobes also higher and 5° closer to main beam
	σ = 0.005 S	13.0	-3.5	30°	-10 dB	$35^{\circ}/325^{\circ}$	
H = 1.0 m σ = 0.01 S L = 100 m	12 SWG	13.0	-3.5	34°	-11 dB	$40^{\circ}/320^{\circ}$	Patterns slightly narrower with thinner wire. Extra side lobes - appear with thinner wire
	16 SWG	13.0	-3.5	30°	-12.5 dB	$40^{\circ}/320^{\circ}$	

Table 2

ELEVATION DETAIL

Fixed parameters	Variable parameter	Freq MHz	Absolute power gain dBi	Beamwidth -3 dB points	Side lobe level rel to main lobe	Take-off angle	Angle of first major side lobe	Remarks
L = 100 m 12 SWG σ = 0.01 S	H = 1.0 m	3.0	-10	54°	-9 dB	35°	110°	Whole pattern tilted slightly upwards at increased height
	H = 2.0 m	3.0	-10	56°	-9 dB	38°	112°	
H = 1.0 m 12 SWG σ = 0.01 S	L = 100 m	3.0	-10	54°	-9 dB	35°	110°	Better low angle performance. More side lobes and slightly higher
	L = 300 m	3.0	-8.5	22°	-7 dB	17°	53°	
H = 1.0 m 12 SWG L = 100 m	σ = 0.01 S	3.0	-10	54°	-9 dB	35°	110°	Performance very similar. Main lobe slightly narrower
	σ = 0.005 S	3.0	-10	50°	-9 dB	35°	105°	
H = 1.0 m σ = 0.01 S L = 100 m	12 SWG	3.0	-10	54°	-9 dB	35°	110°	Almost identical patterns. Side lobe level down with thinner wire
	16 SWG	3.0	-10	52°	-10 dB	35°	110°	
L = 100 m 12 SWG σ = 0.01 S	H = 1.0 m	13.0	-3.5	20°	-6 dB	16°	44°	Pattern slightly higher in elevation. Side lobe level higher
	H = 2.0 m	13.0	-0.5	20°	-4.5 dB	17°	47°	
H = 1.0 m 12 SWG σ = 0.01 S	L = 100 m	13.0	-3.5	20°	-6 dB	16°	44°	Similar low angle performance. Many more side lobes but not very pronounced
	L = 300 m	13.0	-4.5	18°	-3 dB	17°	30°	
H = 1.0 m 12 SWG L = 100 m	σ = 0.01 S	13.0	-3.5	20°	-6 dB	16°	46°	Similar performance. Main lobe slightly narrower. Side lobes slightly higher
	σ = 0.005 S	13.0	-3.5	18°	-5.5 dB	15°	40°	
H = 1.0 m σ = 0.01 S L = 100 m	12 SWG	13.0	-3.5	20°	-6 dB	16°	45°	Patterns practically identical
	16 SWG	13.0	-3.5	20°	-6 dB	15°	45°	

Table 3

PERFORMANCE DIFFERENCES OBSERVED ON TRIALS

FREQ 11.238 MHz

Antenna type	Signal median	Noise median	S-N ratio	Comment
Beverage	22.0 dB	0 dB	22 dB	
"	25.0 dB	0 dB	25 dB	
Monopole	16.0 dB	10 dB	6 dB	
"	17.0 dB	18 dB	-1 dB	Interference during noise meas

Table 4

DISTRIBUTION OF S-N RATIOS (%)

Antenna type	S-N ratios					
	>15 dB	>20 dB	>25 dB	>30 dB	>35 dB	>40 dB
Beverage	99.4	70.03	29.33	6.6	0.7	0.17
"	99.73	86.23	53.6	22.1	3.63	0.33
Monopol	5.77	4.4	2.93	1.63	0.0	0.0
"	5.73	0.23	0.00	0.0	0.0	0.0

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No.	Author	Title, etc
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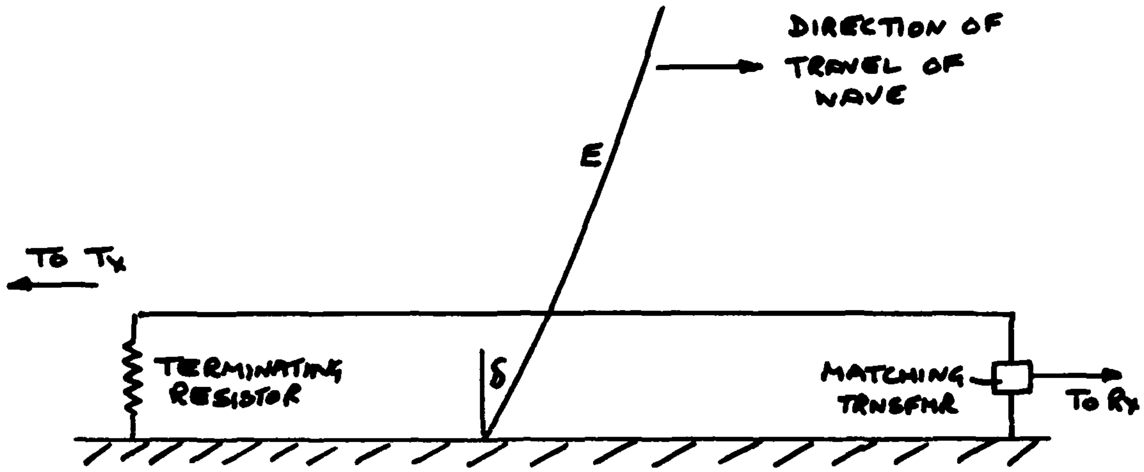

Fig 1a.

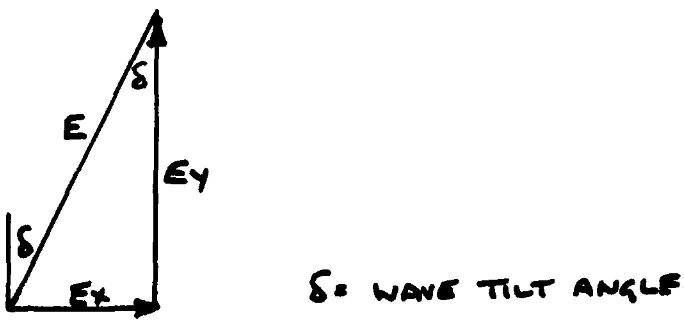

Fig 1b.

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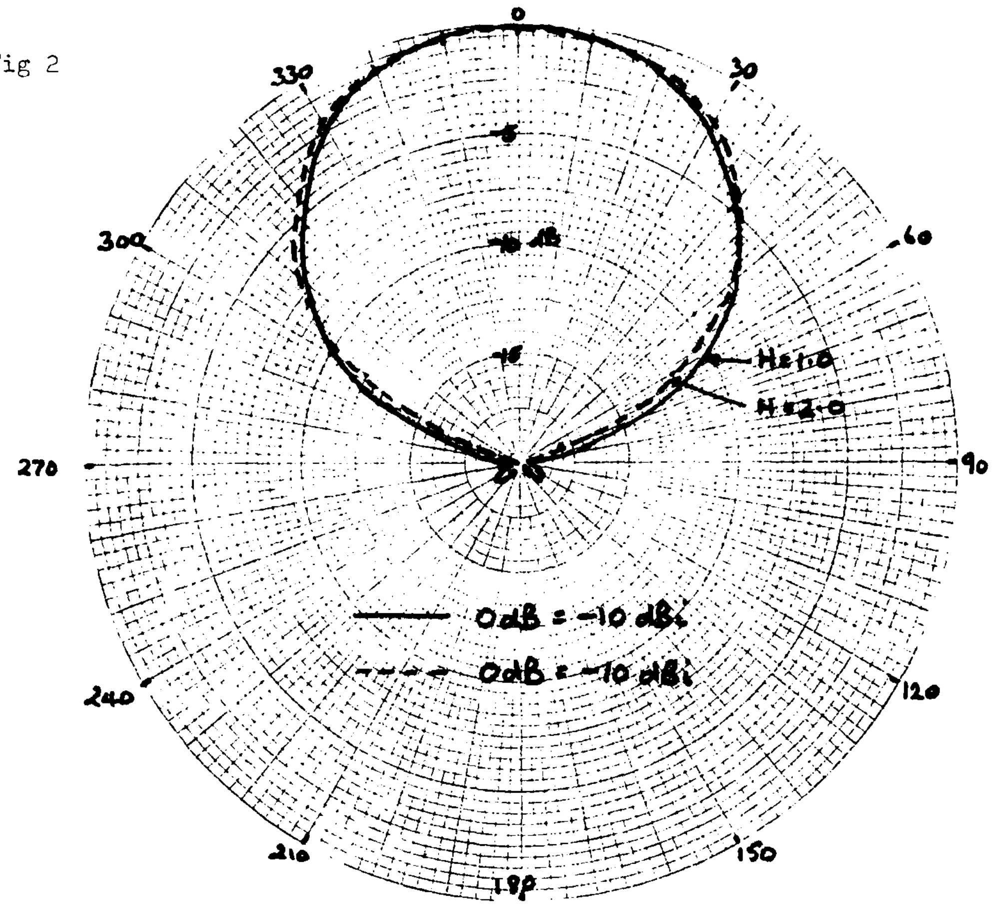
Fig 1a&b Diagrams showing effect of wave tilt on electric field component Ex

Fig 2



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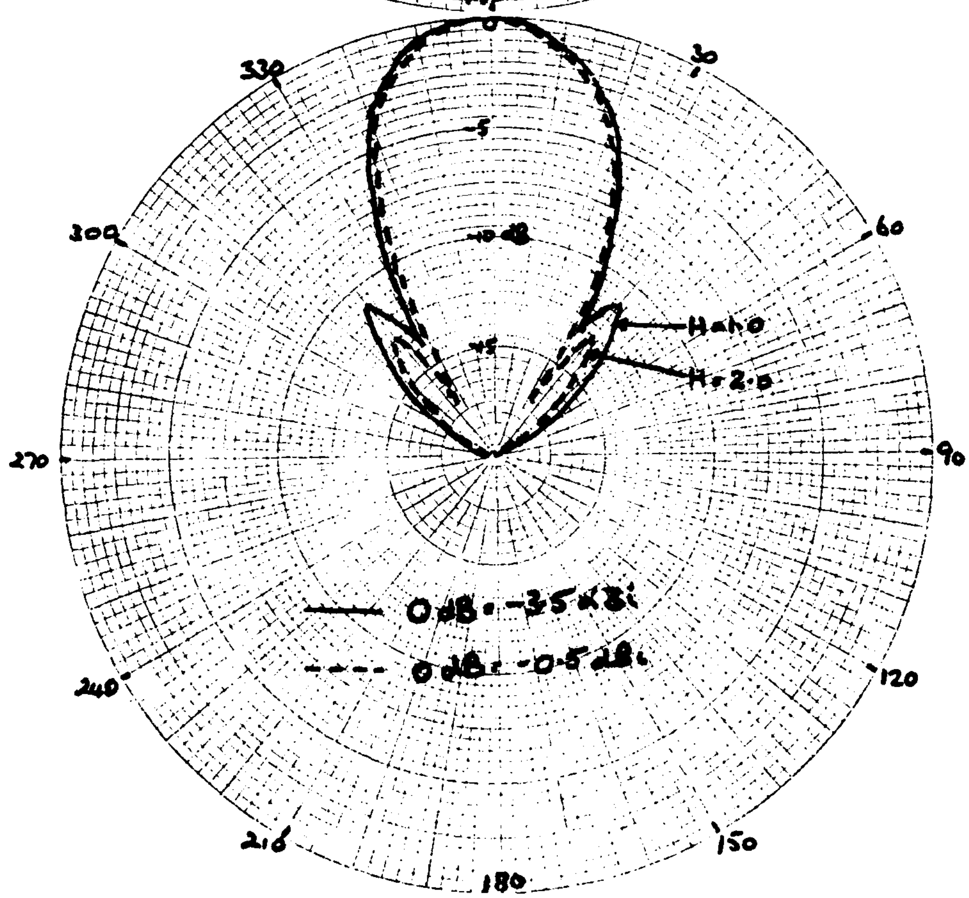

13 MHz

Fig 2 Azimuthal patterns at 0° elevation, antenna length = 100 m, conductivity = 0.01 S, E_r = 12.0, wire size = 12 SWG

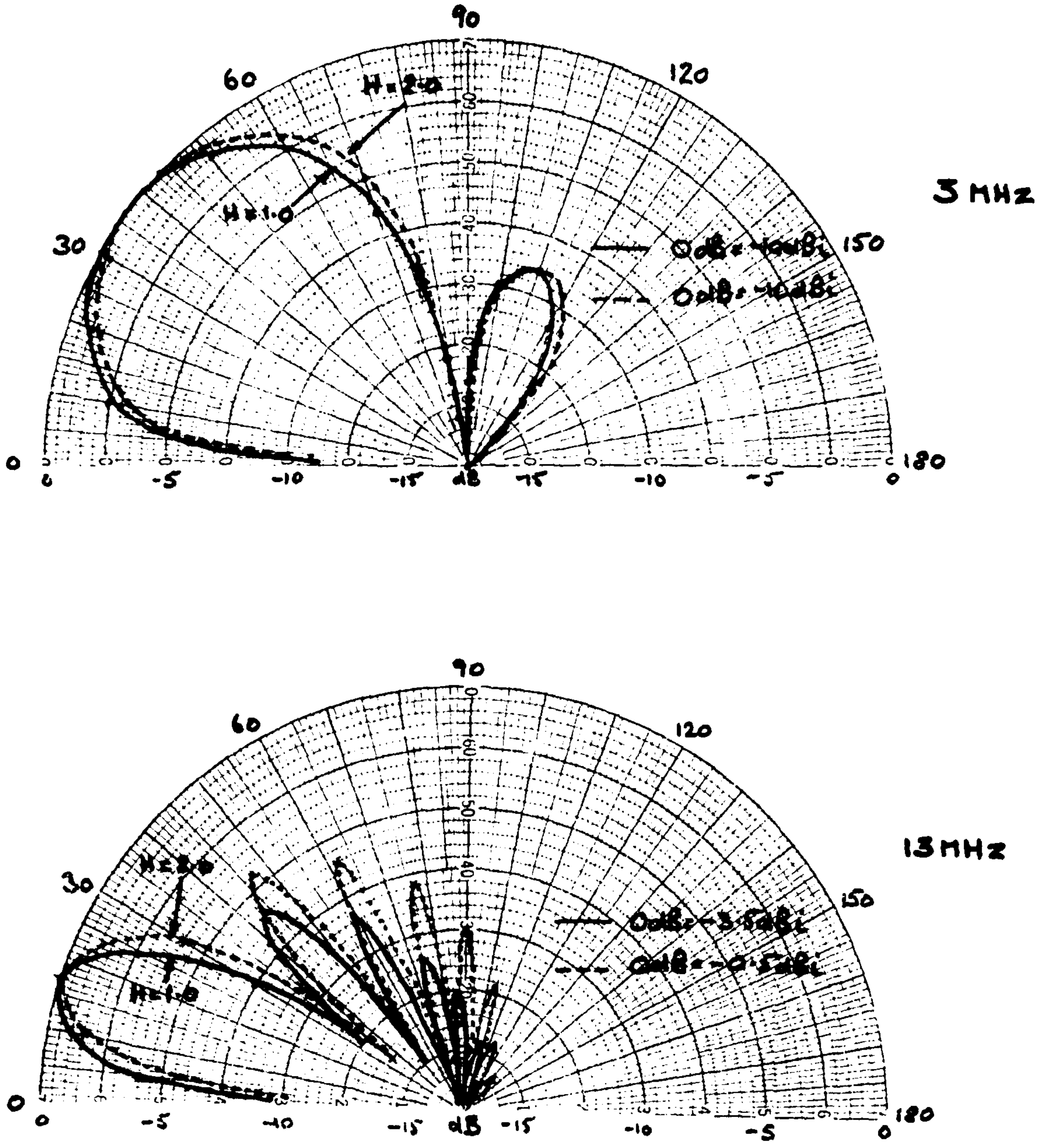

Fig 3 Elevation patterns at 0° azimuth, antenna length = 100 m, conductivity = 0.01 S, E_r = 12.0, wire size = 12 SWG

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Fig 4

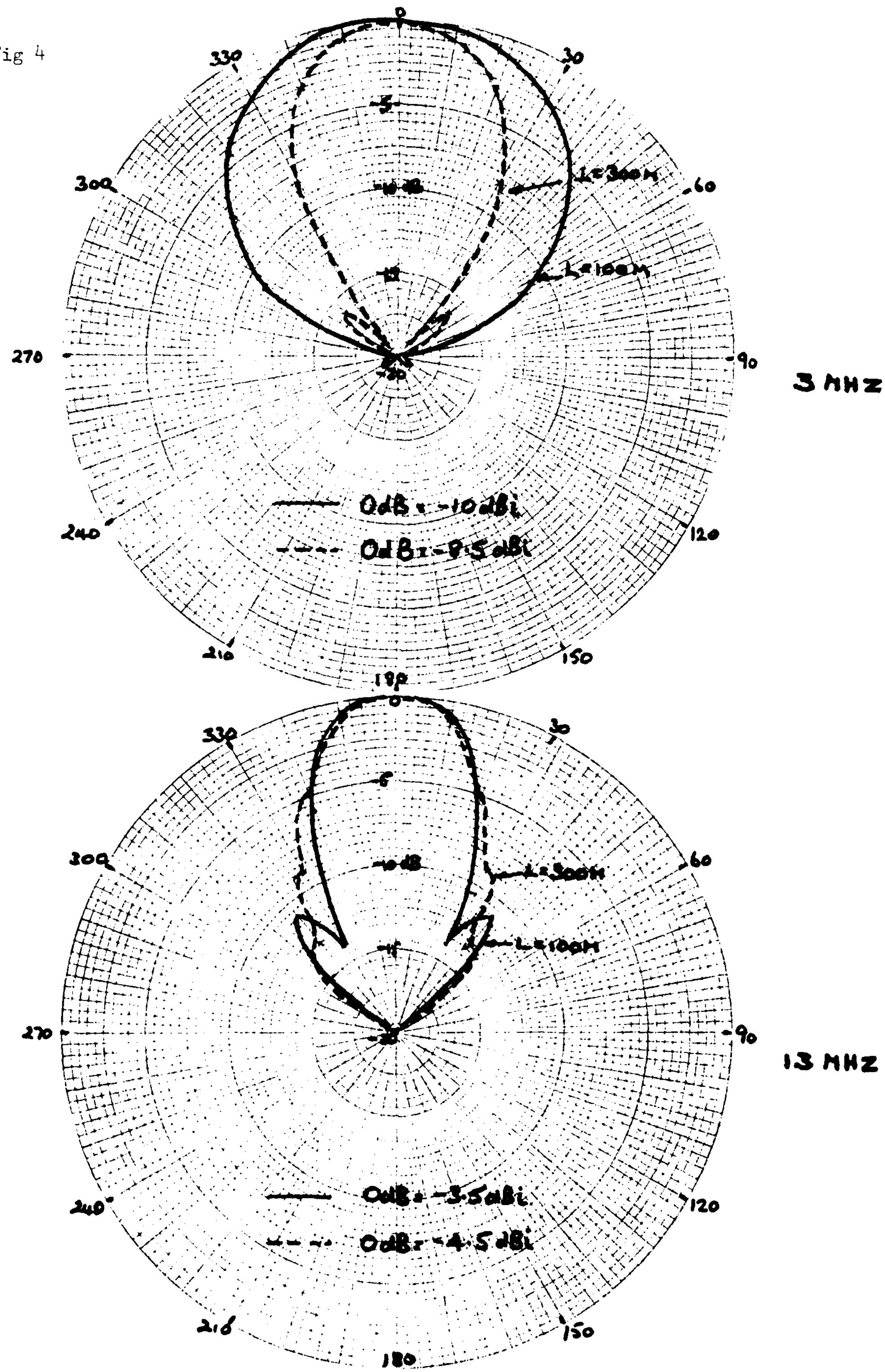


Fig 4 Azimuthal patterns at 0° elevation, antenna height = 1.0 m, conductivity = 0.01 S, E_r = 12.0, wire size = 12 SWG

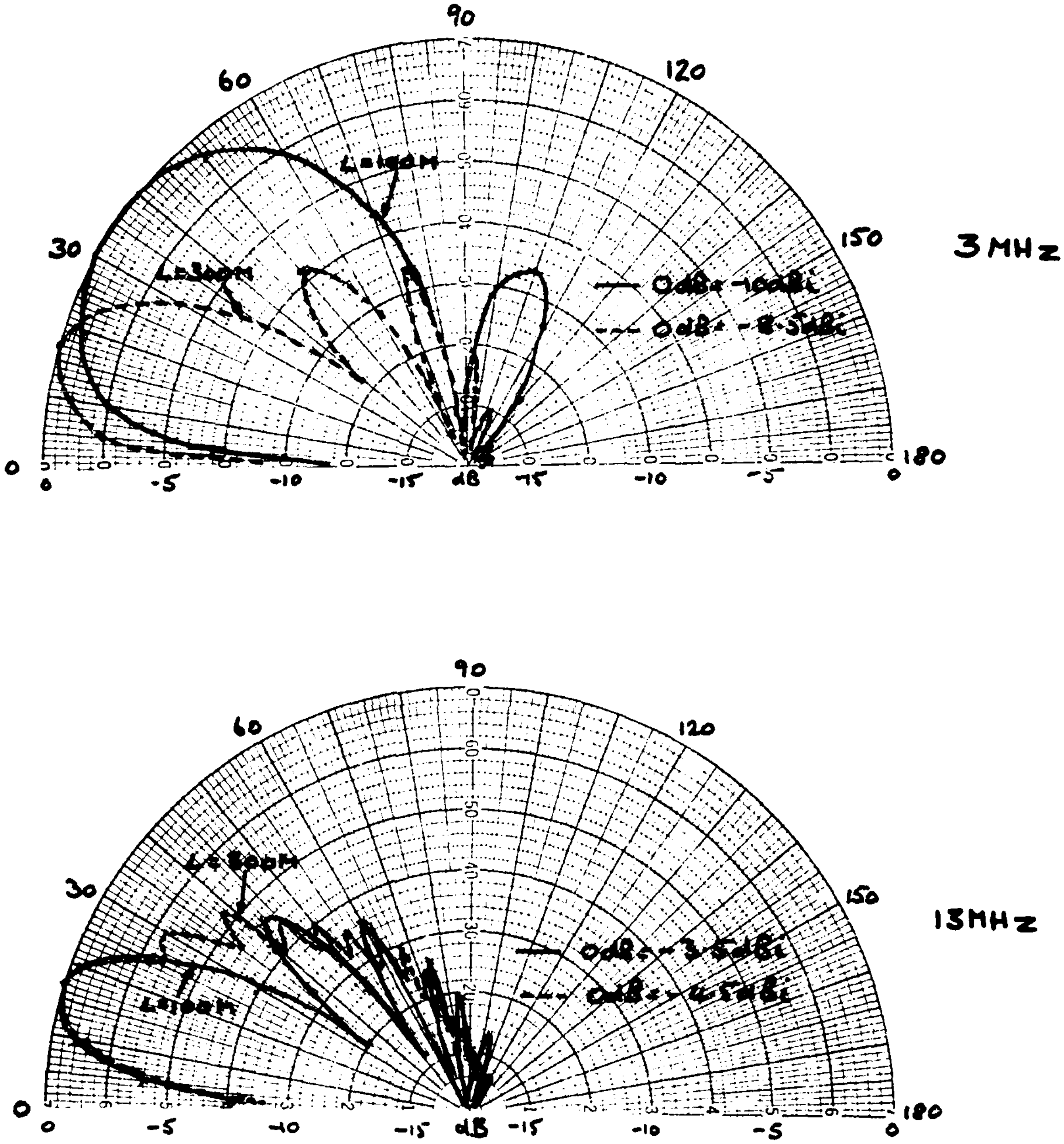


Fig 5 Elevation patterns at 0° azimuth, antenna height = 1.0 m, conductivity = 0.01 S, E_r = 12.0, wire size = 12 SWG

Fig 6

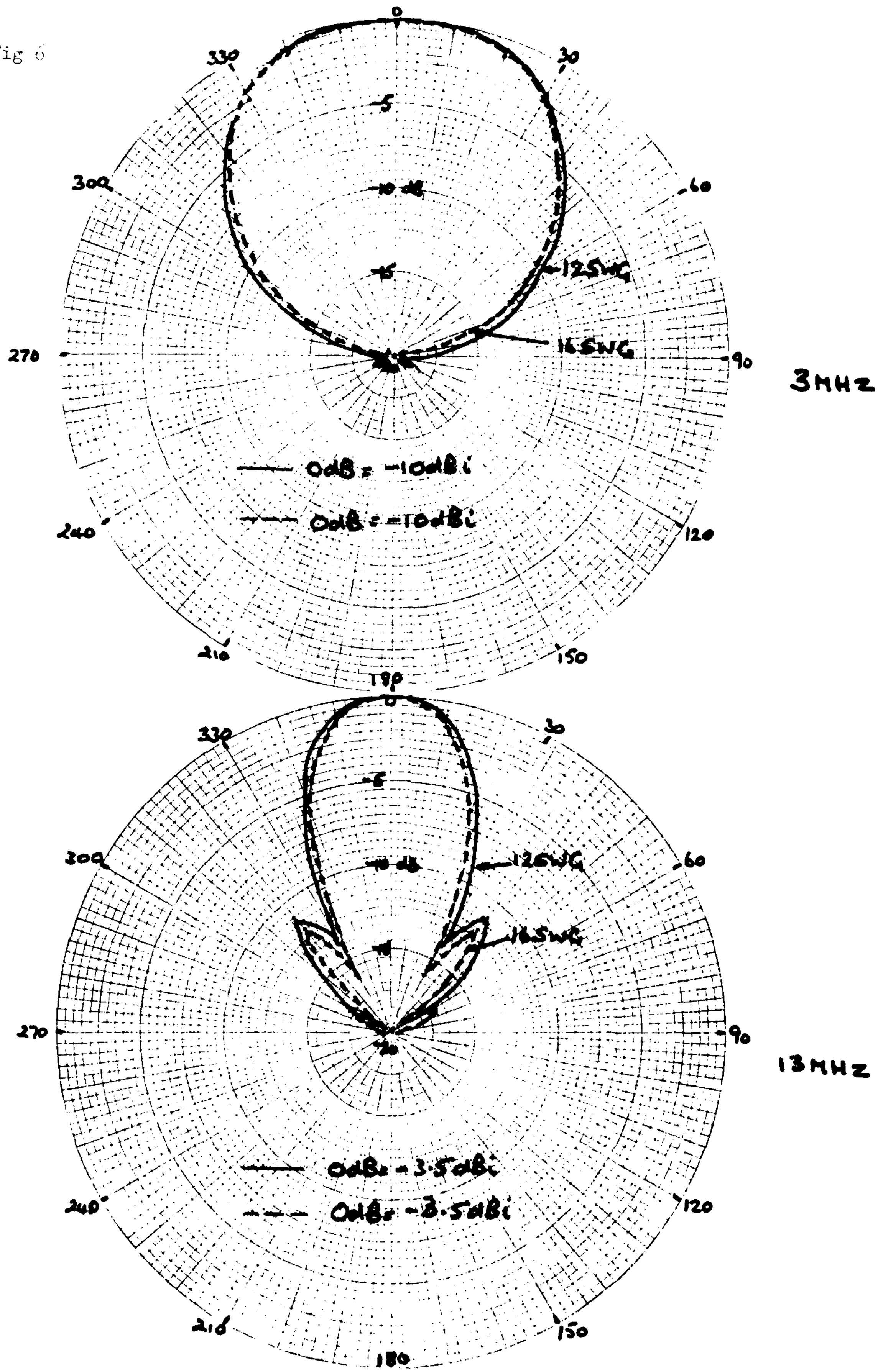
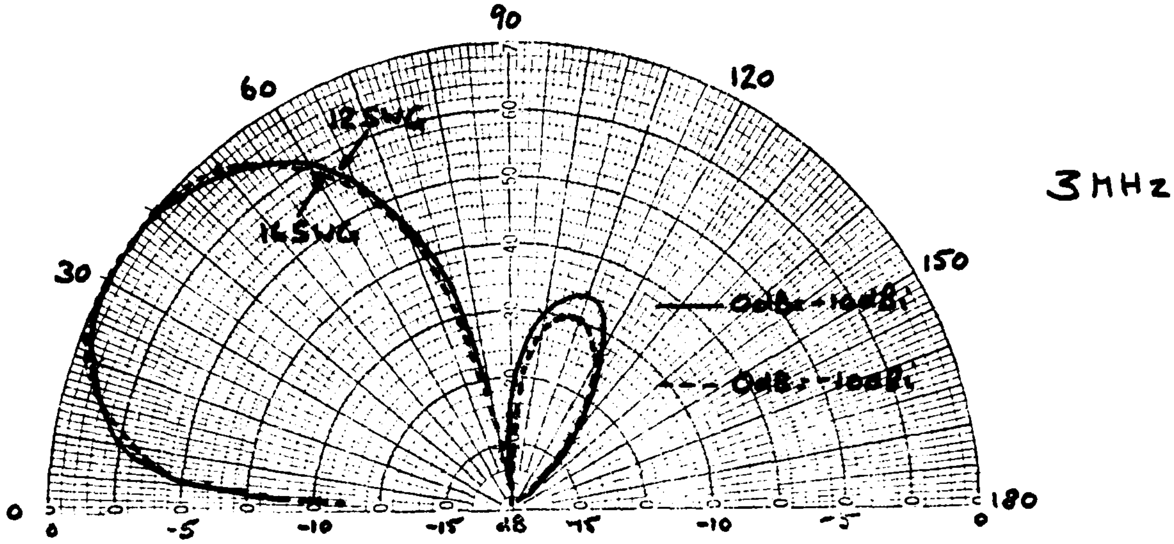


Fig 6 Azimuthal patterns at 0° elevation, antenna height = 1.0 m, conductivity = 0.01 S, E_r = 12.0, antenna length = 100 m



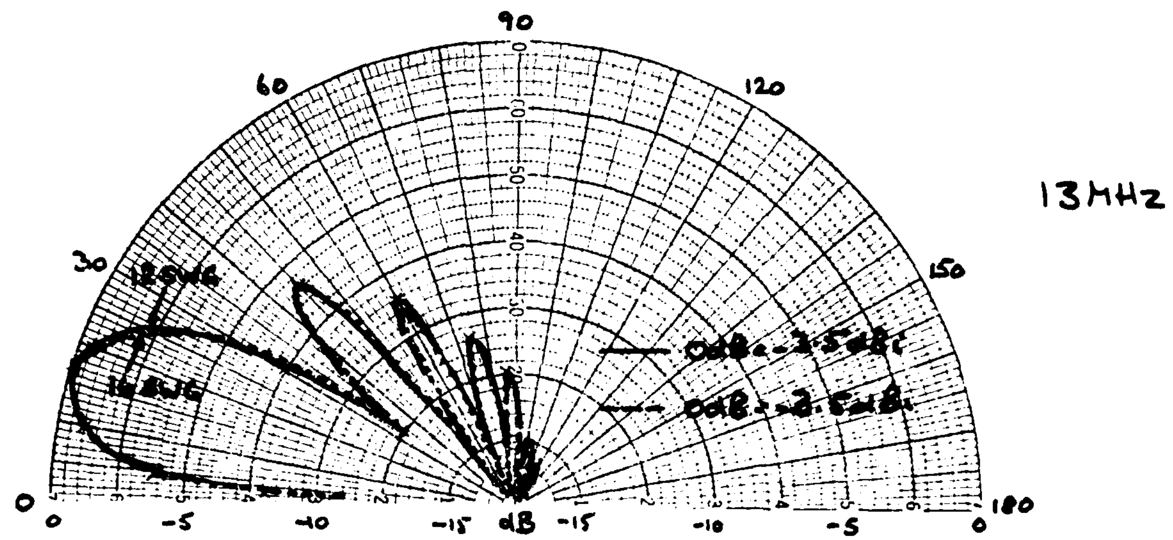


Fig 7 Elevation patterns at 0° azimuth, antenna height = 1.0 m, conductivity = 0.01 S, E_r = 12.0, antenna length = 100 m

Fig 8

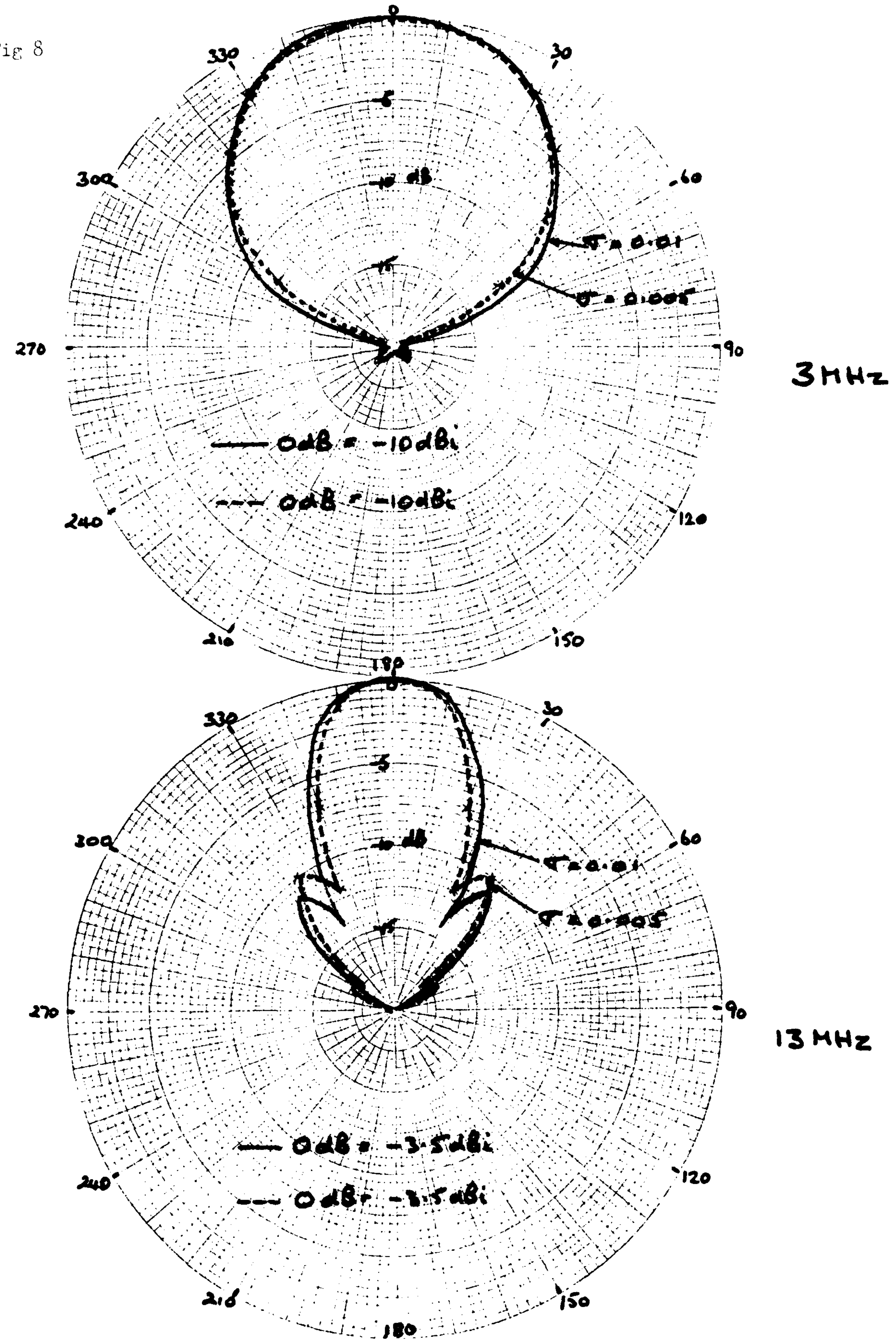
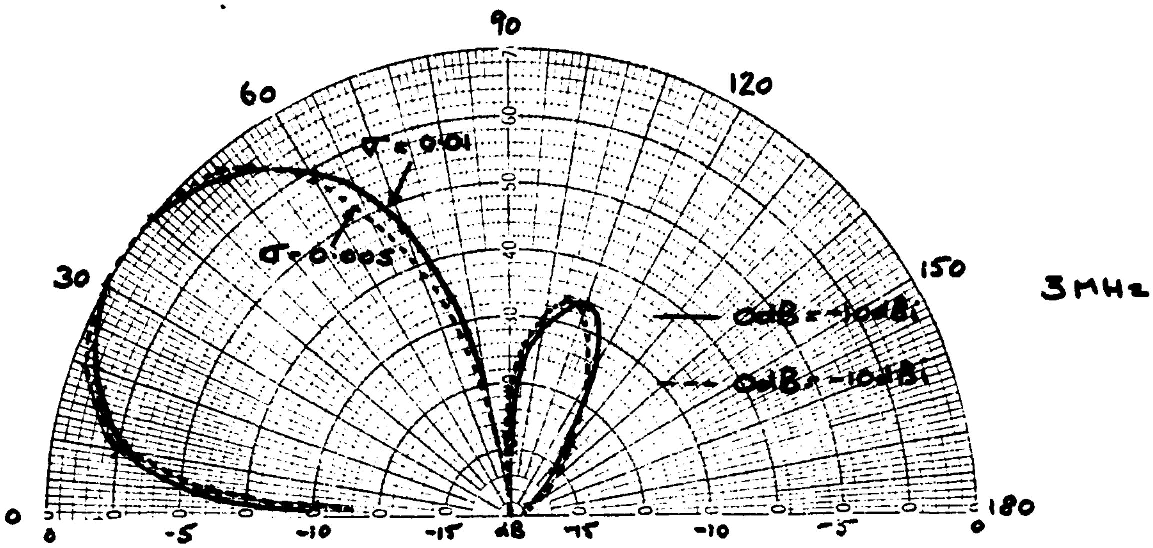


Fig 8 Azimuthal patterns at 0° elevation, antenna height = 1.0 m, antenna length = 100 m, E_r = 12.0, wire size = 12 SWG



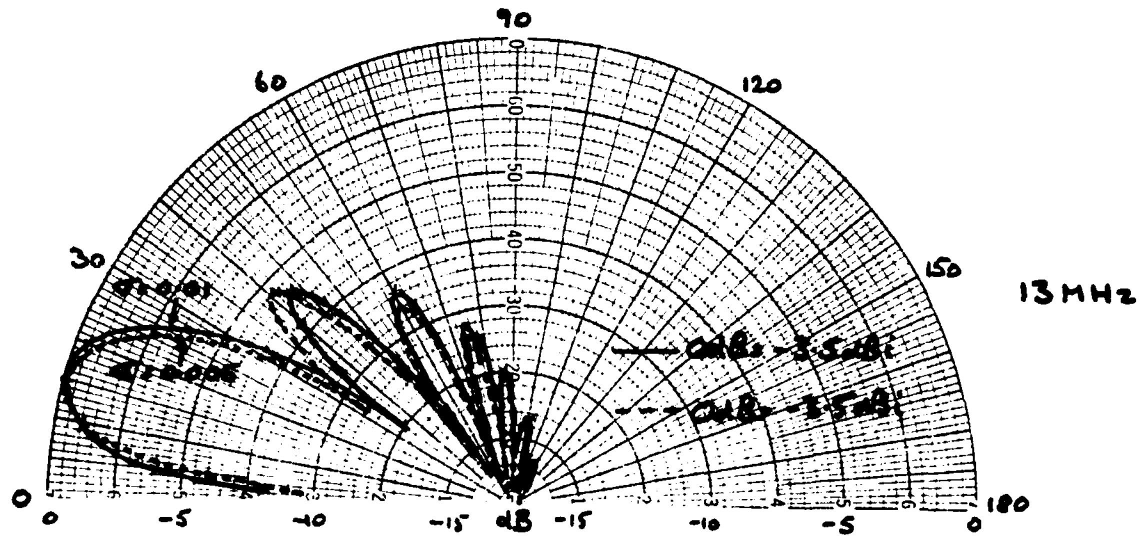
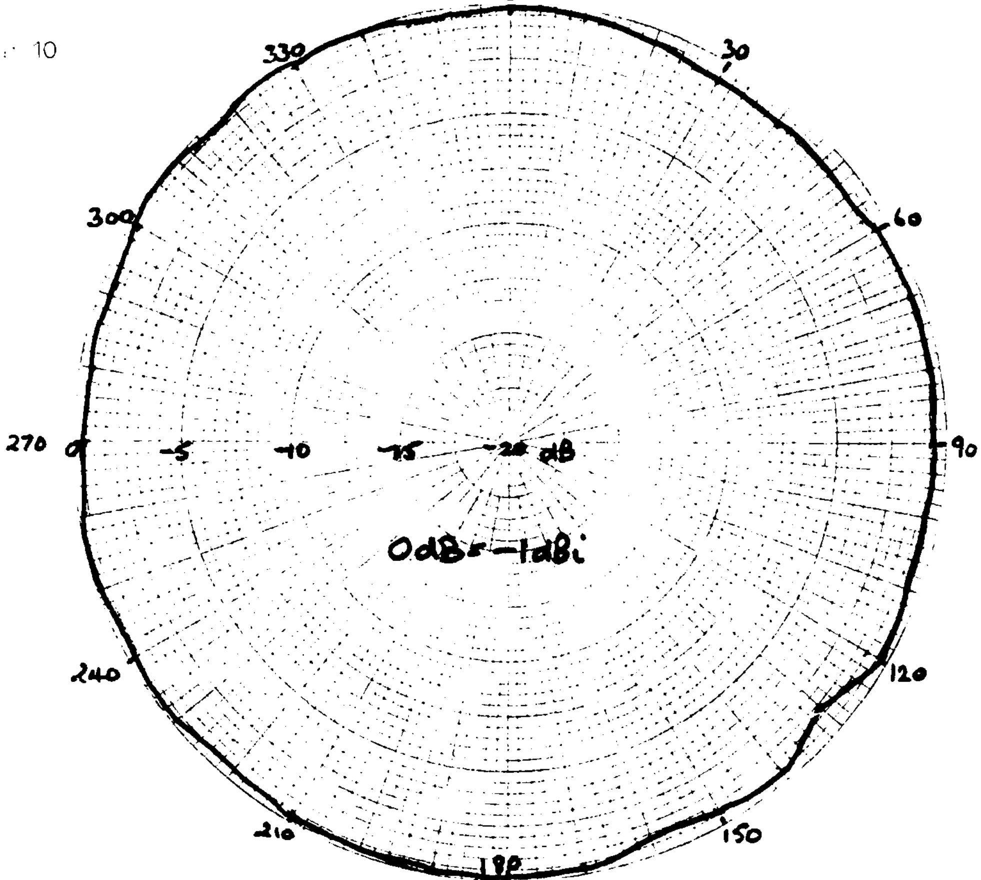
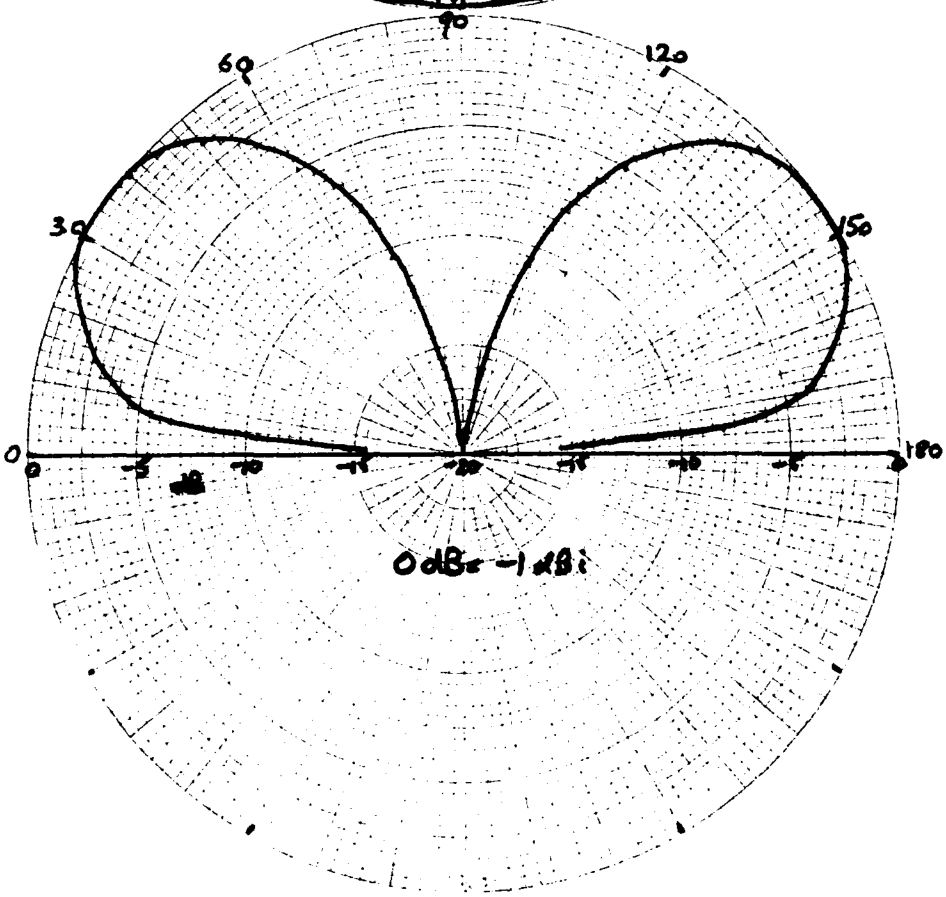


Fig 9 Elevation patterns at 0° azimuth, antenna height = 1.0 m, antenna length = 100 m, E_r = 12.0, wire size = 12 SWG

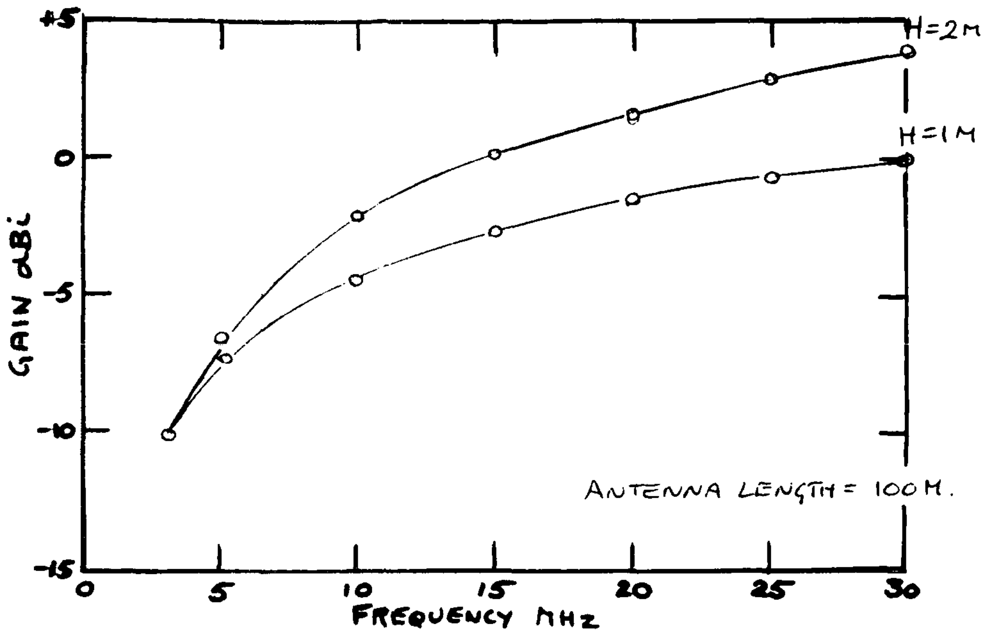


13MHz
AZIMUTHAL
PATTERN
AT 3°
ELEVATION



13MHz
ELEVATION
PATTERN
0°–180°
AZIMUTH.

Fig 10 Typical monopole patterns based on measurements



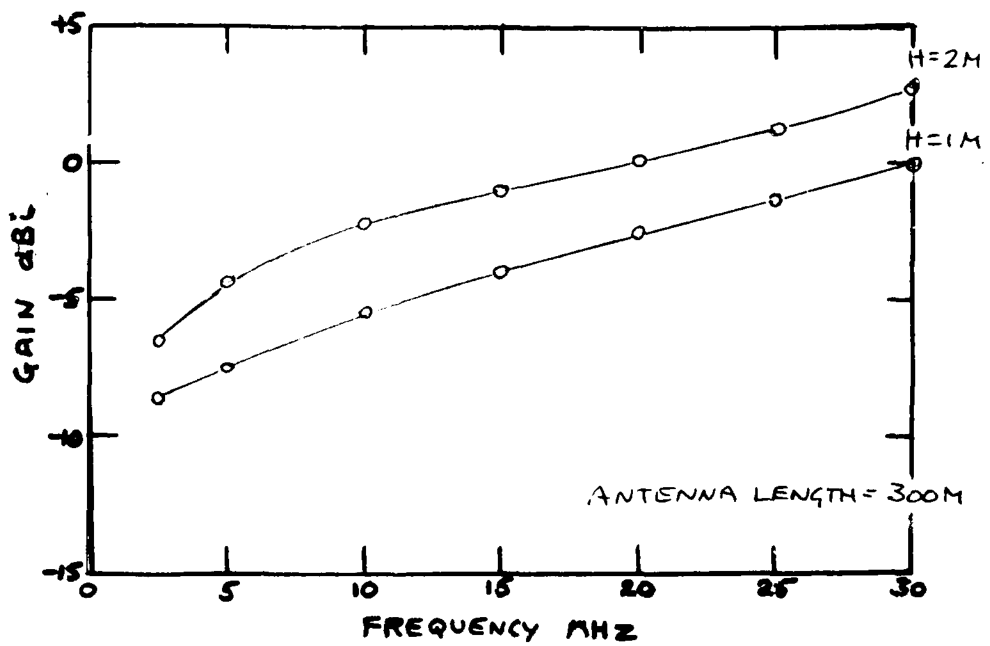


Fig 11 Theoretical surface wave gain of Beverage antenna for two different lengths and two different heights. Conductivity = 0.01 S

Fig 12

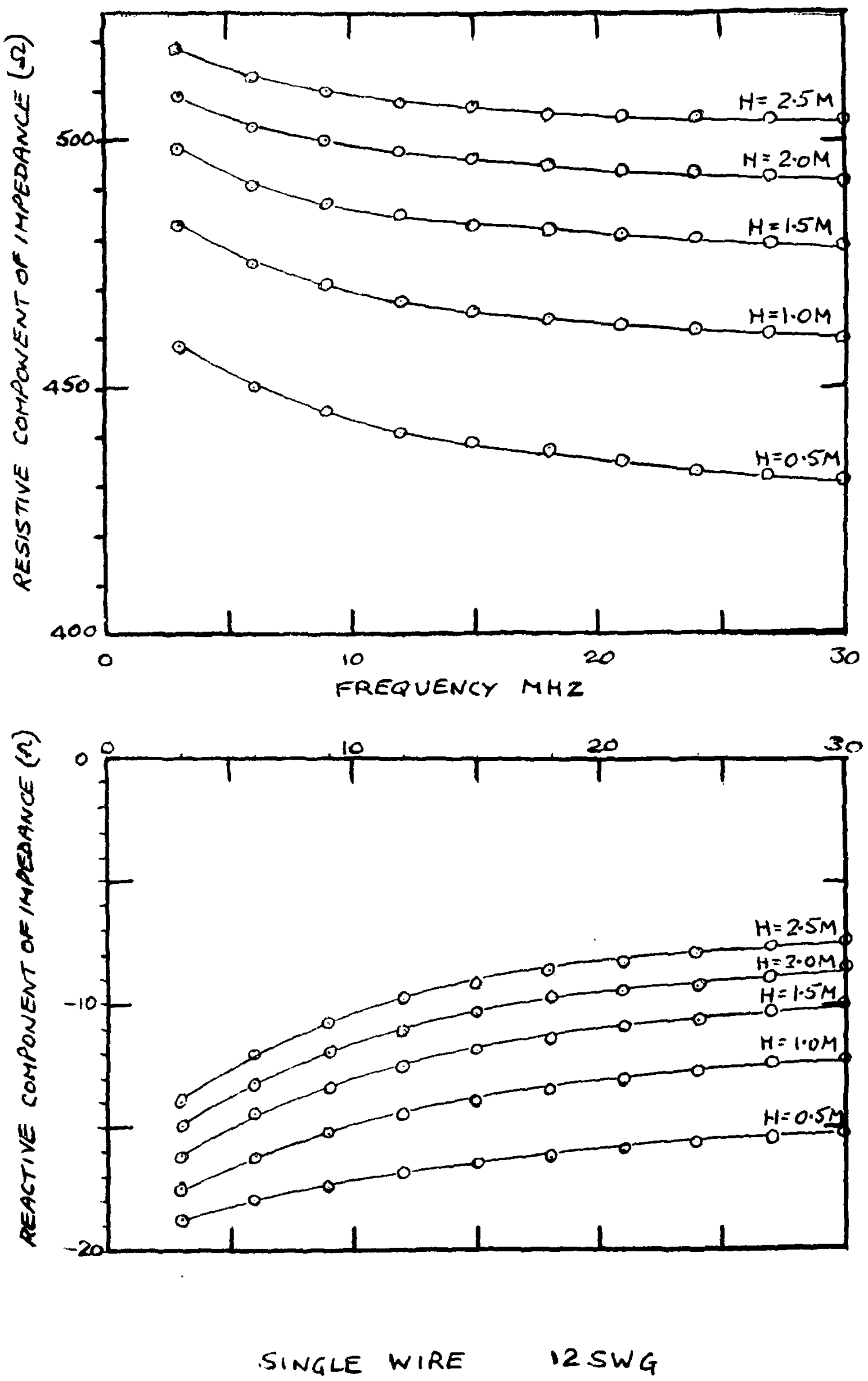


Fig 12 Antenna impedance vs antenna height

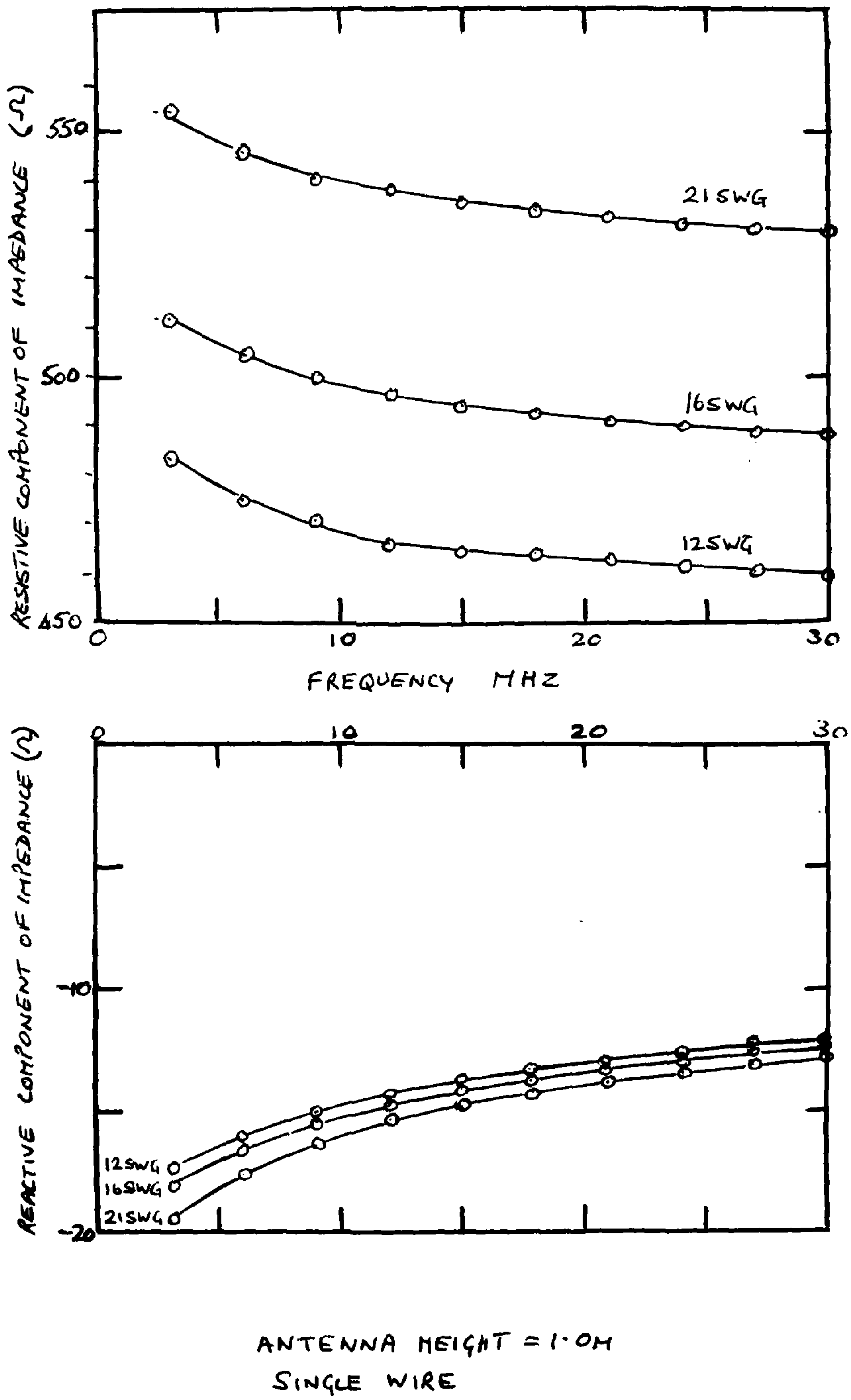


Fig 13 Antenna impedance vs wire size

Fig 14

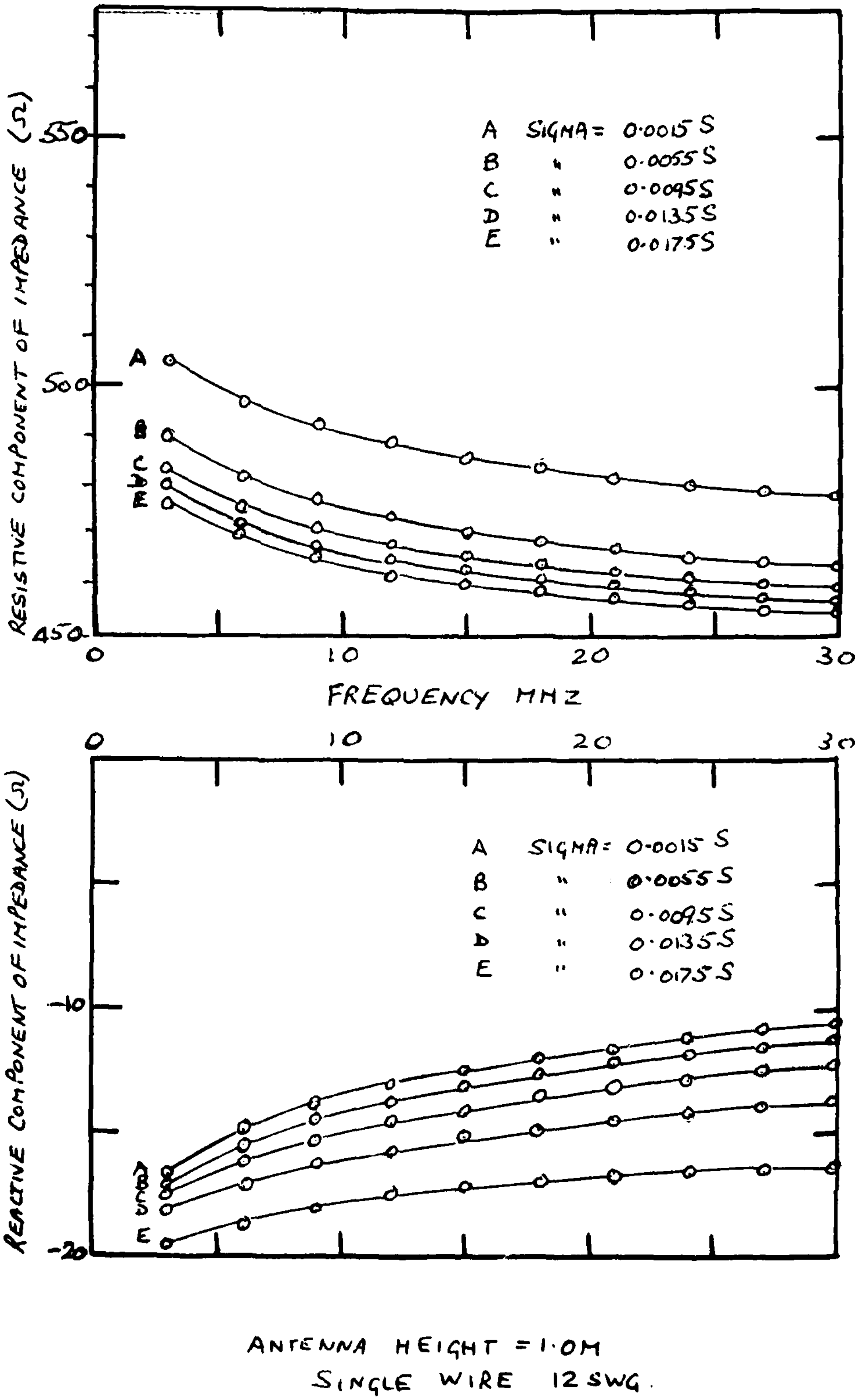


Fig 14 Antenna impedance vs ground conductivity

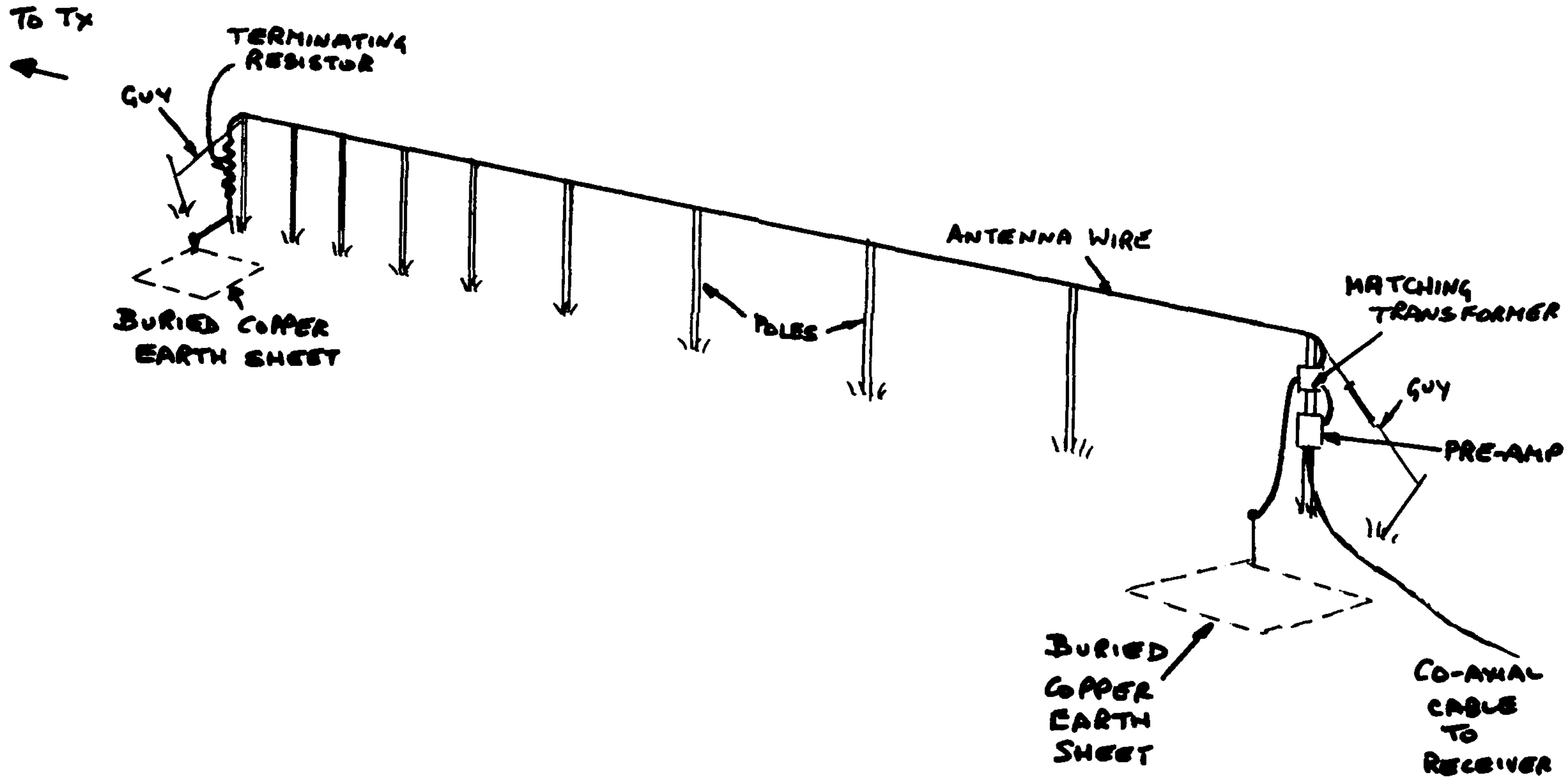


Fig 15 Schematic diagram of Beverage construction

Fig 16 Photograph of beverage showing matching transformer

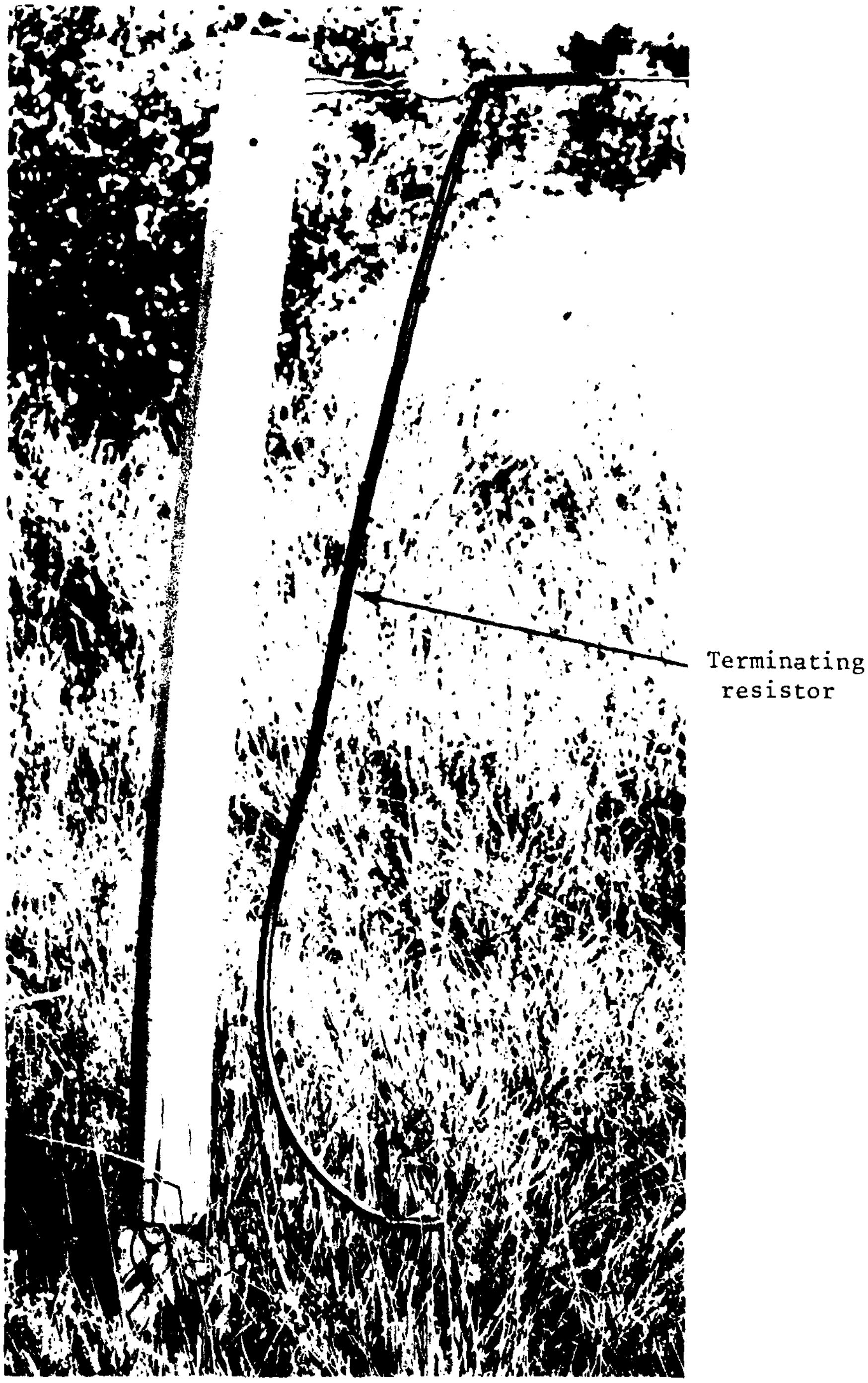


Fig 17 Photograph of beverage showing terminating resistor

Matching
transformer

Fig 18 A close-up view of a typical matching transformer

REPORT DOCUMENTATION PAGE

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17. Abstract

This Memorandum has been written to fill a need for practical advice on the design, construction and operation of a simple, single element, Beverage antenna.

Theoretical results are presented which show the performance likely to result from using differing antenna heights, lengths and wire sizes and from operating with different ground conductivities.

The assessment of performance and conclusions are based upon practical experience by the author in using this type of antenna.

RAE Form A143

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