A LIMITED COMPARISON OF PREDICTED AND MEASURED RESULTS FOR AN HF GROUND-ARRAYED LOG PERIODIC DIPOLE ARRAY

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Abstract: Measurements of the in-situ radiation pattern of a full scale horizontally polarised HF log periodic antenna are compared with predicted results from two different computer programs. The limited results suggest that more attention should be paid to ground effects at low take-off angles. While the predicted results are in good agreement with each other for take-off angles below the peak of the pattern, they tend to diverge above the peak.

1. INTRODUCTION

Prior to the advent of numerical techniques based on the method of moments as exemplified by the Numerical Electromagnetics Code NEC2 [Burke and Poggio; 1981], the author used a subroutine of a program, commonly referred to as ITS78, for the prediction of HF system performance [Barghausen et al.; 1969], for the design of horizontally polarised HF log periodic dipole arrays (LPDA's). In the initial stages of this unpublished work in the mid 1970's it became necessary to evaluate the performance of at least one of the LPDA's to convince potential clients that the program could in fact be used on a routine basis for this type of design. More recently it was decided to examine the original results using NEC2 to predict the performance of the LPDA. In view of the problems associated with the measurement of the gains and radiation patterns of HF antennas in general and the paucity of published results, the findings of this revised study may be of interest to other researchers and antenna designers.

Section 2 surveys some programs which have been widely used for the evaluation of HF communication systems. These programs incorporate subroutines which can be used to predict the performance of a variety of HF antennas. In Sections 3 and 4 the physical and electrical details of the particular LPDA examined in this work using measured and predicted results, are given. Section 5 discusses the measurement procedure. The measured and predicted results are compared in Section 6.

2. BRIEF DISCUSSION OF THE ANTENNA SUBROUTINE PACKAGES OF SOME PROGRAMS FOR THE PREDICTION OF THE PERFORMANCE OF HF COMMUNICATION SYSTEMS

Algorithms used for the prediction of HF antenna performance in ITS78 are those described in two reports by Ma and Walters [1967, 1969]. Two updated versions of the HF prediction program ITS78 are in common use at present. These are IONCAP [Teters et al.; 1983] and HFMUFES4 [Haydon et al.; 1976]. In the course of these updates the antenna subroutines were rewritten and algorithms for additional antennas included. Errors found in the ITS78 version were corrected. For some reason the horizontal LPDA was omitted from IONCAP while HFMUFES4 does not contain the algorithm for a vertical LPDA found in IONCAP. Table 1 lists the various antennas which are catered for in the programs HFMUFES4 and IONCAP.

As a result of the positive response to the two reports and the computer algorithms, a textbook dealing with the problems of antennas over lossy ground and which describes the mathematical bases for the various algorithms, was prepared by Ma [1974]. The main reference is the report by Ma and Walters [1969].

In evaluating the gain of LPDA's, the treatment of Ma [1974] uses a three term trigonometric expansion for the current distribution as proposed by King and Wu [1965] for dipole elements. This approach is valid only when the half length of the antenna element does not exceed 5/8 wavelength and the elements are symmetrically located. For the case under consideration the half length of the longest element was about 21 meters, or approximately 3/8 wavelength at the test frequency of 5.27 MHz. Expansion of the current distribution using five terms [Chang and King; 1968a, 1968b] could also be used and is suggested by Ma [1974] for arrays in which the elements are not symmetrically located. The major contribution to the radiation field of an LPDA is from a limited number of elements in the active region. Only a small amount of RF energy travels to longer elements beyond this region . In view of this it is likely that the three term method would still be an adequate overall approximation at higher frequencies where the longer elements violate the 5/8 wavelength restriction.

Provision is made in the above programs for the inclusion of ground effects using the appropriate plane wave reflection coefficients so that the unavoidable real problem of ground arraying HF antennas can be analysed. No provision is made for the inclusion of the effects of diameter to length ratios or conductivity of the wires to be used in the construction of the antennas. This is generally not a serious problem for HF antennas. A more serious problem not addressed by these programs, is the sag expected in suspending a large LPDA between masts. The effects of sagging can only be reduced by considerable extra effort in mechanical design and construction.

Although the intended application of the algorithms is for the evaluation of HF antenna performance over real ground, this author has also used them successfully for the design of some thin wire antennas at VHF and UHF by scaling frequencies and dimensions.

The above programs enable the prediction of off-azimuth gain. During the course of generating data at various azimuths for the plotting of gain contours of log periodic antennas over real ground, it was found that the ITS78 gain subroutines in Barghausen et al. [1969] did not predict the same gain at zenith (theta = 0 degrees) for pattern cuts at azimuths of 0, 90 and 180 degrees. The predictions for cuts at azimuths of 0 and 180 degrees agreed at zenith and also agreed with the predicted gains using the gain subroutines of Haydon et al. [1976], which in turn agreed at zenith for all three azimuth directions.

It is of interest to note that the original version of the algorithms in ITS78 were used in the preparation of at least one report containing predicted on azimuth radiation patterns of various antennas over sea water and good and poor ground [Thomas and DuCharme; 1974].

This report has been widely used by engineers involved in the prediction of HF system performance to evaluate potential antenna requirements.

3. DESIGN PARAMETERS CONSIDERED IN THIS PAPER

The design procedures for LPDA's are generally known and found in many standard antenna texts and handbooks. Since the handbook by Smith [1966] was used as a guide in the electrical/mechanical construction the reader is referred to this book for convenience.

The intended band of operation was from 4 to 30 MHz. A longest element length of 42.13 meters was chosen. Physical constraints on the size of the antenna resulted in the choice of a geometric shortening factor of 0.87 and an half angle of 15.0 degrees between the array tips and the feedline. This corresponds to a spacing factor between elements of 0.12. This is less than the optimum value for maximum gain given in Figure 4.12 of Smith [1966]. According to this figure the free space gain would be roughly 0.3 dB below the maximum for the chosen value of the shortening and spacing factors. This is hardly of any consequence for HF antenna design. Table 2 lists the electrical design parameters for the LPDA. For comparison a sample input file for analysing the LPDA using NEC2 is given in Table 3.

It was decided to erect the array with the horizontally polarised elements half their total length above ground. In view of the fact that the position of the active region, or the elements making the greatest contribution to the radiated field, is displaced from that of resonance for a single dipole towards the shorter elements, the resultant height of the active region above ground was less than a quarter of a wavelength.

4. CONSTRUCTION AND SITING OF THE LPDA

The mechanical and corona design considerations given in Chapter 6 of Smith [1966] for an antenna capable of handling 3 kWatts of RF power were followed. Stranded hard drawn aluminum wire with a diameter of 5 millimeters was used throughout. The unloaded impedance of the transmission line coupling alternate dipoles with a 180 degree phase reversal was chosen as 450 ohms. For the prototype antenna reinforced glass plastic (fibreglass) catenaries[1] were used.

The antenna was to be installed for tests at a Post Office HF transmitting site at Olifantsfontein, south of Pretoria, South Africa. A best estimate of ground conductivity of 0.004 Siemens/m at the site was obtained from a survey of ground conductivities based on measurements of groundwave attenuation at frequencies near 500 kHz [Vice; 1954]. A

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[1] *It later became evident that the intense ultra-violet radiation experienced at the altitude of the site (1530 meters or 5000 feet above sea level) caused degradation of the resin used in the construction of the catenaries. For all subsequent versions a catenary of prestressed artificial fibres covered by a plastic sheath with an ultra-violet resistant filler was used. The tradename for this catenary rope is PARAFIL. It is manufactured by ICI in the UK. This type of catenary has been extremely successful and has to date lasted 15 years at this altitude.*

value of 12.0 was assumed for the relative dielectric constant of the ground. This value is representative of average ground [Saveskie; 1977].

The antenna was constructed on site with the array laid on the ground and tensioned in this position. Once all mechanical checks were completed the LPDA was hoisted into position with the rear element tensioned at a height of 21 meters between two 25 meter high masts. A bridle attached to the tops of the masts was used to reduce sag in the longest element. The catenaries were suspended between these rear masts and shorter creosoted wooden masts positioned each side of the projected axis and in line with the apex of the antenna. The feedline was tensioned to a similar short mast near the apex. The heights of attachment of the catenaries and feedlines were adjusted to place the first element at the required feed height of 1.49 meters, half the length of the shortest element. The transmission line extended 10.5 meters beyond the longest element and was terminated in a short circuit.

The input impedance of the LPDA was found to be approximately 200 Ohms, with a VSWR of less than about 2.0 from 4 to 30 MHz. Since measurements were to be made in the receive mode a 200:50 Ohm balun was used for matching.

The terrain on which the antenna was installed sloped gently downwards in the direction of the apex with a slope of approximately 1.5 degrees under the antenna. The feedpoint was 42 meters from a 2.5 meter high chain link security fence with continuous strands of barbed wire along the top. A site plan is shown in Figure 1. The position of other antennas to the rear of the test antenna are not shown. At an elevation angle of 10 degrees for the farfield ray the closest edge, centre and furthest edge of the first Fresnel zone were estimated to be at about 60, 500 and 3000 meters from the shortest element respectively at the measurement frequency. A substantial section of the fence was therefore well within the region of the Fresnel zone. Figure 2 shows a cross section of the terrain along the projected axis of the LPDA, measured from the position of the shortest element. Positive range is in the direction of the main lobe of the antenna.

5. MEASUREMENT PROCEDURE

At the time that the measurements were made in 1974 no facilities existed for the in situ measurement of the performance of HF antennas. The procedure outlined in Barker [1973] was therefore used as a guideline for the development of suitable instrumentation and procedures.

The transmitting site was at this time in regular use for long-distance HF communications. A frequency of 5.27 MHz at which the interference from other transmitters was expected to be minimal, was chosen. In order to further reduce potential adjacent channel intermodulation products which could interfere with the measurements, a Rohde and Schwarz tunable notch filter was used at the input of the receiver. The receiver was a Rohde and Schwarz Model HFH field strength meter with suitable dynamic range and an output for an analogue recorder. The deflection on the analogue recorder was calibrated by means of a signal generator.

The transmitter package was to be towed behind a helicopter at a fixed altitude along the projected axis of the LPDA. This package presented the most problems because of initial lack of stability under tow and transistor breakdown resulting from electrostatic discharge on landing. The final configuration consisted of a battery pack, a crystal controlled oscillator at the selected frequency and a power amplifier which fed a tuned dipole with a total length of 2.4 meters through an earthed balanced isolation transformer. The dipole ends were loaded with 120 millimeter hollow copper spheres (flotation balls for a cistern). The transformer and electrostatic discharge streamers, similar to those found on aircraft and attached to the spheres, finally eliminated the discharge problem. A 1.2 meter long wooden broom handle passed through the instrumentation package at right angles to the dipole and also had hollow copper spheres attached at the ends. Small ring bolts were provided on the package and at the ends of the dipole for the attachment of a small stabilising windsock on loan from an airfield. By replacing a hollow sphere with a solid metal sphere of the same dimensions either horizontal or vertical polarisation could be obtained as required while maintaining aerodynamic stability regardless of polarisation. The package was attached to an helicopter by means of a 6 meter long heavily weighted steel cable on a quick-release catch and a 20 meter length of plastic rope. The weighted cable and release catch were safety requirements for the helicopter. In flight the transmitter package was stable in attitude from almost zero to about 45 knots. The package's position was about 10 meters below and to the rear of the helicopter during flight.

The intention was that the pilot of the helicopter would calibrate his barometric altimeter at a landing zone next to the antenna. The helicopter would then be flown to a barometric height of about 300 meters (1000 feet). The flight was to be at fixed barometric height and at a constant speed of about 30 knots in a straight line over the antenna on a course along its projected axis. Since no suitable transportable navigation equipment was available, a number of ground control points were selected along this course using 1:10 000 ortho-photo maps. Whenever the pilot was directly above one of these points he was to advise the observers on the ground by radio. The end of the LPDA with the shortest elements was also a control point, the only one which the ground staff could use as a reference to mark the instant at which the package was directly over the feedpoint of the LPDA. The instants at which the pilot reported crossing the control points were marked on the chart recordings of the analogue output of the fieldstrength meter.

6. RESULTS OF THE LPDA ANALYSIS AND MEASUREMENTS

Figure 3 is a copy of a typical analogue recording. Points 2, 3 and 4 marked on the curve correspond respectively to the pilot's estimate of when he was over the smallest element of the antenna and two control points 2.49 and 4.08 kilometers from point 2 in the direction of the main lobe. The peak signal corresponds to a level approximately 100 dB in excess of 0.1 microVolts at the input to the receiver. The nulls in the trace occurred when the helicopter turned at the start or end of the run.

Data regarded as reliable were obtained from only five runs, including two pairs in opposite directions. The reason for this was that the required course intersected the glide-path for a nearby airfield. The height restriction of 1000 feet was originally imposed for air safety reasons. Many runs had to be aborted in mid-flight in order to yield airspace to in-coming aircraft, or because of lack of fuel.

By using the known positions of the ground control points and the barometric height of the helicopter and assuming constant flight speed between the control points, it was possible to scale amplitudes off the chart recordings at roughly equal angular increments. A slant range correction factor obtained using the height and estimated ground range was added to the scaled data.

A comparison of the two sets of paired runs in opposite directions over the antenna showed that the estimate of ground position was affected by a parallax error. An attempt was made to allow for this error by adding a correction based on the distance that the transmitter package trailed behind the position of the pilot and the estimated position of the active region in order to correct for the phase center of the antenna. A further correction for the parallax in the pilot's reported position was based on the ground crew's estimate of when the transmitter package was directly over the shortest element of the antenna. A final check was to compare amplitudes of two consecutive runs in opposite directions at the point where the pilot claimed to be above the shortest element. By evaluating the relative change in position which would correspond to this difference in power level, it was possible to shift the relative position of the recorded curve in order to place the package over the smallest element. The assumption was made that the signal levels for the pair of runs would be the same during this portion of the flight.

Figure 4 shows a plot of the average normalised measured polar diagram for the two pairs of runs in opposite directions. Also shown are normalised polar diagrams predicted using NEC2 [Burke and Poggio; 1981] and the gain subroutines of HFMUFES4 [Haydon et al.; 1976]. The range spread of the measured data for the four runs used is shown in Figure 5. The total spread is seen to be less than about 3 dB over most of the angular plot. The results are discussed in detail below.

At take-off angles below the region of peak gain at an elevation angle theta between 35 to 40 degrees, the normalised polar plots in Figure 4 show that the predicted results exceed the measured results by an amount which increases steadily to about 4 dB at theta equal to 85 degrees. In this region of the polar diagram there is good agreement between the results predicted using NEC2 and HFMUFES4. Above the peak in the direction towards the backlobe one notes that the difference between the measured results and those predicted by NEC2 is less than 1 dB up to a value of theta of about -40 degrees. It increases steadily to about 4 dB at theta equal to -55 degrees. It reaches a value of about 8 db at theta equal to -70 degrees. The difference between the data predicted using HFMUFES4 and the measured data, on the other hand, is less than as about 2 dB for a value of theta between +65 and -70 degrees.

The lack of reasonable agreement between the measured and two sets of predicted data at take-off angles below that at which the peak occurs cannot be explained in terms of the slope of the terrain alone. The possibility that the ground effects were not predicted adequately in the standard version of NEC2 and that the security fence could have played a role were investigated. Use of the Sommerfeld/Norton ground option in the NEC2 predictions had little effect at a test frequency of 5.27 MHz. The difference between the NEC2 predictions with this option and those using the Fresnel plane-wave reflection coefficients was less than 0.1 dB. A detailed discussion of the effect of finite ground planes and the use of the Fresnel plane-wave reflection coefficients and the more accurate Sommerfeld/Norton method for interaction distances less than one wavelength, is given in Volume 1, Section IV of Burke and Poggio [1981]. An attempt was made to model the effect of the security fence by treating it as five strands of wire spaced 0.5 meters apart and positioned as shown by the solid lines indicating the fence in Figure 1. This, surprisingly, also had little effect on the NEC2 predicted data. The shape of the predicted polar plots were not overly sensitive to a change in the ground parameters. While the experimental method used may appear primitive it is encouraging to note that the spread in the four sets of data obtained and shown in Figure 5 is relatively small over a significant portion of the polar plot. It is believed that the discrepancy between the measured and predicted data below the peak of the pattern cannot be explained in terms of measurement error alone. The patterns predicted by the two methods agree well in this region but differ increasingly above the peak.

The predicted maximum on azimuth gains for the LPDA deployed as described were 8.1 and 8.7 dBi for HFMUFES4 and NEC2 respectively. Figure 6 shows the predicted on azimuth gain patterns for HFMUFES4 with ground reflection coefficients and NEC2 with the Sommerfeld Norton option. The polar plots are normalised to the peak gain predicted by NEC2. The differrence is less than 1 dB for values of theta from 85 to -20 degrees. This difference increases steadily to about 2 dB at theta equal to -45 degrees. At theta equal to -70 degrees it has increased to about 6 dB. It is believed that the differences between the two sets of predicted data are probably due to the three-term assumed current distributions [King and Wu; 1965] used in the algorithms in HFMUFES4 as described by Ma [1974]. It is possible that the use of five terms to describe the current distribution [Chang and King; 1968a, 1968b] and suggested by Ma [1974] for use to treat arrays whose elements are unsymmetrically distributed, could improve the match in the predicted data. An investigation of the current terms predicted by HFMUFES4 for log periodic arrays and comparison of these with NEC2 predicted values could further develop undestanding of the problem.

It is seldom (if ever) that one finds the actual measured gain of an HF antenna given in the measured results. In view of the admittedly simple technique used for the measurements it is hardly surprising that in this case the gain was not measured directly. The time service ZUO at the time that measurements were made still transmitted at 5 MHz on a vertical cage monopole. The transmitted time signal was switched several times between the LPDA and the cage monopole and monitored at a point about 1000 km away. It was concluded that the relative field strengths as measured were more or less in accordance with the relative gains predicted for these two types of antennas.

7. CONCLUSIONS.

Comparison of the measured and two sets of predicted data suggests that more work may be required to resolve the differences. It was noted that the two prediction methods in this case generally agreed well over most of the range of elevation angles. The NEC2 predictions included the effect of real ground either by using the reflection coefficient approximation or the Sommerfeld/Norton method. The results obtained using these two options were in excellent agreement with each other for the case under consideration. The subroutines of the HFMUFES4 predictions use a reflection coefficient approximation for cases in which real ground is to be included. Establishing the cause of the discrepancies between the NEC2 and HFMUFES4 predictions will require more work. While this may be justifiable for theoretical work, it is doubtful whether this would make much difference in practice in terms of HF comunications systems planning.

The measured normalised pattern does not agree with either of the sets of normalised predicted patterns for angles below that at which the maximum gain occurs. In view of the fact that the total spread of the measured data for the two pairs of runs in opposite directions is relatively small it is felt that the discrepancy cannot be ascribed solely to faulty or inaccurate measurements. On the basis of predicted results using NEC2 and a multiple wire model for the fence it is believed that the fence had little influence on the measured radiation pattern. The slope of the ground is also believed not to contribute significantly to the shape of the measured pattern.

It is concluded that in the case of HF antennas more work needs to be done on the verification of predicted radiation patterns with measured results for full-scale HF antennas before all sources of uncertainty can be eliminated.

As far as is known this is the first published comparison between radiation patterns predicted by NEC2 and HFMUFES4 and measurements performed on an HF antenna.

It is suggested that those interested in more details concerning HFMUFES4 or IONCAP contact the Institute for Telecommunication Sciences, US Department of Commerce, Boulder, Colorado. Failing this, the author would be prepared to provide copies or appropriate references to reports and computer programs.

8. ACKNOWLEDGEMENTS.

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		HFMUFES4	IONCAP
1)	Horizontal terminated rhombic	*	*
2)	Terminated sloping rhombic	*	*
3)	Side loaded vertical half-rhombic	*	
4)	Sloping double rhomboid	*	
5)	Interlaced rhombic		*
6)	Vertical monopole with no ground screen	*	*
7)	Vertical monopole with ground screen	*	
8)	Horizontal half-wave dipole	*	*
9)	Vertical dipole	*	
10)	Arbitrarily tilted dipole	*	
11)	Horizontal Yagi	*	*
12)	Curtain array with screen	*	*
13)	Terminated sloping Vee	*	*
14)	Inverted "L"	*	*
15)	Sloping long wire	*	
16)	Horizontal log periodic dipole array	*	
17)	Vertical log periodic monopole array (approximated as vertical monopoles)		*

Table 1. List of HF antennas for which algorithms are provided (*) in HFMUFES4 and IONCAP. Ground effects are included by means of reflection coefficients.

Total rear element length	42.13m
Height of rear element	21.065m
Feed height at shortest element	1.494m
Array slope measured from vertical	75.0
Unloaded transmission line impedance	450 ohms
Angle between array axis and element tips	15
Geometric ratio of element length	0.87
Number of elements	20
Distance to short on transmission line beyond the longest element	10.53m

Table 2. Design parameters for the horizontally polarised log periodic dipole array.

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CM LPA DATA FOR COMPARISON W. OUTP. FROM HFMUFES4. PROGAM
CM ANTENNA AT 5.27 MHZ. TAU = 0.87, 450 OHM, 20 ELEMENTS, OVER
CM GROUND ER=12, S=0.004
CM ALPHA = 15.00. AS PER MA'S WORK. MEASUREMENTS AT
CE OLIFANTSFONTEIN.
GW 1,3,-5.577,1.494,1.494,-5.577,-1.494,1.494,0.004
GW 2,3,-6.410,1.718,1.718,-6.410,-1.718,1.718,0.004
GW 3,3,-7.368,1.974,1.974,-7.368,-1.974,1.974,0.004
GW 4,3,-8.469,2.269,2.269,-8.469,-2.269,2.269,0.004
GW 5,3,-9.734,2.608,2.608,-9.734,-2.608,2.608,0.004
GW 6,3,-11.189,2.998,2.998,-11.189,-2.998,2.998,0.004
GW 7,3,-12.860,3.446,3.446,-12.860,-3.446,3.446,0.004
GW 8,3,-14.782,3.961,3.961,-14.782,-3.961,3.961,0.004
GW 9,3,-16.991,4.553,4.553,-16.991,-4.553,4.553,0.004
GW 10,5,-19.530,5.233,5.233,-19.530,-5.233,5.233,0.004
GW 11,5,-22.448,6.015,6.015,-22.448,-6.015,6.015,0.004
GW 12,5,-25.803,6.914,6.914,-25.803,-6.914,6.914,0.004
GW 13,5,-29.658,7.947,7.947,-29.658,-7.947,7.947,0.004
GW 14,5,-34.090,9.134,9.134,-34.090,-9.134,9.134,0.004
GW 15,5,-39.184,10.499,10.499,-39.184,-10.499,10.499,0.004
GW 16,7,-45.039,12.068,12.068,-45.039,-12.068,12.068,0.004
GW 17,9,-51.769,13.871,13.871,-51.769,-13.871,13.871,0.004
GW 18,11,-59.504,15.944,15.944,-59.504,-15.944,15.944,0.004
GW 19,13,-68.396,18.327,18.327,-68.396,-18.327,18.327,0.004
GW 20,15,-78.616,21.065,21.065,-78.616,-21.065,21.065,0.004
GW 21,3,-89.149,1.494,21.065,-89.149,-1.494,21.065,0.004
GE 1
FR 0,0,0,0,5.27,0
TL 1,2,2,2,-450.0
TL 2,2,3,2,-450.0
TL 3,2,4,2,-450.0
TL 4,2,5,2,-450.0
TL 5,2,6,2,-450.0
TL 6,2,7,2,-450.0
TL 7,2,8,2,-450.0
TL 8,2,9,2,-450.0
TL 9,2,10,3,-450.0
TL 10,3,11,3,-450.0
TL 11,3,12,3,-450.0
TL 12,3,13,3,-450.0
TL 13,3,14,3,-450.0
TL 14,3,15,3,-450.0
TL 15,3,16,4,-450.0
TL 16,4,17,5,-450.0
TL 17,5,18,6,-450.0
TL 18,6,19,7,-450.0
TL 19,7,20,8,-450.0,0.0,0.0,0.0,0.00
TL 20,8,21,2,-450.0,0,0.0,0.0,10E+10
EX 0,1,2,10,1.0
LD 5,0,0,0,3.6E07
GN 0,0,0,0,12.0,0.004
RP 0,19,1,1110,90.0,0.0,-5.0,0.0
RP 0,19,1,1110,0.0,180.0,5.0,0.0
PT -1,1,1,1
EN
```

Table 3. Sample input file for NEC2 for a horizontally polarised HF LPDA.

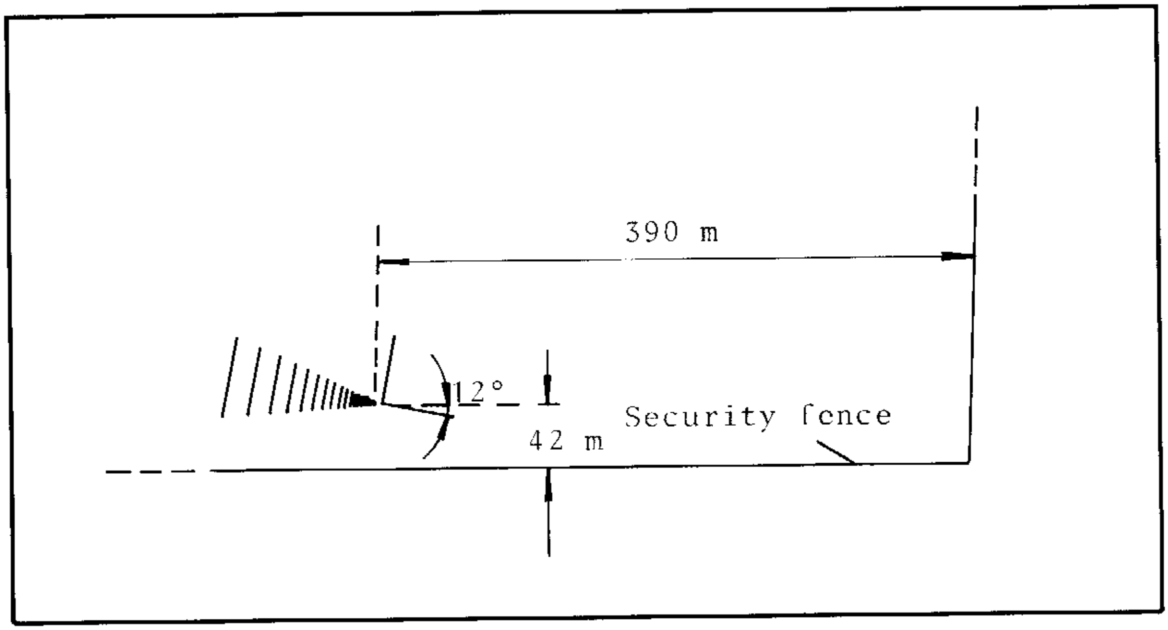

Figure 1. Site plan showing relative positions of HF LPDA and security fence.

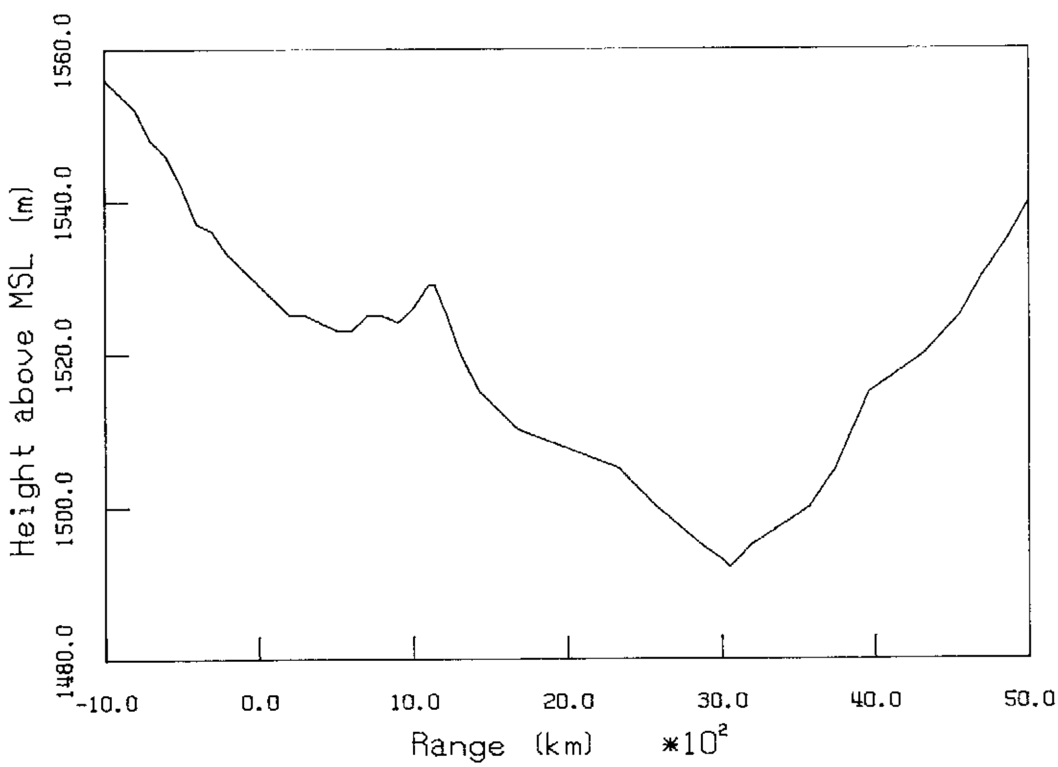

Figure 2. Terrain profile along projected axis of HF LPDA. Height is in meters above mean sea level. Positive range is in direction of main lobe.

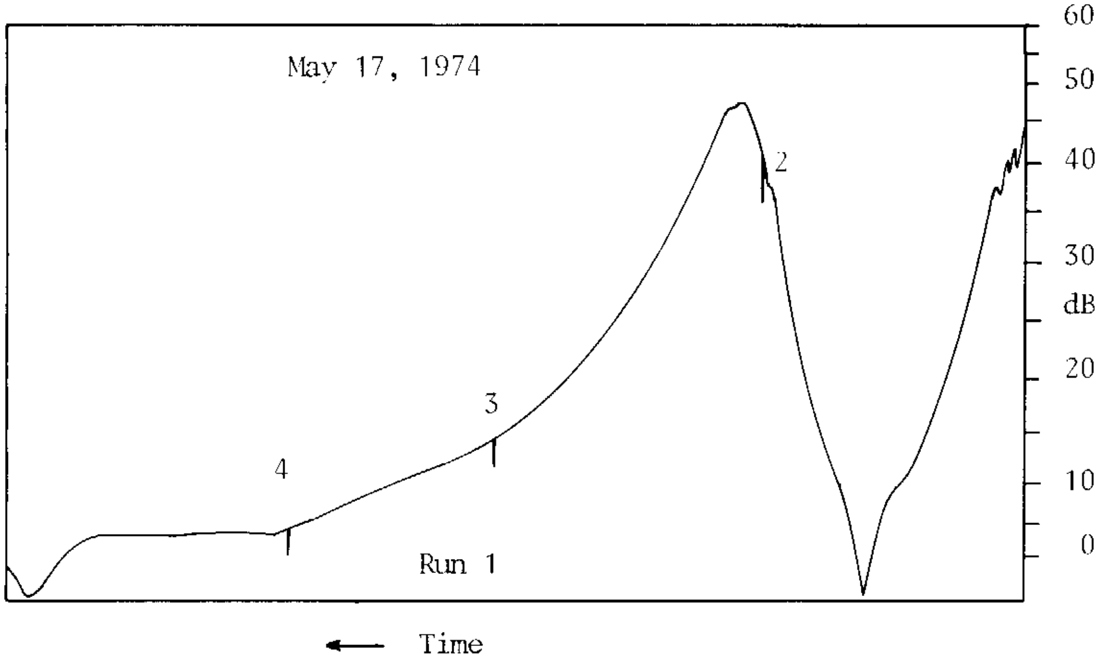

Figure 3. Typical analogue output of HF fieldstrength meter for an helicopter/ transmitter run along the axis of the LPDA.
Control pt 2, over shortest element.
Control pts 3 and 4, 2.49 and 4.08 km respectively in direction of main lobe.

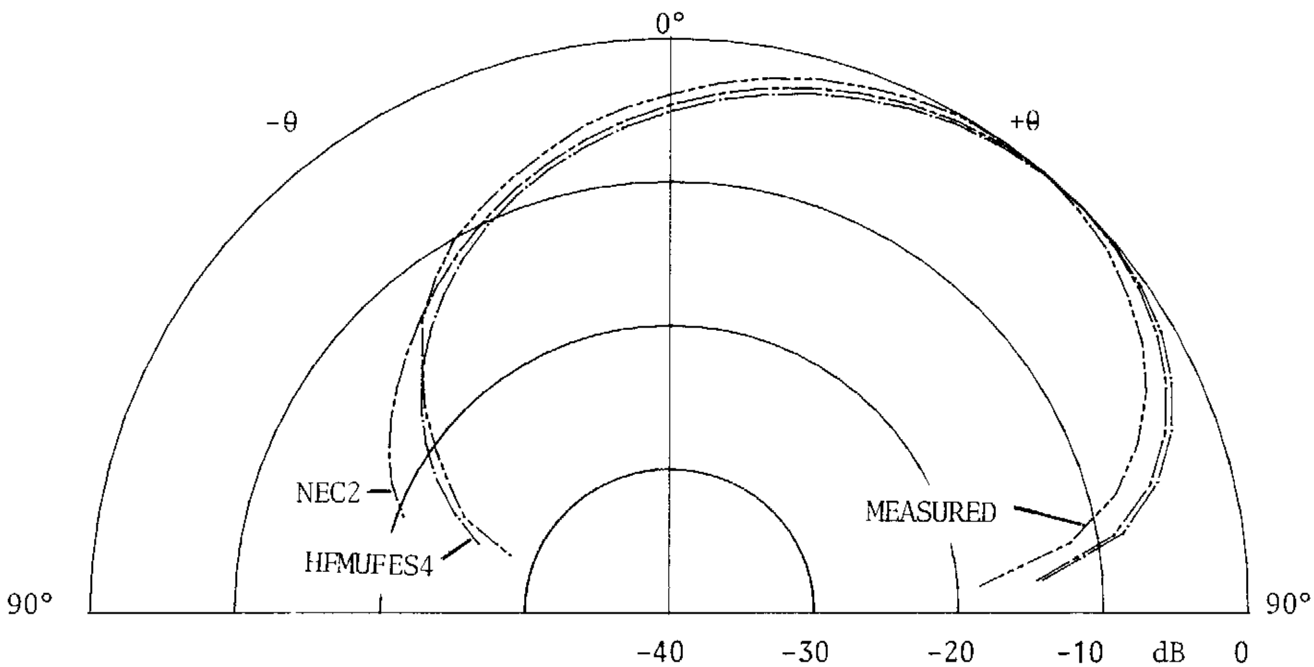

Figure 4. Comparison of normalised measured and predicted radiation patterns of horizontal HF LPDA at 5.27 MHz.

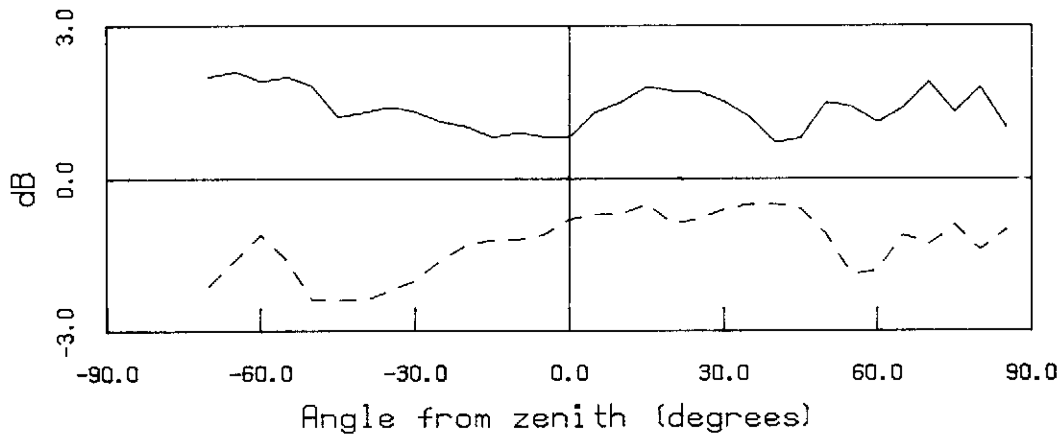

Figure 5. Spread of measured data for two pairs of data sets about the mean value. ———— upper limit. ------------ lower limit.

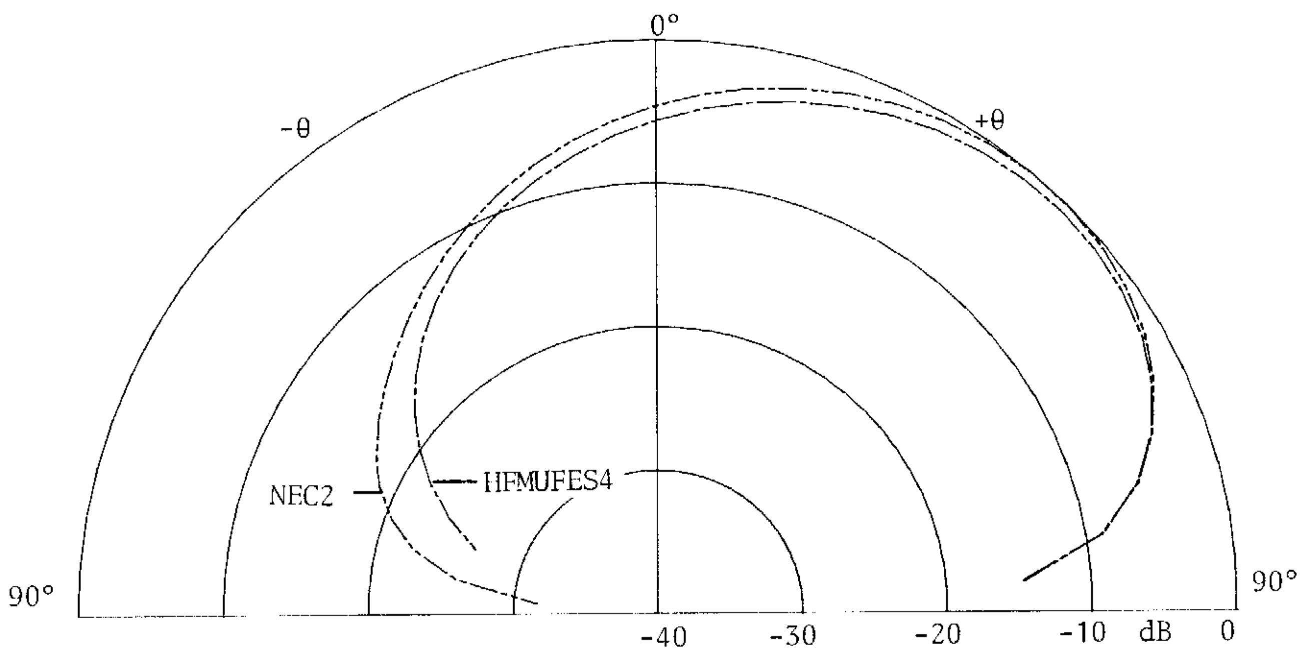

Figure 6. Comparison of NEC2 and HFMUFES4 predicted radiation patterns for the HF LPDA at 5.27 MHz, normalised to a peak predicted gain of 8.7 dBi for NEC2.