MODELLING BY NEC OF AN HF LOG-PERIODIC ANTENNA

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ABSTRACT

The Numerical Electromagnetics Code (NEC) is a computer code for analysing the electromagnetic response of an arbitrary structure consisting of wires and surfaces in free space or over a ground plane. It is based on the application of the Method of Moments to solve the electric field integral equation. A practical application of NEC which involved calculation of the impedance of a vertically polarised HF log-periodic antenna and comparison with measurements is described. A technique for improving the accuracy of the numerical calculations is discussed in addition to methods for accurately measuring impedances of antennas employing balanced two-wire transmission line feeders.

1. INTRODUCTION

This paper describes the author's experience in a practical application of NEC which involved calculation of the impedance of a vertically polarised HF log-periodic antenna (LPA), and comparison with measurements. The LPA considered is a proprietary design which was originally designed for use in broadband high-gain, steerable linear arrays for HF transmitters and receivers.

2. NUMERICAL MODELLING OF AN HF LOG-PERIODIC ANTENNA

For broadband linear arrays the elements of the array must be very closely spaced at the low frequency end of the operating band to minimise grating lobes at the upper frequency limit. At such close spacings the mutual impedances between elements of such an array have a significant effect on the impedance of each element which may vary substantially with frequency and steer angle. The LPA investigated here employs a novel element construction for the high-frequency radiators, and varying design parameters, σ and τ along the structure in an attempt to deal with mutual effects in an optimum manner.

As a first step towards investigating mutual impedance effects in a linear array of LPAs, an attempt was made to develop a model of a single LPA for use with NEC. An essential requirement for such a model, if it is to be useful for analysing arrays of, say, 8 or more LPAs, is that the number of wire segments be kept to a minimum so that computer core storage and processing time requirements do not limit the size of the array to be analysed.

A schematic of the LPA under investigation is shown in Figure 1. The construction is largely conventional in that guyed front and rear masts with catenary wires are used to support the radiating dipole elements which are fed by a two-wire balanced transmission line. (Guy wires and other wires supporting the radiating elements are not shown in Figure 1.) A balun at the feed point of the LPA permits connection to a 50 ohm coaxial system. The arrangement used for coupling the low frequency conventional dipole radiators to the two-wire feeder is shown in Figure 2. The high frequency radiators, commonly referred to as 'extended aperture elements', are shown in Figure 3, and differ from the low frequency dipoles by virtue of having an additional closely-spaced wire parallel to each of the driven arms of the dipole of approximately double the length of each half of the dipole. An additional unusual feature of the LPA is that the element spacings and lengths do not conform to a true log-periodic geometry with constant σ and τ along its length, and the wire diameters are equal for all elements rather than proportional to the element length.

The model initially chosen for the single LPA is as shown in Figure 1. No attempt was made to model in detail the complex structure connecting the two-wire feed to the dipole elements, each driven element being represented by a single wire with crossed transmission lines connected between the centres of adjacent pairs of elements. The parasitic elements associated with the 'extended aperture elements' were simply modelled as two wires with the same spacing, length and centre-gap as the actual antenna.

No attempt was made to include catenary or guy wires, partly to minimise the number of wires required for the model, and also because their effect was considered to be small due to insulators being inserted at relatively close spacings to suppress induced currents on these portions of the structure. Comparison of calculated results using this model with NEC and measured impedances were encouraging, but showed that an improved numerical model would be required if close agreement of measurements and calculation were to be achieved. As shown in the Smith Chart plots of Figure 4, the magnitude or the measured and calculated impedances are similar, but the phase angle of the reflection coefficient is in error by about 0.15λ for the frequency range shown. (The frequency range covered in these plots is near the lower end of the operating band.) Note that this is an expanded Smith Chart with a maximum VSWR of 2.5:1.

It was reasoned that the most significant source of error was likely to be due to the simplified model used for the region connecting the dipoles and the two-wire feeder. This problem has been considered in detail (R.W.P. King, The Theory of Linear Antennas; Chapter 11, Harvard Univ. Press, 1958) for various configurations of two-wire lines feeding dipoles, however extensions of these techniques to the problem considered here appears somewhat intractible. An alternative approach which was also considered was to model the region near the junction of the two-wire feeder and a single driven element using NEC. This approach was not pursued, as the geometry is such that wire junctions with 90° bends, abrupt changes in wire radii and multiple wire junctions would be involved. Reports from other NEC users suggest that such configurations should be avoided where possible.

In order to further simplify the problem of obtaining a simple LPA model for use with NEC, a single 'extended aperture element' was fabricated and its impedance measured. The impedance of the single 'extended aperture element' near resonance was also calculated using NEC with the simple model shown in Figure 5. The calculated and measured impedances are shown in Figure 6. It is seen that the calculated impedance of the 'extended aperture' element near resonance is of the order of 200 ohms, which is substantially greater than a simple dipole (~ 70 ohms). The measured impedance is similar to that calculated, however the former has a significantly greater capacitive reactance at all frequencies. This is attributed, to a first order, to the capacitance between the two halves of the assembly connecting the driven elements of the dipole to the two-wire feeder, no attempt having been made to accurately model this region.

If a parallel capacitance is added to the calculated impedance to match the measured impedance near resonance, the new 'calculated' impedance agrees more closely with the measured impedance as shown in Figure 7. An independent measurement of the static (dc) capacitance between the two halves of the centre portion of the dipole assembly was found to agree quite closely with that calculated above (4.5 pF calculated from the difference between measured and calculated impedances near resonance, and 5 pF static capacitance measured).

By adding a similar capacitance in parallel with the feedpoint of each element in the LPA model, the plots of measured and 'calculated' impedance become as shown in Figure 8. It can be seen that the agreement is substantially improved compared with the original calculations. Figure 9 compares measured and calculated impedances over a band 10 MHz wide above the low frequency operating limit. The agreement is very close. The narrow blip near the centre of the measured curve is unexplained; it is not evident in the calculated curve, however this may be due to the 'removal' of low frequency elements in the model of the LPA as the frequency increases.

3. THE MEASUREMENT PROBLEM

When comparing measured and calculated impedances of antennas it is necessary to consider the possible sources of error in the measurements. This is particularly important for antennas fed by two-wire transmission lines since most impedance measurement systems operate with 50 ohm coaxial transmission line test ports, and a balun must therefore be used to enable measurement of balanced impedances. Since the perfect balun does not exist, measurement errors will normally be introduced.

However, there are techniques that can be used to minimise such errors. For example, if the vector accuracy enhancement techniques as described in HP Application Note 221A, June 1980 are applied to an automated 50 ohm coaxial network analyser followed by an imperfect balun, then most of the significant errors due to system imperfections can be eliminated by calibrating the system with three standard terminations on the two-wire terminals of the balun. The terminations normally used for calibration are a short-circuit, open-circuit, and a resistance equal to the two-wire terminal impedance of the balun. This latter impedance is the reference impedance for all measurements made following calibration. The first two standard impedances usually are easily realised at HF, however the matched two-wire line termination may present some difficulties. The latter problem may be alleviated by fitting coaxial connectors to each of the balanced output ports of the balun and terminating each of these ports with high-quality coaxial resistors each equal in value to half the desired two-wire impedance. Since coaxial resistors are available in a range of resistance values, calibration at the characteristic impedance at most two-wire transmission lines is possible. The main source of error with this technique is the discontinuity between the coaxial connectors and the two-wire transmission line, which should be small at HF frequencies.

A further source of errors in the above is the rejection of unbalanced voltages at the 'balanced' output terminals of the balun. These errors cannot be easily quantified.

4. CONCLUSION

The results presented show that accurate results can be obtained for complex structures provided that steps are taken to accurately model the feed region of centre-driven elements. A technique for accurate impedance measurement of antennas driven by two-wire balanced transmission lines was also outlined.

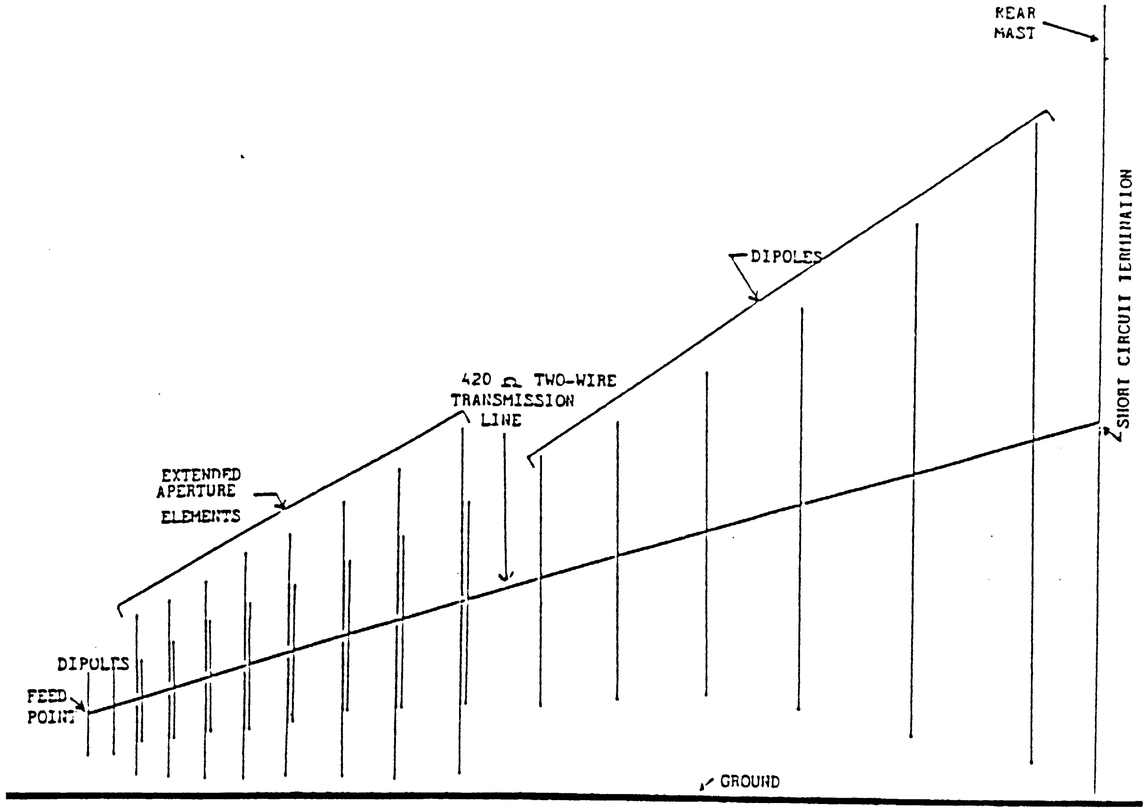

FIGURE 1 SCHEMATIC OF VERTICAL LPA
(APPROX 1/200TH FULL SIZE)

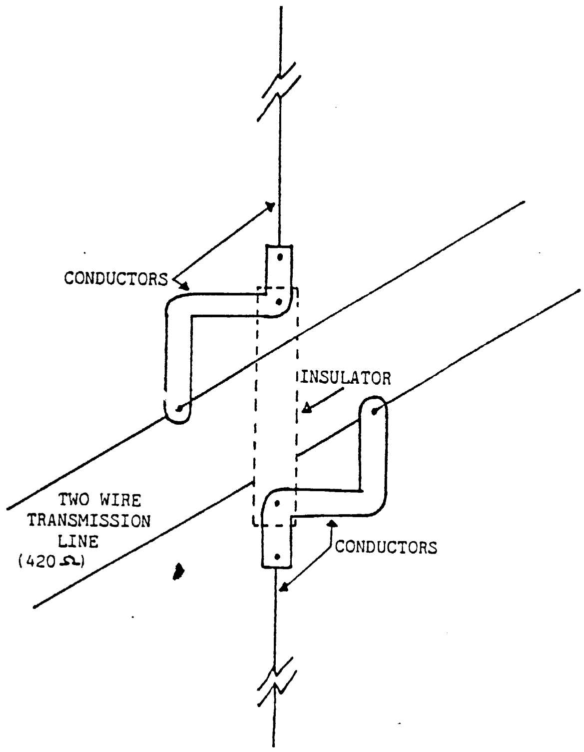

FIGURE 2 DETAILS OF DIPOLE TO TWO-WIRE TRANSMISSION LINE CONNECTION

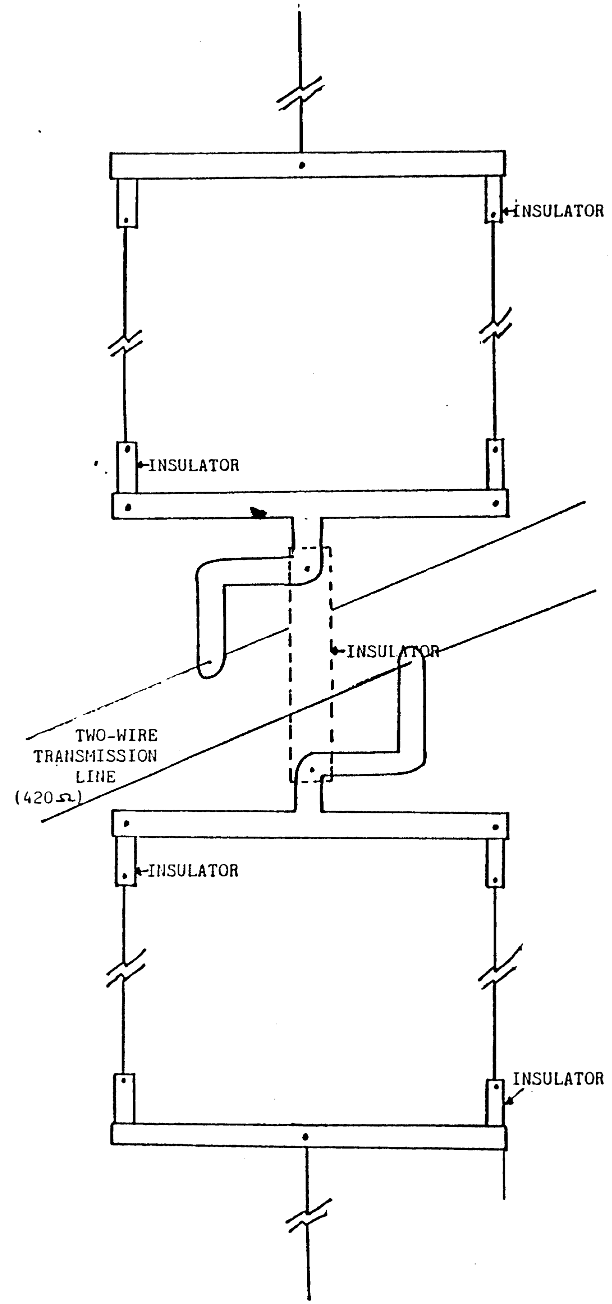

FIGURE 3 DETAILS OF "EXTENDED APERTURE" ELEMENT TO TWO-WIRE TRANSMISSION LINE CONNECTION

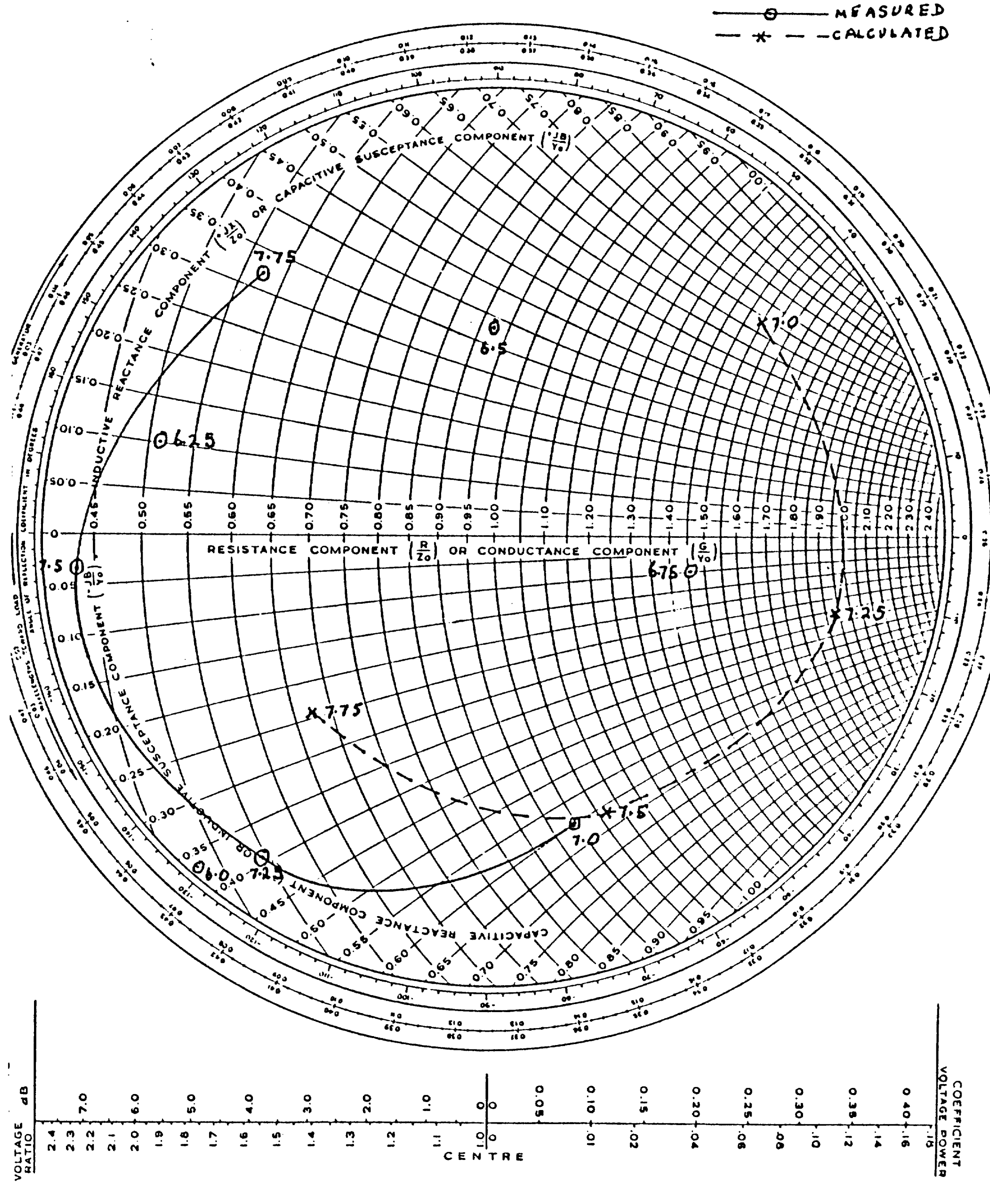

FIGURE 4 INITIAL COMPARISON OF MEASURED AND CALCULATED IMPEDANCES OF VERTICAL LPA (FREQUENCIES IN MHz)

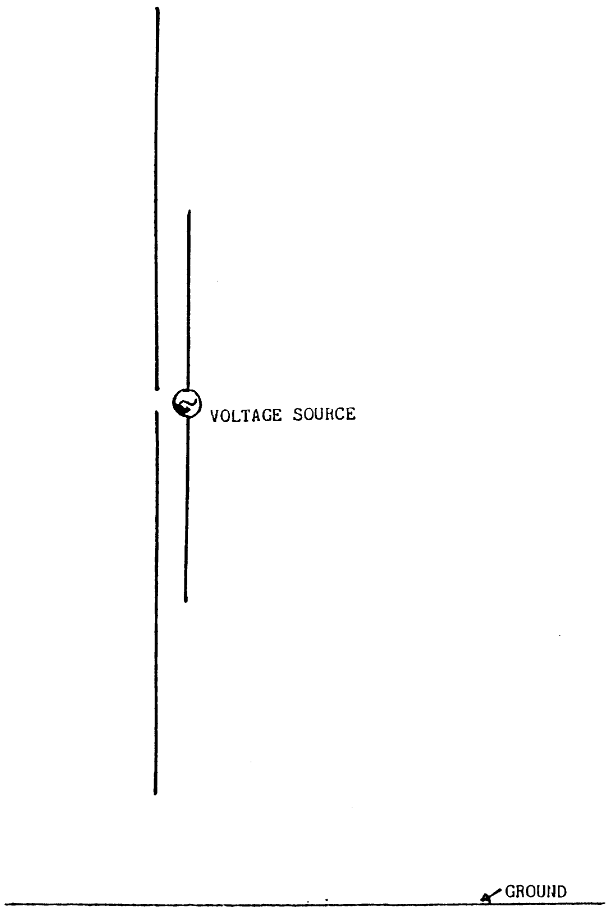

FIGURE 5 MODEL OF "EXTENDED APERTURE" ELEMENT FOR NEC

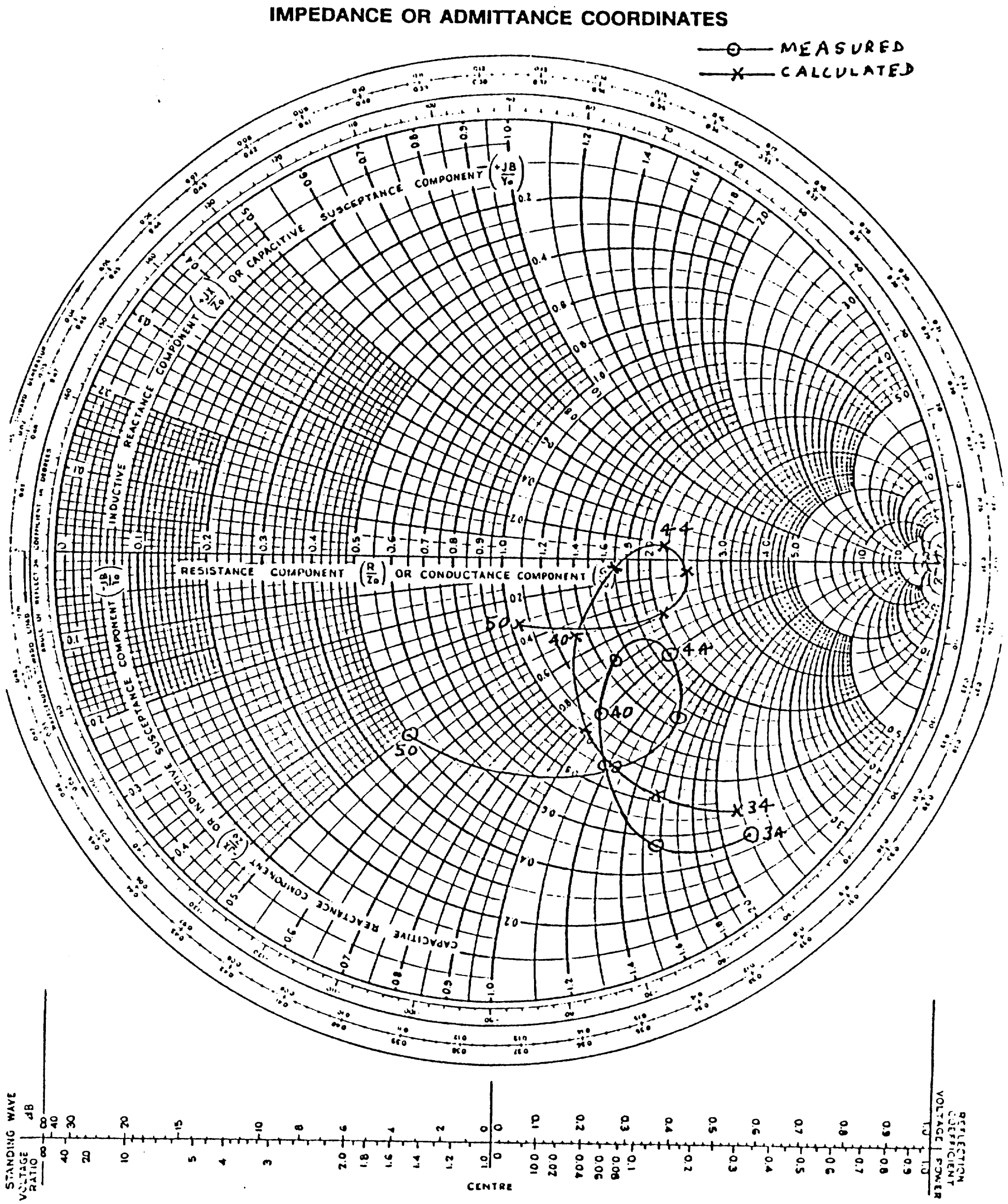

FIGURE 6 INITIAL COMPARISON OF MEASURED AND CALCULATED IMPEDANCES FOR SINGLE "EXTENDED APERTURE" ELEMENT (FREQUENCIES IN MHz)

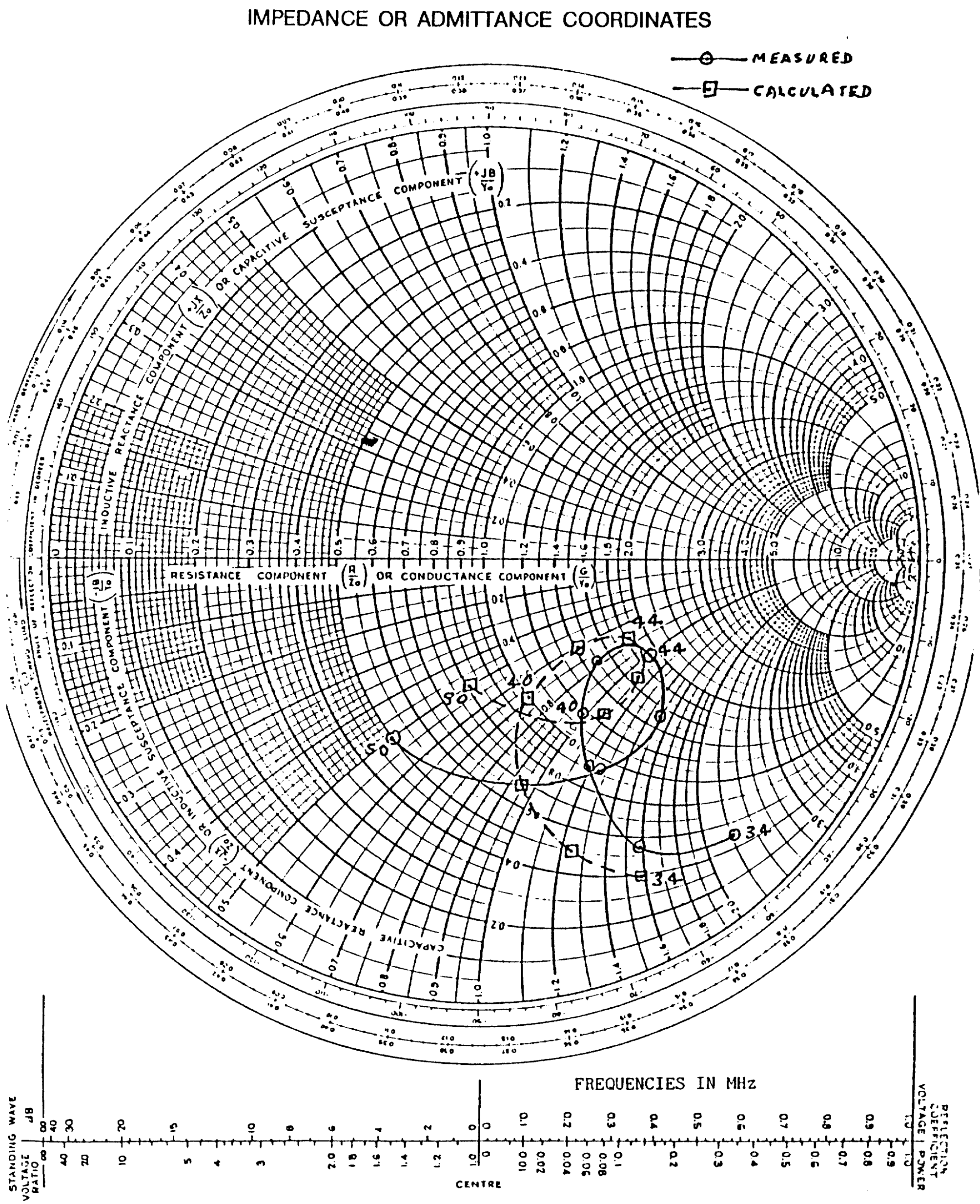

FIGURE 7 COMPARISON OF MEASURED AND CALCULATED IMPEDANCES FOR SINGLE "EXTENDED APERTURE" ELEMENT WITH SHUNT CAPACITANCE IN PARALLEL WITH FEED POINT

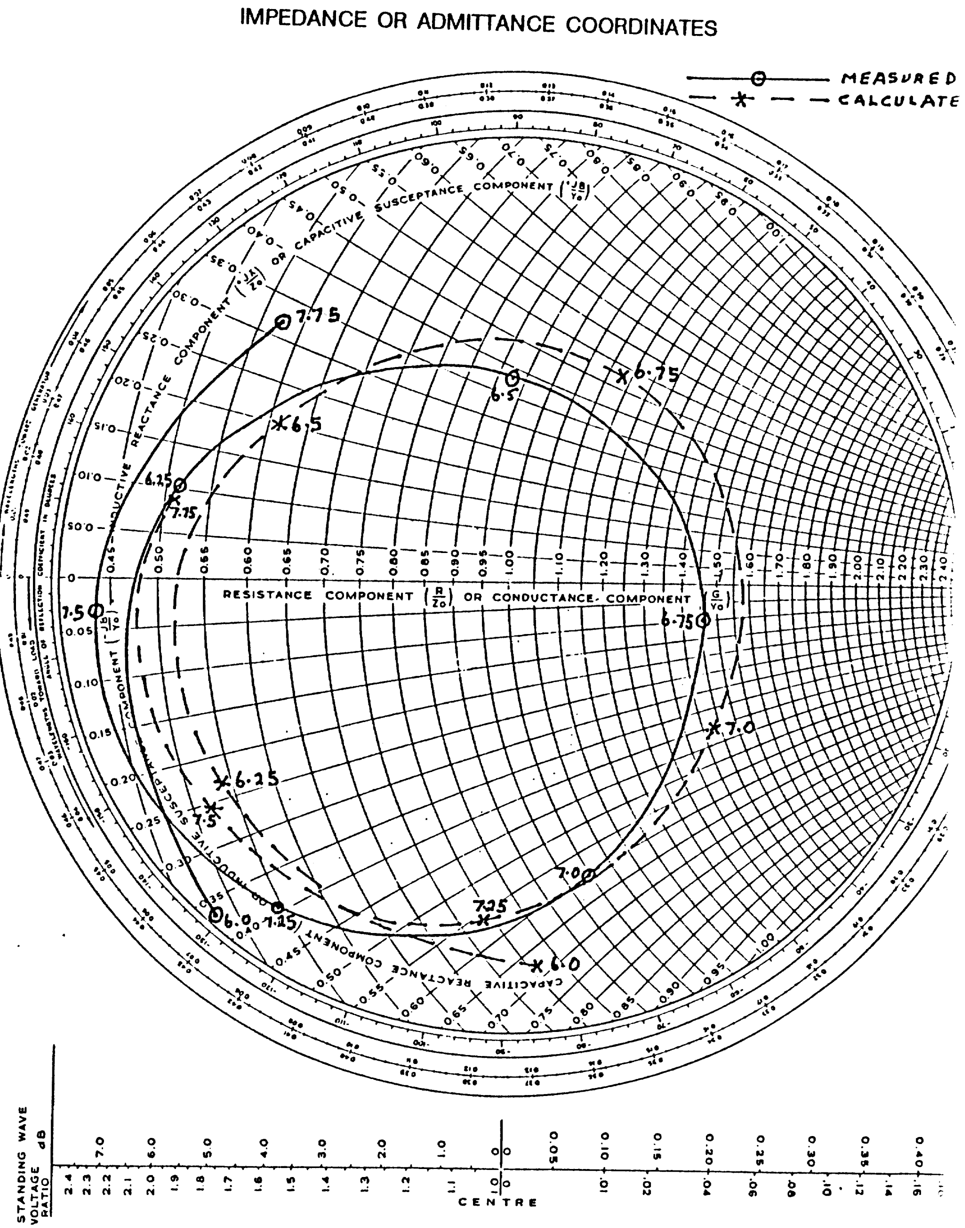

FIGURE 8 IMPEDANCE OF VERTICAL LPA CALCULATED WITH MODIFIED TRANSMISSION LINE LENGTHS & IMPEDANCES (FREQUENCIES IN MHz)

VERTICAL LPA

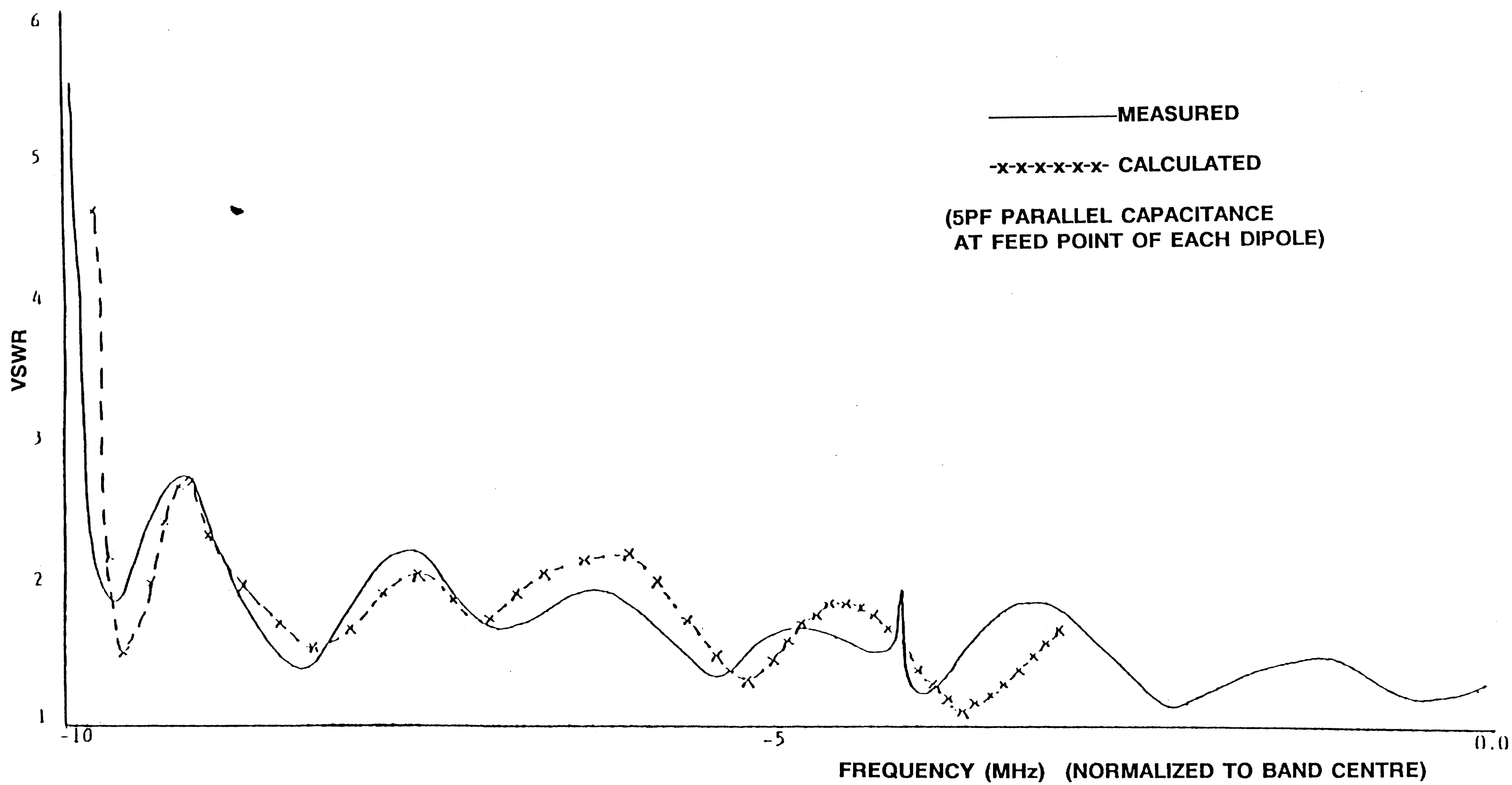

FIGURE 9 COMPARISON OF MEASURED AND CALCULATED VSWRs FOR VERTICAL LPA