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A STUDY OF AM TOWER BASE IMPEDANCE

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THE PROBLEM IN HISTORICAL PERSPECTIVE

The design of matching networks and power division networks for non-directional and directional antennas used for medium wave (standard broadcast) stations depends upon knowledge of the load impedance of the antenna system. Over the years many attempts have been made to predict the impedance of the conventional monopole over a radial wire ground screen. Many published computations were referenced to measurements made at high frequencies, where the center conductor of the feed line was extended through a copper ground plane as an antenna (Figure 1)[1,2]. A medium wave tower antenna has a much more complicated base geometry than this and its impedance is demonstrably different For example, 50 Ohms or so is typical for a base driven tower, while 37 Ohms is shown in [2] R.W.P. King's "*The Theory of Linear Antennas*".

S. A. Schelkunoff [3] treated antennas as a transmission line problem in terms of characteristic impedance. Some workers have used his theory to good advantage in predicting AM tower impedance. Until recently use of his methods resulted in the most accurate predictions of measured base impedance.

In an effort to achieve more realistic estimations of tower impedances several empirical curves have been developed over the years. One such curve appeared in the NAB Engineering Handbook [4] through several revisions (Figure 3). The information for this curve was compiled by my father, J.B. Hatfield. This curve was incorrectly labeled as to electrical height and, as a result, was never very useful or accurate. The correctly labeled curve (Figure 4) gives results that are a closer match to experience (i.e. 50 Ohms resistance for a 90 degree tower).

George Mather, in his June 1952 article in Electronics, page 143, and in a paper prepared for the Canadian Ministry of Transportation [5] presented curves of the tower impedance based upon measurements of more than 150 towers. I have used this curve with some success in calibrating various calculation techniques.

PROBLEMS IN MEASUREMENTS AND COMPUTATIONS OF TOWER IMPEDANCE

Several writers, including R.W.P. King, [2] have dealt with the effect of the tower base capacitance upon the measured impedance. The interaction can be quite large for towers with a high reactance. Most empirical curves of measured impedances ignore base capacitance effects.

Another factor that affects base impedance is the inductance of the feedline from the Antenna Tuning Unit (ATU) to the tower. Long feedlines can have more inductance than the output leg of the matching "T" network. I measure the resistance and reactance at the tower base and then repeat the measurement at the output of the ATU. A slight impedance transformation can occur due to transmission line effects.

When the reactive component of the tower impedance is large the base capacitance must be taken into account when computations are made. The average tower, using the most commonly available brand of base insulator, has from 75 to 100 pF capacitance from the base plate to ground. Austin ring transformers used for lighting can double this capacitance. Static drain coils, isocouplers, and lighting chokes can also affect the measured base impedance.

RECENT ADVANCES IN COMPUTATIONAL METHODS

These days many engineers use some sort of "Method of Moments" program to compute tower impedance. MININEC and its various clones are relatively "user friendly". Various tricks must be employed if one is to get useful answers; however, computed results must be verified by measurements.

In the last decade two papers treating this subject [1,6] have been published in "IEEE Transactions On Broadcasting". The 1983 paper by Wright, Klock and Jubera [1] studied the effect of guy wires, guy wire insulators, and base capacitance upon tower base impedance. The reference impedance data (used as a benchmark for the measured and calculated impedances presented in the paper.), however, was measured using an antenna geometry similar to Figure 1 and does not include the effects of the base geometry of an actual tower. The 1989 article by Chiodini [6] demonstrated that their moment method results agreed well with his measurements for towers of 96^{o} and 105^{o} physical height.

Ron Rackley, of du Treil, Lundin, & Rackley, increases the electrical length of the towers used in the computation so that measured results are matched. Adding about 6.7% to the tower height gives 50 Ohms for a quarter wave tower. Radiation efficiency is increased about 3% by this change in tower height. The results of this computation, shown as data points on Mather's 1952 "Electronics" empirical curve, are depicted in Figure 5. The computed impedances, using the technique, diverge from the empirical curve for taller towers and other correction factors must be applied to the tower height.

For a thick (8 foot face) guyed tower (120 electrical degrees) Rackley increased the height by 12.5% and added two reactances to the base of his MININEC tower model. The model and a computed vs measured curve are shown in Figure 6. There is good agreement between measured and computed impedances as a function of frequency. This apparent increase in tower height is, in all probability, due to the large cross section of the tower and the accompanying increase in capacitive coupling to ground relative to thinner towers.

A good match to the 1952 Mather experience curve can be made with MININEC using the model shown in Figure 7. The tower height is unmodified while the tower base is modeled as a thin filament with a lumped capacitance of 100 pF. The tower feed is modeled as a horizontal two meter length of tubing. To properly match the 1952 empirical curve, 5 +j43 Ohms must be added to all the computed impedances. The result (Figure 8) is a good approximation to the impedances shown in the empirical curve over the range of tower heights shown.

APPLICATIONS TO FIELD WORK

The measured self impedances of the towers in an array can be used to correct the driving point impedances computed by MININEC. Moment method programs like MININEC compute AM tower mutual impedances more accurately than self impedances. This is due to the fact that the self impedance can be considered to be sensitive to the conditions at the base of the towers (a situation difficult to model using moment method programs) while mutual impedance involves coupling along the entire tower length. The difference between the measured self impedance and the self impedance computed by MININEC is added to the driving point impedances computed by MININEC.

When this technique is applied to a specific case the results are mixed. The networks in a three tower array at the low end of the band were adjusted to drive point impedances calculated from measured self and mutual impedances. When the array was initially powered up the magnitudes of the impedances of the terminations for the lines were within the following percentages of 50 Ohms: Tower #1 +20%; Tower #2 +4%; Tower #3 (with a negative resistance) -27% at the bus. These results give one confidence in the accuracy of the measured self and mutual impedances. A successful D. A. Proof of Performance was made on this antenna system without any further adjustments.

The measured self impedances were also used to adjust the drive point impedances computed by MININEC. The results of both procedures are shown below for comparison.

	Adjusted MININEC Drive Points	Drive Points From Measured Selfs & Mutuals
Z_1 =	38 + j62	37 + j71
Z_2 =	24 + j36	21 + j41
Z_3 =	-7 + j11	-22 + j11

The impedances for the first two towers given by the two methods are in reasonable agreement but the results for the third tower are much more problematical.

Tower heights that are not near resonance (i.e. 90^o or 180^o) have base impedances that are well predicted by MININEC. A 70 degree self supporting tower, for example, measured 24 -j41 Ohms while the MININEC self impedance for this tower was 25 -j47 Ohms. This resistance is predicted by the radiation resistance curve (Figure 2 of this paper) in the 1937 Brown, Lewis & Epstein paper. A 64.4 degree guyed tower, on the other hand, measured 19 -j103 Ohms and MININEC predicted 15 -j137 Ohms. The resistance of the self supporting tower and the reactance of the guyed tower are both well outside the confines of the empirical curves of Figure 5.

CONCLUSION

While newer prediction methodology using method of moments for determining AM tower impedance is in closer agreement with measured values than older methods, measurements must be relied upon in critical situations to accurately determine self and drive point impedances. In any case, because of the substantial variation in the electrical characteristics of ostensibly similar towers within and between different installations, it is vitally important that computations be calibrated by measured impedances.

REFERENCES

[1] S.M. Wright, P.W. Klock, J.D. Jubera, "The Impedance of the Guyed Quarter Wave Monopole", IEEE Transactions on Broadcasting, Vol. BC-29, No.1, March 1983.

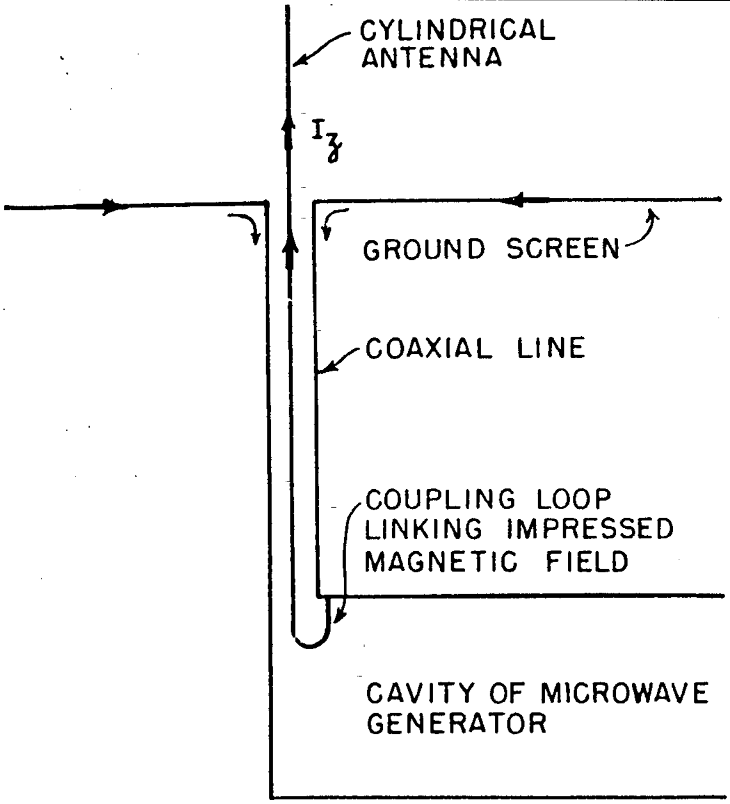
[2] R.W.P. King, "*The Theory of Linear Antennas*", Harvard University Press Cambridge, Mass., 1956.

[3] S.A. Schelkunoff, H.T. Friis, "*Antennas: Theory and Practice*", John Wiley & Sons, Inc., New York, 1966.

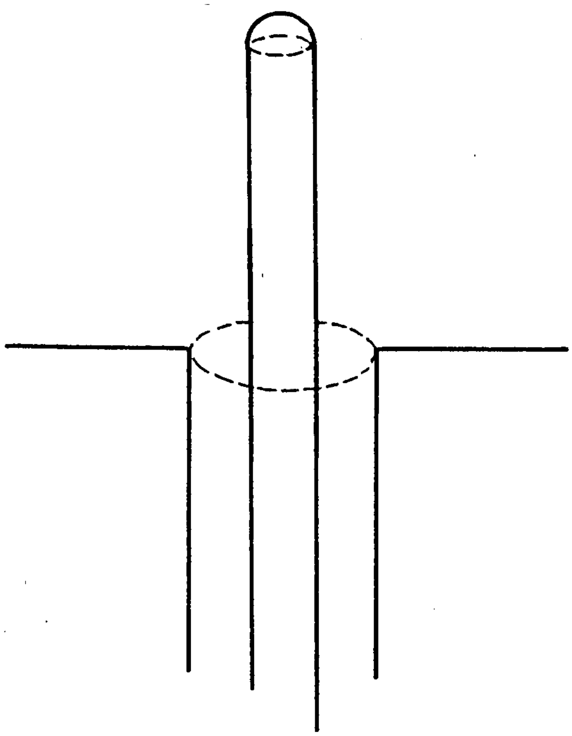
[4] A.P.Walker, G.W. Bartlett, "NAB Engineering Handbook", McGraw-Hill Book Company, Inc., New York, 1960.

[5] "Vertical Radiator Characteristics Uniform Cross Section Base Insulated Guyed Tower", George Mather & Associates, October 1982.

[6] T. Chiodini, "Moment Method Predicted Impedances Compared to Actual Measured Impedances of Directional Arrays", IEEE Transactions on Broadcasting, Vol.35, No. 2, June 1989.



Transmitting system with coaxial line.



Coaxial drive.

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FIGURE 1

FROM "THE THEORY OF LINEAR ANTENNAS"
BY R.W.P. KING pg. 845

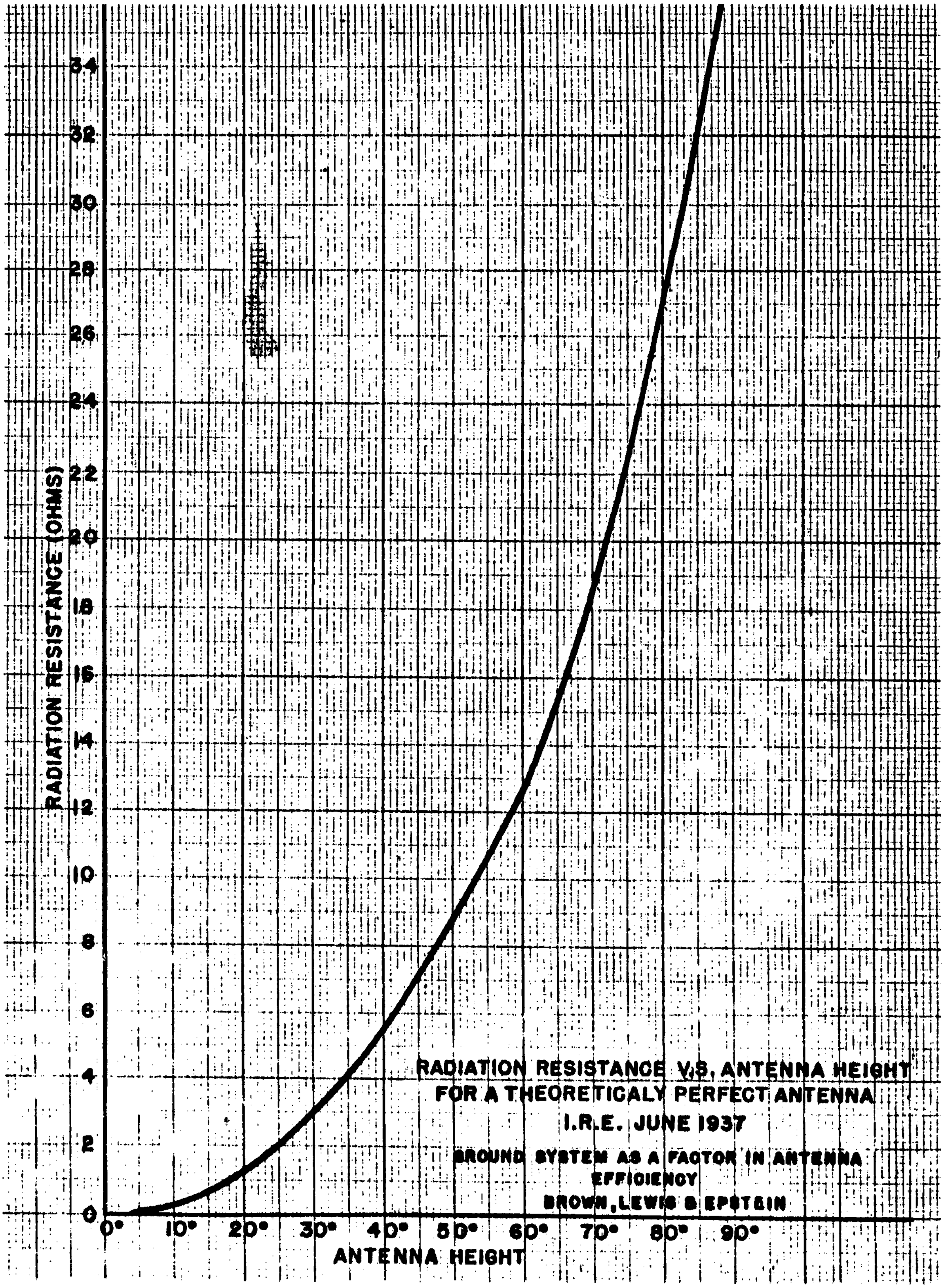

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FIGURE 2

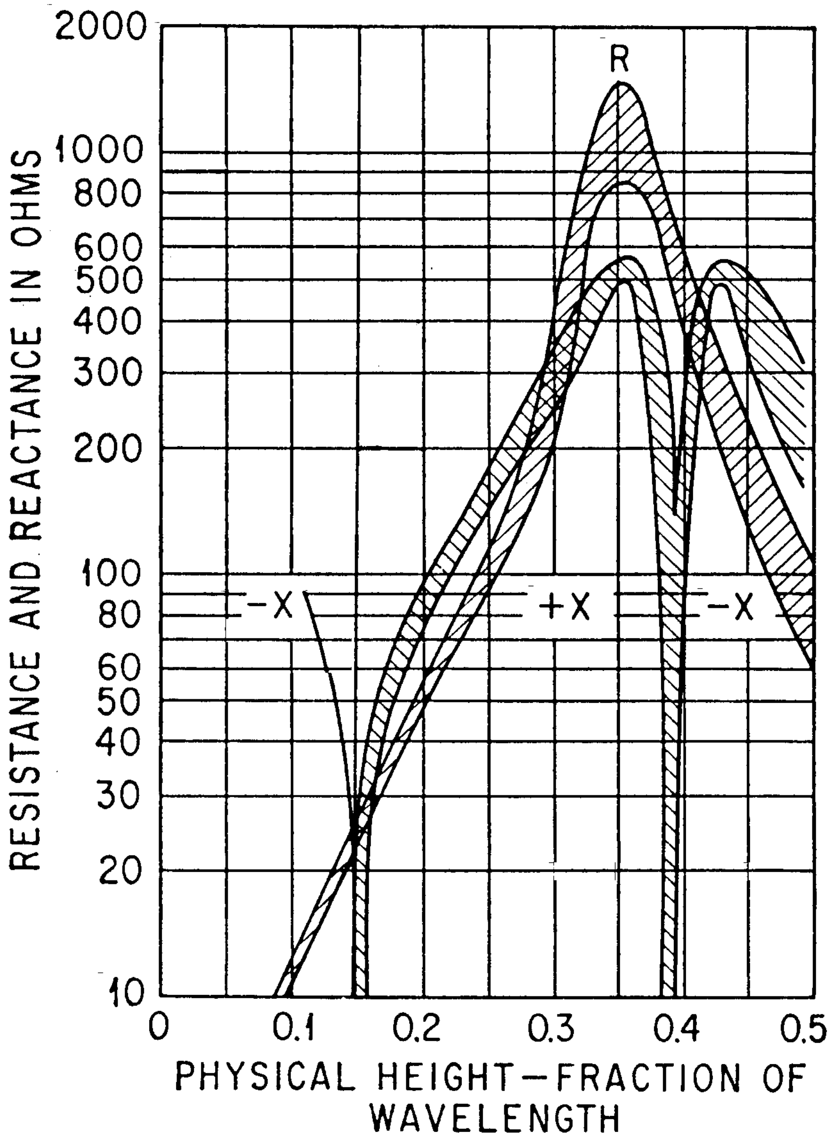

FIG. 9-15. Average characteristics for guyed radiators of uniform cross section. Data compiled from measurements of KNX and KIRO's 4-ft triangular radiators and a large number of 12- to 18-in. triangular radiators. (*Prepared by J. B. Hatfield.*)

HATFIELD & DAWSON CONSULTING ENGINEERS	FIGURE 3 J.B. HATFIELD EMPIRICAL TOWER IMPEDANCE CURVES AS SHOWN IN 5TH EDITION (1960) "NAB ENGINEERING HANDBOOK" WITH PHYSICAL HEIGHTS INCORRECTLY LABELED.

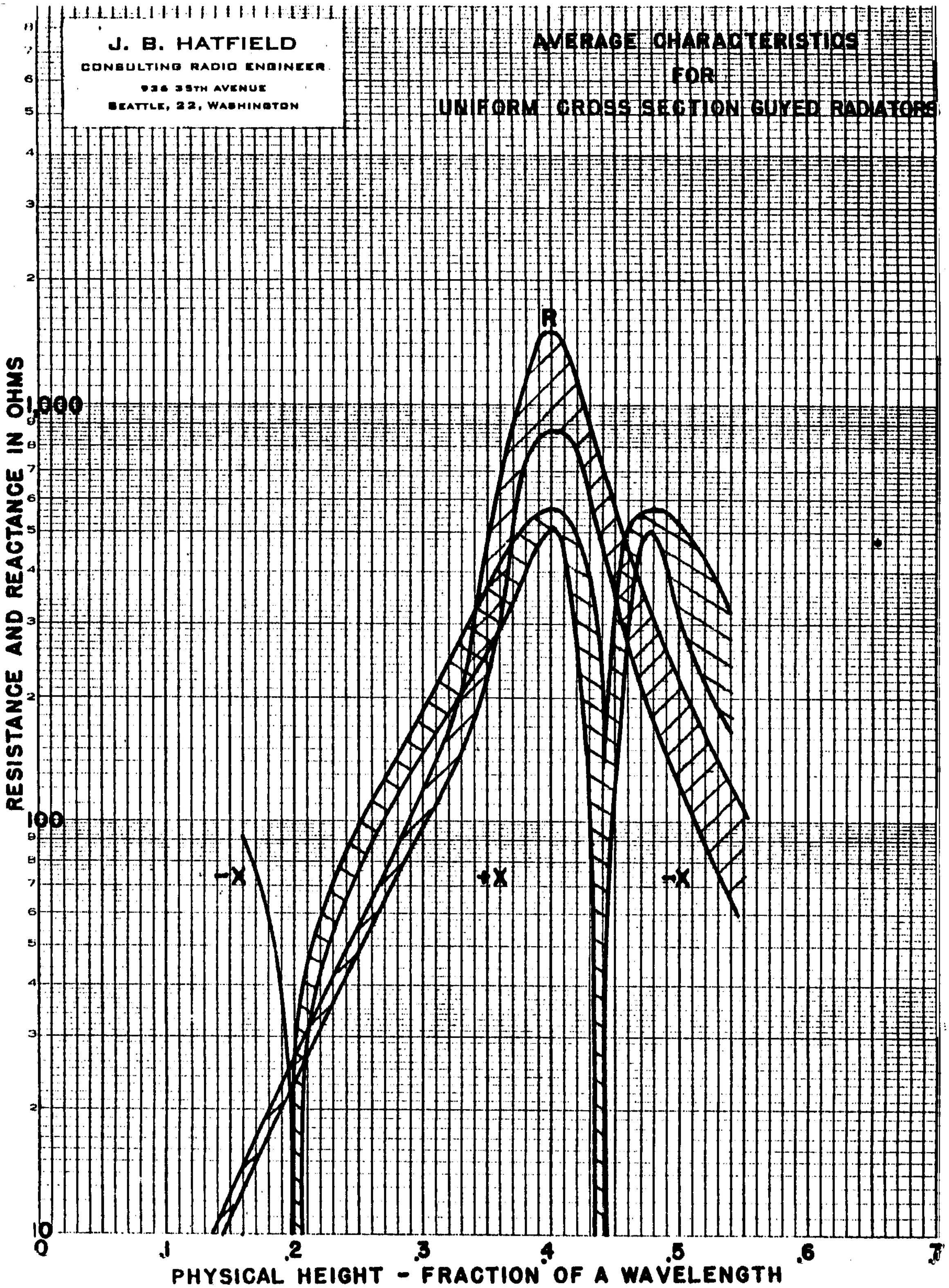

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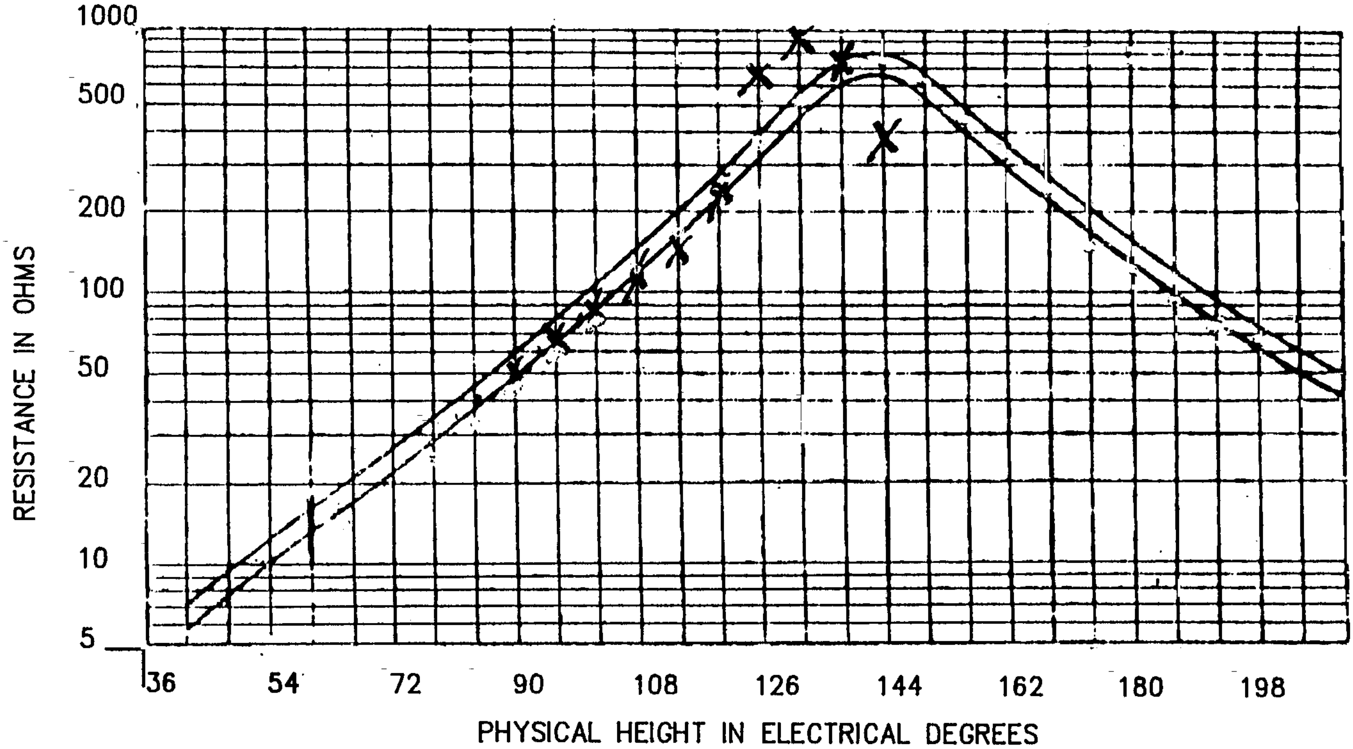
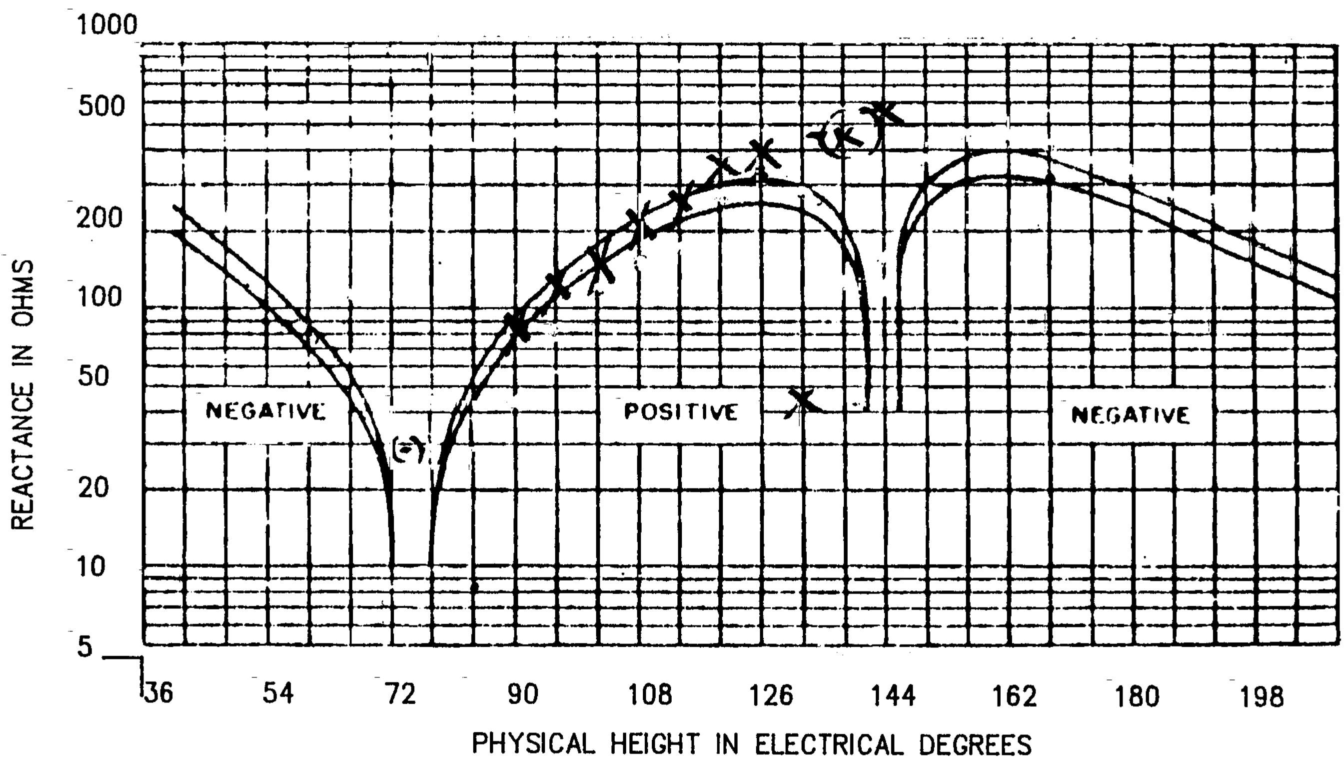
FIGURE 4

CORRECT VERSION OF J.B. HATFIELD EMPIRICAL TOWER IMPEDANCE CURVES





HATFIELD & DAWSON **CONSULTING ENGINEERS**	FIGURE 5 TOWER SELF IMPEDANCE COMPUTED BY INCREASING PHYSICAL HEIGHT BY 6.7%. "X"s ARE COMPUTED VALUES PLOTTED ON EMPIRICAL MEASUREMENT CURVES. THIS HEIGHT INCREASE YIELDS A MININEC COMPUTED RESISTANCE OF 50 OHMS FOR A 90 DEG. TOWER.

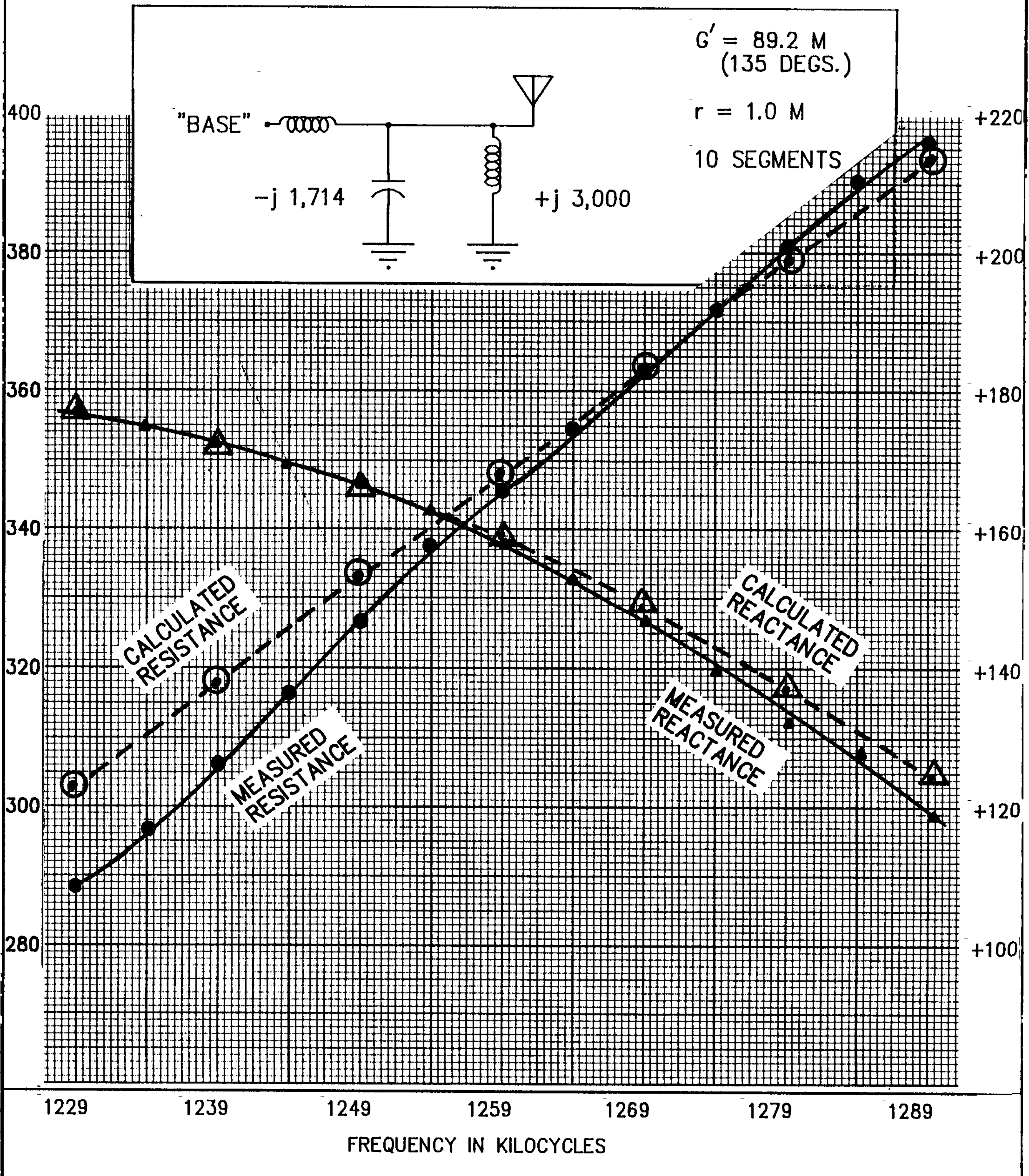


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FIGURE 6

RHODES, GREECE
TOWER MODEL
MEASUREMENT AND ANALYSIS BY RON RACKLEY

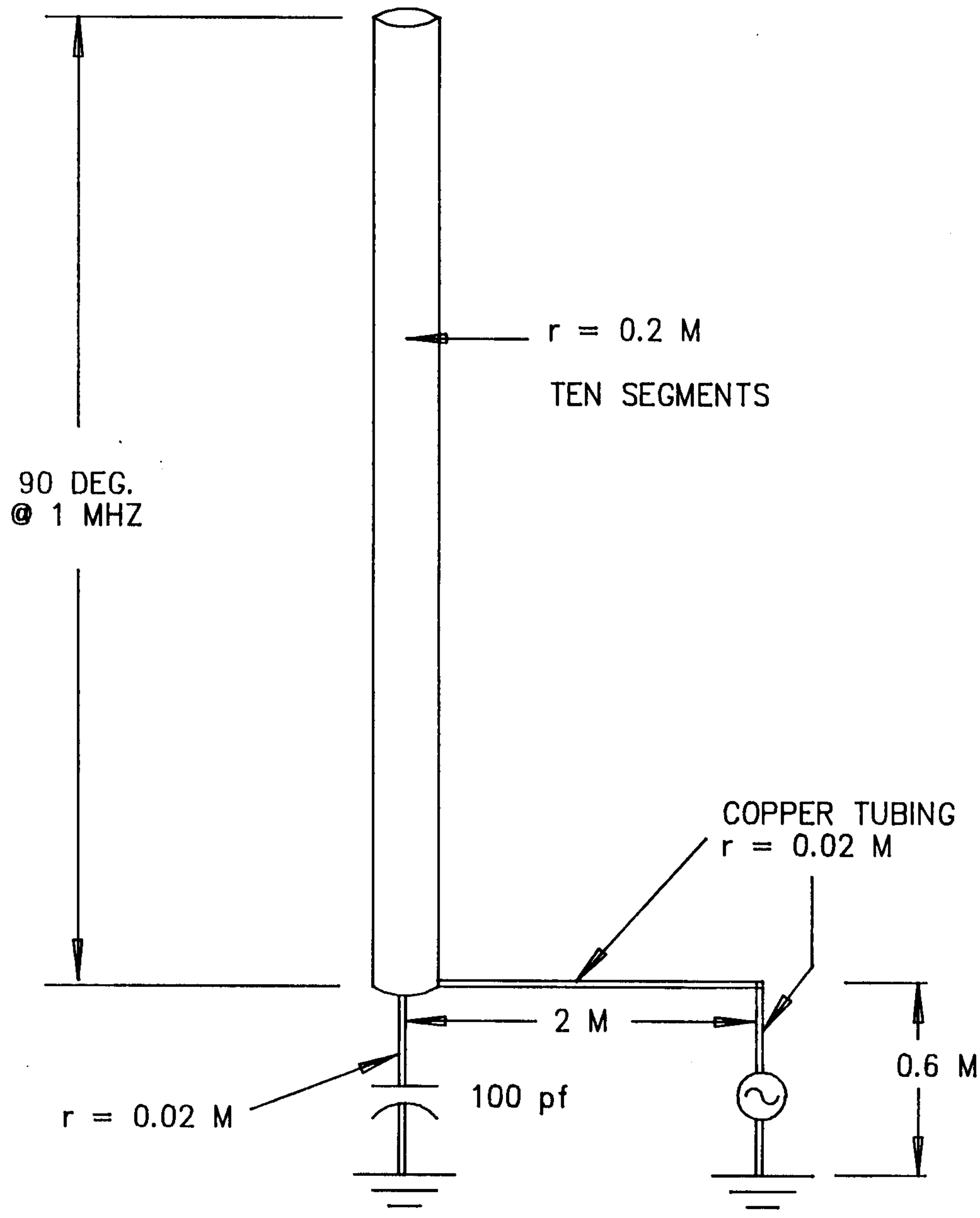

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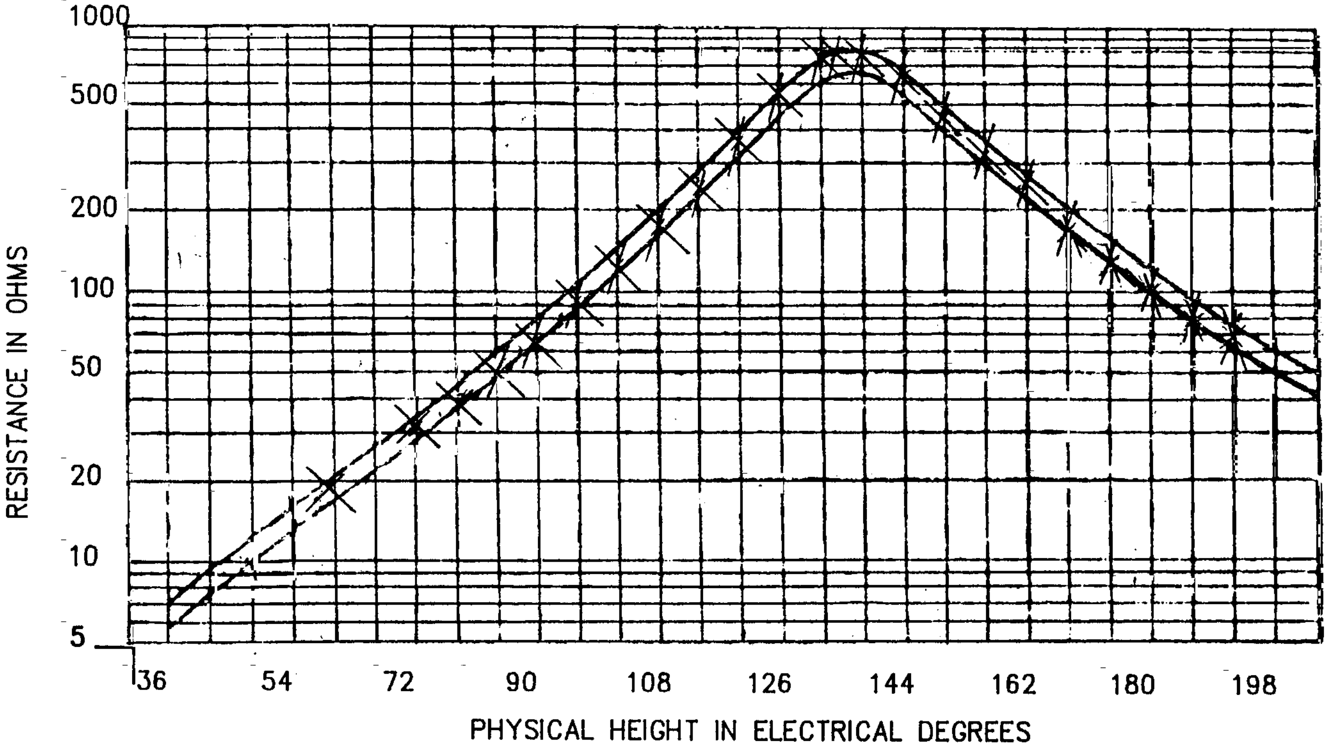
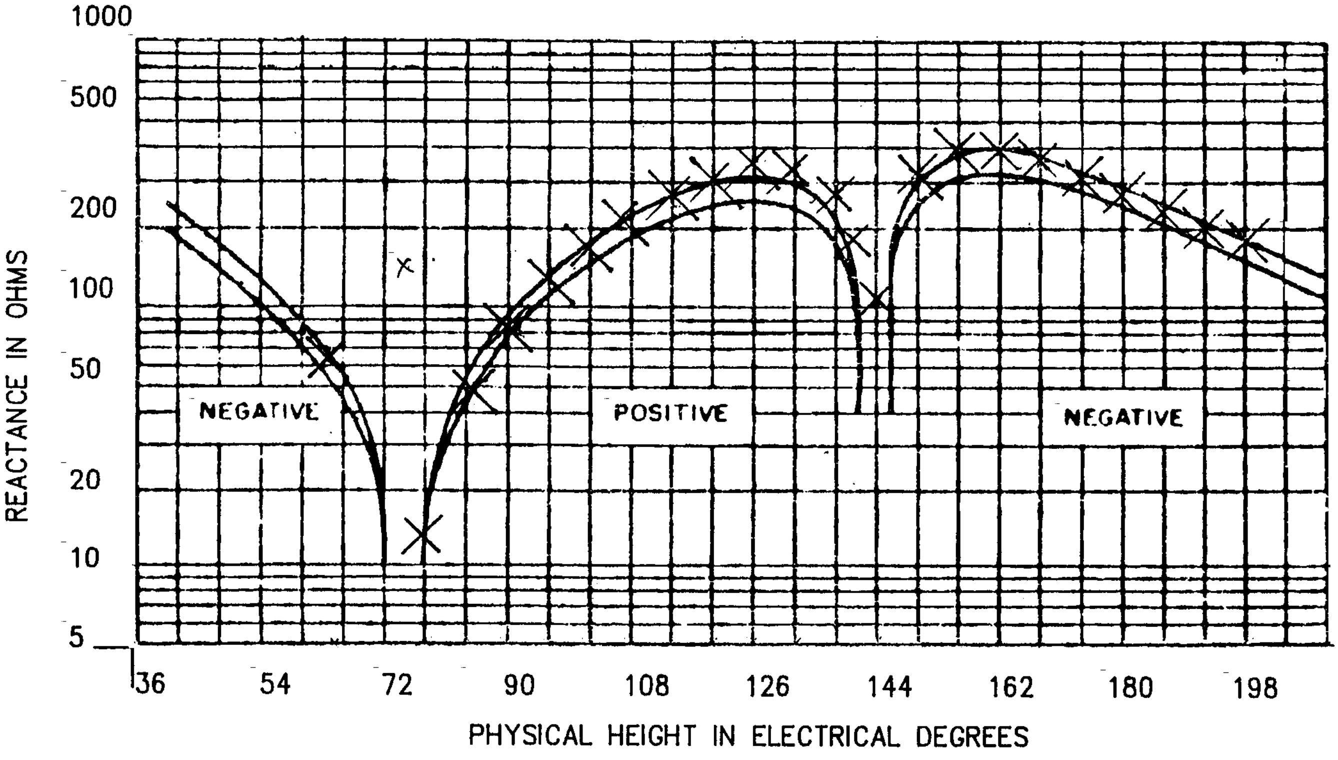
FIGURE 7

TOWER & FEED MODEL
FOR MININEC IMPEDANCE COMPUTATIONS





HATFIELD & DAWSON CONSULTING ENGINEERS	FIGURE 8 SELF IMPEDANCE OF MONOPOLE OVER A RADIAL WIRE GROUND SCREEN. MODELED BY MININEC (SEE FIGURE 7) AND CORRECTED BY ADDING 5 +j43 TO COMPUTED IMPEDANCE. COMPUTED DATA POINTS PLOTTED ON EMPIRICAL CURVES FROM ELECTRONICS MAGAZINE ARTICLE (JUNE 1952 pg.143)