HATFIELD & DAWSON
CONSULTING ELECTRICAL ENGINEERS
4226 SIXTH AVE. N.W.
SEATTLE, WASHINGTON 98107

JAMES B. HATFIELD, PE
BENJAMIN F. DAWSON III, PE
THOMAS M. ECKELS, PE

PAUL W. LEONARD, PE

TELEPHONE
(206) 783-9151

MAURY L. HATFIELD, PE
CONSULTANT

NUMERICAL ELECTROMAGNETIC CODE ANALYSIS OF AM DIRECTIONAL ANTENNA NULLS AND THE "PROXIMITY EFFECT"

JAMES B. HATFIELD

9/87

PREPARED FOR THE 37TH ANNUAL
BROADCAST SYMPOSIUM
BROADCAST TECHNOLOGY SOCIETY
IEEE

NUMERICAL ELECTROMAGNETIC CODE ANALYSIS OF AM DIRECTIONAL ANTENNA NULLS AND THE "PROXIMITY EFFECT"

James B. Hatfield

Hatfield & Dawson Consulting Engineers, Inc.
4226-6th Ave. NW
Seattle, WA 98107

ABSTRACT

Common AM directional antenna designs are based upon certain simplifying assumptions about the nature of the distribution of the currents flowing in the array elements. The major assumptions are that the current distributions are sinusoidal in shape, that the phase variations along the lengths of the elements are the same for each element, and that the current parameters (ratio and phase) at the point on the tower where they are sampled by the antena monitor system are an accurate depiction of the ratios and phases of the fields leaving the towers ("Field Parameters").

The numerical electromagnetic code (NEC) can be used to compute the current distributions in the individual elements of an antenna array. These computed current distributions for an AM array, based on the FCC "Theoretical Field Parameters", result in pattern nulls that are displaced in both depth and angular location from the locations calculated by the usual DA pattern analysis technique using the same parameters. The ratios and phases of the fields leaving the antenna elements can be determined from the current distributions modeled by the NEC. When the NEC field ratios and phases are used to calculate the theoretical fields of a directional antenna using the traditional equation (FCC's RADIAT program) the resulting DA patterns are similar in shape to those calculated by the NEC. When array "near field" calculations are made with "field parameters" calculated from the NEC current distributions the, predicted fields are different from those calculated using methods relying upon the usual "proximity effect" corrections. NEC far field and near field calculations along "null" radials (calculated by the NEC) do not converge for distances up to 40 km from the array center.

INTRODUCTION:

The patterns of medium wave AM directional antenna systems are formed by the vector sums at the various azimuths of the RF fields from the array elements. The relative relationships among these fields as they leave the array elements are specified by the "Field Ratios and Phases". These are the "Theoretical Parameters" used by the Commission for directional antenna pattern determination. When AM directional antenna systems are installed the pattern shape is determined by analysis of field intensity measurements. The pattern shape is controlled by adjusting the relative magnitudes and phases of the currents flowing in the towers used in the array. These "Antenna Parameters" are observed at the bases of the towers or at the point of maximum current ("Loop"). Adjustments are usually made on the array so that the Antenna Paramters are close to the Field Parameters. The array elements are driven at their bases when "Method of Moments" computer programs (usually NEC, MININEC or similar codes) are used to calculate AM directional antenna pattern shape. When the FCC Theoretical Field Parameters (ratios and phases of the fields leaving the antenna elements) are used in these calculations, pattern shape detail in the area of pattern minima or "nulls" is different from that obtained when the same parameters are used with the equation normally used to calculate AM patterns (Equation #1 of Section 73.150 of the FCC "Rules & Regulations"). This difference in the shape of pattern minima is observable in AM D.A. patterns regardless of tower height.

The "Antenna Parameters" are usually not the "Field Parameters". The tower currents at the point of observation used by the Antenna Monitor System usually do not have the same relationship relative to each other as the fields leaving the towers. It is the purpose of this paper to examine the nature of these relationships.

ANALYSIS OF AM ANTENNAS USING "NEC" AND "MININEC"

A report (CRC Report No.1379, Appendix A) by G.M. Royer of the Canadian Department of Communications presents pattern calculations on the directional antenna system of a Canadian AM station using the Numerical Electromagnetic Code (NEC). The array that was studied consisted of three towers in line driven with base current ratios of 0.538/1.0/0.484 and end tower base current phases of plus and minus 97.5 degrees respectively. The spacing was 90 degrees between adjacent towers and the towers were 72 degrees tall.

Figure One, taken from Royers report, shows how the pattern forms in the null region. Each curve shows the same section of the null as observed from different distances and normalized to one kilometer. The fields are shown unattenuated.

Figure Two shows the null region, calculated by the NEC, of the far field unattenuated inverse distance field pattern, normalized to one kilometer, on the same plot as the pattern predicted by FCC equation #1. The base parameters that were used for the NEC modeling were used as field parameters for FCC Equation #1. There is an angular displacement of the null between the two calculated patterns. The field parameters resulting from the NEC current distributions are obviously not the same as the base current parameters.

To investigate these effects NEC was used to model a simple three tower array of quarter wave height towers with 90 degree spacing, 1/2/1 base current ratios and -90, +90 degree relative base current phasing at the end towers. The theoretical horizontal plane pattern given by the FCC computer program RADIAT (RADIAT is a computerized version of FCC Equation #1 that also calculates pattern size, loop impedances, FCC Standard Pattern as a function of elevation angle, etc.) for 5 KW total integrated power flow using these field parameters is shown in Figure Three. In this "Cardiod" pattern the field goes to zero in line with the north end of the array. The results in the null region using NEC are shown in Figure Four. There is a minor maximum inline with the north end of the array. Once again, the field parameters that form the pattern are seen to be different from the base current parameters used to drive the array. This discrepancy can be resolved by deriving the field parameters for a given set of base current input parameters from the current distributions calculated by the NEC program.

The NEC code calculates the magnitudes and relative phases of the currents along the lengths of the towers. The magnitudes of the tower currents for these particular three tower array parameters are shown superimposed upon each other in Figure Five. The currents have been normalized to their base values for comparison. Although the overall size of the current distributions decreases as one moves from tower one to tower two to tower three, the relative current magnitudes as a function of tower height do not differ greatly.

When the phase of each tower current relative to its own base current is plotted as a function of tower height, as shown in Figure Six, we see that the phase shift of each current as a function of tower height is different for each tower.

This phase shift of antenna current along the tower length is a function of the antenna drive parameters and mutual coupling. It could be expected that phase shift occuring in tower currents as they travel up the tower from the tower base would cause the field parameters to differ from the base parameters.

When the radiation function is applied to the infinitesimal current elements and integrated over the length of a tower the field from that tower is determined. For identical, equal height, uniform cross-section towers the field from each tower is proportional to the complex sum of the current elements calculated by NEC for that tower. The field parameters can then be found by taking the ratios of the magnitudes of the current summations and the differences of the phase angles of the current summations for the various towers.

For the example under discussion the field ratios given by NEC are 0.518 / 1.0 / 0.492 while the phases of the fields are -91.2 / 0 / +90.72 degrees respectively. When the fields are calculated with FCC Equation #1 using these field parameters we see the results plotted as data points in Figure Seven superimposed upon the NEC plot of Figure Four. Thus the NEC code and FCC Equation #1 give the same results when the correct field parameters are used with FCC Equation #1.

For experimental verification of the ability of NEC and MININEC type codes to predict tower current distributions, Ron Rackley, P.E. has kindly provided a set of measured current distributions that he modeled using MININEC III. He studied a 198 degree tall three tower array that has theoretical field ratios of 0.51 / 1.0 / 0.51 and field phases of -95.5 / 0 / +95.5 degrees.

The spacing is 115.3 degrees between adjacent elements. The calculated versus measured current distributions for the three towers are shown in Figure Eight. Since it was not possible to gather data on the relative phase angle of the current along the height of the tower only the measured current magnitude is shown as a function of tower height. Reasonable agreement is shown between the measured and MININEC III values, given that standard conductive guy wires support these towers.

Paul Leonard, P.E. and I modeled a four tower inline array, equally spaced with 90 degrees between adjacent towers. Fred Volken graciously provided measured current distributions for this array. The towers were 126 degrees tall. Figures Nine and Ten show the measured and calculated current distributions for this array. Mr. Leonard and I did not exactly replicate the parameters shown by the antenna monitor when the current distribution measurements were made.

The antenna parameters are monitored near the point of maximum current in the operating array.

Figure Eleven is the horizontal plane unattenuated far field pattern at one kilometer predicted by MININEC using different parameters from those used to model the tower current distributions of this array. The field parameters resulting from the MININEC current distributions were used as input for the RADIAT program and the data points shown in Figure Eleven were taken from the pattern calculated by RADIAT.

Since the first and third towers are 180 degrees apart we drove them with equal phase and amplitude base currents to get an inline null. The ratio of the minimum to maximum fields calculated by the MININEC program was 120 dB. The null was well defined and exactly inline with the towers. The magnitudes and angles of the current distributions of the two towers, as a function of tower height, were identical to the fourth decimal place. The antenna parameters and field parameters were the same.

With all four towers active in the array the current ratio of the third tower, at the loop, averaged (for three sets of operating parameters) 5.6% lower than the field ratio for that tower. The phase angle of the current at the loop averaged 1.4 degrees lower than the phase angle of the field. The various parameters are shown in Figure Twelve. At the base of the tower the current ratio was, on average, 30% lower while the phase averaged 12 degrees higher than the corresponding field parameters.

This shows that setting up field nulls with tower pairs to calibrate the antenna monitor can give unreliable results. This is due to the fact that the relationship between the ratios and phases of the currents in the towers of an AM array and the field ratios of those towers is a variable function of the mutual coupling between towers and the drive parameters.

The differences shown in Figure Twelve between the base, loop and field parameters are instructive in several ways: (1) For tall towers sampling the currents at the bases of the towers results in sampled antenna parameters that are further from the field parameters than tower parameters sampled at the loop; (2) The agreement between antenna parameters sampled at the loop or the base of a tower and the field parameters is a function of how the tower is driven; (3) As the antenna current parameters are varied the difference between them and the field parameters varies.

Figure Thirteen illustrates the geometrical assumptions behind FCC Equation #1. There are several additional implicit assumptions used in the derivation of this expression: (1) the observation point is far enough away from the reference point of the array that straight lines drawn between the observation point and the array elements are parallel; (2) the "inverse distance" variation of the magnitudes of the fields traveling from the elements to the observation point is the same for each tower; (3) the differences in phase between the fields as they arrive at the observation point from the array elements are determined by the combination of the relative phases of the fields as they leave the antenna and the differences in the lengths of the parallel paths to the observation point. Equation One of Figure Thirteen is derived from the accompanying sketch using these assumptions. Equation One is a simplified version of FCC Equation #1 that gives unattenuated horizontal plane far fields on a "per unit" basis (i.e., does not include the one kilometer inverse distance pattern size constant). When FCC Equation #1 is used the implicit assumption is made that the pattern shape does not vary with distance. Both experience and logic tell us that this is not the case. Equation Two of Figure Thirteen was derived without making the simplifying assumptions used to derive Equation One of Figure Thirteen. Equation Two uses the law of cosines so that the magnitudes and phases of the fields arriving at the observation point are functions of the actual path lengths to the individual array elements. The difference between these two expressions (the cause of the "proximity effect") is that while Equation One gives a pattern of constant shape that shrinks with increasing distance from the reference point of the array (tower #1 in this case) Equation Two results in a pattern shape that changes as a function of distance between the array reference point and the observer. As the distance from the reference point of the array to the observer increases the results given by the two expressions will converge. Equation Two (a version of which is used by RADIAT for its near field calculation option) is used to calculate corrections for the "proximity effect". When the pattern size constant, or field of the reference tower, is multiplied by Equation Two the correct horizontal plane inverse field at a given distance and azimuth is determined if the ratios and phases of the fields actually produced by the currents flowing in the array elements are used.

The curves shown in Figure Fourteen are horizontal plane unattenuated inverse fields as a function of distance along the null azimuth (along the line of the towers as predicted by FCC equation #1 using theoretical field parameters) of the three tower array described in Figure Three. The array is driven with base current parameters adjusted to be the same as the theoretical field parameters shown in the that figure. The fields predicted by Equation Two using the theoretical field parameters go to zero with increasing distance. The fields predicted by NEC using both near and far field geometry assumptions converge at distances greater than a kilometer from the array reference point and vary from that point inversely as the distance.

The field parameters given by the NEC current distribution summations can be applied to Equation Two for a more realistic depiction of the near fields along the null azimuth of this array when it is driven at the base with the theoretical field ratios and phases. The result is the set of data points plotted on Figure Fourteen. These data points converge with the curves of the fields predicted by NEC for distances greater than one kilometer. For distances less than a kilometer the calculated fields that result from using the correct field parameters in Equation Two converge with fields predicted by Equation Two when the theoretical field parameters are used.

The conclusion to be drawn from all this is that field parameters determined by the actual distributions of the currents flowing in the array elements parameters must be employed if proximity effects are to be accurately determined by expressions like Equation Two of Figure Thirteen. Neither the operating licensed antenna parameters nor the theoretical field parameters will result in accurate calculations of the near fields along the null azimuths of AM directional arrays.

CONCLUSION

The field parameters of AM directional arrays can be calculated as a function of the base or loop current antenna parameters using the NEC or MININEC computer code. The calculated results show that the relationships between the base, loop and field parameters are a function of the drive parameters and the mutual coupling between the elements of the array.

This means that trying to relate antenna monitor readings to field parameters by measuring nulls from tower pairs will frequently not yield accurate results for arrays of more than two towers.

When the field paramaters derived from the current distributions calculated by NEC are used with FCC Equation #1 the resulting patterns agree with those predicted by NEC.

The field parameters resulting from the actual currents flowing in the elements of an array must be used to accurately calculate near fields for proximity effect corrections. The field parameters calculated from NEC current distributions are usually not the same as either the theoretical field parameters or the licensed operating antenna parameters of an AM station.

When an array is adjusted the field parameters resulting from a given set of base current drive parameters can be found by using the NEC code. This can be useful for the adjustment of most arrays (unequal height towers, tall towers and short towers).

This paper was presented in the hope that more people will become aware of the usefulness of NEC and MININEC programs for the analysis of AM directional antennas. Many more interesting areas of the art of AM DAs can be explored using these programs. Much more experimental verification of these techniques remains to be done. I hope to report more measurement results in the future.

I would like to thank Dr. R. Adler, P.E. for his help in running NEC III and in helping me to understand the Numerical Electromagnetic Code; Paul Leonard, P.E. for his help and consultation in running MININEC; Ron Rackley, P.E. for his measured and MININEC III current distributions; and Fred Volken for the measured current distributions on the four tower array.

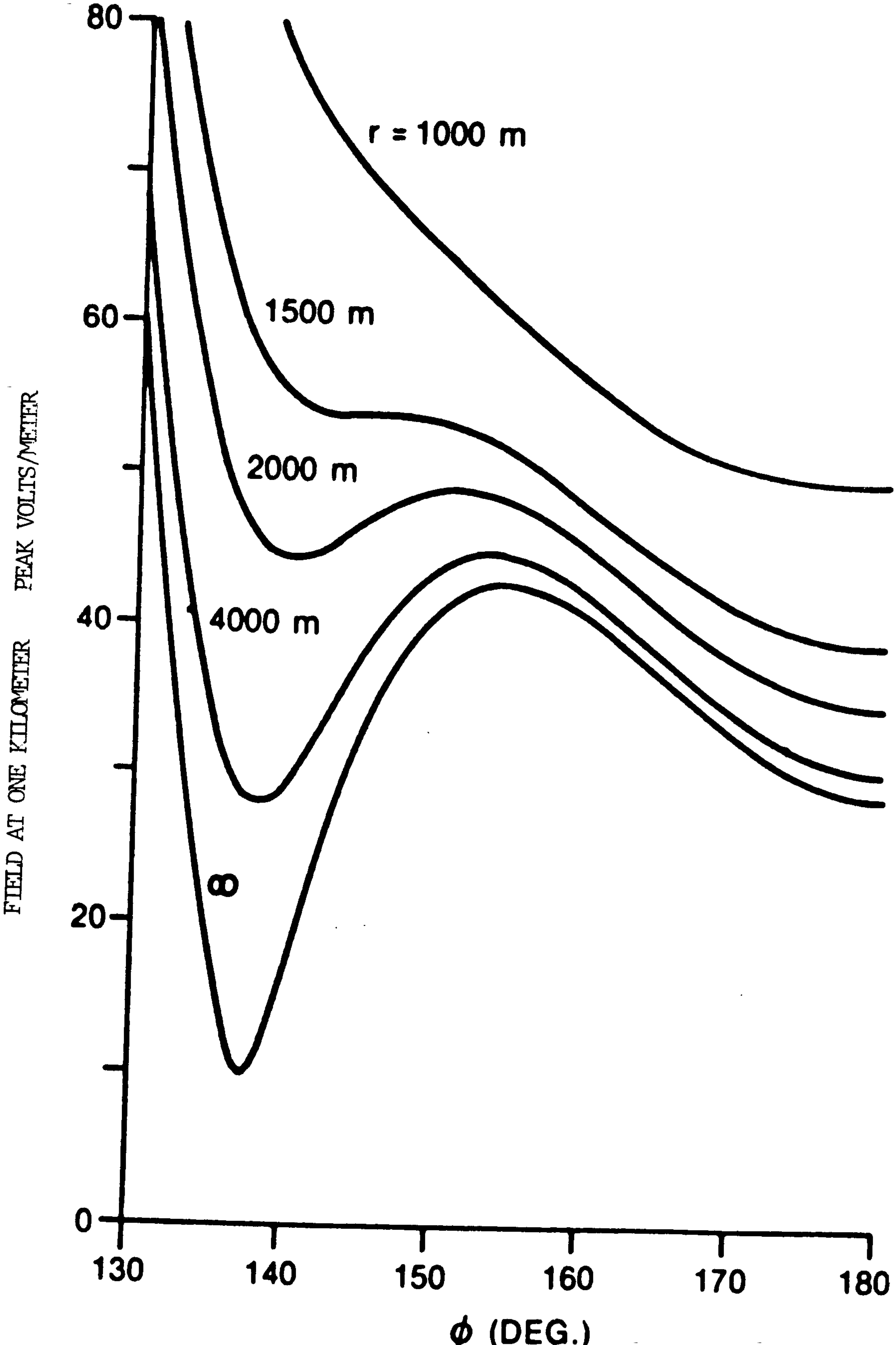


FIG. ONE Variation in 3-tower in-line pattern null with distance from array (modified from CRC RPT. No. 1379)

MODIFIED FROM CRC RPT. NO. 1379

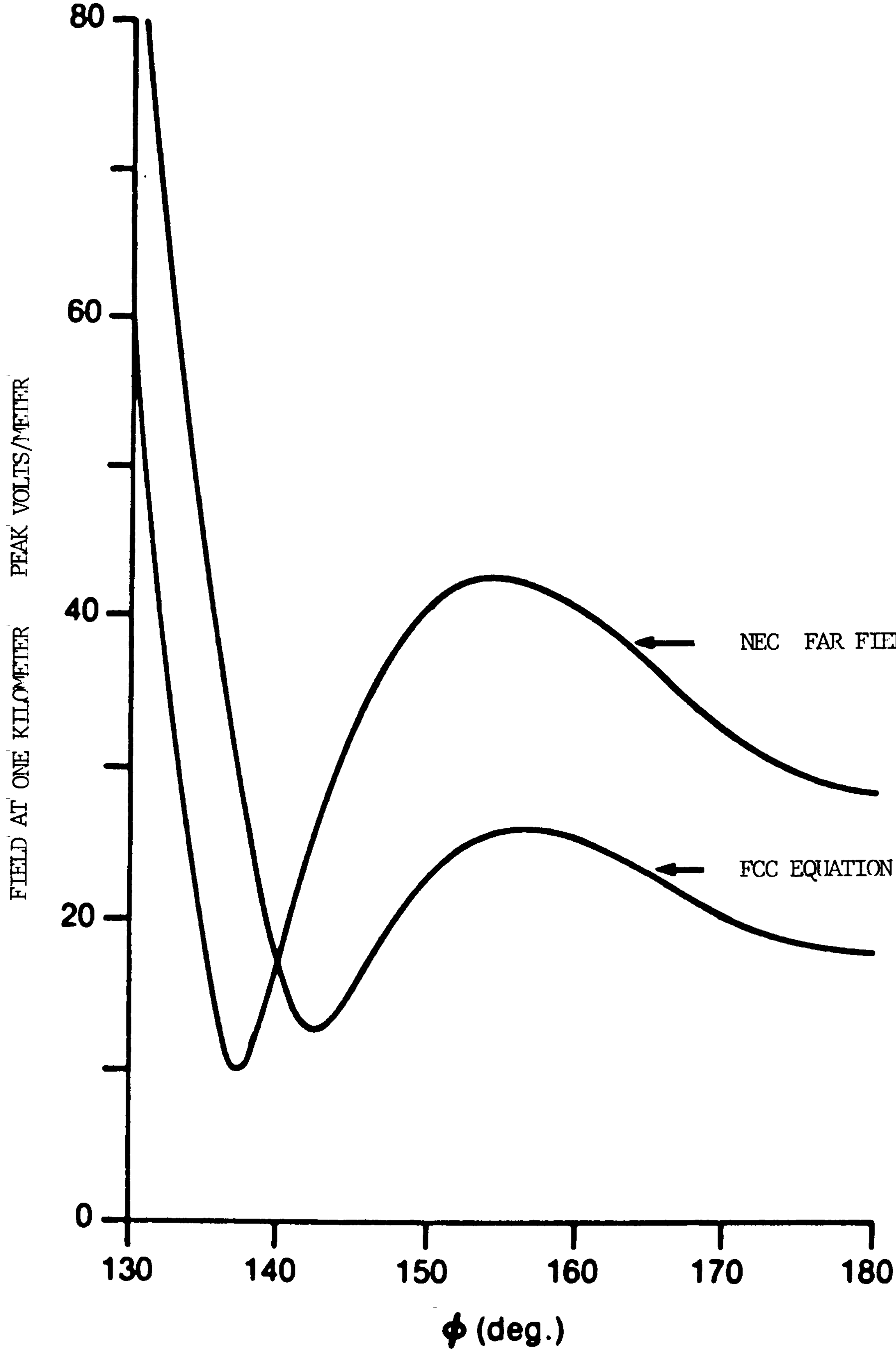
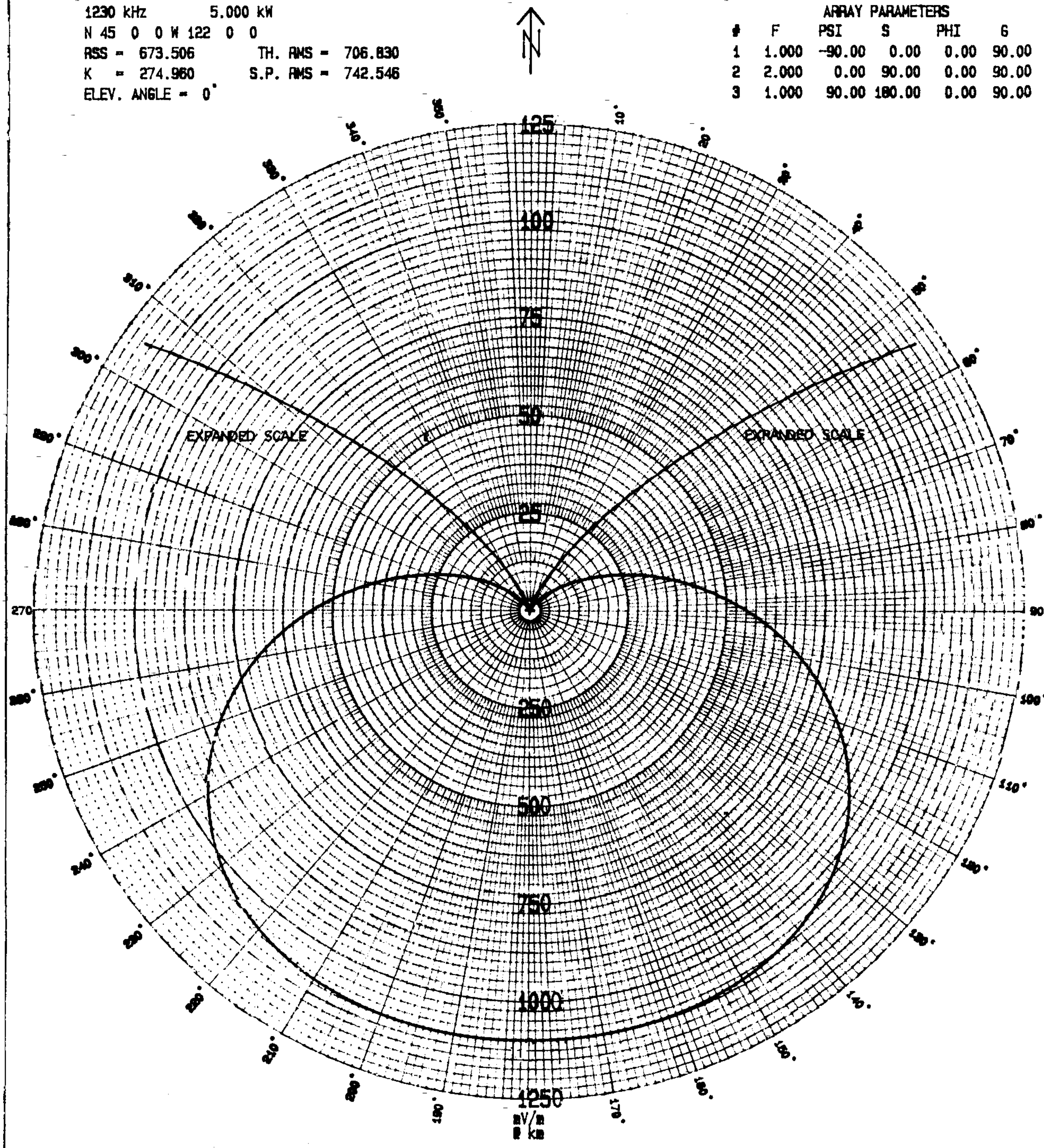


FIG. TWO Displacement of null between farfield calculations by NEC & FCC Equation #1.

1230 kHz 5.000 kW
N 45 0 0 W 122 0 0
RSS = 673.506 TH. RMS = 706.830
K = 274.960 S.P. RMS = 742.546
ELEV. ANGLE = 0°

ARRAY PARAMETERS

#	F	PSI	S	PHI	G
1	1.000	-90.00	0.00	0.00	90.00
2	2.000	0.00	90.00	0.00	90.00
3	1.000	90.00	180.00	0.00	90.00



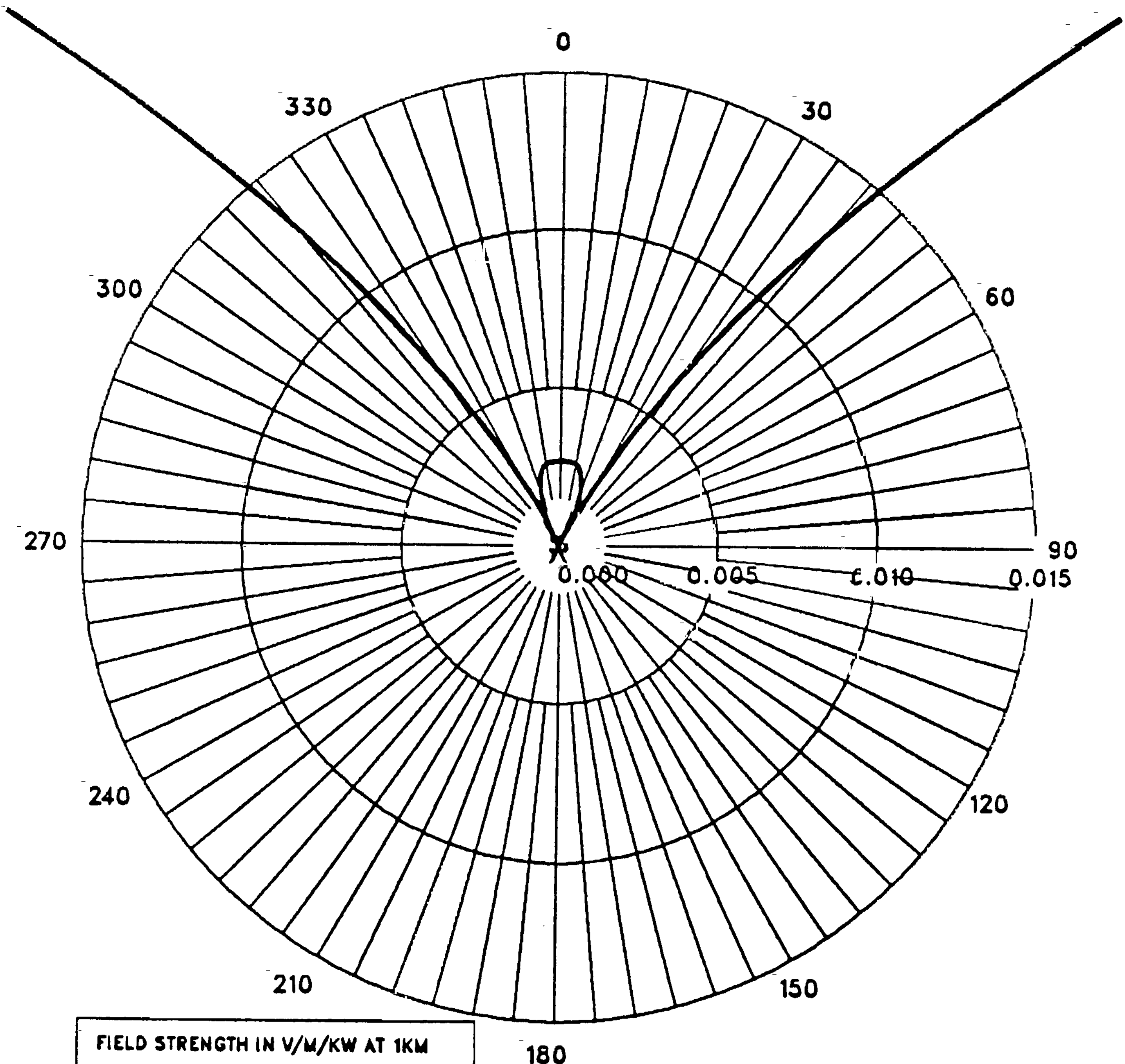
HATFIELD & DAWSON
CONSULTING ENGINEERS

FIG. THREE

Far field theoretical field parameter pattern at one kilometer calculated by FCC's RADIAT

3 ELEMENT PHASED ARRAY / 90 DEG. ELEMENTS / 90 DEG. SPACING

1 MHZ. FAR–FIELD APPROXIMATION



FIELD STRENGTH IN V/M/KW AT 1KM

THEORETICAL PARAMETERS

TWR	BASE CURRENT RATIO	PHASE	SPACING	ORIENTATION
1	1	-90	0	0
2	2	0	90	0
3	1	+90	180	0

ANGLES IN DEGREES TRUE

FIG. FOUR Null detail of NEC farfield pattern

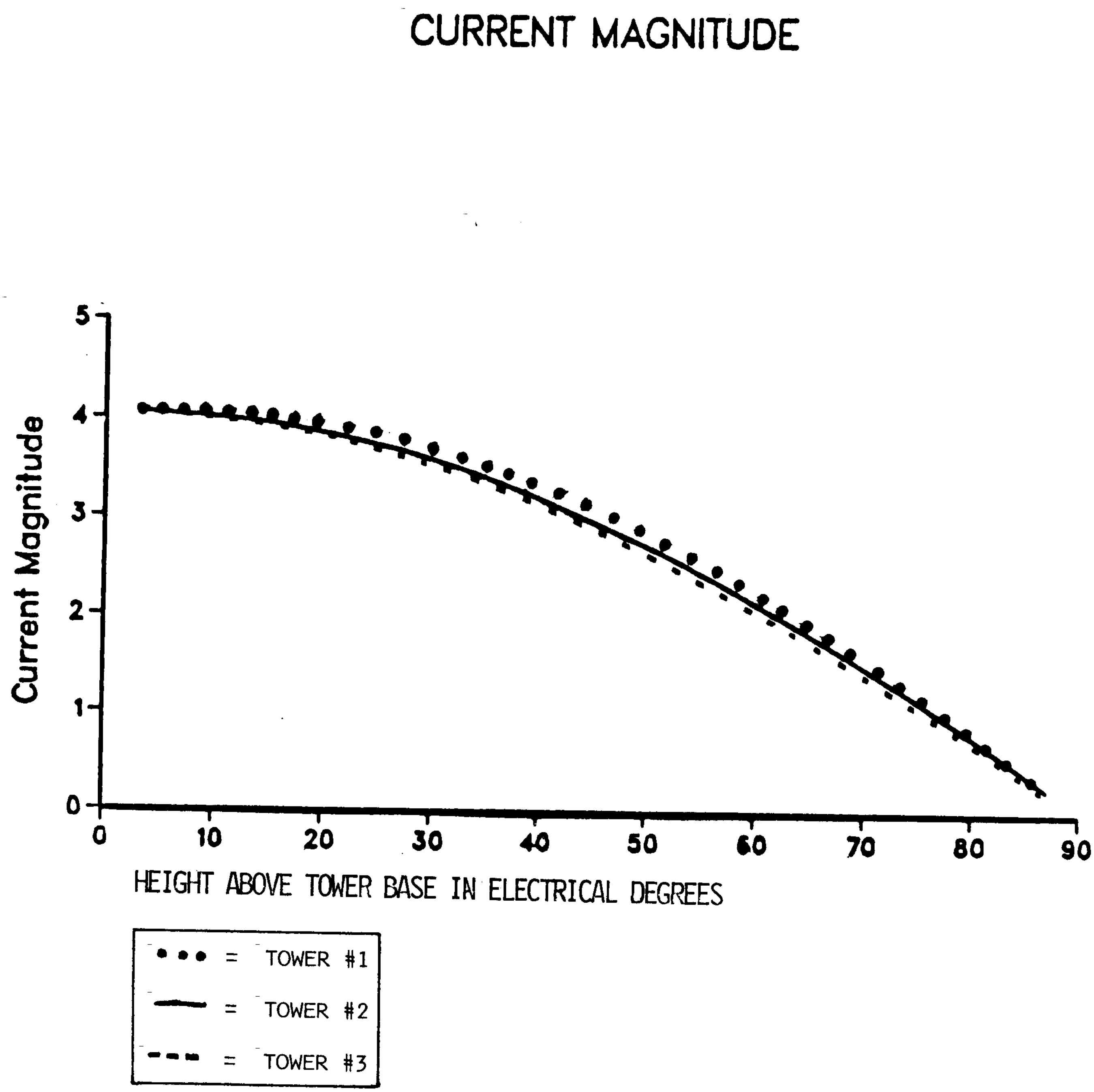
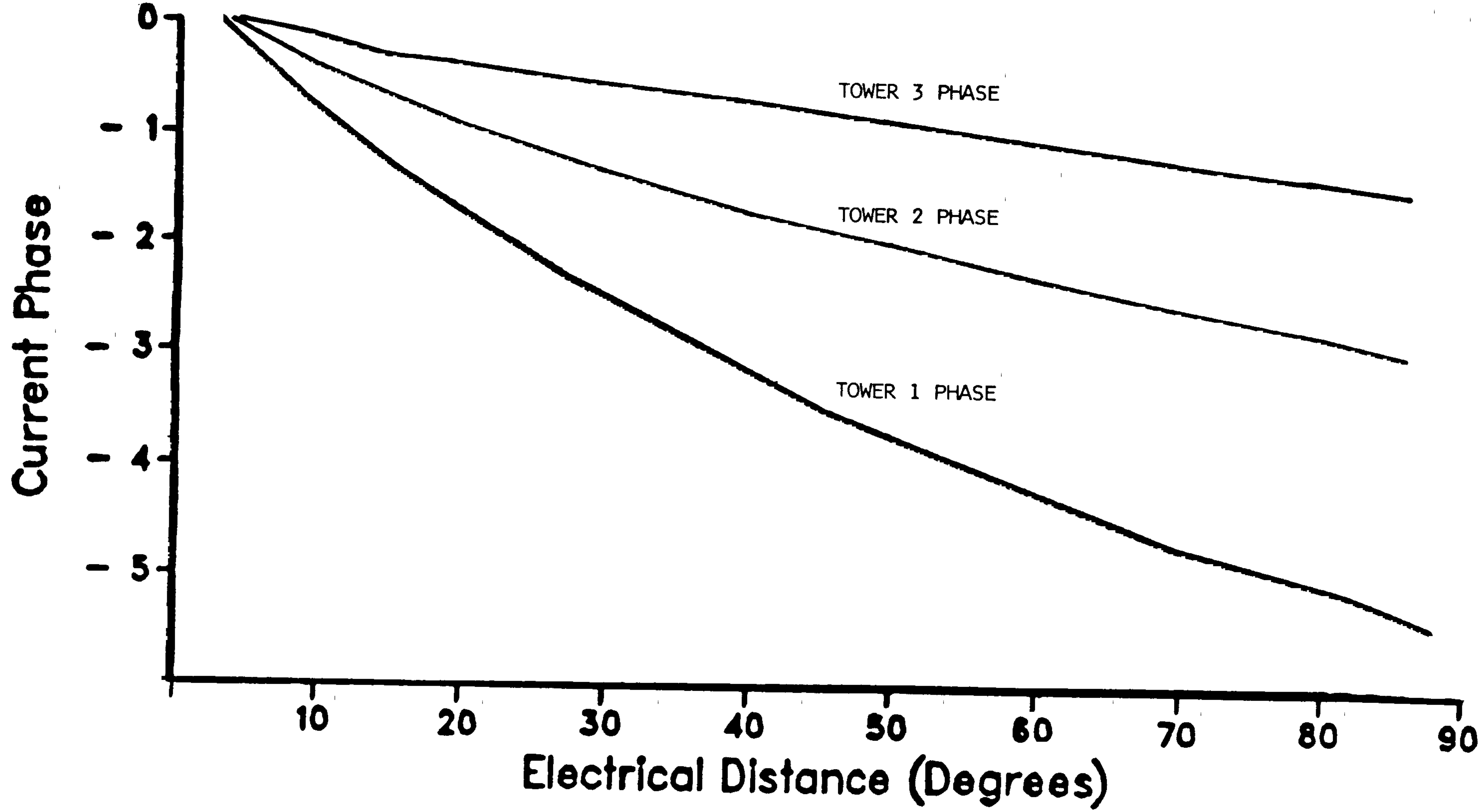


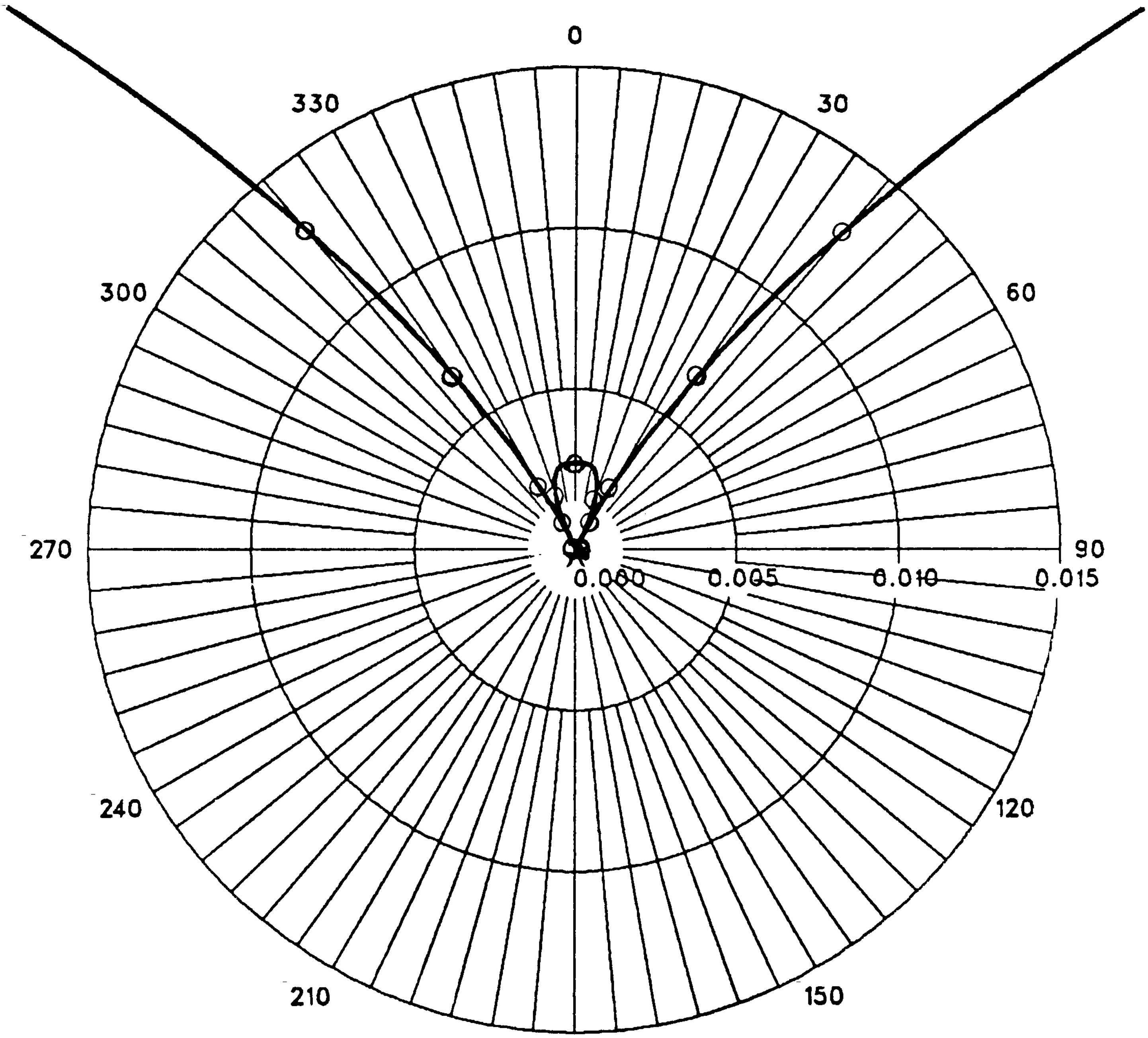
FIG. FIVE NEC calculated current distributions of 3-tower array whose patterns are shown in FIGS. 3 & 4

FIG. SIX NEC calculated variation of phase along lengths of towers whose patterns are shown FIGS. 3 & 4



3 ELEMENT PHASED ARRAY / 90 DEG. ELEMENTS / 90 DEG. SPACING

1 MHZ. FAR-FIELD APPROXIMATION



FIELD STRENGTH IN V/M/KW AT 1 KM
ANGLES IN DEGREES TRUE
O RADIAT THEO. FIELDS FOR ACTUAL FIELD PARAMETERS

FIG. SEVEN

Comparison of NEC and RADIAT calculated null detail. NEC calculated field parameters used for RADIAT

THEORETICAL PARAMETERS

TWR	BASE CURRENT RATIO	PHASE	SPACING	ORIENTATION
1	1	-90	0	0
2	2	0	90	0
3	1	+90	180	0

ACTUAL FIELD PARAMETERS CALCULATED BY NEC

TOWER	RATIO	PHASE
1	1.036	-91.2°
2	2.000	0°
3	0.984	+90.7°

MEASURED AND MININEC III CALCULATED CURRENT DISTRIBUTIONS

CURVES = MININEC III VALUES (MODELED BY RON RACKLEY, P.E.)
DOTS = MEASURED CURRENT VALUES

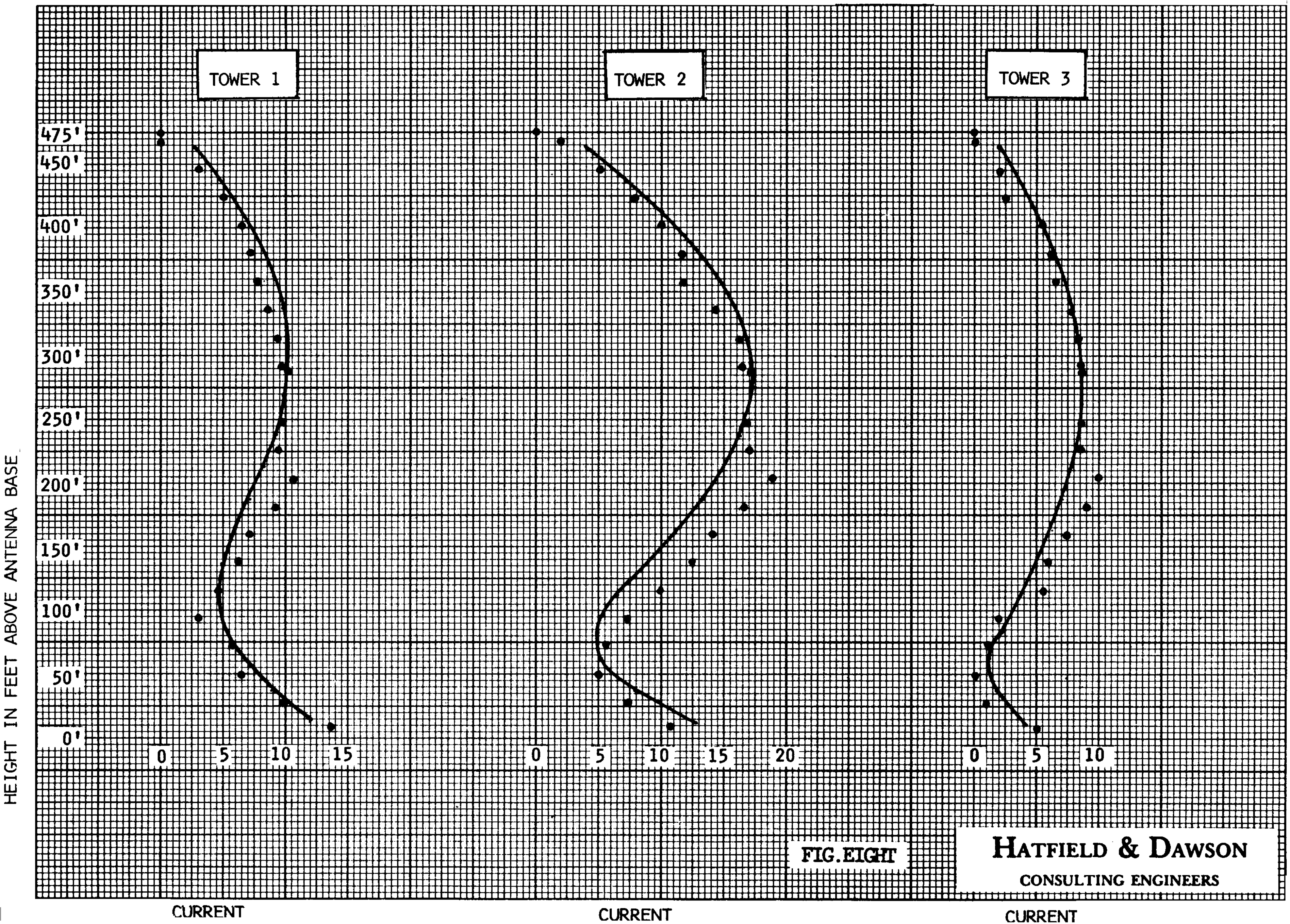


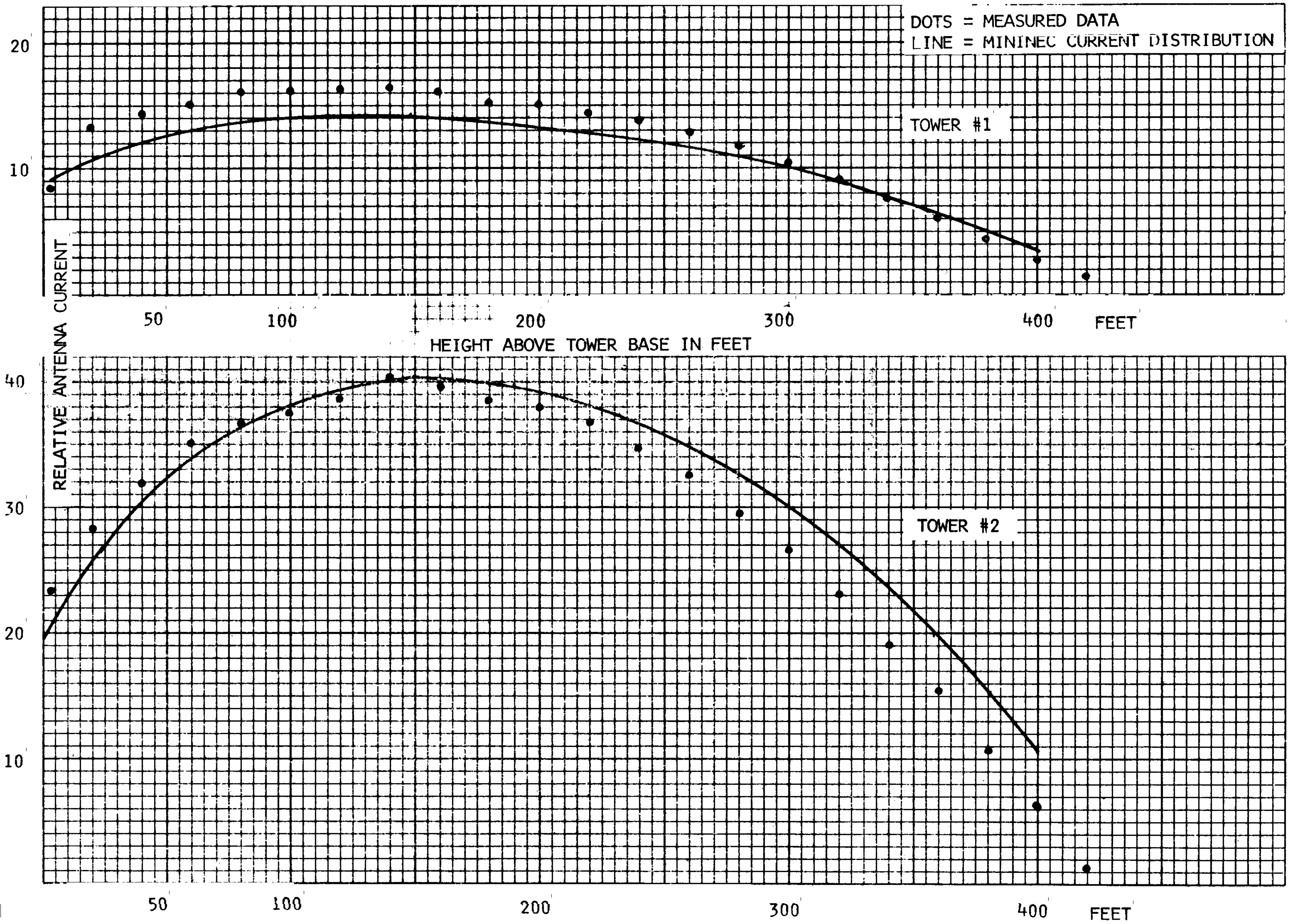
FIG. EIGHT

HATFIELD & DAWSON
CONSULTING ENGINEERS

MEASURED AND MININEC MODELED CURRENT DISTRIBUTIONS

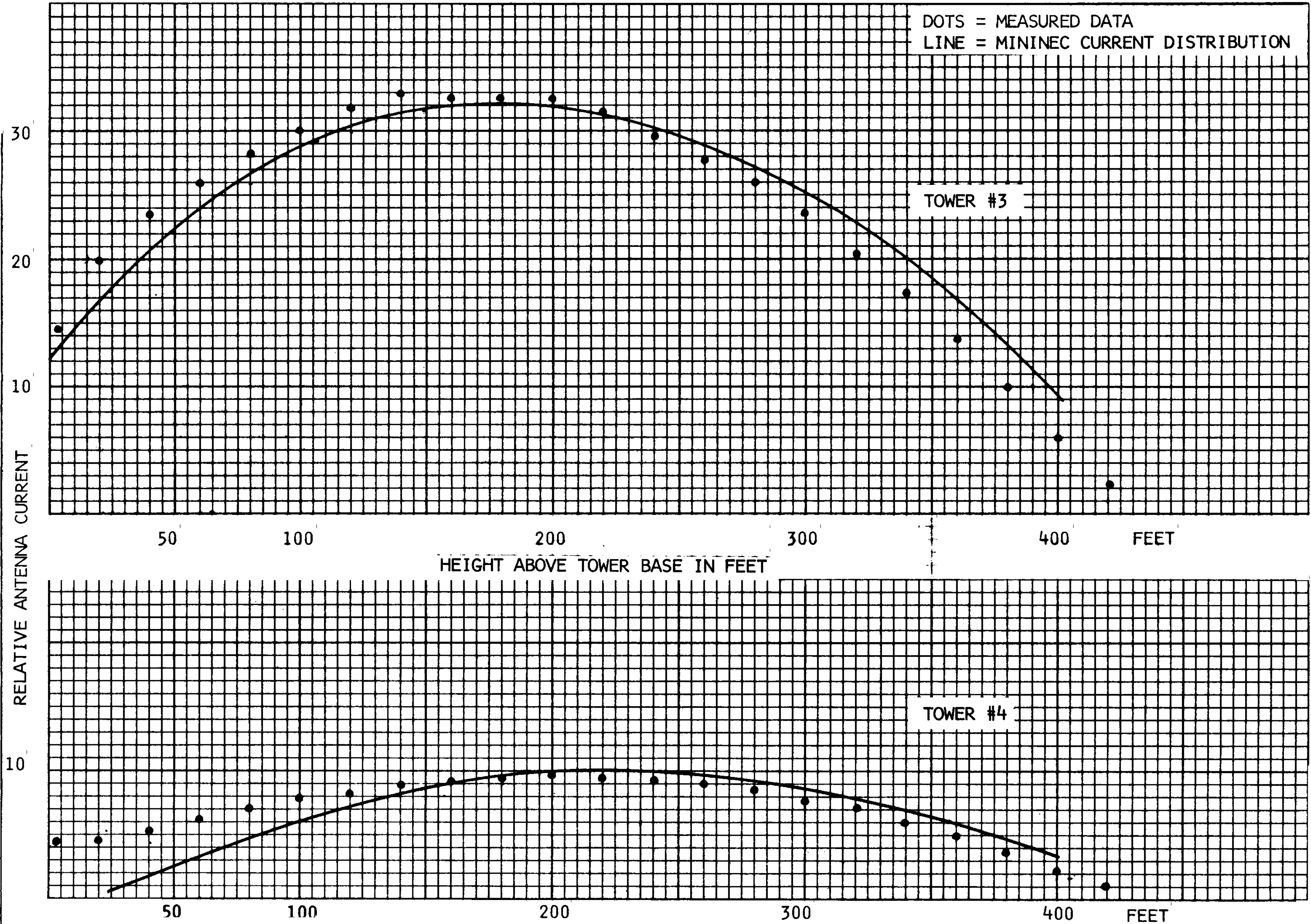
HATFIELD & DAWSON
CONSULTING ENGINEERS

FIG. NINE



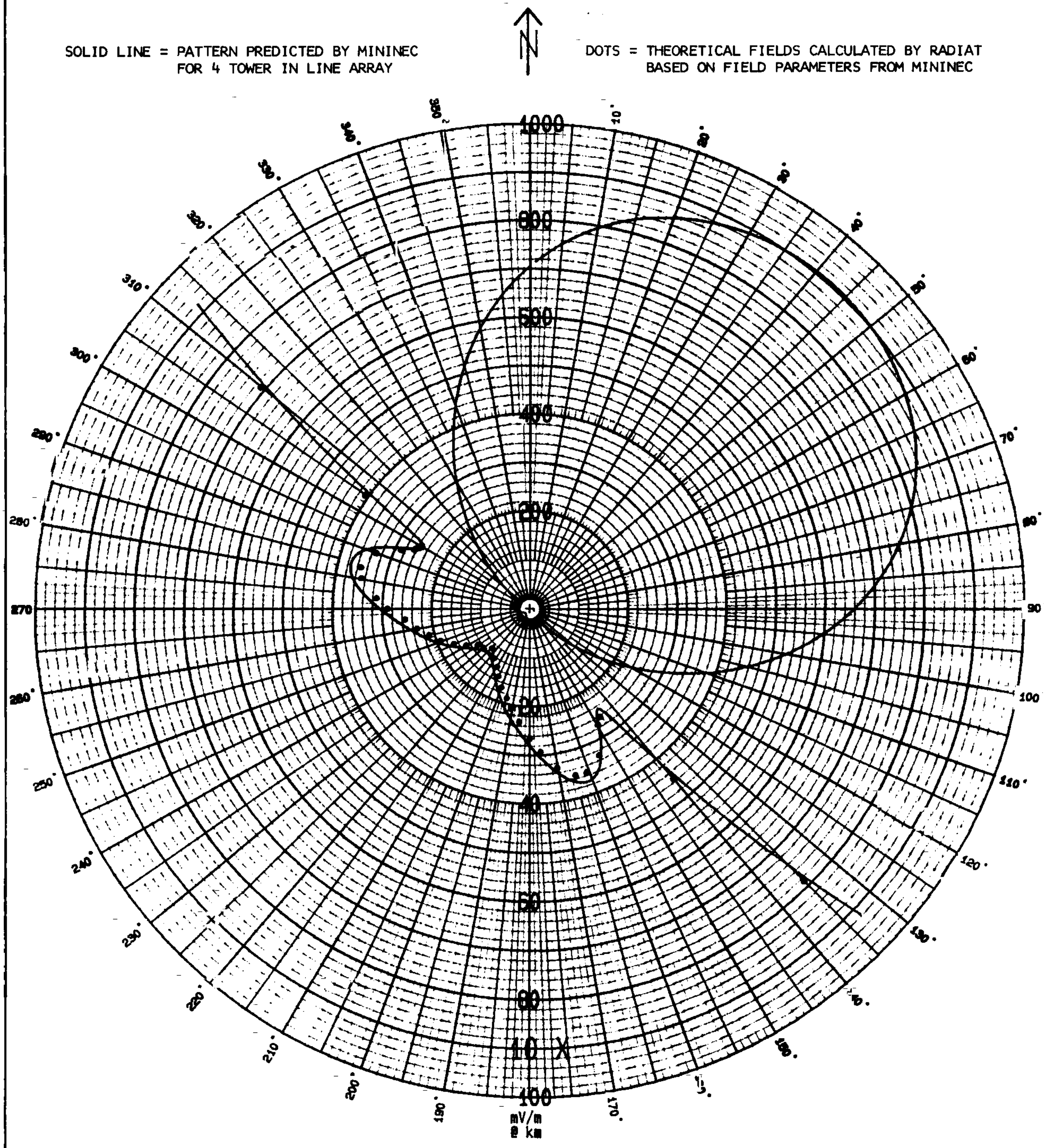
MEASURED AND MODELED MININEC CURRENT DISTRIBUTIONS

FIG. TEN



SOLID LINE = PATTERN PREDICTED BY MININEC FOR 4 TOWER IN LINE ARRAY

DOTS = THEORETICAL FIELDS CALCULATED BY RADIAT BASED ON FIELD PARAMETERS FROM MININEC



HATFIELD & DAWSON
CONSULTING ENGINEERS

FIG. ELEVEN

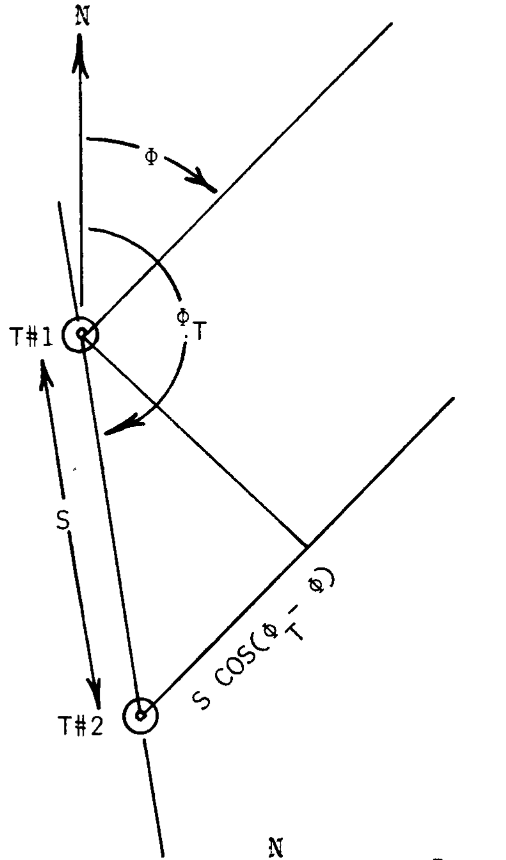
Far field patterns at one kilometer using MININEC and RADIAT. Field parameters for RADIAT calculated by MININEC

	BASE PARAMETERS		CURRENT LOOP PARAMETERS		FIELD PARAMETERS	
	% CHANGE IN CURRENT RATIO	PHASE CHANGE	%CHANGE IN CURRENT RATIO	PHASE CHANGE	RATIO	PHASE
#1	REFERENCE		REFERENCE		1.00	0
#2	-13.7	+7°	-2.7	+1°	2.93	-114°
#3	-30	+11°	-6.1	+1.2°	2.93	+127.4°
#4	-76	+16.6°	-13.9	+0.6°	1.22	+7.4°
#1	REFERENCE		REFERENCE		1.00	0
#2	-10.7	+12°	-4	+2°	2.99	-134°
#3	-29	+12°	-5	+1.4°	2.38	+101°
#4	-60.5	-2.7°	-10.7	+0.1°	1.21	-27.3°
#1	REFERENCE		REFERENCE		1.00	0
#2	-11.7	+11°	-2	+1.4°	2.65	-127.4°
#3	-30.5	+14°	-5.7	+1.7°	2.12	+112.6°
#4	-74.5	+23.4°	-13.3	-0.4°	0.97	+0.9°

FIG. TWELVE How monitored tower current parameters change in relation to field parameters as a function of antenna monitor sample location and antenna parameter adjustment.

EQUATION ONE

$$E = F_1 + F_2 \angle \underline{S\cos(\Phi_T - \Phi) + \Psi_2} \quad \text{FAR FIELD}$$

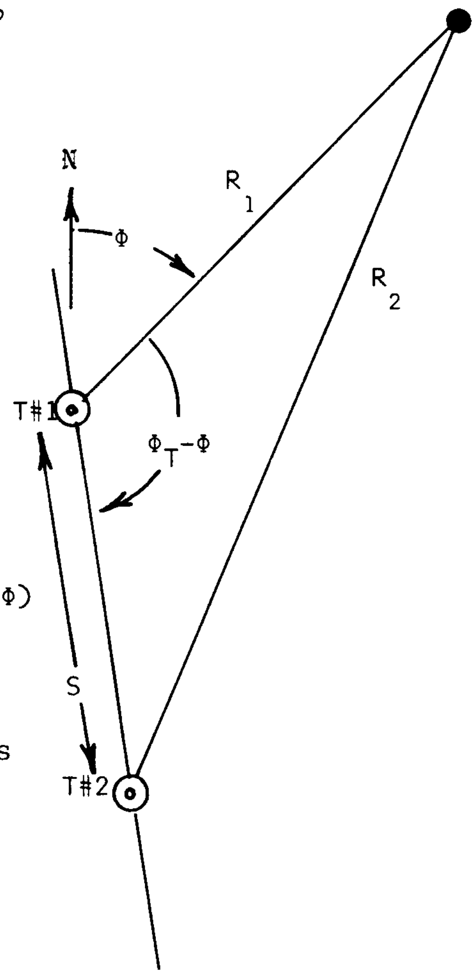


Ψ_2 = PHASE OF TWR#2 RELATIVE TO TWR#1

F_1, F_2, RELATIVE FIELD RATIOS OF TOWERS

EQUATION TWO

$$E = F_1 \angle \underline{-R_1} + \frac{R_1}{R_2} F_2 \angle \underline{-R_2 + \Psi_2} \quad \text{NEAR FIELD}$$



$$(R_2)^2 = (S)^2 + (R_1)^2 - 2(S)(R_1)\cos(\Phi_T - \Phi)$$

FIG. THIRTEEN Illustration of geometrical assumptions used for traditional pattern calculation formulas

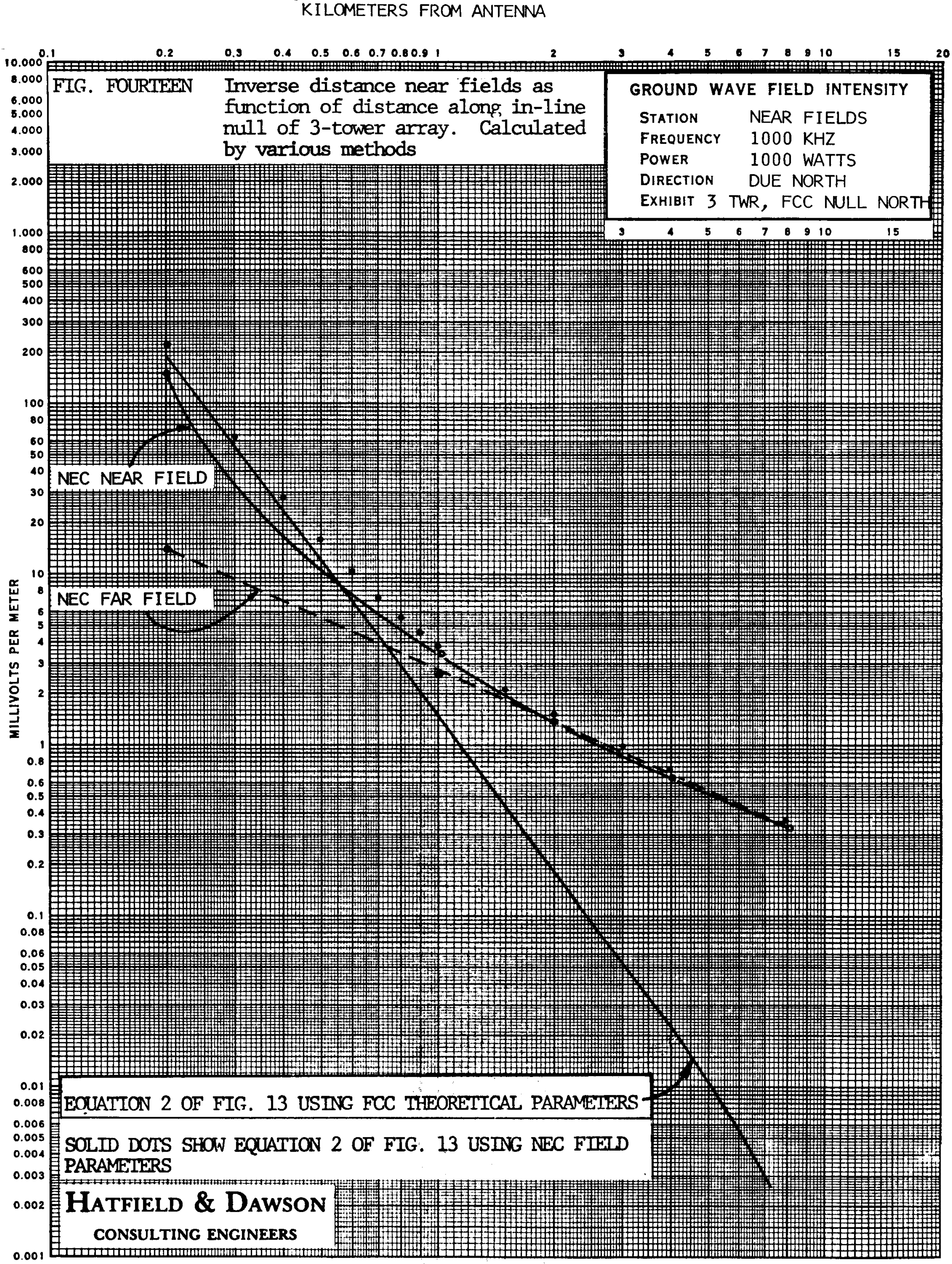


FIG. FOURTEEN Inverse distance near fields as function of distance along in-line null of 3-tower array. Calculated by various methods