VERIFYING THE RELATIONSHIPS BETWEEN AM BROADCAST FIELDS AND TOWER CURRENTS

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Abstract

The relative fields from the individual towers of an AM broadcast directional antenna array can be related to the voltages at the bases of the towers that are necessary to create those fields. The base voltages are used as sources for a modified version of Mininec III. The tower base currents computed by Mininec III for those tower base voltages are used to adjust the array of towers so that the correct far field pattern is achieved.

In the past, patterns for AM directional arrays have been brought into adjustment by a process of trial and error. The Mininec calculation procedure can reduce the amount of field work that is required to produce a properly functioning AM directional antenna system.

We have used the technique to adjust a variety of AM arrays in the past year. Adjustments are made so that the relative base currents of the towers are at the computed values, transmission lines are properly terminated, and field measurements are conducted without any further adjustments. In all cases so far, where re-radiating objects are not present, the resulting measured patterns have been within the tolerances of the FCC.

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INTRODUCTION

AM (Amplitude Modulation) standard broadcast stations operate in the U.S. in the medium frequency band between 540 and 1600 kiloHertz. They frequently use directional antennas consisting of arrays of vertical radiators (towers) to allow operation without violating the interference rules of the FCC (Federal Communications Commission). Simplified mathematical expressions have been used since the 1930's to calculate the directional patterns for the electric fields radiated from these arrays. There have not been mathematical expressions that could accurately relate the drive voltages at the bases of the towers, or the tower currents, to the far field radiation pattern. The only practical way to calculate far field pattern shape has been to add the contributions to the far field of the radiation from the individual towers.

FCC DIRECTIONAL ANTENNA PATTERN FORMULA

Parallel ray geometry combined with the orientation and spacing of the towers is used to compute AM directional antenna pattern shape. The electrical constants used for calculating the pattern shape are the relative magnitudes and phases of the far field contribution of the radiation leaving each tower and a factor used to specify pattern size. The electrical and physical array constants that are used in the expression for calculating AM direction antenna pattern shapes from parallel ray geometrical assumptions are called "Field Parameters". The FCC requires that the DA (Directional Antenna) horizontal plane pattern be computed according to

$$E_{th} = k\,[f_1 \angle \underline{S_1 \operatorname{Cos}(\Phi_1 - \Phi) + \Psi_1} + \ldots f_N \angle \underline{S_n \operatorname{Cos}(\Phi_n - \Phi) + \Psi_n}\,]$$

where:

- E_{th} Inverse distance far field at one kilometer
- k Pattern size constant
- f_n Field ratio of tower "n"
- S_n Spacing of tower "n" in degrees from reference point
- Φ_n Orientation of nth tower from reference point
- Φ Orientation of observation point
- Ψ_n Phase angle of tower "n" (See Figure One)

Operating impedances and pattern size are calculated using "Loop Currents". Currents flowing in the towers are assumed to have sinusoidal distributions. The "Loop" is located at the point of maximum current on the tower. The relative magnitudes (ratios) and phases of the Loop Currents of the various towers were assumed to be the same as those of the fields of the towers. (The FCC DA pattern formula uses the relative magnitude of the field from the tower and the phase angle of the current "Loop" of the tower as though the tower currents and fields were synonymous.)

The magnitudes and phases of the loop currents are measured by the antenna monitor and sample system that are installed at AM directional arrays by requirement of the FCC. A substantial percentage of AM directional arrays in the U.S.A. use towers that are a quarter wave or less in physical height with the current loop at the base of the tower.

HOW DA ARRAYS HAVE BEEN ADJUSTED

All AM directional antennas in the U.S. must be adjusted so that the field intensities of their measured patterns are less than the field intensities of the Standard Pattern at all azimuths. Interference and protection from interference are determined using the Standard Pattern. The Standard Pattern is calculated from the Theoretical Pattern (described above) according to

$$E_{std} = 1.05\ [(E_{th})^2 + (Q)^2]^{1/2}$$

where E_{std} = Standard Pattern Field
E_{th} = Theo. Pattern Field
Q = Tolerance Factor

When adjustments are made to the phasing, power division and matching networks that are used to control the station's Directional Antenna pattern, the currents measured by the antenna monitor are set to the field parameter ratios and phases. In most cases this is just the starting point in the procedure that is used to create the correct pattern for the directional array. The correct pattern is not usually achieved when the antenna currents are set to the field parameters because the field contribution of each radiator is not exactly proportional to the loop current. Great emphasis is placed on pattern minima since they are used to supress radiation in those directions where interference could be created. The radiated field intensity is monitored in the direction of the minima (frequently called "Nulls" even though the theoretical pattern field does not go to zero) while adjustments are made to the DA array. This trial and error procedure continues until the field intensities in the nulls are within the Standard Pattern.

USING MININEC TO RELATE TOWER FIELDS TO TOWER CURRENTS

The trial and error procedure that is used for the adjustment of AM directional arrays can be greatly reduced or eliminated in many cases. The current or voltage at the base of a tower can be linearly related to the field from that tower by using the familiar "N" port admittance and impedance parameters. For base currents a matrix can be formed from

$$E_1/k_1 = V_1 = I_1(Z_{11}) + I_2(Z_{12})$$

For the base voltages we have

$$E_1/k_2 = I_1 = V_1(Y_{11}) + V_2(Y_{12})$$

Where E_1 is the field from tower one, the Y's are the self and mutual admittances and the k's are the constants of proportionality between the fields and base currents and voltages of the towers. For Mininec we want the base drive voltages so we will limit ourselves to the admittance parameters.

For Mininec the Far Zone E-Field is:

$$\bar{E}|\bar{R}| = \frac{jkn}{4\pi} \frac{e^{-jk|\bar{R}|}}{R} \bar{F}[\bar{R}]$$

where

$$\bar{F}[\bar{R}] = \int_L \bar{I}(s) e^{-jkR\cdot\bar{r}(s)} ds$$

where

$$R = \bar{R}/|\bar{R}|$$

For an array of vertical radiators the "Z" component of the far zone E field in the horizontal or X/Y plane can be approximated as

$$E_1 = K_a \int_L I(s)\, ds$$

(where L is over the length of the vertical radiator)

since the terms in the more complete expression are approximately the same for all the towers in the array for great distances in the horizontal plane. This says that the far field from a tower in a vertical array is proportional to the summation of the current moments for that tower. And for Mininec this would be

$$E_1 = K_a\, \Sigma I(\Delta s).$$

Where Δs is the segment length and I is the current associated with segment length (Δs).

The expression used to form the matrix is

$$E_1/k_2 = K_a/k_2\, \Sigma I(\Delta s) = V_1(Y_{11}) + V_2(Y_{12}).$$

If we define $Y_{11}(k_2/K_a) = T_{11}$ and $Y_{12}(k_2/K_a) = T_{12}$ we have

$$E_1/k_a = \Sigma I(\Delta s) = V_1(T_{11}) + V_2(T_{12}).$$

Since we are interested in the field parameters relative to a reference tower we have

$$F_2 = E_2/E_1 = \frac{\Sigma I_2(\Delta s_2)}{\Sigma I_1(\Delta s_1)}$$

Where F_2 = Field ratio and Phase of tower #2

PRACTICAL IMPLEMENTATION OF THE TECHNIQUE

Mariabeth Silkey has modified the Mininec program to list the sums of the current moments for each wire and the field parameters as their complex ratios relative to tower (wire) one. (See Figure Two) To compute the "T" transfer parameters the towers are driven one at a time with one volt at the base segment. The "T" parameters in the matrix column with non-zero voltage are then equal to the respective tower current moment summation. The matrix that is formed from the equations relating the field parameters to the base segment drive voltages [$F_1 = 1 = V_1(T_{11}) + V_2(T_{12})\ldots$, $F_2 = V_1(T_{21}) + V_2(T_{22})\ldots$etc.]

is inverted to find the base drive voltages for Mininec that give the correct pattern. The current pulses (taken from the listed Mininec output currents) for the wire segments closest to the tower height where the antenna current is sampled give the correct relative adjustment parameters. The array is then adjusted so that the antenna monitor indicates those ratios and phases.

MEASURED RESULTS

We have adjusted several directional antennas using this technique without having to resort to trial and error field adjustment. I will discuss three examples. In all three examples antenna currents were monitored at the bases of the towers. Figures 3, 4, and 5 show the measured and standard horizontal plane patterns of the three stations.

A two tower array with unequal height towers (0.36λ and 0.18λ) that had inductive loading at the center of the taller tower was modeled using Mininec III. After computing the correct base current parameters it was necessary to apply a correction to account for the interaction of the tower base impedance with the base insulator capacitance. The impedance of the tall tower was quite high while the impedance of the short tower was almost two orders of magnitude lower than the capacitive reactance of the base insulator. Therefore a correction had to be applied only to the taller tower.

Neither the inductance of the coil at the center of the tall tower nor the capacitance of the base insulator were known or easily measurable. Measured impedances on both towers were available that were made with the inductive loading and the bases of the towers in a variety of open and short circuit configurations. The load inductance at the center of the tall tower and the capacitance of the base insulator at the tall towers were adjusted in the model until the computed Mininec values matched the measured values. When the array was adjusted to the computed base current parameters (the field ratio and phase angle of the tall tower were 0.83 and -94 degrees while the antenna monitor ratio and phase angle for this tower were 0.11 and -9.5 degrees) the measured operating base impedances were close to the predicted values and the measured fields were within the Standard Pattern (Figure Three).

An equal height 0.24λ three tower "dog leg" (not in a line) array was adjusted to the base current parameters computed from the Mininec procedure. The field ratios and phases of the end towers were 0.87 and -82.2 degrees and 0.348 and +88.4 degrees while the computed antenna monitor parameters were 0.85 and -77.3 degrees and 0.358 and +96 degrees respectively. The results are shown in Figure Four.

An unequal height (two towers 0.25λ and two towers 0.21λ) four tower parallelogram array (towers located at the corners of a parallelogram in the horizontal plane) was adjusted according to the Mininec procedure. The non-reference tall tower had computed monitor ratio and phase that were 3% and 2 degrees higher than the field parameters. One of the shorter towers had antenna monitor ratio and phase that were 39% and 6.6 degrees higher, respectively, than the field ratio and phase. The other short tower had computed monitor ratio and phase that were 25% higher and 3.7 degrees more negative, respectively, than the field ratio and phase for that tower. The measured and Standard Pattern for this array are shown in Figure Five.

DETUNING TOWERS

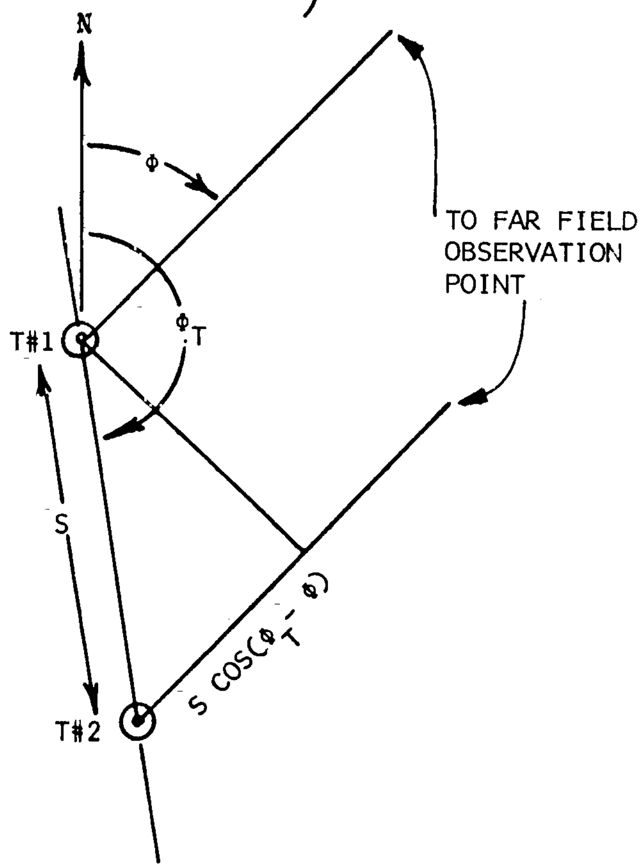
Our success in adjusting AM directional arrays using tower base current parameters computed from the Mininec III current moment summations and the field parameters has led us to use the procedure for all of our AM directional antenna work. In those cases where nearby conducting objects such as buildings or power transmission towers and lines cause scattering and re-radiation of the incident fields we have had some success in pattern adjustment using the procedure. When we have been able to realistically model the towers and re-radiating objects pattern minima have been brought below the standard pattern. In two specific cases the pattern minimas were brought within tolerance when the arrays were adjusted to the computed base current parameters. In two other situations we were not able to define the situation well enough to make an adequate model.

We have successfully detuned two towers in an AM array to allow omni-directional operation from a third tower. The magnitudes of the field parameters of the towers to be de-tuned were set at 10^{-6} and the computed base drive voltages that produced these fields were applied to the Mininec model of the array. The impedances of the de-tuned towers in the driven array were computed by Mininec. The real part of the impedance was typically two orders of magnitude lower than the imaginary part. Therefore the towers can be detuned by applying the conjugate of the reactive component of the operating impedance obtained from Mininec between the bases of the towers and ground (when towers are driven by base voltages that cause the fields of the de-tuned towers to be 10^{-6} of the field from the tower that is not de-tuned). When the model is run on Mininec with the grounded segments loaded with the de-tuning reactances some degredation of the de-tuning effect is observed (compared to the case where de-tuning is achieved by applying base drives), however, the scattered fields from the de-tuned towers are still several orders of magnitude below the fields from the tower that is not de-tuned.

CONCLUSION

Field parameters were devised so that AM directional antenna patterns could be computed. A realistic method to relate the field parameters to tower currents and tower base drives only became possible with the advent of numerical computer techniques. Method of moments procedures are not perfect for all AM antenna problems but they are more realistic than basing one's computation on assumed sinusoidal current distributions. By using programs like NEC-3 and Mininec III AM design engineers can compute base current parameters for AM directional antennas that produce measured patterns that are close to the calculated patterns and are within the limits of the FCC standard pattern. These results take much longer to achieve using trial and error in the field.

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



Ψ_1 = PHASE OF TWR#2 RELATIVE TO TWR#1

F_1, F_2, RELATIVE FIELD RATIOS OF TOWERS

Φ = AZIMUTH FROM TRUE NORTH OF OBSERVER

Φ_T = AZIMUTH OF TOWER #2 FROM TRUE NORTH

S = SPACING BETWEEN TOWERS

K = PATTERN SIZE CONSTANT

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FIGURE ONE

PARALLEL RAY GEOMETRIC DEFINITION OF VARIABLES USED IN FCC FORMULA. 2 TOWER CASE

******************** CURRENT DATA ********************

WIRE NO. 1 :

PULSE NO.	REAL (AMPS)	IMAGINARY (AMPS)	MAGNITUDE (AMPS)	PHASE (DEGREES)
1	9.095311E-04	-3.636486E-04	9.795341E-04	-21.79251
2	9.086882E-04	-8.286002E-04	1.229753E-03	-42.36056
3	9.06157E-04	-1.138403E-03	1.455019E-03	-51.48056
4	9.019329E-04	-1.404209E-03	1.668918E-03	-57.2871
5	8.960054E-04	-1.63982E-03	1.868646E-03	-61.3476
6	8.883638E-04	-1.850787E-03	2.05295E-03	-64.35934
7	8.789975E-04	-2.03963E-03	2.220974E-03	-66.68592
8	8.678955E-04	-2.207602E-03	2.372077E-03	-68.53825
9	8.550523E-04	-2.35535E-03	2.505751E-03	-70.0478
10	8.404679E-04	-2.483219E-03	2.621596E-03	-71.30115
11	8.241522E-04	-2.591416E-03	2.719313E-03	-72.35768
12	8.061287E-04	-2.680108E-03	2.798718E-03	-73.25964
13	7.864429E-04	-2.749494E-03	2.859757E-03	-74.03777
14	7.651715E-04	-2.799871E-03	2.902545E-03	-74.71497
15	7.424431E-04	-2.831748E-03	2.92746E-03	-75.30856
16	7.184927E-04	-2.846074E-03	2.935365E-03	-75.83168
17	6.938214E-04	-2.844919E-03	2.928302E-03	-76.29421
18	6.718878E-04	-2.842873E-03	2.921192E-03	-76.70264
19	6.199983E-04	-2.701561E-03	2.771791E-03	-77.07464
20	5.710868E-04	-2.560293E-03	2.623212E-03	-77.42571
21	5.219313E-04	-2.405406E-03	2.46138E-03	-77.75758
22	4.722622E-04	-2.235733E-03	2.285068E-03	-78.07253
23	4.220665E-04	-2.051194E-03	2.094167E-03	-78.37274
24	3.714227E-04	-1.852094E-03	1.88897E-03	-78.66021
25	3.204414E-04	-1.638862E-03	1.669896E-03	-78.93671
26	2.692316E-04	-1.411886E-03	1.437327E-03	-79.20391
27	2.178703E-04	-1.171338E-03	1.191428E-03	-79.46332
28	1.663499E-04	-9.168622E-04	9.318307E-04	-79.71646
29	1.144542E-04	-6.468022E-04	6.568507E-04	-79.96516
30	6.140066E-05	-3.559713E-04	3.61228E-04	-80.21348
E	0	0	0	0

0.116 ∠44.6

TWR 1 MAG .2467563 PHI -72.00002 ← CURRENT MOMENT SUMMATION

WIRE NO. 2 :

PULSE NO.	REAL (AMPS)	IMAGINARY (AMPS)	MAGNITUDE (AMPS)	PHASE (DEGREES)
31	7.785375E-03	3.275514E-03	8.446364E-03	22.81778
32	7.341167E-03	3.050669E-03	.0079498	22.56564
33	6.973733E-03	2.871914E-03	7.541939E-03	22.38278
34	6.596929E-03	2.694953E-03	7.126167E-03	22.22081
35	6.199053E-03	2.513696E-03	6.689314E-03	22.07239
36	5.77604E-03	2.325949E-03	6.226771E-03	21.93411
37	5.326588E-03	2.130913E-03	5.737014E-03	21.80398
38	4.850613E-03	1.928398E-03	5.219881E-03	21.68067
39	4.34862E-03	1.718508E-03	4.675871E-03	21.56317
40	3.821357E-03	1.501473E-03	4.105751E-03	21.45067
41	3.269517E-03	1.277525E-03	3.510244E-03	21.34248
42	2.69338E-03	1.046749E-03	2.889633E-03	21.238
43	2.092149E-03	8.088297E-04	2.243054E-03	21.13662
44	1.462361E-03	5.62451E-04	1.566797E-03	21.03766
45	7.929214E-04	3.034183E-04	8.489917E-04	20.93978
E	0	0	0	0

1 ∠0°

TWR 2 MAG .2961073 PHI 21.99993 ← CURRENT MOMENT SUMMATION

TOWER	MAGNITUDE	PHASE
1	1	0
2	1.199999	93.99995

} FIELD PARAMETERS

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FIGURE TWO

MININEC OUTPUT CURRENTS MODIFIED TO SHOW CURRENT MOMENT SUMMATION AND FIELD PARAMETERS

900 KHZ 0.500 KW

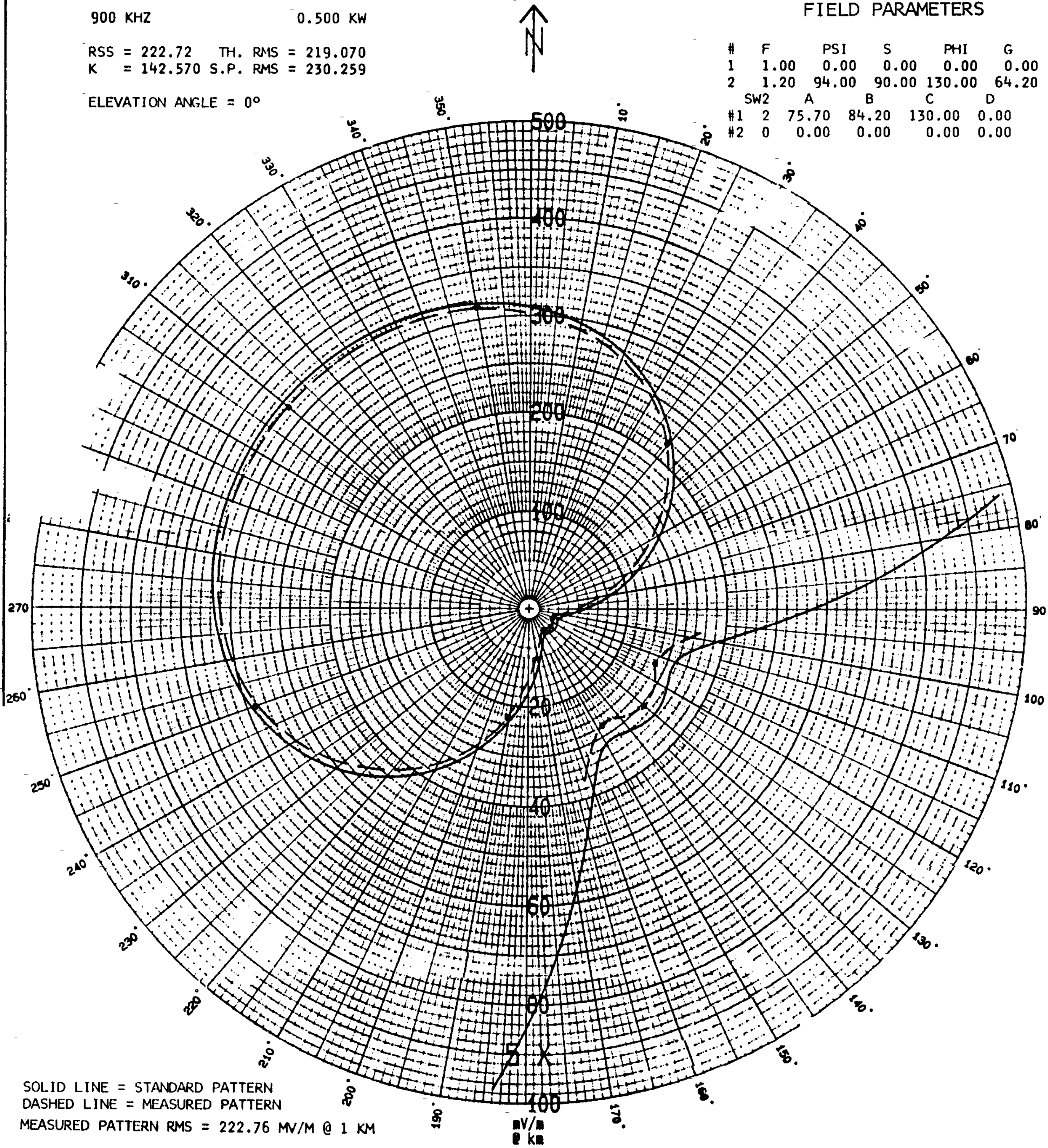
RSS = 222.72 TH. RMS = 219.070
K = 142.570 S.P. RMS = 230.259

ELEVATION ANGLE = 0°

FIELD PARAMETERS

#	F	PSI	S	PHI	G
1	1.00	0.00	0.00	0.00	0.00
2	1.20	94.00	90.00	130.00	64.20

	SW2	A	B	C	D
#1	2	75.70	84.20	130.00	0.00
#2	0	0.00	0.00	0.00	0.00



SOLID LINE = STANDARD PATTERN
DASHED LINE = MEASURED PATTERN
MEASURED PATTERN RMS = 222.76 MV/M @ 1 KM

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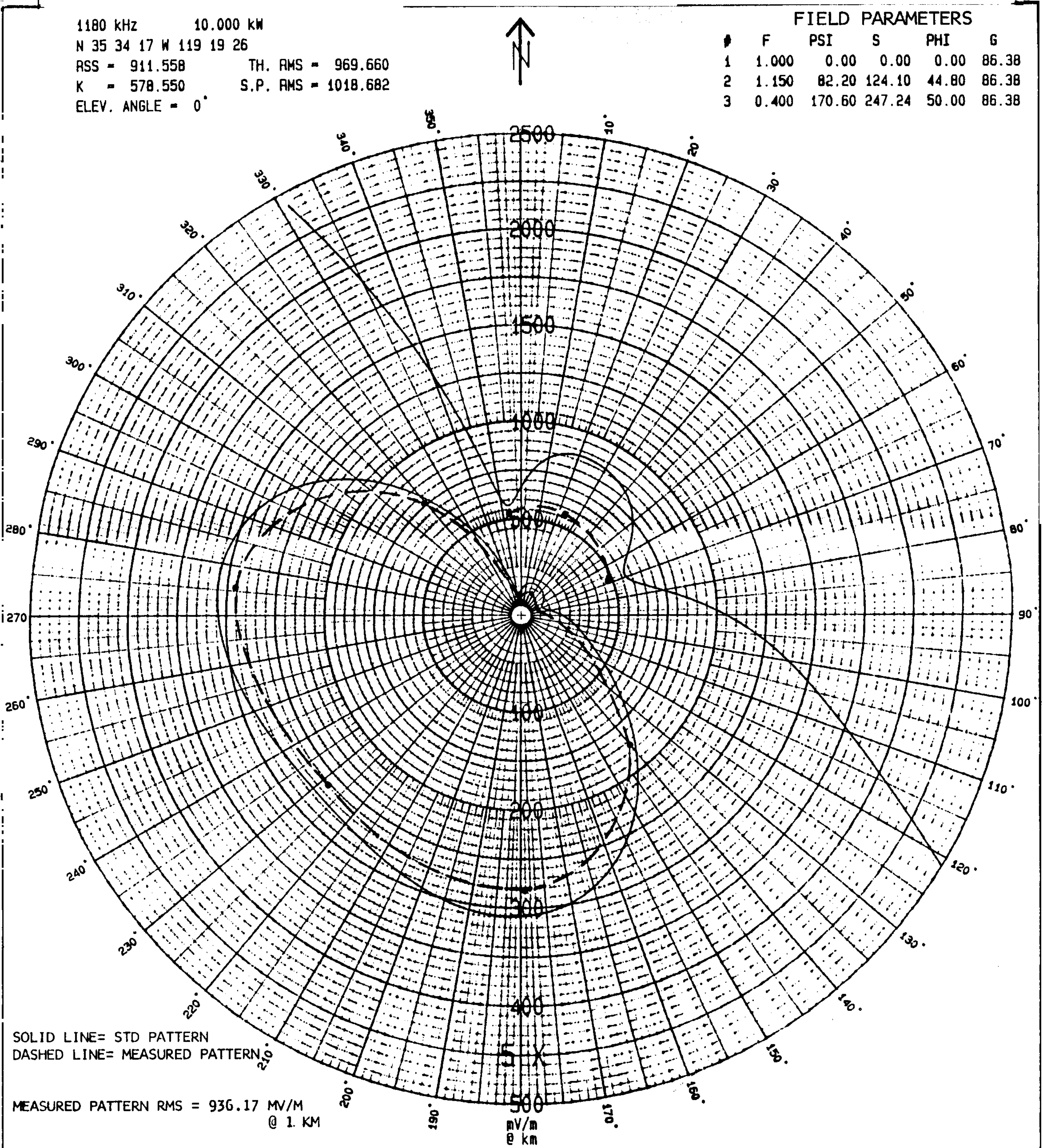
FIGURE THREE

TWO TOWER ARRAY. UNEQUAL HEIGHT
WITH CENTER OF TALL TOWER INDUCTIVELY LOADED

1180 kHz 10.000 kW
N 35 34 17 W 119 19 26
RSS = 911.558 TH. RMS = 969.660
K = 578.550 S.P. RMS = 1018.682
ELEV. ANGLE = 0°

FIELD PARAMETERS

#	F	PSI	S	PHI	G
1	1.000	0.00	0.00	0.00	86.38
2	1.150	82.20	124.10	44.80	86.38
3	0.400	170.60	247.24	50.00	86.38



SOLID LINE= STD PATTERN
DASHED LINE= MEASURED PATTERN

MEASURED PATTERN RMS = 936.17 MV/M
@ 1 KM

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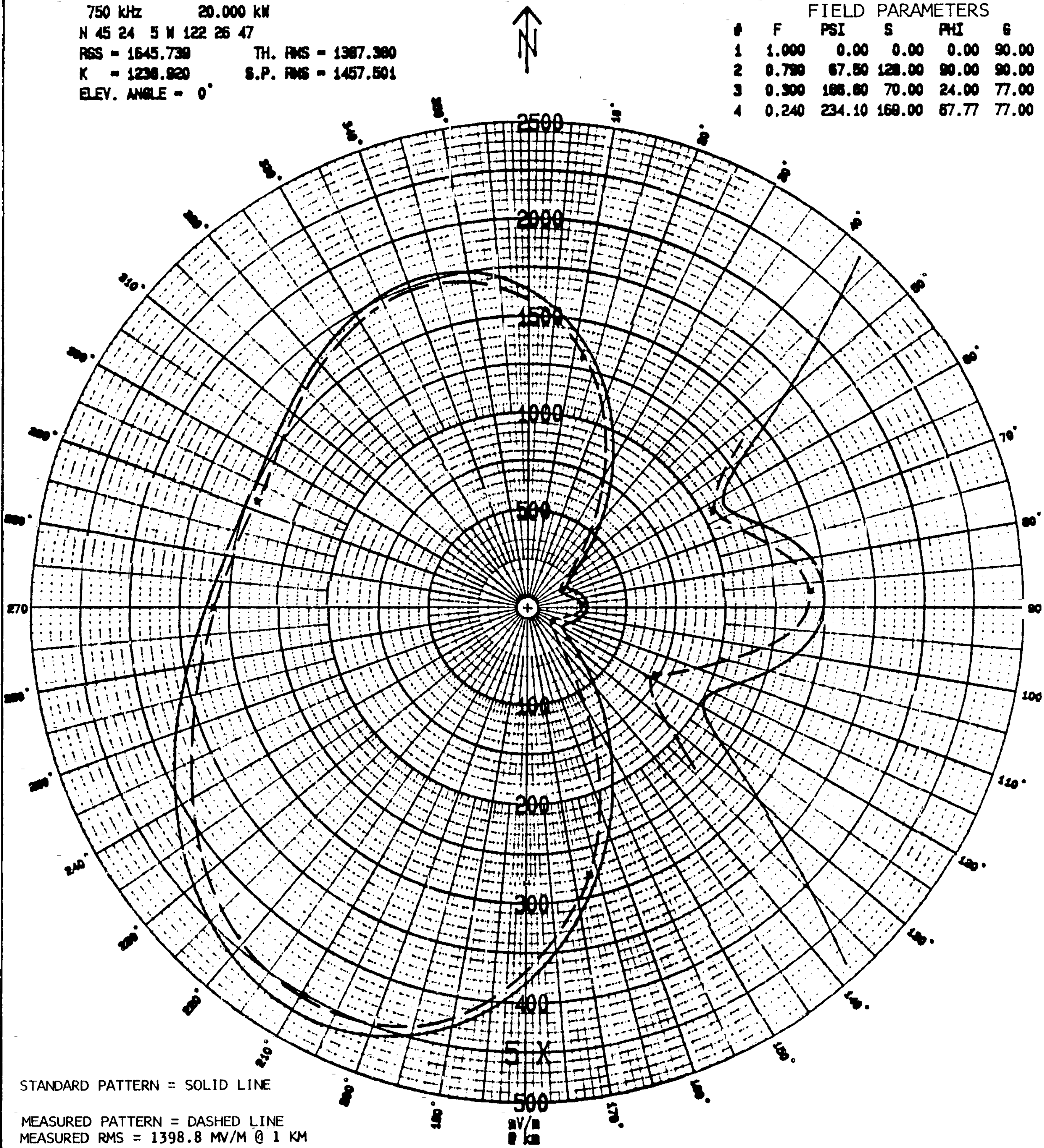
FIGURE FOUR

THREE TOWER "DOG LEG" ARRAY

750 kHz 20.000 kW
N 45 24 5 W 122 26 47
RSS = 1645.739 TH. RMS = 1387.380
K = 1238.920 S.P. RMS = 1457.501
ELEV. ANGLE = 0°

FIELD PARAMETERS

#	F	PSI	S	PHI	G
1	1.000	0.00	0.00	0.00	90.00
2	0.790	67.50	128.00	90.00	90.00
3	0.300	186.80	70.00	24.00	77.00
4	0.240	234.10	160.00	67.77	77.00



STANDARD PATTERN = SOLID LINE

MEASURED PATTERN = DASHED LINE
MEASURED RMS = 1398.8 MV/M @ 1 KM

HATFIELD & DAWSON CONSULTING ENGINEERS	FIGURE FIVE FOUR TOWER PARALLELOGRAM ARRAY TOWER PAIRS DIFFERENT HEIGHTS