RELATIVE TOWER CURRENTS AND FIELDS IN AN AM DIRECTIONAL ARRAY

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Abstract

The equation that is used to calculate the radiation patterns of AM directional arrays for facilities authorized by the Federal Communications Commission (FCC) is based upon simplified ray geometry that requires the use of quantities known as Field Parameters. The Field Parameters are the relative magnitudes and phases of the electric fields as they leave the towers and the corresponding physical dimensions of the array. These are the parameters that are used by the FCC to officially designate the shape of AM directional antenna patterns for domestic (i.e., construction permits, etc.) and international notifications. When AM directional arrays are adjusted, the antenna monitor ratios and phases are set to be the same as the construction permit Field Parameters. After this is accomplished, it is usually necessary to "field adjust" the array to get the correct pattern.

With the help of method of moments techniques, the antenna monitor parameters that give the correct pattern can be calculated from the field parameters. The base voltages can be computed from the linear relationship between the relative fields and the base voltages. The computed voltages can then be used as sources for MININEC III. The base currents computed by MININEC III for those base voltages are used to determine the antenna monitor parameters that result in the correct directional antenna (DA) pattern.

Calculating the antenna monitor parameters that give the correct DA pattern means that trial and error field adjustment is not necessary in those situations where re-radiating objects are not present. Thin re-radiating objects, such as AC power transmission towers, can be included in the computation when they can be accurately located and described. Detuning impedances from the floated towers to ground are easily calculated from the output of the MININEC III program.

Examples of the use of this technique are shown in this paper.

INTRODUCTION

This paper includes materials and examples originally published in references [1-5]. The basic ideas and concepts of those papers are clarified, expanded and given additional theoretical justification herein.

Engineers have usually tuned AM directional arrays by adjusting the networks that control the power division and tower current phase angles so that the antenna monitor indicates the field ratios and phases shown on the station's construction permit. If there is something unusual about the array such as self supporting towers, towers of different height, or sectionalization, a fair amount of trial and error is necessary to bring the pattern nulls below the limits of the Standard Pattern. This is also true for arrays using tall towers. Even the patterns of arrays with short towers are not always within the Standard Pattern when the antenna monitor indicates the construction permit field ratios and phases.

We have never been able to analytically predict reliable relationships between the field parameters and the antenna current parameters indicated by the antenna monitor. One of the reasons for this is that there has not been a way to make a realistic calculation of the behavior of the antenna current distributions of the towers used in an AM directional array. The magnitudes of the currents have been assumed to be sinusoidal. The phase angle of the current at a given point in a tower has been determined using an analogy from transmission line theory. Schelkunoff transmission line theory is reasonable for determining tower base impedance but it is not too helpful for determining the currents on towers in the presence of complex mutual coupling between array elements. We have used sinusoidal tower current distributions to compute AM directional antenna pattern size and shape because there has been no other alternative, and because it is the only way to make the calculations manageable on a practical basis. In most cases the pattern sizes so calculated have proven to be reasonably accurate but none of these convenient assumptions provide a pathway toward an understanding of the relationship between tower current parameters and the field parameters.

The field ratios, current loop phase, physical spacing and orientation, and pattern size constant are used to perform the AM directional antenna pattern computation described by equation #1 of Section 73.150 of the Commission's "Rules and Regulations". The current "Loop" is assumed to be the point of maximum current on the tower. The FCC DA (Directional Antenna) horizontal plane pattern is computed according to:

$$E_{th} = k[f_1 \underline{/S_1 \cos(\Phi_1-\Phi) + \Psi_1} + \ldots f_n \underline{/S_n \cos(\Phi_n-\Phi) + \Psi_n}\ ] \quad (1)$$

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)

This equation describes the directional antenna pattern computation in familiar language by defining the relative RMS magnitude and phase angle of the vertical component of the resultant electric field vector in the far field as a sum of polar complex numbers that are very like those used in circuit analysis. This allows one to visualize the DA antenna design and analysis problem in terms that are similar to those used for circuit design.

Looking at this equation from a geometrical perspective it can be seen that the ratios and phases that are employed in the calculation must be those of the fields leaving the towers. These fields are the contributions from the towers that form the far field pattern. The assumption is made in the equation of Section 73.150 that the relative phase angles of these fields as they leave the towers are the same as those of the loop currents.

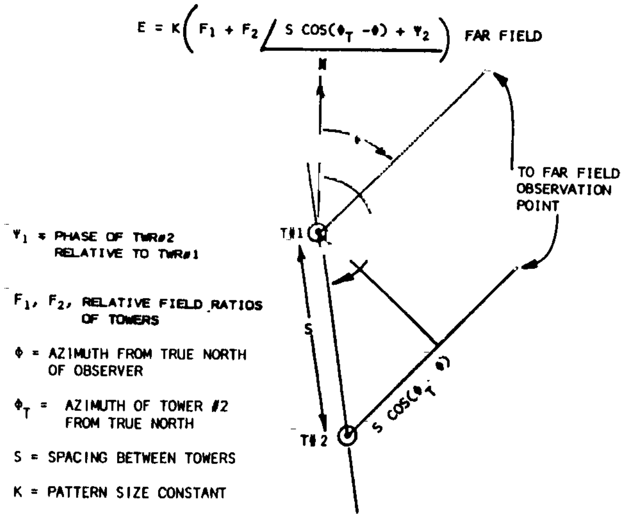

FIGURE ONE

PARALLEL RAY GEOMETRIC DEFINITION
OF VARIABLES USED IN FCC FORMULA (EQUATION #1)
2 TOWER CASE

INSIGHTS FROM MOMENT METHODS

It is possible to build a bridge between the several viewpoints from which AM directional antenna behavior is observed. Using method of moments procedures such as the MINI-NUMERICAL ELECTROMAGNETIC CODE (MININEC) we can relate the field parameters to the antenna monitor base current parameters and the base drive voltages that are necessary for MININEC computations. As observed above, the field parameters provide a useful tool for visualizing the AM directional antenna design problem. When they are used in conjunction with method of moments procedures, a more powerful analytic method becomes available.

Method of moments computer programs use numerical techniques to apply fundamental electromagnetic principles to antenna and radiation problems. Radiating structures are modeled as assemblages of thin wires. The thin wires are broken up into discrete sections called segments. In MININEC the current is specified at the beginning of each driven segment. This makes MININEC a particularly useful tool for analyzing AM antennas.

This form of analysis provides a much more realistic assessment of tower current distributions and their relationships to the fields radiated from AM directional arrays.

Comparison of measured tower current distributions and those computed by MININEC are shown in Figures 2 and 3 for 5/8 wave towers. These Figures show the magnitudes of the tower current distributions on a single tower used for non-directional operation and on three towers used in an operating directional array. It can be seen that, when compared to measured results, MININEC provides a realistic computation of the magnitudes of the current distributions on towers used in a directional array.

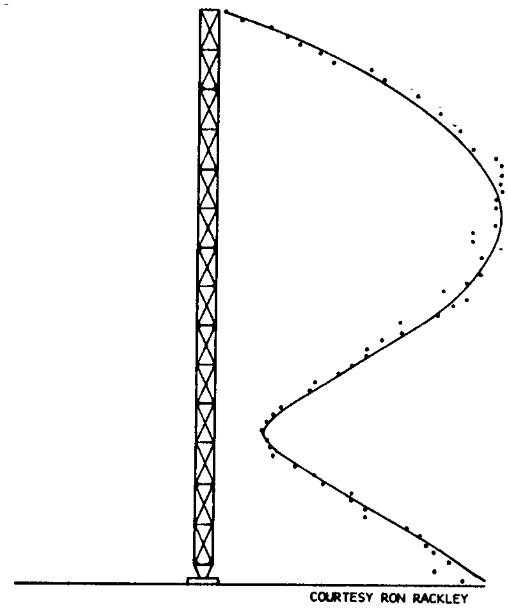

FIGURE TWO

CURRENT DISTRIBUTION ON 5/8 WAVE TOWER

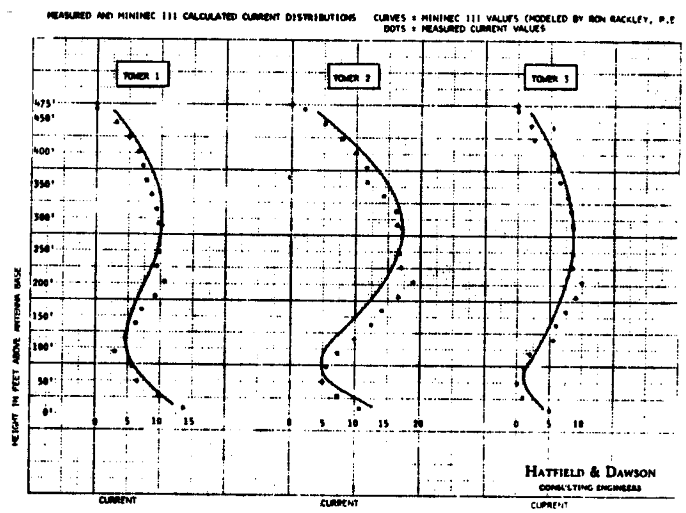

FIGURE THREE

Reference [9] presents patterns calculations on an AM station using the Numerical Electromagnetics Code (NEC). The array had three towers that are 90 degrees in height with 90 degrees spacing between adjacent towers. To calculate the DA (Directional Antenna) pattern, the tower base currents were set to the design field ratios and phases. The resulting far field pattern minimum was displaced several degrees from its intended location (Fig 4).

In reference [1], a paper published in 1987, we showed the results of a similar analysis using NEC II. The array had three 90 degree tall towers in a line with 90 degree spacing between adjacent towers. The towers were driven with currents in the end towers that had ratios that were 0.5 and phases that were +/- 90 degrees referred to the center tower. These were the field parameters that produced a single in line zero null. The far field pattern (Fig 5) computed by NEC II had two nulls spaced 26 degrees on each side of the line of the towers.

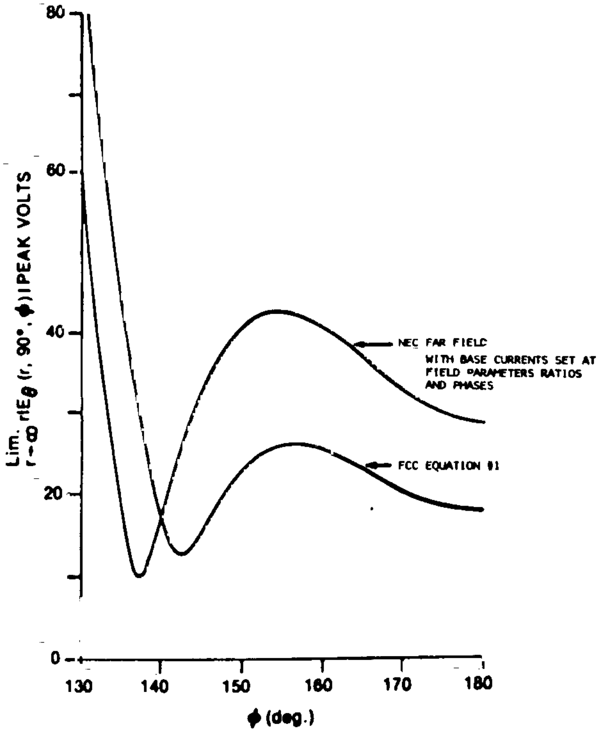

FIGURE FOUR

DISPLACEMENT OF NULL BETWEEN FARFIELD CALCULATIONS BY NEC AND FCC EQUATION #1

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

1@-90, 2@0, 1@90 / 1 MHZ. / FAR-FIELD APPROXIMATION

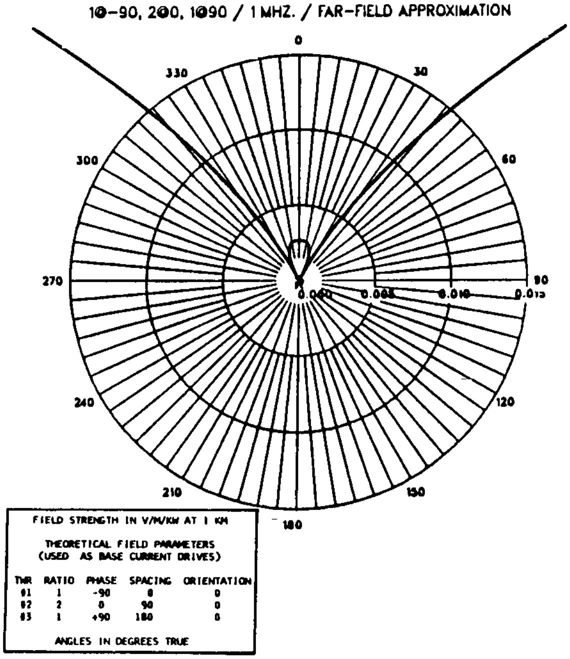

FIGURE FIVE

NULL DETAIL OF NEC FARFIELD PATTERN

These two examples show definite differences between the base current parameters that must be used to produce the desired pattern and the theoretical field parameters.

If we look at the currents flowing in the three towers in the second example (Figs 6,7) we see that the normalized magnitudes have similar distributions. However, the currents undergo different amounts of phase shift in each tower between the base and the top of the tower. This results in the ratios and phases of the fields leaving the towers (Field Parameters) being different from the ratios and phases of the base currents (Base Current or Antenna Monitor Parameters).

CURRENT MAGNITUDE

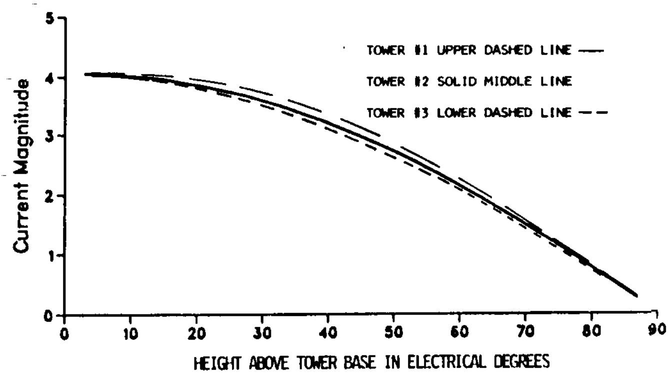

FIGURE SIX

NEC CALCULATED CURRENT DISTRIBUTIONS OF 3-TOWER ARRAY WHOSE PATTERN IS SHOWN IN FIGURE FIVE

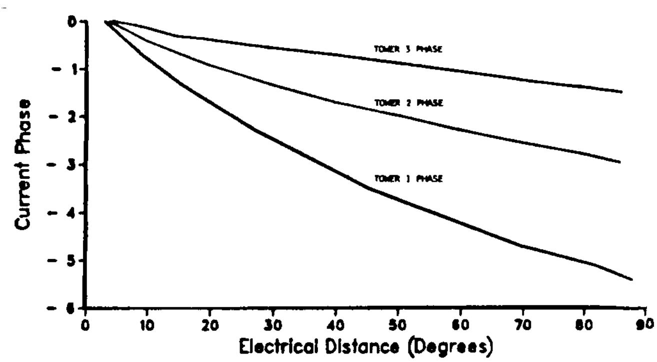

FIGURE SEVEN

NEC CALCULATED VARIATION OF PHASE ALONG LENGTHS OF TOWERS WHOSE PATTERN IS SHOWN IN FIGURE FIVE

RELATING ANTENNA CURRENT PARAMETERS TO FIELD PARAMETERS

I. Thin Uniform Cross Section Vertical Towers

A method used at the Harris Corporation for a number of years and discussed in references [3,4,5,6] relates AM directional array tower base voltage drives to field parameters (the method of moments programs in common use require that the voltages be specified at the driving points of radiation systems that are modeled). This technique is an application of standard network theory. A linear two port system has the following relationships (these and several other sets of two port parameters are shown in [7]) between the voltages and currents at the ports:

$$V_1 = I_1(Z_{11}) + I_2(Z_{12}) \qquad (2)$$

$$V_2 = I_1(Z_{21}) + I_2(Z_{22}) \qquad (3)$$

and

$$I_1 = V_1(Y_{11}) + V_2(Y_{12}) \qquad (4)$$

$$I_2 = V_1(Y_{21}) + V_2(Y_{22}) \qquad (5)$$

where, for arrays of towers:

V_1, V_2, and I_1, I_2 are the voltages and currents at the base of towers 1 and 2.

The Zs and Ys are the corresponding self and mutual impedances and admittances at the bases of the two towers.

Antenna arrays are linear systems in that the field from a given tower is proportional to the voltage or current at the base of that tower when everything else is held constant. If we call the fields from towers one and two, E_1 and E_2, and the complex constants of proportionality K_1 and K_2, respectively, we have for the admittance expressions:

$$E_1/K_1 = I_1 = V_1(Y_{11}) = V_2(Y_{12}) \qquad (6)$$

$$E_2/K_2 = I_2 = V_1(Y_{21}) + V_2(Y_{22}) \qquad (7)$$

For MININEC the Far Zone E-Field is [8]:

$$\bar{E}(\bar{R}) = \frac{jkn}{4\pi} \cdot \frac{e^{-jk|\bar{R}|}}{|\bar{R}|} \cdot \bar{F}(\bar{R}) \qquad (8)$$

where

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

and

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

Since the terms in these expressions are approximately the same for all of the towers (vertical uniform cross section radiators) in the array at great distances in the horizontal plane, the far zone electric field can be approximated as:

$$E_1 = K_a \int_L I(s)\, ds \qquad (9)$$

(where L is over the length of the vertical radiator, I(s)ds is the infinitesimal current moment, and K_a is the complex constant of proportionality between the radiated field at a given distance and the integral of the current moments.)

Therefore, we can say that the far field from a tower in a vertical array is approximately proportional to the summation of the current moments for that tower.

And for MININEC this would be:

$$E_1 = K_a \Sigma I_1(\Delta s_1) \qquad (10)$$

$$E_2 = K_a \Sigma I_2(\Delta s_2) \qquad (11)$$

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

When we combine the relations between the fields, the current moment summations and the admittance equations we have:

$$E_1/K_1 = K_a/k_1 \;\; \Sigma I_1(\Delta s_1) = V_1(Y_{11}) + V_2(Y_{12}) \qquad (12)$$

$$E_2/K_2 = K_a/K_2 \;\; \Sigma I_2(\Delta s_2) = V_1(Y_{21}) + V_2(Y_{22}) \qquad (13)$$

We can now define transfer parameters that relate the tower base voltages to the unattenuated far field electric field contributions and current moment summations of the towers as follows:

$$T_{11} = Y_{11}(K_1/K_a),\; T_{12} = Y_{12}(K_1/K_a) \text{ and}$$

$$T_{21} = Y_{21}(K_2/K_a),\; T_{22} = Y_{22}(K_2/K_a).$$

When these terms are substituted into Equations (12) and (13), we have the expression that is used to find the voltage drives for MININEC computations from a given set of field parameters.

$$E_1/K_a = \Sigma I_1(\Delta s_1) = V_1(T_{11}) + V_2(T_{12})$$

$$E_2/K_a = \Sigma I_2(\Delta s_2) = V_1(T_{21}) + V_2(T_{22}) \qquad (15)$$

The field parameters are given by the ratio of these expressions. If tower #1 is the reference tower, the field ratio and phase of tower #2 is:

$$F_2 \angle \Psi_2 = \frac{E_2}{E_1} = \frac{\Sigma I_2(\Delta s_2)}{\Sigma I_1(\Delta s_1)} \qquad (16)$$

The T parameters are found by driving each tower with one volt. In MININEC the undriven towers are shorted to ground so their base voltages become zero.

$$T_{11} = \Sigma I_1(\Delta s_1), \quad V_2 = 0 \tag{17}$$

$$T_{12} = \Sigma I_1(\Delta s_1), \quad V_1 = 0 \tag{18}$$

$$T_{21} = \Sigma I_2(\Delta s_2), \quad V_2 = 0 \tag{19}$$

$$T_{22} = \Sigma I_2(\Delta s_2), \quad V_1 = 0 \tag{20}$$

where all terms except segment lengths are complex numbers.

If we apply a similar line of reasoning to the two tower impedance equations (2,3) we have (with tower one as reference):

$$F_2 \angle \Psi_2 \quad \frac{\Sigma I_2(\Delta s_2)}{\Sigma I_1(\Delta s_1)} = \frac{I_{b1} \angle \phi_1 (z_{21}) + I_{b2} \angle \phi_2 (z_{22})}{I_{b1} \angle \phi_1 (z_{11}) + I_{b2} \angle \phi_2 (z_{12})} \tag{21}$$

where I_1, I_2 and the z parameters are complex numbers, and I_{b1}, ϕ_1 and I_{b2}, ϕ_2 are the base current ratios and phases of towers one and two respectively.

Equation (21) is the ratio of (21A) and (21B).

$$E_1 = \Sigma \; I_1 \; (\Delta s_1) = I_{B1} z_{11} + I_{B2} z_{12} \tag{21A}$$

$$E_2 = \Sigma \; I_2 \; (\Delta s_2) = I_{B1} z_{21} + I_{B2} z_{22} \tag{21B}$$

The z parameters are found by floating the undriven towers. When the undriven towers are floated by loading the base segment with 1 megohm the base current goes to zero.

$$z_{11} \quad \frac{\Sigma I_1(\Delta s_1)}{I_{B1}}, \quad I_{B2} = 0 \tag{22}$$

$$z_{12} = \frac{\Sigma I_1(\Delta s_1)}{I_{B2}}, \quad I_{B1} = 0 \tag{23}$$

$$z_{21} = \frac{\Sigma I_2(\Delta s_2)}{I_{B1}}, \quad I_{B2} = 0 \tag{24}$$

$$z_{22} = \frac{\Sigma I_2(\Delta s_2)}{I_{B2}}, \quad I_{B1} = 0 \tag{25}$$

Where I_{B1} and I_{B2} are the complex base currents given by MININEC for towers 1 and 2 respectively for the specified conditions. Any convenient voltage can be used for the driven tower when the MININEC computations are made.

Equation (21) gives a direct relationship between the field ratios and phases and the antenna monitor base current ratios and phases. The equations can be solved directly, once the z parameters are determined, if one desires to calculate the field parameters for a given set of base current parameters. To find the base current parameters that are required to produce a given set of field parameters, a matrix that is formed from the z parameter Equations (21A) and (21B) must be inverted. No further recourse to MININEC is required. Base current parameters can be calculated for any given set of field parameters for arrays with four towers or less using an HP41CV pocket calculator.

II. Non Uniform Cross Section and Self Supporting Towers

A similar line of reasoning to that developed above can be applied to the situation where radiators cannot be reasonably represented by an equivalent vertical cylinder. For self supporting towers a "stick" model must be constructed with thin wires depicting important structural features. Since the currents in all of the wires are not parallel to the vertical axis the simplified current moment summation approach will not work. The additional step of computing the vertical component of the radiated electric field must be taken. The part of the method of moments code that computes the far field must be modified so that separate electric fields are calculated for each group of wires that is used to represent a tower. Thereafter, the method is the same as that employed when using current moment summations.

From Equations (6) and (7) the fields can be represented (where the following symbols represent complex numbers) by:

$$E_1 = V_1(Y_{11})K_1 + V_2(Y_{12})K_1 \tag{26}$$

$$E_2 = V_1(Y_{21})K_2 + V_2(Y_{22})K_2 \tag{27}$$

If the transfer parameters are:

$$\tau_{11} = Y_{11}(K_1), \quad \tau_{12} = Y_{12}(K_1) \tag{28}$$

$$\tau_{21} = Y_{21}(K_2), \quad \tau_{22} = Y_{22}(K_2) \tag{29}$$

The vertical electric field components are given by:

$$E_1 = V_1(\tau_{11}) + V_2(\tau_{12}) \tag{30}$$

$$E_2 = V_1(\tau_{21}) + V_2(\tau_{22}) \tag{31}$$

The transfer parameters that relate the base drive voltages directly to the fields are evaluated using the procedure outlined in the previous section (Equations 17-20).

The relationships between the directional antenna tower base currents and the inverse distance far fields are:

$$E_1 = I_1(Z_{11})\kappa_1 + I_2(Z_{12})\kappa_1 \tag{32}$$

$$E_2 = I_1(Z_{21})\kappa_2 + I_2(Z_{22})\kappa_2 \tag{33}$$

The parameters relating the base currents to the fields are defined as follows:

$$\zeta_{11} = Z_{11}\kappa_1, \ \zeta_{12} = Z_{12}\kappa_1 \tag{34}$$

$$\zeta_{21} = Z_{21}\kappa_2, \ \zeta_{22} = Z_{22}\kappa_2 \tag{35}$$

The expressions relating the fields to the base currents then become:

$$E_1 = I_1(\zeta_{11}) + I_2(\zeta_{12}) \tag{36}$$

$$E_2 = I_1(\zeta_{21}) + I_2(\zeta_{22}) \tag{37}$$

These zeta parameters are then evaluated as follows:

$$\zeta_{11} = \frac{E_1}{I_1}, \ I_2 = 0; \quad \zeta_{12} = \frac{E_1}{I_2}, \ I_1 = 0$$

$$\zeta_{21} = \frac{E_2}{I_1}, \ I_2 = 0; \quad \zeta_{22} = \frac{E_2}{I_2}, \ I_1 = 0$$

If tower #1 is the reference tower the base current monitor parameters are related to the field parameters by:

$$F_2 \angle\Psi_{2-} = \frac{E_2}{E_1} = \frac{I_{b1} \angle\phi_{1-} (\zeta_{21}) + I_{b2} \angle\phi_{2-} (\zeta_{22})}{I_{b1} \angle\phi_{1-} (\zeta_{11}) + I_{b2} \angle\phi_{2-} (\zeta_{12})} \tag{38}$$

The constants of proportionality between the base currents and field parameters are related as follows:

$$\tau_{mn} = T_{mn}(K_a) \tag{39}$$

$$\zeta_{mn} = Z_{mn}(K_a) \tag{40}$$

(K_a is defined by Equation (9).)

APPLICATIONS TO AM DIRECTIONAL ANTENNAS

Equations (21) and (38) indicate that the relationship between the base current (or loop current) parameters and field parameters is determined by a set of constants that are complex numbers. Table one shows what this means for a specific four tower array. As the field parameters are changed, the current ratios and phases at the bases and the loops of the towers differ from the field ratios and phases by varying amounts. The loop ratios and phases are closer to the field ratios and phases than are the base current ratios and phases. The loop ratios are not, however, within the FCC 5% tolerance of the field ratios for this example in most instances.

When the base voltages given by the inversion of a matrix formed from Equations (14) and (15) for a specific set of field parameters are used to compute a far field 1 km unattenuated inverse distance pattern for a four tower array the plot shown in Figure 8 results. The fields given by the FCC's RADIAT (a computerized version of Equation (1) and the expressions shown in the appendix) for the same set of field parameters are depicted by the dots in the region of the pattern where the null detail is expanded. It can be seen that the use of the expressions relating the tower currents and the fields to compute inverse distance fields at one kilometer with the MININEC program produces results that are in good agreement with the fields computed using the standard equations used by the Commission.

	BASE PARAMETERS		CURRENT LOOP PARAMETERS		FIELD PARAMETERS	
TWR	% CHANGE IN CURRENT RATIO	PHASE CHANGE	%CHANGE IN CURRENT RATIO	PHASE CHANGE	RATIO	PHASE
#1	REFERENCE		REFERENCE		1.00	
#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	
#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	
#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°

TABLE ONE

HOW MONITORED TOWER CURRENT PARAMETERS CHANGE IN RELATION TO FIELD PARAMETERS AS A FUNCTION OF ANTENNA MONITOR SAMPLE LOCATION AND ANTENNA PARAMETER ADJUSTMENT

MEASURED RESULTS

We have adjusted several directional antennas using this technique (Equations 14-20) without trial and error field adjustment. All of the arrays had uniform cross section guyed towers. In the three examples discussed below, antenna currents were monitored at the bases of the towers. Figures 9, 10, and 11 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 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 tower 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 (Fig 9). See paper entitled "Analysis of a Sectionalized Tower as an Element in a Medium Wave Phased Array Using the Method of Moments" by B. F. Dawson in this issue for more detail on the above two tower array.

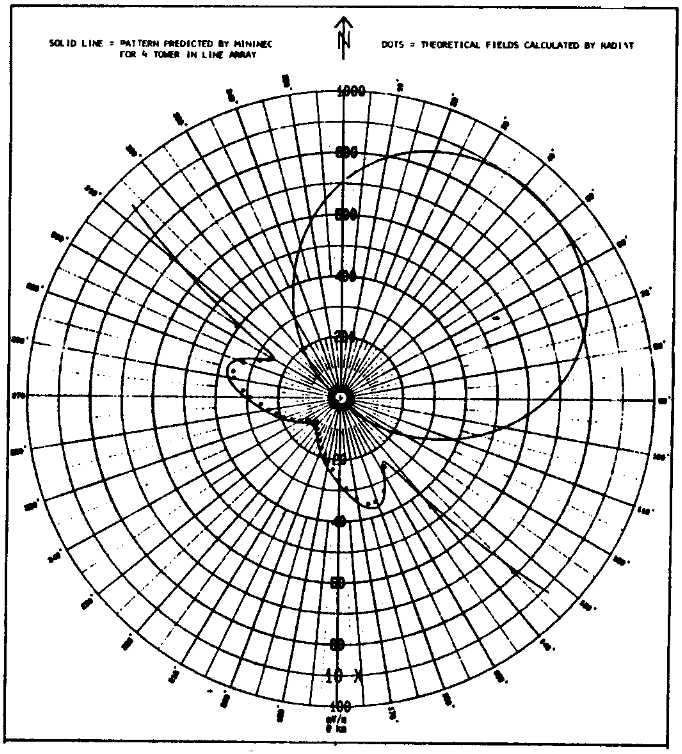

FIGURE EIGHT

FARFIELD PATTERNS AT ONE KILOMETER
USING MININEC AND RADIAT

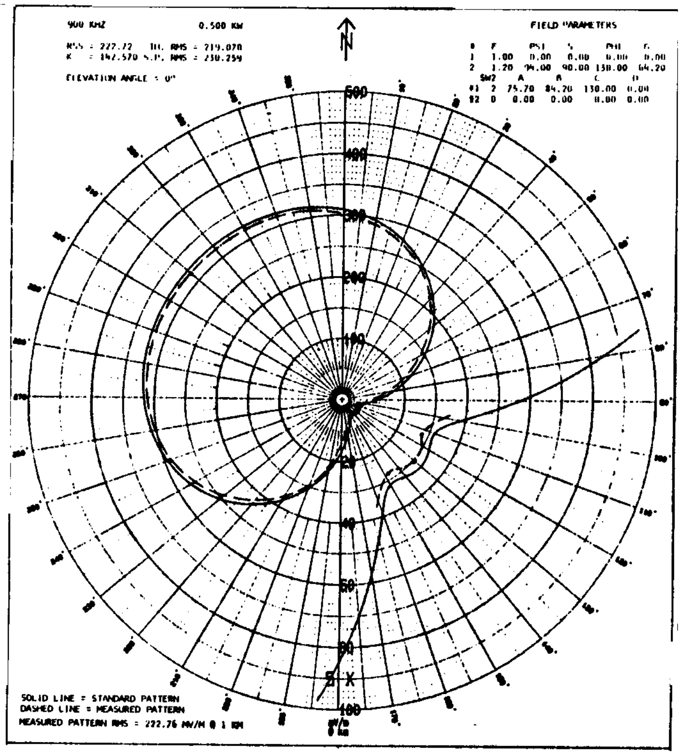

FIGURE NINE

2-TOWER ARRAY. UNEQUAL HEIGHT
WITH CENTER OF TALL TOWER INDUCTIVELY LOADED

An equal height 0.24λ three tower "dog leg" (not in line) array was adjusted to the base current parameters computed from the MININEC procedure. The field ratios and phases of the 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 10.

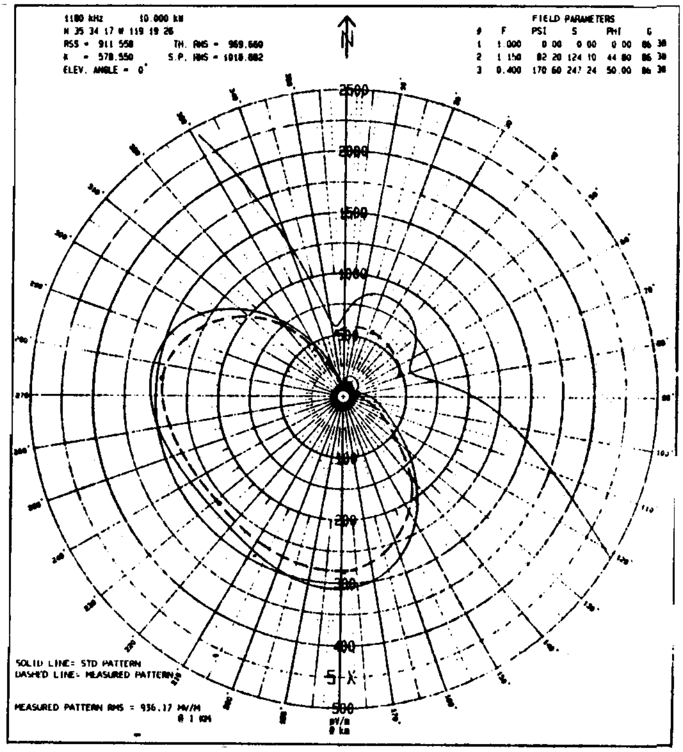

FIGURE TEN

3-TOWER "DOG LEG" ARRAY

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 ratios and phases that were 3% and 2 degrees higher than the field parameters. One of the shorter towers had antenna monitor ratios and phases that were 39% and 6.6 degrees higher, respectively, than the field ratios and phases. The other short tower had computed monitor ratios and phases that were 25% higher and 3.7 degrees more negative, respectively, than the field ratios and phases for that tower. The Measured and Standard Patterns for this array are shown in Figure 11.

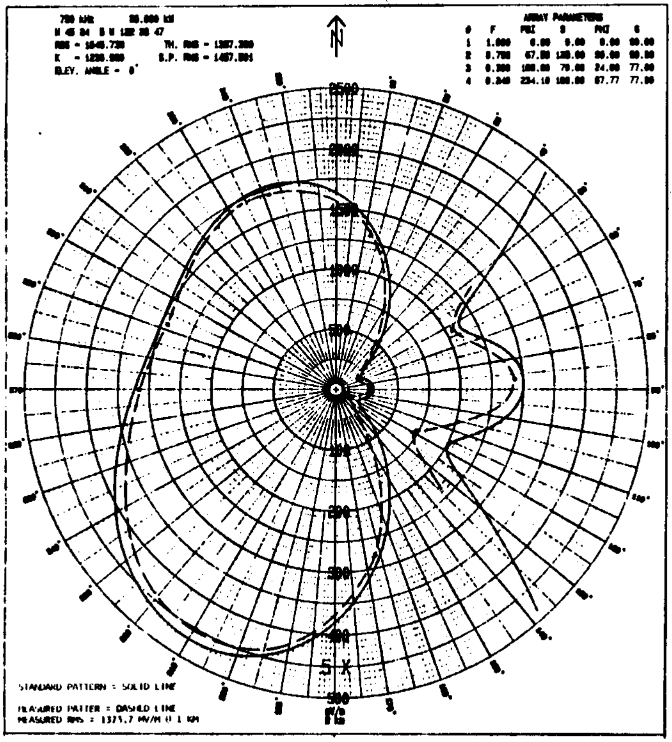

FIGURE ELEVEN

4-TOWER PARALLELOGRAM ARRAY
TOWER PAIRS DIFFERENT HEIGHTS

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 omnidirectional operation from a third tower. The magnitudes of the field parameters of the towers to be detuned 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 detuned 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 (when towers are driven by base voltages that cause the fields of the detuned towers to be 10^{-6} of the field from the tower that is not detuned) between the bases of the towers and ground. When the model is run on MININEC with the grounded segments loaded with the detuning reactances, some degradation of the detuning effect is observed (compared to the case where detuning is achieved by applying base drives); however, the scattered fields from the detuned towers are still several orders of magnitude below the fields from the tower that is not detuned.

CONCLUSION

Field parameters are useful for visualizing how patterns are created by the summation of the individual fields radiated by the towers of an AM directional antenna. When basic circuit concepts are combined with PC versions of method of moments programs like MININEC, the desired antenna monitor ratios and phases can be computed from the field ratios and phases shown on the AM construction permit. Use of these computed antenna monitor ratios and phases has allowed us to adjust AM directional arrays, without employing the usual trial and error field procedures, so that the measured patterns are within the standard pattern. A relatively short amount of time spent at the computer by the consulting engineer can replace a much greater amount of time spent in the field.

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APPENDIX

FORMULAS GIVEN BY THE FCC FOR DETERMINING DIRECTIONAL ANTENNA PATTERN SIZE AND SHAPE

$$E(\phi, \theta)_{th} = \left| k \sum_{i=1}^{n} F_i f_i(\theta) \angle S_i \cos\theta \cos(\phi_i - \phi) + \psi_i \right| \quad (1)$$

where:

$E(\phi, \theta)_{th}$ Represents the theoretical inverse distance fields at one mile for the given azimuth and elevation.

k Represents the multiplying constant which determines the basic pattern size. It shall be chosen so that the effective field (RMS) of the theoretical pattern in the horizontal plane shall be no greater than the value computed on the assumption that nominal station power (see § 73.14(c)) is delivered to the directional array, and that a lumped loss resistance of one ohm exists at the current loop of each element of the array, or at the base of each element of electrical height lower than 0.25 wavelength, and no less than the value required by § 73.189(b)(2) of this part for a station of the class and nominal power for which the pattern is designed.

n Represents the number of elements (towers) in the directional array.

i Represents the i^{th} element in the array.

F_i Represents the field ratio of the i^{th} element in the array.

θ Represents the vertical elevation angle measured from the horizontal plane.

$f_i(\theta)$ Represents the vertical plane distribution factor of the i^{th} antenna.

For a typical vertical antenna with a sinusoidal current distribution:

$$f(\theta) = \frac{\cos(G \sin\theta) - \cos G}{(1 - \cos G)\cos\theta} \quad (2)$$

where G is the electrical height of the tower.

See also Section 73.190, Figure 5.

S_i Represents the electrical spacing of the i^{th} tower from the reference point.

ϕ_i Represents the orientation (with respect to true north) of the i^{th} tower.

ϕ Represents the azimuth (with respect to true north).

ψ_i Represents the electrical phase angle of the current in the i^{th} tower.

The standard radiation pattern shall be constructed in accordance with the following mathematical expression:

$$E(\phi, \theta)_{std} = 1.05 \sqrt{[E(\phi, \theta)_{th}]^2 + Q^2} \quad (3)$$

where:

$E(\phi,\theta)_{std}$ Represents the inverse fields at one mile which are deemed to be produced by the directional antenna in the horizontal and vertical planes.

$E(\phi,\theta)_{th}$ Represents the theoretical inverse distance fields at one mile as computed in accordance with Eq. 1, above.

Q is the greater of the following quantities:

$$0.025\, g(\theta) E_{rss}$$

or

$$6.0\, g(\theta) \sqrt{P_{kw}}$$

where:

$g(\theta)$ Is the vertical plane distribution factor, $f(\theta)$, for the shortest element in the array (see Eq. 2, above; also see Section 73.190, Figure 5). If the shortest element has an electrical height in excess of 0.5 wavelength, $g(\theta)$ shall be computed as follows:

$$g(\theta) = \frac{\sqrt{[f(\theta)]^2 + 0.0625}}{1.030776} \quad (4)$$

E_{rss} Is the root sum square of the amplitudes of the inverse fields of the elements of the array in the horizontal plane, as used in the expression for $E(\phi, \theta)_{th}$ (see Eq. 1, above), and is computed as follows:

$$E_{rss} = k \sqrt{\sum_{i=1}^{n} F_i^2} \quad (5)$$

P_{kw} Is the nominal station power, expressed in kilowatts; see Section 73.14(c). If the nominal power is less than one kilowatt, $P_{kw} = 1$.

$$K = \frac{(C1)(\sqrt{P_{nom}})}{rms_{hem}}$$

where:

K = the no-loss multiplying constant;

$C1$ = 152.15158 mV/m; this is the horizontal radiation from a standard hemispherical radiator in millivolts per meter at one mile; this was derived in Constants for Directional Antenna Computer Programs, 43 FCC 2d 544, 28 RR 2d 959 (1973);

P_{nom} = the nominal power in kilowatts;

rms_{hem} = the root-mean-square effective field intensity over the hemisphere, which may be obtained by integrating the rms at each vertical elevation angle over the hemisphere. The Commission's computer performs the integration using the trapezoidal method of approximation:

$$rms_{hem} \simeq \sqrt{\frac{\pi\Delta}{180}\left[\frac{rms_0^2}{2} + \sum_{m=1}^{l} rms_{m\Delta}^2 \cos m\Delta\right]}$$

where:

Δ = the interval, in degrees, between the equally-spaced sampling points at the different vertical elevation angles θ;

m = integers from 1 to l, which give the elevation angle θ in degrees when multiplied by Δ;

l = one less than the number of intervals; it is equal to $90/\Delta - 1$;

rms_θ = the root-mean-square field intensity at the specified elevation angle θ:

$$rms_\theta = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n} F_i f_i(\theta) F_j f_j(\theta) \cos \Psi_{ij} J_0(S_{ij} \cos\theta)}$$

where:

i = i^{th} tower;
j = j^{th} tower;
n = number of towers in the array;
F_i = field ratio of the i^{th} tower;
$f_i(\theta)$ = vertical radiation characteristic of the i^{th} tower;
F_j = field ratio of the j^{th} tower;
$f_j(\theta)$ = vertical radiation characteristic of the j^{th} tower;
Ψ_{ij} = difference in the electrical phase angles of the currents in the i^{th} and j^{th} towers in the array;
S_{ij} = spacing in degrees between the i^{th} and j^{th} towers in the array;
$J_0(S_{ij} \cos\theta)$ = Bessel function of the first kind and zero order of the apparent spacing between the i^{th} and j^{th} towers.

Next, the no-loss loop current (the current at the current maxima) for a typical tower is computed:

$$I_i = \frac{KF_i}{(C2)(1 - \cos G_i)}$$

where

I_i = the loop current in amperes in the i^{th} tower;
K = the no-loss multiplying constant computed above;
F_i = the field ratio for the i^{th} tower;
$C2$ = 37.250479; this was derived in Constants for Directional Antenna Computer Programs, supra;
G_i = the height, in electrical degrees, of the i^{th} tower.

NOTE.—If non-typical towers are used, different loop current equations may be required.

If the tower is less than 90 electrical degrees in height, the base current is computed by multiplying the sine of the tower height by the loop current.

Using the no-loss currents, the total power loss would be:

$$P_{loss} = \frac{R}{1000} \sum_{i=1}^{n} I_i^2$$

where:

P_{loss} = the total power loss in kilowatts;
R = the assumed resistance in ohms; for standard pattern calculations, this would be at least one ohm;
i = the i^{th} tower;
n = the number of towers in the array;
I_i = the loop current (or base current if the tower is less than 90 electrical degrees in height) for the i^{th} tower.

Finally, the multiplying constant must be adjusted to change the assumption from nominal power being radiated to nominal power being the input power to the array prior to taking account of the assumed loss resistance:

$$K_0 = K \sqrt{\frac{P_{nom}}{P_{nom} + P_{loss}}}$$

where:

K_0 = the multiplying constant after adjustment for the assumed loss resistance;
K = the no-loss multiplying constant computed above;
P_{nom} = the nominal power in kilowatts;
P_{loss} = the total power loss in kilowatts.

The multiplying constant K0 is then used to compute the theoretical pattern used in generating the standard pattern.

[FR Doc.76-17167 Filed 6-14-76;8:45 am]