RELATIONSHIPS BETWEEN BASE DRIVES AND FIELDS IN BROADCAST MEDIUM WAVE DIRECTIONAL ANTENNAS

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Abstract

FCC specifications for the patterns of AM standard broadcast medium wave directional antennas include constants known as the "field parameters". The field parameters for each tower in an AM directional array are the ratios of the magnitudes and time phases, relative to an arbitrary reference, of the electric field component of the radiation that results from the summation of the current moments in that particular element of the directional array.

The field parameters and voltage drive parameters are not the same. The correct base drive voltages for method of moments programs can be found by inverting a matrix that is formed using the field parameters and antenna current moment summations for the various array elements. These voltages, when used as base drives for AM antenna modeling with the NEC program, produce horizontal plane antenna patterns that have the same shape as FCC patterns.

The inverse of this procedure involves loading the drive segments with resistances so that the base currents are proportional to the drive voltages. The field parameters are then found by ratioing the summations of the current moments for the array elements. These techniques can also be used to de-tune re-radiating objects.

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The electrical parameters that are officially listed by the FCC for the purpose of specifying pattern shape for AM standard broadcast directional antennas are called "field parameters". One of the radiators is chosen as the reference tower and the parameters of the other radiators are specified relative to that tower. The field parameters are the relative ratios and phases of the magnitudes of the electric field components of the electromagnetic waves leaving the towers along the horizontal plane.

Section 73.150(b)(5) of the "Rules" requires submission of the relative field ratios and phases of the array when an application is made to the FCC for a permit to construct an AM directional antenna. The mathematical expressions used to generate the pattern size and shape (see Appendix) are functions of the relative field ratios and antenna current phases. The implicit assumption that is made here is that the phases of the antenna loop currents are identical to the field phases. The list of equations used by the Commission that are shown in the appendix of this report contains an expression that relates loop currents to field ratios:

$$Ii = \frac{KFi}{(C2)\ (1-\cos Gi)}$$

This equation says that the loop current and the field ratio of a given tower in a directional array are proportional to each other.

The conclusion to be drawn from the above observations is that it is assumed in the "Rules and Regulations" of the FCC that the relative ratio and phase of the loop current (current at the current maxima) is the same as field ratio and phase for a given tower in an AM directional array. The expectation by the Commission that the antenna current parameters should be identical to the field parameters is also implied by Section 73.151(a)(2)iii of the FCC "Rules" which requires that if the design field parameters and the monitored antenna current parameters of the adjusted array are different "... a full explanation of the reasons for these differences shall be given."

Station licenses list parameters that must be maintained during station operation to demonstrate that the pattern of the radiated fields is within specified limits. These "antenna parameters" are the ratios and phases of the antenna currents monitored at a specific location on the towers. The antenna current is monitored at the point of maximum current or at the base of the tower. These operating antenna parameters are, in practice, carefully distinguished from the field parameters. Only the field parameters (along with other necessary electrical and physical parameters ((element spacings, heights and orientations)) that are necessary for proper description of the array) are used for international notifications and calculations of interference.

It has been standard practice in the past to build and adjust AM directional arrays under the assumption that the field parameters and the antenna parameters are synonymous. It was thought that this was a particularly safe assumption for uniform cross section guyed towers whose height was in the vicinity of a quarter of a wave length.

When one looks at the antenna parameters and the field parameters from a moment method perspective their differences become apparent. The radiated electric field from a tower is proportional to the summation of the current moments of that tower. The magnitude and phase of the current in each tower varies from segment to segment in such a fashion that there is not a fixed relationship between the field parameters for that tower and the antenna parameters given by the current at any fixed point on the tower. While the antenna and field parameters may be similar for towers 90 degrees and shorter they diverge sharply with increasing tower height and are obviously different for unequal height towers and towers of radically different cross section.

The conclusion to be drawn from these considerations is that the current sources used to drive AM directional antennas must usually have relative magnitudes and phases that are different from the relative field magnitudes and phases given by FCC records if the correct pattern is to be achieved.

Four terminal network theory can be used to relate the driving voltages and fields of the towers in an AM directional array. In this way the voltage drives that are necessary to achieve the correct pattern can be found for a given set of field parameters. The resulting voltage drives are used for method of moments modeling and the necessary antenna current parameters are found in the antenna current output provided by the program.

A method used at the Harris corporation for a number of years and discussed in "Modelling A Standard Broadcast Directional Array With The Numerical Electromagnetics Code,"[1] involves determining the constants of a matrix through the use of a program like NEC. The equations forming the two tower matrix are:

$$E_1 = T_{11} V_1 + T_{12} V_2 \quad \text{and} \quad E_2 = T_{21} V_1 + T_{22} V_2$$

The "E" variables are the field parameters, the "V" variables are the base voltage drives while the "T" variables in each column are the current moment summations for the towers resulting from driving the towers one at a time with one volt and with the undriven tower shorted. Once the "per unit" current moment summations are known through repeated runs of the NEC, or some other program, the matrix can be inverted to find the voltages for any given set of field parameters.

R. Adler has been loading the drive segments with large resistances when he models AM arrays. This gives equivalent current sources for NEC voltage drives that are scaled to antenna current parameters. When the array is modeled in this fashon the field parameters can be found by summing the current moments for each tower. The voltage drives for the unloaded array can then be found by applying the matrix inversion technique to the resulting field parameters after the "per unit" current moment summations are determined.

It is thus possible to use a method of moments program like NEC or MININEC and find field parameters from antenna current parameters or antenna current parameters from field parameters. We use a version of MININEC III that has a few lines of code added to sum the current moments and to calculate the relative field parameters.

Re-radiating utility towers can be de-tuned by modeling them as a part of the AM array. The "per unit" current moment summations are found for the array elements and for the towers to be de-tuned, and the matrix inversion procedure is used to find base voltage drives. The normal array field parameters are used in the matrix while very small field

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[1] By C.W. Trueman, published in IEEE Transactions on Broadcasting, Vol. 34, No. 1, March 1988.

ratios are used for the towers that are to be de-tuned. A NEC run using the resulting base drives yields the base impedances for the array and for the re-radiating towers. Conjugate reactance loading from the base of the re-radiating tower to ground will minimize pattern distortion effects. For towers close to the array the resistive component of the base impedance could be a large positive number. In this case the re-radiating tower would have to be actively driven to completely de-tune it. Passive loading is usually sufficient for minimizing pattern distortion.

APPENDIX

FCC Mathematical Expressions For Directional Antenna Systems From <u>Federal Register,</u> Vol. 41, No. 116, Tuesday, June 15, 1976 pp. 24134-36.

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

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:

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

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:

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

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:

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

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:

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

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

$$K=\frac{(C1)\,(\sqrt{P_{\text{nom}}})}{\text{rms}_{\text{hem}}}$$

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:

$$\text{rms}_{\text{hem}}\simeq\sqrt{\frac{\pi\Delta}{180}\left[\frac{\text{rms}_0^2}{2}+\sum_{m=1}^{l}\text{rms}_{m\Delta}^2\cos m\Delta\right]}$$

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:

$$\text{rms}_\theta=\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n}F_if_i(\theta)F_jf_j(\theta)\cos\Psi_{ij}J_0(S_{ij}\cos\theta)}$$

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;

$C2$ = 37.256479; 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:

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

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:

$$K_\Omega=K\sqrt{\frac{P_{\text{nom}}}{P_{\text{nom}}+P_{\text{loss}}}}$$

where:

K_Ω = 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 KΩ is then used to compute the theoretical pattern used in generating the standard pattern.

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