4.10
COMPUTER SIMULATION OF AM RADIO ANTENNA SYSTEMS

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INTRODUCTION

Antenna systems have been analyzed and designed using computer simulation for many years by academics and those designing antennas for the military. By comparison to electromagnetic simulation of aircraft and ship structures, modeling medium wave antenna systems is an almost trivial exercise. It has been this writer's, and other consultants', experience that a relatively short time spent modeling an AM array can save a great deal of trial and error standing out in the rain and cold with two-way radios tuning up a directional array (DA).

FCC EQUATIONS AND MOMENT METHODS

The two pages of equations labeled Figure 4.10-1, published by the FCC in the *Code of Federal Regulations*, have been the basis of AM DA design, with few modifications, since the 1940's. *Equation (1)* of this Figure determines the basic pattern shape, while the other formulas deal with pattern size, vertical angle and standard pattern computations.

The term *moment methods* refers to the fact that electromagnetic fields from antennas are proportional to the area under the tower current distribution curve. The units of this area are (amperes) $\times$ (length) which is of the same form as the mechanical turning moment used in civil engineering. Moment method programs find the area under the current distribution curve by a process of numerical integration where the incremental area is the product of the tower current at a point and an incremental distance.[1]

Most moment method programs compute far field horizontal plane pattern shape by using the same mathematical expressions as FCC *Equation (1)*, although with different notation. The major difference between moment method computations and the FCC equations shown in Figure 4.10-1 is that the FCC formulas for vertical plane field and pattern size computations assume sinusoidal tower current distributions, while all moment method field and pattern size computations are derived from Maxwell's equations in integral form and are scaled to the specified input power.

The moment method equation for the horizontal plane far fields from a tower can be boiled down to:

$$E = \frac{\pi}{3} \sum i \cdot \Delta l$$

The inverse distance field, in mV/m, at 1 km, from a tower is 1.0472 times the sum of the incremental tower current moments in amp-degrees. This summation of incremental current moments over the length of the tower is usually called the *tower moment*.

Since the field from each tower in an array is 1.0472 times the tower moment of that tower, the field ratio of each tower is the ratio of the tower moment of that tower to the tower moment of the reference tower. The tower moment is a polar number, with a magnitude and angle. The phase angle of the field ratio is found by subtracting the angle of the reference tower moment from the tower moment angle of the tower in question.

PRODUCING THE CORRECT PATTERN WITH MOMENT METHOD PROGRAMS

The FCC equations use variables called *field ratios* and *current phases.* These field parameters are specified in FCC Form 301 applications and on licenses as *theoretical parameters.* The current phase, in practice, refers to the relative phase angle of the *antenna loop* current. The loop current refers to the maximum antenna current. The FCC equations are based upon the assumption that the loop current phase angle and the phase angle of the contribution of the tower to the far field are the same. It is important to note that FCC *Equation (1)* uses the field ratio as the relative contribution of the tower in question to the far field. The phase angle used in the equation is the phase angle of that far field contribution. In fact, the ratio and phase angle of the field parameters are determined by the behavior of the tower as a whole. The ratio and phase angle of the tower loop current is seldom, if ever, the same as the actual field ratio and phase angle. This difference is the reason that antenna monitor readings do not usually match the theoretical parameters. If we can compute what the antenna monitor ratios and phase angles should be we can avoid a great deal of trial and error.

The antenna system can be thought of as a black box where the inputs are voltages and the outputs are fields. The antenna system is linear, so the inputs and outputs can be related by a series of constants even if the towers are not all of the same height.

If one includes mutual impedance, the relationship between the voltage drives and fields for a two tower array is of the following form:

$$E_1 = V_{11}T_{11} + V_{12}T_{12}$$
$$E_2 = C_{21}T_{21} + V_{22}T_{22}$$

"E" represents the FCC field parameters (ratios and phases), "V_{11}", "V_{22}", are the tower base drive voltages, "V_{12}", "V_{21}", are the tower base voltages induced by the other towers, and the "T" is the constant that relate them. The "T" constants are found by shorting the respective towers to set the pertinent base voltages to zero.

Moment method computer programs devoted to broadcast antennas solve these equations for the base voltages necessary to produce the proper pattern. Base drive parameters for the correct FCC pattern can be computed by some method moment programs for top loaded or self supporting towers.

Antenna monitor ratios and phase angles can be found by calculating the ratios and relative phase angles of the computed tower currents at the location on the tower where the antenna monitor samples the current.

Some programs include a provision for current drives. If the antenna sample system is well characterized (sample line lengths and sample transformer sensitivities are known) the correct base current ratios and phases can be determined and used as base drives for computation of the pattern as adjusted.

Near-Fields and Proximity Effect

FCC *Equation (1)* calculates the pattern shape using the assumption that lines are parallel between the towers and the location where the field is being calculated. This assumption is true only at some distance from the array. Closer than this to the towers the pattern is not properly formed. The measured fields close to the antenna on null radials will not be the same as FCC *Equation (1)* would predict even though the patten is properly adjusted. This has been called the *proximity effect* and may, or may not, be an important factor depending upon array geometry.

The proximity effect occurs in an area called the *array near-field*. Accurate computations of the fields in the array near-field region can be made with moment method programs. These near-fields can then be compared to FCC *Equation (1)* fields computed at the same locations for analysis.

Field strength meters use shielded magnetic field sensing loops and convert the magnetic field component of the radiated signal to equivalent electric field units. The magnetic field is multiplied by 377 to A/m to V/m. The conversion factor of 377 only applies to plane wave fields and, in the presence of reradiating objects, may result in an improper indication of the equivalent electric field. Magnetic fields and electric fields are computed separately by the near-field computational portion of the NEC and MININEC family of programs. As a result measurement anomalies resulting from non-plane-wave conditions can be determined.

Impedance

Tower self impedances computed by method of moment program are benchmarked to values computed in R.W.P. Kings' *Theory Of Linear Antennas.* The King values for monopole antennas are based upon measurements made at high frequencies using the center conductor of a coaxial cable projecting through a copper sheet ground plane to which the outer conductor is connected. This results in resistance and reactance values that differ significantly from the resistance and reactance of a base insulated guyed tower over a radial wire ground system. The shunt capacitance of the tower base insulator can have a significant transforming effect upon high tower base impedances. Tower feed connections also add a significant inductive reactance to the tower reactance.

These defects in the computation of tower impedance can be corrected by the addition of reactance to the tower model (Figure 4.10-3) or by increasing the tower height by about 6.7%. It must be noted, however, that the fields and tower radiation efficiencies computed by moment method programs for actual tower heights are close to measured values and also to those shown by FCC graphs (see Figure 4.10-2).

Detuning Towers

When making field strength readings it is sometimes necessary to detune nearby reradiating objects which cause localized perturbations in the measured fields. The moment method programs can be used to determine whether the reradiating object affects the station's pattern or only the measurements near the reradiating object.

An effective method for detuning towers is to treat the tower as a part of the array. The field parameters for the detuned tower are set to zero as a program data input. When the computed drive voltage (and phase) are applied to the tower to be detuned, along with the proper drives to the array, and the computation is performed, the impedance of the tower to be detuned is noted. If the reactive component is approximately ten times the resistive component for the detuned tower it can be detuned by loading it with the conjugate of the computed impedance. If the computed reactance is $-j450\ \Omega$ the tower would be detuned by $+j450\ \Omega$ across its base to ground.

If the resistive part of the detuned tower impedance is large, and negative, it may, in addition, have to be loaded by a resistance in series with the detuning reactance. If the resistive component of the detuned tower impedance is large and positive it will have to be driven with a small amount of power.

The effects of the shunt capacitive reactance of the tower base insulator must be taken into account when detuning a tower. The best procedure for being sure that a tower is properly detuned is to send someone a third of the way up the tower with a current sensing device (if the tower is over about 130° tall the height will be greater, see Figure 4.10-6). The detuning reactance is adjusted until a tower current minimum is observed at the detuning point. A field set with the

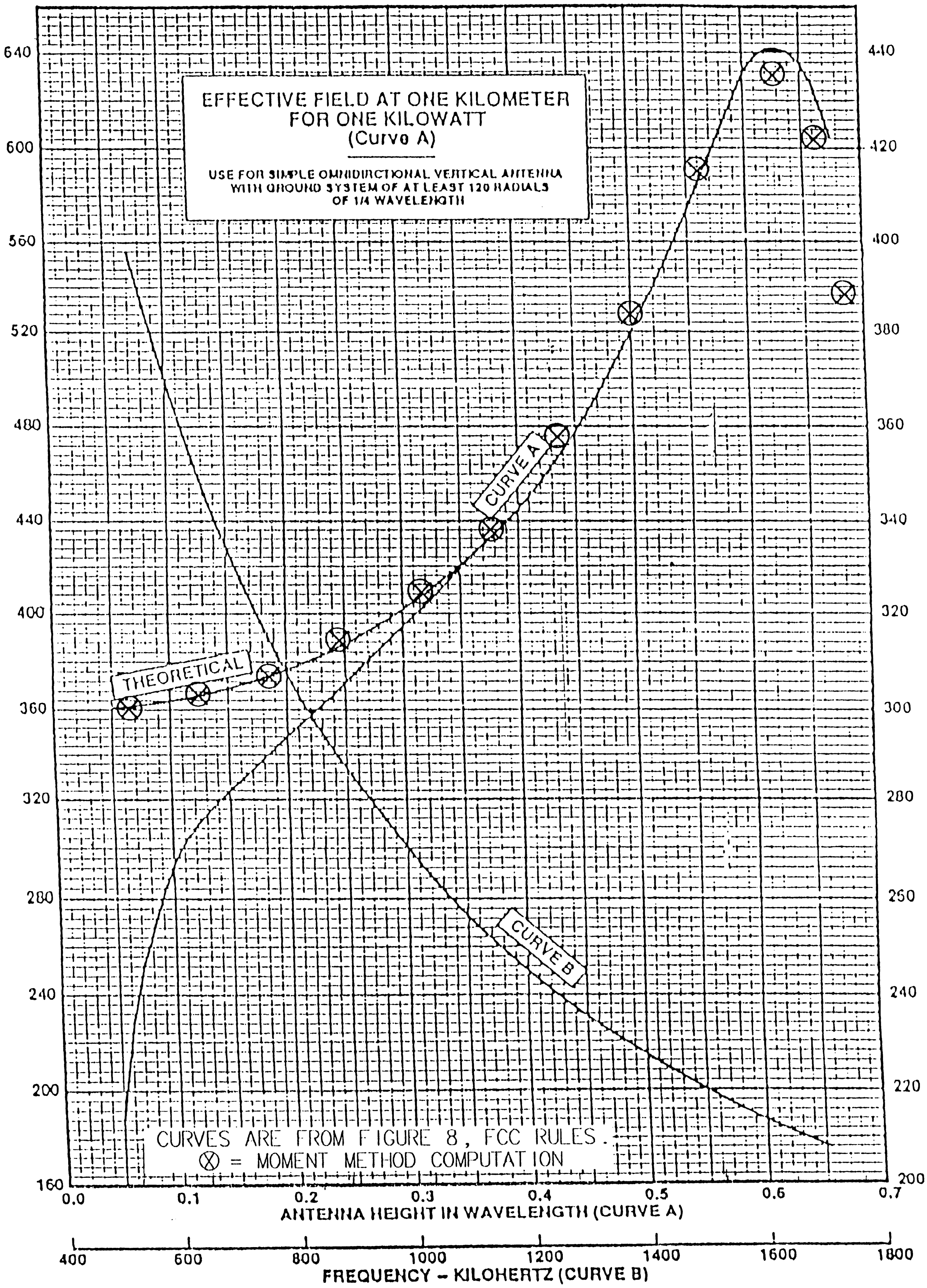


Figure 4.10-2. Lossless inverse field at one kilometer.

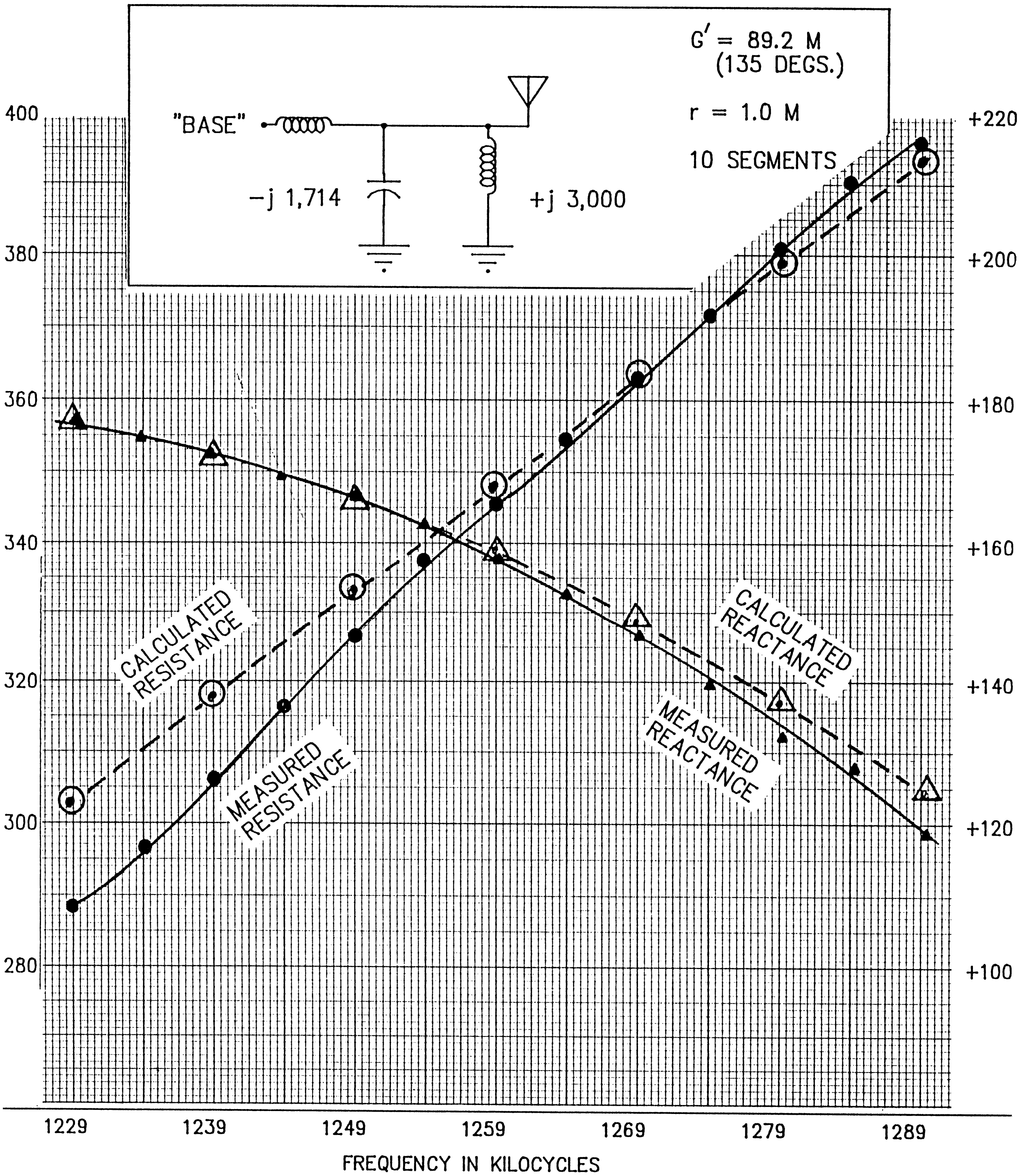


Figure 4.10-3. Rhodes, Greece tower model measurement and analysis by Ron Rackley.

loop shield shorted out through use of a screw can provide a sensitive indication of when the tower current minimum is reached.

This procedure is based upon the fact that towers are detuned in the horizontal plane by having the area under two-halves of the tower current distribution curve being equal and opposite in phase. If the current on a 90° tower is nearly sinusoidal the area under the curve is given by the cosine function. On a per unit basis the cosine is 0.5 at 30° and one-half of the area is one-third of the way up the tower.

Figure 4.10-4 shows the effects upon the nondirec-

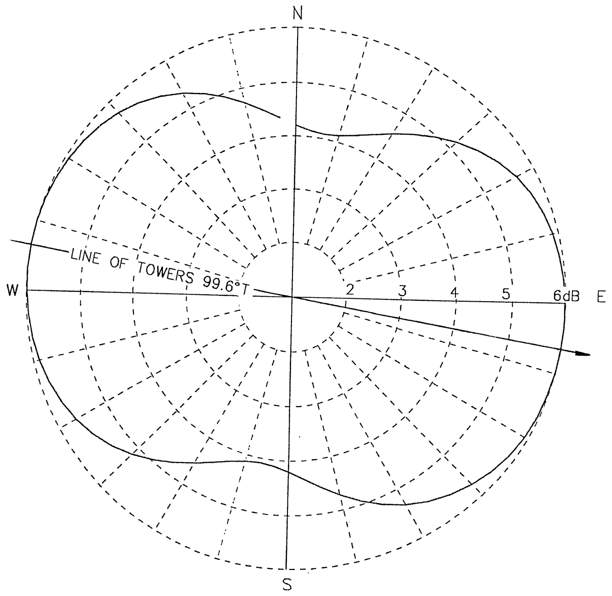


Figure 4.10-4. Non-directional patter, 3-tower array center tower driven, end tower floated, 100 pf to ground.

tional fields of the center tower of a 90° tall three tower array when the end towers are not detuned.

While detuning drastically lowers the fields in the horizontal plane it can cause large increases in vertical plane fields. Figure 4.10-5 illustrates this effect upon a four tower 110° array near a tall (5/8 wave) detuned tower. For a daytime directional, this effect may not be important, but it could have a disastrous effect upon radiation minima at night at high pertinent vertical angles.

Matching Antenna Monitor and Theoretical Field Parameters

The location on a detuned tower where the antenna current goes through a minimum and a reversal of phase angle is at the center of the area of the current distribution curve. The current at this location is proportional to the tower moment and hence the radiated field from the tower. If a sample loop is placed at this location and the sample system is the same for all towers of equal height, then the antenna monitor parameters will be the same as the theoretical field parameters.

The sample loop location for identical antenna monitor and theoretical field ratios and phase angles is shown in Figure 4.10-6 as a function of antenna height. For towers below 110° the sample loop should be placed one-third of the way up the tower. It is necessary, of course, that the rest of the sample system be identical, with equal length, same type, sample lines up to the loops and identical sample loops on all towers, with all loops oriented in the same direction.

When the towers are of different heights, the monitor ratios can be determined by taking the ratios of the computed currents one-third of the way up the towers. The monitor phase angle relative to the reference tower will be the same as the relative theoretical field phase angle.

The ratio of the current at a point on a tower to the tower moment is nearly constant for varying drive conditions. For different height towers the monitor ratio one third of the way up the tower for tower two of a two tower array is $(M_1/I_1) \times (I_2/M_2) \times F_2$. "M" refers to the tower moment for the respective numbered towers, "I" is the current on the tower one third of the way up the tower (slightly higher for towers over 130°) and "F" is the field ratio for the non-reference tower, while the monitor phase angle for the non reference tower is the same as the theoretical field phase angle. The tower moment and corresponding sample current can be calculated for each tower separately, independently of drive conditions, and the correction factor for the antenna monitor current ratio of the non-reference tower will be accurate for all field parameters.

When the antenna monitor sample loops are located at the tower height shown in Figure 4.10-6, the correction to the antenna monitor sample current ratio for

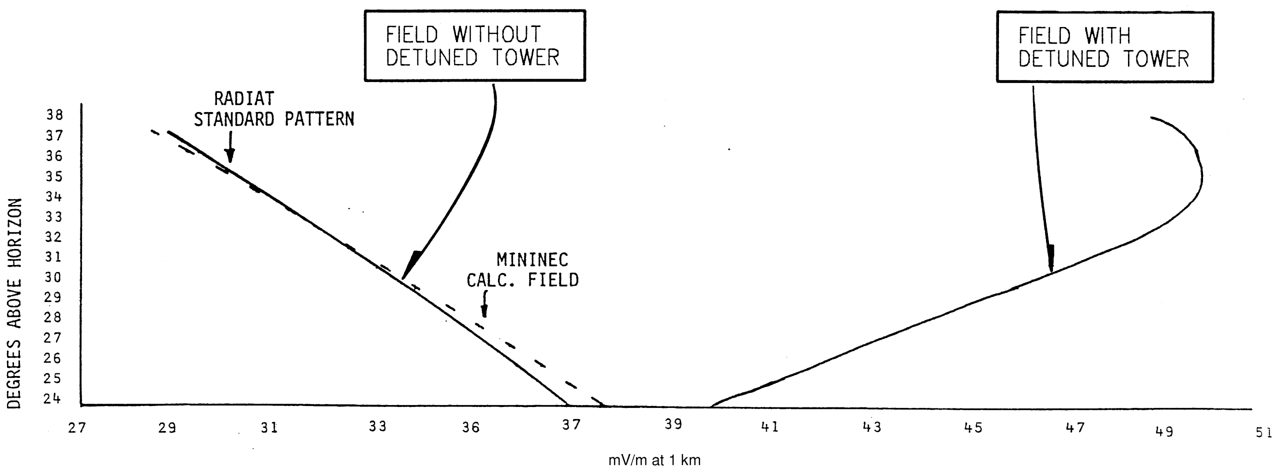


Figure 4.10-5. Effect of detuned tower on vertical angle radiation.

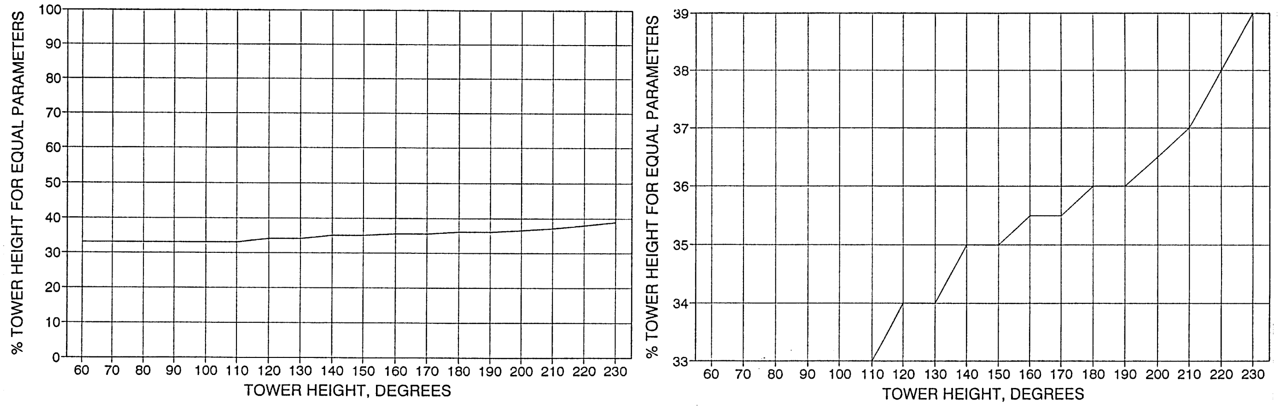
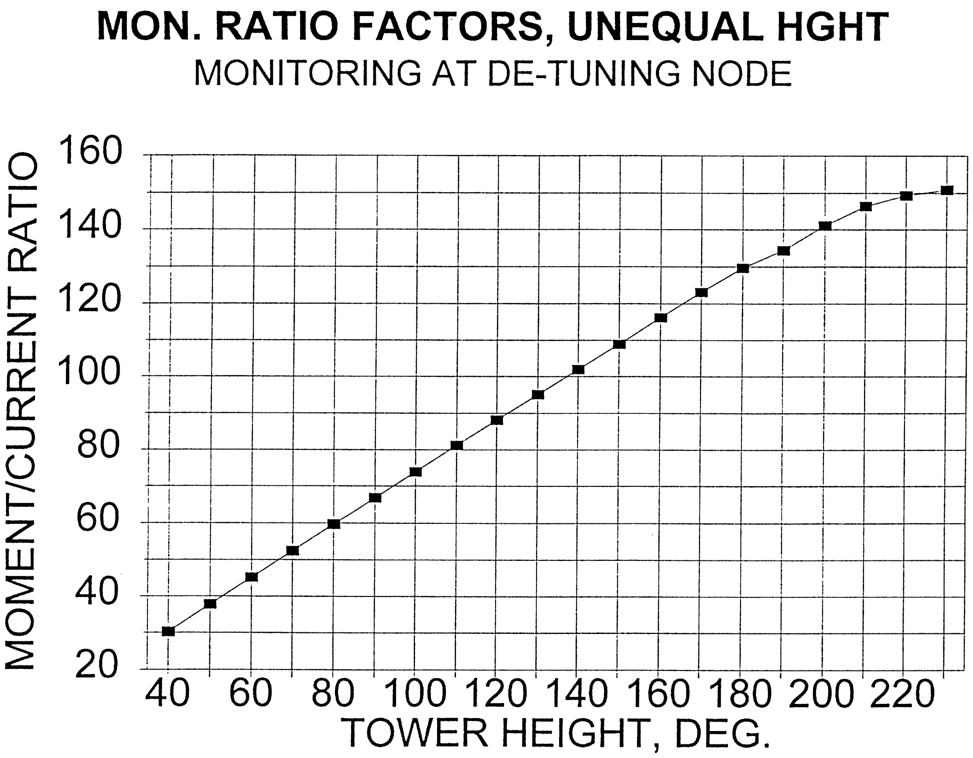


Figure 4.10-6. Percent of tower height where current ratios are same as field ratios and location of detuning current minimum.

towers whose height is different from the reference tower can be found by using the tower moment to sample current ratio factors (M/I) shown in Figure 4.10-7. To find the correct antenna monitor current ratio for a tower that differs in height from the reference tower, multiply the reciprocal of the M/I factor for tower height by the M/I factor for the tower height. This result is multiplied by the theoretical field ratio of the tower in question to determine the corrected antenna monitor current ratio for that tower.

Since the fields differ from "M" by a constant, one could, in theory, determine the correction to the monitor ratio for unequal height towers by measuring the tower currents at the sample location and the fields at the same distance from each tower (or use FCC *Figure 8* from Section 73.190, shown as Figure 4.10-2) under identical tower drive conditions, and compute the correction to the antenna monitor current ratio from the above relationship. This is not always a practical procedure, however, due to the limitations of measurement accuracy and the difficulty of isolating the tower to be measured.



HEIGHT, DEGREES	FACTOR
40	30.28
50	37.72
60	45.09
70	52.39
80	59.63
90	66.8
100	73.9
110	81.15
120	88.12
130	95.06
140	101.9
150	108.9
160	116.1
170	123.1
180	129.7
190	134.4
200	141.2
210	146.4
220	149.3
230	150.9

Figure 4.10-7. Chart and nomograph of tower height factors for correcting field ratios for unequal height towers.

Arrays Near Reradiating Objects

Figure 4.10-8 shows a typical problem that arises when an AM array is near a power transmission line. There are several effects that occur simultaneously:

- The current flowing through the transmission line towers and skywires causes large changes to the ratio of the electric and magnetic components of the radiated field of the array
- The power line may only affect the accuracy of nearby field strength readings but not the inverse distance pattern of the station
- The power line may affect both the field strength readings and the station pattern.

These effects can be separated out by modeling the power line and the AM array and then computing the near electric and magnetic fields along with the far-field pattern as influenced by the power line. A 1 Ω loss pattern can be computed by subtracting the square of the loop currents (maximum currents on the printout) from the station input power. Corrections to the field strength meter readings can be calculated from the magnetic near-field data.

In one instance there were three tall guyed communications towers within a mile of an AM array. The array and the guyed towers were modeled and the stations pattern was scalloped as shown in Figure 4.10-9. The computed pattern did not exceed the standard pattern so no attempt was made to detune the communications towers.

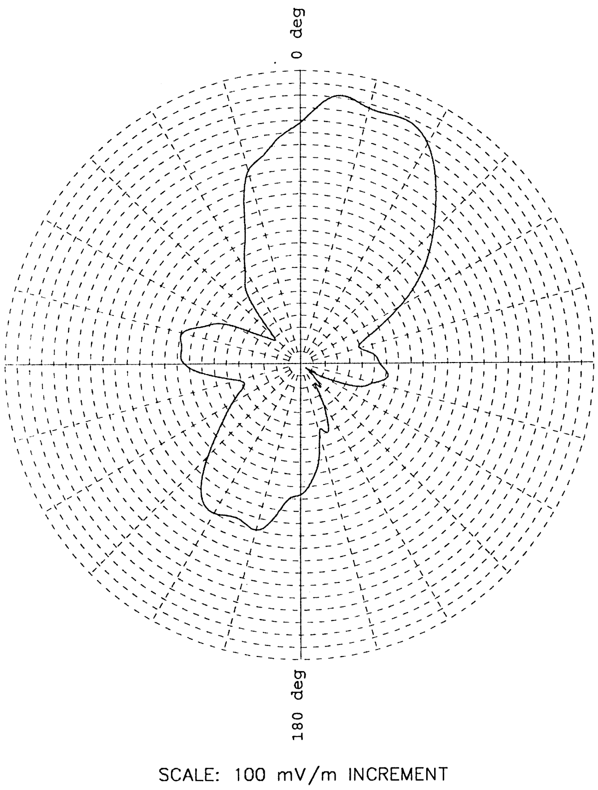


Figure 4.10-9. Example of the effect of a nearby reradiation on a DA pattern.

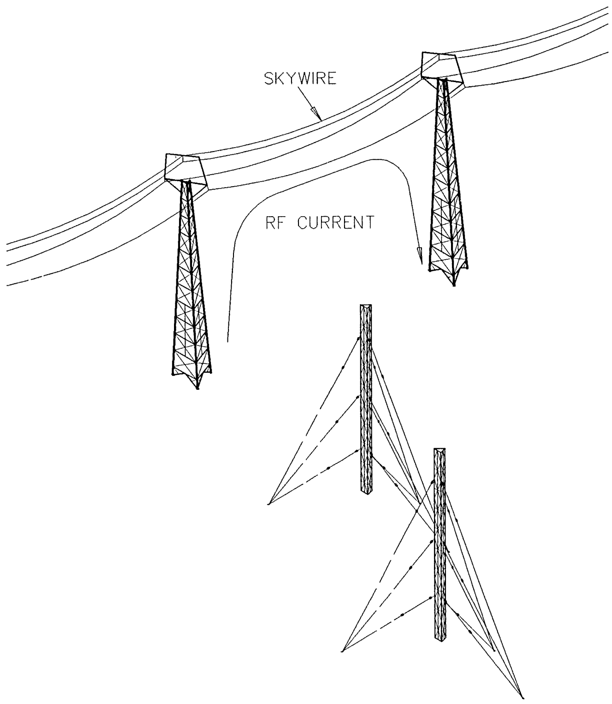


Figure 4.10-8. Two tower array with power line and skywire.

Top Loading

To determine the effects of modest amounts of guy wire top loading, a 76° non-directional tower was modeled as top loaded to 8° and 14°. The top loading, in electrical degrees, was simply the length of uninsulated guy wire connected to the top of the tower. Horizontal skirts were also added to the ends of the guy sections to determine their effects.

Eight degrees of top loading increased the resistive component of the base impedance by 45% while the reactance was reduced to 12% of the un-top loaded base reactance and went from capacitive to inductive. Adding horizontal skirts caused a further 16% increase in base resistance while the reactance became more inductive by a factor of five.

Fourteen degrees of top loading produces results that are, practically speaking, indistinguishable from skirted 8° of top loading with regard to resistance and reactance. Adding skirts to 14° of top loading tripled the inductive reactance and increased the resistance by 28%.

The conclusions are: top loading makes short antennas more inductive; the Q of the antenna is worse with skirted top loading and optimum with modest (8°) unskirted top loading. For all top loading from 0° to 14°, skirted or not, the inverse field at 1 km. only varied from 310 to 314 mV/m. So one can conclude that 8° to 14° of top loading has only a minor effect on tower radiation efficiency.

COMPUTING HUMAN EXPOSURE TO RF FIELDS FROM AM ARRAYS

Human exposure to magnetic and electric fields from AM towers can be computed using moment method programs. Licensed facilities in this country are restricted to a maximum power of 50 kW, so the FCC exposure limits are reached at a distance from each tower that is much less than the distance between adjacent towers. For this reason each tower can be treated as a separate case if no other sources of exposure are present at the site.

Tables 1 through 4 of distances to fences around AM towers shown in *Supplement A to OET Bulletin 65 (Edition 97-01)* were based upon moment method computations. The Commission has accepted such computations for RF guidance level determination for many years.

Figure 4.10-10 shows a computation of the electric and magnetic fields around an AM tower. The measured fields agree quite closely with the computed values. The figure also shows that one must model the tower carefully if correct results are to be achieved.

KEY TERMS

Antenna Monitor Parameters. The relative antenna current magnitudes and phase angles at a specified location on the towers.

Current Loop. The maximum current location on a tower. This is at the base of the tower for tower heights of a quarter wave or less.

Electrical Degrees. A unit of distance proportional to the free space wavelength at the frequency of interest. One wavelength is 360° and a quarter wave tower has an electrical height of 90°.

Field Parameters. The relative magnitude and phase of the contribution to the far electric field of each tower in an AM array.

Inverse Field. The electric far field of an AM antenna at 1 km that is not attenuated by earth losses and varies with distance R proportional to 1/R.

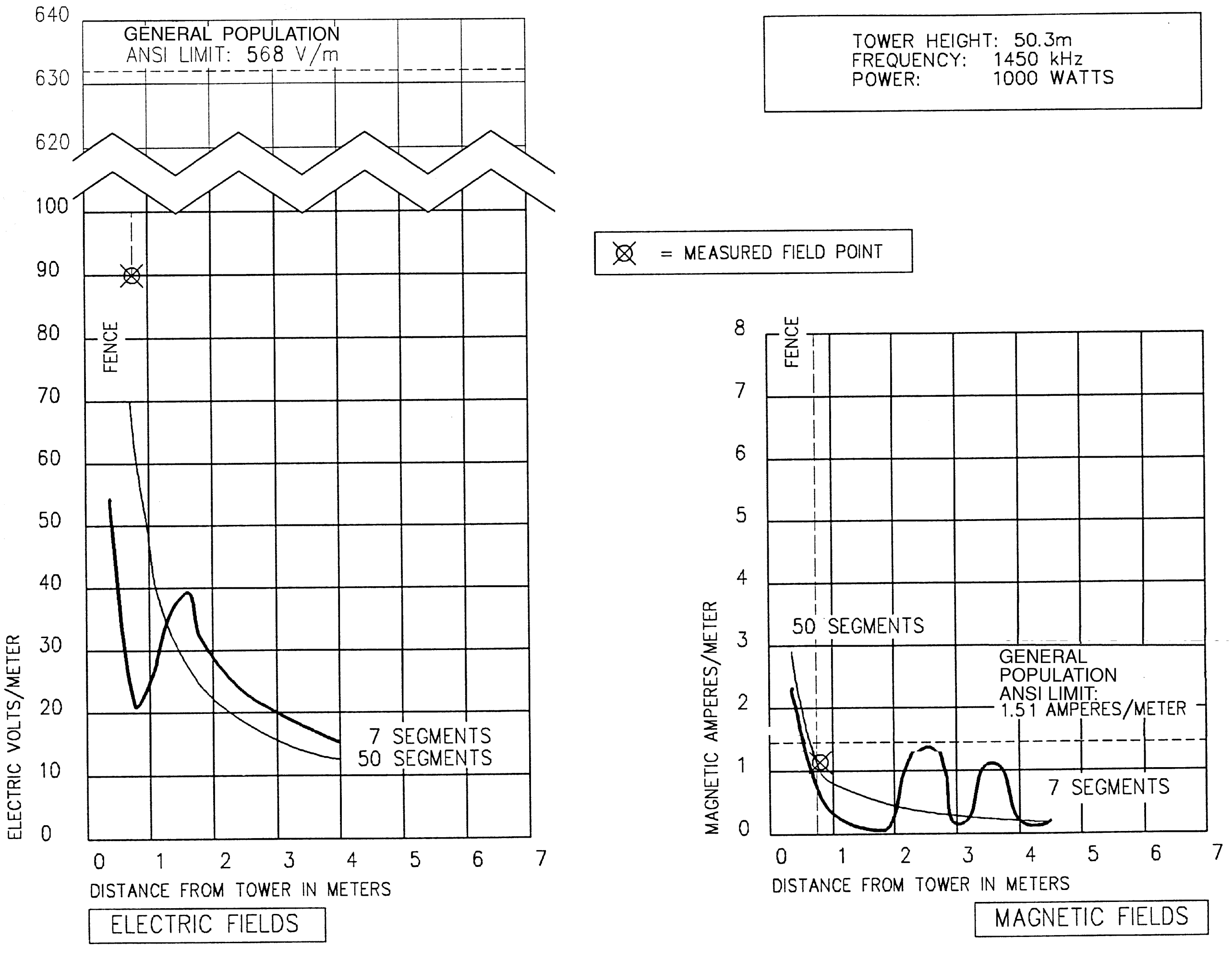


Figure 4.10-10. Electric and magnetic fields at 1 meter above ground near an AM tower.

Method of Moments. In the method of moments the integral equations relating antenna currents to radiated electric and magnetic fields is approximated by a set of linear equations. In these equations the differential distance is expanded to finite size, (segment) and the integral is replaced by a summation of a fixed number of current-segment products. When the matrix formed by these linear equations is inverted, the unknown variables can be expressed in terms of known input variables and numerically evaluated.

Sinusoidal Current Distribution. Antenna current that varies with antenna height proportional to the sine or cosine of the antenna height in electrical degrees.

BIBLIOGRAPHY

47 CRF Part 73, Subpart A (October 1, 1997).

Federal Communications Commission Office of Engineering & Technology. *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Field*, OET Bulletin 65, Edition 97-01, Supplement A, August 1997.

The Federal Register, June 15, 41(116).

King, R. W. P., 1956. *The Theory of Linear Antennas*, Harvard University Press, Cambridge, MA.

Lahm, K., "Excitation Sampling in MW Directional Arrays," Broadcast Technology Society 44th Annual Symposium, September 1994.

Westburg, J. M., "Matrix Method for Relating Base Current Ratios to Field Ratios of AM Directional Stations," *IEEE Trans. On Broadcasting 35(2)* 1989.

Whitaker, Jerry C., "Computer Analysis of Antenna Systems," *The Electronics Handbook*, pp. 1353–1357, CRC Press & IEEE Press, 1996.

ADDITIONAL SOURCES OF INFORMATION

Short Course on Modeling Broadcast Antennas, Applied Computational Electromagnetic Society, Richard W. Adler, Executive Officer, ECE Department, Code ECAB, Naval Postgraduate School, 833 Dyer Road, RM 437, Monterey, CA 93943-5121, Phone:408-646-1111, Fax: 408-649-0300, e-mail: RWA@IBM.NET.

NEC-AM, Copyright 1988, is available from David J. Pinion, P.E. at 1202 East Pike St., Suite 1217, Seattle, WA 98122-3934, Phone: (206) 323-4631.

Phasor Professional is available from Jerry M. Westberg, 3326 Chapel Valley, Quincy IL 62301, Phone: (217) 223-6702.

MININEC Broadcast Professional for Windows is available from EM Scientific Inc., 2533 N. Carson Street, Suite 2107, Carson City, Nevada 8906-0147, Phone: (702) 888-9449, Fax: (702) 883-2384, e-mail: 76111.3171@compuserve.com, Website: http://www.sierra.net/emsci/.

RULES AND REGULATIONS

(Eq. 1)

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

where:

$E(\phi, \theta)_{th}$ Represents the theoretical inverse distance field at one kilometer 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) if 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 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:

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

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).

Figure 4.10-1(a). Formulas given by the FCC for determining directional antenna pattern size and shape taken from the Federal Register.

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:

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

where:

$E(\phi, \theta)_{std}$ Represents the inverse distance fields at 1 km 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 1 km as computed in accordance with Eq. 1.

Q is the greater of the following two quantities:

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

or:

$$10.0g(\theta)\sqrt{P_{kw}}$$

where:

$g(\theta)$ Is the vertical plane distribution factor, $f(\theta)$, for the shortest element in the array (see Eq. 2, 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:

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

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), and is computed as follows:

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

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

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

where:

K = the no-loss multiplying constant;
$C1$ = 244.86422 mV/m; this is the horizontal radiation from a standard hemispherical radiator in mV/m at 1 km.
P_{nom} = the nominal power in kw;
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:

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

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:

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

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 characteristics of the j_{th} tower;
F_j = field ratio of the j_{th} tower;
$f_j(\theta)$ = vertical radiation characteristics 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 ith and jth towers in the array;
$J_o(S_{ij} \cos \theta)$ = 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;
G_i = the height, in electrical degrees, of the i_{th} tower.

Figure 4.10-1(b). Formulas given by the FCC for determining directional antenna pattern size and shape. Taken from the Federal Register.

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 kw;
R = the assumed resistance in Ω; for standard pattern calculations this would be at least 1 Ω;
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:

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

where:

K_Ω = the multiplying constant after adjustment for the assumed loss resistance;
K = the no-loss multiplying constant;
P_{nom} = the nominal power in kw;
P_{loss} = the total power loss in kw.

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

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Figure 4.10-1(c). Formulas given by the FCC for determining directional antenna pattern size and shape taken from the Federal Register.