IMPROVED NIGHT INTERFERENCE PROTECTION FOR AM STATIONS

James B. Hatfield
Hatfield & Dawson Consulting Engineers Inc
4226 6th Ave. N.W.
Seattle, Wa 98107

ABSTRACT

Radiation from standard broadcast AM stations travels greater distances at night than during the day due to skywave propagation. This can cause interference to other stations operating on the same frequency at relatively great distances. To maintain interference levels below specified limits the FCC regulations provide a method for determining radiation limits at calculated angles above the horizon. The radiation at these vertical angles is given by the "vertical plane radiation" formula ‹Equation (2) ›, and the FCC AM directional antenna formula ‹Equation (1)› when a station uses a directional antenna.

The formulas that are used to calculate the radiation at angles above the horizon are derived by assuming a sinusoidal current distribution. The phase shift of the antenna current over the length of the tower is ignored. A more realistic current distribution and hence vertical angle radiation can be computed using numerical methods. Several different AM antenna systems have been analyzed using MININEC to determine vertical angle radiation and the results compared to the vertical angle radiation predicted by formulas presently used by the FCC.

The improved computation of the AM nighttime interfering fields indicates that existing FCC methods underpredict the levels of potential interference in many instances where tall towers are used. AM antenna design using modern numerical techniques such as the method of moments produces more accurate radiation calculations resulting in reduced interference potential at night from new facilities.

COMPUTING FCC DIRECTIONAL ANTENNA PATTERNS

The directional antenna patterns for AM medium wave broadcast facilities in this country are determined through the use of equations (1) and (2). The angular variables are given in terms of the clockwise azimuth from true north, the vertical angle in degrees above the horizon and spacings and phases in electrical degrees. These expressions yield the far field, no loss, inverse distance field strength at one kilometer. The far field is assumed to exist at distances from the array great enough for rays from the antenna elements to the observation point to be effectively parallel. Equation (1) is the summation of a series of polar numbers, one for each tower, with the magnitude given by the product of the pattern size factor, the relative far field contribution from the given tower, and a weighting factor that is proportional to the radiation from the tower at a given vertical angle. The angle of the polar number is determined from the distances between elements, the phase angle of the far field contribution of the given element, and the path length differences resulting from the horizontal angular displacement of the element from the reference point and

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the angle of the observation point above the horizontal.

The angles of the polar numbers are determined by parallel ray geometry while the magnitudes of the polar numbers are determined by functions that are derived from an assumed sinusoidal tower current distribution. The effects of the phase shifts of the tower currents as a function of the tower heights are not included in these equations. In situations where tower current phase shift is significant the fields at vertical angles that are computed using these expressions may be unrealistic.

The limits established by the FCC on the radiated fields from AM directional antennas are derived from the "theoretical pattern" equations just described and are called the "Standard Pattern".

DETERMINING LIMITS ON VERTICAL RADIATION

The signals radiated at various vertical angles at night from AM antennas can be transmitted greater distances via skywave propagation than daytime ground wave signals. Variability in the reflections from the ionosphere make skywave propagation a statistical phenomenon. Various measurements and calculation techniques have been combined over the years in an attempt to arrive at a reasonable prediction methodology. Figure (1) is typical of the curves used by the FCC for determining skywave signal strength as a function of distance from an AM antenna, and the vertical plane field strength of that antenna, at the "pertinent vertical angle". Figure(2) depicts the geometry by which the "pertinent vertical angles" are determined.

Equations (1) and (2) are used to design AM directional antennas to limit the radiation in the vertical plane so as not to exceed the interference limits determined by the skywave methodology outlined above, in combination with other administrative rules and procedures.

A MORE REALISTIC VERTICAL PLANE FIELD COMPUTATION

Method of moments programs yield tower current distributions that are likely to be more realistic than the sinusoidal current distributions used to calculate the fields from AM towers and directional arrays. The differences between the fields calculated using the two methods are likely to be greater for taller towers where the tower current phase shift, which is ignored by the sinusoidal approach, is greater. The following examples illustrate the effects that occur in a variety of situations.

I. A Single Tall Tower

An example of how a tall tower can be used to limit skywaves at relatively high vertical angles is shown in Figure (3). This curve depicts the relative field in the vertical plane, calculated for an assumed sinusoidal distribution, from a tower 0.6 wavelengths tall. The minimum can be used to reduce the interference to co-channel stations within a few hundred miles of the tower.

Figure (4) shows the fields from this tower in the vertical plane as computed by MININEC and by Equation (2). The minimum given by MININEC is not as deep as that calculated by Equation (2) and it occurs at a different vertical angle. The actual interference levels will obviously be much higher than those predicted by Equation (2).

II. Four Tower Array

The horizontal plane pattern of a four tower in line array is shown in Figure (5). These towers are 0.3 wavelengths tall. The vertical plane fields for this array in the region of the horizontal plane minima are shown in figure (6). Fields computed by MININEC and Equation (1) are depicted in comparison the maximum fields allowed at these angles by the FCC Standard Pattern.

It can be seen that the numerically computed fields agree reasonably well with the fields computed by Equation (1) and are all within the standard pattern limits. This is caused by the fact that the phase shifts of the tower currents are small enough that the two computation methods yield similar results.

III. Unequal Height Two Tower Array

The horizontal plane pattern of an unequal height two tower array is shown in Figure (7). One of the towers is 0.45 wavelengths tall while the other tower is half that tall. Figure (8) shows the FCC standard pattern limits in the vertical plane at an azimuth near the horizontal plane pattern minimum and the vertical plane fields for two sets of antenna adjustment parameters as calculated by MININEC.

The vertical plane pattern for this array was computed by MININEC using the design field parameters. The inverse fields exceeded the standard pattern limits in the horizontal plane by almost 50%. At the higher vertical angles the fields fell within the standard pattern limits. When the actual array was adjusted in the field to obtain the design field parameters, the measured fields agreed with those calculated by MININEC and the array was readjusted so that the horizontal plane field fell to 82.3 mV/m (see Figure (8)). The fields at the lower vertical angles are within the standard pattern limits for this adjustment, while the fields at the higher vertical angles exceed the standard pattern limits.

DISCUSSION

These three examples demonstrate that the accuracy of FCC Equations (1) and (2) in predicting vertical plane radiation from AM antennas is a function of the phase shifts of the currents flowing along the antennas. The total phase shift of the current in the single tall tower (0.6 wavelength) from its base to its top is +170 degrees. The total phase shift of the antenna currents in the four tower example (equal heights of 0.3 wavelengths) ranges from -25 to -40 degrees. Accurate computation of the phase shift of the currents in taller towers must be considered if excessive vertical angle radiation from these towers is to be avoided. Numerical computation techniques provide a means of reducing nighttime AM interference by giving a more complete picture of the current distributions in AM broadcast antennas.

When a program such as NEC or MININEC is used to compute the horizontal plane pattern of an AM broadcast station's directional antenna the agreement achieved with the pattern given by FCC Equation (1) is very good when the base drive voltages that result in the correct far field parameters (field ratios and phases used in FCC Equation (1)) are used. The exception to this rule is the unequal height two tower array discussed in example III above. The horizontal plane pattern given by FCC Equation (1) has minima that are 50% lower than the MININEC far field pattern minima for the same field parameters. The measured field strengths for the actual antenna system agree with the MININEC computations.

Using FCC far field parameters for the design of AM directional antennas does not always result in as much field suppression at specified angles as is indicated by the use of FCC Equation (1). To provide nighttime interference protection by reducing the fields at the higher vertical angles for the unequal height two tower array discussed above the horizontal plane standard pattern field limits must be exceeded in the pattern minima. When field parameters are used that do not cause the horizontal plane standard pattern limits to be exceeded, the radiation at vertical angles above thirty degrees exceeds the limits of the vertical plane standard pattern, and nighttime interference is increased.

The FCC requires that an AM directional antenna "proof of performance" be conducted for all new AM directional antenna installations. The FCC rules state that the Proof of Performance must show that the measured horizontal plane ground wave pattern of an AM directional antenna installation is within the confines of the FCC horizontal plane standard pattern. This results in increased nighttime interference from this particular array.

FCC EQUATIONS

1. *General equations*

The theoretical directional antenna radiation pattern is calculated by means of the following equation, which sums the field strength from each element (tower) in the array.

$$E_T(\varphi, \theta) = \left| K_L \sum_{i=1}^{n} F_i f_i(\theta) \angle \underline{\psi_i + S_i \cos\theta \cos(\varphi_i - \varphi)} \right| \quad (1)$$

where:

$$f_i(\theta) = \frac{\cos(G_i \sin\theta) - \cos G_i}{(1 - \cos G_i)\cos\theta} \quad (2)$$

where:

- $E_T(\varphi, \theta)$: theoretical inverse distance field strength at one kilometre in mV/m for the given azimuth and elevation;
- K_L : multiplying constant in mV/m which determines the pattern size (see paragraph 2.5 below for derivation of K_L);
- n : number of elements in the directional array;
- i : denotes the ith element in the array;
- F_i : ratio of the theoretical field strength due to the ith element in the array relative to the theoretical field strength due to the reference element;
- θ : vertical elevation angle, in degrees, measured from the horizontal plane;
- $f_i(\theta)$: ratio of vertical to horizontal plane field strength radiated by the ith element at elevation angle θ;
- G_i : electrical height of the ith element, in degrees;
- S_i : electrical spacing of the ith element from the reference point in degrees;
- φ_i : orientation of the ith element from the reference element (with respect to True North), in degrees;
- φ : azimuth with respect to True North, in degrees;
- ψ_i : electrical phase angle of field strength due to the ith element (with respect to the reference element), in degrees.

Equations (1) and (2) assume that:

- the current distribution in the elements is sinusoidal,
- there are no losses in the elements or in the ground,
- the antenna elements are base-fed, and
- the distance to the computation point is large in relation to the size of the array.

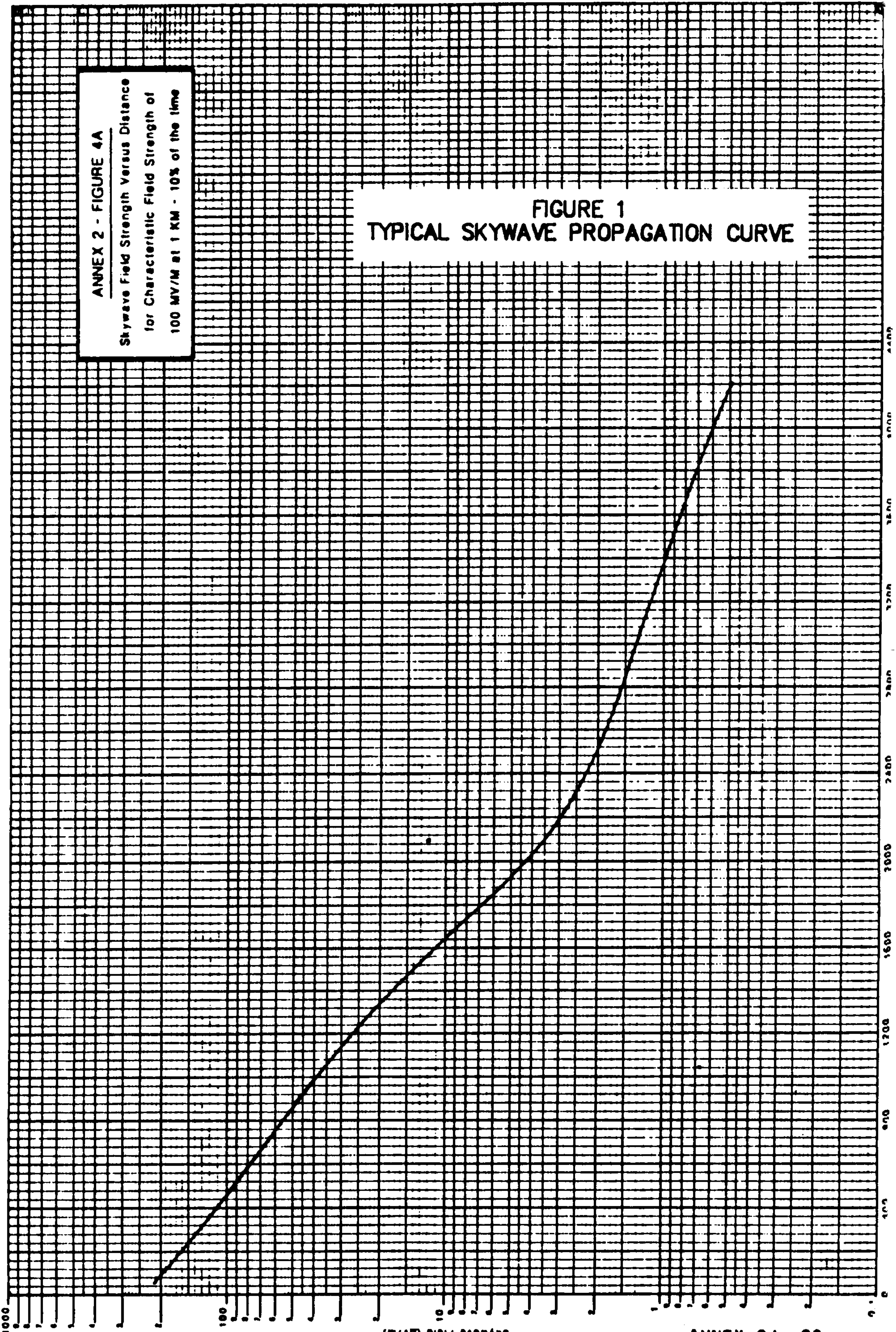


FIGURE 1
TYPICAL SKYWAVE PROPAGATION CURVE

ANGLES OF DEPARTURE
VERSUS
TRANSMISSION RANGE

1 for use in computing 50% signals

2 and 3 for use in computing 10% signals

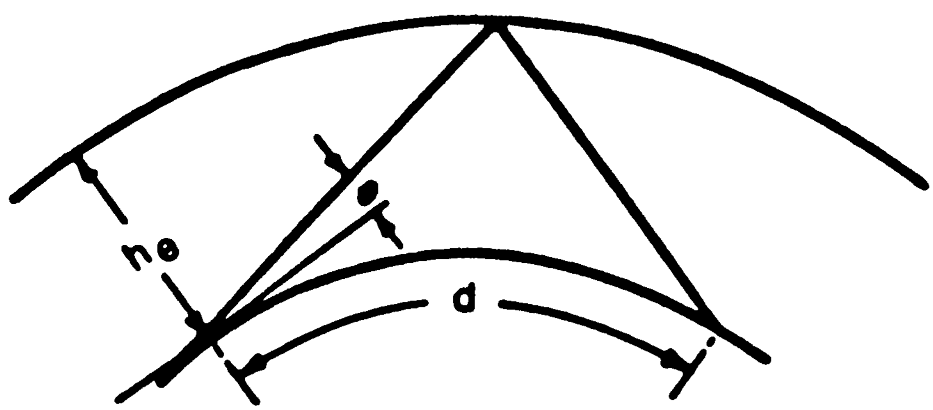


FIGURE 2
GEOMETRY FOR DETERMINING
PERTINENT VERTICAL ANGLES

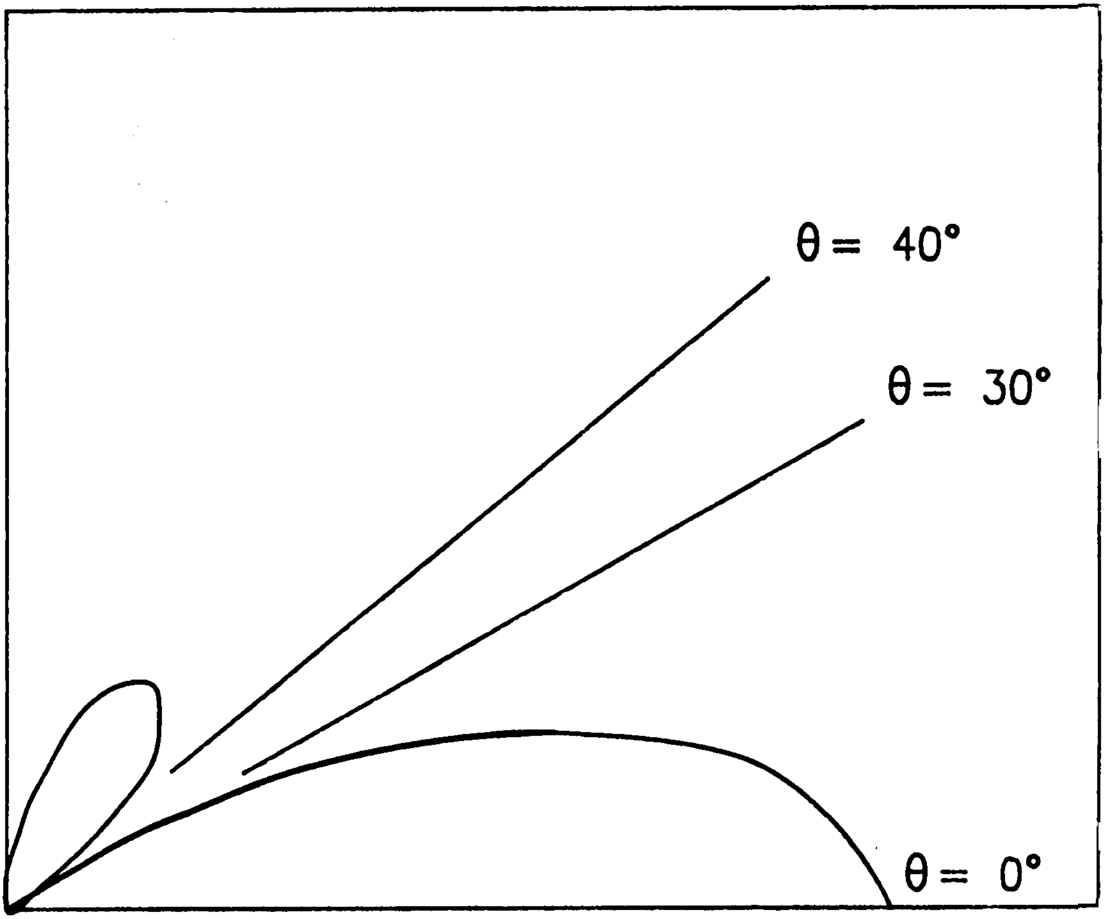


FIGURE 3
RELATIVE 0.6 WAVELENGTH TOWER
FIELDS IN THE VERTICAL PLANE

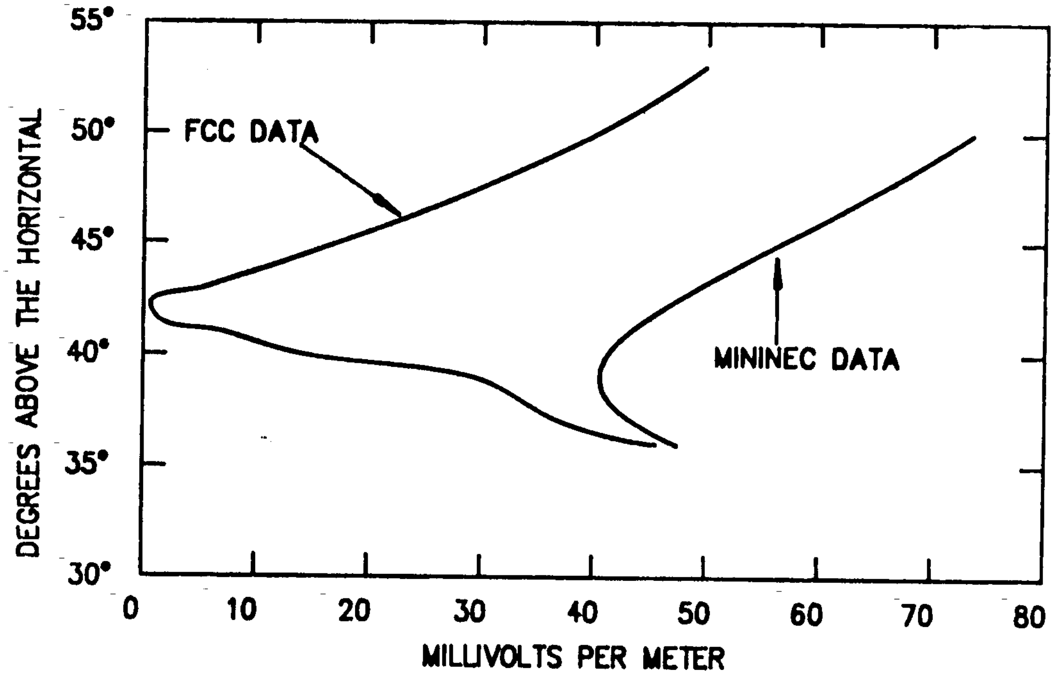


FIGURE 4
0.6 WAVELENGTH TOWER

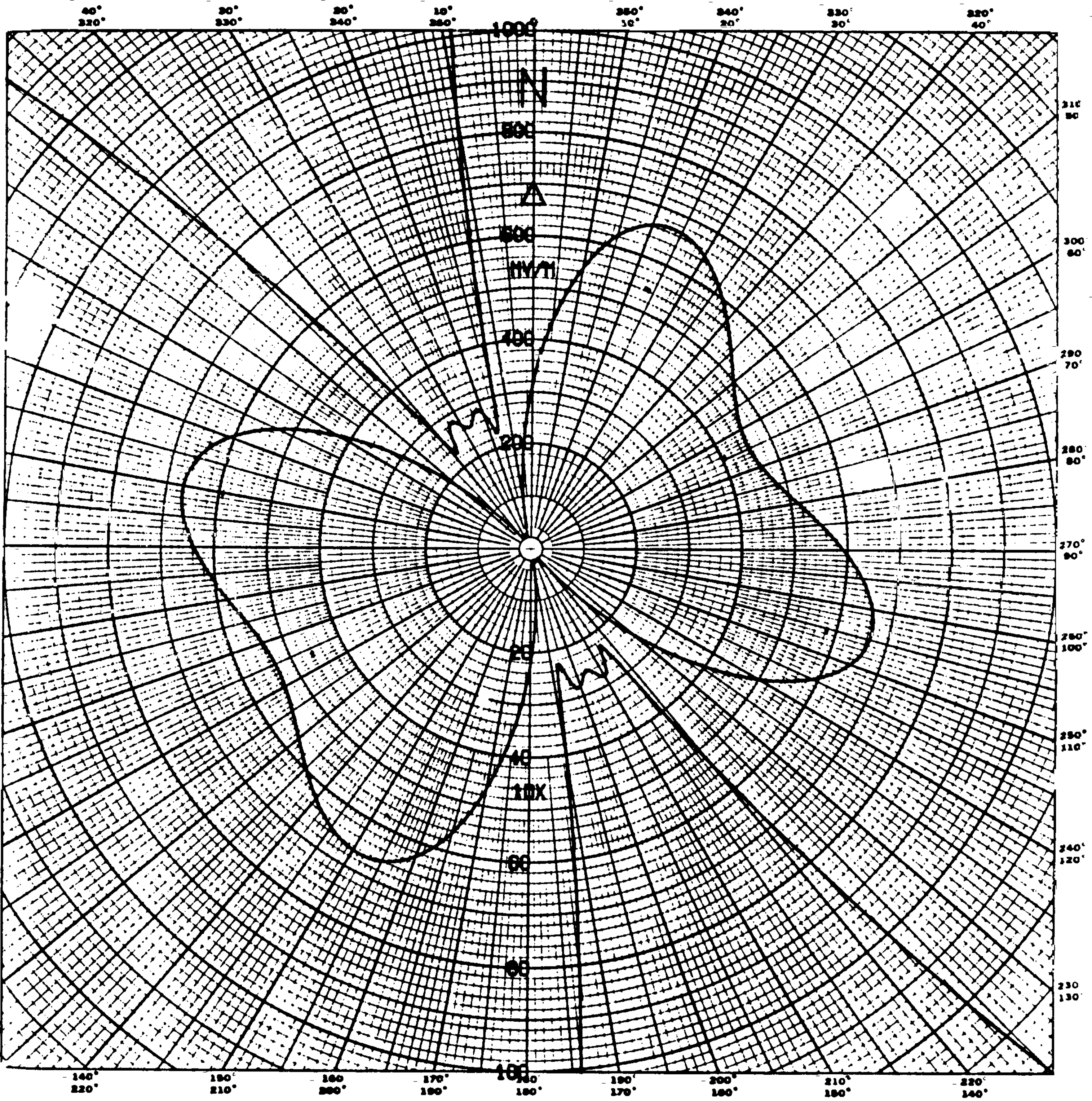


FIGURE 5
HORIZONTAL PLANE STANDARD PATTERN FOR FOUR TOWER
0.3 WAVELENGTH EQUAL HEIGHT IN LINE ARRAY

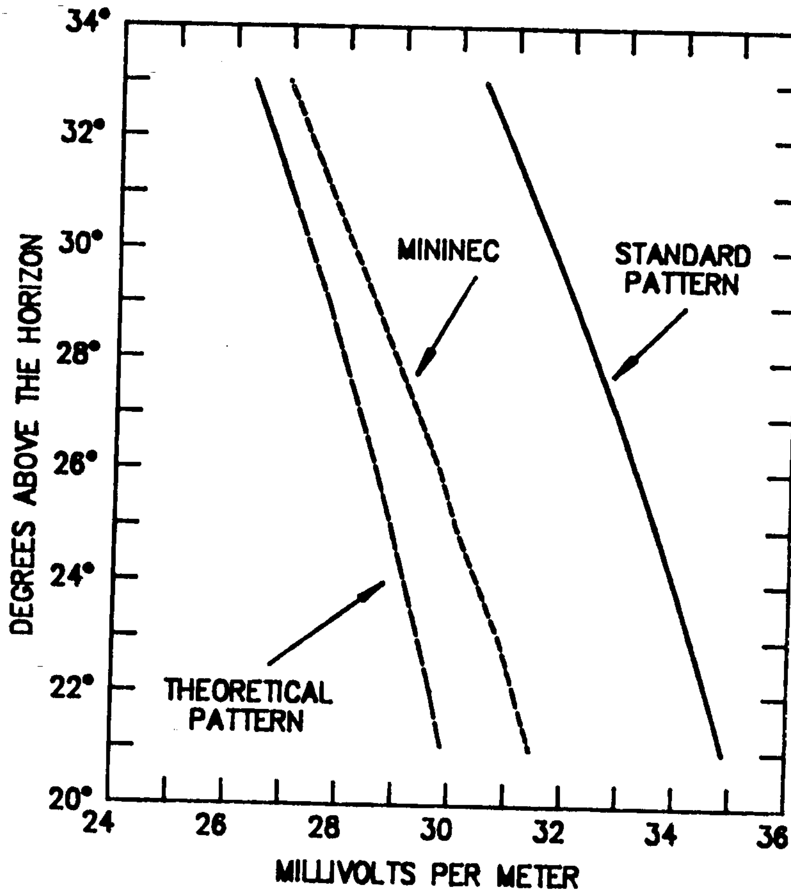
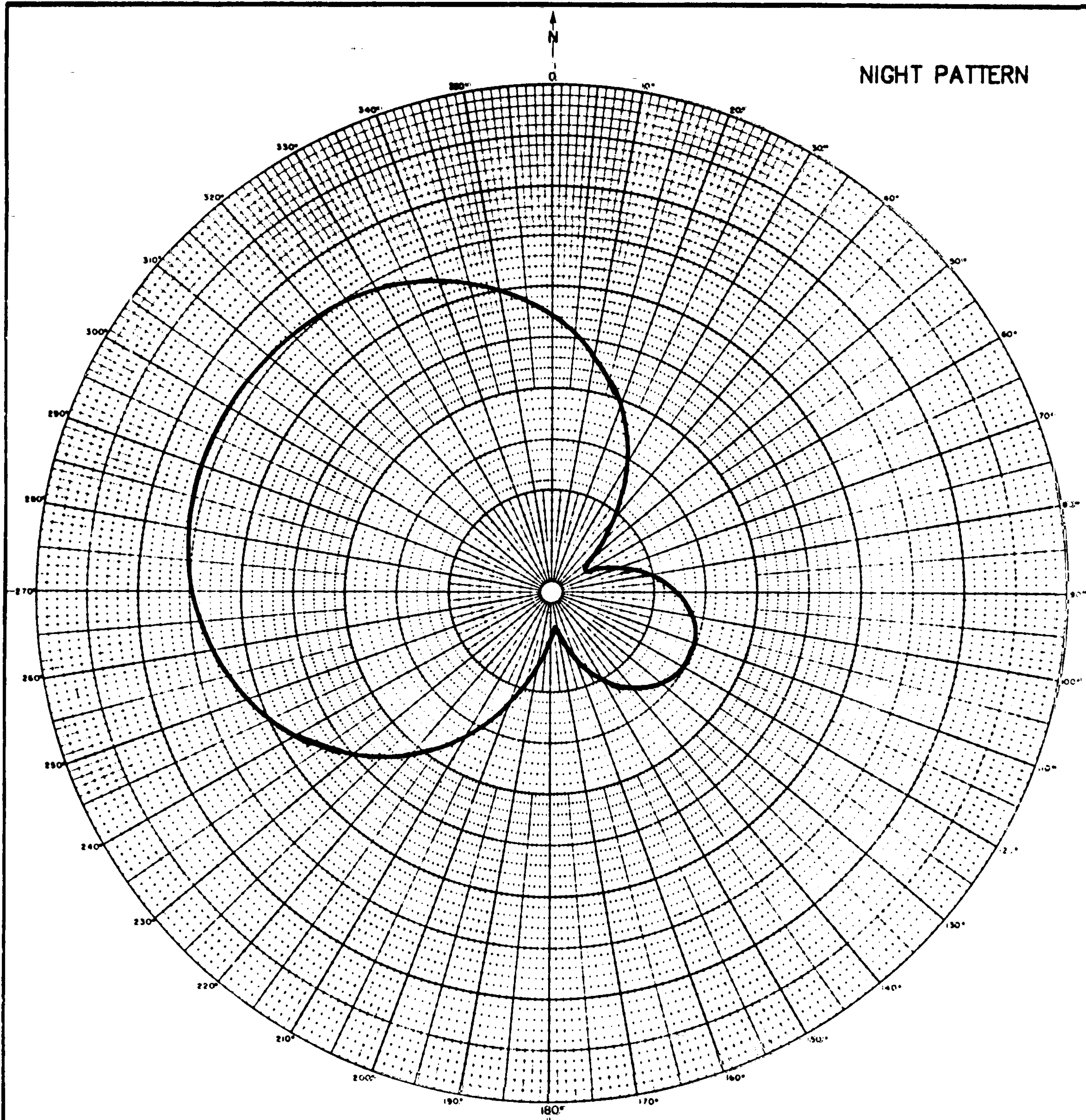


FIGURE 6
FOUR TOWER ARRAY



TOWER No.	AZIMUTH IN DEG.	SPACING IN DEG.	FIELD RATIO	PHASE ANGLE	TOWER HEIGHT IN DEGREES
1	0.0	0.0	1.00	0.0	160.2
2	297.5	90.0	0.84	-134.0	80.1

SHORTEST TOWER IN ARRAY IS #2 TOWER. NO TOP LOADED TOWERS.

FIGURE 7
HORIZONTAL PLANE STANDARD PATTERN FOR
UNEQUAL HEIGHT TWO TOWER ARRAY

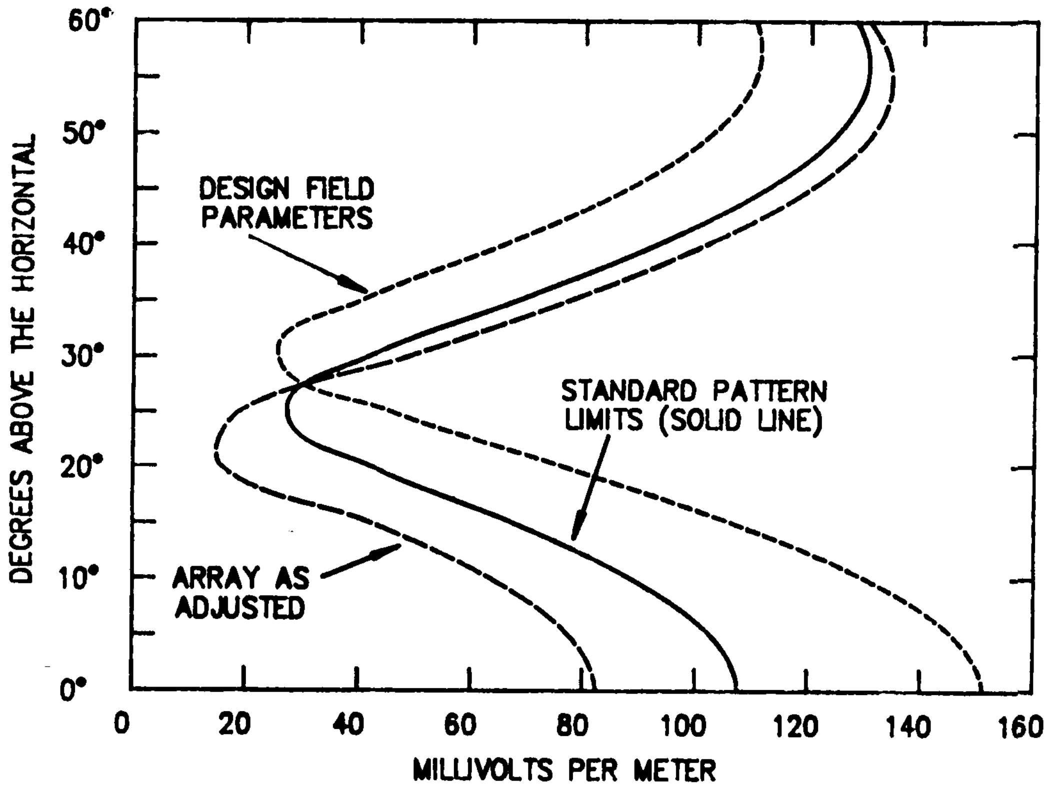


FIGURE 8
UNEQUAL HEIGHT TWO TOWER ARRAY