A MODERN METHOD OF PREDICTING AM TOWER VERTICAL RADIATION

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

ABSTRACT

The fields from AM antennas at angles above the horizon have usually been calculated using equations that are based on approximations of the tower current distributions. The familiar equations for vertical angle radiation that have been derived for single towers, arrays of towers, and top loaded and/or sectionalized towers all use an assumed sinusoidal current distribution. More accurate and realistic depictions of antenna current distributions are provided by computer programs using numerical methods such as NEC and MININEC.

This paper compares the fields from AM antennas in the vertical plane as computed by the usual sinusoidal distribution based equations and the MININEC program. Directional and non-directional antennas are examined. In many cases the nighttime interference levels are higher than previously thought. This is due to the fact that the existing formulas used to calculate vertical angle radiation from AM antennas frequently underpredict the interfering fields.

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). 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 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.

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 216 degree tower. 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 114 degrees tall and widely spaced (228 degrees). This array has been in use since 1980 and has been very stable. The RSS to RMS ratio of the theoretical pattern is 0.76 which is among the lowest of any of the American four tower arrays.

This antenna system was partially re-built after being damaged and re-adjusted to monitor parameters shown by MININEC to yield the correct horizontal plane pattern. The vertical plane fields for this adjustment in the region of the horizontal plane minima are shown in figure (6). Fields computed by MININEC and Equation (1) are depicted for comparison with 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.

Figures Nine and Ten show the calculated vertical plane fields with the base current parameters adjusted to the construction permit ratios and phases. Azimuths where interference protection is required at specified vertical angles are shown in these and subsequent figures. It can be seen that the computed fields exceed the Standard Pattern in the directions depicted in figures Nine and Ten.

The directional antenna of this station was adjusted originally by trial and error in 1980 to overcome nearby re-radiating objects. One of these objects was a tower that was over 5/8 wavelengths tall at the operating frequency of the array. The vertical fields, computed without the re-radiating tower, exceeded the Standard Pattern slightly at only one azimuth. This is shown in Figure Eleven.

The relative location of the nearby 5/8 wavelength tower is depicted in Figure Thirteen. This tower was detuned so that the fields from it in the horizontal plane were minimized. A MININEC computation was performed to show the effect of the de-tuned tower on the vertical plane radiation from the array at a critical protection azimuth. It was necessary to actively drive the tower with the MININEC program to achieve horizontal plane de-tuning. The vertical fields from the array in the presence of the de-tuned tower are shown in Figure Twelve. While the horizontal field of the de-tuned tower was reduced to three parts in a million relative to the reference tower of the array its effect on the vertical plane radiation of the array was to increase it to more than 170% percent of the Standard Pattern at the critical azimuth (See Figure Twelve).

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 160 degrees 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 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 (216 degrees tall) 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 114 degrees) 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.

De-tuning an object for minimum horizontal field can have the effect of increasing the vertical angle radiation of a DA-N array. The horizontal plane radiation pattern of a nighttime array is, in some cases, a poor indication of the antennas performance in the vertical plane. Adjustment of DA-N arrays so that the measured patterns are within the horizontal plane Standard Patterns does more harm than good in many cases.

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.

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

where:

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

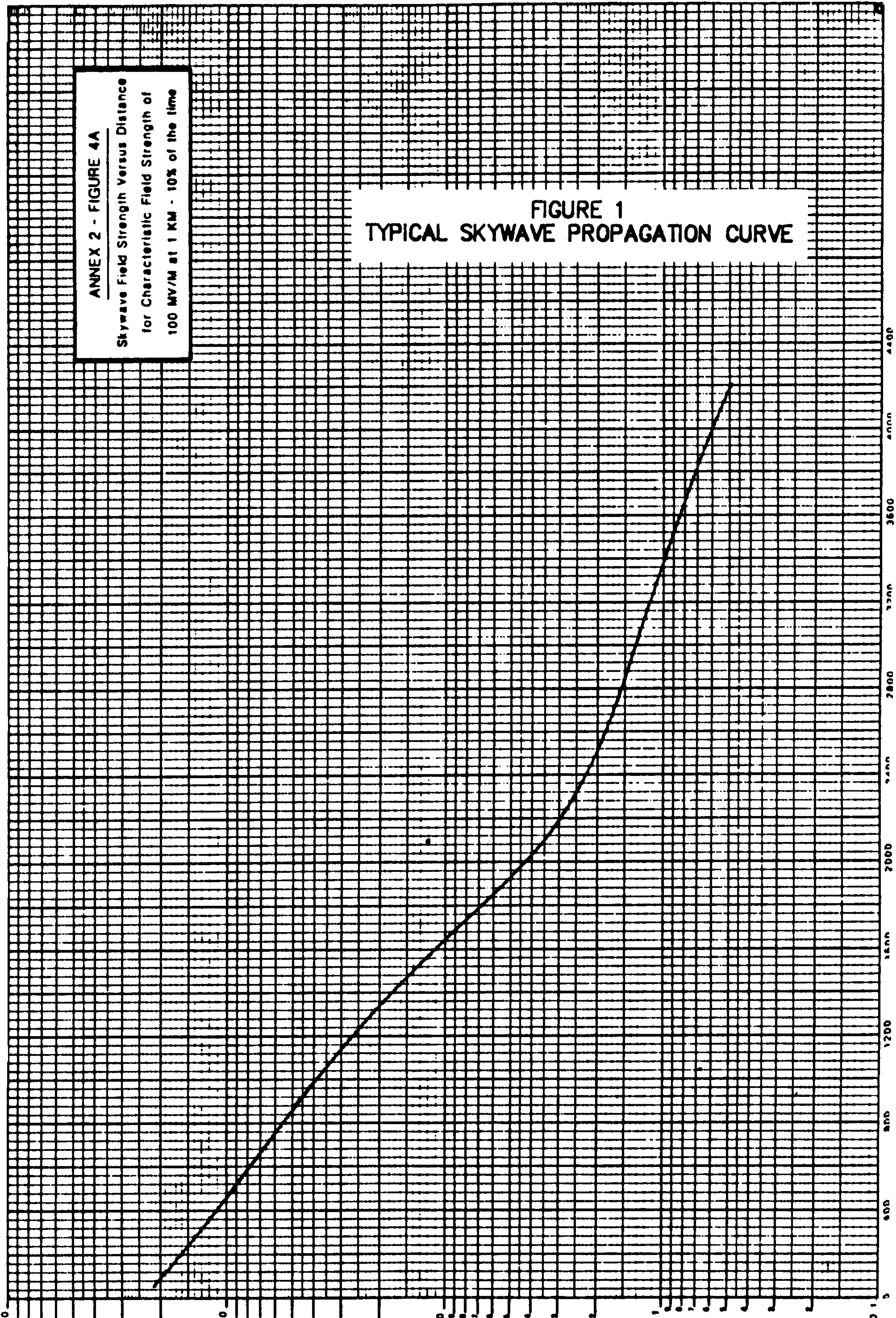
where:

- $E_T(\varphi, \theta)$: 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

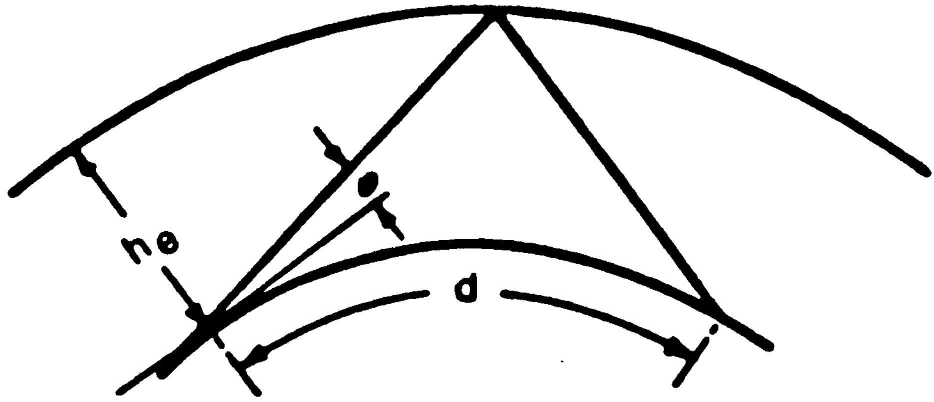


FIGURE 2
GEOMETRY FOR DETERMINING
PERTINENT VERTICAL ANGLES

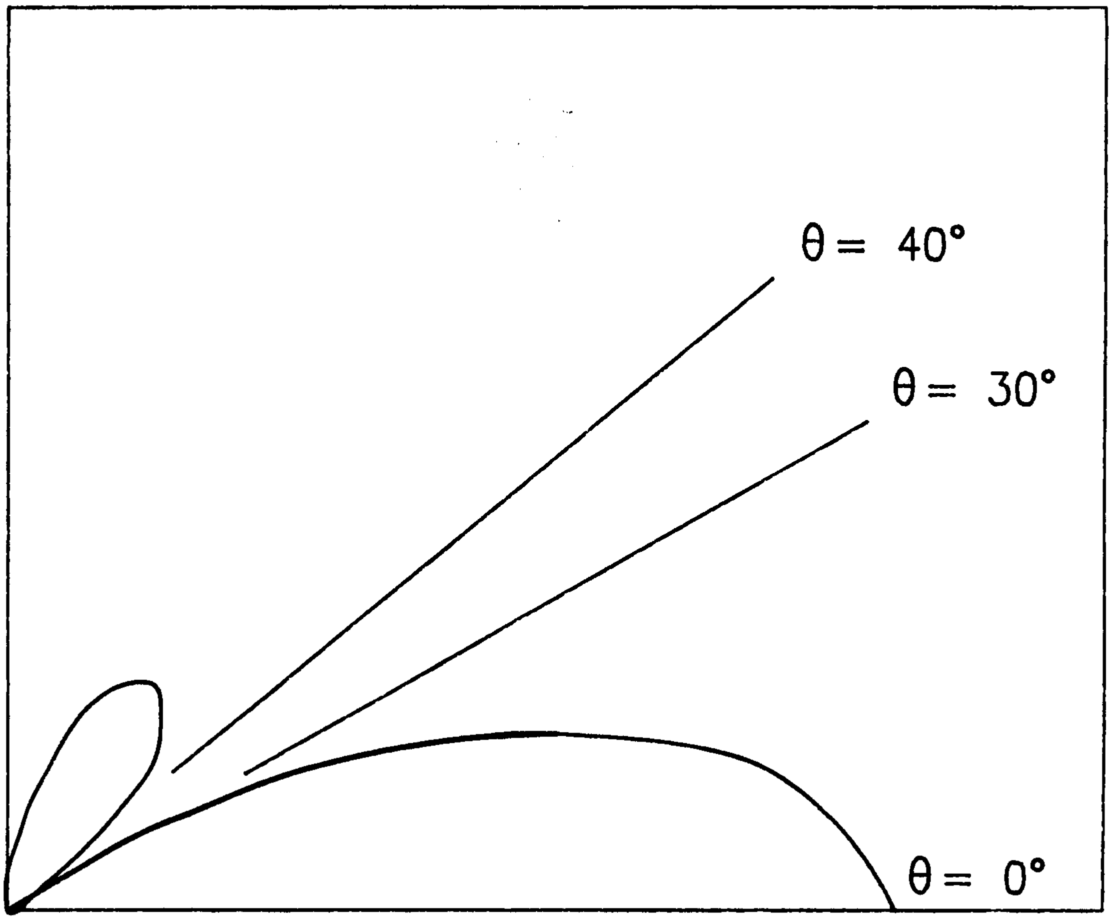


FIGURE 3
RELATIVE 0.6 WAVELENGTH TOWER
FIELDS IN THE VERTICAL PLANE

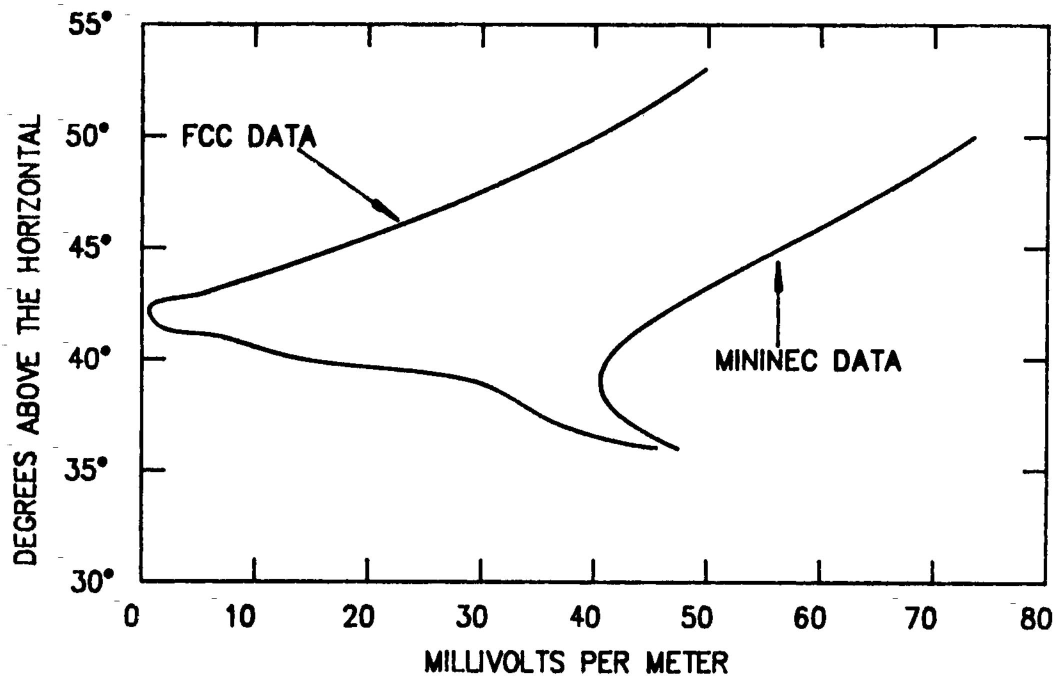


FIGURE 4
0.6 WAVELENGTH TOWER

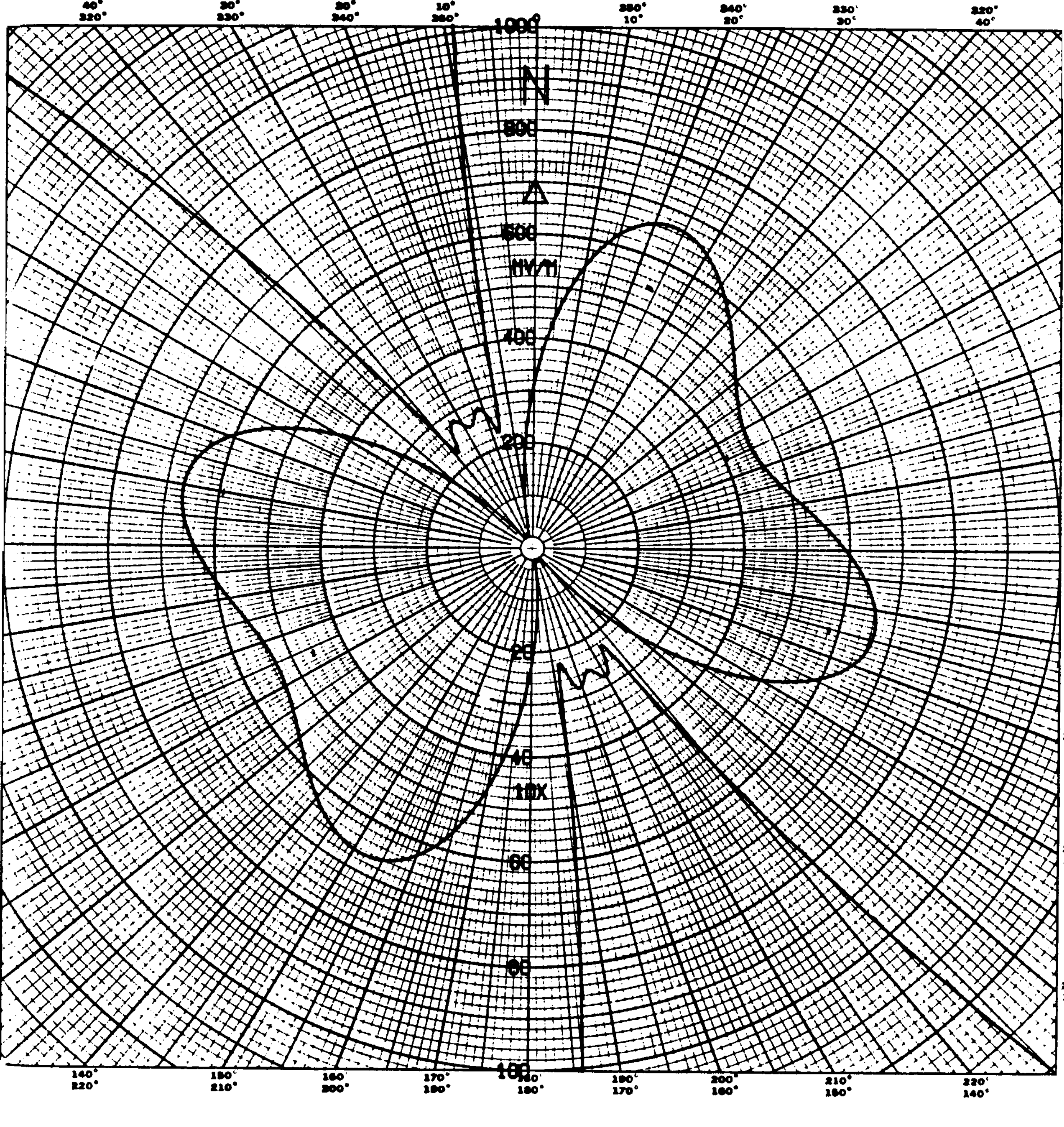


FIGURE 5
HORIZONTAL PLANE STANDARD PATTERN FOR FOUR TOWER
0.3 WAVELENGTH EQUAL HEIGHT IN LINE ARRAY

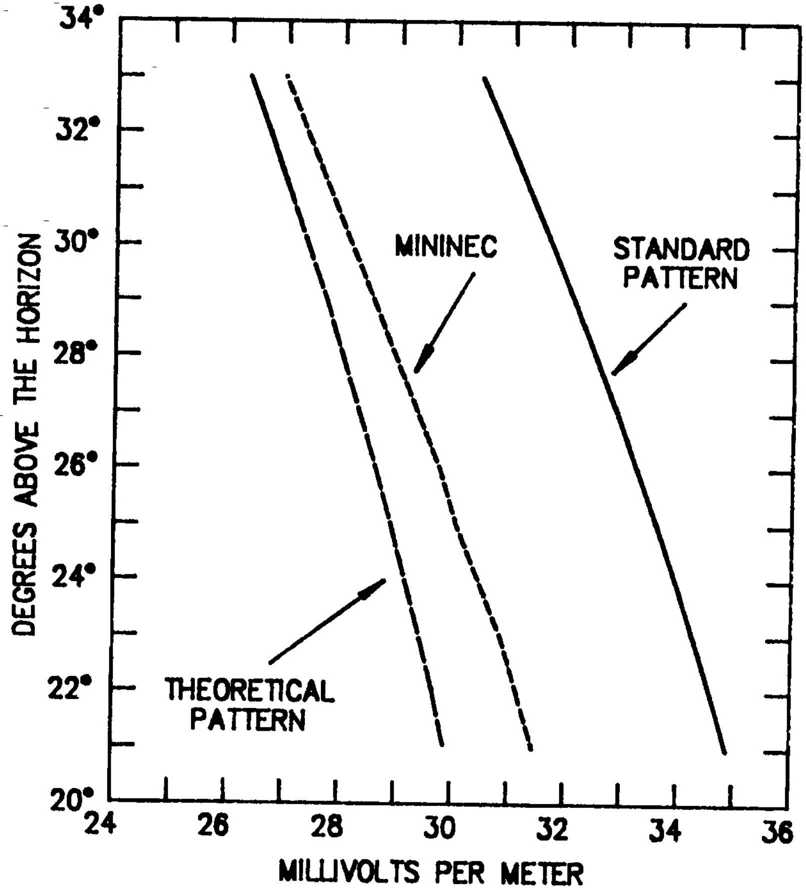
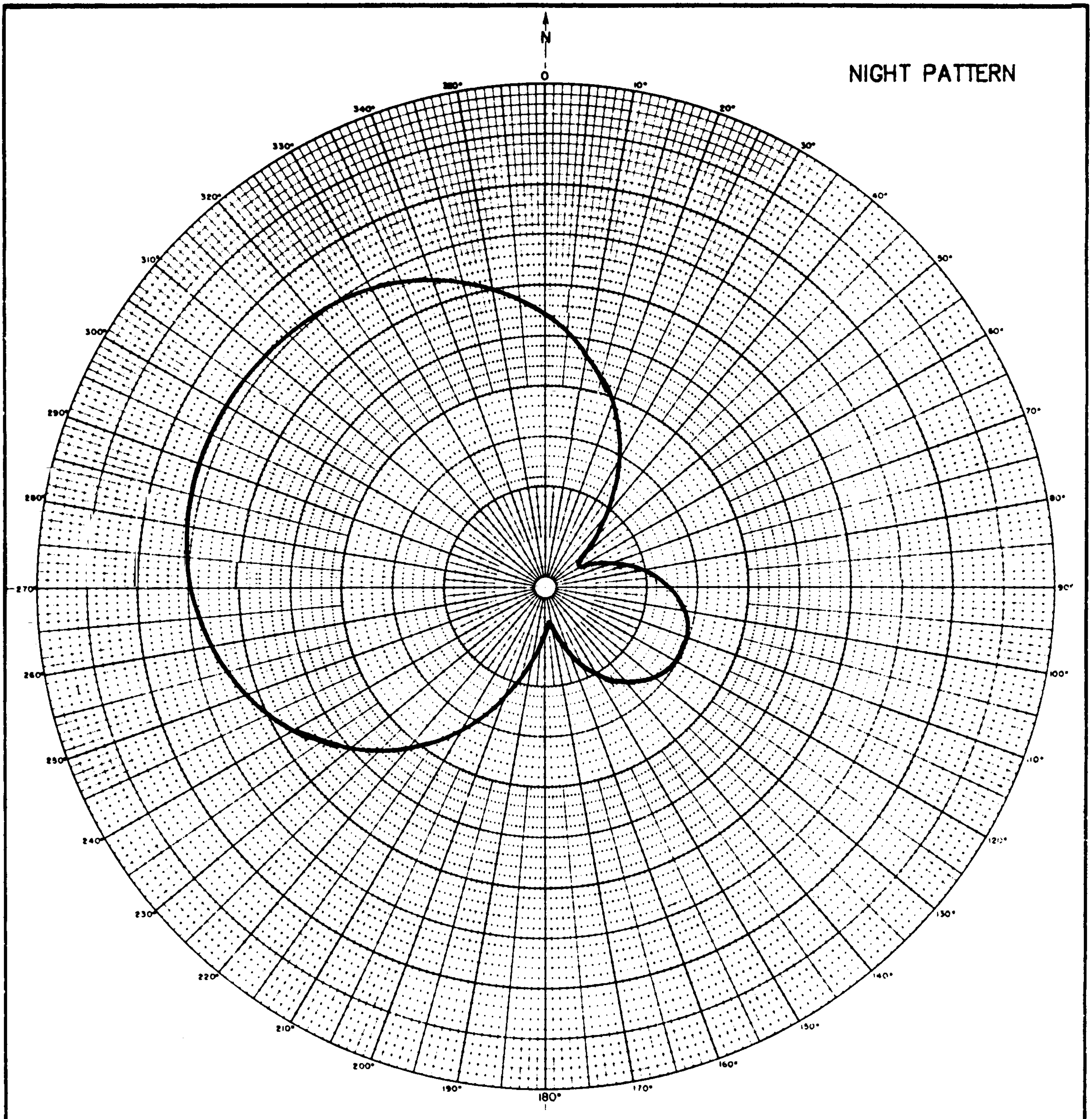


FIGURE 6
FOUR TOWER ARRAY



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

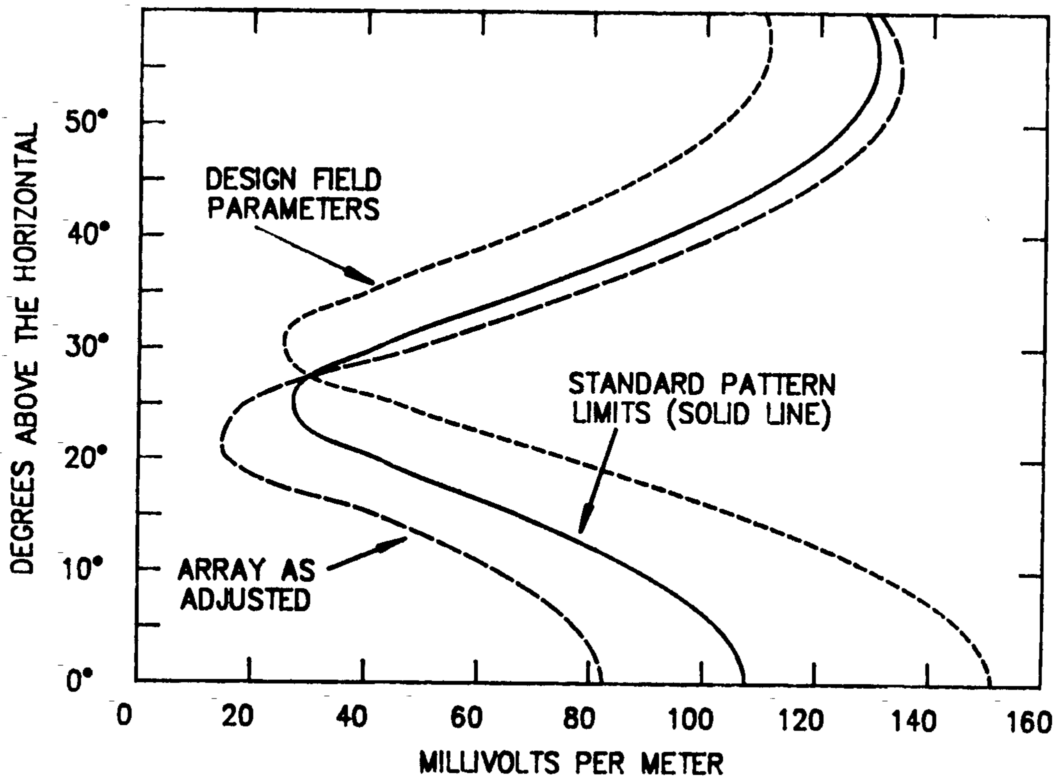
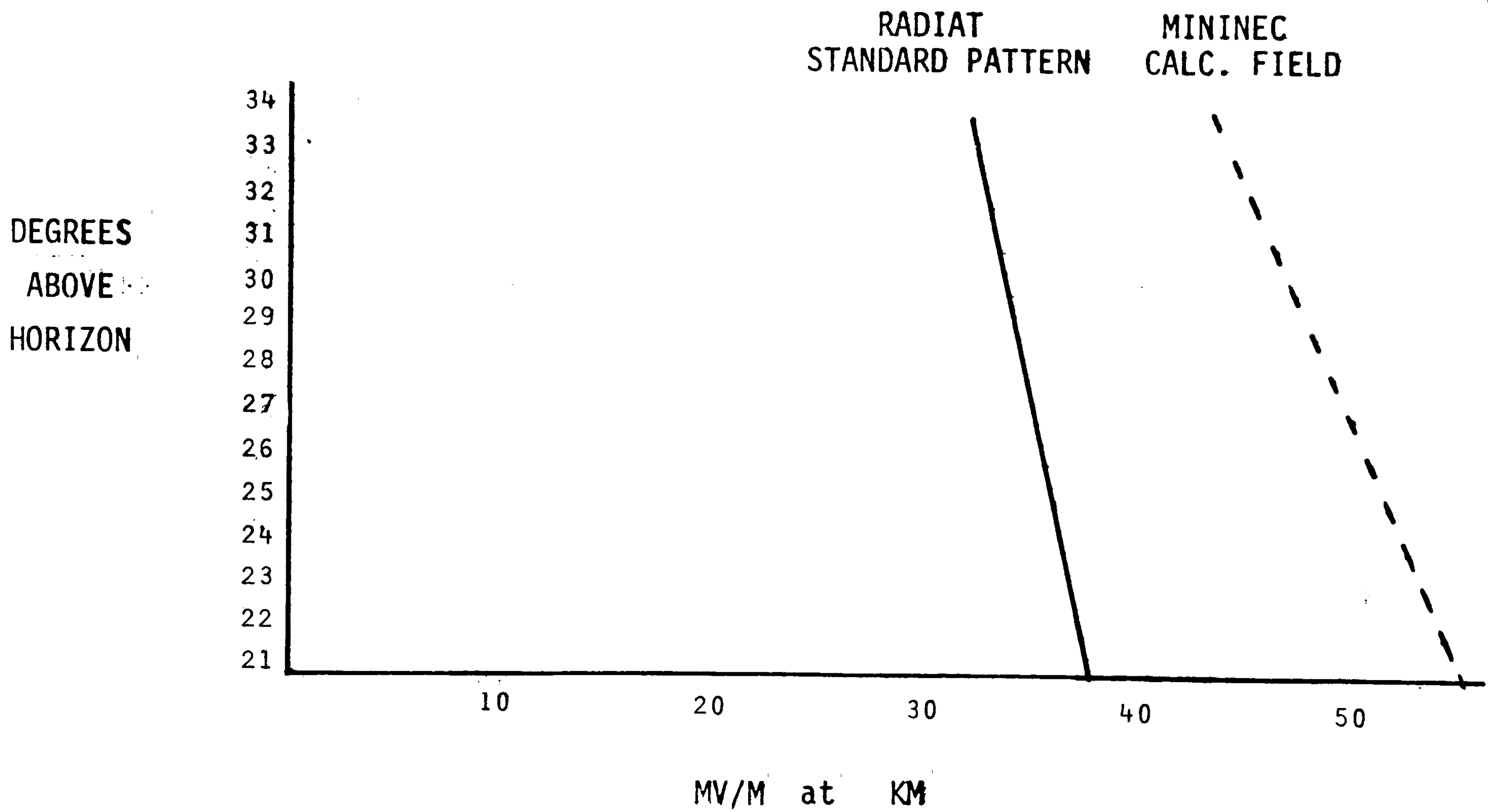


FIGURE 8
UNEQUAL HEIGHT TWO TOWER ARRAY



RADIAT
STANDARD PATTERN
MININEC
CALC. FIELD
DEGREES
ABOVE
HORIZON
34
33
32
31
30
29
28
27
26
25
24
23
22
21
10
20
30
40
50
MV/M at KM

FIGURE 9

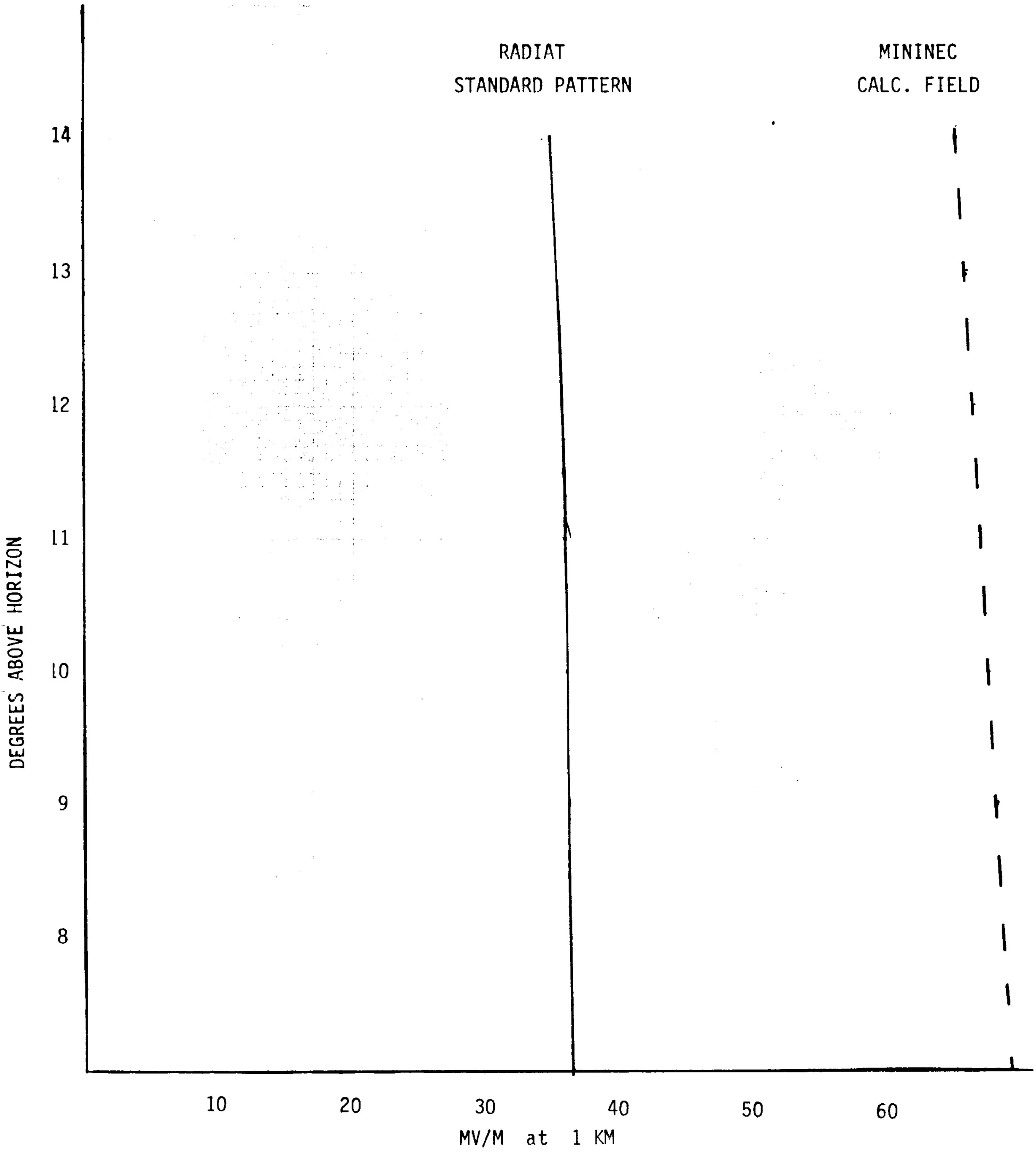
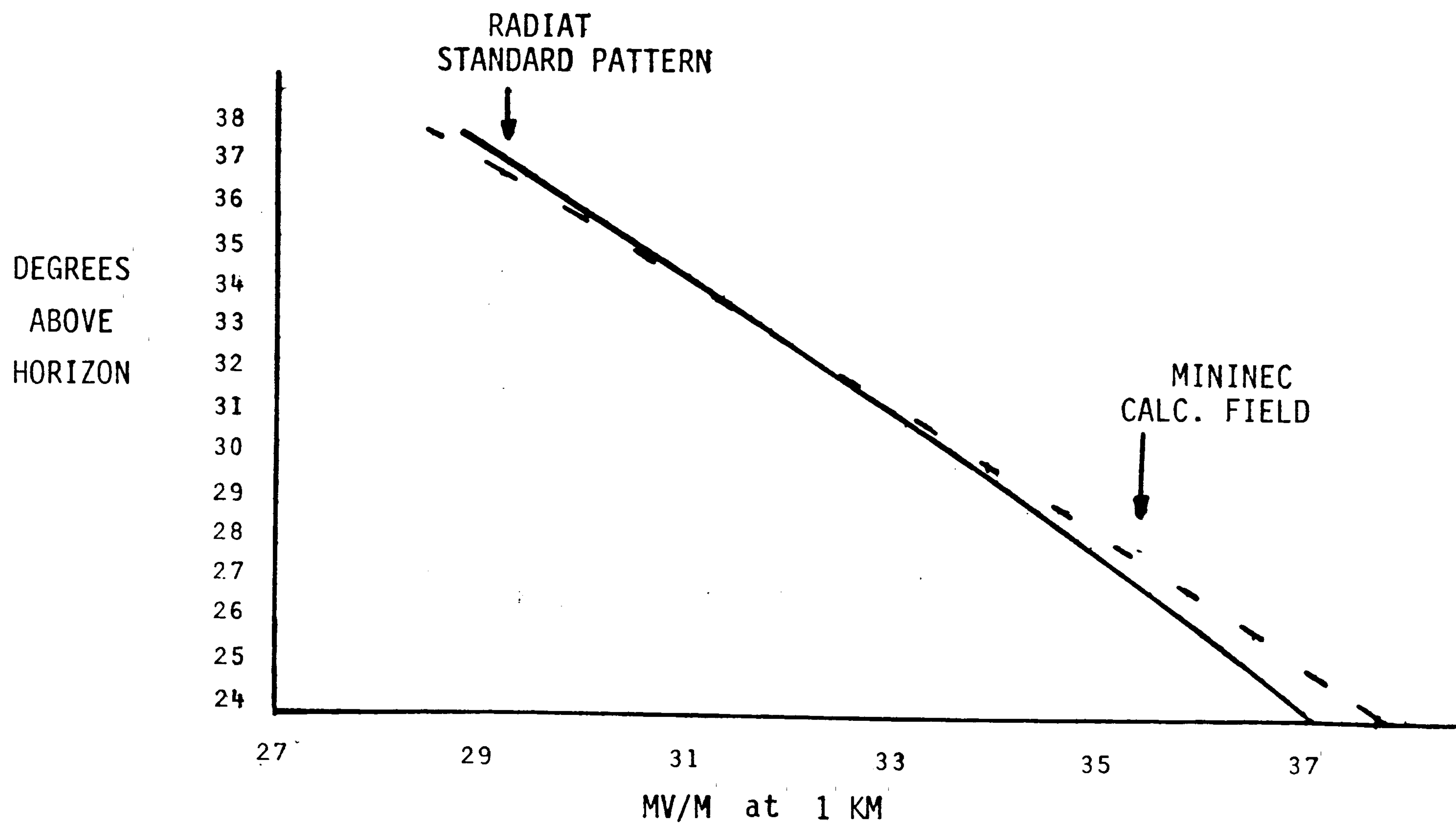

RADIAT
STANDARD PATTERN
MININEC
CALC. FIELD
14
13
12
11
10
9
8
DEGREES ABOVE HORIZON
10
20
30
40
50
60
MV/M at 1 KM

FIGURE 10


RADIAT
STANDARD PATTERN
MININEC
CALC. FIELD
DEGREES
ABOVE
HORIZON
38
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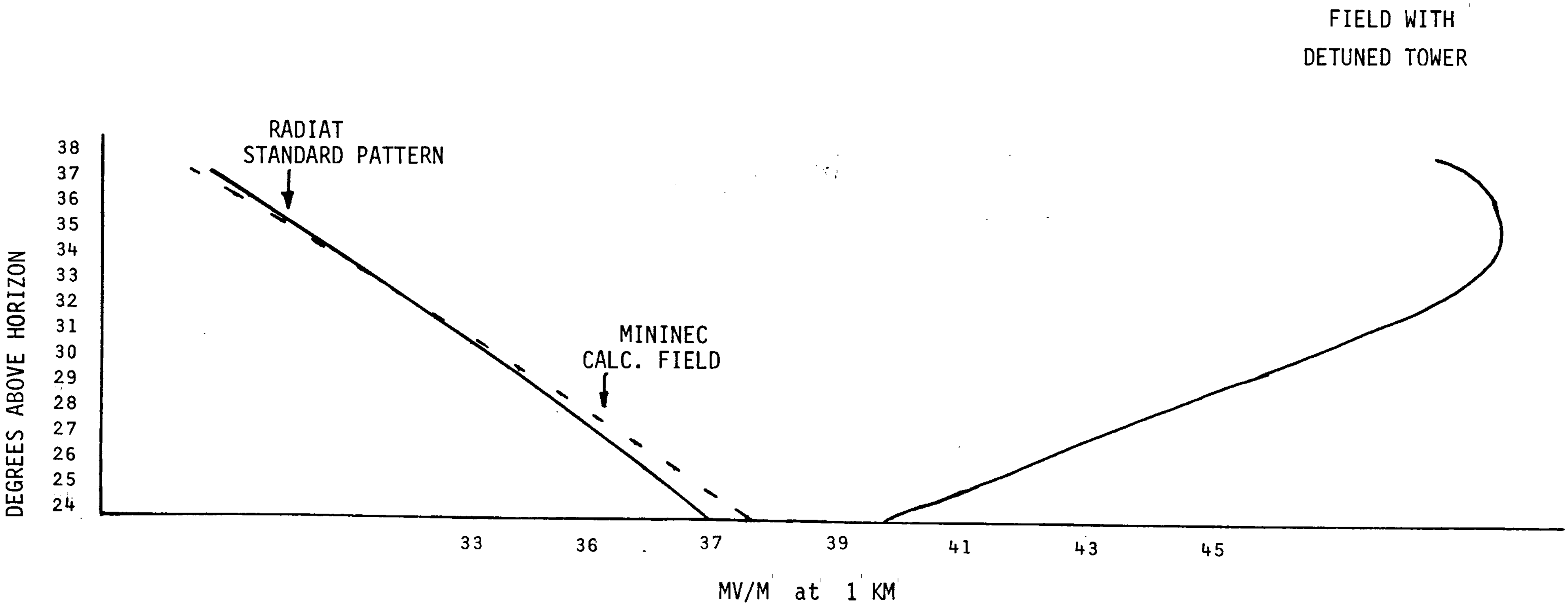
37
MV/M at 1 KM

FIGURE 11


FIELD WITH
DETUNED TOWER
RADIAT
STANDARD PATTERN
MININEC
CALC. FIELD
DEGREES ABOVE HORIZON
38
37
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39
41
43
45
MV/M at 1 KM

FIGURE 12

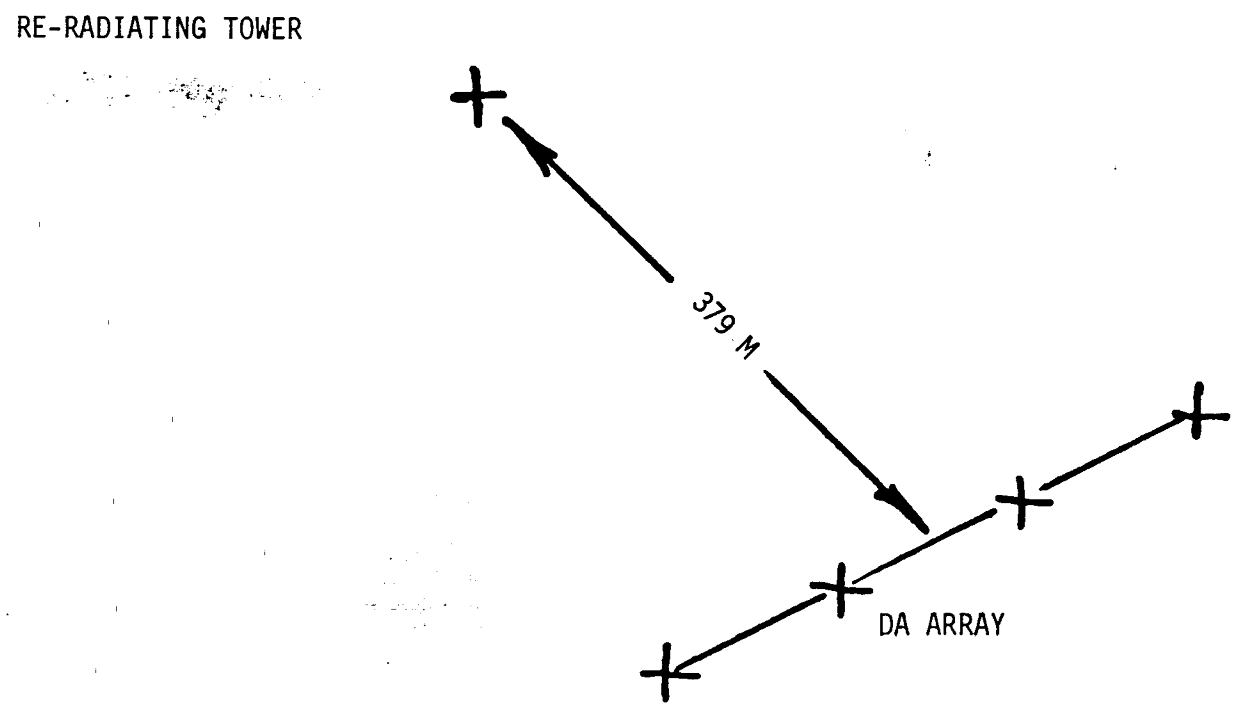

FIGURE 13