41 FR 24131 (June 15, 1976)
60 FCC 2d 927
37 RR 2d 649

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

FCC 76-511
40888

In the Matter of Amendment of the rules governing the design and measurement of radiation patterns for standard broadcast stations with directional antennas	)	Docket No. 20645

REPORT AND ORDER
(Proceeding terminated)
Adopted: June 1, 1976; Released: June 7, 1976

By the Commission: Commissioner Reid absent.

1. This proceeding was instituted as a result of a recommendation by the Association of Federal Communications Consulting Engineers (AFCCE), an organization which represents many consulting engineers practicing before the Commission. *Notice of Proposed Rule Making in Docket No. 20645*, FCC 75-1262, 40 FR 54826 (1975). Amendments to Sections 73.150 and 73.152 of our rules were proposed. Those sections govern the design of directional antenna patterns for standard broadcast stations. As extended, comments were due on January 29, 1976, and reply comments were due on February 9, 1976.

2. Comments were submitted by AFCCE, Ralph Bitzer, Hatfield and Dawson, Robert A. Jones, E. Harold Munn, and Robert M. Silliman and John A. Moffet d/b/a Silliman, Moffet and Kowalski (SMK). Reply comments were received from Clear Channel Broadcasting Service (CCBS), an informal organization composed of the licensees of certain Class I-A clear channel broadcast stations.

3. Presently, the rules require that a proposed directional antenna pattern be computed with an assumed loss resistance of one ohm located at the loop (or the base if the tower is less than one-quarter wavelength) of each tower. The proposed rules would keep the one ohm loss requirement only as an upper limit on the effective field (RMS) of the pattern. The lower limit on the theoretical RMS would be the value required by Section 73.189(b)(2) for a station of the proposed class, as adjusted for the nominal power of the station. All of the parties commenting applauded the proposed modification and urged its adoption. However, AFCCE and CCBS argue that the minimum efficiency specified in Section 73.189(b)(2) should be adjusted by the factor of 1/1.05 to compensate for the factor of 1.05 used in computing the standard pattern.

4. In paragraph 16 of the *Notice* we discussed our proposals to make minor changes in the manner in which patterns must be plotted and submitted in order to foster uniformity and clarity. Also in paragraph 16, we discussed some minor changes in the definitions used in computing the modified standard pattern pursuant to Section 73.152. The changes were designed to clarify some ambiguities in the present rule. Most parties did not comment on these proposals. However, Hatfield and Dawson indicated that they were in favor of these modifications. AFCCE indicated agreement with one exception and suggested two additional modifications. As proposed, the rules would have required that rectangular plots of patterns be labeled in increments of not less than 10 degrees. AFCCE suggests that labeling in 10 degree increments would unduly clutter the pattern and recommends 20 degree increments instead. AFCCE also suggests that we specifically permit the use of logarithmic scales on rectangular plots. CCBS agrees with AFCCE's suggestions. AFCCE also agrees with our proposal to replace the variable "Q" used in Section 73.152 with another letter to avoid confusion with the "Q" representing a different quantity in Section 73.150. However, AFCCE indicates that our proposed replacement of "Q" by "J" might also result in confusion due to the extensive use of a lower case "j" in other areas of engineering calculations. CCBS replies that all letters of the alphabet are used in one equation or another, and that any letter alleviating the present ambiguity would be suitable. Therefore, CCBS sees no reason why "J" should not replace "Q".

5. The proposed modifications included an attempt to eliminate the possibility of zero "null fill" even with the quadrature addition of "Q" in both the standard and modified standard patterns. We noted that the amount of null fill is presently determined, in part, by $f(\theta)$, the vertical plane distribution factor for the shortest element in the array. If the shortest tower is greater than one-half wavelength, $f(\theta)$ has a value of zero at some vertical angle. This leads to the possibility of a prediction of no radiation in a particular direction since even the term designed to compensate for a null in the theoretical pattern is reduced to zero. Therefore, we proposed to calculate $f(\theta)$ based on the shortest tower in the array, or, if the shortest tower were taller than one-half wavelength, on an assumed tower height of one-half wavelength.

6. Many of the comments dealt with this proposal. Several of those commenting noted that $f(\theta)$ for towers greater than one-half wavelength has values, at certain vertical angles, greater than $f(\theta)$ for one-half wavelength towers. Thus, our proposed solution would eliminate the problem of zero nulls, but would create a misleading, small amount of null fill in other areas. Before discussing the various suggestions aimed at solving this problem, we will define a new variable to make the discussion of the alternatives unambiguous. We will replace the variable $f(\theta)$ in the definition of "Q" in Section 73.150 and in the equation in Section 73.152 with the variable $g(\theta)$. Thus, for instance, in Section 73.150, we have:

Q is the greater of the following quantities:

$$0.025\ g(\theta)\ E_{rss} \quad \text{or}$$

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

In our present rules, then, $g(\theta)$ is equal to $f(\theta)$ for the shortest tower.

7. Hatfield and Dawson suggested that, in cases where the shortest tower is greater than one-half wavelength, $g(\theta)$ be the $f(\theta)$ for the shortest tower or $f(\theta)$ for a one-half wavelength tower, whichever is greater. SMK proposed that $g(\theta)$ be the greater of $f(\theta)$ for the shortest tower and $f(\theta)$ for the tallest tower, but if the shortest tower is greater than one-half wavelength, then $g(\theta)$ should be the greater of $f(\theta)$ for the tallest tower and $f(\theta)$ for a one-half wavelength tower. AFCCE proposes, and CCBS agrees, that $g(\theta)$ include a quadrature component of 0.15. Thus, AFCCE and CCBS would prefer that $g(\theta)$ be computed as follows:

$$\sqrt{f(\theta)^2 + 0.15^2}$$

Then, it would be normalized so that it is equal to one when θ is equal to zero.

8. All parties proposing these modifications indicated that our normal assumption of sinusoidal current distribution in a thin wire was sufficiently incorrect for electrically tall towers that one of these methods is necessary to compensate for the differences between the actual situation and the assumption. To achieve further accuracy, Hatfield and Dawson would provide for experimental determination of $f(\theta)$ based on actual measurements.

9. Our present rule concerning the calculation of modified standard patterns (note to Section 73.152(a)(2)) is silent on the question of overlapping spans of augmentation. However, it has been our policy to prohibit such overlap. SMK have proposed that the note be amended to permit overlap of spans of augmentation, but have not proposed the method by which this would be accomplished. SMK indicate that it is their experience that situations may arise where more than one augmentation is necessary and it is possible that these augmentations may overlap.

10. In its reply comments, CCBS raises several issues which it says must be resolved in this proceeding so that studies made in conjunction with Docket 20642[1] will be more meaningful. Specifically, CCBS asks that an addi-

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1/ In Docket 20642 we are looking toward the amendment of the rules which govern the use of the 25 clear channels listed in Section 73.25(a) of our rules. See *Notice of Inquiry and Notice of Proposed Rule Making in Docket 20642*, FCC 75-1331, released December 12, 1975.

tional "Q", independent of the vertical angle, be utilized in computing the standard pattern. This is necessary, says CCBS, to take into account the effects of guy wires, imperfections and asymmetries in the ground system, and similar departures from the idealized conditions assumed in the present calculations. This second "Q" would be the same amplitude as the present "Q" on the horizontal plane, but would not vary with the vertical angle as does the present "Q". CCBS also proposes to change the method of computing the "Q" (which we have proposed to denote as "J" in this proceeding) used in the equation for the augmented pattern in Section 73.152. This "Q" is used in determining the maximum amount of augmentation, and is multiplied by what we have redescribed as $g(\theta)$ to determine the augmented radiation in the vertical plane. Since $g(\theta)$ is always less than one if θ is greater than zero and is equal to one if θ is zero, the maximum augmentation always occurs on the horizontal plane. CCBS points out that an array which is adjusted so that it is sufficiently different from the predicted pattern that augmentation is required may very well have its maximum difference from the predicted values at a vertical angle above the horizontal. Thus, CCBS proposes that "Q" in the augmented pattern be determined experimentally from skywave measurements including directional to non-directional ratio tests. In the absence of such determinations, CCBS proposes that nulls in arrays include a factor on the order of ten percent of the RMS or RSS. CCBS also wants to amend the rules to predict the propagation of skywave signals by what CCBS calls more accurate methods.

DISCUSSION

11. Our reasons for proposing the amendment setting the one-ohm-loss RMS as an upper bound and the minimum efficiency specified in Section 73.189 (b)(2) as a lower bound were fully discussed in our *Notice*; further elaboration is unnecessary. Since all parties are in favor of the one-ohm-loss RMS being the upper bound and since we agree such a change would be in the public interest, we will adopt that amendment.[2/] However, AFCCE and CCBS propose that the lower bound which we proposed be multiplied by 1/1.05 to further decrease the lower bound. This would compensate for the addition of the extra five percent when the standard pattern is computed, and amounts to a request that the standard RMS meet minimum efficiency rather than the theoretical RMS. The rationale underlying the standard pattern is discussed in our *Report and Order in Docket 16222*, 27 FCC 2d 77, 20 RR 2d 1745 (1971). As indicated there, one of the main purposes of the adoption of the standard pattern was to achieve a uniform method of determining the tolerance needed in adjusting patterns. Previously, this tolerance was determined by the applicant who specified maximum expected operating values (MEOV) which often reflected allocation considerations instead of the necessary tolerance for

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2/ Attached hereto is Appendix B which describes the method of calculating the multiplying constant for a theoretical pattern with an assumed loss resistance of one ohm per tower.

14. With regard to SMK's request that the note to Section 73.152 (a)(2) be amended to specifically state that overlapping spans of augmentation are permitted, we note that SMK has not proposed a method of calculating the augmentation in the area of overlap. Moreover, our experience with modified standard patterns has indicated that it is unnecessary to propose spans which overlap. Accordingly, we will not adopt the requested provision; instead, we will modify the note to clearly prohibit such overlap. However, since our experience with modified standard patterns is somewhat limited due to the relatively few stations which have availed themselves of the rule, we stand ready to institute an inquiry into this area in the future should this prohibition become a problem.

15. The argument by CCBS that several issues must be resolved in this proceeding so that meaningful studies relating to Docket 20642 can be made is not persuasive. The addition of a second "Q" to take account of departures from idealized conditions is, we believe, unnecessary. The first "Q" is designed to do just that; in addition, there is a five percent tolerance added into the standard pattern calculations to cover such eventualities. It is also unnecessary to have a "Q" which is independent of vertical angle. Similarly, we will not adopt the proposal to determine "J" in the equation in Section 73.152 on an experimental basis using directional to non-directional ratio tests. While it may be true that the vertical radiation of a pattern sufficiently distorted to require augmentation may not have a "J" which is proportional to $g(\theta)$, we have consistently held that there is no effective method of determining the actual vertical radiation characteristics of an array other than inference from the horizontal pattern. *Capital Cities Broadcasting Corp.*, 20 FCC 2d 768 (1969); 49 FCC 2d 626 (1974), *supplemented in* 51 FCC 2d 649 (1975).[4/] We think that the state of the art has not changed sufficiently since those decisions that effective measurements are now possible. Accordingly, we continue our policy that the vertical radiation pattern must be inferred from the horizontal pattern, and we continue to believe that the method described in Section 73.152 is an appropriate method of inference. As for the use of directional to non-directional ratio tests based on actual skywave measurements, we note that our rules make no provision for the use of such measurements. Consideration of a possible amendment to permit such measurements is well beyond the scope of this proceeding. Similarly, we reject the proposal by Hatfield and Dawson that the $f(\theta)$ or $g(\theta)$ be determined from measurements. It must be remembered that one of the aims of the adoption of the standard pattern was to eliminate the need for referring to measurements other than to establish compliance with the standard pattern. Once it is proven that the actual pattern is within the bounds of the standard pattern, the standard pattern radiation values are utilized in all future studies. We do not wish to incorporate the measured data into our determinations unless absolutely necessary. In that case, we have provided two methods of augmentation in Section 73.152 of our rules. We think that is sufficient.

4/ The latter decision was recently affirmed by the United States Court of Appeals for the District of Columbia Circuit. *WBEN, Inc. v. Federal Communications Commission*, No. 74-1601 (filed May 18, 1976). 175 US App DC 363, 535 F 2d 1325, 37 RR 2d 675

21. We are aware that most engineering consultants depend on computer calculations of directional antenna patterns. We are in favor of this development. However, we are also aware that some consultants are using computers to develop the parameters for an array based on certain constraints concerning, the number of towers, land area, protection requirements, and so forth. While we find nothing wrong with this method *per se*, we note that the computer's tendency to work with eight or nine significant figures leads some consultants to specify field ratios or phasing with unrealizable precision. While we do not think that a rule is necessary at this stage, we note that field ratios and phasing for the various elements in a directional array should not be specified with more precision than can be indicated on the proposed antenna monitor and/or base current meters.

22. There remains the question whether the amendments which we adopt herein should apply to pending applications. Some of the amendments, such as the changes dealing with the one-ohm-loss requirement, are not involved in this question since any application which complies with the present rule will also comply with the proposed rule. However, other amendments, such as the adoption of $g(\theta)$ for towers greater than one-half wavelength, set restrictions that could adversely affect pending applications. With regard to the adoption of $g(\theta)$, we stated in our *Notice, supra*, at para. 14, that the situation which would arise when "Q" is zero and when the theoretical pattern is also zero, leading to a predicted radiation of zero, is "a condition which, in practice, is impossible to attain or maintain." Accordingly, we will apply the amended rules to all pending, as well as future, applications so that unrealistic situations will be avoided.

23. The text of the rule amendments which we are adopting is set forth in Appendix A.

24. Accordingly, IT IS ORDERED that effective July 15, 1976, Part 73 of the Rules and Regulations IS AMENDED as set forth in Appendix A hereto. Authority for this action is found in Sections 4(i) and 303(r) of the Communications Act of 1934, as amended.

25. IT IS FURTHER ORDERED that this proceeding IS TERMINATED.

FEDERAL COMMUNICATIONS COMMISSION

Vincent J. Mullins
Secretary

Attachments: Appendices

NOTE: Rules changes herein will be covered by T.S. III(76)-1.

APPENDIX A

1. In Section 73.150 paragraphs (a), (b)(1)(i) and (b)(2) are amended to read as follows:

Section 73.150 Directional antenna systems

(a) For each station employing a directional antenna, all determinations of service provided and interference caused shall be based on the inverse fields of the standard radiation pattern for that station. (As applied to nighttime operation the term "standard radiation pattern" shall include the radiation pattern in the horizontal plane, and radiation patterns at angles above this plane, as required by paragraph (b)(1) of this section.) In the event of a discrepancy between the calculated and plotted values of a standard pattern, the calculated values will prevail with respect to protection of domestic stations while the plotted (notified) values will prevail with respect to protection of foreign stations.

> NOTE: Applications for new stations or for major changes in existing stations *must* use a standard pattern. Stations proposing minor changes may, if they wish, utilize the formerly acceptable theoretical pattern with maximum expected operating values (MEOV) unless the minor change would modify an existing standard pattern.

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(b)(1)(i) The standard radiation pattern shall be based on the theoretical radiation pattern. The theoretical radiation pattern shall be calculated in accordance with the following mathematical expression:

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

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 Section 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 section 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:

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

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:

$$E(\phi,\theta)_{std} = 1.05\sqrt{\{E(\phi,\theta)_{th}\}^2 + Q^2} \qquad \{Eq.\ 3\}$$

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:

$$0.025\ g(\theta)\ E_{rss} \quad \text{or}$$

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

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:

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

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:

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

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

(ii) * * *

(2) All patterns shall be computed for integral multiples of five degrees, beginning with zero degrees representing true north, and, shall be plotted to the largest scale possible on unglazed letter-size paper (main engraving approximately 7" x 10") using only scale divisions and subdivisions of 1, 2, 2.5, or 5 times 10^{nth}. The horizontal plane pattern and other azimuthal patterns shall be plotted on polar coordinate paper, with the zero degree point corresponding to true north. Patterns for elevation angles above the horizontal plane may be plotted in polar or rectangular coordinates, with the pattern for each angle of elevation on a separate page. Rectangular plots shall begin and end at true north, with all azimuths labelled in increments of not less than 20 degrees. If a rectangular plot is used, the ordinate showing the scale for radiation may be logarithmic. Minor lobe and null detail occurring between successive patterns for specific angles of elevation need not be submitted. Values of field strength on any pattern less than ten percent of the maximum field strength plotted on that pattern shall be shown on an enlarged scale. Rectangular plots with a logarithmic ordinate need not utilize an expanded scale unless necessary to show clearly the minor lobe and null detail. The direction and distance toward each existing station with which interference may be involved shall be indicated on the horizontal plane pattern, and, as appropriate, on patterns for other angles of elevation, with all directions referred to true north.

NOTE: * * *

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2. Section 73.152(a)(2) is amended to read as follows:

Section 73.152 Modification of directional antenna data.

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(a)(2) Where any excessive measured field does not result in objectionable interference to another station a modified standard radiation pattern shall be submitted, encompassing all measured fields, and shall supersede the previously submitted standard radiation pattern for that station in the pertinent mode of directional operation.

NOTE: Where measured fields exceed the values shown on the standard radiation pattern, but objectionable interference does not result, and, accordingly, a modified standard radiation pattern is submitted, the modified pattern may be larger than the original pattern (*i.e.*, have a higher RMS value) if the measured fields systematically exceed the confines of the original pattern. The larger pattern shall be computed by using a larger multiplying constant, k, in the theoretical pattern equation (Eq. 1) in Section 73.150 (b)(1)(i). Alternatively, where the measured field exceeds the pattern in discrete directions, but objectionable interference does not result, the pattern may be expanded over sectors including these directions. A combination of both types of expansion may sometimes be desirable. Where sector expansion, or "augmentation", is desired, it shall be achieved by application of the following equation:

$$E(\phi,\theta)_{aug} = \sqrt{\{E(\phi,\theta)_{std}\}^2 + \{J\, g(\theta) \cos (180 \frac{D_A}{S})\}^2}$$

where:

$E(\phi,\theta)_{std}$ is the standard pattern field at some particular azimuth and elevation angle, before augmentation, computed pursuant to Section 73.150(b)(1)(i), Eq. 3.

$E(\phi,\theta)_{aug}$ is the field in the direction specified above, after augmentation.

$J = \sqrt{\{E(\phi,\theta)_{aug}\}^2 - \{E(\phi,\theta)_{std}\}^2}$ in which $E(\phi,\theta)_{aug}$ and $E(\phi,\theta)_{std}$ are the fields in the horizontal plane at the main azimuth of augmentation (*i.e.*, θ = zero degrees; ϕ = main azimuth of augmentation).

$g(\theta)$ is defined in Section 73.150(b)(1)(i).

S is the angular range, or "span", over which augmentation is applied. The span is centered on the main azimuth of augmentation. At the limits of the span, the augmented pattern merges into the unaugmented pattern. Spans shall not overlap one another.

D_A is the absolute horizontal angle between the azimuth at which the augmented pattern value is being computed and the main azimuth of augmentation. (D_A cannot exceed 1/2 S.)

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41 FR 24135 (JUNE 15, 1976)
60 FCC 2d AT 937
37 RR 2d AT 657

APPENDIX B

METHOD OF CALCULATION OF MULTIPLYING CONSTANTS USED IN COMPUTER PROGRAMS FOR STANDARD BROADCAST DIRECTIONAL ANTENNA CALCULATIONS

The various steps in the calculation of the multiplying constant are:

a) Compute the no-loss multiplying constant; that is, the multiplying constant assuming that the nominal power is radiated.

b) Compute the no-loss loop currents (base currents if the tower is less than 90 electrical degrees).

c) Compute the total power loss using the no-loss currents.

d) Adjust the multiplying constant to take account of the power loss; that is, adjust so that the nominal power is the input power to the array rather than the radiated power.

NOTE: In the following description, the angle θ is the vertical elevation angle above the horizontal plane. Also, the term "*rms*" means the root-mean-square field intensity based on a multiplying constant of one.

The no-loss multiplying constant is computed by the power flow integration method:

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

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:

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

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;

$J_o(S_{ij} \cos \theta)$ = 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:

$$I_i = \frac{K F_i}{(G2)(1 - \cos G_i)}$$

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:

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

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:

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

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