AN EVALUATION OF ANSI C95.1-1982: Criteria for Distance Determinations

The American National Standards Institute, Inc., has issued ANSI C95.1-1982, reference (1), which establishes safety levels and guidelines with respect to human exposure to radio frequency electromagnetic fields in the frequency range 300 kHz to 100 GHz. One of the more significant changes in the new guidelines is the frequency dependency aspect.

Table 1 provides the Radio Frequency Protection Guides (RFPG) for human exposure to electromagnetic energy at radio frequencies from 300 kHz to 100 GHz. The protection guides are in terms of the mean squared electric (E^2) and magnetic (H^2) field strengths and in terms of the equivalent plane-wave, free-space power density as a function of frequency.

The table shows that the RFPGs are constant for the frequency ranges, 0.3-3 MHz, 30-300 MHz, and 1.5-100 GHz, which in terms of the power density values are 100 mW/cm^2, 1.0 mW/cm^2, and 5mW/cm^2, respectively. The other two frequency ranges, 3-30 MHz and 300-1500 MHz have frequency dependency relationships as indicated. The overall relationship is shown graphically by the solid lines in Figure 1, which is a plot of column 4 of Table 1 with respect to frequency.

Figure 2 represents another method for presenting the safety levels established in the ANSI C95.1-1982 Standard as a function of frequency between 300 kHz and 100 GHz. The three scales show the RFPGs of Table 1 as a function of frequency. The exposure limit for a particular frequency is read just opposite that frequency on each of the three scales.

One of the concerns with the more stringent recommended safety levels is how far must personnel now be away from a radiating source of electromagnetic radiation to be "assured" that personnel are not exposed to levels that are greater than those recommended in the ANSI C95.1-1982 Standard?

In the past, where the constant value of ten (10) mW/cm^2 (dashed line of Figure 1) has been used as the safety level, it was relatively simple to determine the anticipated far-field hazard distance from the familiar free-space, far-field Friis power density equation ($P_D = P_T G_T / 4 \pi D^2$). This is still the case for those portions of the new standard where the recommended safety levels are independent of frequency—specifically: 300 kHz-3 MHz (100 mW/cm^2), 30 MHz-300 MHz (1.0 mW/cm^2) and 1500 MHz-100 GHz (5.0 mW/cm^2).

For those portions of the standard where the recommended safety levels vary as a function of frequency, that relationship has been introduced into the power density equation. Accordingly, the far-field distance, at which the exposure criterion is equalled, can be determined using the average power of the transmitter, the antenna gain and the frequency at which the transmitter is operated.

For the frequency range 3-30 MHz, where the safety level in terms of average power density has been established as $900/f^2$ mW/cm^2, the far-field distance, in meters, at which the exposure criterion is equalled, can be determined from the following equation:

$D = 2.0 \times 10^{-3} f_{MHz} (P_T G_T)^{0.5}$ meters, Equation 1

where D is the distance in Meters,

f is the frequency in Megahertz,

PT is the average power of the transmitter in Watts, and

GT is the numerical gain ratio of the transmitting antenna.

Equation 1 can also be expressed in dB notation as follows:

$20 \log D = 10 \log P_T + 10 \log G_T + 20 \log f_{MHz} - 50.535$ dB meters. Equation 2

Figure 3 provides a nomogram for determining that distance in meters for the frequency range 3-30 MHz. An example is shown for the following parameters.

Transmitter Average Power (P_T):	5000 Watts
Antenna Gain (G_T):	40 (16 dB)
Frequency:	16 MHz

1 Frequency Range Megahertz (MHz)	2 Mean Squared Electric Field Strength E^2 (V^2/m^2)	3 Mean Squared Magnetic Field Strength H^2 (A^2/m^2)	4 Power Density (mW/cm^2)
0.3 - 3	400 000	2.5	100
3 - 30	$4000(900/f^2)$	$0.025(900/f^2)$	$900/f^2$
30 - 300	4000	0.025	1.0
300 - 1500	4000(f/300)	0.025(f/300)	f/300
1500 - 100 000	20 000	0.125	5.0

Table I. Radio Frequency Protection Guides.

Note: f is the frequency in Megahertz (MHz)

All values averaged over any 0.1-hour period.

RADIO FREQUENCY PROTECTION GUIDES (RFPG) FOR PERSONNEL EXPOSURE TO RF/MICROWAVE RADIATION

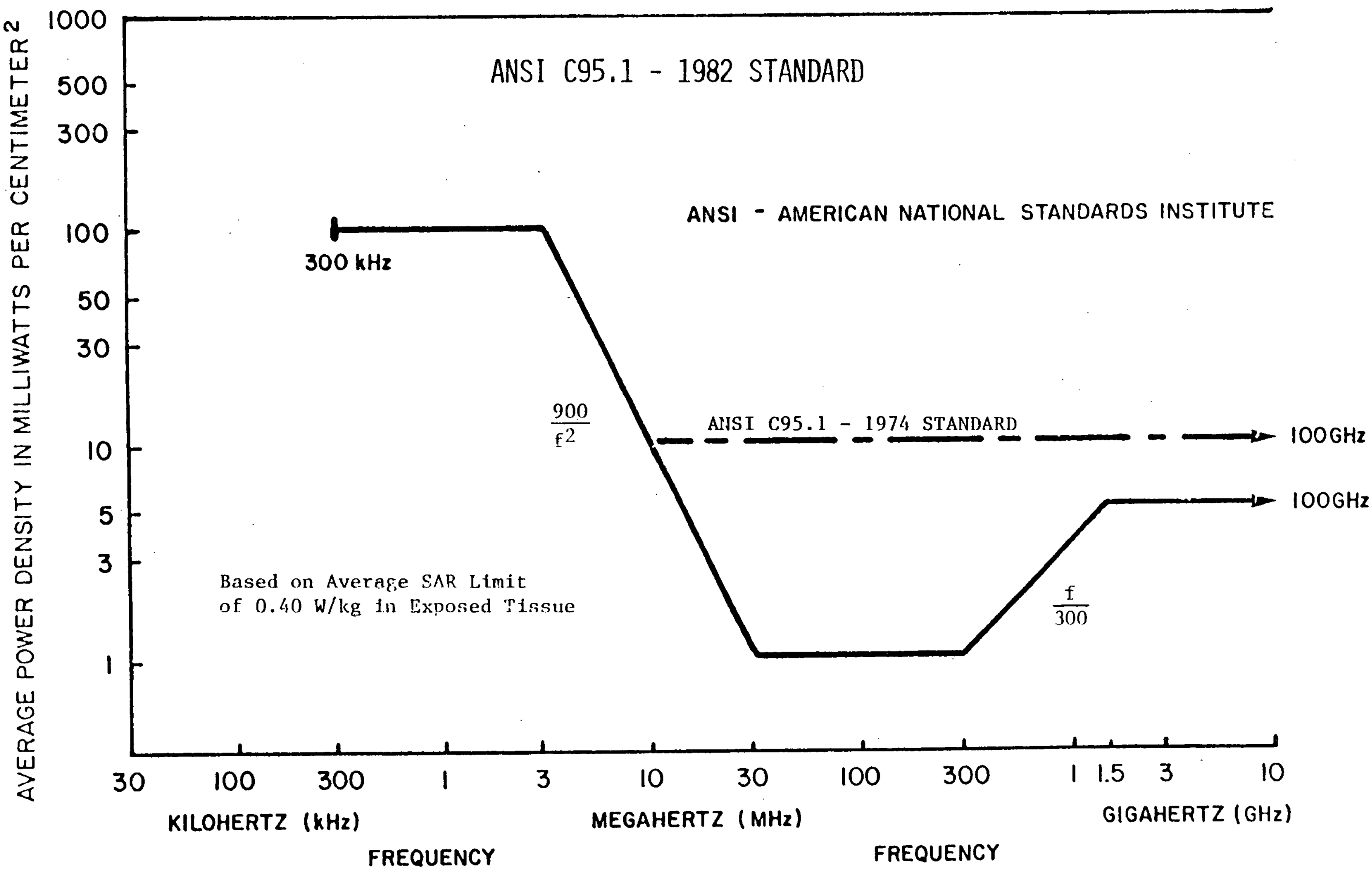

Figure 1. Plot of Average Power Density (mW/cm^2) versus Frequency.

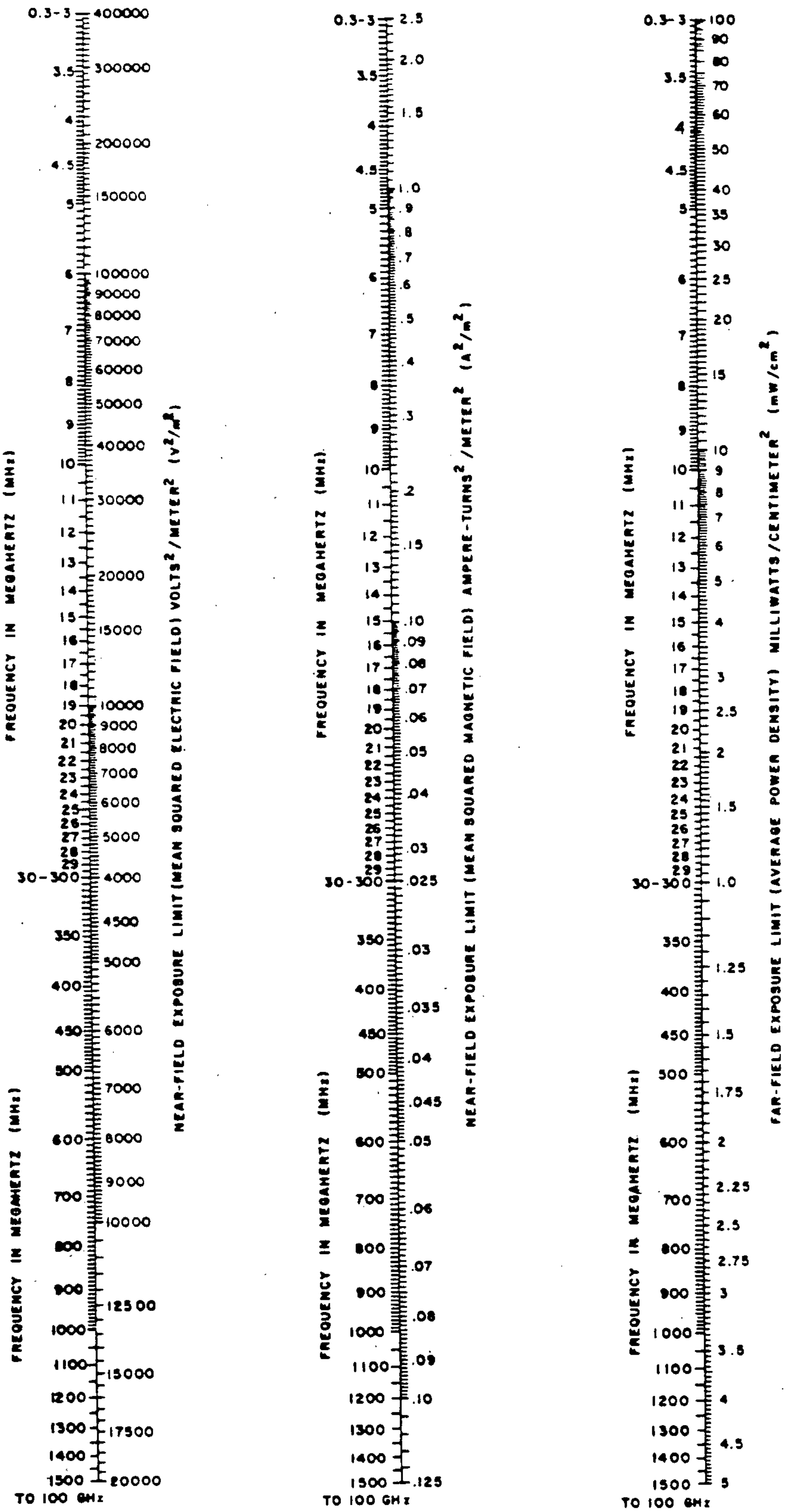

Figure 2. ANSI C95.1-1982 Standard.

A straight-edge is placed between 5000 watts on the P_T scale and 40 (16 dB) on the G_T scale. Where that line (1) crosses the reference line, a "reference" point is established for the second line indicated by (2). That line is drawn between the "reference" point on the reference line and the frequency of 16 MHz on the Frequency in Megahertz (MHz) scale. The distance is determined where that line (2) crosses the Distance in Meters scale. For this example, the distance is approximately 21 meters. It should be emphasized that the nomograms are based on "far-field" conditions. For element (linear-type) antennas, distances obtained which are less than one-sixth wavelength (where the radiation field is equal to the induction field) may not necessarily assure a "safe" distance. If the determined distance were less than one-sixth wavelength for the frequency of concern, other methods should be used. At this and shorter distances, the relative size of the antenna in wavelengths to those distances becomes a factor in determining the magnitude of the field strengths. Reference (2) provides an insight of the effect of antenna size on the relative magnitude of the electric and magnetic field strengths as a function of the parameter (fre-

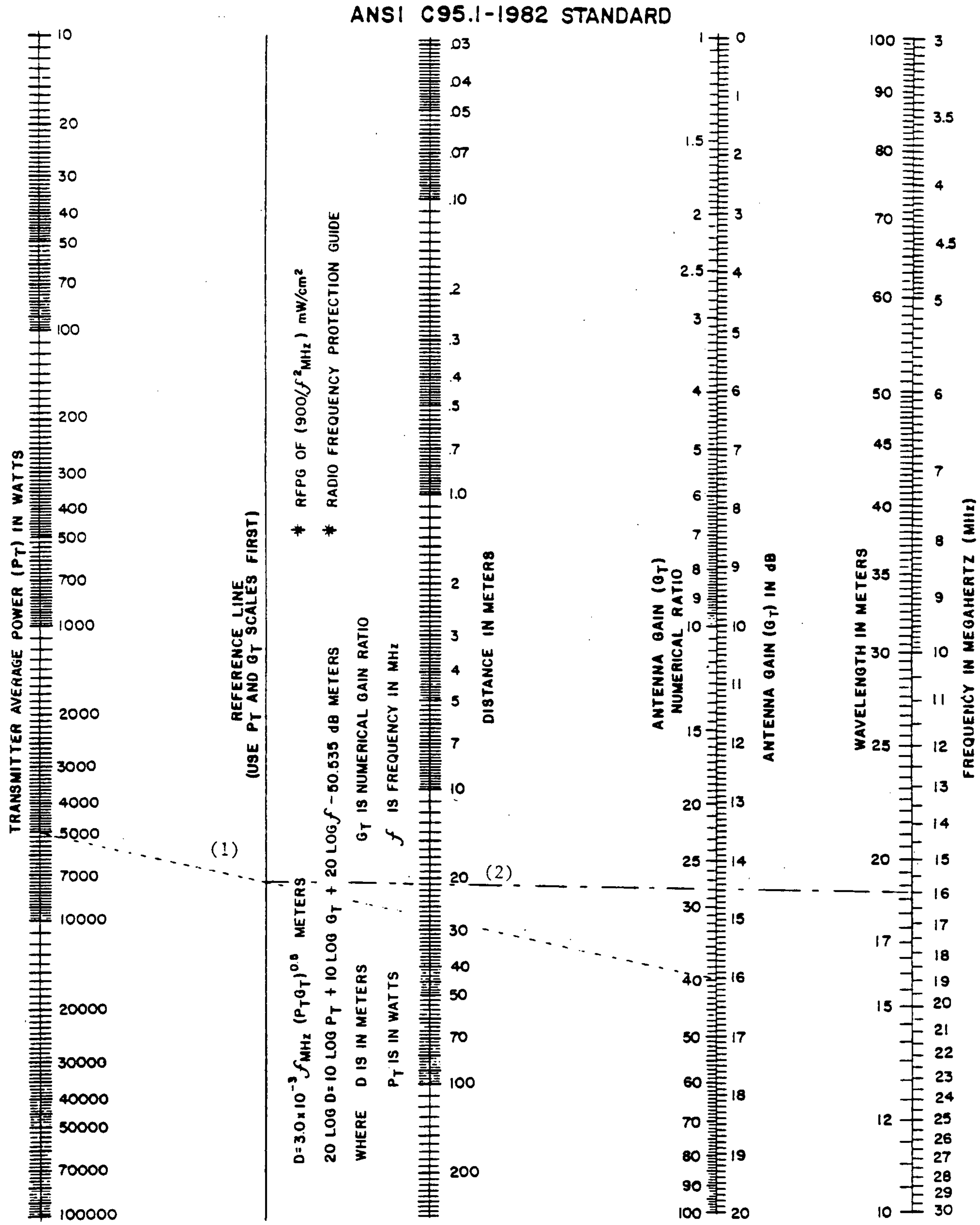

Figure 3. Nomogram (1) for Determining Exposure Far-Field Distance in Frequency Range 3 to 30 Megahertz.

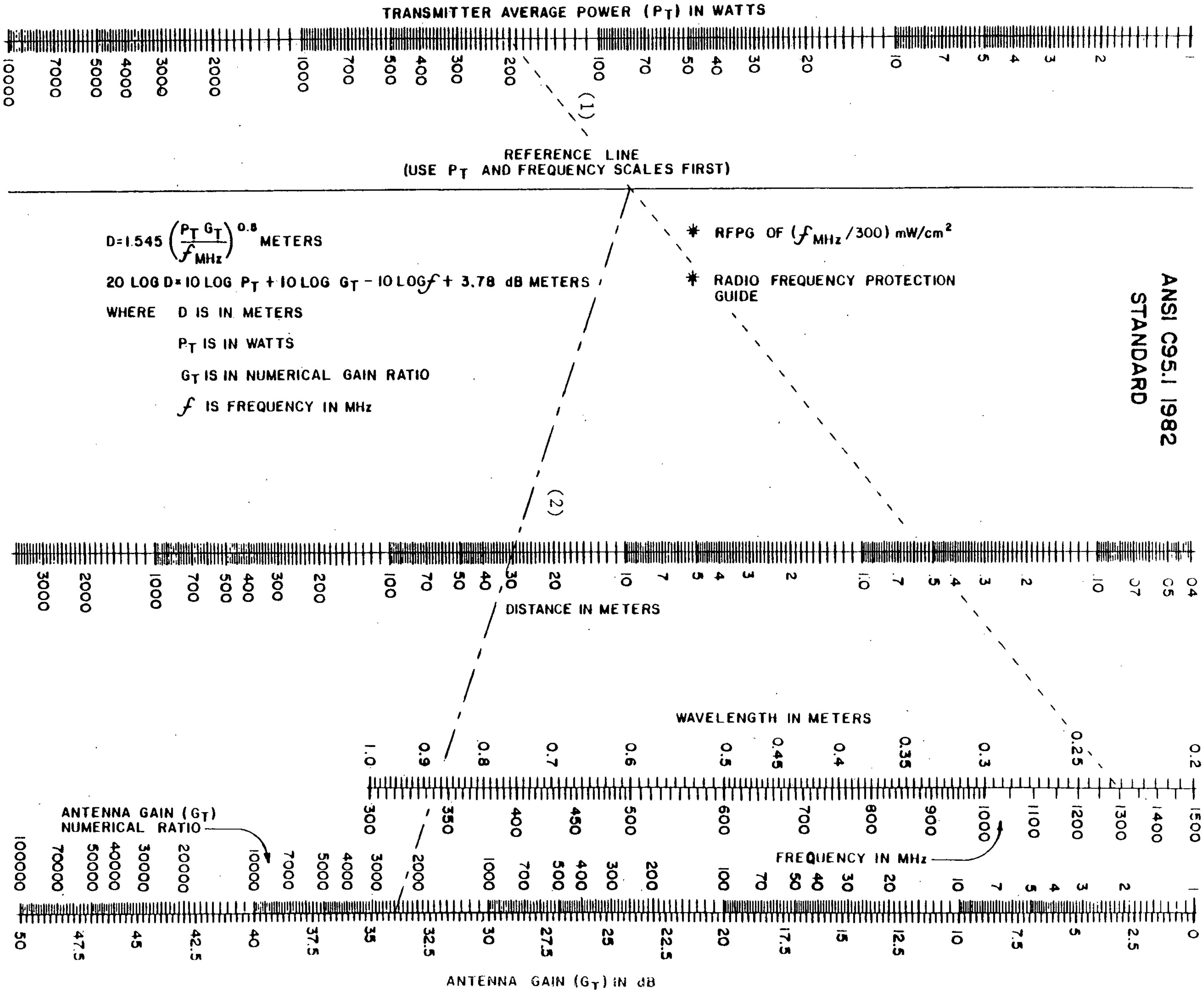

Figure 4. Nomogram (2) for Determining Exposure Far-Field Distance in Frequency Range 300 to 1500 Megahertz.

quency x distance). This and other curves and computer programs exist which can be used to determine field strengths in the near field of antennas.

The nomogram can also be used in "reverse" order to determine how much one would have to change frequency, power and/or antenna gain to bring the average power density level at a certain distance below the criterion set by the ANSI C95.1-1982 Standard. Assume personnel must be in an area 50 meters from an antenna with a gain of 50 (17 dB) which is fed by a transmitter operating at a frequency of 18 MHz. The problem becomes one of determining the "maximum" average power of the transmitter that would keep the average power density below the criterion of the ANSI standard at that distance of 50 meters with the transmitter operating at 18 MHz into a 17 dB antenna. The straight-edge is placed between 50 meters on the distance scale and 18 MHz on the frequency scale and noting where the straight-edge extends to the reference line and place a "mark" there. The straight-edge is then placed between that "mark" on the reference line and 17 dB (50 times) on the antenna gain (G_T) scale. The straight-edge crosses the transmitter average power scale at a value of about 18200 watts. Thus, any transmitter average power less than that value should result in average power densities less than the criterion for the conditions stated. Similarly, it would be possible to change the frequency and/or the antenna gain to achieve the desired result.

For the frequency range 300-1500 MHz, where the safety level in terms of average power density has been established as f/300 mW/cm^2, the far-field distance, in meters, at which the exposure criterion is equalled, can be determined from the following equation:

$$D = 1.545\,(P_T G_T / f_{MHz})^{0.5} \text{ meters,} \qquad \text{Equation 3}$$

where D is the distance in Meters,

f is the frequency in Megahertz,

PT is the average power of the transmitter in Watts, and

GT is the numerical gain ratio of the transmitting antenna.

Equation 3 can also be expressed in dB notation as follows:

$$20 \log D = 10 \log P_T + 10 \log G_T - 10 \log f + 3.78 \text{ dB meters.} \qquad \text{Equation 4}$$

Figure 4 provides a nomogram for determining that distance in meters for the frequency range 300-1500 MHz. An example is shown for the following parameters.

Transmitter Average Power (P_T):	200 Watts
Antenna Gain (G_T):	2500 (34 dB)
Frequency:	1300 MHz

A straight-edge is placed between 200 watts on the PT scale and 1300 MHz on the frequency in MHz scale. Where that line (1) crosses the reference line, a "reference" point is established for the second line indicated by (2). That line is drawn between the "reference" point on the reference line and the value of 2500 (34 dB) on the G_T scale. The distance is determined where that line crosses the Distance in Meters scale. For this example, the distance is approximately 30 meters. Again it should be emphasized that the nomograms are based on "far-field" conditions. For element (linear-type) antennas, distances obtained which are less than one-sixth wavelength may not necessarily assure a "safe" distance. For aperture-type antennas, distances obtained using the nomogram that are less than the far-field distance of $2L^2/\lambda$ will be conservative, where L denotes the widest dimension of the aperture antenna.

Although the two nomograms are specifically designed for those portions of the ANSI C95.1-1982 standard where the exposure safety levels exhibit a frequency dependency, the nomograms can also be used to determine the exposure far-field distance for the "flat" portions of the standard where the exposure safety levels are constant, that is, independent of frequency. In these cases, it becomes simply a matter of using the "end-points" of the frequency scale as one of the parameters in using the nomograms. For the 300 kHz to 3MHz range, the 3 MHz end-point on the frequency scale of nomogram (1) (Figure 3) would be used. For the 30-300 MHz range, either the 30 MHz "end-point" on nomogram (1) or the 300 MHz "end-point" on nomogram (2) (Figure 4) could be used. For frequencies between 1500 MHz and 100 GHz, the 1500 MHz "end-point" on nomogram (2) would be used.

In developing the nomograms, consideration was given whether to place the equivalent plane-wave free-space power density levels or wavelength in meters opposite the frequency scales. It was decided that the wavelength in meters would be more appropriate on the nomograms in order that one may more readily "see" the relative relationship between the determined exposure far-field distance and the wavelength applicable to the frequency of concern. On that basis, it was felt that a separate plot (Figure 2) could reflect the exposure levels as a function of frequency with all three equivalent values represented — the mean squared electric (E^2) and magnetic (H^2) field strengths and the equivalent plane-wave, free-space power densities.

The nomograms provide a useful tool in determining potential hazard distances and can serve as a check for other methods of hazard distance determinations. It should be emphasized that the nomograms are based on the equivalent plane-wave free-space power density considerations and distances obtained should be checked when the restrictive conditions specified earlier apply. Curves and computer programs exist for applying correction factors in the near-field of antennas. Reference (2) provides an example of how the magnitude of the field strengths from element antennas is affected by the relative size of the antenna and the distance from the antenna. Reference (3) shows how the magnitude of the field strengths from an aperture-type antenna varies with distance.

References

1. American National Standards Institute, Inc., "Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz", *American National Standard, ANSI C95.1-1982, September 1, 1982.*

2. Mills, A. H. and Pelland, P. L., "Field Intensities Around a Dipole Antenna for Distances Comparable to Antenna Length", *1966 IEEE International Electromagnetic Compatibility Symposium Record.*

3. Jacobs E., "Fresnel Region Patterns and Gain Corrections of Large Rectangular Antennas", *Proceedings of the Fifth Conference on Radio Interference Reduction and Electromagnetic Compatibility*, Chicago, Illinois, 6-8 October 1959.

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