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OF
DEFENSE**

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**techniques and instrumentation for the
measurement of potentially hazardous
electromagnetic radiation at
microwave frequencies**

ANSI C95.3-1973



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Techniques and Instrumentation for the
Measurement of Potentially Hazardous
Electromagnetic Radiation at Microwave Frequencies

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Foreword

(This Foreword is not part of the American National Standard Techniques and Instrumentation for the Measurement of Potentially Hazardous Electromagnetic Radiation at Microwave Frequencies, C95.3-1973.)

In 1960, the American Standards Association approved the initiation of the Radiation Hazards Standards project under the co-sponsorship of the Department of the Navy and the Institute of Electrical and Electronics Engineers. The scope was defined as follows:

"Hazards to mankind, volatile materials and explosive devices which are created by man-made sources of electromagnetic radiation. The frequency range of interest extends presently from 10 kHz to 100 GHz. It is not intended to include infrared, X-rays, or other ionizing radiation."

Under this authorization, the American Standards Association Committee C95 was organized with six subcommittees concerned with:

- I. Techniques, Procedures, and Instrumentation
- II/III. Terminology and Units of Measurements
- IV. Safety Levels and/or Tolerances with Respect to Personnel
- V. Safety Levels and/or Tolerances with Respect to Electro-Explosive Devices
- VI. Safety Levels and/or Tolerances with Respect to Flammable Materials

Presently, the Co-Secretariats of the American National Standards Committee C95 are the Naval Electronic Systems Command of the Department of the Navy and the Institute of Electrical and Electronics Engineers. The above Subcommittees have remained in effect. Current officers are

Saul W. Rosenthal, *Chairman*

Stephen Caine, *Secretary*

To date, two standards of the C95 committee have been issued. These are: American National Standard C95.1-1966, Safety Level of Electromagnetic Radiation with Respect to Personnel, prepared by Subcommittee IV, and American National Standard C95.2-1966, Radio Frequency Radiation Hazard Warning Symbol.

This standard sets forth evaluation techniques and instrumentation to determine the existence of a potentially hazardous situation due to electromagnetic radiation.

Suggestions for improvement gained from using this standard are welcomed. They should be sent to the American National Standards Institute, 1430 Broadway, New York, N. Y. 10018.

The Standards Committee on Radio-Frequency Radiation Hazards, C95, which reviewed and approved this standard, had the following personnel at the time of approval:

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American Industrial Hygiene Association	H. W. Speicher
American Insurance Association	G. Whelpley
American Mutual Insurance Alliance	William J. Uber
	Kenneth F. Kroupa (<i>Alt</i>)
American Petroleum Institute	Arthur F. Miller
American Society of Safety Engineers	Robert P. Gleason
Armed Forces Institute of Pathology	R. E. Stowell
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Subcommittee I, "Techniques, Procedures and Instrumentation," was directly responsible for the development of this standard. A list of the members and other persons who contributed to this effort follows:

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W. W. Mumford, January 8, 1963–July, 1970

R. C. Baird, July, 1970–

Acting Secretaries

Paul C. Constant, Jr, Prior to April 7, 1960

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American National Standard Techniques and Instrumentation for the Measurement of Potentially Hazardous Electromagnetic Radiation at Microwave Frequencies

1. Scope

1.1 Purpose. Subcommittee I on Techniques, Procedures, and Instrumentation was originally organized on April 7, 1960, to

“Establish specifications for techniques and instrumentation used in evaluating hazardous radio-frequency radiation.”

On January 8, 1963, the intent of the scope was clarified by specific reference to mankind, flammable volatile materials, and explosive devices; thus the purpose was extended to

“Establish specifications for techniques and instrumentation to be used in evaluating radio-frequency hazards to mankind, flammable volatile materials, and explosive devices.”

1.2 Application and Limitations. As indicated above, the scope of Subcommittee I includes hazards to flammable volatile materials and explosive devices. However, the required specifications and definitions relating to the measurement of the quantities associated with hazards to fuel and ordnance are not yet available. Rather than wait for such specifications and definitions, it seemed both necessary and desirable to prepare this standard which is devoted exclusively to personnel hazards.

Although the frequency range specified in American National Standard C95.1-1966, Safety Level of Electromagnetic Radiation with Respect to Personnel, is 10 MHz to 100 GHz, the emphasis here is on techniques suitable for measuring power density at microwave frequencies.

NOTE: The lower limit of the microwave frequency range is not well defined but is usually considered to be about 1 GHz. However, the techniques described here can, under the proper circumstances, be useful at lower frequencies (perhaps as low as 300 MHz) if sufficient care is taken with the measurements.

Further, these techniques are generally applicable only in the far field, but reasonably accurate measurements can be made whenever the following necessary conditions are satisfied.

(1) The transmitting antenna and any scattering objects must be in the far field of the receiving antenna

(2) The receiving antenna must be at least several “aperture diameters” removed from the transmitting antenna and any scattering objects

NOTE: The term “aperture diameter” is used here to indicate the largest dimension of the radiating portion of a transmitting antenna or scattering object.

(3) The transmitting antenna and any sources of multipath scattering must be contained within the main beam of the receiving antenna.

Thus, leakage measurements and measurements in the reactive near field are specifically excluded. However, measurements can be made in the radiating near field with a receiving antenna which is small compared to the source antenna if the three conditions above are satisfied. Such measurements will usually be more difficult than far-field measurements because the orientation and position of the probe must be systematically varied to locate the regions of maximum power density. This can often be a laborious and time-consuming task.

The reasons for these restrictions are related to the quantity to be measured, namely, power density W . This is not the place to discuss the relative merits of power density as a reliable indicator of hazardous electromagnetic fields. It is sufficient to point out that there are some rather compelling reasons for measuring $|E|^2$ (or $|E|$) instead, where E is the resultant electric field vector at the measure-

ment point (see Ref 18). Note that for plane waves, $|E|^2$ is simply related to W , so either quantity is equally valid. However, where strong multipath components exist or in the near-field regions (both reactive and radiative near fields are included) power density can be extremely difficult to measure and may not be the most meaningful quantity. For example, two waves of equal amplitude and frequency traveling in opposite directions combine to give a time-average power density of exactly zero, yet very intense fields will exist in certain regions. In this case $|E|^2$ provides a better indication of the potential hazard, particularly for the lower frequencies where penetration into the body is greater.

Early concern about electromagnetic hazards centered on high-power microwave radar installations. For microwave and higher frequencies, and for measurements performed at a distance of several "aperture diameters" or more from the source, power density is a meaningful quantity. Unfortunately, the term has been almost universally adopted as a hazard indicator without regard to frequency, field configuration, ease of measurement, or the mechanisms which actually produce the biological damage.

Below 1 GHz, $|E|^2$ appears to be at least as good as W , if not better, as a hazard indicator. Therefore, the basic techniques for measuring electric field strength that have been developed over the years can be applied to RF hazard measurements. However, the instrumentation specified in existing field-strength measurement standards (that is, American National Standards C63.2-1963, C63.3-1964, C63.4-1963) is in general not suitable for high-intensity fields due to inadequate shielding, insufficient input attenuation, etc.

It is in consequence of the above considerations that the restrictions and limitations given at the first of this section have been imposed upon this standard.

2. Electromagnetic Environment

2.1 Nature of Potentially Hazardous Radiation Fields. In general, radiation fields will exhibit both spatial and temporal variations which will be functions of the physical environment as well as the nature of the RF

source. The reflectivity of both natural and man-made structures will result in nonuniform power densities over any region of interest due to the establishment of standing waves. This spatial variation of the electromagnetic field is caused by the interaction of the flow of RF energy reflected from prominent features of the physical environment or from the multiplicity of sources. These peaks in the electromagnetic distribution are separated by at least a half wavelength, that is, they may be from a fraction of a centimeter to many meters apart, depending on the frequency of the source and the angles of arrival of the interfering waves. A change in frequency can result in a large change in energy distribution. Temporal variations can occur as a result of scanning antennas, moving vehicles, etc.

Further, even when the physical environment is otherwise static, perturbations in the RF field will be caused by the introduction of test equipment and/or personnel to monitor its intensity. To ensure that safety requirements are met, it is imperative that any measurement program take account of the possibility of these and other variations discussed in Section 2.3. It should, therefore, include a sufficiently large sampling of data to preclude omission of hazardous combinations of conditions.

2.2 Sources. Sources of dangerous radiation have widely different characteristics which impose a requirement for versatility upon the monitoring equipment. Pertinent characteristics are as follows.

(1) *Modulation.* The specific characteristics of the radiated signal in both the time and frequency domains are of prime importance

(2) *Antenna Pattern.* Some systems radiate in the same direction continually while others sweep the region of interest by either mechanical or electronic scanning techniques

(3) *Frequency.* Dangerous power levels may be present at frequencies spread over several octaves

(4) *Polarization.* Vertical linear, horizontal linear, elliptical, and circular polarization are all in general use

2.3 Typical Environment. The electromagnetic environment is determined by many factors. The direction of power flow from the

sources, the direction and distance of the sources and prominent features of the physical environment, the polarization, frequency, and strength of the sources are some of them. The variable nature of these factors and their effects on the resultant electromagnetic field must be understood to successfully design and operate instruments which measure the electromagnetic environment and to obtain sufficient data to ensure personnel safety.

In a typical radar site or communications complex, multipath interference often makes it difficult to obtain meaningful measurements. The region of concern may be irradiated from different directions by multiple sources with different characteristics, and will encompass structures causing standing waves. This leads to a complex radiated field with "hot" spots at different locations for different frequencies. Further, at least some of these may be time dependent if the sources utilize moving antenna beams. Even when the polarization characteristics of all threatening sources are known beforehand, it is possible for certain types of structures (such as gratings or angled supports) to modify the polarization in the region under investigation.

Radiation leakage from poorly designed electronic equipment presents special problems. The source of radiation is never clearly defined at the outset; the leakage is present by accident, not by interest. It could be coming from a crack in the shielding cabinet or from poorly bypassed connecting cables. The polarization of the electromagnetic field and the location of the leak are not known ahead of time. This is a special case of the general near-field situation, and the same problems can exist for all near-field measurements, whether the radiation is intentional or accidental.

A general theoretical treatment of the leakage (near-field) problem is beyond the scope of this standard. The survey techniques differ from those associated with the radiating antennas of radars and other communication equipment. In the leakage case, the location of the source is found by trial and error. A "sniffer" type of instrument is indicated; a nondirectional nonpolarized detector is desirable. The probing is done in the immediate vicinity of the equipment where directive pickup antennas would give poor readings because of their inability to respond to multi-

path signals and because of inaccurately known gain reduction factors in the near field. The following material is directed toward other than leakage problems.

3. Theoretical Calculations

3.1 Technical Considerations. The calculation of expected power-density levels may be a complex procedure. In addition to the usual factors such as peak power, pulse duration, and pulse recurrence frequency, consideration must also be given to antenna radiation patterns, antenna placement, scanning rates, and so on. It is also necessary to consider corrections for near-field effects. Calculations that should be satisfactory for the first-order computation of the maximum field intensity may be made by the methods cited below.

Calculations, which should be performed in advance of on-site measurements, require the following information on system operating parameters. These will be necessary to obtain the average radiated power from the antenna and the resultant power density at any point in space:

- Rated peak power (PP)
- Pulsewidths available (PW)
- Pulse repetition frequency (PRF)
- Duty factor
- Antenna
 - type and size
 - gain
 - orientation limits
 - beam width
 - height above ground
- Operating frequency (f)
- Orientation angles required to support system missions
- System insertion losses

The maximum peak power is used, and a pulse duration and pulse repetition frequency are selected that will most closely approximate, but not exceed, the maximum rated duty factor. If the maximum value of the average power density in the near field is less than the radiation protection guide limit (RPGL), no further calculations are necessary unless reflections could occur that might increase the

power density. (See American National Standard C95.1-1966.) In the case of multiple sources, the effects of each source must be considered to get the combined effect.

3.2 Parabolic Antennas — On Axis. The field in front of an antenna can be characterized by referring to three separate regions.

(1) *Reactive Near-Field Region.* This is the region of space immediately surrounding the antenna where the reactive components predominate and energy is stored in the field. This region usually extends only a few wavelengths from the antenna and is, therefore, not ordinarily important at microwave frequencies.

(2) *Radiating Near-Field Region.* This is the next region (sometimes called the Fresnel region). Here the antenna gain and the angular distribution of the radiated field vary with distance from the antenna. This is because the phase and amplitude relationships of the waves arriving at the observation point from different areas of the antenna change with distance.

(3) *Far-Field Region.* This region (sometimes called the Fraunhofer region) is the one sufficiently far from the source where the phase and amplitude relationships of the waves arriving from different areas of the antenna do not change appreciably with distance. The antenna gain and angular pattern are essentially independent of distance, and the power density is inversely proportional to the square of the distance from the source. Although the transition from the radiating near field is a gradual one, the far-field region is commonly assumed to begin at a distance of about $2D^2/\lambda$ and extends to infinity (D being the largest aperture dimension and λ the wavelength). For accurate measurements this criterion may not be adequate and should not be applied indiscriminately.

To compute an approximate value of the maximum power density W in the radiating near field for a circular dish transmitting antenna, use¹

$$W = \frac{16P}{\pi D^2} = \frac{4P}{A} \quad (\text{Eq 1})$$

¹ An alternative method of calculating W is given in the Appendix.

where

- P = radiated power
- D = effective diameter of antenna
- A = effective area of antenna

NOTE: If P is average power, W is average power density; if P is peak power, W is peak power density. Average power is used for calculating personnel hazards.

If this computation gives a power density less than the RPGL, then there is no need for further calculations, since Eq 1 gives the maximum power density that can exist on the axis of the beam of an antenna focused at infinity in the absence of reflections. (An antenna focused at a lesser distance could give a higher power density in the region of its focal point, but this condition is not usual.)

If the computation from Eq 1 reveals a power density greater than the RPGL, then one assumes that this value may exist any place in the near-field region, and attention is directed to the far-field region.

In the far-field region, the approximate free-space power density on the beam axis may be computed from

$$W = \frac{GP}{4\pi r^2} = \frac{AP}{\lambda^2 r^2} \quad (\text{Eq 2})$$

where

- λ = wavelength
- r = distance from antenna
- G = far-field antenna gain (power ratio)

The near-field equation 1 is valid for distances less than²

$$r_1 = \frac{\pi D^2}{8\lambda} = \frac{A}{2\lambda} \quad (\text{Eq 3})$$

For distances greater than r_1 Eq 2 should be used. The errors associated with these equations are less than 1.5 dB and are on the safe side since greater than actual power densities are predicted.

These equations do not include the effect of ground reflections. Values of power density as much as four times the free-space value can result when the main beam is directed toward a planar ground or reflecting surface. If the

² See Ref 8 for the derivation and discussion of Eqs 1–3.