GENERAL SAFETY PRECAUTIONS

MICROWAVE RADIATION

POWER DENSITY AND SAFE WORKING DISTANCES

IN FRONT OF RADAR ANTENNAS

1. GENERAL

1.01 It has been suggested that measurements be made of the power density of radar antennas before permitting work on poles, roofs, or towers in the vicinity of a radiation posted area. The reason for this suggestion is that the added height might bring personnel into the more intense field of radiation along the axis of a radar beam.

1.02 This section calls attention to some of the difficulties that tend to discourage the making of such measurements and suggests practical alternatives.

2. DIFFICULTY OF MEASURING

2.01 A major obstacle is that measuring microwave power density in the field with laboratory precision requires expensive apparatus which must be duplicated for each frequency band in which radar systems operate. An approximate cost estimate for covering all presently used bands is $25,000, excluding the expense of the vehicle used to transport the equipment and of an engine-alternator used to supply power. In addition to this large initial investment, there is the limitation that the equipment can be operated only by highly qualified engineering personnel. The sophistication of microwave measurement techniques calls for a high order of technical proficiency and considerable engineering intuition in the interpretation of results.

2.02 The more carefully measurements must be made, the less probable it is that they will be made frequently. For the measurements to be of any value, however, they must be made at frequent intervals because power density at any point is subject to change. For example, a building might be erected near a radar system in such a manner as to set up reflections and drastically alter the previously existing field pattern. Also, nearly all military electronic systems, including radars, undergo occasional changes intended to improve performance. Modification kits are installed which alter radar repetition rate, pulse length, and output power. Sometimes high-power klystrons are substituted for magnetrons and occasionally antennas are replaced by others with different characteristics. A location that is safe today may become hazardous tomorrow as a result of such equipment modifications.

2.03 The small number of locations where an individual telephone company might need to use precision measuring equipment, the need for making frequent measurements, and the difficulty of making the measurements, together with the size of the investment required, point to the desirability of finding a more practical approach to the problem of determining power density. One effective solution would be a small and inexpensive instrument that an intelligent layman could operate, i.e., a device for measurement of power density comparable to the familiar hand-carried Geiger counter used for measurement of ionizing radiation. Also, there have been inquiries from the telephone companies concerning the possibility of obtaining a microwave dosimeter which could be carried on the person, preferably an instrument capable of giving an audible alarm when allowable levels of power density are exceeded.

2.04 The Armed Forces are actively encouraging the electronics industry to work on such devices. Recently, one concern has announced development of a portable microwave radiation detector; another concern has produced a dosimeter small enough to be carried in the shirt pocket. Similar devices are understood to be under development by several other concerns.

2.05 A portable power density meter or dosimeter would be ideal for telephone company use, if it were sufficiently accurate and reliable. The design of microwave radiation detectors is, however, a new art, still in its infancy. The first instruments developed are by no means the final answer to the problem. They have numerous limitations; for example, they tend to be frequency sensitive and in many cases a separate instrument must be used for each radar frequency band. There are also problems of polarization, of shielding or shadowing of the instrument by the user's body, etc. Until such time that the performance of these very new devices can be carefully investigated, some other method of determining power density would appear to be necessary.

3. COMPUTATION METHOD

3.01 Rather than using radiation detectors of uncertain dependability or making laboratory-type field measurements, it should be possible to compute power density at a given point with sufficient accuracy for Operating Company purposes. Although the computation approach, with its necessary simplifying assumptions, may not be highly precise, the measurement method is about equally imprecise. Measurements are subject to errors of considerable magnitude. Under some circumstances, the power readings will fluctuate over a wide range if the exploring horn is moved only a few feet. It will be necessary to allow for the lack of precision of either method by employing an adequate factor of safety.

3.02 Because safe working distances based on either power density measurements or computations are subject to change without notice, the telephone company should check frequently with the cognizant military people concerning the status of their radar modification program. Power density should be recomputed and safe working distances revised as required.

Field Regions

3.03 The field in front of the usual parabolic antenna consists of two separate regions:

(a) The "near field," or Fresnel region — the area where the radiation pattern is approximately cylindrical

(b) The "far field," or Fraunhofer region — the area beyond the Fresnel region in free space, where the radiation pattern is essentially conical and power density along the beam falls off inversely with the square of the distance.

Symbols and Equations

3.04 The following symbols are used in the equations given below for computing distance and power density:

D = antenna diameter (for circular "dish" antenna)

G = power gain of antenna with respect to an isotropic source, expressed as a ratio (not as gain in dB)

P = average radar power output, ***not*** peak power

λ = wavelength

r = distance from antenna, along beam axis

w = power density

3.05 Consistent units must be used when substituting actual values for these symbols in the equations. For example, if w is to be expressed in milliwatts per square centimeter, then r, D, and λ must be in centimeters and P in milliwatts.

3.06 The computation of the value of power density in the near field, assuming a circular dish antenna, can be determined by

$$w = \frac{16P}{\pi D^2} \qquad (1)$$

3.07 The distance from the antenna to the outer end of the Fresnel region, again assuming a dish antenna, is given by

$$r_1 = \frac{\pi D^2}{8\lambda} \qquad (2)$$

If the antenna aperture is not circular, an equivalent value of D may be calculated from

$$D = \lambda \sqrt{\frac{G}{6E}} \qquad (3)$$

where

D = diameter in cm

G = gain (numerical power ratio)

λ = wavelength in cm

E = efficiency (For search radars to correct for lower antenna efficiency due to beam shaping, use $E = 0.55$. For height-finder radar antennas, use $E = 1.00$.)

Example for ARSR-1 FAA search radar having the following characteristics:

Efficiency	0.55
Frequency	1300 MHz
Antenna gain	34.5 dB (10- by 40-ft parabolic section)

Calculate wavelength in cm.

$$\lambda = \text{wavelength} = \frac{30{,}000{,}000}{1{,}300{,}000} = 23 \text{ cm}$$

$$G = \text{antenna gain} = \log^{-1} 3.45 = 2820$$

$$\frac{G}{6E} = \frac{2820}{6 \times 0.55} = 855$$

$$\sqrt{\frac{G}{6E}} = \sqrt{855} = 29.2$$

$$D = 29.2 \times 23 \text{ cm} = 672 \text{ cm}$$

3.08 In the Fraunhofer region, the power density on the beam axis may be computed from

$$w = \frac{GP}{\pi r^2} \qquad (4)$$

Allowance for Reflection

3.09 There is a possibility that power density may be increased as much as four times by reinforcement due to reflections from the ground. In the near field, the maximum density could reach a value of $64P/\pi D^2$. It is unlikely, however, that reinforcement would occur in the Fresnel region unless the antenna were pointed downward toward the ground. Reflections are much more likely to occur in the far field and an allowance for maximum reinforcement has been included in Eq. (4). Omitting this allowance from Eq. (1) and including it in Eq. (4) means, of course, that if the power at the boundary between Fresnel and Fraunhofer zones is computed by both equations, the two results would differ by a factor of 4 (or 6 dB).

Determining Boundaries of Hazardous Areas

3.10 To establish the boundaries of a hazardous area, substitute the maximum permissible exposure level (10 milliwatts per square centimeter) for w in Eq. (4) and solve for r. If r is less than r_1, computed from Eq. (2), no hazard exists. If r is greater than r_1, the radar system is at the center and r is the radius of a circular hazardous area (assuming the radar antenna can be rotated).

3.11 The distance r_1 in Eq. (2) and r in Eq. (4) both refer to distance along the radar beam axis. This is the controlling distance because power density is highest on the axis. The difference between power density on the beam axis and the off-axis power density will be sufficient at many locations, particularly those in the Fraunhofer region, to add materially to the margin of safety.

Sample Computations

3.12 The ARSR-1 radar used by the FAA has the following characteristics:

Frequency	1300 MHz
Repetition rate	360 Hz
Pulse length	2 μsec
Peak power	500 kw (or 500,000,000 mV)
Antenna size	40 ft by 11 ft
Antenna gain	34.5 dB

$$\text{Time for 1 cycle} = \frac{1}{360} \text{ sec or } 2780\ \mu\text{sec}$$

$$\text{Average power} = \frac{2 \times 500{,}000{,}000 + (2780 - 2) \times 0}{2780} = 360{,}000 \text{ mw}$$

$$\text{Wavelength} = \frac{30{,}000{,}000}{1{,}300{,}000} = 23 \text{ cm}$$

Antenna gain $= \log^{-1} 3.45 = 2820$

Let $w = 10$ mw/cm². Then from Eq. (4),

$$r^2 = \frac{2820 \times 360{,}000}{10\pi} = 32{,}300{,}000 \text{ cm}^2$$

$$r = 5680 \text{ cm or } 186.3 \text{ ft}$$

Calculate D from Eq. (3).

$$D = 672 \text{ cm}$$

Then from Eq. (2),

$$r_1 = \frac{\pi \times (672)^2}{8 \times 23} = 7700 \text{ cm or } 253 \text{ ft}$$

Since $r_1 > r$, there is no hazardous area. This can be verified from Eq. (1), again using $D = 672$ cm:

$$w = \frac{16 \times 360{,}000}{\pi \times (672)^2} = 4.06 \text{ mw/cm}^2$$

3.13 The FPS-6 radar used by the USAF has the following characteristics:

Frequency	2800 MHz
Average power	3600 watts
Antenna size	30 ft by 7.5 ft
Antenna gain	7400

$$\text{Wavelength} = \frac{30{,}000{,}000}{2{,}800{,}000} = 10.7 \text{ cm}$$

Let $w = 10$ mw/cm². Then from Eq. (4),

$$r^2 = \frac{7400 \times 3{,}600{,}000}{10\pi} = 848{,}000{,}000 \text{ cm}^2$$

$$r = 29{,}100 \text{ cm or } 955 \text{ ft}$$

Calculate D from Eq. (3).

$$D = 507 \text{ cm}$$

Then from Eq. (2),

$$r_1 = \frac{\pi \times (507)^2}{8 \times 10.7} = 9434 \text{ cm or } 309 \text{ ft}$$

Since $r > r_1$, it may be assumed that there is a hazardous area with a radius of 955 feet.

> *Note:* If there were no ground reflections, the radius would be half this value, or 478 feet. Thus, if the edge of the posted area is about 470 to 480 feet from the radar, it signifies that on actual measurement no reflection effects were noted. In the absence of measurements, it should always be assumed that reflections are occurring.