valid

Glaser

AMERICAN INDUSTRIAL HYGIENE ASSOCIATION

one of the

NON-IONIZING RADIATION GUIDE SERIES

see last page

"Radio Frequency and Microwave Radiation"

I. Band Limits

Frequency	10 Mhz - 300GHz
Wavelength	30 m - 0.1 cm
Photon energy	4×10^{-8}eV - 4×10^{-3}ev

To designate various microwave and radio frequency segments of the electromagnetic spectrum, a system of letter abbreviations is used. These are given in Table I.

The units of frequency listed in Table I are: kilohertz (KHz), (thousands of cycles) per second; megahertz, MHz, (millions of cycles) per second; and gigahertz, GHz, (thousands of millions of cycles per second). See Table I.

TABLE I
Spectral Bands

ELF	Extremely low frequencies	0 - 3 KHz
VLF	Very low frequencies	3 - 30 KHz
LF	Low frequencies	30 - 300 KHz
MF	Medium frequencies	300 - 3000 KHz
HF	High frequencies	3 - 30 MHz
VHF	Very high frequencies	30 - 300 MHz
UHF	Ultra high frequencies	300 - 3000 MHz
SHF	Super high frequencies	3 - 30 GHz
EHF	Extremely high frequencies	30 - 300 GHz

These bands are further subdivided into radar and microwave communication bands and are often identified with alphabetical notations. Although these are a convenient form of nomenclature, they have no official status and there is not always agreement as to the frequency limits associated with each band. One of the more common band letter designation systems is indicated in Table II.

II. Sources, Uses

Microwaves are usually generated by special types of electron tubes or semiconductor devices. Some of the more common electron tube devices are magnetrons, klystrons and backward wave oscillators. Among the many semiconductor devices are the IMPATT (impact avalanche transit time) diode, Gunn effect diode and tunnel diode. These sources may emit radiation in a continuous mode, as is usually the case in communications applications and heating appliances or in an intermittent or pulsed mode, as is usually the case with radar systems. Typical devices which emit microwave radiation include communication transmission systems, radar units, medical diathermy and microthermy, induction heating units and microwave oven appliances.

The high voltages required to operate the electron tubes used in microwave transmitting systems may produce ionizing radiation in the form of x-rays. This occurs because certain

TABLE II
Band Letter Designation Systems

BAND DESIGNATION	NEW FREQUENCIES (GHz)*	OLD FREQUENCIES (GHz)
A	0.1 to 0.25	
B	0.25 to 0.50	
C	0.50 to 1.00	3.90 to 6.20
D	1.00 to 2.00	
E	2.00 to 3.00	
F	3.00 to 4.00	
G	4.00 to 6.00	
H	6.00 to 8.00	
I	8.00 to 10.00	
J	10.00 to 20.00	
K	20.00 to 40.00	10.90 to 36.00
Ka	Discontinued	26.00 to 40.00
L	40.00 to 60.00	0.340 to 1.55
M	60.00 to 100.00	
P	Discontinued	0.225 to 0.39
Q	Discontinued	36.00 to 46.00
S	Discontinued	1.55 to 5.20
V	Discontinued	46.00 to 56.00
W	Discontinued	56.00 to 100.00
X	Discontinued	5.20 to 10.90

* Mil Std 463, 2 March 1972.

electronic tubes, such klystron, magnetron, traveling wave and high voltage thyratron, possess the basic physical parameters which allow them to act as x-ray generators.

III. Antennas

A. SHAPE: At microwave frequencies it is possible to radiate electromagnetic energy in such a manner that the radiated energy gives increased power in a particular direction. This is accomplished by the antenna. The directivity and focusing effects of antennas in the microwave region are very similar to a spotlight producing a beam of light. Antennas are produced in many configurations.

In the radio-frequency, a single vertical metallic rod is utilized as an antenna whereas the television frequencies because of the need for directionality, require an antenna consisting of a horizontal rod with a second rod used as a reflector. At the higher microwave frequencies the antenna configuration is usually a parabolic section of metal, either circular or rectangular, and may be as small as 76.2 cm (30 in.) in diameter or as large as 45.72 m (150 ft.) in diameter.

B. ANTENNA FEED SYSTEM: Since most microwave antennas utilize reflectors to form and focus the beam, some method for getting the microwave energy to the reflector must be used. This is accomplished by the *antenna feed system*. This may be a very simple horn at the end of the waveguide aimed at the reflector, or a complicated system designed for specific beam patterns.

IV. Polarization

The antenna concentrates the microwave energy into a shaped beam which consists of a radiation field. This field is made up of an electric field (E-field) and a magnetic field (H-field). In free space, these two fields are at right angles to each other and move through space at the speed of light. The polarization of an antenna is defined as the direction of the electric field vector component of the radiated field with respect to the earth's surface. The various types of polarization are:

a. Linear Polarization
b. Elliptical Polarization
c. Circular Polarization

For maximum transfer of energy, a receiving antenna must have the same polarization as the transmitting antenna. That is not to say that antennas which are not of the same polarization cannot be used together. In the case where the antennas are not the same, the energy transferred depends on the exact polarization of each antenna. For example, if the transmitting antenna is circularly polarized, and the receiving antenna is linearly polarized, then the receiving antenna only detects half of the energy beamed at it. Each combination must be analyzed as a separate case.

V. Interaction With Matter

Microwave radiation, like other forms of electromagnetic energy, may be absorbed, reflected or transmitted when it impinges upon or interacts with matter. The frequency of the radiation as well as the conductivity, dielectric constant and permittivity of the material upon which the radiation impinges, determine the relative extent of absorption, reflection or transmission. The lower the dielectric constant of the material, the greater the penetration of microwave radiation. Animal tissue, for example, simultaneously absorbs, reflects and transmits microwave energy. Metals with their characteristically high conductivity reflect rather than transmit microwaves, therefore, copper or aluminum for example are well suited for use as waveguides and protective barriers. Non-biological effects also must be considered. For instance, flash bulbs have been ignited and sparks drawn from hand-held metal pieces in microwave fields. Interference with the proper functioning of certain cardiac pacemakers has also been related to the presence of rf and microwave radiation.

VI. Mode of Interaction With Biological Systems

Microwaves interact with matter primarily through the conversion of electromagnetic energy to potential molecular energy in the absorbing medium. Dissipation of the potential energy results in the production of heat. Wavelengths less than 3 cm are absorbed primarily by the skin; those from 3 to 10 cm penetrate more deeply, whereas those from 25 to 200 cm penetrate deepest and may cause damage to internal body organs. The human body is thought to be essentially transparent to wavelengths greater than 200 cm, i.e. very little interaction with tissue takes place. The depth of penetration of microwaves into the body is approximately equal to 0.1 of the wavelengths between 3 cm and 200 cm.

The organs of the human body which are of primary interest from the standpoint of microwave exposure are those which are relatively avascular; i.e. they do not have a high capacity for removing heat through the circulation of blood.[1] The organ of greatest concern is the eye (potential cataract production), followed by the hollow viscera and testes.[2] The possibility that microwaves may interact with the central nervous system (CNS) at the molecular and cellular level, without significant heating, has been suggested by several Soviet investigators.[3,4] The phenomenon of "pearl chain formation" is an example of a non-thermal biological system response in which microorganisms or small cells become aligned in a specific pattern in a microwave field. The biological effects of microwave radiation are summarized in Table III.

TABLE III
Characteristics of Microwave Radiation[9]

FREQUENCY MHz	WAVELENGTH cm	SITE OF MAJOR TISSUE EFFECTS	MAJOR BIOLOGICAL EFFECTS
More than 10.000 (10 GHz)	Less than 3	Skin (Outer layer of skin reflect and absorb)	Heating of skin
10.000–1.000	3-30	Skin and eye (Energy penetrates more deeply into skin)	Development of cataracts
1.000–150	30-200	Internal body organs (Very deep penetration, possibly of heat	Potential for overheating internal body organs
Less than 150	More than 200	Body is thought to be transparent	Unknown

VII. Measurements and Evaluation

Parameters which should be determined in assessing a potential hazard include the average energy flux or power density (usually measured in milliwatts per square centimeter, $mW \cdot cm^{-2}$), the wavelength of the energy, the portion of the body exposed, and the duration of exposure. The equipment and techniques associated with the measurement of microwaves are complex. Most measuring devices are based on bolometry, calorimetry, and voltage and resistance changes in detectors.[5] Low frequency radiation of less than 300 MHz may be measured with loop or short whip antennas. A particularly troublesome problem is the measurement of microwave radiation levels in the near or reactive field where unpredictable radiative patterns may be produced. Because of this, magnetic field as well as the electric field must be measured. In general, measurement devices should be equipped with antenna probes which are electrically small so as to minimize perturbation of the field, the impedance should be matched so that there is no backscatter from the probe to the source, the probe should behave as an isotropic receiver, it should be sensitive to all polarizations, the response time should be adequate for handling the peak to average power of the radiation and the overall response of the instrument should be flat over a broad band of frequencies.

VIII. Recommended Maximum Exposures

A. American National Standards Institute (ANSI)[6]

1. *Power Density:* 10 $mW \cdot cm^{-2}$ maximum allowable exposure level for periods of 0.1 hour or more.
2. *Energy Density:* 1 m $W \cdot cm^{-2}$ (3.6 $J \cdot cm^{-2}$) maximum exposure level during any 0.1 hour period.
3. Electric field strength of 200 $V \cdot m^{-1}$.
4. Magnetic field strength of 0.5 $A \cdot m^{-1}$.

Part 1 and 2 of the ANSI Standard are currently the adopted OSHA standard.[7]

B. American Conference of Governmental Industrial Hygienists (ACGIH)

The threshold Limit Value for occupational exposure to microwave radiation in the frequency range of 100 MHz to 100 GHz where power densities are known and exposure time controlled, is as follows:

1. For average power density levels up to but not exceeding 10 $mW \cdot cm^{-2}$, total exposure time shall be limited to the 8 hour workday (continuous exposure).
2. For average power density levels from 10$mW \cdot cm^{-2}$ up to but not exceeding 25 $mW \cdot cm^{-2}$, the total exposure time shall be limited to no more than 10 minutes for any 60 minute period during an 8 hour workday (intermittent exposure).
3. For average power density levels in excess of 25$mW \cdot cm^{-2}$, exposure is not permissible (ceiling value).

C. U.S. Army/Air Force - 1965[8]

$T_p = \frac{6000}{W^2}$ for T_p less than 1 hour,

10 $mW \cdot cm^{-2}$ for periods greater than 1 hour.

Where T_p is the permissible time of exposure in minutes during any one hour period and W is the power density in milliwatts per square centimeter within the area to be occupied. In practice, the formula should not be used for power densities above 55 $mW \cdot cm^{-2}$. Power densities of 100 $mW \cdot cm^{-2}$ or greater are denied exposure levels.

D. U.S.S.R. - 1958

Radiation Frequency

1. 1.5 to 30 MHz
   30 to 300 MHz
   greater than 300 MHz

Maximum Recommended Level

20 volts per meter (V/m)
5/Vm
1×10^{-5} W/cm^2 (6 hour day)
1×10^{-4} W/cm^2 (2 hours per day)
1×10^{-3} W/cm^2 (15 minutes per day with protective goggles)

E. Czechoslovakian Soc. Rep.

Radiation Frequency

1. 0.01 to 300 Mhz
   300 Mhz

Maximum Recommended Level

10 V/m (8 hour day)
2.5×10^{-6} W/cm^2 (8 hour day CW operation)
1.0×1.0^{-6} W/cm^2 (8 hour day pulsed)

Values for shorter exposures are computed using a dose reciprocity relationship.

IX. Control

The responsibility for controlling hazards caused by microwave radiation rests with supervisory personnel. All personnel should receive initial and periodic indoctrination and training in methods for controlling exposures. Specific control measures may include: 1) mapping out of unsafe areas, 2) posting of warning signs, 3) establishing procedures for excluding unauthorized persons, 4) excluding persons from unsafe areas, 5) establishing safe work practices and engineering controls such as shielding and interlocks, 6) providing protective equipment, if needed, 7) establishing microwave radiation and medical monitoring and 8) maintaining strong supervisory influence over microwave operations.

X. References

1. **Cleary, S. F.:** *The Biological Effects of Microwave and Radio Frequency Radiation.* CRC Critical Review in Environmental Control. 1st Ed. 2nd Iss. p. 257 (1970).
2. **Carpenter, R. L. and C. A. Van Ummersen:** *J. Microwave Power.* 3:3 (1968).
3. **Tolgskaya, M. S. and Z. V. Gordon:** Transaction Institute of Labor Hygiene and Occupational Diseases of the Academy of Medical Science. p. 99 (1960).
4. **Orlova, A. A.:** Proceedings on Labor Hygiene and the Biological Effects of Electromagnetic Radio Frequency Waves. p. 25 (1959).
5. **Bowman, R.:** *Biological Effects and Health Implications of Microwave Radiation.* U. S. Government Printing Office. (1970).
6. **American National Standards Institute,** Standard C95.1. (1974). *Safety Level of Electromagnetic Radiation with Respect to Personnel.* New York. (1974).
7. **U. S. Department of Labor,** Title 29, Code of Federal Regulations, Sec. 1910.97, Washington, D. C., Occupational Safety and Health Administration. (1972).
8. **U. S. Department of the Army,** TB MED 270: *Control of Hazards to Health from Microwave Radiation.* Washington, D. C. (1965).
9. **Tyler, Paul E., Ed.:** Biologic Effects of Nonionizing Radiation. Ann. NY Acad. Sci. 241:1. (1975).

Prepared under the auspices of the Non-ionizing Radiation Committee: Thomas K. Wilkinson, Chairman; Richard F. Boggs, Ph.D.; Robin J. DeVore; Walter L. Eneidi; Donald A. Greschaw; Alphonse F. Klascius; Charles R. McHenry; Gordon C. Miller; Wordie H. Parr; Uwe Reischi, Ph.D.