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**Conference of Radiation Control
Program Directors, Inc.**

Instrumentation for Nonionizing
Radiation Measurement

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(Continued on inside back cover)

Instrumentation for Nonionizing Radiation Measurement

Office of Science and Technology
Division of Physical Sciences
Acoustics Branch
Electromagnetics Branch
Electro-Optics Branch

and

National Bureau of Standards
Electrosystems Division

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CONFERENCE OF RADIATION CONTROL PROGRAM DIRECTORS, INC.
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Rockville, Maryland 20857

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FOREWORD

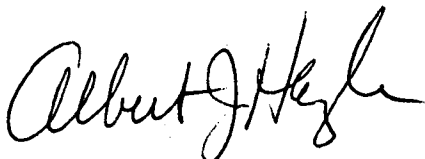
The Conference of Radiation Control Program Directors is comprised of all directors of radiation control programs in the 50 states, the Territories, and some large municipal agencies. The Conference was formed to help exchange information among State and Federal agencies, in areas of mutual concern or interest. Additional objectives and purposes of the Conference are to:

1. Promote radiological health in all aspects and phases.
2. Promote cooperative enforcement programs with Federal agencies and between related enforcement agencies within each State.
3. Collect and make accessible to all radiation control program directors information and data to help them fulfill their duties.
4. Foster uniformity of radiation control laws and regulations.
5. Support programs which will contribute to radiation control.
6. Assist members in their technical work and development.
7. Exercise leadership with radiation control professionals and consumers in radiation control development and action.

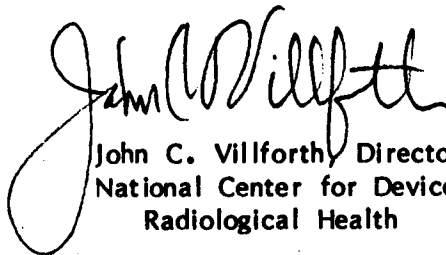
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The Center, by contract and direct operations, supports the Conference of Radiation Control Program Directors in its objectives and activities for an action oriented Federal/State partnership to achieve and maintain comprehensive radiological health protection. Selected reports of the Conference are published by the Center and are generally available for purchase from the Government Printing Office or the National Technical Information Service.

Readers are encouraged to report errors or omissions to the Conference or the Center. Your comments or requests for further information are also welcome.



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Conference of Radiation Control
Program Directors, Inc.



John C. Villforth, Director
National Center for Devices and
Radiological Health

PREFACE

This document is a product of the Conference of Radiation Control Program Directors' Subcommittee G-3 on Nonionizing Radiation Measurements. Subcommittee G-3 was established in 1979 to help ensure adequate quality of measurements needed for nonionizing radiation safety. In recent years, the Committee has assisted the National Bureau of Standards in its study of the "Requirements for an Effective National Nonionizing Radiation Measurement System" and has conducted surveys regarding (a) regulations existing in the various States and (b) State priorities on the matter of nonionizing radiation exposure hazards.

The specific purpose of this document is to assist State and local radiation protection personnel in selecting instruments for the investigation of potential nonionizing radiation hazards. For measurements involving radiofrequency radiation, 60 Hz fields, and ultrasound, most, if not all, of the commercially available instruments are listed. For optical measurements it was not feasible to include every manufacturer, and in this case only representative instruments are listed.

Specifications listed in this report are taken from data sheets distributed by the manufacturers. Neither the Conference of Radiation Control Program Directors, the National Center for Devices and Radiological Health, nor the National Bureau of Standards has verified the accuracy of the information presented in this directory. The inclusion or omission of a company or an instrument in the directory does not constitute an endorsement or rejection of that company or instrument. References cited in the report call attention to those cases where Federal agencies have conducted instrument evaluations.

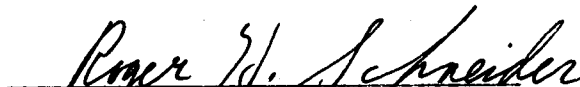
The majority of the work involved in the preparation of this document was contributed by members of the National Center for Devices and Radiological Health, Division of Physical Sciences and the NBS Electrosystems Division. The Committee particularly appreciates the contributions of: T. Whit Athey, Tadeusz Babij, Owen Ellingson, Michael Haran, Bruce A. Herman, William A. Herman, Robert Landry, and Harold F. Stewart of the National Center for Devices and Radiological Health; and Ronald McKnight, National Bureau of Standards.

Members of the Committee on Nonionizing Radiation Measurements who contributed to the development include Frank Bradley (NY), Suzie Kent (TX), and Charles Tedford, Chairman (AZ). Federal Resource Personnel who participated include Howard Clark (NBS), Norbert Hankin (EPA), William A. Herman (NCDRH) and Frank Tipton (OSHA). The Conference of Radiation Control Program Directors received direct financial support from the National Bureau of Standards. This document was published by the National Center for Devices and Radiological Health.

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ABSTRACT

National Center for Devices and Radiological Health, National Bureau of Standards, and the Conference on Radiation Control Program Directors, Inc. Instrumentation for Non-ionizing Radiation Measurement. HHS Publication FDA 84-8222 (January 1984)(pp. 27).

The successful evaluation of a given exposure to nonionizing radiation requires several steps. The source must be identified and characterized so that one may select the most appropriate measurement technique and instrument. The use of any instrument requires an understanding of the nature of the quantity to be measured, and of the limitations of the instrument to be used. Finally, one must have a knowledge of the pertinent safety standards or guidelines to determine the significance of the measured values. This report describes this evaluation process for optical, radiofrequency/microwave, ELF (powerline frequency), and acoustic radiation. It includes many practical measurement considerations and a comprehensive listing of the specifications and applications of commercially available instruments.

INTRODUCTION

Ionizing radiation (including x-, gamma-, and particulate radiation) has long been known for the ability to produce biological damage. Each quantum or particle of ionizing radiation contains enough energy to break organic chemical bonds, thus ionizing biologically significant molecules. Nonionizing radiation contains much less energy per quantum and is incapable of ionizing such molecules. Nevertheless, it possesses the potential for harm. There are three recognized categories of nonionizing radiation: (1) radiofrequency radiation (including microwave), (2) optical radiation, and (3) acoustic radiation. The first two are forms of electromagnetic energy (see Figure 1); the third type comprises mechanical vibrations.

Recent years have seen dramatic expansion in applications of lasers, medical ultrasound, and microwave technology. With these advancements in technology have come new concerns about the potential biological significance of human exposure to this type of radiation. Both biological research and exposure standards have undergone substantial development.

All of these events underscore the need for a concise compendium of information on instrumentation for measurement and evaluation of nonionizing radiation sources and environments, especially for governmental radiation professionals at the State and local levels. This publication describes commercial instrumentation for each of the three nonionizing radiation areas. A brief introduction is provided to each topic, followed by an explanation of fundamental quantities and units. A description of available instrumentation is provided for each topic, along with a brief discussion of current standards and guidelines. Because the number of instruments and components used for measurement of optical radiation is so unwieldy, this document describes only generic instrument characteristics for this area. Instruments for the very-low-frequency band of the radiofrequency spectrum have been treated in a separate section because of the dominating influence of specialized high-voltage transmission line measurements at these frequencies. Sonic and infrasonic radiation are not treated.

OPTICAL RADIATION MEASUREMENT INSTRUMENTATION

INTRODUCTION

Optical radiation is electromagnetic radiation having wavelengths near or in the visible region, specifically between x-rays and microwaves. This is represented by the central portions in Figure 1.

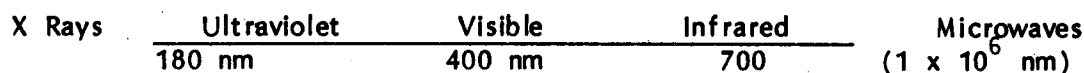


Figure 1. Optical spectrum range.

A wide variety of electronic products emit optical radiations either as necessary and intended output or as a byproduct of operation. Typical sources include incandescent, fluorescent, and other general lighting products, high intensity discharges (including welding devices), and special purpose sources including strobe lamps, lasers, searchlights, germicidal and tanning lamps.

Optical sources vary widely in fundamental characteristics, from devices that emit in a very narrow wavelength band (monochromatic) to those that emit over wide bandwidths (e.g., blackbody emitters); from tightly confined spatial fields (collimated) to isotropic radiators (e.g., the sun). Temporal characteristics vary greatly from femtosecond (10^{-15} sec.) pulses to continuous emitters. The instruments used to measure optical radiations typically consist of input optics, a detector, signal processing system, and a readout unit.

QUANTITIES AND UNITS

The essential radiometric quantities and units of interest for hazard evaluation are defined and illustrated in Figure 2. While certain quantities in Figure 2 could be presented differently (1-4), this nomenclature is recommended to express the results of optical radiation measurements. These quantities may, on occasion, be further applied in describing the distribution of radiations within the spectrum. Thus, spectral irradiance (irradiance per unit wavelength) or spectral radiance (radiance per unit wavelength) are frequently utilized.

Another aspect of nomenclature is the naming of various regions of the spectrum (5). The lines of demarcation between, and the terminology for, regions of the optical spectrum vary from one group of specialists to another. For example, the wavelength separating the visible from the ultraviolet portion of the electromagnetic spectrum is 380 nanometers (nm) for some and 400 nm for others. Similarly, the lower limit of "UVA" may be 315 nm or 320 nm depending on specialty. The separation between "UVC" and "UVB" may be 280 nm or 290 nm, again depending on who uses the terms. A given region of the spectrum has been known to carry two or more names. For example UVB has been referred to as erythema UV, and UVC as germicidal or actinic UV. At the longer wavelength regions of the optical spectrum, one encounters an uncertain division between visible and infrared and several arbitrary subdivisions of infrared into near infrared and far infrared. Indeed the upper and lower limits of the optical spectrum are not agreed upon. Therefore, if names are used, one must precisely define them.

1. Total power or energy collected in an integrating sphere.

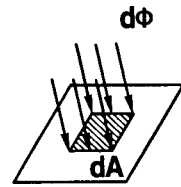
Radiant Energy Q (J)

Radiant Flux Φ (W)

$$\Phi = dQ/dt$$

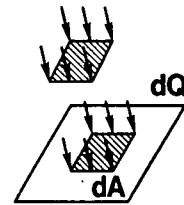
2. Irradiance E (W/m²) for a continuous source.

$$E = d\Phi/dA$$



3. Radiant Exposure H (J/m²) for a pulsed source.

$$H = dQ/dA$$



4. Radiance (Luminance) L (W/m²·sr)

$$L = d^2\Phi/d\omega dA \cos\theta$$

dA = elemental area contained in given point

$d\omega$ = elemental solid angle containing given direction.

θ = angle between normal to elemental area and given direction.

Φ = angle in plane of elemental area.

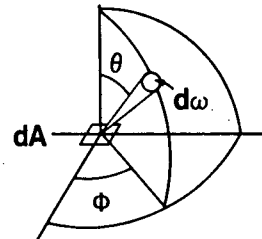


Figure 2. Selected radiometric quantities (7).

INSTRUMENTS AND MEASUREMENTS

Selection of instrumentation requires a clear appreciation of the intended application. In the most general sense, optical radiation can be separated in two broad groupings: coherent and noncoherent.

COHERENT SOURCE MEASUREMENT

General Consideration

Specialized instruments have evolved for the measurements of radiation from coherent sources (laser). Lasers present unique measurement situations because certain laser devices:

- Emit tightly collimated beams with resultant high irradiances; and
- Emit energy in extremely short pulses with resultant high peak powers.

Either of these conditions can lead to damage of detectors and present potential biological hazard. The use of conventional optics (lenses or plane parallel surfaces) in the measurement of coherent radiation can introduce errors caused by interference phenomena. Thus, detectors and input devices must be chosen with care. Detectors, implying all input surfaces and surfaces receiving or responding to incident radiation, must have a damage threshold sufficient to withstand high peak powers or the high irradiances which may be present in a given beam spatial distribution. Selection of a detector may be further complicated by the duration of the emissions.

Continuous-Wave (CW) Laser Measurements

A windowless silicon detector instrument has a spectral response over the wavelength range of 200-1100 nm. The sensitivity of the bare silicon detector is wavelength dependent with the maximum sensitivity in the 700-900 nm region. The use of a radiometric filter, wedge window, or selected filters can reduce the effective spectral response to specific wavelength ranges. Measureable power levels range from 10^{-8} watts to 10^{-3} watts and can be extended to 10^{+2} using an attenuator or diffuser.

Calorimeter instruments incorporate radiation-absorption materials having temperature changes which can be detected, generally by thermocouples, to measure the laser power or energy. The radiation absorbing detector may be a flat black painted disk or a volume of glass. Absorbers may have other configurations such as a truncated cylinder, polygon or a modified disk. The temperature differential may be measured between the disk and a heat sink, or between the absorbing disk and reference disk. Calorimeters can be used to measure CW radiation from approximately 1 mW to more than 100 W depending on the absorber and the wavelength. Pulsed energy radiation can be measured from 10 mJ to 10,000 J, depending on the absorber and wavelength and pulse duration (See "Pulsed Laser Measurements" below). The response time can range from 10 seconds to 10 minutes depending on the energy/power range and absorber design.

Pyroelectric detectors use material that possesses a permanent electric polarization that is temperature dependent. The absorption of laser power or energy causes a temperature change that results in an electrical change in the detector. The pyroelectric detectors are capacitive, rather than resistive, and the instrument has an excellent high-frequency response. In addition, the detector has a flat spectral response from 250 nm - 20,000 nm (depending on entrance window), and has a high sensitivity and a wide

dynamic range. Since measurement of a CW signal is dependent on a change in the electrical potential across the detector, a chopper (internal or external) is usually incorporated in the instrument system for CW laser measurements.

Pulsed Laser Measurements

Several parameters must be considered in the measurement of pulsed lasers. In addition to the measurement of average power or energy of the laser beam with a silicon or pyroelectric detector, the peak power, pulse duration, pulse repetition rate, and the other temporal characteristics of the pulse must be measured. A procedure for making these additional measurements would be to couple the detector through an amplifier to a storage oscilloscope. The resulting measurement of the pulse characteristics (pulse width, pulse shape, repetition rate) allows a calculation of the power or energy of the pulsed laser radiation. It should be emphasized that meaningful measurements require accurate calibration of the complete instrument system for power or energy at the wavelength(s) of interest.

Specific Measurement Applications

Laser Light Shows

The laser beam from commonly used projectors is in the visible wavelength range and power levels vary from milliwatts to watts. Laser beams reflected from mirrors or other specular surfaces are potentially hazardous. CW measurement of stationary beams can be made with all three types of detectors so long as the damage threshold of a detector is not exceeded. Movement or scanning of the beam using mirrors presents an apparent "pulsing" of the beam as it is moved across a detector. In addition to a power measurement, the temporal pulse characteristics, and pulse rate, usually have to be measured using a silicon detector, amplifier and oscilloscope, in order to calculate any potential hazard that may be associated with a moving laser beam.

Laser energy may also be reflected from imperfect, diffuse surfaces. The incident energy is usually scattered and has a lower average irradiance after scatter (local "hot spots" may occur). Power measurements can be made with a silicon detector. The hazard to the eye, however, may be more dependent on the light reradiating from the diffuse surface and radiance measurements may be necessary. For this type of measurement, a silicon detector can be used to measure the radiation through two apertures that are separated by a known distance. The apertures serve to define the source to derive the radiance based on a measurement of irradiance of the source.

Medical Lasers

The use of lasers for medical application (in ophthalmology, dermatology, surgery, and therapy) is widespread and expanding rapidly. Examples of visible lasers used in medicine are the argon, krypton, and ruby lasers. Examples of infrared lasers are Nd-YAG and CO₂. Federal regulations require the manufacturer of these products to incorporate a method of measuring output power or energy levels.

Direct beam measurements usually would require the use of a detector having a relatively high damage threshold. Measurement of stray or scattered radiations may also be necessary and detectors of greater sensitivity may be required. Measurements of irradiance and/or radiance can be made with a silicon detector for visible wavelengths. A pyroelectric detector may be employed for infrared lasers.

Construction Industry Lasers

Alignment lasers are usually helium-neon lasers with power levels in the 1-5 mW range. Power measurements can be made with a silicon or a pyroelectric detector.

Lasers used for leveling usually operate with a scanning or rotating beam. The power or energy in the resulting pulses can be measured with a silicon detector of a known aperture, an amplifier, and an oscilloscope.

Industrial Drilling, Cutting, and Welding

The laser specifications (CW or pulsed, wavelength, repetition rate, power or energy levels) will determine the type of detector to be used for the measurement of power or energy levels. Pulsed laser radiation will require additional instrumentation which may include an oscilloscope and high speed detector to characterize the temporal distribution.

Industrial systems frequently use enclosed systems and evaluation will require instrumentation suitable for measurement of stray, scattered, or leakage radiations through ports, vents, and viewing optics.

For many laser systems, there will also be optical radiations associated with the "pumping" or excitation of the laser medium. Measurement of these "collateral radiations" is performed as a noncoherent measurement problem.

Noncoherent Radiation-Source Measurement

Ultraviolet

If it is suspected that a source is emitting hazardous ultraviolet radiations, one may proceed in either of two ways. The most thorough analysis will entail the use of a spectroradiometer (6) for the measurement of spectral irradiance. (Out-of-band emissions; i.e. visible and infrared wavelengths, can introduce serious errors in the intended measurement; i.e., ultraviolet. Care must be taken to select a spectroradiometer which is relatively free of this problem.) The extent of the hazard is then quantified by applying a set of biological weighting factors to the radiometric data. One of the most widely used criteria is the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLV) for radiation at wavelengths of less than 315 nanometers.

An alternate method for estimating the potential hazard is to use an Ultraviolet Hazard Monitor which provides a direct estimate of the potential hazard for wavelengths less than 315 nanometers. Direct reading instruments are commercially available. These devices usually employ a filter-detector system which provides the instrument with a spectral response according to the ACGIH TLV's or some other biological weighting function such as an erythema action spectra.

It is usually not necessary to measure the emissions from broken mercury lamps since it is well established that these emit hazardous levels of ultraviolet radiation when operated. However, if documentation of ultraviolet emissions from these broken lamps is needed, instrumentation to measure spectral irradiance or direct reading instruments, as described above, may be used to assess the potential hazard.

Visible and Infrared Sources

If a retinal hazard is suspected, it will be necessary to determine the spectral radiance of the source. This is because of the well-established relationship between the radiance of a source and the resulting retinal irradiance. When a source's spectral radiance is known, it is possible to apply the ACGIH TLV's for retinal photochemical injury from chronic blue-light exposure and from infrared radiation. In general, the evaluation of retinal hazards from visible-light or infrared sources requires the use of a spectroradiometer.

Although the skin is far less vulnerable than the retina to injury from visible and infrared radiation, there may be some situations in which a skin hazard can be significant. Measurement of the high levels involved will normally require an instrument such as a calorimeter or a pyroelectric radiometer. The resulting measurements may be compared to skin-exposure limits established for lasers, which can pose similar hazards.

STANDARDS AND GUIDELINES

Standards promulgated by NCDRH relating to Optical Radiation from electronic products are:

LASER PRODUCTS 21 CFR 1040.10 EFFECTIVE 8/2/76

The laser standard is applicable to the manufacturer of laser products. This standard requires the manufacturer to certify the compliance of the product.

The standard also specifies requirements for labeling, certain engineering safety features, including interlocks, beam attenuators, etc., and user safety information.

HIGH INTENSITY MERCURY VAPOR DISCHARGE LAMPS 21 CFR 2040.30 EFFECTIVE 3/7/80

The mercury vapor lamp performance standard was promulgated to reduce the possibility of injury from exposure to shortwave ultraviolet radiation from broken mercury or metal halide lamps. The standard permits two types of lamps:

- regular, non-self-extinguishing mercury vapor lamps clearly marked with an "R" and intended for use in areas not occupied by people, such as in remote roadway lighting, parking lots, warehouses, etc. A warning label for lamp packaging and advertising is also specified.
- self-extinguishing lamps clearly marked with a letter "T" that are designed to self extinguish within 15 minutes if the outer envelope is broken. They are intended for use in areas where the public might be exposed as in schools, auditoriums, gymnasiums, etc. Requirements are specified for labeling, caution and/or warning statements and adequate user information.

SUNLAMP PRODUCTS AND ULTRAVIOLET LAMPS INTENDED FOR USE IN SUNLAMP PRODUCT 21 CFR 1040.20 EFFECTIVE 5/7/80

The sunlamp performance standard was promulgated to reduce the possibility of sunlamp-related injury by reducing unnecessary UV radiation, providing adequate labeling and user information and adequate protective eyewear and timers.

PROPOSED SUGGESTED STATE REGULATIONS FOR LASERS

The suggested State regulations provide detailed information in three areas:

General Provisions

Registration Procedure; and

Laser Radiation Protection Provisions.

The classification of laser products in these regulations follows the classification requirements of 21 CFR 1040.10. Exposure requirements are based on the maximum permissible exposure limits (MPE's) of ANSI-Z136.1 for the user of laser products.

OTHER USEFUL GUIDELINES ARE:

American National Standard for the Safe Use of Lasers, ANSI Z136-1980.

American Conference of Governmental Industrial Hygienists Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment.

U.S. Dept. of Labor, OSHA regulation for the construction industry:
29 CFR 1926.54, Nonionizing Radiation.

INSTRUMENTS FOR THE MEASUREMENT OF RADIOFREQUENCY/MICROWAVE RADIATION

INTRODUCTION

This section will provide an introduction to radiofrequency (RF)/microwave electromagnetic fields and a description of instruments available for their measurement. Only commercially available instruments will be treated; prototype or experimental instruments are not included. The instruments described herein are useful over most of the frequency range from 0.1 Hz up to 26 GHz, but no single instrument can cover this entire range. Instruments must be chosen by frequency range, field strengths, etc., according to the specific application as described later in this section.

QUANTITIES AND UNITS

Electric fields are specified in terms of the electric field strength (or voltage gradient) in the units of volts per meter (V/m). Magnetic fields are specified as magnetic field strength (H) or magnetic flux density (B), where $B = \mu H$ and μ is the magnetic permeability. In the MKS system the units of H are amperes per meter (A/m); B is specified in the cgs unit, gauss, or in the MKS unit, tesla (T) (One tesla = 10^4 gauss).

In air (and for most practical purposes in biological tissue as well) $\mu = 1$ in the cgs system, so that B, measured in gauss, is equal to H, measured in (the cgs unit) oersted ($1 \text{ oersted} = 10^3/4\pi \text{ A/m} = 79.577 \text{ A/m}$). This is the reason why the magnetic field strength, H, is sometimes given (somewhat incorrectly) in terms of gauss instead of oersteds or A/m.

In the region of space immediately surrounding a radiating source, an antenna, or reflector, the relative strength and orientation of the electric and magnetic fields will be determined by the geometry of the source (or reflector) as well as the location of the measurement point. In this region, called the near field, the electric and magnetic fields must be measured separately since their interrelationship is not usually known. However, at distances from the source greater than $2d^2/\lambda$, where λ is the wavelength and d is the largest physical dimension of the source, the electric and magnetic fields assume a fixed relationship characteristic of the far field.

In the far field of a source, measurement of either the electric or the magnetic field is sufficient to determine the other. In this case one can specify the electromagnetic field in terms of the power flowing through a unit area, i.e., the power density. Commonly used units for power density include milliwatts per square centimeter (mW/cm^2) and watts per square meter (W/m^2).

None of the instruments described herein, which have power density readout units, actually measures power density directly. Rather, the field probe is sensitive to either the electric or magnetic field, and the equivalent far-field power density is displayed on the meter. Below about 100 MHz, the electric and magnetic fields are customarily specified rather than the power density, even in the far field.

Electric and magnetic fields are vector quantities, possessing, in addition to magnitude, a direction or polarization. The electric or magnetic field sensor can detect only the component of the field parallel to the sensor (single-axis sensors). Most survey instruments are built with three mutually orthogonal field-sensing elements, and

their outputs are summed to produce a signal proportional to the total field. Some instruments may still have some polarization sensitivity. For example, some manufacturers advise against making electric field measurements when the field is parallel to the probe handle due to pickup on the leads.

Measurement techniques are discussed in detail in the ANSI C95.5-1981 standard, "Recommended Practice for the Measurement of Hazardous Electromagnetic Fields - RF and Microwave" (8). These techniques are useful from approximately 1 MHz to 100 GHz, and both near- and far-field measurements are discussed. A detailed discussion of radiofrequency instrumentation, including both broad-band and narrow-band equipment, can be found in Reference 9.

INSTRUMENTS AND MEASUREMENTS

All electromagnetic field instruments employ either electric- or magnetic-field detectors, even though some have a power density readout. At frequencies which are sufficiently low that "power density" is not an appropriate term, the readout will usually be in terms of the corresponding field units (i.e., V/m or A/m). It should be noted, however, that even the higher frequency instruments are still nothing more than either electric- or magnetic-field detecting instruments. In a few instruments this is made more explicit (and appropriate) by having the readout in terms of V^2/m^2 (or A^2/m^2) instead of mW/cm^2 .

Some desirable characteristics for instruments include:

- isotropic response,
- should not cause significant field perturbation,
- dynamic range of at least 20 dB without changing the probe,
- rejection of out-of-band frequency components,
- rejection of electric fields by magnetic field sensors (and vice versa),
- insensitivity to temperature/humidity changes,
- insensitivity of electronics to RF interference, and
- availability of calibration data over frequency range.

BROADBAND INSTRUMENTS

A summary of commercially available broadband electric and magnetic field instruments is given in Tables 1 and 2. Probes have three orthogonal sensors unless otherwise labeled. Users should be aware that the presence of out-of-band frequency components may cause invalid readings. There is also the possibility that a strong magnetic field will disrupt the operation of an electric field meter and vice versa. Instruments can be permanently damaged by exposure to field levels above the manufacturer's specifications.

Table 1. Broadband RF/microwave survey instruments

Manufacturer/Instrument Model Number		Price	Frequency Range	Sensor Type (E=electric, H=magnetic)	Quantity Reported (E=V/m, H=A/m, S=mW/cm ²)	Field Strength	Dynamic Range (Full Scale Reading) Equivalent Power Density (mW/cm ²)
● Aeritalia (Amplifier Research) TE 307							
(w/Fiber Optic Link)		3760					
Probes					E or H		
(1)	13RV1001-1	840	4-500 MHz	E		10 V/m	0.027
(2)	14RV1001-1	840	1.5-500 MHz	E		100 V/m	2.7
(3)	15RV1001-1	840	1-500 MHz	E		1000 V/m	270
(4)	16RV1001-1	1040	2-100 MHz	H		10 A/m	3770
(5)	17RV1001-1	1040	2-100 MHz	H		1 A/m	37.7
(6)	19RV1001-1	1250	0.005-2.5 MHz	E	(switch selectable) <	10/100/1000 V/m	N/A
(7)	19RV1001-2	1250	0.005-2.5 MHz	E		1/10/100 V/m	N/A
(8)	19RV1001-3	1250	0.02-10 kHz	E		10 ² /100 ³ /1000 ⁴ V/m	N/A
(9)	19RV1001-4	1250	0.02-10 kHz	E		10 ² /10 ³ /10 ⁴ V/m	N/A
● EIT					E ² or S		
Meter w/Precision Fiber Optic Link 679/1079		9300					
(10)	Probe 979	1500	0.1-12 GHz (useable to 40 GHz)	E (single axis)		140 V/m	5
● Electromechanics Co.							
Meter 6640		9900		E or H			
Probes							
(11)	3201	1400	0.1 Hz-50 KHz	H (single axis)		80μA/m-0.8 A/m	N/A
(12)	3202	1400	0.1 Hz-50 KHz	H		0.8-80 A/m	N/A
(13)	3204	1400	0.1 Hz-50 KHz	H		2 - 2500 A/m	N/A
(14)	3302	1600	0.1 Hz-50 KHz	E		20 μV/m-0.2 V/m	N/A
● General Microwave							
(15)	Raham 1	950	0.3-18 GHz	E (single axis)	S	87/275/870 V/m	2/20/200
(16)	Raham 2	795	0.01-3 GHz	E	S	87/275/870 V/m	2/20/200
(17)	Raham 3	1500	0.3-18 GHz	E	S	8.7/27/87/275 V/m	.02/.2/2/20
(18)	Raham 4*	1520	0.01-26 GHz	E	S	8.7/27/87/275 V/m	.02/.2/2/20
(19)	Raham 4A	1520	0.2 MHz-26 GHz	E	S	87/275/870 V/m	2/20/200
(20)	Raham 12 (Raham 1 & 2)	1295	0.01-18 GHz	E (single axis)	S	87/275/870 V/m	2/20/200

Table 1. Broadband RF/microwave survey instruments (continued)

Manufacturer/Instrument Model Number	Price	Frequency Range	Sensor Type	Quantity Reported	Full Scale Readings	
					Field Strength	Power Density (mW/cm ²)
● Holaday Industries						
(21) HI 3001 with E Probe	2495	0.5-1000 MHz	E	E ²	10 ² /10 ³ /10 ⁴ /10 ⁵ / /10 ⁶ /10 ⁷ V ² /m ²	0.03-2650
(22) STH-01 Optional H Probe	600	3-300 MHz	H	H ²	0.1-1 A/m	0.38-37.7
(23) HI-3002 (includes E and H Probes)	2795	0.5-6000 MHz	E	E ²	10 ⁴ /10 ⁵ /10 ⁶ /10 ⁷ V ² /m ²	0.26-2650
		5-300 MHz	H	H ²	.1/1/10/100 A ² /m ²	0.38-3770
(24) HI-3003 (3 axis switches)	3750	0.5-6000 MHz	E	S	87/192/275/615 V/m	2/10/20/100
HI-3004 (same as 3002 w/o H-field probe)	2395					
● Instruments for Industry						
(25) RHM-1	1195	0.01-220 MHz	E	E	3/10/30/100/	.0024/.026/
(26) RHM-2	1375	0.01-220 MHz	E	E	/300 V/m	.24/2.6/24
(27) EFS-9	595	0.01-220 MHz	E (single axis)	E	"	"
(28) EFS-2 (pulse capability)	945	0.01-220 MHz	E	E	"	"
(29) EFS-3 (monopulse capability)	1145	0.01-220 MHz	E	E	"	"
● Narda Microwave						
8616 Meter } one used with	1220			S	(Three Ranges)	
8611 Meter } following:	350			S		
(30) 8621B probe	1450	0.3-26 GHz **	E		8.6-275 V/m	0.2/2/20
(31) 8623B probe	450	" " **	E		20-614 V/m	1/10/100
(32) 8631 probe	975	10-300 MHz	H		0.02-0.73 A/m	0.2/2/20
(33) 8633 probe	975	" "	H		0.05-1.6 A/m	1/10/100
(34) 8635 probe	2950	10-300 MHz	H		0.5-16 A/m	10 ³ /10 ⁴ /10 ⁵
(35) 8644 probe	2650	10-3000 MHz	E		86-2750 V/m	20/200/2000
(36) 8652 probe	300	0.3-10 MHz	H			
(37) 8662 probe	1200	0.3-300 MHz	E			
8619 meter (used with 8633/35/44 probes)	1500			E ² or H ²		

* Older units must be modified to meet low frequency (10-30 MHz) published specifications.

** These probes will operate to 40 GHz. Calibration for 26-40 GHz available.

Table 2. Instruments capable of measuring emissions from specific products (based on manufacturers' data)

Product	Instruments (numbers refer to Table 1 entries)	
	E Field	H Field
Microwave Diathermy - - - - -	10,15,16,17,18,19, - - - - 20,21,23,24,30,31,35	Not Required
Microwave (cw) Industrial - - - Equipment	10,15,16,17,18,19, - - - - 20	Not Required
Radar (Microwave-Short Pulse) -	15,17,30,35 - - - - -	Not Required
Shortwave Diathermy - - - - -	1,2,3,16,18,19,20,21,- - - 23,24,25,26,35,37	4,5,22,23,32, 33,34
RF Sealers - - - - -	1,2,3,16,18,19,20 - - - - 21,23,25,26,35,37	4,5,22,23,32, 33,34
Video Display Terminals - - - -	Active Antenna & - - - - Spectrum Analyzer or EMC receiver, 6, 7,20	11,12 (one-axis probe), shielded loop and spec- trum analyzer, EMC receiver.
Police Radar - - - - -	10,15,17,18, - - - - - 19,20,30,31	Not Required
Microwave Intrusion Alarms/ - - Door Openers	10,15,17,18 - - - - - 19,20,30,31	Not Required
Mobile and Hand Held - - - - - Transceivers	1*,2*,3*,10*,15*, - - - - 16*,17*,18*,19*,20, 21*,23,24,25*,26*, 30*,31*,37*	4*,5*,22,23,32, 33,34
Microwave Ovens - - - - -	(See section on oven - - - instruments)	Not Required

*Partial frequency coverage.

MICROWAVE OVEN SURVEY INSTRUMENTS

Several instruments are commonly used by microwave oven manufacturers in evaluating oven emissions. These instruments are listed in Table 3. The National Center for Devices and Radiological Health (NCDRH) has published a guide for field testing microwave ovens for compliance with the microwave emission and safety interlock operation requirements of the Federal radiation safety performance standard (10). It presents background material and complete instructions for carrying out the necessary tests. It has been prepared to provide a detailed reference document that will be particularly useful to FDA, State, and local radiation control personnel responsible for the field testing of microwave ovens.

Table 3. Instruments currently used in microwave oven manufacturers' compliance testing programs

Narda Microwave Corporation	Holaday Industries
Narda Model 8100*	Holaday Model 1700
Narda Model 8110B*	Holaday Model 1501
Narda Model 8201	(S/N-20915 and above)
Narda Model 8250	Holaday 1510
Simpson Electric Company	
Simpson Model 380 M	

* Suitable for testing 915 MHz ovens

There are also on the market several inexpensive (less than \$50) devices which are supposed to indicate when levels above a threshold are exceeded at 2450 MHz. Some of these instruments have been evaluated by NCDRH and the conclusion of this study (11) was:

Based on the findings presented above, it seems clear that there are serious questions about the ability of each of these instruments to distinguish oven leakage levels which exceed the requirements of the Federal Performance Standard for Microwave Ovens (21 CFR 1030.10) from lower levels which do not.

STANDARDS AND GUIDELINES

In the United States the principal standard is that of the American National Standards Institute (ANSI) which is reevaluated approximately at 5-year intervals. This standard is a voluntary guide for exposure, but in 1971 the U.S. Department of Labor adopted the then existing ANSI guideline and gave it an official standing. The main feature of this standard is the exposure limit of 10 mW/cm^2 as averaged over any 6-minute period. The Department of Defense has used similar standards since about 1953, but adopted a higher limit in 1975 for the frequency range below 10 MHz where previous standards, including ANSI, did not apply. A summary of Federal standards is given in Table 4.

A completely revised standard covering the frequency range from 300 KHz to 100 GHz was issued by ANSI in 1982 (12). This frequency-dependent standard is illustrated in Table 5 and Figure 3.

A few states have standards regulating RF/microwave radiation. These standards, mostly patterned after federal standards, are summarized in Table 6.

Table 4. Federal occupational RF/microwave standards

Organization	Frequency	Power Density (S)
U.S. Dept. of Labor Occupational Safety and Health Administration 29 CFR 1910.97-1971	10 MHz-100 GHz	$S < 10 \frac{\text{mW}}{\text{cm}^2}$ averaged over any any 6 minute period
U.S. Air Force AFOSH Standard 161-9 October 10, 1978	10 kHz-10 MHz	$S < 50 \frac{\text{mW}}{\text{cm}^2}$ averaged over any 6 minute period
	10 MHz-300 GHz	$S < 10 \frac{\text{mW}}{\text{cm}^2}$ averaged over any 6 minute period
All exposures shall be limited to a maximum (peak) E-field of 100 kV/m		
U.S. Navy MIL HDBK-238 August 10, 1973	100 MHz-100 GHz	$S < 10 \frac{\text{mW}}{\text{cm}^2}$ averaged over any 30 second period greater than 3 sec

Table 5. ANSI C95.1-1982 Radiofrequency Protection Guide*

Frequency Range (MHz)	Power Density (mW/cm ²)	Electric Field		Magnetic Field	
		E (V/m)	E ² (V ² /m ²)	H (A/m)	H ² (A ² /m ²)
0.3-3	100	633	400,000	1.58	2.5
3-30	$900/f^2$	63(30/f)	4,000(900f ²)	0.158(30/f)	0.025(900/f ²)
30-300	1.0	63	4,000	0.158	0.025
300-1500	f/300	63($\sqrt{f/300}$)	4,000(f/300)	0.158($\sqrt{f/300}$)	0.025(f/300)
1500- 100000	5.0	142	20,000	0.354	0.125

* Exclusions: (1) At frequencies between 300 kHz and 100 GHz, the protection guides may be exceeded if the exposure conditions can be shown by laboratory procedures to produce specific absorption rates (SARs) below 0.4 W/kg as averaged over the whole body, and spatial peak SAR values below 8 W/kg as averaged over any 1 gram of tissue. Furthermore, (2) At frequencies between 300 kHz and 1 GHz, the protection guides may be exceeded if the radiofrequency input power of the radiating device is 7 watts or less.

Table 6. Summary of State and local RF/microwave standards

Jurisdiction	Frequency	Emission Exposure	Remarks
Alaska	915 & 2450 MHz (microwave ovens)	1 mW/cm ² @ 5 cm from oven 5 mW/cm ² @ 5 cm from oven	At factory During use
California	3 MHz - 300 GHz	< 10 mW/cm ² , average	Occupational exposure standard
Massachusetts	0.3 - 3 MHz 3 - 30 MHz 30 - 300 MHz 300 - 4000 MHz 4000 - 10 ⁴ MHz	20 mW/cm ² 180/f ² mW/cm ² 0.2 mW/cm ² f/1500 mW/cm ² 1.0 mW/cm ²	Population standard
New York (NY City)	915 & 2450 MHz (microwave ovens)	1 mW/cm ² @ 5 cm from oven 5 mW/cm ² @ 5 cm from oven	At factory and after servicing During use
Oregon-State	915 & 2450 MHz (microwave ovens)	1 mW/cm ² @ 5 cm from oven 5 mW/cm ² @ 5 cm from oven	At factory and after servicing During use
Oregon (Multnomah Co.)	Standard identical to Massachusetts, above.		
Oregon (Portland)	0.1 - 29.99 MHz 30 - 300 MHz 300 - 10,000 MHz	500 μW/cm ² , average 100 μW/cm ² , average 500 μW/cm ² , average	Population standard
Rhode Island	915 & 2450 MHz (microwave ovens)	1 mW/cm ² @ 5 cm from oven 5 mW/cm ² @ 5 cm from oven	At factory During use
Texas	10 MHz - 100 GHz	< 10 mW/cm ² , average	Occupational and non- occupational standard *
	915 & 2450 MHz (microwave ovens)	1 mW/cm ² @ 5 cm from oven 5 mW/cm ² @ 5 cm from oven	At factory During use
Vermont	10 MHz to 100 GHz	< 10 mW/cm ² , average	Occupational and non- occupational standard

* Federal Communications Commission licensees are exempt.

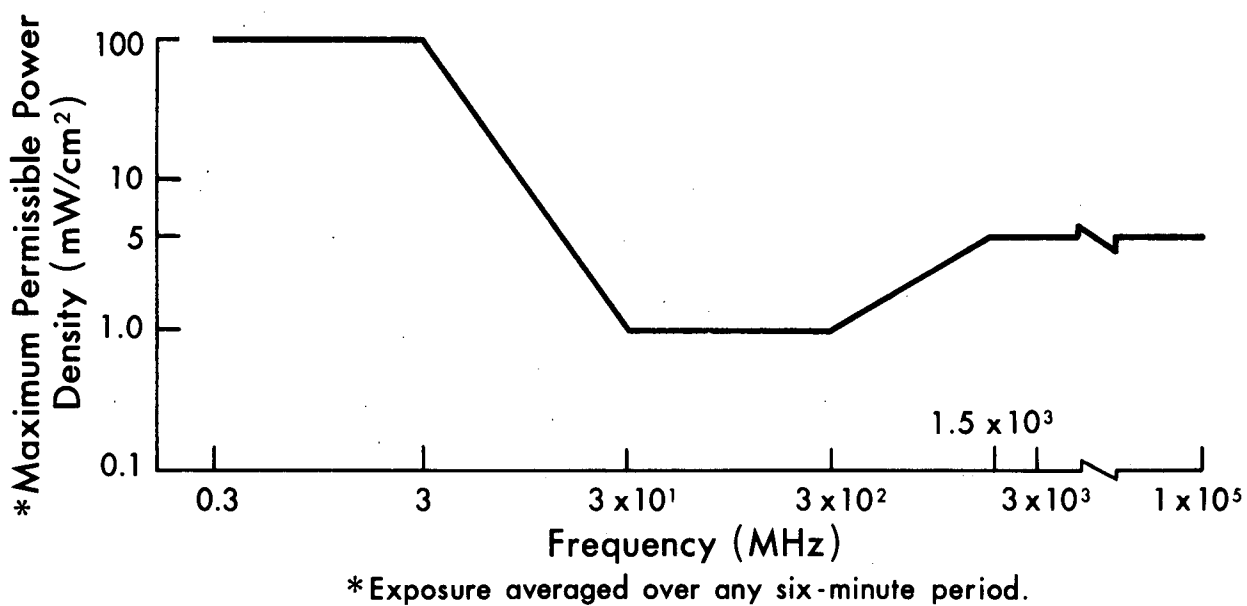


Figure 3. ANSI C95.1-1982. Radiofrequency protection guide.

INSTRUMENTS FOR THE MEASUREMENT OF ELECTRIC AND MAGNETIC FIELDS NEAR HIGH-VOLTAGE POWER TRANSMISSION LINES

INTRODUCTION

In the United States nearly all electric power is transmitted through overhead power lines operating at 60 Hz. As lines operating above 500 kilovolts become more common, there is an increasing interest in the measurement of the associated electric and magnetic fields.

There are a few prototype high-voltage direct current (DC) power transmission lines now operating. The measurement of the DC electric and magnetic fields requires different instruments and techniques from the AC measurements and will be discussed separately.

QUANTITIES AND UNITS

The discussion of quantities and units in the section on RF/microwave radiation applies also to fields associated with power lines. In the powerline area electric fields are normally reported in volts per meter (V/m) and magnetic fields in amperes per meter (A/m), or gauss (for magnetic flux density).

INSTRUMENTS AND MEASUREMENTS

MEASUREMENT OF FIELDS NEAR HIGH-VOLTAGE AC POWER LINES

The subject of electric and magnetic field measurements near AC power lines has been treated in detail in a report by the U.S. National Bureau of Standards (13), and in summary but comprehensive form in the Institute of Electrical Engineers (IEEE) Standard No. 644-1979 (14). These documents should be consulted where more information is required.

At the AC power line frequency of 60 Hz (corresponding to a wavelength of about 5000 kilometers), all measurements will be in the near field of the source, and the electric and magnetic fields must be measured separately. All available instruments for this frequency measure fields along one direction only. To obtain other components of the fields, the probe or instrument must be physically reoriented. A list of commercially available AC instruments is given in Table 7.

Typical electric and magnetic field profiles measured under actual power lines are given in References (15-17). Measurement techniques are discussed there also.

MEASUREMENT OF THE ELECTRIC FIELD, THE CURRENT DENSITY AND THE SPACE CHARGE DENSITY NEAR HIGH VOLTAGE DC (HVDC) TRANSMISSION LINES

The magnitudes of the electric field and the space charge or current density near the surface of the earth have been of interest in the field of atmospheric electricity (thunderstorm research) for several decades. Some of these instruments have been adapted for measurement of the same parameters near HVDC transmission lines. A vibrating-plate type of DC meter, originally developed for use in measurement and control

functions in processes involving the static charging of nonconducting surfaces, has also been adapted for electric field measurements near HVDC transmission lines. Reference (18) contains a general description of the various types of instruments which have been developed, some guidance in adapting experimental designs and commercial instruments to this special use, and a discussion of problems incident to the use of such equipment near HVDC transmission lines.

Table 7. 50/60 Hertz instruments

Manufacturer/Instrument	E-Field Full Scale	H-Field Full Scale	Price
Monroe Model 238A-1	5/10/25 kV/m	N/A	\$595
Electric Field Meas. Co. Model 111	1/3/10/30/100/ 300/1000/3000/ 10000/30000/ 100000 V/m	.01/.03/.1/.3/ 1/3/10/30/100/ 300/1000 A/m	\$1200
Addresses: Monroe Electronics, Inc. 100 Housel Avenue Lyndonville, NY 14098 (716) 765-2254		Electric Field Measurement Co. P. O. Box 326 West Stockbridge, MA 01266 (413) 637-1929	

It has been shown (19) that vibrating-plate probes are susceptible to errors when operating in the presence of large space charge current densities which may be found in certain laboratory environments. Sources of errors in the use of "Wilson Plates" for measuring the ion current density at ground level in the vicinity of HVDC transmission lines are described in Reference (20).

Tables 8 and 9 contain the commercially available instruments for the measurement of DC electric fields and charge densities.

Table 8. DC electric field meters

Manufacturer	Model	Full Scale	Price
Electric Field Measurement Co. *Requires Model 111 AC field meter.	112*	10/30/100/300/ 1000/3000/10000/ 30000/100000/ 300000 V/m (\pm)	\$800
Monroe Electronics, Inc.	245	.1/.2/.5/1/2/5/ 10 kV/cm (\pm)	\$1850
	245K	(Model 245 x 2)	\$1850
Trek, Inc.**	354	Digital, to ± 100 kV/m	\$695

** Address at end of Table 9.

Table 9. Charge Density Meters (Ion Counters)

Manufacturer	Model	Range	Price
Dev Industries	Beckett	Mobility: 3-0.0032 cm ² /Vs Ion Density: Not Specified	\$2135

Addresses:	Trek, Inc. 1674 Quaker Road Barker, NY 14012-9990 (716) 795-3211	Dev Industries 5721 Arapahoe Ave Boulder, CO 80303 (303) 442-3510
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STANDARDS AND GUIDELINES

There are no mandatory national personnel exposure standards for either static or 60 Hz electric or magnetic fields. The New Jersey Commission on Radiation Protection recently adopted an interim guideline for maximum permissible electric field strength measured at a height of one meter above ground at the edge of any electric power transmission line right-of-way of 3000 V/m.

INSTRUMENTS FOR MEASUREMENT OF ULTRASONIC RADIATION

INTRODUCTION

Ultrasound has found increasing use in recent years in medicine, industry, and consumer products. Many applications involve human exposure either incidentally, as in the use of ultrasound intrusion detectors, or as an essential part of a medical procedure, such as fetal monitoring, ultrasound therapy, or diagnostic echo imaging. Ultrasound exposures require quantification and inevitably raise questions concerning risk to human health. This section will discuss the instruments available for measurements, provide some general information about the application of ultrasound, and present relevant exposure standards.

Ultrasound measurements and applications will be divided into two categories, liquid-borne and airborne. Many applications in these two categories are illustrated in Figure 4.

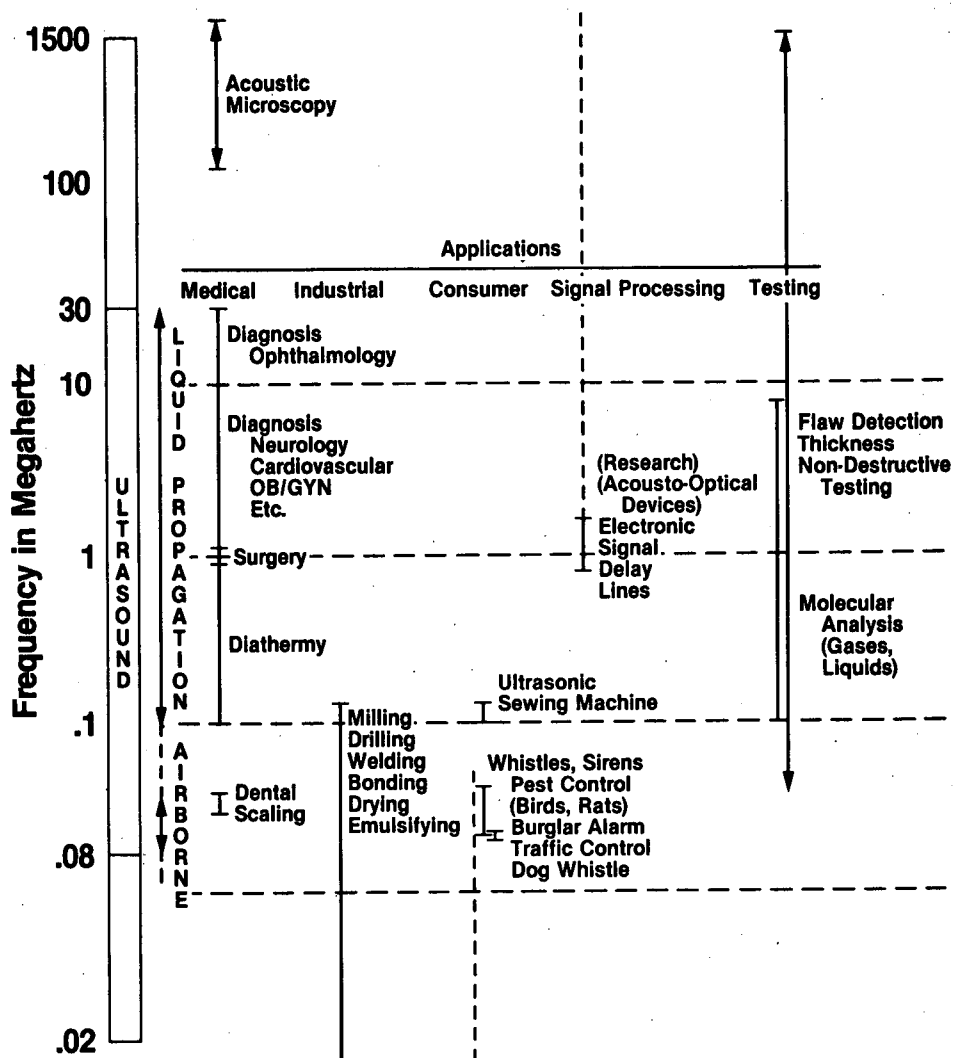


Figure 4. The ultrasound spectrum with applications.

LIQUIDBORNE ULTRASOUND

Liquidborne ultrasound is used in both medicine and industry. Medical use of ultrasound is a large and rapidly growing field and involves the most widespread instance of human exposure to ultrasonic radiation. Medical applications include dental scaling, physical therapy and hyperthermia, pulse-echo diagnostic imaging, and doppler shift detection of moving structures and blood flow velocity as well as surgical techniques, such as cataract removal, treatment of the inner ear, and welding of tissue (21).

Industrial uses of liquidborne ultrasound include cleaning, welding, soldering, nondestructive testing, imaging techniques and sonar for commercial as well as military purposes.

AIRBORNE ULTRASOUND

Ultrasound energy in the range of 16 kHz to 100 kHz is used in a variety of consumer and industrial applications, although most are below 50 kHz. For consumer devices the intended transmitting medium is usually air while industrial processes usually use liquid or solid materials as propagating media. In the latter situation there typically is attendant acoustic energy radiated into the surrounding atmosphere.

Currently marketed consumer products using airborne ultrasound include intrusion alarms, television remote controls, rodent and pest repellers, automatic door openers, dog repellers, and guidance devices for sightless people.

Industrial applications involving ultrasound include cleaning and degreasing, drilling, welding plastics and metals, emulsifying, homogenizing and vaporizing liquids. These devices produce airborne ultrasound only as stray radiation. Of course, several of the consumer type devices (intrusion alarms, pest repellers) are also found in industrial situations and vice versa.

QUANTITIES AND UNITS

LIQUIDBORNE ULTRASOUND

The total ultrasonic output power of a device is measured in watts (W) whereas the instantaneous levels at a particular point in space and time can be given as pressure in dynes per square centimeter (dyn/cm^2) or as intensity measured in watts per square centimeter (W/cm^2). Other factors which may be necessary to characterize the exposure can include frequency in Hertz (Hz or s^{-1}), pulse duration in seconds (s) and pulse repetition frequency (Hz).

AIRBORNE ULTRASOUND

Quantitative measurement of both audible acoustic and ultrasound levels is usually given in terms of sound pressure level (SPL). A logarithmic scale is used, and relative SPLs are given in terms of dB (decibels) with respect to a reference level (SPL_r). The equation used to compare SPLs is:

$$\text{dB} = 20 \log (\text{SPL}/\text{SPL}_r)$$

The standard reference level usually used is 20 micropascals (μPa), where 1 pascal equals 1 newton per square meter. This reference pressure corresponds approximately to the weakest sounds a human being can hear (in the audible range obviously), which is approximately 10^{-12} watts per square meter.

Airborne exposure criteria are usually given in 1/3-octave bands. An octave is simply a frequency band whose highest frequency is twice that of the lowest.

INSTRUMENTS AND MEASUREMENTS

LIQUIDBORNE ULTRASOUND

From a practical standpoint there are basically two types of measuring instruments available. The first type measures total power, and the second measures the spatial and/or temporal characteristics of the ultrasound field and thus provides a capability to determine the intensity distribution of the field.

In the first category there are commercial radiation force devices that generally employ large area detectors (21). The response time is slow compared to pulse repetition periods commonly used in medical applications so these devices measure the acoustic power emitted by the transducer as averaged over time and space. Typically these radiation force systems register the spatial average temporal average (SATA) acoustical power in watts. A list of manufacturers is found in Table 10. The price range is \$150-\$2500.

To measure the spatial and temporal characteristics of ultrasound fields, a detector is needed which is small compared to the ultrasonic wavelength and which has a fast response time, flat frequency response over the range of interest, high sensitivity, low noise, and wide acceptance angle. Miniature piezoelectric hydrophones, although not ideal, have generally been favored for measuring the spatial and temporal field distribution for diagnostic and therapeutic equipment (22). Miniature hydrophones respond to the pressure of the incident ultrasound and ideally have active elements less than or equal to the size of the wavelength of ultrasound. These probes can be used to measure the spatial peak temporal peak (SPTP) value of acoustic pressure and determine the time regime for pulsed ultrasound.

Hydrophone manufacturers are listed in Table 11. Prices for these hydrophones range from \$250 to \$2000. Those made from polymer materials are recommended for pulsed ultrasound because of their flat frequency response. Since ultrasound intensity is proportional to the square of the pressure, these probes can determine an intensity profile as well, and can be calibrated to yield the SPTP acoustic intensity, in W/cm^2 (22).

AIRBORNE ULTRASOUND

The determination of decibel levels at various positions in an airborne ultrasound field can be made with a commercially available system. This system includes a capacitor microphone sensing element, flat in frequency response within the range of interest, and signal processing circuitry. Typically, this circuitry includes a set of 1/3-octave filters so that the total SPL within any particular 1/3-octave frequency range is shown on the meter. Thus a spectrum of SPL as a function of frequency (to 1/3-octave resolution) can be obtained by stepping through the filter set (27).

Table 10. Ultrasonic wattmeters

Model	Price	Power Range	Resolution*	Calibration Accuracy*	Source
OHMIC UPM-30	\$500	0-30 Watts (Therapy)	150 mW	+6% (>5 W)	OHMIC Instruments 102 Chew Avenue St. Michaels, MD 21663 (301) 822-4844
UMR-3C	\$2,500	0-30 Watts (Therapy)	25 mW	+6% (>1 W)	UMA, Inc Route 3, Box 18D Elkton, VA 22877 (703) 298-9421
1138	\$1,500	0-25 Watts (Therapy)	500 mW	+10% (>10 W)	Birtcher Corp. 4501 N. Arden Dr. El Monte, CA 91734 (213) 575-8144
UTD-1	\$295	0-15 Watts (Therapy)	2 Watts	+25% (>10 W)	Bio-Tek Instruments One Mill Road Burlington, VT 05401 (802) 863-1880
UMR-4B	\$1,800	0-100 mW (Diagnostic)	0.1 mW	+20% (1-5 MHz)	UMA, Inc. Route 3, Box 18D Elkton, VA 22877 (703) 298-9421

*As determined by NCDRH.

A total measuring system that can be used for airborne ultrasound is manufactured by B&K Instruments (Bruel & Kjaer Precision Instruments, 185 Forest Street, Marlborough, MA 01752) and includes a 2209 sound level meter, 4149 microphone ($\frac{1}{2}$ inch), 1616 1/3-octave filter set, and a 4220 calibration pistonphone. Other microphones can be used with this system, as long as their frequency response is flat within the required frequency range. The frequency range of the sound level meter, in conjunction with the microphone and filter set is from 20 Hz (1/3-octave centered at 20 Hz) to 40 kHz (1/3-octave centered at 40 kHz). The pistonphone produces a pure 250 Hz tone at 124 dB and is used to calibrate the system. Overall system operation is within +3 dB over the entire range of interest. The price of the system is approximately \$7000.

STANDARDS AND GUIDELINES

LIQUIDBORNE ULTRASOUND

There are no guidelines pertaining to the ultrasonic output of industrial devices except as might be relevant to stray airborne ultrasound. In the medical field there are two major current guidelines. One is a mandatory standard pertaining to ultrasound therapy devices and promulgated by the Food and Drug Administration, 21 CFR 1050.10 (25). The second is a suggested set of voluntary guidelines developed by the American Institute

Table 11. Miniature ultrasonic hydrophones

Source	Material	Diameter	Preamp.	Price
Danish Institute of Biomedical Engineering Park Alle 345 DK-2600 Glostrup Denmark	Polymer	0.5 and 1.0 mm	No	\$1,000 - \$1,500
Nuclear Assoc. 100 Voice Road Carle Place, NY 11514 (516) 741-3910	Polymer	0.5 mm	Yes	\$2,000
Medisonic 21 Greenhill Crescent Holywell Industrial Est Watford, Hertfordshire UK	Ceramic	0.25 mm	Yes	\$ 500
Dapco Industries 199 Ethan Allen Hgy Ridgefield, CN 06877 (203) 438-9696	Ceramic	0.6 mm	No	\$ 350
Nortec Corp. 3001 George Washington Way Richland, WA 99352	Ceramic	0.5 and 1.0 mm	No	\$ 250
Machlett Labs. 1063 Hope St. Stamford, CN 06907 (203) 348-7511	Polymer	0.5 and 1.5 mm	Yes	\$2,000

of Ultrasound in Medicine (AIUM) and the National Electrical Manufacturers Association (NEMA) (AIUM/NEMA Safety Standard for Diagnostic Ultrasound Equipment) (26).

The specific criteria given by these documents are sufficiently complicated to prohibit listing them in this section but the objective of both these standards is to ensure that sufficient information concerning the output characteristics of the equipment is given to allow medical personnel to make informed judgments when utilizing these devices. These characteristics include total power output, frequency and pulse characteristics and spatial distribution of intensity among others. Accuracy requirements for labels and meters giving the above information are specified as are minimum requirements for instrumentation necessary to determine the output characteristics.

AIRBORNE ULTRASOUND

Criteria limiting human exposure to airborne ultrasound have been suggested by several sources (24,27).

In England, a voluntary standard developed by W.I. Acton allows sound pressure levels to 75 dB within 1/3-octave bands centered on frequencies up to 20 kHz (over a working day). Permitted levels are 110 dB in 1/3-octave bands centered on 25 kHz and above. Parrack, in the United States, proposed exposure limits to the ANSI (American National Standards Institute) Working Group S3-W40. These limits were set at 80 dB per 1/3-octave up to 16 kHz (center frequency) range, 105 dB for the 20 kHz 1/3-octave band, 110 dB for the 25 kHz 1/3-octave band and 115 dB for higher frequencies. These limits are for approximately 8 hours per day, 5 days a week. The American Conference of Governmental Industrial Hygienists (ACGIH) also recommends Parrack's criteria.

Grigor'eva of the Soviet Union proposed an allowed level of 120 dB for exposure to ultrasound noise above 20 kHz, 90 dB within the 1/3-octave band centered at 16 kHz and 12.5 kHz, and 85 dB for the 1/3-octave band centered at 10 kHz. Currently the only official American standard limiting exposure to ultrasonic energy is the United States Air Force Regulation 161-35. This document requires ear protection whenever SPLs exceed 85 dB per 1/3-octave, within the frequency range of 12.5 kHz to 40 kHz. These criteria (above 25 kHz) seem extremely conservative when compared with the other proposals. The Canadian Department of National Welfare has recommended allowed levels of 80 dB from 6.3 kHz to 20 kHz (center-frequency of 1/3-octave bands) and 110 dB beyond 20 kHz centered 1/3-octave bands.

The above criteria, as well as those proposed by the International Radiation Protection Association (IRPA) (23) are summarized in Table 12. A more extensive review of the literature can be found in Reference (27).

Table 12. Exposure limits to airborne acoustic energy (db) at the workplace

Mid frequency of 1/3-octave band (kHz)	SPL within 1/3-octave band (db relative to 20 μ Pa)					
	Acton (1975)	Grigor'eva (1966)	USAF (1976)	Health & Wel- fare/Canada (1980)	ACGIH (1981)	IRPA (Prpsd)
8	75	a	a	80	80	80
10	75	85	a	80	80	80
12.5	75	90	85	80	80	80
16	75	90	85	80	80	80
20	75	120 ^b	85	80	105	80
25	110	120 ^b	85	110	110	110
31.5	110	120 ^b	85	110	115	110
40	a	120 ^b	85	110	115	110
50	a	120 ^b	a	110	115	110

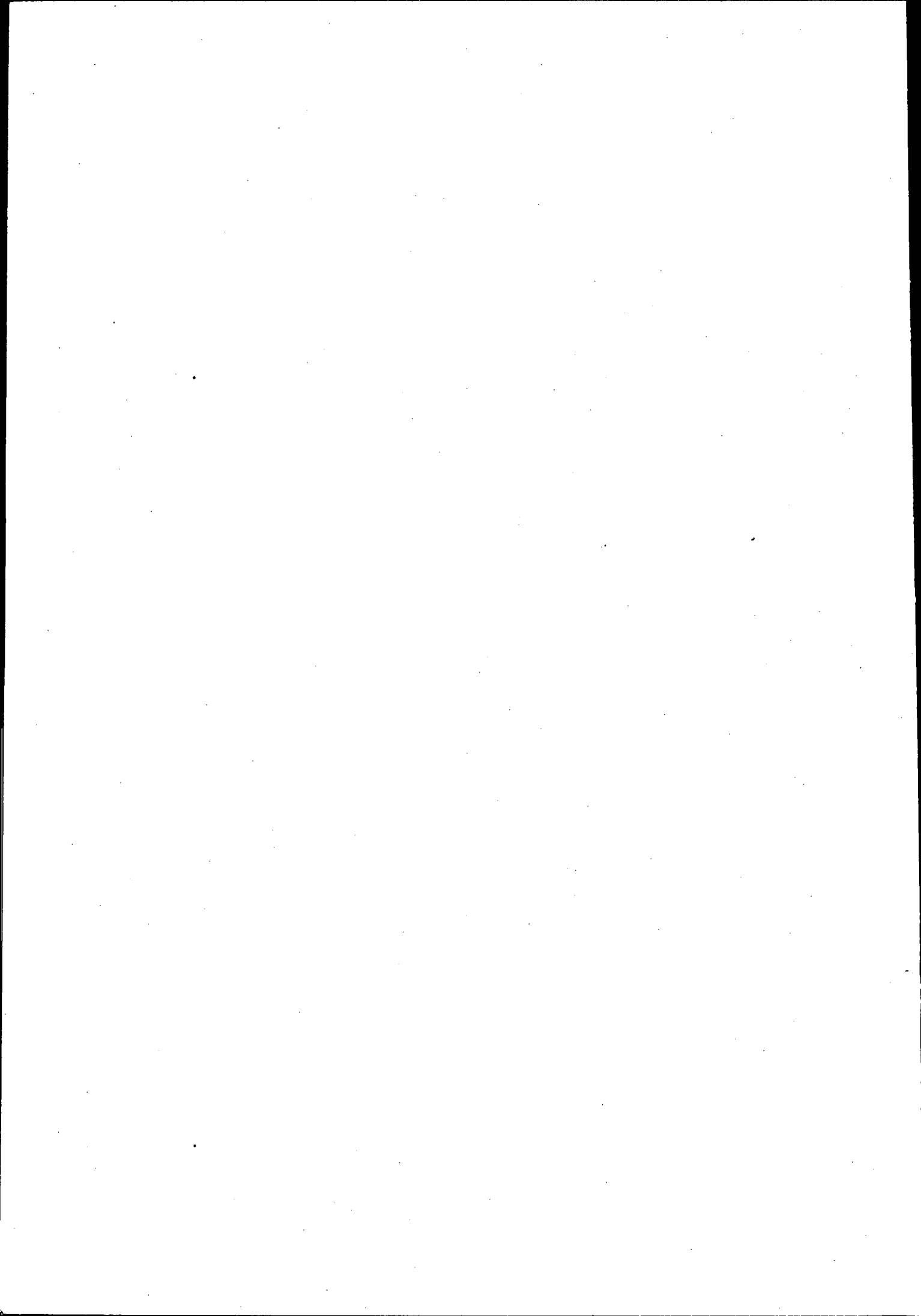
^a No levels specified

^b 120 dB is allowed for additive value over all frequencies above 20 kHz.

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