Industry Canada Industrie Canada

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Spectrum Management and Telecommunications Policy

Guidelines for the Measurement of Radiofrequency Fields at Frequencies from 3 kHz to 300 GHz

Canada

Aussi disponible en français

DEPARTMENT OF INDUSTRY

RADIOCOMMUNICATION ACT

Notice No. SMBR-002-00 — Guidelines for the Measurement of Radiofrequency Fields at Frequencies from 3 kHz to 300 GHz

Industry Canada announces publication for comments of “Guidelines for the Measurement of Radiofrequency Fields at Frequencies from 3 kHz to 300 GHz”.

Health Canada publishes the document “Safety Code 6” which sets forth the limits of exposure to radiofrequency fields.

These guidelines for the measurement of radiofrequency fields at frequencies from 3 kHz to 300 GHz are published to provide guidance to interested parties to verify compliance with the Safety Code 6 requirements of BPR-1 or CPC-2-0-03, as applicable. Any comments on these guidelines may be submitted to the Director General, Spectrum Engineering Branch, Department of Industry, 300 Slater Street, Ottawa, Ontario, K1A 0C8, or at the following Internet address: broadcast.gazette@ic.gc.ca

Comments should be submitted no later than 90 days from the date of publication of this notice. Comments received will be made available on written request to the Director General, at the above-mentioned address.

Copies of this Gazette Notice and “Guidelines for the Measurement of Radiofrequency Fields at Frequencies from 3 kHz to 300 GHz” are available electronically on the Internet at the following address:

http://strategis.ic.gc.ca/spectrum for the English version
http://strategis.ic.gc.ca/spectre for the French version

July 31, 2000

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Director General
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CONTENTS

1 INTRODUCTION

1.1 Background

The use and application of electrical devices has steadily increased over the past decades resulting in a corresponding increase in electro-magnetic (EM) fields (also termed non-ionizing radiation) in the environment. Public concern over the exposure to these fields has prompted many scientists and researchers to investigate possible effects and risks to human health.

Throughout the world, considerable research effort has been devoted to determine the effects of non-ionizing radiation exposure on human and Public Authorities responded to this concern by issuing exposure limits and safety guidelines for exposure to radiofrequency fields.

Health Canada has issued a document entitled '***Safety Code 6***' which outlines recommended limits of exposure to radio-frequency electro-magnetic (RF) fields from 3 kHz - 300 GHz. In conjunction with this guideline, Industry Canada requires an assessment of non-ionizing radiation as part of the environmental review process for all telecommunication service licence applications. In order to assist the applicants on the subject, the Department has developed software programs to predict levels of RF energy near transmitter sites. However, field measurement may still be required in certain cases to evaluate the actual levels of radiofrequency fields.

1.2 Scope

1.2.1 Purpose

This document outlines some principles and background information for the measurement of radiofrequency electromagnetic fields. It also provides a number of recommended measurement procedures for the different types of telecommunication services. The techniques for both the near field and far field measurements are based on the instrumentation that is currently available. The recommended procedures are not considered to be appropriate for the measurement of electromagnetic fields in the reactive near field region.

The document is to be used by people who work in the RF discipline and with the assumption that the user has a basic knowledge of electromagnetic field theory and practice.

The recommended procedures do not extend to measurements in the very low frequency band (below 1 kHz).

1.2.2 Measurements

The procedures presented in this document may be used for the following:

1. Measurement of radiating EM fields
2. Measurement of leakage and re-radiated EM fields
3. Measurement of induced EM fields in the body

1.2.3 Sources of Emission

Sources of emission in the present context refer to the different types of radio frequency transmitters employed in the different telecommunication services. These transmitters may exhibit very different spectral, spatial and temporal characteristics due to the nature and the requirements of each type of service. The recommended procedures take into consideration the normal features and the circumstances of each type of service and the characteristics of the transmitters and radiation patterns.

2 MEASUREMENT PARAMETERS

2.1 Frequency Range

2.1.1 3 kHz to 300 MHz

Services in this frequency range include maritime navigational communications, areonautical radionavigation and radiocommunication, analog AM radio broadcasting, shortwave broadcasting, land mobile communication and fixed services, VHF radio (FM) and television broadcasting and amateur radio communication.

Measurement procedures and techniques over this frequency range vary according to the frequency and the type of service. In general, for services below 300 MHz, measurements of both the electric (E) fields and the magnetic (H) fields may be required. In addition, in cases of some high power transmissions, e.g. AM radio service, measurements of induced current and contact current may also be required.

2.1.2 300 MHz to 300 GHz

Services in this frequency range include UHF television and digital radio broadcasting, fixed, landmobile/PCS and satellite systems. Over this frequency range, the wavelengths of the electromagnetic fields and the dimensions of the antenna are relatively short, measurement locations are usually situated in the far field region, and in general, only electric (E) field measurements are required. In the far field region, the magnetic (H) field and the electric (E) field are related by a constant. In this case, measuring only the $| E |^2$ component can approximate the power density.

2.2. Source Parameters

Radiofrequency electromagnetic sources radiate energy into space through antennas installed on towers and buildings. These sources have widely different characteristics and thus require proper selection of instrumentation in hazard determination. Below are the pertinent characteristics of these sources.

2.2.1 Modulation

Transmitted electromagnetic waves may have various forms. The most fundamental form is a continuous wave (CW) or un-modulated carrier in which the wave oscillates at a single frequency. Such carriers may be modulated by another signal or message. When a CW wave is modulated by pulsing, or by varying its amplitude, frequency or phase, the wave is called a pulse, an amplitude, a frequency, or a phase-modulated wave, respectively.

2.2.2 Near Field and Far Field Regions

The space around a radiating antenna can be divided essentially into two regions, the near field and the far field region. For an antenna with a maximum overall dimension that is small compared to the wavelength, the near field region is mostly reactive and the electric and magnetic field components store energy while producing little radiation. This stored energy is transferred periodically between the antenna and the near field. The reactive near field region extends from the antenna up to a distance R.

$$R = \frac{\lambda}{2\pi} \tag{2.1}$$

where "λ" is the wavelength.

There is no general formula for estimation of the field strength in the near field for small antennas. Exact calculations can be made only for well-defined sources such as dipoles and monopoles.

For antennas large in terms of wavelength, the near field region consists of the reactive field extending to the distance given by (2.1), followed by a radiating region. In the radiating near field, the field strength does not necessarily decrease steadily with distance away from the antenna, but may exhibit an oscillatory character.

The criterion commonly used to define the distance from the source where the far field begins is that the phase of the fields from all points on the radiating antenna does not differ more than λ/16. The distance from the antenna corresponding to this criterion is:

$$R = \frac{2a^2}{\lambda} \tag{2.2}$$

Where "a" is the greatest dimension of the antenna.

For a paraboloidal circular-cross-section antenna, a realistic estimate for R, which provides close agreement with experimental results, can be obtained using the following relationship:

$$R = 0.5\frac{a^2}{\lambda} \tag{2.3}$$

where "a" denotes the antenna diameter.

In the radiating near field, the electric field strength (E) and magnetic field strength (H) are interrelated with each other as:

$$\frac{E}{H} = h \tag{2.4}$$

The power density S is:

$$S = \frac{E^2}{h} = H^2 h \tag{2.5}$$

where “η” is the intrinsic impedance. The value of “η” may vary with the distance in the near field region. In the far field region, the field has a predominantly plane wave character, i.e., the electric field vector is perpendicular to the magnetic field vector, and they are both transverse to the direction of propagation. The ratio of the electric field strength to the magnetic field strength is constant at any location and in free space it is equal to:

$$\frac{E}{H} = h = 377\Omega \tag{2.6}$$

Section 4.2 provides a detailed description of reactive near field, radiating near field and far field regions.

2.2.3 Power Levels and Power Density

Radiated power is frequently expressed in decibels above 1 mW (dBm) or 1 W (dBW) reference power levels. Depending upon the type of service and source, the range of typical power radiated by transmitting antennas is from under 1 W or 0 dBW (e.g. portable transmitters) to over 100 kW or 50 dBW or higher (e.g. radars, VLF transmitters). For safety and efficiency, it is important to have the information on the radiated power, prior to taking measurements.

For antennas with reflectors, such as parabolic dishes, the maximum power density (within the antenna beam) in the radiating near field region can be conservatively estimated as:

$$S = 4\frac{P_a}{A} \tag{2.7}$$

where P_a is the power into the antenna, and A is the physical aperture area.

In the far field region, the power density on the antenna axis can be calculated from the expression:

$$S = \frac{P_a G}{4\pi r^2} \qquad (2.8)$$

where r is the distance from the antenna and G is the antenna directive gain.

The directive gain of an antenna in a given direction is 4π times the ratio of the radiation intensity in that direction to the total power radiated by the antenna.

The antenna gain is related to the antenna dimensions by the following equation:

$$G = \frac{4\pi A_e}{\lambda^2} \qquad (2.9)$$

where A_e is the effective area of the antenna, $A_e = pA$, A is the physical surface area on the antenna, p is the antenna efficiency and λ is the wavelength. It should be noted that the effective area of some antennas, e.g. linear arrays, has to be derived by other means since the physical area may not be easily determined.

The free-space electric field strength (rms value) at a distance r, from a source with effective radiating power P_e (the source average output power multiplied by the antenna gain), on the antenna axis is equal to:

$$E = \frac{\sqrt{30 P_e}}{r} \qquad (2.10)$$

And E is expressed in volts per meter (V/m).

2.2.4 Radiation Pattern

Electromagnetic waves are radiated into space by means of antennas. The radiation pattern of an antenna determines the spatial distribution of the radiated energy. A pattern taken in the plane containing the electric field vector is referred to as an E-plane pattern. A pattern taken in a plane perpendicular to an E-plane is called an H-plane pattern. The directional pattern of an antenna describes how much it concentrates energy in one direction in preference to radiation in other directions.

In the near field, the radiation pattern of an antenna changes with distance from the source, whereas in the far field no significant change with distance occurs.

2.2.5 Polarization

The orientation of an electric field vector in the plane orthogonal to the direction of propagation is called polarization. If the electric field vector is always oriented in a given direction, the wave is linearly polarized. If the electric field vector rotates around the direction of propagation, maintaining a constant magnitude, the wave is circularly polarized. If the extremity of the electric field vector traces an ellipse, the wave is elliptically polarized. The rotation of the electric field vector occurs in one of two directions, either clockwise or counter-clockwise.

It is difficult to predict the orientation of the electric field in the near field region, as the transmitting antenna cannot be considered as a point source in this region. In the far field region, the antenna becomes a point source, the electric and magnetic components of the field become orthogonal to the direction of propagation and their polarization characteristics do not vary with distance.

2.2.6 Single or Complex

At a measurement survey site, there may be only a single source or several sources of electromagnetic fields. A single source may have strong harmonic content that can produce electromagnetic fields at multiple frequencies. In addition, several types of RF sources such as AM, FM, TV, land-mobile and fixed transmitters may commonly be installed on an antenna farm or multiple-use tower and can produce a complex electromagnetic environment. In these situations, it is difficult to estimate the maximum expected field levels. Both broadband and narrowband instrumentation should be employed to fully characterize the electromagnetic environment.

2.3 Radiation Leakage

At many transmitting sites, there may be unexpected radiation leakage emanating from electronic equipment (e.g. power amplifiers), a crack in the shielding cabinet or conduit, a joint between transmission cables or sections of waveguide. These leakages can result in localized hot spots with the electromagnetic fields in excess of the exposure limits. The nature of the leakage fields is similar to that of the near field around an antenna. Therefore, any type of polarizations may exist in the vicinity of the leak location. There is no reliable method to predict the extent of the leakage radiation, or the type of the field produced (reactive or radiating). In general, the location of the leak is not known and may only be detected by trial and error. Although many types of instruments are available for field measurements, those that have isotropic characteristics are generally better suited to probe radiation leakage.

2.4 Secondary Radiation

RF electromagnetic energy from an active radiator induces electric charges or currents on ungrounded or poorly grounded conducting objects such as metal flag poles, sign posts, window frames, fences and walls of metallic buildings. The amount of the induced current depends on the physical characteristics of the object (size, shape, orientation with respect to the source) and the frequency of the incident field. This current produces its own electric and magnetic fields in close proximity to the object. The produced fields, which are generally reactive, interact with the incident field and may result in so-called "hot spots" or the enhanced E and/or H fields close to the object surface. Since the conducting objects act as secondary radiators when exposed to ambient RF fields, they are sometimes referred to as passive or parasitic re-radiators. The enhanced fields generally diminish to the ambient levels in the surrounding areas within very short distances of the secondary source. Field strength reduction is generally exponential with highest strengths on the surface of the re-radiating object. The enhanced fields are highly non-uniform in their spatial distribution on the re-radiating object and are generally difficult to predict by theoretical methods. Hot spots are best evaluated by measurements.

2.5 Induced and Contact Currents

An RF field induces an alternating electric potential on ungrounded or poorly grounded conducting objects. When a person touches such objects, RF current flows through the person's body to the ground. This type of current is known as contact current. Even though a person may not be touching a metallic object, RF current that is induced in the body by RF fields may also flow through the body to the ground. This type of current is referred to as induced body current. Modest levels of these RF currents may cause perception, while higher values may result in shock or burns. The 1999 version of ***Safety Code 6*** includes recommended limits for both contact and induced currents in the frequency range from 3 kHz to 110 MHz, with the intention to reduce the potential for shock or burns. Under certain exposure conditions, the contact and induced currents shall be evaluated as they may exceed the limits, even though the field strength limits are not exceeded. These conditions may occur when the electric field strength is as low as 20-25 % of the exposure limit.

2.6 Specific Absorption Rate (SAR)

Specific absorption rate (SAR) is the rate of RF energy absorption per unit mass in the body. SAR has units of joules per second per kilogram or watts per kilogram (W/kg). This parameter is used as a primary indicator of RF energy absorbed in the body when quantifying the biological effects and thus defining the basic exposure limits. At frequencies between 100 kHz and 10 GHz, SAR limits take precedence over field strength and power density limits and shall not be exceeded. When carrying out compliance evaluation, the SAR should be determined for cases where exposures take place at a distance of 0.2 metres or less from the source. For conditions where SAR determination is impractical, field strength or power density measurement shall be carried out.

2.7 Measurement Errors

The following factors affect the measurement accuracy of radiofrequency electromagnetic fields:

1. If the probe is very close to an active radiator, coupling may occur between the probe's antennas and the radiator.

2. The ground as well as nearby objects such as a metallic wall can cause partial or total reflection or scattering of the incident waves. These reflections or scattering combine with the energy received directly from the source, and create interference patterns or multipath effects that may enhance or reduce the field strength at the measurement location.

3. Fields may have several frequencies because of multiple sources of emission or a single source with strong harmonic content or both.

4. Certain types of modulation may affect the reliability of measured results.

5. Spurious responses of the probes may be a factor, for example, the H field probe may be sensitive to electric fields, and vice versa.

6. Temperature and humidity may affect the accuracy of the measuring probe. Be sure that these are within the working range of the probe. Under very low and high temperature and humidity conditions, correction factors would have to be applied to the measurement data.

7. Errors may result from un-calibrated or mis-calibrated measuring instruments.

3 INSTRUMENTATION

3.1 Types of Measuring Instruments

A typical RF field or power density measurement device is composed of a probe, leads and metering instrumentation. The probe is used to detect the field. It can either be a conventional antenna or another type of sensor. The performance and the application of the measuring instrument as a whole depend to a large extent on the design and characteristics of the probe. The detected signal is carried by the leads to the metering instrumentation. To reduce the coupling of the leads with the surrounding field in order to minimize any disturbance, the leads take the form of high resistance wires. The metering instrumentation is primarily designed to process and display received field density.

The RF measurement device may be either broadband or narrowband. A broadband device responds uniformly over a wide frequency range and requires no tuning. A narrowband device may also operate over a wide frequency range, but the reception bandwidth is narrow, and the device must be tuned to the frequency of interest. Narrowband and wideband devices have their own advantages and disadvantages depending on the spectral environment and the type of measurements that are projected.

3.1.1 Electric and Magnetic Field Strength Meters

Electric and magnetic field strength meters are narrowband devices. They consist of an antenna, cable(s) to carry the signal from the antenna, and a signal conditioning/readout instrument. Field strength meters may use linear antennas, such as monopoles, dipoles, loops, biconical or conical log spiral antennas, horns or parabolic reflectors. The appropriate field parameters can be determined from a measurement of voltage or power at the selected frequency and at the antenna terminal. The electric (or magnetic) field strength can be derived from information on the antenna gain or antenna factor and the loss in the connecting cable.

3.1.2 Spectrum Analysers

Spectrum analysers are essentially broadband tunable receivers whose reception bandwidth may be set over a wide range of frequencies. They are used to measure the power at the antenna terminal at the selected frequency(ies). If used in combination with a narrowband selective antenna, the overall device becomes in concept similar to a field strength meter. However, spectrum analysers can also be connected to relatively short antennas to produce a broad response over a given frequency range. In this case, the analyser will display the spectrum of ambient signals and thus will permit to ascertain the frequencies involved and their relative contribution to the overall power density.

3.1.3 Power Density Meters

Power density meters are generally isotropic and broadband devices. However, there are conceptual differences among these devices in the way the fields are detected and processed. The instruments described in the following sections have essentially the same basic components, i.e. a probe, a connecting cable and a conditioning display unit. They are limited to those types which are currently available and which can provide reasonable accuracy in both near field and far field situations.

Measurements conducted with a power density meter may produce erroneous readings when the connecting cables are inadvertently aligned with the electric field. This is due to the fact that high resistance leads carrying the signal act as a more efficient antenna at low frequencies (such as in AM broadcasting band) than the short dipoles in the probe.

3.1.3.1 Diode Rectifiers

Multiple diodes and antenna elements (short dipoles or loops) are arranged in a suitable configuration to sum all three spatial field components independently of polarization and direction of incidence. Three elements, in an orthogonal arrangement, is required for an isotropic instrument which can be used in any orientation with respect to the field. Dipoles respond to the electric field, loops to the magnetic field. To achieve a uniform response over the desired frequency range, the size of the dipole or the loop must be small compared to the wavelength of the highest frequency to be measured.

Schottky diodes, in general, exhibit some photovoltaic effect. Beamlead hybrid types exhibit this effect to a much greater extent and may produce erroneous readings when illuminated by sunlight or strong incandescent light. Therefore, optically opaque shielding is required to eliminate this effect.

Diode instruments are non-linear with respect to field strength. At low levels, the rectified voltage is proportional to the square of E (or H). At higher levels, the rectified voltage becomes directly proportional to E (or H). This change in characteristic requires that the range of operation of the diode be restricted to low levels to provide a true indication of $|E|^2$ or $|H|^2$. When the diodes are operated at higher levels, it is required that the output voltages of the individual elements be modified (generally squared) prior to their summation. When diode instruments are used in pulsed fields they usually change from an average to a peak detecting device, hence, measurement errors may be large in fields of high peak to average ratio.

When adapted to broadband operation, the upper frequency range of a diode-based instrument is currently above 12 GHz. The low-frequency limit is below 400 kHz. The burnout characteristics can be in the hundreds of mW/cm^2 range.

Diode detectors, depending on design, may be temperature sensitive. Variations in output with ambient temperature will typically be less than 0.05 dB per °C. Diode units also may be modulation sensitive if the square-law region is exceeded, resulting in errors dependent upon the type of modulation.

3.1.3.2 Active Antenna

It is difficult to make accurate, broadband E and H field probes that cover the long wavelength (1000 m) region, using the conventional means described above. In order to provide a flat frequency response and adequate sensitivity in a dipole probe, the load impedance of the detector and the high impedance lead in combination must be greater than the antenna (source) impedance. One solution is to provide a high impedance RF buffer amplifier that is connected directly to a monopole or loop antenna and which acts as the load. This is practical for frequencies between 10 kHz and several hundred MHz. Commercially available magnetic and electric field probes, using active electronics, operate at frequencies as low as 60 Hz.

A second problem associated with probes without active electronics is that of isolating the signal carrying leads from the antenna/detector combination. This problem may become severe below about 100 MHz, and particularly below 10 MHz. This is due to the fact that the typical high resistance signal carrying leads serve as a low-pass filter, and their ability to separate the low frequency detected signal from the RF field being measured becomes more difficult as the two frequencies approach each other. This results in excessive sensitivity and poor antenna patterns in passive probes.

Finally, at frequencies above about 300 MHz, where "free-space" or uniform irradiation conditions exist, both the sensor and the metal enclosure of the survey instrument can be exposed to similar levels of RF, and scattering from the enclosure to the sensor (probe) can cause significant errors.

Active electronic probes eliminate the use of such leads entirely by including the visual display (readout) with the metal box containing the active electronics. A fibre optic data link can be provided for a remote readout.

3.1.3.3 Displacement-Current Sensors

In addition to short dipoles and monopoles, a form of parallel plate capacitor, called a displacement-current sensor can be used to measure electric fields normal to its surface or normal to any large conducting surface. Instruments designed primarily for measuring fields associated with video display terminals, are based on the displacement-current sensor concept.

Displacement-current sensors are typically used at frequencies in the LF and VLF regions, e.g., from DC to a few hundred kHz but may effectively be used at frequencies as high as a few hundred MHz.

3.1.3.4 Electro-Optical (Photonic) Sensors

This type of electromagnetic field sensor utilizes a non-metallic, passive sensing element (electro-optic modulator) with a very broadband response (DC to 20 GHz) that converts electromagnetic field strength information to instantaneous modulation of a laser beam. The laser energy is transmitted via fibre optics to the modulator.

The modulator impresses amplitude modulation on the laser beam, in proportion to the instantaneous amplitude of the RF electromagnetic field to which the modulator is exposed. The amplitude-modulated laser beam is then carried from the modulator to a photodetector that converts the modulated optical beam to an electrical signal that represents the instantaneous amplitude of the RF field strength. This signal is then detected and processed before being sent to for display.

The above system has been used with electrically small dipoles as an electric field sensor as well as with no antenna (where the electro-optic modulator itself serves as the E field sensor). In addition, conventional antennas can be connected to a commercially available electro-optic modulator via a short lead, to provide a non-metallic, passive RF link to the antenna.

3.1.3.5 Thermocouples

The detection elements are thin-film type thermocouples. Parts of the film perform the functions of the antenna element. Some low frequency probes also use loop antennas terminated with thermocouple detectors. The DC output of the thermocouple is proportional to the square of the electric field strength. The major limitation of the thermocouple type radiation monitors is the burnout characteristic. The burnout characteristic is typically 3 times full scale in terms of average values. Newer designs of thermocouple instruments have burnout ratings of 15 to 20 times full scale. Thin resistive films provide very broad bandwidth.

3.1.4 Shaped Frequency Response

Safety limits for field strength and power density in Canada are frequency dependent. Probe designs, which rely on dipole-diode elements separately or in conjunction with thermocouple elements, may be designed to have a “sensitivity versus frequency” characteristic that is the inverse of the standard. This allows the summation and weighing of multiple frequency signals in conformity with the frequency dependent safety limits. The readout of such devices is in % of the standard. The probes may be tailored to a specific American National Standards Institute (ANSI) or Canadian Standard.

Shaped frequency response probes may cover only a portion of the frequency range of the standard. Additional probes may be used to complement each other and provide a wider measurement range. When complementary probes are used, these should exhibit good rejection of out-of-band signals.

3.1.5 Combined Electric and Magnetic Field Probes

Devices described in Section 3.1.3.1 to 3.1.3.5 employ separate probes to measure the electric and magnetic field components. In the near field region of an RF source, the relative values of the electric and magnetic fields vary considerably with respect to one another, depending on the distance from the source.

Also, in typical situations, fields may vary rapidly with time. To measure both electric and magnetic field strengths, which vary over time and space, one must place an electric field probe and then a magnetic field probe at exactly the same point. However a measurement uncertainty results, since the field under study may change during the finite time that elapses between the successive measurements.

A broadband isotropic probe system to measure the electric and magnetic fields simultaneously can be produced with a set of three mutually orthogonal dipole elements and a set of three mutually orthogonal loops that are physically located within a very small (compared with the shortest wavelength) volume. These elements are described in Section 3.1.3.1. Since the lengths of the dipoles, or the diameter of the loops, are kept small for uniform frequency response, the electric field pickup will be negligible. Thus, the mutual coupling between any of the probe elements is minimized by the use of electrically small antennas. Detectors based on the use of square law operated diodes or thermocouple are used to provide a signal to the electronic circuits to perform summing, data processing or conversion.

3.1.6 Induced Current Meters

Induced current meters display the amount of current induced through the body to ground when an individual is standing in an electric field created by a high power transmitter. These currents can provide an indication of energy absorbed by the body.

Induced current meters are generally stand-on devices that measure the induced current flowing through the subject's feet to ground. The stand-on baseplate is made of two stainless steel plates and is, in fact a capacitor/resistor network. The meter reads the current flowing through the resistor connected between the capacitor plates. The size of the baseplate is kept small to minimize any pick-up of electric field from the sides of the baseplate.

There are also the clamp-on induced current meters that can measure directly the induced current in arms and legs using clamp-on sensors. Typical frequency range of commercial meters is from 10 kHz to 100 MHz.

3.1.7 Contact Current Meters

Contact current meters display the amount of current through the body caused by contact with a 'hot' metallic object located in the vicinity of a high power transmitter.

Contact current meters generally feature an insulated contact probe for contact with the 'hot' object. Together with a stainless steel baseplate and internal circuitries, the measured current simulates the equivalent induced current by a barefoot individual gripping the 'hot' metallic object. Typical frequency range of this type of meter is from 3 kHz to 30 MHz.

3.2 Desirable Performance Characteristics

There are certain characteristics, which are desirable in a survey instrument. They can be arranged in two classes: physical characteristics and electrical performance characteristics.

3.2.1 Physical Characteristics

3.2.1.1 Portability

The instrument should be lightweight and small to permit convenient operation under restrictive conditions. The weight should be kept as low as is practical in keeping with good engineering practice. The volume should be convenient for hand held operation.

3.2.1.2 Durability

The display and other components of the device should be durable and able to withstand shock and vibration associated with transportation and handling under difficult conditions. A storage case should be provided.

3.2.1.3 Effects of Temperature, Humidity and Pressure

The accuracy of the device should be specified in terms of effects of temperature, humidity and atmospheric pressure. The extent of the effect of these parameters should be taken into account.

3.2.1.4 Display

The markings should be large enough to be easily read at arm's length. For shaped frequency response probes with an the analog type readout, the applicable safety standard should appear within the central one-third of the full scale reading of the dial. If more than one range of sensitivity is provided, the full-scale value of the selected range should be indicated. In any case, the analog or digital readout should provide a clear indication of the units being displayed.

3.2.1.5 Adjustments

The device should have a minimum number of controls. The functions associated with the controls should be clearly labelled and the operating procedures relatively simple.

3.2.1.6 Simplicity

Complicated operating procedures should be avoided. The information provided in the instruction manual should be sufficient to make accurate measurements.

3.2.2 Electrical Performance Characteristics

3.2.2.1 Power Supply

The instrument should be battery operated. The battery should be easily replaceable or rechargeable. A test switch or some other means should be provided to indicate their condition. The instrument should be capable of operating within its rated accuracy for at least eight hours before replacement or recharging of the batteries becomes necessary.

3.2.2.2 Polarization Factor

Probe antennas based on multiple dipoles or loops will respond to all polarization components of the electromagnetic field. A device based on a single antenna may respond to the same field by physical rotation of the single antenna about its axis.

3.2.2.3 Display Units

The instrument should indicate one or more of the following parameters:

(1) average "equivalent plane-wave" power density in milliwatts per square centimetre (mW/cm^2)

(2) mean-squared electric field strength in volts squared per metre squared (V^2/m^2);

(3) mean-squared magnetic field strength in amperes squared per metre squared (A^2/m^2)

Some instruments display "equivalent plane-wave" power density as derived from the field quantities (E field and H field) being measured.

Instruments with a shaped-frequency response should indicate in terms of "percent of exposure limit" based on the appropriate safety standard.

3.2.2.4 Frequency Range

The manufacturer should specify the frequency range of the device. The dynamic range for flat frequency response probes should be at least 10 dB below the lowest value and 5 dB above the highest value of the safety standard. These limits should also apply to shaped-frequency response instruments.

3.2.2.5 Coupling and Response to Other Radiations

The probe should only respond to the field component being measured, i.e. a dipole antenna should respond to the electric field and should not interact with the magnetic field and vice versa.

The specified accuracy of the instrument should take into account effects such as ionizing radiation, artificial light, sunlight, etc.

3.2.2.6 Shielding

The housing of the instrument and antenna cables should be designed to reduce or eliminate electromagnetic interference. The shielding should be effective under conditions in which the maximum coupling or "pickup" occurs for the unintentional receiving elements.

3.2.2.7 Out-of-Band Response

The manufacturer should specify the out-of-band response characteristics of the instrument to assist the user in selecting an instrument for a particular application.

3.2.2.8 Modulation

The device should indicate RMS value of the electromagnetic fields. However, the device may also be equipped with a switch for CW and amplitude-modulated continuous wave (AM-CW) modes. The device should also be able to average the narrowest pulse-modulated envelope of a non-continuous wave field that is expected to be encountered by the surveyor.

3.2.2.9 Static Electricity

Static charges are often induced on the probe of the survey instrument. The device should not indicate false levels due to a response to static charges. Windy or dry conditions may also influence the reading of the survey instrument.

3.2.2.10 Recorder Output

It may be desirable to equip the instrument with a recorder output. This will enable the measurement of hazardous fields without endangering the operator. It will also facilitate spatial and time averaging.

3.2.2.11 Response Time

The response time is generally defined as the time required for the instrument to reach 90 % of its final value when exposed to step function CW RF energy. The user should be made aware of the response time of the instrument.

3.2.2.12 Special Features

The following is a list of options that can be provided with the instrument:

(1) A "peak-hold" circuit. This is useful when the amplitude of the field is changing during the measurement;

(2) An alarm or test switch to indicate that the preset level has been exceeded. Also a means should be provided to alert the user that the measured signal is overloading the instrument;

(3) A data-logging function, which can provide an average, maximum and minimum values of the field components being measured. This function could provide a real-time average of the measured fields with an averaging time specified by the user, (e.g.. six minutes).

3.2.2.13 Stability

The instrument should be able to operate continuously for 10 to 30 minutes without the need to reset the device. Automatic electronic reset circuitry can be used to avoid the necessary shielding of the sensitive probe from ambient RF fields during the reset process. This is a desirable feature, particularly when performing RF surveys in situations where broadcasting or other major communication towers are involved. In such environments, RF-free locations may not be available. The instrument should not be sensitive to thermal variations within the range of normally encountered temperature extremes. The manufacturer should specify the maximum zero drift for each range.

3.2.2.14 Accuracy

Absolute field strength uncertainties (or accuracy) of within ± 1 dB are desirable but difficult to achieve. Uncertainties of ± 2 dB or higher may be acceptable if the considered levels are well below the safety standards. In any case, the uncertainty factor should be provided with the instrument and taken into consideration in the survey report. The instrument specifications should also address the instrument's ability to respond to amplitude-modulated (AM) fields such as pulsed radar signals as well as a multiplicity of signals, which might simultaneously illuminate the probe. The instrument readout should permit resolution of the measured field strength to within at least 5 % of the full-scale value.

3.3 Calibration

To ensure the safety of personnel, compliance with safety guidelines and to provide a basis for comparing the results of RF hazard, it is recommended that calibration be performed on instruments used for measuring various RF fields.

Existing calibration methods are based on the premise that a known field strength can be established through measurements, calculation, or a combination of both. The device to be calibrated is placed in this standard field and the meter indication is compared with the known field value. There are three basic approaches for producing a standard calibrating field: the free space standard field method, guided-wave method and the TEM Cell method. The selection of technique is dictated by the nature of the probe under investigation, the frequency range, the accuracy required and the available hardware for calibration.

3.3.1 Methods

3.3.1.1 Free Space Standard Field Method

The objective is to establish a reliable and known calibration field by the free space method. In most experimental setups, a microwave transmitter is employed to generate the reference field. The power density at a point is related to the power delivered to the transmitting antenna, the effective gain of the antenna on the on-axis distance of that point from the antenna.

It is to be noted that this arrangement is valid only when the device being calibrated is sufficiently small and far enough away from the transmitting antenna so that the amount of energy reflected back into the transmitting system is insignificant.

It is recommended that calibration should only be performed by qualified personnel in a laboratory furnished with proper equipment, and for field measurements, the calibration of the measuring instruments should be verified at the site using a portable TEM cell.

The main sources of error in the free-space method are multi-path interference from components that are part of the experimental setup and uncertainties in the antenna gain determination. Errors may be also be caused by misalignment of the transmitter antenna axis to the measuring probe.

3.3.1.2 Rectangular Waveguides

Rectangular waveguides will provide sufficiently uniform fields to be considered for calibration purpose. These fields are also predictable. The probe to be calibrated is inserted into the waveguide through a hole in the sidewall and positioned in the centre of the guide where the field is nearly uniform. The access hole is kept as small as possible to minimize its effect on the field distribution. The equivalent power density at the centre of the waveguide can be determined in terms of the square of the electric field.

When compared to the free space standard field calibration method, the rectangular waveguide takes considerably less space and requires little electromagnetic power. The disadvantage is that the maximum transverse dimension of the waveguide must be less than the wavelength at the highest calibration frequency to avoid higher order modes that result in complicated field distributions. Hence, this method is generally useful only for frequencies below 2.6 GHz.

3.3.1.3 Calibration using TEM Cells

The transverse electromagnetic cell, commonly known as TEM cell is another guided wave method for calibrating electromagnetic field probes. The basic TEM cell is a section of two-conductor transmission line operating in the transverse electromagnetic mode, hence the name. The main body consists of a rectangular outer conductor and a flat central conductor located midway between the top and bottom walls. The dimensions and the tapered ends of the TEM cell are chosen to provide a standard 50 Ω characteristic impedance along the entire length of the cell. In the centre of the calibration zone, halfway between the centre conductor and the top or bottom wall of the cell, the electric field is vertically polarized and uniform. The wave impedance (E/H) will be close to the free-space value of 377 Ω.

TEM cells may be made in various sizes to accommodate particular needs and frequency ranges. However, since the width must be less than a half-wavelength to avoid higher order modes in the cell, the useful upper frequency of a TEM cell is approximately 500 MHz. There are several factors that need to be considered in more detail when designing or using a TEM cell, IEEE Standard (C95.3) entitled "Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields, RF and Microwave" provides valuable and detailed information on electrical characteristics, standing waves, size of the probe to be calibrated with respect to plate separation, etc.

3.3.1.4 Magnetic Field Generators

At low frequencies the axial magnetic field (in A/m) at the centre of a circular loop wire is simply the current (in amperes) divided by the loop diameter (in meters). For a single-turn coil in free space, a loop becomes self-resonant when the circumference approaches the free space wavelength. For multi-turn coils, the resonant frequency is lower because of capacitance between the turns. Using a coil with a total wire length less than λ/10, the input impedance is very low but the field strength value can easily be calculated. This type of coil is useful for probe calibration purposes up to about 30 MHz.

There is also another coil arrangement named Helmholz. It consists of two flat coils on the same axis, both carrying current in the same direction. This type of coil system generates a more uniform magnetic field over a larger volume than the single coil. Helmholtz coils are useful up to about 10 MHz. This frequency limit is dictated by the dimensions of the coil which must be small compared with the wavelength.

3.3.1.5 Standard Probe Method

This method is the simplest, and may be the best method of calibrating hazard meters for general field use. The object is to have a stable and reliable probe that has been calibrated accurately (by one of the previously discussed techniques) for use as a "transfer standard." The standard probe is used to measure the field strength produced by an arbitrary RF field-generating device, e.g., antenna or TEM cell, over a particular region in space (or in a waveguide system). Then an un-calibrated probe is placed at the same location in the field that the standard probe occupied, and the un-calibrated probe's meter reading is compared with the known, measured value of the field, based on data obtained with the standard probe. The transmitter and field-generating device used during this process must generate a field that has the desired magnitude and which is constant with time and the field should be uniform over the region where the unknown probe is placed. Accuracies of about ± 2 to 3 dB are readily attainable with this method. The advantages of this approach are convenience, reliability, and simplicity. A potential source of error when using the transfer standard to calibrate another probe is the difference in the receiving patterns of the two probes. Also, in the near field of a radiator, the size of the probe's sensor is important. Ideally, the standard and unknown probes should be nominally identical and the calibration should be conducted in a field relatively free of spatial variations due to multipath interactions between the probe, the radiator, the anechoic chamber and other field generating components. In TEM cells or parallel plate transmission systems, capacitive coupling between the probe and the centre plate and the walls of the cell can create calibration errors. The transfer standard probe should be stable, rugged, and not easily burned out; it should have a large dynamic range, cover a broad frequency range, and possess an isotropic response.

3.3.2 Evaluation of Survey Instruments

Survey instruments have to be evaluated to determine the uncertainties or errors that may occur when the instrument is used to make field measurements. This evaluation also permits the development of procedures that can minimize errors in measurements. The following is a list of parameters that should be investigated:

(1) Absolute Calibration - Should be performed at field levels that produce indications that equal or exceed the mid-scale readout of the instrument.

(2) Linearity of the instrument - In order to establish the linearity of the instrument, measurements should be made at field levels that produce indications of 25, 50, 75 and 100 percent of full scale, on each range of the readout device.

(3) Frequency response - The frequency response of the instrument over the band of interest should be established. The response should be relatively flat over the specified frequency range (± 1 to 3 dB).

(4) Out of Band response - The sensitivity of the instrument as a whole should be evaluated for fields at frequencies outside the specified frequency range of the instrument.

(5) Near Field response - The magnetic field response of an electric field instrument and vice versa should be evaluated.

(6) Polarization - Any variation of the readout as the probe is rotated about the axis of the handle should be noted.

(7) Lead Pickup - Variations in response as the probe handle is rotated through the E plane or any extraneous pickup should be noted and quantified.

(8) Temperature response - Changes in the response of the instrument to a given field over the temperature range of interest should be determined.

(9) Supply Voltage response - For battery operated RF survey meters, the overall accuracy of the instrument should be tested for deviations from the nominal voltage rating of one or more of the batteries.

(10) Drift and Noise - Short and long term stability of the instrument should be determined with respect to full scale on each measurement range of the instrument, in the absence of electromagnetic fields.

3.3.3 Practical Measurement Accuracy

Several methods for calibrating meters have been discussed and the uncertainties associated with each method were estimated. It is important to understand that one cannot expect to achieve the same accuracy when using the meters for practical measurement applications. Some of the reasons are as follows:

(1) Meters are usually calibrated in nominally plane wave or uniform fields. Such fields are not always encountered in practice, and the sensor may not respond in the same way to non-planar fields (fields with large spatial gradients).

(2) With most calibration methods, only the sensor (probe) is exposed to the field while, in practice, the complete system, including the indicating unit

and connecting cable, is immersed in the field. Errors can also result from spurious responses from other parts of the instrument including readout meter (case) and cable. The overall uncertainty added by the above factors is difficult to assess and will vary with the type of meter and usage situation. However, if good measurement procedures are followed, accuracies of ± 1 to 3 dB can be expected in practice, with greater uncertainties in near field situations and at higher frequencies (shorter wavelengths), or in areas where large reflecting objects are present.

4 MEASUREMENT

4.1 Preliminary Considerations

Before carrying out a survey of potentially hazardous EM fields, it is important to determine as many of the known characteristics of the sources of these fields as possible. This will permit a better evaluation of the expected field strength and, consequently, a more appropriate selection of test instruments and test procedures.

A checklist of source characteristics should include:

(1) Type of RF generator and the output power.

(2) Carrier frequency(ies).

(3) Modulation characteristics, e.g., peak and average values, waveform, signal duty factor, pulse width, pulse-repetition frequency, etc.

(4) Intermittency, e.g., scanning beams, operational duty factors.

(5) Number of sources. If more than one source is present, are some or all of the signals coherent? Are intensities likely to add linearly or will they create interference patterns (standing waves etc.)?

(6) Spurious frequencies including radiated harmonics.

A checklist of field characteristics may include:

(1) Distance of source to test site.

(2) Type of antenna and properties including gain, beam-width, elevation and azimuth patterns, orientation, physical size with respect to the distance of the area being surveyed (i.e. near field, etc.).

(3) Polarization.

(4) Existence of absorbing or scattering objects likely to influence the field distribution at the test site.

A review of such a checklist is a necessity if the surveyor is to avoid some simple, but often surprising situations. For example, it is necessary to know the location of the source and RF propagation path during surveys with hand held probes. Only then can an appropriate assessment of the effect of the presence of the surveyor's body be made, and measurement errors avoided. Another example common in leakage situations is the possibility that the levels of the EM fields may be hazardous to the surveyor and may produce malfunction in the instrument electronics if it was not designed for operation in the presence of such fields.

Evaluation of Expected Field Strength

If the fields are far fields or radiating near fields of an antenna, then the material on theoretical calculations of exposure fields in Section 4.2 can be used to obtain field strength estimates. General references on antennas and hazard surveys are useful.

Field enhancement due to ground reflections could increase by as much as a factor of four times and even more if focusing effects are present. On the other hand, it should be recognized that such fields measured in the absence of a person may be misleading relative to hazards. For example, a person exposed in front of a reflecting plane reduces the magnitude of the standing wave.

In the case of low frequencies or small aperture antennas, the existence of potentially hazardous reactive near fields becomes relevant. Since these fields cannot be calculated with accuracy, measurements of E and H are usually required. However, one can always utilize the general property (Ref. [8]) that reactive fields predominate at distances d close to sources where $2Bd/8<<1$. Reactive near field amplitudes diminish as $1/d^2$ or faster, whereas radiation far field amplitudes diminish as $1/d$. General texts can sometimes be used to estimate E and H field values at these lower frequencies, and specific literature on the propagation characteristics of various broadcasting and communication antennas can be used to estimate either near or far fields from these sources.

Determination of Type of Instrument Required

Although many instruments designed for the measurement of electromagnetic fields are broadband in nature, none of them cover the entire frequency range of interest and all parameters of potential interest. Some general considerations in the selection of an instrument include the following:

(1) **Frequency**. Frequencies must be determined in advance so that proper instruments and measurement methods can be selected. The presence of several frequencies dictates the use of a broadband device with true RMS response.

(2) **Response Time**. It is usually desirable to begin a survey using an instrument with a response time (integrator time-constant) of one second or less (the "fast" setting on some commercial instruments). This enables a coarse measurement or the detection of pulse-modulated or intermittent fields, e.g., those created by a scanning radar beam. A "peak hold" feature on some survey instruments can provide an accurate indication of moderately fast bursts of RF energy (duration greater than several milliseconds). Once a high field strength zone is located, a slower time constant (3 seconds or more) should be used to obtain the time averaged

value of the field strength. If the hazard meter still indicates that an intermittent field exists, other means of recording and averaging should be used. Data logging systems are available specifically for use with RF hazard meters.

(3) **Peak Field Limitations.** Knowledge of the peak field limitations of the instrument is necessary to protect probes from damage in some low-duty-factor pulsed fields, such as those associated with radars.

(4) **Polarization.** Knowledge of the polarization of the fields enables a surveyor to use a non-isotropic probe for hazard surveys. In the absence of such knowledge, an isotropic probe is highly desirable both for ensuring accuracy and ease of performance of the survey in a reasonable period of time.

(5) **Dynamic Range.** The maximum anticipated field strengths should be estimated before measuring emissions from an RF source. A survey instrument capable of withstanding continuous exposure to field strengths (E^2 or H^2) of at least ten times the predetermined value should be chosen in order to avoid destruction of the probe sensing elements or the high resistance leads connected to those elements. In addition, adequate sensitivity is required to ensure a reasonable signal-to-noise ratio when the minimum expected field strengths are being measured.

(6) **Near Field Measurement Capabilities.** If a leakage situation exists or if the fields in close proximity to a source are to be measured, care must be taken to select a suitable instrument.

If possible, one should estimate the maximum expected field levels in order to facilitate the selection of an appropriate survey instrument. In many cases it may be best to begin by using a broadband instrument capable of accurately measuring the total field from all sources, including reflections. If the total field does not exceed the relevant exposure guideline in accessible areas, and if the measurement technique employed is sufficiently accurate, this would mean compliance with that particular guideline, and further measurements would be unnecessary.

When using a broadband survey instrument an average exposure level may be determined by slowly moving the probe in first a horizontal and then a vertical direction. An average can be estimated by observing the meter reading during this scanning process. A maximum field reading is also desirable, and, if the instrument has a "peak hold" feature, this can be obtained by observing the peak reading according to the instrument instructions. Otherwise, the maximum reading can be determined by simply recording the peak during the scanning process.

The term "hot spots" has been used to describe locations where peak readings occur because of local field distortions or other perturbations in the field and such readings are often found near conductive objects.

In many situations there may be several RF sources. For example, a broadcast antenna farm or multiple-use tower could have several types of RF sources including AM, FM, and TV, as well as land-mobile and microwave transmitters. In such a situation it is generally useful to use both broadband and narrowband instrumentation to fully characterize the electromagnetic environment.

Broadband instrumentation could be used to determine what the overall field levels appeared to be, while narrowband instrumentation would be required to determine the relative contributions of each signal to the total field.

At frequencies above 300 MHz it is usually sufficient to measure only the electric field (E), or the mean squared electric field, in the far field. However, at lower frequencies both the electric (E) and magnetic field (H) shall be measured.

In many situations a relatively large sampling of data will be necessary to spatially resolve areas of field intensification that may be caused by reflection and multipath interference. Areas that are normally are accessible to the general public should be examined in detail to determine exposure potential.

If narrowband instrumentation and a linear antenna are used, field intensities at three mutually orthogonal orientations of the antenna must be obtained at each measurement point. The values of E^2 or H^2, will then be equal to the sum of the squares of the corresponding orthogonal field components.

If an aperture antenna is used, it should be rotated in both azimuth and elevation until a maximum is obtained. The antenna should then be rotated about its longitudinal axis and the measurement repeated so that both horizontally and vertically polarized field components are measured.

When making measurements, procedures should be followed which minimize possible sources of error. For example, when the polarization of a field is known, all cables associated with the survey instrument should be held perpendicular to the electric field in order to minimize pickup. Ideally, non-conductive cable, e.g., optical fibre, should be used, since substantial error can be introduced by cable pick-up.

Interaction of the entire instrument (probe plus readout device) with the field can be a significant problem below approximately 10 MHz, and it may be desirable to use a self-contained meter for measuring electric field at these frequencies. Also, at frequencies below about 1 MHz, the body of the person making the measurement may become part of the antenna, and error from probe/cable pickup and instrument/body interaction may be reduced by supporting the probe and electronics on a dielectric structure made of wood, styrofoam, etc. In this connection, it is also desirable to remove all unnecessary personnel from an area where a survey is being conducted in order to minimize errors due to reflection and field perturbation.

In areas with relatively high fields, or pulsed fields with high peak powers, it is a good idea to occasionally hold the probe fixed and rotate the readout device and move the connecting cable while observing the meter reading. Any significant change usually indicates pickup in the leads and interference problems. When a field strength meter or spectrum analyser is used in the above environments, the antenna cable should occasionally be removed and replaced with an impedance-matched termination. Any reading on the device indicates pickup or interference.

Substantial errors may be introduced due to zero drift. If a device is being used which requires zeroing, it should frequently be checked for drift. This should be done with the probe shielded with metal foil, with the source(s) shut off, or with the probe removed from the field

4.2 Procedures

4.2.1 General Considerations

Prior to making measurements one should estimate the expected field strength and determine the type of instrument required, as discussed in 4.1. Some additional approaches and equations for calculating field strength in various situations are given below. The measurement procedures to be used may differ, depending on the source and propagation information available.

Technical Considerations of RF Source Characteristics

Although the prediction of power density levels in the vicinity of RF sources is complicated by many factors, useful estimates can be made. The quality of such calculations will depend on the analytical approach used as well as on the accuracy of the values of the peak power, pulse duration, pulse repetition rate, antenna radiation patterns, antenna placement, and scanning rates that are used in theoretical computations. Corrections for near field effects may also be appropriate. The operating parameters listed below must be specified adequately so that the true average radiated power from the antenna, and resulting power density at a distant point can be calculated.

For all sources (pulsed or CW) the antenna type and size, gain, antenna pattern including E and H plane beam widths and sidelobe distribution, antenna height above ground, operating frequency, antenna beam orientation (all possible cases) and the attenuation of the transmission line that connects the RF generator to the antenna must be known or estimated. For the calculation of the expected power density levels of pulse-modulated sources, the maximum possible values of peak power, pulse duration, and pulse repetition rate which closely approximate, but do not exceed the maximum rated duty factor of a transmitter should be used. In the case of multiple sources, the contribution of each source must be considered when estimating the combined effect.

Antennas - On Axis

The space around an antenna can be sub-divided into three zones:

(1) **Reactive Near Field Zone.** This is the volume of space immediately surrounding the antenna or leakage source where the reactive (non-radiating) components predominate and energy is stored in the field. The reactive near field extends to a distance of approximately one wavelength from the antenna, except for the case of electrically large antennas (whose physical size is greater, in any dimension, than several wavelengths).

(2) **Radiating Near Field Zone (Fresnel Zone).** In this zone, which starts at a distance from the antenna where the reactive field has diminished to an insignificant amount, the antenna gain and the angular distribution of the radiated field vary proportionally with distance from the antenna. This is because the phase and amplitude relationships of the various waves arriving at the observation point from different areas of the antenna change with distance. For reflector type antennas, such as parabolic dishes, the radiation is somewhat more complex in its distribution pattern.

(3) **Far field Zone (Fraunhofer Zone).** This is sufficiently far from the source that 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 non-radiating near field is a gradual one, the far field region is commonly assumed to begin at a distance of about $2a^2/\lambda$ for antennas with equiphase excitation and extends to infinity ("a" being the largest linear aperture dimension and λ the wavelength at the frequency of interest).

This criterion is not adequate for all types of antennas and should not be applied indiscriminately.

To compute an approximate value for the maximum power density "W" in the Fresnel and far field regions of an antenna, use the equation (2.8) of Section 2.2.3.

For commonly used horn and reflector antennas, the maximum power density W_m expected in the radiating near field can be estimated by equation (2.7) of Section 2.2.3.

The values predicted by Eq. (2.7) will be within ± 3 dB of the correct value (in the absence of reflections) for square apertures with uniform, cosine, and cosine square amplitude tapers, and for circular apertures with tapers ranging from uniform up to $(1-q^2)^3$ (Ref. [9]). (The taper or aperture field distribution of circular apertures can be represented by the function $(1-q^2)^p$, where $q=r/a$, in which a is the outside radius of the circular aperture and r is a radius within the aperture. When the exponent "p" increases, the field distribution becomes more highly tapered, i.e., it becomes more concentrated at the aperture centre. When p decreases and approaches zero, the aperture field distribution approaches uniform illumination.)

If a computation indicates that the approximate power density is substantially less than the exposure limit recommended in ***Safety Code 6***, then there is usually no need for further calculation since Eq. (2.7) provides the maximum power density that can exist on the axis of the beam of an antenna that is focused at infinity, in the absence of reflections. (An antenna focused at a lesser distance could produce a higher power density in the region of its focal point, but this condition is unusual.)

If the computation from Eq. (2.7) reveals a power density value that is equal to or greater than the recommended exposure limit, then it must be assumed that this value may exist at any point in the radiating near field region and attention should be directed to the exposure fields in the far field regions.

Equations (2.7) and (2.8) do not include the effect of ground reflections. Values of power density that exceed the free space value by a factor of four times can result when the main beam is directed toward a planar ground or reflecting surface. If the shape of the reflecting surface is such that it produces focusing effects, even greater values may result. After considering the sources of error cited above one may calculate the distance to the boundary of the potentially hazardous zone (in the presence of reflections) as follows;

$$r = \sqrt{\frac{GP}{pW}} \tag{4.1}$$

Antennas - Off Axis

It is more difficult to calculate the power density off the axis of the main beam, and requires the solution of complex mathematical equations. One approach reveals that the collimated beam in the radiating near field falls off with increasing distance approximately 12 dB per unit of antenna radius. Many antennas do not have simple shapes or illumination tapers. In such cases, the approximate formula above will not apply directly, and a more complex analysis is indicated. However, a high order of precision is not warranted when computing the expected power density because of the many physical parameters in the environment that create significant variations in the values predicted by idealized computations.

Scanning Correction

In the case of scanning antennas, the average power density at a fixed point will be reduced by the value of the effective antenna-pattern beamwidth divided by the scanning angle (the number of degrees of antenna rotation during a scan). This assumes that a constant rotational velocity is used, and that the antenna rotates in one direction, rather than stopping after a scan, and reversing direction. Accordingly, the potentially hazardous distance is decreased by at least the square root of this ratio (if the period of rotation is less than the averaging time specified in ***Safety Code 6***). The antenna's effective beamwidth in the far field will, in general, be somewhat different from the 3 dB beamwidth. The exact value depends upon the form factor of radiation pattern and associated sidelobes.

In the Fresnel Zone, the effective angle of the beamwidth will vary with distance. Here the average power density W of the scanning antenna is given approximately by the following relationship:

$$W = \left(\frac{2P}{A}\right)\left(\frac{a}{2\pi r}\right)\left(\frac{360}{\theta}\right) \qquad \theta > \left(\frac{a}{2\pi r}\right) \times 360 \qquad (4.2)$$

And,

$$W = \frac{4P}{A} \qquad \theta < \left(\frac{a}{2\pi r}\right) \times 360 \qquad (4.3)$$

where:
θ = the scanned angle, in degrees,
P = the average power transmitted,
A = the effective area of the antenna
a = antenna diameter or width
r = distance from the antenna

If the source and propagation information on which the choice of measurement procedures is based has been deemed adequate, then the surveyor, after making estimates of expected field strengths and selecting an instrument, may proceed with the survey. The surveyor should use a high-power probe with the range switch set on the most sensitive scale. The high-intensity field areas, e.g., the main beam of a directional antenna, should be approached from a distance to avoid probe burnout. The surveyor then gradually proceeds to move progressively closer to the regions of higher field strength. Extreme care must be exercised to avoid overexposure of the surveyor and survey instrument.

On the other hand, if the information is not well defined (for example, reports of strong, intermittent interference), then it may be difficult to make a hazard survey without first conducting an empirical hazard assessment. A survey for potentially hazardous fields of unknown frequency, modulation, distribution within an area, etc. may require use of several instruments. Examples of such instruments are spectrum analysers or field strength meters that display frequency-domain information with a means to analyse amplitude modulation characteristics, and which have a wide dynamic range, e.g., 60 dB in power. After this preliminary procedure is performed, it may be possible to continue a more meaningful survey with isotropic survey instruments.

4.2.2 Far Field Measurements: Single Source

The measurement of a linearly polarized plane-wave field whose source location, frequency, and polarization are known may be performed with a tunable field strength meter of acceptable accuracy, which covers the frequency range of interest. This instrument is used with a calibrated conventional antenna such as a standard-gain horn or dipole. Alternatively, an isotropic hazard probe may be used.

Multipath reflections may create highly non-uniform field distributions, particularly at frequencies in excess of 300 MHz. The spatial average of the field within that area should be considered as the appropriate level for comparison with whatever exposure limit is being employed as a criterion. Measurements near metallic objects should be made with the edge of the probe at least 3 "probe lengths", e.g., 20 cm, from the object.

While mounting or holding the measuring antenna or probe, care must be taken to avoid reflections or perturbations of the field by support structures or by the operator's body. Where required, to avoid field perturbation, metallic portions of the measuring device, or support structure, should be covered with absorbing material of appropriate quality. Where possible, probe interconnect cables should be oriented normal to the electric field. When that is not practical, or where several multipath effects produce fields originating from multiple directions, metallic cables should be covered with absorber unless tests demonstrate that the cable position does not affect the measurement. Dielectric fixtures should be as small as possible (minimum reflection cross section) and should be of low dielectric-constant material, or be less than one-quarter wavelength in effective thickness T_E. The effective thickness is given by:

$$T_E = T\left(e_r\right)^{\frac{1}{2}} \qquad (4.4)$$

where T is the physical thickness, and $,_r$ is the relative permittivity. Even dielectric slabs ($,_r > 2$) can significantly alter plane wave fields if the effective thickness is greater than 0.1 wavelengths. For highest accuracy, sources of error can be accounted for, so that the true field strengths may be ascertained with less than ± 2 dB of uncertainty. To obtain this level of accuracy at frequencies above approximately 300 MHz, a scanned measurement or many point measurements per wavelength must be performed in order to obtain information on the variations in field strength in that area due to multipath and other reflections.

4.2.3 Far Field Measurements: Complex Source

When measuring the fields from multiple, relatively distant sources of unknown frequency, polarization, or direction of propagation, a broadband isotropic probe is required. Since standing wave effects and multiple-source field interactions must be accounted for, it is necessary to scan a volume of space in the zone of interest. The area should be divided into a grid of one metre squares and measurements should be taken at each grid intersection. Scans should also be made in the vertical plane at grid intersection points.

In the case of multiple sources of unknown polarizations, a single axis probe (linear dipole) cannot be used to provide accurate data in a reasonable length of time, since measurements with three orthogonal orientations of the probe must be performed to ensure that all components of the field are accounted for. If a single axis probe or linearly polarized antenna must be used, one must ensure that the field being measured is time invariant. Even if an isotropic probe is used, it must be relatively free from sources of measurement errors caused by reflections from the probe, cables, readout case, and the surveyor. The use of long (many metres) high resistance or fibre optic probe interconnect cables will minimize the reflection problems mentioned above.

4.2.4 Near Field Measurements

Since large field gradients exist in the near field of an active radiator or passive re-radiator, their measurement requires the use of a probe with an electrically small array of three orthogonal dipoles, and for frequencies below approximately 300 MHz, an array of three electrically small orthogonal loops, in order to provide satisfactory performance for the resolution of these spatial gradients. Otherwise, a large probe will measure the spatially averaged value (one with an effective area greater than one-quarter wavelength in cross section). In addition, a small antenna array produces minimal perturbation of the field and the radiation characteristics of the source are not modified (alteration of reactive near fields). Since the polarization of the fields in near field situations is usually unknown, under most circumstances an isotropic probe must be used. If the frequency and polarization are known, a broadband instrument is not required. Instead, a narrowband probe with uniform response in a single plane (similar to some commercial, microwave oven survey instruments with two orthogonal dipoles) may be used.

4.2.5 Specific Absorption Rate (SAR) Measurement

A very careful and well-documented assessment of ***SAR*** has to be performed for conformity with the requirements in ***Safety Code 6***. It should be remembered that the internal field within a human body, and thus the ***SAR***, are not related to the external field in a simple way.

Determination of ***SAR*** for near field exposures of humans is difficult and can be done only on simulated models of the human body under laboratory conditions. To be valid, they have to be reliable and reasonably accurate. Examples of numerical methods for ***SAR*** calculations are the impedance method, the method of moments and the finite-difference-time-domain (FDTD) technique. Detailed representations of the complex geometry and composition of the human body have been made available using data from computerized tomography and magnetic resonance imaging scans. Recent advances in computers (memory and speed) and in the FDTD technique have led to the development of a tool for analysis of ***SAR*** in the human head from various cellular telephones. This numerical tool allows a detailed modeling of anatomically relevant human inhomogeneities, such as those in the head that are difficult to model experimentally. Software for numerical calculation of local and regional ***SAR*** is commercially available, but at the time of writing, there is not enough information to discuss the calculation accuracy.

Measurement methods have been developed for determination of ***SAR*** in experimental animals and models made of tissue-equivalent synthetic material. Such simulated models are referred to as phantoms. Measurement methods are used to verify the accuracy of numerical calculations. There are two basic methods for ***SAR*** measurements. One is to use a temperature probe to measure the temperature change caused by the heat produced by the absorbed RF energy, and then calculate ***SAR*** from:

$$SAR = c\frac{\Delta T}{\Delta t} \tag{4.5}$$

where ΔT is the temperature rise (in $^{\circ}$C) within the time interval Δt (in seconds), and c is the tissue (or phantom material) specific heat capacity, in J/kg$^{\circ}$C. Calculations of ***SAR*** from temperature rise can be done only if the temperature rise is linear with time. This method is appropriate for local ***SAR*** measurement when the exposure levels (irradiating fields) are intense enough so that heat transfer within and out of the body does not influence temperature rise. The second basic method for ***SAR*** determination is to measure the electric field inside the body with implantable electric field probes and then calculate the ***SAR*** from:

$$SAR = \frac{sE^2}{r} \tag{4.6}$$

where σ is the tissue conductivity (S/m), *E* is the rms electric field strength induced in the tissue (V/m) and r is the mass density (kg/m^3). This method is suitable only for measuring ***SAR*** at specific points in the body and for low values of ***SAR*** where the absorbed energy is insufficient to cause a detectable change in temperature. Instrumentation for this type of ***SAR*** measurement method usually includes an implantable electric field probe, a phantom and a computer controlled system for positioning the probe. This instrumentation has recently become commercially available and has been used to test portable transmitters for compliance evaluation.

4.2.6 Induced Current and Contact Current Measurement

Safety Code 6 requires that access to high field strength areas be restricted so as to limit the induced current and contact current experienced by a person so exposed, and acceptable limits of induced current and contact current are prescribed. Induced current is RF current induced in a human body through exposure to RF fields. The induced current can be measured by means of a special clamp-on current probe. Contact current is RF current that flows through a human body that is in contact with ungrounded or poorly grounded conductive objects in which RF potentials have been induced due to exposure to RF fields. The contact current flowing in the body is determined by the frequency and strength of the RF field, the size and shape of the body, and the body’s impedance, which in turn depends on several factors, such as height, weight, body composition (i.e. fat vs. lean tissue), and the nature and degree of contact. Contact current is determined with an electric circuit simulating the impedance of a human body grasping an insulated, conductive object energised by an RF field. Further discussion concerning measurement of induced current and contact current may be found in ***Safety Code 6.***

REFERENCES

(1) Health Canada, Health Protection Branch 'Limits of Human Exposure to Radiofrequency Fields in the Frequency range from 3 kHz -300 GHz'- (Safety Code 6), 99-EHD-237, 1999

(2) National Health and Welfare, Health Aspects of Radiofrequency and Microwave Radiation Exposure, Part 1, Environmental Health Criteria Document, Report No. 77-EHD-13, 1977.

(3) IEEE C95.3-1991 Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave, IEEE Inc., New York 1991.

(4) Cleveland R. 'Evaluating Compliance with FCC Specified Guidelines for Human Exposure to Radiofrequency Radiation' FCC OST Bulletin No. 65, Federal Communication Commission, Washington, DC, Oct. 1985

(5) M.A. Stuchly and S.S. Stuchly, "Measurements of electromagnetic fields in biomedical applications," CRC Critical Review in Biomedical Engineering, vol. 14, Issue 3, pp. 241-288, 1987.

(6) R.A. Tell, "RF hot spot fields: the problem of determining compliance with the ANSI radiofrequency protection guide,"1990 NAB Engineering Conference Proceedings, pp. 419-431.

(7) H.I. Bassen and T.M. Babij, "Experimental techniques and instrumentation," in Biological Effects and Medical Applications of Electromagnetic Energy, O.P. Gandhi, ed., pp. 141-173. Englewood Cliffs, NJ: Prentice Hall, 1990.

(8) R.W.P. King, "Electromagnetic Engineering", vol. I, McGraw-Hill, New York, 1945.

(9) W.W. Mumford, "Some Technical Aspects of Microwave Radiation Hazards", IRE Proceedings, no. 49, Feb. 1961, pp. 427-447.

(10) Richard A. Tell, 'Recommended Practice for Measuring Radiofrequency Fields Associated with Land Mobile, Cellular and PCS Base Stations for Compliance with Safety Code 6', June 1999

(11) Industry Canada RSS- 123, Issue 1 'Low Power Licensed Radiocommunication Devices', February 1996

(12) Industry Canada RSS-102, Issue 1 'Evaluation Procedure for Mobile and Portable Radio Transmitters with respect to Health Canada's Safety Code 6 for Exposure of Human to Radio Frequency Fields', September 1999

APPENDIX 1

SECTION A

PROCEDURES FOR MEASURING THE LEVELS OF RF ENERGY AT, AND IN THE VICINITY OF FM/DIGITAL RADIO, VHF/UHF/DIGITAL TV AND MDS TRANSMITTING SITES

1 INTRODUCTION

This part of the appendix covers transmitting facilities involving FM Radio (88-108 MHz), Digital Radio (1452-1492 MHz), VHF, UHF, Digital TV in the bands 54-72 MHz, 76-88 MHz, 174-216 MHz, 470-806 MHz and MDS operations in 2596-2686 MHz. Field measurements should be done by qualified personnel who have a good understanding of broadcasting operations and of broadcasting facilities. The following procedures apply to all classes of undertakings, including low power stations.

2 RELATED DOCUMENTS

Pertinent documents on the subject of Non-Ionizing Radiation (NIR) are listed below:

- BPR-1, Section 8, which specifies the circumstances under which measurement of radiofrequency energy may be required.
- Health Canada, ***Safety Code 6*** - "Limits of Human Exposure to Radiofrequency Electromagnetic Fields in the Frequency Range from 3 kHz to 300 GHz".
- The main body of the document "GUIDELINES FOR THE MEASUREMENT OF RADIO FREQUENCY FIELDS AT FREQUENCIES FROM 3 kHz TO 300 GHz", of which this Appendix is part. It discusses the various problems with respect to the measurements of RF fields and the characteristics and limitations of various instruments.
- The 'HIFIELD' Prediction program, Industry Canada.

3 MEASUREMENT ZONE

3.1 Estimating Appropriate Measurement Distances

The maximum radial distance(s) to which measurements should be undertaken at an antenna site should be estimated by first performing a theoretical analysis of the power density contributions of each transmitter. This analysis should take into account the permissible power density contribution at each frequency in use, the vertical and horizontal location of each antenna on the supporting structure(s), azimuth and elevation patterns of each antenna, the type(s) of modulation, the polarization of the radiating antenna(s), the terrain elevations near the site and the maximum ERP of each transmitting facility.

Power density prediction programs, such as 'HIFIELD', may be used to estimate the critical distances within which locations exceeding the ***Safety Code 6*** levels may occur. It should be noted that most programs of this type have built-in assumptions and safety margins and the calculated maximum measurement distances may be somewhat conservative.

When taking radiation patterns into account in calculations relating to estimating maximum measurement distances, appropriate allowances should be made for variations due to the antenna support structure(s). The use of Expansion (E) and Quadrature (Q) allowance factors, as envisaged in 'HIFIELD', may be appropriate, depending upon the antenna.

3.2 Layout of Measurement Points

The layout of measurement points depends on the system under consideration. Measurements should be taken along at least eight equally spaced radials, extending from a central reference point at the site (e.g. the base of the tower) to the maximum assessment distance, as determined in Section 3.1 above. If measurements are to be made at specific individual points rather than continuously, the distance between measurement points should be no greater than two metres.

The number of radials may have to be increased, and/or the maximum distance from the central reference point may have to be extended if readings suggest that additional measurements should be taken in order to ensure compliance with the ***Safety Code 6*** limits at all locations on or near the site, where public access is possible.

4 MEASUREMENT

4.1 Method of Measurement

For single-station sites, measurements can be made using an appropriately calibrated device of either the broadband or single frequency type. The main text of the document of which this is an appendix (i.e. third reference in 2.0 above) discusses such measuring equipment.

For multi-station sites, the use of a broadband total power density-measuring device is appropriate. A spectrum analyser may be used to determine all the sources of emission received at the site, and:

- In the absence of contributors from below 30 MHz and above 300 MHz, measurement could be done using a device having a "flat" amplitude-frequency response.

- In the presence of contributors below 30 MHz and above 300 MHz, the instrument should be a "weighted response" device exhibiting the recommended ***Safety Code 6*** curve.

The surveyor's "scan" of each measurement point should follow the suggestions discussed in Section 4.2 (of the main document). Normally, these are done holding the probe away from the body, with no other object present within a few metres from the surveyor. The body of the surveyor should not lie in the path of the signal measured, neither in front of, nor behind, the probe. To better illustrate this, assuming the surveyor faces the source of the signal measured, his/her arm should be stretched out sideways to hold the probe that should preferably, in turn, be pointed towards the signal source.

In those instances where a tripod is used, the tripod should be non-metallic to avoid any disruptive effect. The resonance of such a device can fall near the frequencies involved and the parasitic disturbance can substantially disrupt the local field.

If analog TV station(s) are involved and where there is a hot spot exceeding 75 % of the permissible power density, both the peak and the average readings, over a period of one (1) minute, should be recorded.

More closely spaced measurements are required near potentially reflective objects such as walls, fences etc. whether or not these are located along the radials chosen. Measurements closer than 20 cm from an object are not considered valid.

4.2 Measurement Report

A test report should include the following data:

- A general description of the site and the transmitting facility;

- A statement of compliance/non-compliance to the ***Safety Code 6*** limits;

- Highlight any measured values in excess of 50 % of the applicable limit and the location of these points (or zones);

- Provide a description of the means by which the applicant will prevent general access to, or warn of, locations and "hot spots" exceeding the appropriate recommended limits.

SECTION B

PROCEDURES FOR MEASURING THE LEVELS OF RF ENERGY AT AND IN THE VICINITY OF AM RADIO TRANSMITTING SITES

1 INTRODUCTION

This part of the appendix covers AM Radio Broadcasting Service in the band 525 to 1705 kHz. Field measurements should be taken by qualified personnel who have a good understanding of broadcasting operations and applications. The same procedures also apply to low power AM stations.

2 RELATED DOCUMENTS

Pertinent documents on the subject of Non-Ionizing Radiation (NIR) are listed below:

- BPR-1 Section 8, which specifies the circumstances under which measurement of radiofrequency energy may be required.
- Health Canada, ***Safety Code 6*** "Limits of Human Exposure to Radiofrequency Electromagnetic Fields in the Frequency Range from 3 kHz to 300 GHz".
- The main body of the document "GUIDELINES FOR THE MEASUREMENT OF RADIO FREQUENCY FIELDS AT FREQUENCIES FROM 3 kHz TO 300 GHz", of which this Appendix is part. It discusses the various problems with respect to the measurements of RF fields and the characteristics and limitations of various instruments.

3 MEASUREMENT ZONE

3.1 Distance Calculation

Due to the distances between the radiators (towers) in AM arrays, each tower must be assessed separately. Alternatively, for each tower, a practical radial distance, where measurement can begin and proceed inward therefrom, can be established using Table 1 (the same table as in Appendix 2 of Broadcasting Procedures and Rules, Part 1 (BPR-1) issued by the Department). The distances in the table were derived using the Numeric Electromagnetic Code (NEC) program, as applied to linear radiators. The model assumes the worst-case distances from single AM towers. In-between distances can be estimated by linear interpolation of the two closest listed distances. If the Table method is used, the measurement zone for each tower should be determined using the relevant input power at its base. While this is only an approximate method, it will be sufficiently accurate in most cases. When in doubt, for low power towers, a minimum measurement radius of 5 metres is suggested.

3.2 Layout of Measurement Points

The ***Safety Code 6*** limits will be found to lie along a locus generally circular or slightly egg-shaped around the foot of each tower. For a detailed measurement, a minimum of four readings should be taken along each radial for each tower, moving inwards from the maximum measurement radius. In general, however, only the 'hottest' tower, i.e. the one with the most current, needs to be considered. The calculated measurement radius may have to be extended if readings at the starting point already exceed the recommended General Public ***Safety Code 6*** limits.

4 MEASUREMENTS

4.1 E field, H field and Power Density Measurements

In general, the measurement zones for AM stations lie in the near and reactive field of the transmitted RF energy and therefore both E field and H field measurements are required. For single-station sites, measurements can be made using an appropriately calibrated device of either the broadband or single frequency type. The main text of the document of which this is an appendix (i.e. third reference in 2.0 above) discusses such measuring equipment.

For multi-station sites the following should be considered:

4.1.1 **Dual AM sites**. As the ***Safety Code 6*** limit in the AM Band becomes frequency dependent at 1 MHz, the simplest approach in determining the distance is to use a power value corresponding to the total for the two stations and using the highest frequency to determine the ***Safety Code 6*** permissible limit. Otherwise, the individual contributions would have to be determined and added (square of each field) to determine compliance, a procedure which requires turning off each station in turn during measurements.

4.1.2 **Shared AM and FM sites**. The difference in weighting is substantial and the percentage contribution of each station may need to be determined by switching off, in turn, each facility. The VHF facility's contribution would have to be established over the area of concern using, preferably, a power density instrument having a "weighted response" exhibiting the recommended ***Safety Code 6*** curve. The sum of the respective AM and FM contributions should be determined to establish the presence of zones exceeding 100 % of the ***Safety Code 6*** limit.

The surveyor's "scan" of each measurement point should follow the suggestions discussed in Section 4.2 (of the main document). Normally, these are done holding the probe away from the body, with no other object present within a few metres from the surveyor. The body of the surveyor should not lie in the path of the signal measured, neither in front of, nor behind, the probe. To better illustrate this, assuming the surveyor faces the source of the signal measured, his/her arm should be stretched out sideways to hold the probe that should preferably, in turn, be pointed towards the signal source.

In those instances where a tripod is used, the tripod should be non-metallic to avoid any disruptive effect. The field disrupting effect on the local field, can invalidate the measurements.

More closely spaced measurements are required near potentially reflective objects such as walls, fences, etc. whether or not these are located along the radials chosen. Measurements closer than 20 cm from an object are not considered valid.

4.2 Induced Current

Induced Current measurements should be done at the calculated distances from the ***Safety Code 6 limits***. A minimum of four(4) measurements should be taken at this distance from the base of the tower(s). Measurement points should be chosen in locations where the highest RF Energy have been recorded or expected.

The actual measurements are done using a properly calibrated Induced Current meter with a broadband human-equivalent antenna (approx. 1.75 metres). If a broadband human-equivalent antenna is not readily available and a person is substituted, be sure that the subject's front/back is in line with the tower.

4.3 Contact Current

Contact current measurements may be required at nearby[1] conductive structures (objects/buildings/fences and guy-wires etc.).

Suitable Contact Current Meters with appropriate grounding plates or clamps must be used for this measurement. It is also important to ensure that the detector probe or connector makes a good contact with the test object.

4.4 Measurement Report

A test report should include the following data:

- A general description of the site and the transmitting facility;
- A statement of compliance/non-compliance to the ***Safety Code 6*** limits;
- Highlight any measured values in excess of 50 % of the applicable limit and the location of these points (or zones);
- Provide a description of the means by which the applicant will prevent general access to, or warn of, locations and "hot spots" exceeding the appropriate recommended limits;
- Address specifically those zones close to metal and potentially reflective objects.

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[1] This must be assessed on a case-by-case basis. The distance within which measurement may be required will be a function of the size and orientation of the conductive structure(s), their distance from the radiators and the power of the station.

Table to Predict the Location of Various Exposure Contours for AM Undertakings

Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Tower base input power (kW)								
		50	25	10	5	2.5	1.0	0.5	0.25	0.10
25	0.06	109	83	60	47	37	27	22	18	13
50	0.13	65	51	37	29	23	18	14	11	8
75	0.19	49	38	28	23	18	13	11	8	6
100	0.25	40	31	23	19	15	11	9	7	5
150	0.38	30	24	18	15	11	8	6	5	4
200	0.5	25	20	15	12	9	7	5	4	3
280	0.74	21	17	12	10	7	5	4	3	2
300	0.75	20	16	11	9	7	5	4	3	<2
400	1.00	16	13	9	7	6	4	3	<2	<2
500	1.25	14	11	8	6	5	3	3	<2	<2
750	1.88	11	8	6	5	4	3	<2	<2	<2
1000	2.50	9	7	5	4	3	<2	<2	<2	<2

Table 1: Distances (in metres) at which fields from AM undertakings are predicted to fall below various field strength levels (from **OST Bulletin no. 65**)

Note : This table can be used for all AM frequencies and tower heights. The entries in this table apply to both electric field strength and the corresponding magnetic field strength (assuming a free-space impedance equal to 377 Ω)

APPENDIX 2

MEASUREMENT PROCEDURE FOR MICROWAVE INSTALLATIONS

1 MEASUREMENT PRECAUTIONS

1.1 Field measurements should be performed only by qualified personnel, who have a good understanding of electromagnetic radiation and communication systems.

1.2 To minimize measurement errors, refer to survey meter manufacturer's guidelines regarding:

(a) environmental conditions appropriate for survey meter use (e.g. min/max limits on temperature, humidity and atmospheric pressure to maintain probe accuracy);

(b) precautions to be taken in the handling of probes to minimize lead pick-up and effects of surveyor's body (e.g. probe to be held out at arm's length facing radiator or at a right angle to the radiator, moving probe cable to see if reading is affected);

(c) symptoms of survey meter overload and precautions to be taken to avoid overload; and

(d) uncertainty of measurements taken in the presence of reflecting objects and multiple radiating sources.

1.3 The procedures that follow assume near field conditions and metering capable of indicating both ***E*** and ***H*** in units of V^2/m^2 and A^2/m^2, respectively. Conversion errors may be encountered using metering in the near field while displaying Power Density (which assumes far field conditions).

2 RELATED DOCUMENTS

2.1 Reference documents are listed below:

"Limits of Human Exposure to Radiofrequency Electromagnetic Fields in the Frequency Range from 3 kHz to 300 GHz, ***Safety Code 6***, Health Canada. (Available from website address: www.hc-sc-gc.ca)

"Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields", Federal Communications Commission/Office of Engineering and Technology, OET Bulletin 65, August 1997.

"IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave", IEEE STD C95.3-1991, Institute of Electrical and Electronic Engineers, 1991.

3 INITIAL PREPARATION BEFORE SITE VISIT

3.1 Establish and record the following information relating to the equipment being surveyed:

(a) equipment manufacturer, model and nomenclature;

(b) operating frequencies;

(c) transmit power;

(d) transmitting equipment LO, IF and other frequencies below 300 MHz (for **H**-field measurements);

(e) transmit antenna gain, beamwidth, antenna orientation (if in fixed position) or rotation angle (less than or equal to 360 degrees) and antenna dimensions;

(f) intended antenna coverage area and sector blanking (if applicable);

(g) typical duty cycle or duration of a typical (or worst-case) transmission; and

(h) applicable Maximum Exposure Limit (MEL) from ***Safety Code 6*** (***SC6***).

3.2 Determine the conditions for the survey, from the list below, after discussions with technical and operations personnel:

(a) typical or worst-case equipment operating conditions;

(b) the worst-case failure mode;

(c) various frequency settings;

(d) various transmitter power levels for different modes of operation;

(e) fixed or normal antenna scan rates; and

(f) maximum transmitter power into a dummy load (if applicable).

3.3 Note any operational or technical irregularities.

3.4 Obtain a copy of previous survey results (if available) for comparison purposes.

3.5 Verify that the measurement instrumentation system will accurately measure the modulation schemes, frequency range and expected levels of interest.

4 REPORT REQUIREMENTS

4.1 Refer to the current version of ***Safety Code 6*** for reporting requirements.

4.2 Data may be presented as written dialogue within the main body of the survey report, in tabular form or on a site map, equipment room floor plan or equipment rack layout. The favoured method is to present survey data graphically on a top-down view of the surveyed location such as a site map or a floor plan, or on views of the transmitting equipment rack layouts.

4.3 Obtain copies of site plan and building floor plan and equipment rack layouts. Each drawing should include all prominent physical structures and/or equipment. Make multiple copies as required on which to mark the test data for the different equipment parameters and test conditions listed in paras. 3.1 to 3.3, applicable measurement parameter (i.e. ***E*** or ***H***), applicable General Public or RF Worker MELs and theoretical assessments of radiation exposures.

4.4 Within the report, clearly identify all over-exposure conditions and the locations where the applicable General Public or RF Worker MELs are reached or exceeded.

4.5 Photographs of the site, equipment room(s) and equipment rack(s) where high radiation levels are measured, would be useful for reference purposes.

4.6 Refer to paras 3.1 to 3.4 for documenting equipment parameters and survey/test conditions.

5 THEORETICAL ASSESSMENT OF RADIATION EXPOSURES

5.1 Refer to ***SC6*** for theoretical estimation of exposure risk. Estimate the radial distance from the radiator, within the antenna coverage area, for which radiated levels will likely not exceed General Public and RF Worker exposure levels. The survey should begin at this distance from the radiator to reduce the risk of over-exposure to survey personnel and damaging the survey meter. Estimate whether the radiated fields to be surveyed exist under far field conditions.

6 MEASUREMENT PRELIMINARIES ON-SITE

6.1 Visually examine the area to be surveyed to identify:

(a) areas in which people may be physically located or pass by in transit;

(b) General Public and RF Worker-only areas;

(c) transmit antenna coverage area;

(d) potential re-radiators of RF energy; and

(e) metallic structures which people may grasp by hand. (Required for Contact Current measurements).

6.2 Address the concerns and questions of site personnel as this may indicate the requirement for additional testing.

7 MEASUREMENT OF RADIATION EXPOSURES

7.1 Consider which of the following is applicable:

If the radiator is not highly directional (i.e. beamwidth > 30 degrees), then assume far field conditions exist beyond a one metre distance for frequencies above 300 MHz. If it is estimated that far field conditions exist, then ***SC6*** permits the measurement of either ***E***, ***H*** or ***PD*** ;

If it is estimated that near field conditions exist, then ***SC6*** requires separate ***E*** and ***H*** measurements within the operating range of commercially available survey instrumentation;. However, if it unknown whether near field or far field conditions exist, then assume near field conditions and separately measure both ***E*** and ***H*** .

7.2 The data recording procedures are as described in Section 3.

7.3 Begin the survey with the measurement of ***E*** . For ease of comparison and explanation of data to interested parties, V/m is the preferred unit of measurement. Using the manufacturers' recommended procedures, verify the operation and calibration of the survey meter with appropriate field sensor head attached.

7.4 Approach the radiator from within the antenna coverage area, starting from a distance greater than the estimated General Public distance. Observe the following when taking measurements:

(a) approach the radiator by walking in a serpentine motion (i.e. left to right and then back again) across the antenna coverage area;

(b) monitor the meter instrumentation while motioning the field probe up and down, or in a circular pattern, between the knees to the top of the head;

(c) do not position your body between the radiator and the field probe. Rather, position the body so that it is to the side of the radiator-to-field-probe axis. This minimizes reflections by the body; and

(d) do not survey within 20 cm of any metallic surface or conductor.

7.5 Approach the radiator from one side of the antenna coverage area. Record the location, distance and angle from the radiator at which MELs are obtained.

7.6 Survey all areas where people may be physically located or pass by in transit and record the data.

7.7 Survey about all potential re-radiators near where people may be physically located or pass by in transit and record the data.

7.8 Refer to ***SC6*** to determine if higher limits than the specified MELs are permissible for maximum exposure duration for time periods less than 0.1 hour.

7.9 Perform time averaging measurements should the radiated field change significantly (more than 25 % per ***SC6***) within a period of 0.1 hours, as first determined by using the maximum peak hold feature on the survey meter to record maximum change over time; otherwise a single measurement is sufficient. ***SC6*** details the procedures to follow. Record the exposure levels incorporating time averaging. Compare these data against the applicable MEL to determine if an over-exposure condition exists.

7.10 Perform spatial averaging measurements wherever an over-exposure condition is noted. Where the field is reasonably uniform (within ± 25 % per ***SC6***), as in the far field for example, measurements in one location representative of where people may be physically located, are sufficient. ***SC6*** details the procedures to follow. Record the exposure levels incorporating spatial averaging. Compare these data against the applicable MEL to determine if an over-exposure condition exists.

7.11 Compare measurements with previous survey results and investigate any obvious discrepancies.

7.12 Peak electric field strength measurements are only required in the vicinity of electromagnetic pulse (EMP) simulators.

7.13 Wherever MELs are reached or exceeded, repeat para 7.3 to 7.10, using instrumentation to measure ***H***, in units of A^2/m^2.

7.14 Repeat the steps for all conditions of interest as determined by paras 3.1 to 3.3.

8 INDUCED CURRENT MEASUREMENTS

8.1 Determine the minimal set of survey locations applicable to Induced Current measurement program by the following:

Identify those locations and equipment operating conditions for which the above radiative measurement program produced over-exposure conditions before spatial and time averaging were applied;

From this set, identify those locations for which the equipment being surveyed was operating within the frequency range for which Induced Current measurements are applicable. (Refer to ***SC6***); and

Identify those locations, if any, where there are long vertical metallic lengths. Examples include metallic poles, stands, stanchions, fence posts, hoists and cables. Add these locations to above set of minimal survey locations for Induced Current measurements.

8.2 Position the human model c/w tripod assembly at the first measurement location.

8.3 Calibrate/Zero the survey instrumentation.

8.4 Power ON the equipment at an appropriate equipment operating condition. Record the induced current produced by the test instrumentation. Do not apply time or spatial averaging to the measured results.

8.5 Repeat for all radiation over-exposure conditions and for all applicable equipment operating conditions.

8.6 Most Induced Current Meters develop measurement data valid for both feet. For data comparison against the single foot MEL condition, as required by ***SC6***, it is valid to measure the current through both feet and then divide by two if using this type of instrument.

8.7 Refer to ***SC6*** to determine if higher limits than the specified MELs are permissible for maximum exposure duration for time periods less than 0.1 hour.

8.8 Perform time averaging measurements or investigations should the radiated field change significantly (more than 25 % per ***SC6***) within a period of 0.1 hours. Otherwise a single measurement is sufficient. ***SC6*** details the procedures to follow. Record the exposure levels incorporating `time averaging. Compare this data against the applicable MEL to determine if an over-exposure condition does indeed exist.

8.9 Perform spatial averaging measurements wherever an over-exposure condition is noted. (Where the field is reasonably uniform (within ± 25 % per ***SC6***), as in the far field for example, a single measurements is sufficient). ***SC6*** details the procedures to follow.

Record the exposure levels incorporating spatial averaging. Compare this data against the applicable MEL to determine if an over-exposure condition does indeed exist.

9 CONTACT CURRENT MEASUREMENTS

9.1 Determine the minimal set of survey locations applicable to Contact Current measurement program by the following:

(a) identify those locations were the radiation measurements produced over-exposure results before spatial and time averaging were applied;

(b) from this set, identify those locations for which the equipment being surveyed was operating within the frequency range for which Contact Current measurements are applicable. (Refer to ***SC6***);

(c) from this set, identify those locations for which a person may come into contact with a metallic object by hand-grip. Select these the locations as where Contact Current measurements are required as a minimum; and

(d) identify those locations, if any, where there are long, vertical metallic lengths or sharp metallic edges. (Examples include metallic poles, stands, stanchions, fence posts, hoists and cables). Add these locations to the above set of minimal survey locations for Contact Current measurements.

9.2 Position the test instrumentation ground plate and meter on ground or floor level, at the first measurement location.

9.3 Fully extend the test instrumentation cabling connecting the ground plate to the meter probe tip assembly in a vertical plane. Ensure the cable pair between the ground plate and meter probe tip assembly are not twisted. Ensure the cable pair maintains a fixed separation distance between each other. Touch the meter probe tip assembly at the metallic location where a person may hand grip metal.

9.4 Calibrate/Zero the survey instrumentation.

9.5 Power ON the equipment at an appropriate equipment operating condition. Record the contact current produced by the test instrumentation. Do not apply time or spatial averaging to the measured results.

9.6 Repeat for all radiative over-exposure conditions and for all applicable equipment operating conditions.

9.7 Most Contact Current Meters develop measurement data valid for both feet. For data comparison against the single foot MEL condition, as required by ***SC6***, it is valid to measure the current through both feet and then divide by two if using this type of instrument.

9.8 Refer to ***SC6*** to determine if higher limits than the specified MELs are permissible for maximum exposure duration for time periods less than 0.1 hour.

9.9 Perform time averaging measurements or investigations should the radiated field change significantly (more than 25 % per ***SC6***) within a period of 0.1 hours. Otherwise a single measurement is sufficient. ***SC6*** details the procedures to follow. Record the exposure levels incorporating and time averaging. Compare this data against the applicable MEL to determine if an over-exposure condition does indeed exist.

9.10 Perform spatial averaging measurements wherever an over-exposure condition is noted. (Where the field is reasonably uniform (within ± 25 % per ***SC6***), as in the far field for example, a single measurements is sufficient). ***SC6*** details the procedures to follow. Record the exposure levels incorporating spatial averaging. Compare this data against the applicable MEL to determine if an over-exposure condition does indeed exist.

10. RADIATION MEASUREMENTS ABOUT TRANSMITTING EQUIPMENT

10.1 The procedures that follow are applicable to radiation measurements on in-service transmitting equipment in equipment rooms and equipment bays, about equipment maintenance/workshop areas and calibration centres.

10.2 Inspect cabinet interlocks to ensure they are operating satisfactorily. Discuss maintenance and operational procedures about the transmitting cabinets performed by maintenance and operational support staff. For example, determine if cabinet door interlocks are defeated for repair or calibration procedures. Test equipment operating under these non-standard interlock configurations.

10.3 The data recording procedures are as described in Section 4.

10.4 Using a calibrated meter with ***E*** field probe, survey all personnel workstation areas. Survey those areas where personnel may position themselves or position their body extremities such as arms and hands.

10.5 Visually examine all waveguide joints for indications of high voltage arcing, in areas where personnel may position themselves or position their body extremities. If waveguide arcing is noted, immediately report it to the equipment maintainers. Cease operation of the transmitting system until the source of the problem has been identified and corrected.

10.6 Survey along RF output power cables, operating dummy loads, exterior waveguides, spaces between rack panels, etc. Note locations of standing waves. Ignore all measurements made within 20 cm of a metallic surface, cable or RF device.

10.7 For each over-exposure condition, and for all equipment racks generating RF energy at frequencies below 300 MHz, repeat the measurements with a magnetic (***H*** field) probe and record the levels found.

10.8 Refer to ***SC6*** to determine if higher limits than the specified MELs are permissible for maximum exposure duration for time periods less than 0.1 hour.

10.9 Perform time averaging measurements should the radiated field change significantly (more than 25 % per ***SC6***) within a period of 0.1 hours, as first determined by using the maximum peak hold feature on the survey meter to record maximum change over time; otherwise a single measurement is sufficient. ***SC6*** details the procedures to follow. Record the exposure levels incorporating time averaging. Compare these data against the applicable MEL to determine if an over-exposure condition exists.

10.10 Perform spatial averaging measurements wherever an over-exposure condition is noted. Where the field is reasonably uniform (within ± 25 % per ***SC6***), as in the far field for example, measurements in one location representative of where people may be physically located, are sufficient. ***SC6*** details the procedures to follow. Record the exposure levels incorporating spatial averaging. Compare these data against the applicable MEL to determine if an over-exposure condition exists.

10.11 Compare measurements with previous survey results and investigate any obvious discrepancies.

10.12 Peak electric field strength measurements are only required in the vicinity of EMP simulators.

11 ABBREVIATIONS AND ACRONYMS

c/w	Complete With	**E**	Electric Field
H	Magnetic Field	MEL	Maximum Exposure Level (from ***SC6***)
PD	Power Density	RF	Radiofrequency
SC6	Health Canada's ***Safety Code 6***		

APPENDIX 3

SECTION A

PROCEDURES FOR MEASURING THE LEVELS OF RF ENERGY ASSOCIATED WITH LAND MOBILE, CELLULAR AND PCS SERVICES

1 INTRODUCTION

This appendix covers transmitting facilities involving land mobile, paging, two-way, trunking, cellular and PCS services, operating in the frequency range of 30 MHz to 2 GHz. Field measurements should be performed by qualified personnel who have a good understanding of wireless operations and facilities. All channels should be turned on at the same time and operating at full power to achieve worst-case situations.

2 RELATED DOCUMENTS

Pertinent documents on the subject of Non-Ionizing Radiation (NIR) are listed below:

Health Canada, ***Safety Code 6*** "Limits of Human Exposure to Radiofrequency Electromagnetic Fields in the Frequency Range from 3 kHz to 300 GHz."The complete document can be obtained at www.hc-sc.gc.ca/rpb

CRC Predict Program - Propagation Prediction Program developed by Communications Research Centre for the VHF / UHF Radio Frequency Bands.

Radiofrequency Power Density calculation Tool (RaPD Tool). Members can obtain a copy from the CWTA, 275 Slater Street, Room 500, Ottawa, Ontario, K1P 5H9.

3 INITIAL PREPARATION

3.1 Station and Site Information

3.1.1 One should obtain the pertinent station and site parameters prior to conducting the survey, but if the information is not complete, collect the necessary data at the site.

Station and site parameters include:

Location - geographical coordinates using GPS
- ground elevation - Above Mean Sea Level (AMSL)

Structure - type: rooftop or tower
- height - Above Ground Level (AGL)

Antenna - the number of antennas located at the site
- height (with respect to the floor or ground)
- manufacturer
- model
- azimuth
- elevation angle
- gain
- antenna patterns
- operating frequency range
- polarization
- mechanical dimensions

Transmitters - number of transmitters
- transmit power
- transmission line loss
- operating frequency

Ancillary equipment

3.1.2 Nearby transmitting stations may affect the field readings, therefore they should be taken into account in the prediction of the flux density at each test point. In general, databases and maps should be searched for any transmitting station within a radius of 200 m of the survey site and any high power transmissions (e.g. AM broadcasting or radar) within 2 km.

Note: When dealing with an antenna farm, a copy of the site drawing indicating the antenna layout, relative position and site characteristics should be obtained. Photos would also be helpful.

3.2 Theoretical Estimate

3.2.1 Establishing grids for measurements around survey station

3.2.1.1 If multiple transmitting antennas are present at various locations at the site, designate a single reference point for estimation purposes.

3.2.1.2 Calculate the distance from the reference point to where the far field begins, using the appropriate equation.

For large antennas:

$$R_f = 0.5\frac{D^2}{l}$$

For small antennas:

$$R_f = 2\frac{D^2}{l}$$

Where R_f is the distance from the reference point that marks the beginning of the far fields (m)

D is the largest dimension of the antenna (m)

l is the wavelength (m)

3.2.1.3 Find the minimum distance from the reference point where the following conditions hold.

$$R^2 \geq \frac{2.56}{4p}\left[\frac{EIRP_1}{L_1} + \frac{EIRP_2}{L_2} + \cdots + \frac{EIRP_n}{L_n}\right]$$

$R \$ R_f$

Where, *R* is the distance from the reference point, refer to as "maximum grid distance" (m).

EIRP is the effective isotropic radiated power for each antenna (W).

L is the ***Safety Code 6*** limit in a specific frequency band (W/m^2).

R_f is the distance from the reference point that marks the beginning of the far fields (m).

3.2.1.4 Draw a square centered about the reference point, using twice the maximum grid distance as the grid's dimension. Divide this square into a grid comprising of smaller squares whose dimensions are based on the wavelength associated with the site's operating frequency. However, for practical measurements 1.0 m by 1.0 m squares will suffice.

3.2.2 Estimate the power density at each point on the grid.

The power density of each point on the grid can be calculated using RaPD Tool or any appropriate formula.

3.2.3 Select the points to be measured points that are 50 % or more of the ***Safety Code 6*** exposure limit as points to be measured at the site and plot them on the grid. For those points less than 50 % of the ***Safety Code 6*** limit, no measurement need be taken. When arriving at the site, additional points should be measured in publicly accessible areas (including roof top of buildings where maintenance work may be required) and areas of potential re-radiating RF energy.

3.3 Equipment Selection and Verification

3.3.1 Select equipment with the following characteristics:

- Covers the operating frequency range to be measured.
- Operates in a high RF field strength environment.
- Operates in the climate and weather condition of the survey locations.

The surveyor should have good knowledge of the equipment and probe (e.g., polarization, behaviour, orientation and the rotation needed to obtain maximum and minimum readings).

3.3.2 Verify that the equipment is calibrated and working correctly. Record the calibration date, the serial number, manufacturer and model of the equipment being used. If the meter is battery operated, ensure that it is fully charged.

3.4 Record Sheet

Set up a recording table, corresponding to the grid, of all points to be measured at the site. There should be at least three columns in the table: the point's relative position, the time the reading was taken, and the reading itself. An area of the sheet should be set up to enter the antenna and transmitter parameters, information regarding the equipment used for the survey, the date, and the weather during the survey. Draw or obtain drawings of the equipment room and test site, noting the relative positions of the antennas, and attach them to the record sheet.

4 MEASUREMENT STEPS

4.1 Verification

4.1.1 Calibrate and test the probe to ensure it is functioning correctly before taking any measurements, as recommended by the manufacturer.

4.1.2 Perform a rapid walk around the site with the general probe, set in the maximum hold position, beginning away from the antenna and walking in, moving the probe in a constant up and down, side to side motion. This procedure is to ensure that the surveyor is not at risk of over-exposure. If the readings exceed the RF Worker limit, retreat and note the location.

4.1.3 If the equipment room is not located in an area that exceeds the RF Workers' limit, perform a quick walk around with the general probe to ensure that the room itself is within the RF Workers' limits. If not, exit the premise immediately and notify the manager.

If the initial readings indicate that the room is within the limits set out in ***Safety Code 6***, check to ensure that there are the same number of transmitters as specified in the preparation calculations. If any of the initial preparation information is contrary to the actual operation setup then recalculate the theoretical estimate with the new data gathered at the site. If all is as expected, continue with the survey.

4.1.4 Verify that the site reflects the description used in the theoretical calculations, by counting the number of antennas, and noting their layout.

4.2 Measurement of RF Energy

4.2.1 Construct the grid and record the locations of any additional points to be measured on the map (e.g., Areas that are publicly accessible and of potential radiating of RF energy).

4.2.2 Approach the points of interest within the grid, starting at the point furthest from the antenna or reference point. Moving the probe in a constant up and down, side-to-side motion (at arm's length) at the specific location, note the variation in readings. If there is little variation in the readings, relative to the accuracy of the instrument, then measure the power density at 1.5 m above the floor or ground. Record these values on the record sheet. However if there is a large variation, greater than 110 % of the relative accuracy of the instrument, spatial averaging is recommended as per ***Safety Code 6***.

4.2.3 Do not position the body between the antenna and the field probe. Rather position the body so that it is to the side of the antenna-to-field probe axis. This minimizes reflections by the body. Do not take measurements closer than 20 cm from potentially reflective objects.

Note: Presently there are no commercially available H field probes beyond 300 MHz.

4.3 Multiple Sources

Some probes are able to measure all frequencies at once so if this type of probe is used then measure all the sources at once. To ensure that all live transmitters are keyed during the test, turn on one by one, checking at all times that the meter reading has increased, reflecting the addition of each transmitter.

If several probes are needed to cover the entire operating frequency range of the site, attention should be paid so that no transmitter is measured twice. Key each transmitter one by one until all transmitters within the first probe's range have been keyed, checking that the meter reading increases, reflecting the addition of each transmitter. Measure the power density at each point, then, turn off the transmitters. Key the next transmitters (those that have not already been turned on) one by one, that fall into the second probe's range, and measure the power density at each point. Repeat the procedure until all transmitters have been keyed once.

For narrowband receivers, key one transmitter at a time and measure the power density at each point. Repeat this procedure for the remaining transmitters.

5 RF CONTACT AND INDUCED CURRENTS

For these services, RF contact and induced body currents are not significant. However, it is recommended not to come in direct contact with any metallic surfaces to avoid a shock due to improper grounding.

6 REPORT

Include in the report:

- a description of the survey site, transmitting facility and photographs if available.
- any observations regarding the climate, time of day, and anything unusual regarding the site or sources.
- a list of technical parameters of the antennas and transmitters including frequency, power, as mentioned in the initial preparation.
- the equipment used (serial number, and manufacturer) along with the calibration date of the instrumentation, so others can repeat the survey.

- the copies of the site map with each of the tested locations clearly identified and the corresponding readings, highlighting those points in excess of 50 % of the safety limit.

- a statement of compliance or non-compliance to ***Safety Code 6*** limits.

- suggestions where appropriate.

SECTION B

PROCEDURES FOR MEASURING THE LEVELS OF RF ENERGY ASSOCIATED WITH THE PORTABLE AND MOBILE UNITS OF LAND MOBILE, CELLULAR AND PCS SERVICES

Measurement procedures for the portable and mobile units of Land Mobile, Cellular and PCS Services, please refer to the document RSS-102, issue 1, September 1999- 'Evaluation Procedure for Mobile and Portable Radio Transmitters with respect to Health Canada's Safety Code 6 for Exposure of Human to Radio Frequency Fields ', published by Industry Canada.

APPENDIX 4

MEASUREMENT PROCEDURES FOR RADAR INSTALLATIONS

1 MEASUREMENT PRECAUTIONS

1.1 Field measurements should be performed only by qualified personnel, who have a good understanding of electromagnetic radiation and radar systems.

1.2 In cases where there is a predicted or known risk of over-exposure to survey personnel, one of four survey approaches may be used depending on the risk assessment;

(a) For high-risk cases, a horn antenna can be placed inside the measurement area (while the radar transmitter is **<u>OFF</u>**) and connected to a spectrum analyser with a low-loss cable of sufficient length to permit data to be taken without risk of overexposure.

(b) For medium risk cases, survey instrumentation may be placed on a tripod inside the measurement area (while the radar transmitter is **<u>OFF</u>**) and the meter is read with binoculars or via an optical link.

(c) For low risk cases, the survey probe may be used for an initial assessment.

(d) Alternately, where it is not necessary that the transmitter operate at full power, the transmitter may be operated at a reduced power level and the data adjusted to take this power reduction into account.

1.3 Where test procedures require a stationary radar beam. Personnel must be vacated from inhabited areas that will be radiated by, either the main beam, or secondary lobes or reflections from the main beam or secondary lobes.

1.4 For measurements on a scanning/rotating antenna, maintain the position of the survey probe long enough to permit the measurement of several sweeps of the antenna. Ensure that the response time of the survey instrument is fast enough for this type of measurement.

1.5 The radar transmitter shall not be tested without an appropriate load.

1.6 Ensure that there is sufficient clearance between a scanning/rotating antenna and survey personnel to avoid physical injury. Throughout the survey, survey personnel should be in constant communication with the radar operator in order to implement parameter changes required by the test program and to be able to quickly curtail transmitter operation in case of emergency.

1.7 To minimize measurement errors, refer to survey meter manufacturer's guidelines regarding:

(a) Environmental conditions appropriate for survey meter use (e.g. min/max limits on temperature, humidity and atmospheric pressure to maintain probe accuracy).

(b) Precautions to be taken in the handling of probes to minimize lead pick-up and effects of surveyor's body (e.g. probe to be held out at arm's length facing radiator or at a right angle to the radiator, moving probe cable to see if reading is affected).

(c) Symptoms of survey meter overload and precautions to be taken to avoid overload.

(d) Uncertainty of measurements taken in the presence of reflecting objects and multiple radiating sources.

1.8 The procedures that follow assume near field conditions and metering capable of indicating **E** and **H** in units of V-squared/m-squared and A-squared/m-squared, respectively. Conversion errors may be encountered using metering in the near field while displaying Power Density (which assumes far field conditions).

2 RELATED DOCUMENTS

2.1 Reference documents are listed below:

- "Limits of Human Exposure to Radiofrequency Electromagnetic Fields in the Frequency Range from 3 kHz to 300 GHz", ***Safety Code 6***, Health Canada, 1999(available from web site address: www.hc-sc.gc.ca/rpb).

- "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields", Federal Communications Commission/Office of Engineering and Technology, OET Bulletin 65, August 1997.

- "IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields – RF and Microwave", IEEE STD. C95.3-1991, Institute of Electrical and Electronic Engineers, 1991.

3 INITIAL PREPARATION BEFORE SITE VISIT

3.1 Establish and record the following information relating to the equipment being surveyed:

(a) Equipment manufacturer, model and nomenclature.

(b) Operating frequencies.

(c) Transmit peak power, pulse duration and pulse repetition rate.

(d) Transmitting equipment LO, IF and other frequencies below 300 MHz (for **H** field measurements).

(e) Transmit antenna gain, beamwidth, antenna orientation (if in fixed position) or rotation angle (less than or equal to 360 degrees) and antenna dimensions.

(f) Intended antenna coverage area (i.e. the area swept by the scanning antenna) and sector blanking (if applicable).

(g) Typical duty cycle or duration of a typical (or worst-case) transmission.

(h) Applicable Maximum Exposure Limit (MEL) from ***Safety Code 6*** (***SC6***).

3.2 Determine the conditions for the survey, from the list below, after discussions with technical and operations personnel:

(a) Under typical or worst-case equipment operating conditions.

(b) Under the worst-case failure mode.

(c) At various frequency settings.

(d) At various transmitter power levels and pulse widths for different modes of operation.

(e) At fixed or normal antenna scan rates.

(f) At maximum transmitter power into the dummy load.

3.3 Note any operational or technical irregularities.

3.4 Obtain a copy of previous survey results (if available) for comparison purposes.

3.5 Verify that the measurement instrumentation system will accurately measure the modulation schemes, frequency range and expected levels of interest.

4 REPORT REQUIREMENTS

4.1 Refer to current ***SC6*** for reporting requirements.

4.2 Data may be presented as written dialogue within the main body of the survey report, in tabular form or on a site map, equipment room floor plan or equipment rack layout. The favoured method is to present survey data graphically on a top-down view of the surveyed location such as a site map or a floor plan, or on views of the transmitting equipment rack layouts.

4.3 Obtain copies of site plan and building floor plan and equipment rack layouts. Each drawing should include all prominent physical structures and/or equipment. Make multiple copies as required on which to mark the test data for the different test conditions identified in para. 3.2, applicable measurement parameter (i.e. **E** or **H**), applicable General Public or RF Worker MELs and theoretical assessments of radiation exposures.

4.4 Within the report, clearly identify all over-exposure conditions and the locations where the applicable General Public and/or RF Worker MELs are reached or exceeded.

4.5 Photographs of the site, equipment room(s) and equipment rack(s) where high radiation levels are measured, would be useful for reference purposes.

4.6 Refer to para. 3.1 to 3.4 for documenting equipment parameters and test conditions.

5 THEORETICAL ASSESSMENT OF RADIATION EXPOSURES

5.1 Refer to ***SC6*** for theoretical estimation of exposure risk. Estimate the radial distance from the radiator, within the antenna coverage area, for which radiated levels will likely not exceed General Public and RF Worker exposure limits. The survey should begin at this distance from the radiator to reduce the risk of over-exposure to survey personnel and damaging the survey meter. Estimate whether the radiated fields to be surveyed exist under far field conditions.

6 MEASUREMENT PRELIMINARIES ON-SITE

6.1 Visually examine the area to be surveyed to identify:

(a) Areas in which people may be physically located or pass by in transit.

(b) General Public and RF Worker-only areas.

(c) Transmit antenna coverage area and sector blanked area.

(d) Potential re-radiators of RF energy.

6.2 Address the concerns and questions of site personnel as this may indicate the requirement for additional testing.

7 MEASUREMENT OF RADIATION EXPOSURES

7.1 The data recording procedures are as described in Section 4.

7.2 Begin the survey with the measurement of **E.** For ease of comparison and explanation of data to interested parties, V/m is the preferred unit of measurement. Using the manufacturers’ recommended procedures, verify the operation and calibration of the survey meter with appropriate field sensor head attached.

7.3 When testing a stationary antenna for a selected radar operating condition, defeat antenna rotation. Then, manually adjust antenna angles such that a worst-case condition is achieved. Otherwise, incorporate the antenna rotational reduction factor into the measurement data as detailed in ***SC6.***

7.4 Approach the radiator from within the antenna coverage area, starting from a distance greater than the estimated General Public distance. Observe the following when taking measurements:

(a) Approach the radiator by walking in a serpentine motion (i.e. left to right and then back again) across the antenna coverage area.

(b) Monitor the meter instrumentation while motioning the field probe up and down, or in a circular pattern, between the knees to the top of the head.

(c) Use the maximum peak hold feature on the survey meter for a sufficiently long period to ensure that maximum amplitude of the pulses and the sweeps (if the antenna is rotating) have been measured.

(d) Do not position your body between the radiator and the field probe. Rather, position the body so that it is to the side of the radiator-to-field-probe axis. This minimizes reflections by the body.

(e) Do not survey within 20 cm of any metallic surface or conductor.

(f) Take into consideration the field strength of the back lobe. Under certain conditions the survey meter could be damaged.

7.5 Survey all areas where people may be physically located or pass by in transit and record the data.

7.6 Survey about all potential re-radiators near where people may be physically located or pass by in transit and record the data.

7.7 Incorporate the antenna rotational reduction factor into the measurement data as detailed in ***SC6*** if MELs are exceeded.

7.8 Refer to ***SC6*** to determine if higher limits than the specified MELs are permissible for maximum exposure duration for time periods less than 0.1 hour.

7.9 Perform time averaging measurements should the radiated field change significantly (more than 25 % per ***SC6***) within a period of 0.1 hours, as first determined by using the maximum peak hold feature on the survey meter to record maximum change over time; otherwise a single measurement is sufficient. ***SC6*** details the procedures to follow. Record the exposure levels incorporating time averaging. Compare these data against the applicable MEL to determine if an over-exposure condition exists.

7.10 Perform spatial averaging measurements wherever an over-exposure condition is noted. Where the field is reasonably uniform (within 25 % per ***SC6)***, as in the far field for example, measurements in one spot representative of where people may be physically located, are sufficient. ***SC6*** details the procedures to follow. Record the exposure levels incorporating spatial averaging. Compare these data against the applicable MEL to determine if an over-exposure condition exists.

7.11 Compare measurements with previous survey results and investigate any obvious discrepancies.

7.12 Repeat the steps described in para. 7.1 to 7.4 for all conditions of interest previously determined in para. 3.2.

7.13 Peak electric field strength measurements are only required in the vicinity of electromagnetic pulse (EMP) simulators.

8 RADIATION MEASUREMENTS AROUND TRANSMITTING EQUIPMENT

8.1 The procedures, which follow, are applicable to radiation measurements on in-service transmitting equipment in equipment rooms and equipment bays, about equipment maintenance/workshop areas and calibration centres.

8.2 Inspect cabinet interlocks to ensure they are operating satisfactorily. Discuss maintenance and operational procedures about the transmitting cabinets performed by maintenance and operational support staff. For example, determine if cabinet door interlocks are defeated for repair or calibration procedures. Test equipment operating under these non-standard interlock configurations.

8.3 The data recording procedures are as described in Section 4.

8.4 Using a calibrated meter with **E** field probe, survey all personnel workstation areas. Survey those areas where personnel may position themselves or position their body extremities such as arms and hands.

8.5 Visually examine all waveguide joints, in areas where personnel may position themselves or position their body extremities, for indications of high voltage arcing. If waveguide arcing is noted, immediately report it to the equipment maintainers. Cease operation of the transmitting system until the source of the problem has been identified and corrected.

8.6 Survey along RF output power cables, operating dummy loads, exterior waveguides, spaces between rack panels, etc. Note locations of standing waves. Ignore all measurements made within 20 cm of a metallic surface, cable or RF device.

8.7 For each over-exposure condition, and for all equipment racks generating RF energy at frequencies below 300 MHz, repeat the measurements with a magnetic (**H**-field) probe and record the levels found.

8.8 Refer to ***SC6*** to determine if higher limits than the specified MELs are permissible for maximum exposure duration for time periods less than 0.1 hour.

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8.10 Perform spatial averaging measurements wherever an over-exposure condition is noted. Where the field is reasonably uniform (within ± 25 % per ***SC6***), as in the far field for example, measurements in one location representative of where people may be physically located, are sufficient. ***SC6*** details the procedures to follow. Record the exposure levels incorporating spatial averaging. Compare these data against the applicable MEL to determine if an over-exposure condition exists.

8.11 Compare measurements with previous survey results and investigate any obvious discrepancies.

8.12 Peak electric field strength measurements are only required in the vicinity of EMP simulators.