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Guideline

Guidelines for the Measurement of Radio Frequency Fields at Frequencies From 3 kHz to 300 GHz

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Preface

This technical guideline, entitled GL-01, Issue 3, *Guidelines for the Measurement of Radio Frequency Fields at Frequencies From 3 kHz to 300 GHz*, replaces GL-01, Issue 2, published in October 2005. Issue 3 has been revised in its entirety to be in accordance with the latest version of Health Canada's Safety Code 6 guidelines.

Issued under the authority of
the Minister of Industry

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DANIEL DUGUAY
Director General
Engineering, Planning and Standards Branch

Contents

1.0 Purpose

This guideline describes the measurement procedures for different types of radiocommunication and broadcasting installations when verifying compliance with the "uncontrolled environment" requirements (including limits, access control, etc.) as set out in Health Canada's *Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz* – commonly known as Safety Code 6. These measurement procedures were developed in consultation with Health Canada.

This document is intended for people working in the radiocommunication and broadcasting industry with the assumption that the surveyor has a basic knowledge of electromagnetic field theory and practice, including an understanding of radio frequency (RF) safety. These procedures do not extend to measurements in the very low frequency band (below 3 kHz).

2.0 Introduction

As outlined in CPC-2-0-03, *Radiocommunication and Broadcasting Antenna Systems*, Industry Canada requires that all radio installations be operated in a manner that complies with Health Canada's Safety Code 6 (SC6) at all times for the purpose of protecting the general public. To determine compliance of these radio installations, Industry Canada has developed various tools, guidelines and documents.

GL-01, *Guidelines for the Measurement of Radio Frequency Fields at Frequencies From 3 kHz to 300 GHz*, is used by the Department to verify SC6 compliance. It covers the measurement procedures for broadcast, microwave, land mobile, paging, cellular, Personal Communications Services (PCS) and radar installations. This guideline document can also be used for other types of services.

Technical Note TN-261, entitled *Safety Code 6 (SC6) Radio Frequency Exposure Compliance Evaluation Template (Uncontrolled Environment Exposure Limits)*, is an evaluation tool to quickly assess the RF exposure compliance for simple radiocommunication antenna sites using mathematical calculations.

Broadcasting Procedures and Rules BPR-1, entitled *General Rules*, specifies the broadcasting application requirements to demonstrate compliance with SC6. BPR-1 contains the description of the required analysis and alternatives depending on the RF exposure results submitted by the proponent.

The Department has its own software tool for conducting SC6 compliance evaluations for radiocommunication and broadcasting sites. External clients may employ prediction methods using spreadsheets or other computational modeling software tools that take into consideration the near-field and far-field regions, as well as the applicable SC6 uncontrolled environment exposure limits to analyze the impact of radiocommunication and broadcasting stations located within the local radio environment.

2.1 Instrumentation

IEEE Std C95.3, *IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz-300 GHz*, or IEC 62232, *Determination of RF field strength and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure,* should be consulted when determining the type and specification of the measuring instruments to be used when performing RF exposure measurements.

2.2 Measurements

The procedures presented in this document may be used to verify compliance with the "uncontrolled environment" limits as set out in SC6 for the following:

1. measurements of radiated electromagnetic (EM) fields;

2. measurements of leakage and re-radiated EM fields; and

3. measurements of induced and contact currents.

2.3 Radiocommunication Services

Services in the frequency range from 3 kHz to 65 MHz include, among others, maritime navigational communications, aeronautical radionavigation and radiocommunication, analog AM radio broadcasting, shortwave broadcasting, land mobile communication and fixed services, VHF 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 65 MHz, measurements of both the electric (E) fields and the magnetic (H) fields may be required. In cases of some high-power transmissions (e.g. AM radio service), measurements of induced current and contact current may also be required.

Services in the frequency range from 65 MHz to 300 GHz include, among others, VHF radio (FM), VHF/UHF television and digital radio broadcasting, fixed, land mobile/PCS and satellite systems. In this frequency range, the wavelengths of the electromagnetic fields are relatively short and the dimensions of the antenna are relatively small. As a result, 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 orthogonal and are related by a constant (the free-space impedance equals 377 Ω). In this case, the power density can be derived from $|E|^2$ divided by the free-space impedance. Consequently, measuring only the E field is sufficient. In addition to field measurements, induced current and contact current may also be required for services operating up to 110 MHz.

Note:	Far-field measurements are valid as soon as the measurements are performed in the far-field region of each radiating element located at the site under study.

2.4 Near-Field and Far-Field Regions

The space around a radiating antenna can be divided essentially into two regions, the near-field region and the far-field region. For an antenna with a maximum overall dimension that is small compared to the wavelength (i.e. electrically small antennas), 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."

$$R = \frac{\lambda}{2\pi} \qquad \text{(eq. 2.1)}$$

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 electrically large antennas, the near-field region consists of the reactive field extending to the distance obtained in equation 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 at which the far field begins is that the phase of the fields from all points on the radiating antenna does not differ by more than λ/16. The distance from the antenna corresponding to this criterion is:

$$R = \frac{2 \cdot D^2}{\lambda} \qquad \text{(eq. 2.2)}$$

where "D" is the largest dimension of the antenna (m) (usually taken as the length).

A realistic practical distance from a large antenna (e.g. a parabolic reflector), which provides close agreement with experimental results, can be obtained using the following relationship:

$$R = 0.5\frac{D^2}{\lambda} \qquad \text{(eq. 2.3)}$$

Further information on near-field and far-field regions can be found in the appendix of Technical Note TN-261, *Safety Code 6 (SC6) Radio Frequency Exposure Compliance Evaluation Template (Uncontrolled Environment Exposure Limits).*

3.0 Evaluation Procedures When Verifying Compliance to SAR-based Limits

When verifying compliance with SC6 requirements, reference levels associated with the uncontrolled environment limits are linked to different basic restrictions (see Annex A). From 3 kHz to 10 MHz, the reference levels are either based on nerve stimulation (NS) or on specific absorption rate (SAR). From 10 MHz to 6 GHz, the reference levels are based on SAR only. Finally, above 6 GHz, the reference limits are based on power density.

A specific reference period is associated with both NS- and SAR-based limits. For NS-based limits, the reference period will be an instantaneous measurement. For SAR-based limits, the reference period is generally associated with exposure over a period of 6 minutes.

This section provides the measurement procedures to determine compliance with SAR-based limits. Section 4 covers specific situations where compliance with NS- or power-density-based limits is required.

3.1 Overview of Radio Frequency Compliance Evaluation Procedures

To verify SC6 compliance with respect to the uncontrolled environment limits (in areas accessible to the public) at a specific site with radiocommunication and/or broadcasting antenna system installations, the following steps should be followed (see flow chart, Annex B):

(1) Prior to on-site measurements, a radio environment search should be performed and data should be gathered for services located within the specified distance from the specific sites under consideration. In particular, the surveyor should gather all data for broadcasting stations within a radius of 1 km; and all data for terrestrial fixed transmitter stations in the land mobile, cellular, PCS, microwave, radar, radiolocation services, etc., within a radius of 100 metres.

(2) A prediction[1] should be made to estimate RF levels for the site being surveyed as a way to identify approximate locations to be measured (e.g. locations where calculations show that the RF level is greater than or equal to 50% of the uncontrolled environment limits).

Note: If the theoretical analysis reveals no location greater than or equal to 50% of the uncontrolled environment limit (in areas accessible to the general public), the site is considered compliant and on-site measurements are typically not required.

(3) The far-field distance should be considered when selecting the measurement locations. Normally, if a location is in the far field of every radiating element present at the site, then E-field measurements are sufficient. Otherwise, for situations where the public has access to the near field, both the E-field and H-field should be measured.

(4) Depending on the frequency bands present at the site and the results of the radio environment

[1] The prediction can be performed using TN-261, spreadsheets or other computational modeling software tools that take into consideration the near-field and far-field regions, as well as the applicable SC6 uncontrolled environment exposure limits to determine the location of the maximum RF exposure levels for the sites in question.

search, either narrowband and/or broadband equipment are selected for on-site measurements.

(5) To determine if time averaging is required for the detailed measurements at the site, the surveyor should initiate a characterization of the various transmissions present at the site with regard to the temporal variation of the RF signals.

Note:	It was observed through numerous departmental measurement audits that signals are generally non-uniform in the first 2 metres above ground (spatial variation). Therefore, spatial averaging between 0.20 and 1.8 metres above ground, rooftop, etc., is required for all detailed measurements (see Section 3.2.3).

(6) Using the locations identified in step 2 as starting points, a walkaround inspection (see Section 3.2.2) of the site should be performed to identify points with high RF levels (≥ 50% of the uncontrolled environment limits, including measurement uncertainty) where detailed measurements must be performed. The layout of the walkaround will be dependent on the site under consideration. The walkaround inspection should normally be based on at least 8 equally spaced radials. However, when radials are difficult to follow, it may be based on a random pattern provided that the same area is covered by the walkaround. In addition, other locations accessible to the general public (e.g. nearby walking trails, viewpoints, resting areas, etc.) should also be covered by the walkaround inspection. Close attention should also be paid to publicly accessible areas in close proximity to the guy wire anchor points (minimum clearance for measurements is 20 cm) where high levels of re-radiation can occur. When 8 equally spaced radials are performed, they should extend from the maximum assessment distance, as determined in step 2 above, to a central reference point at the site (e.g. up to the access control point, such as a fence or base of the towers if accessible by the general public).

If measurements are to be made at specific individual points rather than continuously, the distance between measurement points should be no greater than 2 metres. A minimum of four readings should be taken along each radial for each tower, moving inwards from the maximum measurement radius. 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 SC6 limits at all locations on or near the site, where public access is possible.

(7) On-site measurements should be taken with a clear view of the antennas when possible and at least 20 cm from any objects[2] to avoid coupling effects. In the case of rooftop sites, the measurements should be taken, at a minimum, at the locations where a member of the general public could be exposed to the main and side lobes of the antennas.

(8) Induced and contact current measurement considerations are required if the site being surveyed has transmitters operating at 110 MHz or below.

(9) A written record should be kept of the measurement locations, date, time, weather conditions, ambient temperature, photographs of the site, reading levels and time duration of measurements.

[2] For AM sites, a distance greater than 20 cm is required to ensure that the surveyor does not affect the measurement readings. The use of a fibre optic cable is recommended when performing the measurements.

(10) Measurement uncertainties must be taken into account during the survey.

3.2 Field Strength and Power Density Measurement Procedures

3.2.1 Site Characterization (Temporal Variation)

As indicated in step 5 of Section 3.1, the surveyor should initially characterize the transmission site with regard to the temporal variation of the RF signals. To do so, the survey instrument can be placed (in the far field) approximately where the theoretical evaluation showed the strongest level.[3] The probe should be installed on a non-metallic tripod at a height of between 1 metre and 1.8 metres above the reference plane where the measurements are taken (ground level, rooftop, etc.).

The measurements are first performed continuously over a period of 6 minutes in order to establish the average field strength signal (or average power density). The average field strength will be necessary to evaluate the magnitude of the temporal variations of the signals and to assess whether the total field strength signal variations, based on the average field strength signal, are less than ±20% (or ±36% in power density).[4] To determine the temporal variation, a second set of measurements (continuously over a period of 6 minutes) is then required.

Should the average field strength signal variations be less than ±20% (or ±36% in power density), time averaging will not be required for the remainder of the survey, as the signal is considered temporally uniform (this will normally be encountered for broadcasting sites such as FM stations). In this case, only scanned spatial averaging will be required, as the signal is considered to be spatially non-uniform when in proximity to the ground level. However, if the signal variations are more than ±20% in field strength (or ±36% in power density), both spatial and time averaging continuously over a period of 6 minutes will be required for the remaining measurements, as described in Section 3.2.3.2, given that the signal is considered to be temporally and spatially non-uniform.

Note: Transients in the measurement instrument or instantaneous sporadic electrostatic effects can create spikes in the measured RF signal. When determining the signal variations in time, the temporal peaks created by such spikes should not be considered.

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3 There is no need to find the location with the strongest signal when performing the site characterization. However, at the chosen location, the signal should be strong enough to determine if the signal variation is significant (if applicable). If the RF levels at the site are low, it may be difficult to quantify the signal variation. In this case, the surveyor may assume that the field is stable and carry on with detailed measurements for *site information* purposes. Nonetheless, the main purpose of the field survey is to find and/or remedy points accessible to the general public that have RF levels equal or above the uncontrolled environment limits, including measurement uncertainty.

4 For example, if the measured average power density is 40% of the limit and the measured power density varies between 32% and 51%, the maximum temporal variation of the power density will be approximately 28% ([51%-40%]/40%). Time averaging will not be required, as the maximum temporal variation of the power density is less than 36%.

3.2.2 Walkaround Inspection

Once the temporal characterization is completed, the surveyor should walk around the site with a survey instrument, as described in Section 3.1, step 6, to identify potential locations with strong RF levels. The results of the theoretical evaluation should be used as a starting point. Normally, the walkaround inspection is done by holding the survey instrument away from the body, as the surveyor should not be standing directly in front of or behind the survey instrument (i.e. probe or antenna). There should be no other object located within a few metres of the surveyor. The survey instrument should also be pointing towards the transmitting antennas. The height of the survey instrument should be swept between 0.2 metres and 1.8 metres above ground level or the horizontal reference plane where the measurements are being taken. Locations where the RF levels are greater than or equal to 50% of SC6 limits for uncontrolled environments, with the measurement equipment uncertainty added, should be considered for detailed measurements, including spatial averaging and, as needed, temporal averaging.

3.2.3 Detailed Measurement

Spatial averaging should be performed at every measurement location selected for detailed measurements (see Section 3.2.2). However, depending on the results of the site characterization regarding temporal variation (see Section 3.2.1), spatial averaging over a vertical line representing the vertical extent of a human body can either be obtained through a quick scan (see Figure 1) or through time averaging measurements (see Figure 2) as described in the next two sections.

Note: The surveyor must ensure the proper configuration of the measurement instrument for all SC6 measurements. For example, measurement instruments used in a multi-frequency environment should preferably be capable of summing the normalized exposure levels of all frequencies present by providing the total normalized exposure level. If direct field strength or power density measurements are envisaged, measurements must be done separately for **each frequency**, as the SC6 limits vary with the frequency.

When conducting detailed field strength/power density measurements (e.g. for FM, Digital Radio, VHF/UHF/Digital TV, MDS and cellular transmitting sites), the measurement mode should be set to average root-mean-square (RMS).

3.2.3.1 Time Averaging Not Required (Scanned Spatial Averaging)

If the temporal characterization of the site (see Section 3.2.1) reveals that time averaging measurements are not required, a quick scan with an isotropic probe over the vertical extent of a human body (from 0.2 metres to 1.8 metres) should be done in order to determine the scanned spatial averaging value. Normally, a spatial averaging scan of approximately 30 seconds may be considered provided that the probe has a fast response time.[5] For probes with a response time greater than 1 second, the speed of the vertical scan shall be such that a minimum of 30 samples are taken for performing the spatial averaging.

5 A fast response time is defined as one (1) second or less.

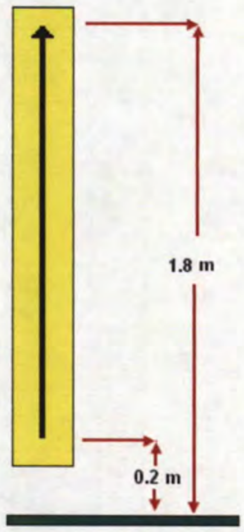

Figure 1: Spatial averaging scan over the vertical extent of a human body (from 20 cm to 1.8 m) for a temporal uniform electric field

> **Note:** If a single axis probe is being used instead of an isotropic probe, detailed spatial averaging will need to be performed.

3.2.3.2 Time Averaging Required (Detailed Spatial Averaging)

If time averaging measurements are required, each point of a 5-point vertical line representing the vertical extent of a human body must be measured continuously and time-averaged over a period of 6 minutes. The 5 points should be evenly spaced (see Figure 2 below). Using the time-averaged value for each point of the 5-point vertical line evaluation determined above, the spatial averaging value is calculated for that specific measurement location by taking the average of the 5 points. The probe might be set on a non-metallic tripod for convenience when performing detailed time and spatial averaging measurements.

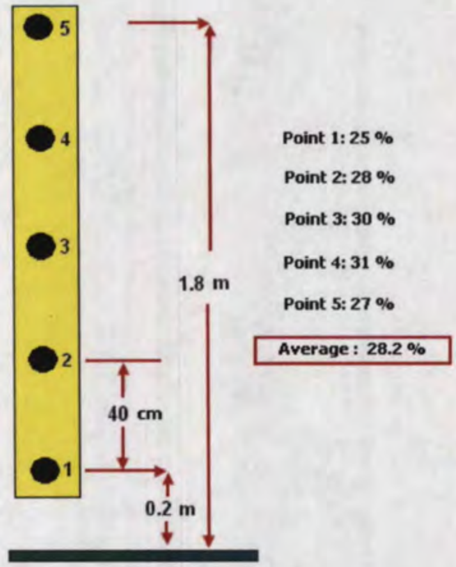

Figure 2: Example of a grid for measurements of a non-uniform spatial and temporal signal level and the calculation of the time-spatial average value as a percentage of SC6 limits (uncontrolled environments)

The following three equations show how to calculate the spatial average using the 5-point vertical line. The first equation is based on probes directly measuring the total exposure in percentage of the limit, whereas the other two equations are based respectively on power density and field strength measurements. Measurement equipment uncertainty shall also be considered when applying these equations.

(A) Calculating spatial average with total exposure values in normalized percentage:

The test point is compliant if:

$$\frac{1}{5}\sum_{j=1}^{5}\left(\frac{Ex\%_{Avg}}{100}\right)_j \leq 1 \qquad \text{(eq. 3.1)}$$

where: $(Ex\%_{Avg})_j$ is the time-averaged total exposure in normalized percentage at the point j on the vertical line.

Eq. 3.1 should be used for measurements in the far field. This first equation assumes that the probe is internally using the square of the field values to determine the normalized exposure level.

(B) Calculating spatial average using power density measurements:

The test point is compliant if:

$$\sum_{i=1}^{N}\left(\frac{S_i}{S_{SC6,i}}\right)\leq 1 \text{ with } S_i=\frac{1}{5}\sum_{j=1}^{5}(S_{Avg,i})_j \qquad \text{(eq. 3.2)}$$

where: N is the total number of frequencies at the site
S_i is the spatial average of the power density for the i^{th} frequency
$(S_{Avg,i})_j$ is the time-averaged power density for the i^{th} frequency and at the point j on the vertical line
$S_{SC6,i}$ is the SC6 power density limit for the i^{th} frequency

Eq. 3.2 can also be used for measurements in the far field only. Given that the probe is measuring power densities, the internal usage of the square of the field values is assumed.

(C) Calculating spatial average using field strength measurements:

The test point is compliant if:

$$\sum_{i=1}^{N}\left(\frac{E_i}{E_{SC6,i}}\right)^2\leq 1 \text{ with } E_i=\sqrt{\frac{1}{5}\sum_{j=1}^{5}(E_{AvgRMS,i})_j^2} \qquad \text{(eq. 3.3)}$$

where: N is the total number of frequencies at the site
E_i is the spatial average of the field strength for the i^{th} frequency
$(E_{AvgRMS,i})_j$ is the time-averaged RMS field strength for the i^{th} frequency and at the point j on the vertical line
$E_{SC6,i}$ is the SC6 electric field strength limit for the i^{th} frequency

Eq. 3.3 may be used for measurements performed in near-field and far-field regions.

Note: In an environment with multiple frequency bands, the measurement instruments are typically capable of summing the combined exposure values without manual calculation by the user.

If single axis measurements are taken, each 6-minute time-averaged RMS field strength measurement $(E_{AvgRMS,i})_j$ should be evaluated by combining the three axis contributions based on the following equation:

$$(E_{AvgRMS,i})_j = \sqrt{\sum_{k=1}^{3}\left[(E_{AvgRMS,i})_{j,k}\right]^2} \qquad \text{(eq. 3.4)}$$

where: $(E_{AvgRMS,i})_{j,k}$ is the time-averaged RMS field strength for the i^{th} frequency and at the point j on the vertical line along the axis k ($k = x$, y and z axis).

3.2.3.3 Applying Measurement Instrument Uncertainty

As indicated in step 10 of Section 3.1, the measurement instrument uncertainty should be added to each measurement before determining compliance (see Annex C). The following two examples show how to consider the uncertainty of the measurement instrument.

Example 1:

The meter shows a reading of 25% of the SC6 limit for uncontrolled environments. If the instrument has an uncertainty of ±3 dB, the percentage could be as high as 50% of the SC6 limit for uncontrolled environments. Therefore, the location should be considered for detailed measurements (see Section 3.2.3).

Example 2:

The meter shows a reading of 10% of the SC6 limit for uncontrolled environments. If the instrument has an uncertainty of ±3 dB, the percentage could be as high as 20% of the SC6 limit for uncontrolled environments. Therefore, the location does not need to be considered for detailed measurements.

3.3 Induced and Contact Current Measurement Procedures

Induced and contact current measurement considerations are required if the transmitters within the environment in question have operating frequencies of 110 MHz or below.

Under certain conditions, the induced current can exceed the limits specified in Table A.4 of Annex A, even though the electric field strengths are below the limits specified in tables A.1 and A.3 of Annex A. These conditions may occur even when the electric field strength is as low as 25% of the exposure limit. Therefore, induced current through a single foot should be measured by using a clamp-on current probe or a low-profile platform consisting of two parallel conductive plates isolated from each other with one located above the other when the electric field is 25% of the uncontrolled environment limit or higher. The initial induced current measurements should be taken at the locations with the highest field strength.

For frequencies between 400 kHz and 110 MHz, a SAR-based induced current limit over a 6-minute reference period should be used and the following steps should be followed when induced current measurements are required and performed with a clamp-on current probe:

(1) The surveyor should visit each location with strong field exposure as identified during the walkaround inspection (see Section 3.2.2 of this guideline). The identified locations should be logged (e.g. photos, geographical coordinates, description of area).

(2) At each location identified in step 1, the surveyor should be standing upright and without touching any metallic objects. The clamp-on probe should be clamped around his/her ankle. The surveyor should modify the position of his/her arms to find the maximum reading. The measurement equipment uncertainty must be added to the measured average RMS current then the square of this value is compared to the square of the induced current limit for uncontrolled environments specified in Table A.4 of Annex A. If time averaging is required based on the site characterization (temporal variation) described in Section 3.2.1, the average RMS value should be obtained over a reference period of 6 minutes, otherwise 30 seconds is considered sufficient (see note below).

Similarly, the contact current can exceed the current limits specified in Table A.5 of Annex A, even though the electric field strengths, which are the major contributor to the contact current, are below the limits as specified in tables A.1 and A.3 of Annex A. These conditions may occur when the electric field strength is as low as 25% of the exposure limit. For any conducting metallic object that a person may come in contact with and that is located in a high-intensity RF field, contact currents should be measured when the electric field strength is 25% of the uncontrolled environment limits or higher. An electric circuit having the impedance of the human body or a clamp-on current probe should be used for measurements.

For frequencies between 100 kHz and 10 MHz (e.g. AM stations), a SAR-based contact current limit with an instantaneous reference period should be used. As such, a measurement time of approximately 30 seconds may be considered to evaluate the **maximum** RMS contact current (including measurement uncertainty). However, depending on the site characterization (temporal variation), the measurement time may be extended to 6 minutes to ensure that the maximum RMS value is captured. To assess compliance, the square of the maximum RMS value (obtained over either the 6-minute or 30-second time period) should be compared to the square of the SAR-based contact current limit specified in Table A.5.

For frequencies between 10 MHz and 110 MHz (e.g. FM and television transmitting sites (TV channels 2 to 6)), a SAR-based contact current limit with a 6-minute reference period should be used. As such, the clamp-on probe should be set to **average** RMS and the square of the measured contact current value (including measurement uncertainty) should be compared with the square of the SAR-based contact current limit specified in Table A.5. If time averaging is required based on the site characterization (temporal variation) described in Section 3.2.1, the average RMS value should be obtained over a reference period of 6 minutes, otherwise 30 seconds is considered sufficient (see note below).

The following steps should be followed when contact current measurements are required and performed with a clamp-on current probe.[6]

(1) Perform a visual inspection of the area around the antenna site for conductive object that can be accessible to the general public. The identified locations should be logged (e.g. photos, geographical coordinates, description of structure).

(2) Conduct E-field or H-field measurements near the conductive object no closer than the recommended minimum separation distances (e.g. 20 cm). If the applicable E-field or H-field limits are exceeded, then the conductive object should be deemed to be an over-exposure point (non-compliance) and no further measurements are required. Otherwise, proceed to step 3 and use a clamp-on current probe.

(3) Perform the measurement with the clamp-on probe around the wrist by touching the structure under test with the index finger while wearing a fabric or rubber glove.

(4) If the contact current limits are exceeded, then the conductive object should be deemed to be an over-exposure point (non-compliance) and no further measurements are required. Otherwise, proceed to step 5.

(5) Perform the measurement with the clamp-on probe around the wrist by touching the structure under test directly with the index finger (without glove) for a continuous reference period of 6 minutes or 30 seconds as described in step 3 and compare the square of the measured average or maximum RMS contact current (including measurement uncertainty) with the square of the contact current limit for uncontrolled environments specified in Table A.5.

Note: A continuous reference period of 6 minutes is applicable for frequencies between 400 kHz and 110 MHz for induced current limits (see Table A.4 of Annex A) and between 10 and 110 MHz for contact current limits (see Table A.5 of Annex A). Consequently, the site characterization with respect to temporal variation (see Section 3.2.1) will determine if time averaging is required. When time averaging is required, the average RMS induced and contact current measurements will be determined over a continuous reference period of 6 minutes. When time averaging is not required, the average RMS induced and contact current measurements may be determined over a continuous reference period of 30 seconds. However, if the induced and contact current measurement values vary significantly (e.g. more than ±20%) in spite of the site characterization (temporal variation), the averaging time should be expanded to 6 minutes.

6 For any conducting metallic object located near a **high-intensity** RF field (e.g. AM stations in the controlled environment), the measurements should not be performed using the clamp-on current probe given that the measurements results could be excessively over the contact current limits for the controlled environment and pose a risk to the surveyor.

4.0 Specific Measurements Procedures

This section provides the measurement procedures for specific types of transmitting sites. Unless otherwise specified, the general measurement procedures detailed in Section 3 are applicable.

4.1 Measurement Procedures for FM, Digital Radio, VHF/UHF/Digital TV and MDS Transmitting Sites

The general measurement procedures, described in Section 3, for verifying compliance with SC6 are applicable to FM, digital radio, VHH/UHF/digital TV and MDS transmitting sites.

In the case of induced and contact currents, measurement considerations are required if transmitters within the environment in question have operating frequencies of 110 MHz or below (see Section 3.3).

4.2 Measurement Procedures for AM Transmitting Sites

Both NS- and SAR-based field strength limits and current limits may apply to an AM station depending on its operating frequency (see tables A.1, A.2, A.4 and A.5 of Annex A). Therefore, the applicable reference periods will either be instantaneous or 6 minutes. Instantaneous reference periods are considered by capturing the maximum RMS field or maximum RMS current values over 30 seconds, whereas a 6-minute reference period implies the measurement of the average RMS field or average RMS current values. As RF measurements for AM stations are typically taken in the near-field region, both electric and magnetic field strengths should be measured when performing detailed measurements.

Due to the distances between the radiators (towers) in AM arrays, each tower must be assessed separately. For each tower, a practical radial distance can be established, where measurement can begin and proceed towards the tower up to the point where public access is restricted (see AM procedure in BPR-1[7]). Fifty percent (50%) of the most stringent electric and magnetic field strength limit (lower value) between the NS-based limit and the SAR-based limit should be selected (see tables A.1 and A.2 in Annex A) when determining the initial measurement distance based on the AM procedure described in BPR-1. When the BPR-1 method is used, the measurement zone for each tower should be determined using the proposed transmitter power at its base. Although this is only an approximate method, it is sufficiently accurate in most cases. When in doubt, a minimum measurement radius of 5 metres is suggested for low-power towers.

The SC6 uncontrolled environment limits are typically 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 (4) readings should be taken along each radial for each tower, moving inwards from the maximum measurement radius. In general, only the "hottest" tower (i.e. the one with the most current) needs to be considered. If SC6 limits for uncontrolled environment are exceeded in areas accessible to the general public for the "hottest" tower, the other towers will need to be considered in order of decreasing tower current. The calculated measurement radius may need to be extended if readings at the starting point already exceed the SC6 limit for uncontrolled environments.

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7 See Broadcasting Procedures and Rules BPR-1 – *General Rules*.

As indicated above, SAR-based and NS-based field strength limits may apply depending on the operating frequency of the AM station. Section 3.2 should be referenced when determining compliance with SAR-based field strength limits. As the radiated power from an AM station varies with modulation, continuous time averaging measurement over 6 minutes will likely be required. However, site characterization with respect to temporal variation (see Section 3.2.1) will confirm whether time averaging is needed. If time averaging is not required, the measurement time may be reduced to 30 seconds. To assess compliance, the square of the average RMS field strength value (obtained over either the 6-minute or 30-second time period) should be compared to the square of the SAR-based field strength limit (see note below for the calculations).

For NS-based field strength limits, the site characterization, the walkaround inspection and the spatial averaging methodology of sections 3.2.1 to 3.2.3 are also applicable. As Safety Code 6 requires an instantaneous reference period to assess compliance with NS-based field strength limits, the maximum RMS field strength over a measurement time of approximately 30 seconds should be measured. However, depending on the site characterization (temporal variation), the measurement time may be extended to 6 minutes to ensure that the maximum RMS value is captured. To assess compliance, the maximum RMS field strength value (obtained over either the 6-minute or 30-second time period) should be compared to the NS-based field strength limit (see note below for the calculations).

Note: For **NS-based limits**, the spatial average is performed by summing the 5 spatial samples of field strengths arithmetically and dividing the result by the number of samples. In the following equation, a single operating frequency is considered. However, the equation is also valid for multiple frequencies if the applicable SC6 limit is the same for all frequencies.

$$\frac{E_{NS}}{E_{SC6-NS}} \leq 1 \text{ to comply with the limits and where } E_{NS} = \frac{1}{5}\sum_{j=1}^{5}(E_{MaxRMS})_j \quad \text{(eq. 4.1)}$$

In the above equation, $(E_{MaxRMS})_j$ is the maximum RMS E-field strength at the point j on the vertical line and E_{SC6-NS} is the NS-based SC6 limit for the E-field. The same equation applies to H-field measurements.

If single axis probes are used, the 3 axis measurements must be combined as follows:

$$(E_{MaxRMS})_j = \sqrt{\sum_{k=1}^{3}\left[(E_{MaxRMS})_{j,k}\right]^2} \quad \text{(eq. 4.2)}$$

where: $(E_{MaxRMS})_{j,k}$ is the maximum RMS E-field at the point j on the vertical line along the axis k (k=x, y and z axis).

Finally, for a site with multiple frequencies and multiple applicable SC6 limits when using a single axis probe, the following general equations are used where i denotes the i^{th} group of frequencies having the same NS-based SC6 limit $E_{SC6-NS,i}$:

$$\sum_{i=1}^{N}\left[\frac{E_{NS,i}}{E_{SC6-NS,i}}\right]\leq 1 \text{ with } E_{NS,i}=\frac{1}{5}\sum_{j=1}^{5}(E_{MaxRMS,i})_j \text{ and with } (E_{MaxRMS,i})_j=\sqrt{\sum_{k=1}^{3}\left[(E_{MaxRMS,i})_{j,k}\right]^2} \quad \text{(eq.4.3)}$$

For **SAR-based limits**, spatial averaging value is based on an RMS calculation of measured field strengths. As indicated above, time-averaged RMS field strength measurements over 6 minutes will also likely be required for AM stations when performing SAR-based measurements. The following general equation applies where the indexes have the same definitions as the above equations and where the SAR-based SC6 limit for the i^{th} group of frequencies having the same limit is represented by $E_{SC6\text{-}SAR,i}$:

$$\sum_{i=1}^{N}\left[\left(\frac{E_{SAR,i}}{E_{SC6-SAR,i}}\right)^2\right]\leq 1 \text{ with } E_{SAR,i}=\sqrt{\frac{1}{5}\sum_{j=1}^{5}\left[(E_{AvgRMS,i})_j\right]^2} \text{ and with } (E_{AvgRMS,i})_j=\sqrt{\sum_{k=1}^{3}\left[(E_{AvgRMS,i})_{j,k}\right]^2}$$

(eq. 4.4)

The same equations apply to NS- and SAR-based H-field measurements.

For AM stations, both induced and contact current measurements should also be taken. The measurement procedures detailed in Section 3.3 should be referenced for the measurement steps. For contact current, given that instantaneous SAR-based measurements are required for AM stations operating frequencies, a measurement time of approximately 30 seconds may be considered to evaluate the maximum RMS contact current. However, depending on the site characterization with respect to temporal variation (see Section 3.2.1), the measurement time may be extended to 6 minutes to ensure that the maximum RMS value is captured. To assess compliance, the square of the maximum RMS value (obtained over either the 6-minute or 30-second time period) should be compared to the square of the SAR-based contact current limit. For the induced current, an SAR-based limit also applies, but the reference period is 6 minutes. However, site characterization with respect to temporal variation (see Section 3.2.1) will confirm whether time averaging over 6 minutes is needed. If not, the averaging time may be reduced to 30 seconds. To assess compliance, the square of the average RMS value (obtained over either the 6-minute or 30-second time period) should be compared to the square of the SAR-based induced current limit.

4.3 Measurement Procedures for Microwave Transmitting Sites (Fixed Point-to-Point)

When field strength measurements are required for microwave transmitting sites, the following considerations are applicable:

If the radiator is not highly directional (i.e. beamwidth > 5 degrees), assume that far-field conditions exist beyond a one-metre distance for frequencies above 300 MHz. If it is estimated that far-field conditions exist, SC6 permits the measurement of E, H or power density (PD).

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

The measurement procedures described in Section 3 for determining SC6 compliance are also applicable for microwave transmitting sites, excluding the induced and contact current measurements, which are not applicable to frequency ranges above 110 MHz.

Note: When the main contributions are from sources at or above 3 GHz, spatial averaging should not be performed given that it may not be conservative enough with respect to the peak spatial average SAR limit over 1 gram of tissue.

Sweep the probe on the vertical extent of the human body (from 20 cm to 1.8 m), and locate the "peak" average RMS level. Record this field strength or power density value and compare the value with the SC6 limits for the uncontrolled environment, including measurement equipment uncertainty.

According to the site characterization with respect to temporal variation, if time averaging is not required, a scan of approximately 30 seconds may be considered by covering the vertical extent of the human body provided that the probe has a fast response time. When time averaging is required, each point should be measured over a continuous reference period of 6 minutes (see Figure 2). Of the 5 time-averaged RMS levels measured, only the "peak" level should be used to compare to the SC6 limits for uncontrolled environments.

In order to demonstrate compliance, the same equations described in Section 3.2.3.2 are applicable except that only the "peak" average RMS level is used as in the following:

(A) Using normalized exposure levels, the test point is compliant if:

$$\frac{Ex\%_{Pk\_AvgRMS}}{100} \leq 1 \qquad \text{(eq. 4.5)}$$

where: $Ex\%_{Pk\_AvgRMS}$ is the peak time-averaged total exposure in normalized percentage among the measurements taken on the vertical line.

Similarly, eq. 4.5 should be used for measurements in the far field. This equation assumes that the probe is internally using the square of the field values to determine the normalized exposure level.

(B) Using direct measurement of power densities, the total normalized exposure level for each point j of the vertical line must first be determined (by adding the normalized contribution for each frequency i at that point). Among the 5 points, only the peak value of the total normalized exposure level associated with each point is kept. This peak value should be smaller or equal to 1 in order to ensure compliance with SC6.

Using the following equation, the test point is compliant if:

$$ExNorm_{Pk\_AvgRMS} \leq 1 \text{ where } ExNorm_{Pk\_AvgRMS} = \max_{j=1to5}\left[\sum_{i=1}^{N}\left(\frac{S_{AvgRMS,i,j}}{S_{SC6,i}}\right)\right] \quad \text{(eq. 4.6)}$$

where: N is the total number of frequencies at the site
$S_{AvgRMS,i,j}$ is the time-averaged power density for the i^{th} frequency at point j on the vertical line
$S_{SC6,i}$ is the SC6 power density limit for the i^{th} frequency
$ExNorm_{Pk\_AvgRMS}$ is the peak value among the 5 points on the vertical line of the total normalized exposure level associated with each point.

Again, eq. 4.6 can also be used for measurements in the far field. As the probe is measuring power densities, the internal usage of the square of the field values is assumed.

(C) using direct field measurements, similarly, the total normalized exposure level for each point j of the vertical line is first determined (by adding the normalized contribution for each frequency i at that point). Among the 5 points, only the peak value of the total normalized exposure level associated with each point is kept. This peak value should be smaller or equal to 1 in order to ensure compliance with SC6.

Using the following equation, the test point is compliant if:

$$ExNorm_{Pk\_AvgRMS} \leq 1 \text{ where } ExNorm_{Pk\_AvgRMS} = \max_{j=1to5}\left[\sum_{i=1}^{N}\left(\frac{E_{AvgRMS,i,j}}{E_{SC6,i}}\right)^2\right] \quad \text{(eq. 4.7)}$$

where: N is the total number of frequencies at the site
$E_{AvgRMS,i,j}$ is the time-averaged field strength for the i^{th} frequency at point j on the vertical line
$E_{SC6,i}$ is the SC6 electric field strength limit for the i^{th} frequency
$ExNorm_{Pk\_AvgRMS}$ is the peak value among the 5 points on the vertical line of the total normalized exposure level associated with each point.

Finally, eq. 4.7 may be used for measurements performed in near-field and far-field regions.

If single axis measurements are performed, for each point j on the vertical line, the time-averaged field strength of each axis $(E_{AvgRMS,i,j})_k$ is combined (for the i^{th} frequency). The resulting total field strength for that frequency at that point $(E_{AvgRMS,i,j})$ is then compared to the SC6 field strength limit for that frequency $(E_{SC6,i})$. This gives the normalized exposure level for the i^{th} frequency at point j. The normalized contribution of each frequency at point j is added in order to obtain the total normalized exposure level at point j. This process is repeated for each of the 5 points on the vertical line. Among the 5 points, the peak value of the total exposure level associated with each point is kept. This peak value should be smaller or equal to 1 in order to ensure compliance with SC6.

Using the following equation, the test point is compliant if:

$$ExNorm_{Pk\_AvgRMS} \leq 1 \text{ where: } ExNorm_{Pk\_AvgRMS} = \max_{j=1to5}\left[\sum_{i=1}^{N}\left(\frac{E_{AvgRMS,i,j}}{E_{SC6,i}}\right)^2\right]$$

$$\text{and where: } E_{AvgRMS,i,j} = \sqrt{\sum_{k=1}^{3}\left[(E_{AvgRMS,i,j})_k\right]^2} \qquad \text{(eq. 4.8)}$$

where: N is the total number of frequencies at the site

$(E_{AvgRMS,i,j})_k$ is the time-averaged field strength for the i^{th} frequency at point j on the vertical line along the axis k (k= x, y and z)

$E_{AvgRMS,i,j}$ is the time-averaged field strength for the i^{th} frequency at point j on the vertical line

$E_{SC6,i}$ is the SC6 electric field strength limit for the i^{th} frequency

$ExNorm_{Pk\_AvgRMS}$ is the peak value among the 5 points on the vertical line of the total normalized exposure level associated to each point.

4.4 Measurement Procedures for Land Mobile, Cellular, PCS and Microwave Point-to-Multipoint Transmitting Sites

Transmitting facilities involving the PCS, as well as land mobile, paging, two-way, trunking and cellular services, are operating in the frequency range of 30 MHz to 3.7 GHz.

The measurement procedures described in Section 3 for determining SC6 compliance are also applicable to these types of sites.

In cases of induced and contact currents (see Section 3.3), measurement considerations are required if transmitters within the environment in question use operating frequencies of 110 MHz or below.

4.5 Measurement Procedures for Radar Transmitting Sites

The measurement procedures described in Section 3 for determining SC6 compliance also apply to these types of sites. Special care must be taken at radar sites due to the possibility of extremely high powers involved.

For radar transmitting sites, special attention shall be paid for temporal averaging over 6 minutes. In cases where there is a predicted or known risk of overexposure to survey personnel, one of the following 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 OFF) and connected to a spectrum analyzer with a low-loss cable of sufficient length to permit data to be taken without risk of overexposure. An attenuator may be required to protect the spectrum analyzer from possible damage.

(b) For medium-risk cases, survey instrumentation may be placed on a tripod inside the measurement area (while the radar transmitter is OFF) 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 into account this power reduction.

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.

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

5.0 Reporting Requirements

GL-08, *Guidelines for the Preparation of Radio Frequency (RF) Exposure Compliance Reports for Radiocommunication and Broadcasting Antenna Systems*, should be used when reporting the RF exposure measurement survey.

References

The following documents are indispensable for the application of this document and should therefore be consulted when performing measurements of RF fields:

(1) Broadcasting Procedures and Rules BPR-1, *General Rules*

(2) Client Procedures Circular CPC-2-0-03, *Radiocommunication and Broadcasting Antenna Systems*

(3) Client Procedures Circular CPC-2-0-20, *Radio Frequency (RF) Fields – Sign and Access Control*

(4) Guidelines GL-08, *Guidelines for the Preparation of Radio Frequency (RF) Exposure Compliance Reports for Radiocommunication and Broadcasting Antenna Systems*

(5) Radio Standards Specifications RSS-102, *Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands)*

(6) Technical Note TN-261, *Safety Code 6 (SC6) Radio Frequency Exposure Compliance Evaluation Template (Uncontrolled Environment Exposure Limits)*

(7) Health Canada's *Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz – Safety Code 6*

(8) Health Canada's *Technical Guide for Interpretation and Compliance Assessment of Health Canada's Radiofrequency Exposure Guidelines*

(9) AS/NZS 2772.2:2011 *Radiofrequency fields Part 2: Principles and methods of measurements and computation – 3 kHz to 300 GHz*

(10) IEC 62232, *Determination of RF field strength and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure*

(11) IEEE C95.3, *Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields with Respect to Human Exposure to Such Fields, 100 kHz-300 GHz.*

Annex A — Safety Code 6 (SC6) Limits for Uncontrolled Environments

Table A.1 – Electric Field Strength Limits for the Uncontrolled Environment From 3 kHz to 10 MHz

Frequency Range	Electric Field Strength (V/m RMS)	Reference Period	Basis for Limit
0.003-10 MHz	83	Instantaneous	Based on Nerve Stimulation
1.1 - 10 MHz	$87/f^{0.5}$	6 min	Based on Specific Absorption Rate

Note: Frequency, f, is in MHz

Table A.2 – Magnetic Field Strength Limits for the Uncontrolled Environment From 3 kHz to 10 MHz

Frequency Range	Magnetic Field Strength (A/m RMS)	Reference Period	Basis for Limit
0.003-10 MHz	90	Instantaneous	Based on Nerve Stimulation
0.1 - 10 MHz	0.73/f	6 min	Based on Specific Absorption Rate

Note: Frequency, f, is in MHz

Table A.3 – Field Strength/Power Density Limits for the Uncontrolled Environment From 10 MHz to 300 GHz

Frequency Range	Electric Field Strength (V/m RMS)	Magnetic Field Strength (A/m RMS)	Power Density (W/m^2)	Reference Period (minutes)
10 - 20 MHz	27.46	0.0728	2	6
20- 48 MHz	$58.07/f^{0.25}$	$0.1540/f^{0.25}$	$8.944/f^{0.5}$	6
48 - 300 MHz	22.06	0.05852	1.291	6
300 – 6 000 MHz	$3.142f^{0.3417}$	$0.008335f^{0.3417}$	$0.02619\ f^{0.6834}$	6
6 000 – 15 000 MHz	61.4	0.163	10	6
15 000 – 150 000 MHz	61.4	0.163	10	$616000/f^{1.2}$
150 000 – 300 000 MHz	$0.158f^{0.5}$	$4.21 \times 10^{-4} f^{0.5}$	$6.67 \times 10^{-5} f$	$616000/f^{1.2}$

Note: Frequency, f, is in MHz

Table A.4 – Induced Current Limits for the Uncontrolled Environment

Frequency Range (MHz)	Induced Current (mA, RMS) Through a Single Foot	Reference Period	Note
0.003 - 0.4	100 f	Instantaneous	Based on Nerve Stimulation
0.4 - 110	40	6 min	Based on Specific Absorption Rate

Note 1: Where the assessment is made of the current flowing through both feet, the results shall be compared to twice the limits for a single foot.

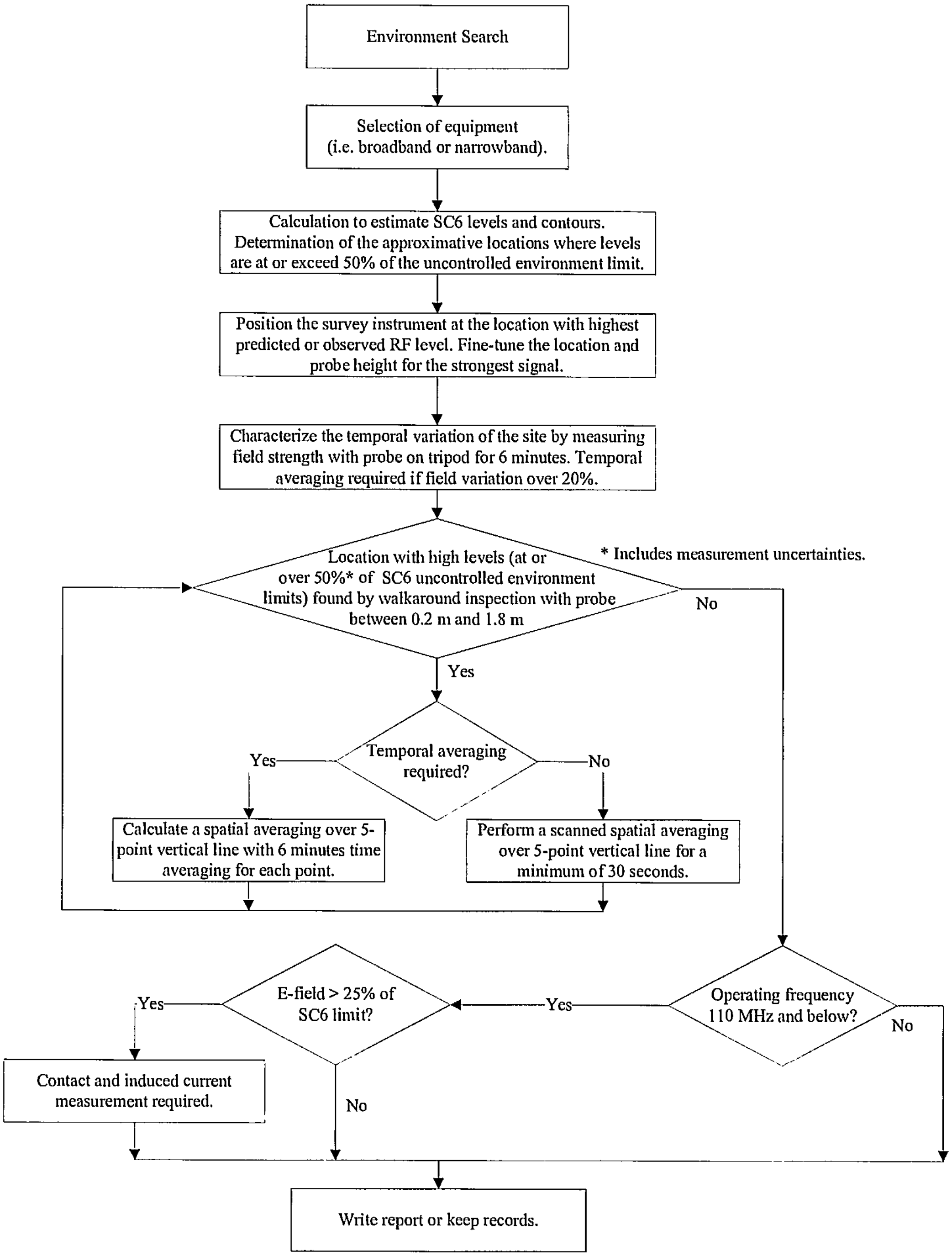
Note 2: Frequency, f, is in MHz.

Table A.5 – Contact Current Limits for the Uncontrolled Environment

Frequency Range (MHz)	Contact Current (mA, RMS) for Finger-Touch	Reference Period	Note
0.003 - 0.1	200 f	Instantaneous	Based on Nerve Stimulation
0.1 - 10	20	Instantaneous	Based on Specific Absorption Rate
10 - 110	20	6 min	Based on Specific Absorption Rate

Note: Frequency, f, is in MHz

Annex B — Generic Flow Chart of the On-site Measurement Procedures



Annex C — Measurement Uncertainties

Measurement Uncertainties

Measurement uncertainties are the result of actual measurement uncertainties and/or instrumentation uncertainties.

Related Documents

For additional information on measurement uncertainties, refer to *Measurement Good Practice Guide*s by the National Physical Laboratory.

Actual Measurement Uncertainties

Actual measurement uncertainties can be minimized by following proper measuring practices and procedures.

Measurement Equipment Uncertainties

Measurement equipment uncertainties are primarily due to the design of the instrument. They can also be affected by other factors, such as environmental conditions, temperature, humidity, etc. Proper calibration of the instrument can largely eliminate the bias errors and a careful selection of instrument type and measuring method can reduce the value of this uncertainty factor.

Requirements for Compliance with Safety Code 6

a. The instrument selected must be of recognized commercial type.

b. Proper calibration of the instrument must be performed in accordance with the manufacturers' recommended calibration period.

c. Correct measurement procedures must be followed.

If the measured RF levels plus the manufacturers' specified measurement equipment uncertainty factor are below the Safety Code 6 (SC6) limits for uncontrolled environments, these exposure levels will be accepted as measured and the site is deemed to be SC6 compliant.

If the measured RF levels plus the manufacturers' specified instrument uncertainty factor exceed the SC6 limits for uncontrolled environments, then corrective remedies must be taken to comply with SC6 requirements (see Client Procedures Circular CPC-2-0-20, *Radio Frequency (RF) Fields – Sign and Access Control*). Alternatively, single frequency measurement of all frequencies present at the site can be conducted and summed together as described in Health Canada's Technical Guide and detailed in this document to improve the instrumentation uncertainty factor.