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Spectrum Management and Telecommunications

Technical Note

# **Safety Code 6 (SC6) Radio Frequency Exposure Compliance Evaluation Template (Uncontrolled Environment Exposure Limits)**

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## List of Acronyms and Abbreviations

ALS	Assignment and Licensing System
e.i.r.p.	Equivalent Isotropically Radiated Power
e.r.p.	Effective Radiated Power
EM	Electromagnetic
LM	Land Mobile
MW	Microwave
RF	Radio Frequency
SC6	Safety Code 6
TN	Technical Note
Z	Impedance

## 1.0 Purpose

The purpose of this document is to provide an evaluation tool to quickly assess the radio frequency (RF) exposure compliance of simple antenna sites. The intent is to provide a nationally consistent approach regarding the evaluation compliance with Canadian RF exposure limits. The method outlined in this document is only valid in the far-field region of antennas. It is not recommended for a detailed RF compliance analysis. For such an approach, an analysis technique based on sound engineering practices using the actual antenna pattern and taking into consideration the contribution of each antenna present at the site, including the radio environment, is required.

## 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 *Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz – Safety Code 6 (2009)* for the purpose of protecting the general public. Applicants must, in addition to their own radio system, consider the contributions of all existing radiocommunication installations within the local radio environment, either when predicting field strength levels or conducting field measurements.

For cases where radiocommunication users and/or service providers have demonstrated (either by means of field measurements or predictions) that the uncontrolled environment exposure limits established by SC6 for areas accessible by the general public are respected, Industry Canada would not normally require area demarcation or access control. Furthermore, Industry Canada requires users and/or service providers of radiocommunication installations to take immediate action to ensure that the general public does not have access to areas where RF exposure exceed SC6 uncontrolled environment limits. The exception to this is that some members of the general public may qualify for the conditions denied for the controlled environment in certain situations. Where technical means such as reducing the transmitter power level or modification to the transmitting facility are not practical, appropriate means of area demarcation and/or access control will be required by the users and/or service providers as outlined in GL-02, *Guidelines for the Protection of the General Public in Compliance with Safety Code 6*.

To assist in field measurements, Industry Canada has published GL-01, *Guidelines for the Measurement of Radio Frequency Fields at Frequencies from 3 kHz to 300 GHz*, and TN-329, *Safety Code 6 (SC6) Measurement Procedures (Uncontrolled Environment)*, which provide guidance to interested parties on verifying compliance with SC6 requirements as applicable. These documents cover the measurement procedures for broadcast, microwave, land mobile, paging, cellular, PCS and radar installations.

Over the past several years, the wireless telecommunications infrastructure has undergone enormous growth resulting in the proliferation of antenna installations. Consequently, an evaluation template to assess RF exposure compliance is a useful tool for the Department. For many simple installations, the template described in this document provides a definitive assessment of compliance in the far-field, for given technical parameters such as power level, proximity to public access areas, antenna height, antenna length and frequency. In the near-field or in a complex radio environment where several antenna towers are installed in the vicinity of a location of interest, a detailed analysis technique may be needed, using sound engineering practices that take into consideration the contribution of each antenna present. This may include an RF software assessment tool or complex spreadsheets.

This technical note outlines an evaluation procedure to determine RF exposure compliance with respect to SC6, which is the second step of a three-step evaluation approach outlined below.

### **3.0 Evaluation Process**

The general SC6 compliance evaluation process consists of a three-step approach.<sup>1</sup> It is anticipated that the evaluation methods applied in Step 1 and Step 2 will screen out most of the simple sites; while flagging those congested sites, such as publically accessible rooftops with multiple antennas, which require a more detailed analysis technique (Step 3).

#### **Step 1 – Attestation or Analysis:**

If the licence application is accompanied by a signed attestation or an acceptable analysis indicating compliance with the uncontrolled environment requirements of SC6, no further action is required. The departmental officer processing the application is expected to exercise judgement on the validity of the submission. If there is any doubt about the compliance or if the application is not accompanied by an attestation or an analysis, then the process moves to Step 2.

#### **Step 2 – TN-261 Non-Exemption Zone Analysis:**

Use the technical parameters of the site and the method outlined in this document to conduct the evaluation. If the site is in compliance according to the procedures indicated in sections 3.1 to 3.4 and 4, there is no need for further evaluation. However, if the site fails the screening method employed in this step, proceed to Step 3.

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<sup>1</sup> *Broadcasting Procedures and Rules (BPR-1) – General Rules* provides the specific requirements for broadcasting applications for demonstrating compliance with SC6. BPR-1 contains the description of the required analysis and alternatives depending on the results submitted by the proponent.

### Step 3 - Detailed Analysis, Field Measurements or Mitigation Measures:

The procedure outlined in Section 3.4 for dealing with multiple antennas and frequency bands is a conservative approach that overestimates the RF signal levels. As the number of antennas and frequency bands increase, the estimated results become less realistic, producing predicted levels that are greater than what would be expected to be measured. A different approach would therefore be required.

The departmental officer may present several options to the applicant to demonstrate compliance with SC6. The applicant may (i) submit detailed calculations, (ii) take measurements, and/or (iii) implement mitigation measures at the site.

- (i) Detailed calculations based on sound engineering practices shall be done for all areas accessible by the general public to demonstrate compliance with the uncontrolled environment limits outlined in SC6. They should include accurate technical parameters for each transmitting antenna, including the vertical and horizontal antenna patterns, frequency, effective radiated power (e.r.p.), antenna height, and in the case of multiple antenna supporting structures, the horizontal position of each antenna referenced to the point of calculation. The calculations may be done using spreadsheets or computational modeling software such as HiField and should take into consideration near-field and far-field regions and the applicable SC6 limits. The departmental officer should verify the calculations, and in the case where the detailed calculation identifies areas accessible to the general public where the RF intensity is above 50% of the uncontrolled environment limit or if the departmental officer is not convinced that the site is in compliance with SC6, he/she may direct the applicant to take measurements or implement mitigation measures.
- (ii) Detailed measurements shall be made to demonstrate that, in areas accessible to the public, the radio frequency fields comply with SC6 uncontrolled environment limits. The applicant must submit a report (see GL-08) to the Department showing details of the measurements. For further information, refer to GL-01, *Guidelines for the Measurement of Radio Frequency Fields at Frequencies from 3 kHz to 300 GHz*, and TN-329, *Safety Code 6 (SC6) Measurement Procedures (Uncontrolled Environment)*. If the results do not demonstrate compliance, the applicant must implement mitigation measures. The departmental officer may specify measurements be taken in certain areas, e.g. areas which are frequented by the public. The departmental officer may also choose to observe the measurements being taken, or verify the measurements by using the Department's own equipment.
- (iii) The applicant may propose mitigation measures to comply with SC6. This may include, but is not limited to, reducing power, changing antennas, or limiting public access to areas in which the RF fields exceed the uncontrolled environment limits published in SC6. For mitigation measures recommended under various circumstances, refer to GL-02, *Guidelines for the Protection of the General Public in Compliance with Safety Code 6*. The departmental officer may specify mitigation measures if the ones proposed by the applicant are not considered adequate. The applicant should advise the Department when the mitigation measures have been implemented.

Although compliance with CPC-2-0-03, *Radiocommunication and Broadcasting Antenna Systems*, and SC6 is a standard condition of authorization, the departmental officer may require that additional specific conditions be met, e.g. the applicant must demonstrate compliance by measurements or mitigation measures before the final authorization will be issued. As well, ongoing conditions may be added to the authorization.

### 3.1 Overview of the Non-Exemption Zone Analysis

This method is based on a modified free-space formula, which takes into consideration reflection and the *Cosine* reduction (Section 3.3) rather than the vertical antenna pattern. Horizontally speaking, the antenna is assumed to be omnidirectional. It is mainly intended for single service cases (single frequency band), e.g. cellular system, where the e.i.r.p. is the summed e.i.r.p. of all the transmitters and channels (Section 3.2). However, the method can be applied to multiple service cases (multiple frequency band) using a conservative approach where all the e.i.r.p. values are summed and applied to the centre of the lowest mounted antenna. The limit at the observation point is assessed against the lowest limit outlined in SC6 for the frequency bands present. Also, the largest antenna and lowest frequency are used to determine where the far-field starts.

Before applying this method, it must first be determined if the point of interest (i.e. the point where compliance evaluation is required) is in the far-field region of the antenna, as outlined in Section 4 (and also in Appendix A). It is important to establish this distance because this method cannot be used to evaluate the near-field situations, since the restricted zone generated (Table 1) is based on the modified free-space formula, which is only valid in the far-field. As shown in Figure 1, the sphere surrounding the antenna represents the near-field/far-field spherical boundary, within which the point of interest cannot lie when applying this method.

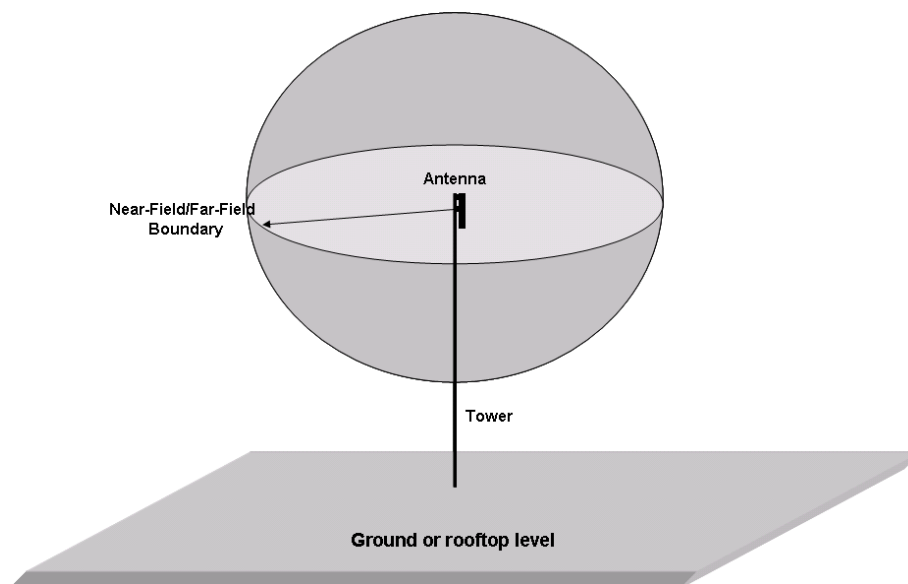
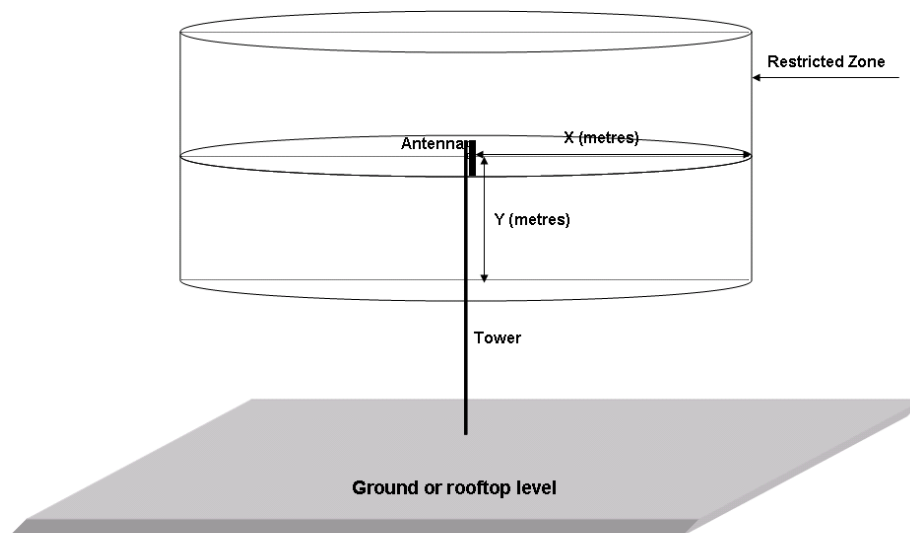


Figure 1 - Near-field/far-field boundary around an antenna

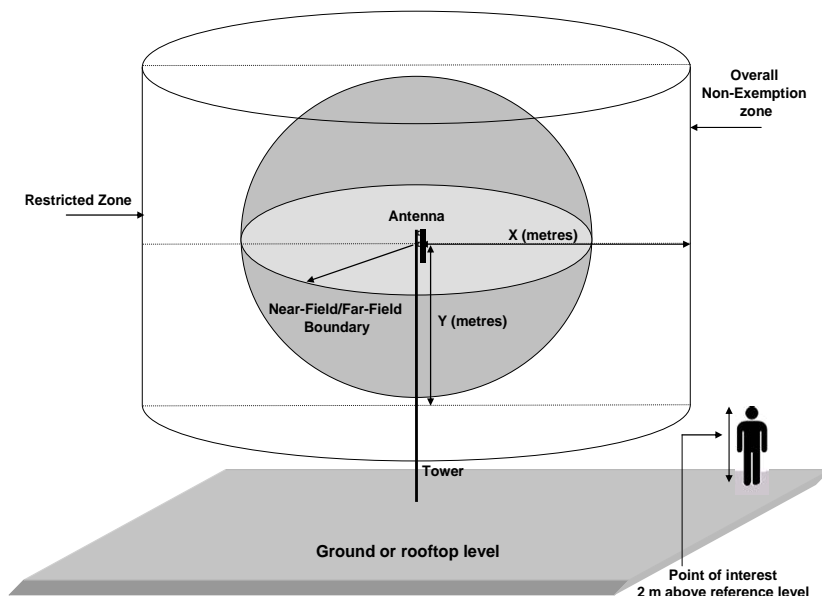
The next step involves using the technical parameters of the antenna and the modified free-space formula to generate a restricted zone around the antenna, within which the point of interest also cannot lie. This restricted zone is represented by a cylinder surrounding the antenna, where the top of the cylinder lies in the horizontal plane passing through the centre of the antenna. It is assumed that the same restriction applies above the antenna, so a mirror image of the cylinder is placed above the horizontal centre axis of the antenna. The result is a larger cylinder with the antenna in the centre, as shown graphically in Figure 2. The total volume of the cylinder now represents the overall restricted zone, where the point of interest cannot lie.



**Figure 2 - Graphical representation of the restricted zone around an antenna**

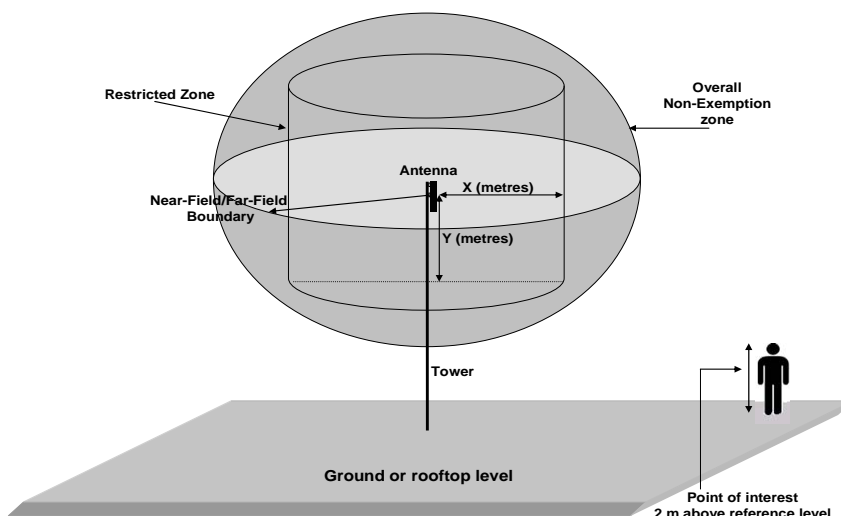
Once established, the near-field/far-field boundary must be used in conjunction with the restricted zone. **The overall larger dimension of both volumes combined is used to determine the new *non-exemption zone*.** If the public only has access to the areas outside the overall non-exemption zone, then the installation is in compliance with SC6. Figure 3 shows a scenario where the restricted zone is larger than the far-field spherical boundary; therefore, the overall non-exemption zone is the same as the restricted zone.





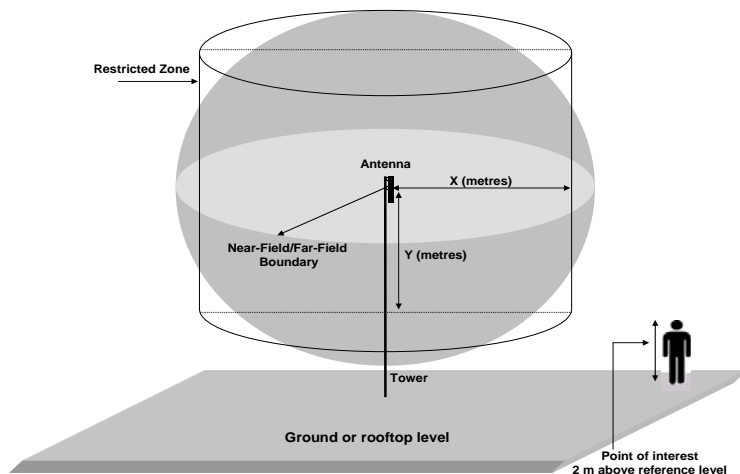
**Figure 3 - An ideal situation for applying the exemption template**

In Figure 4, the restricted zone is smaller than the near-field/far-field spherical boundary. Since the restricted zone is calculated assuming far-field conditions, as the point of interest move outwards towards the far-field spherical boundary, the far-field conditions will be satisfied, and the point of interest is now much further away from the antenna. Therefore, in this scenario (Figure 4), by deduction if the public has no access to the near-field region, then the installation should also be in compliance with SC6 and the overall non-exemption zone is assumed to be the near-field/far-field spherical boundary.

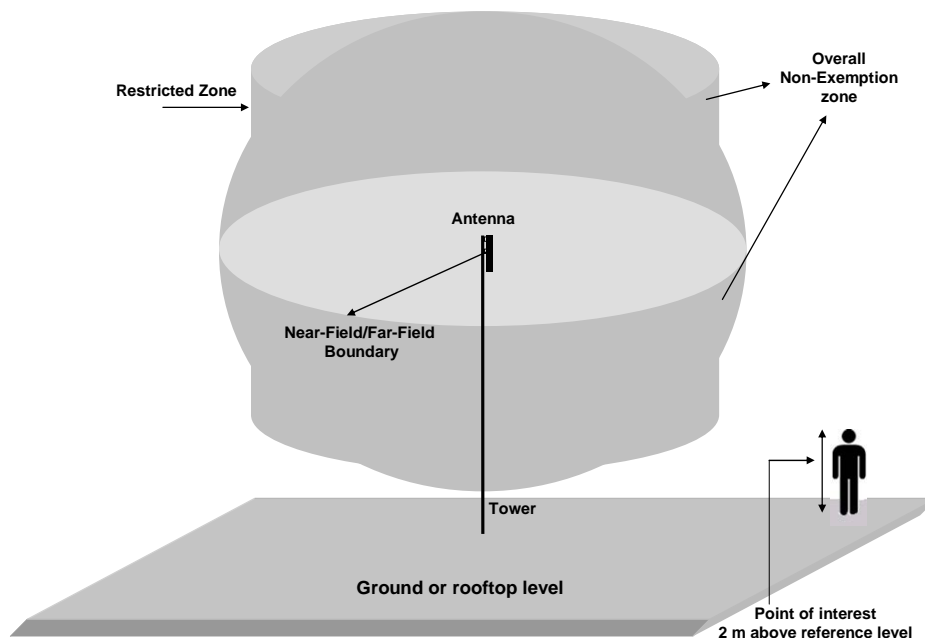


**Figure 4 - If the restricted zone is in near-field, the near-field/far-field boundary becomes the new overall non-exemption zone**

There may be situations where there is a partial overlap of the near-field/far-field spherical boundary and the restricted zone (cylinder), in which case the overall non-exemption zone will take the shape of the combined volume as shown in figures 5 and 6.

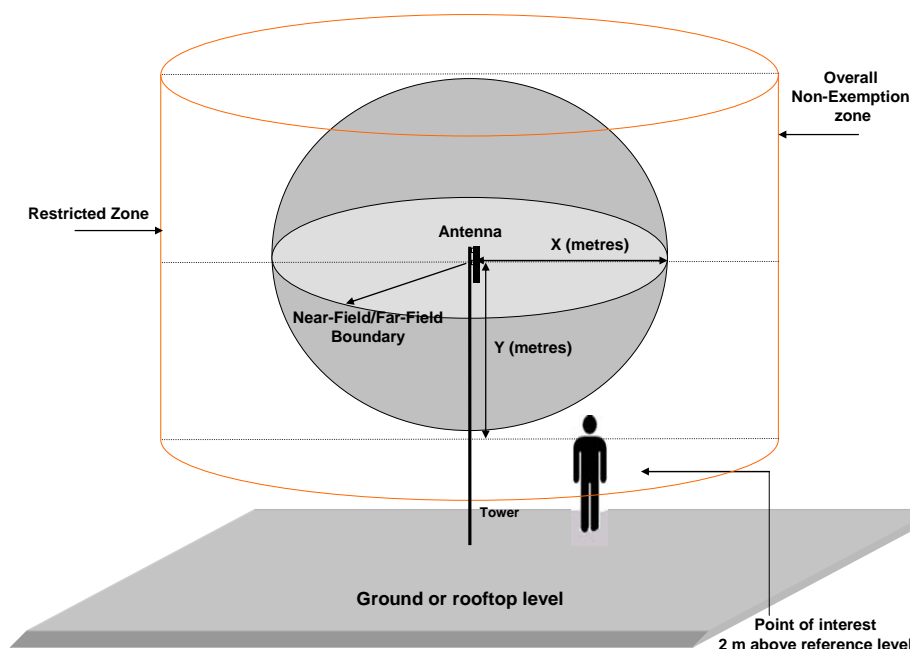


**Figure 5 - If the near-field/far-field boundary (sphere) and the restricted zone (cylinder) intersect, the overall non-exemption zone is the combination of the sphere and cylinder**



**Figure 6 - The overall non-exemption zone is the combination of the sphere and cylinder.**

Figure 7 shows a scenario of non-compliance, where the public access is within the overall non-exemption zone. For this scenario, proceed to Step 3 of the evaluation process.



**Figure 7 - Not applicable because point of interest in the non-exemption zone**

For more complex situations where several antenna towers are installed in the vicinity of a location of interest, a detailed analysis based on sound engineering practices is required. In this instance, the contribution of each antenna must be considered. Complex analyses can be performed using spreadsheets or computational modeling software.

### 3.2 Antenna Gain

Antenna gain  $G$  varies as a function of the off-axis angle, both horizontally and vertically. Studies of several antennas at various frequency bands have shown that the normalized numerical vertical antenna pattern of telecommunication antennas can be approximated and simplified into two functions:  $\cos(\alpha)$  variation for frequency band of 30 to 54 MHz, and  $\cos^3(\alpha)$  variation above 54 MHz where  $\alpha$  is the angle between the antenna boresight direction ( $Y = 0$  m) and the direction of the observation point with respect to the antenna electrical centre, i.e. the off-axis angle. In symbolic terms, this can be shown as:

$$G(\alpha) = \begin{cases} G(0) * \cos(\alpha) & 30 \text{ MHz} \leq f \leq 54 \text{ MHz} \\ G(0) * \cos^3(\alpha) & 54 \text{ MHz} < f \end{cases}$$

Where  $G(0)$  represents the antenna gain at boresight.

$\cos(\alpha)$  can be expressed as  $\frac{X}{\sqrt{X^2 + Y^2}}$  or  $\frac{X}{R}$ , where  $R = \sqrt{X^2 + Y^2}$  is the distance from the antenna centre to the observation point (Figure 6).

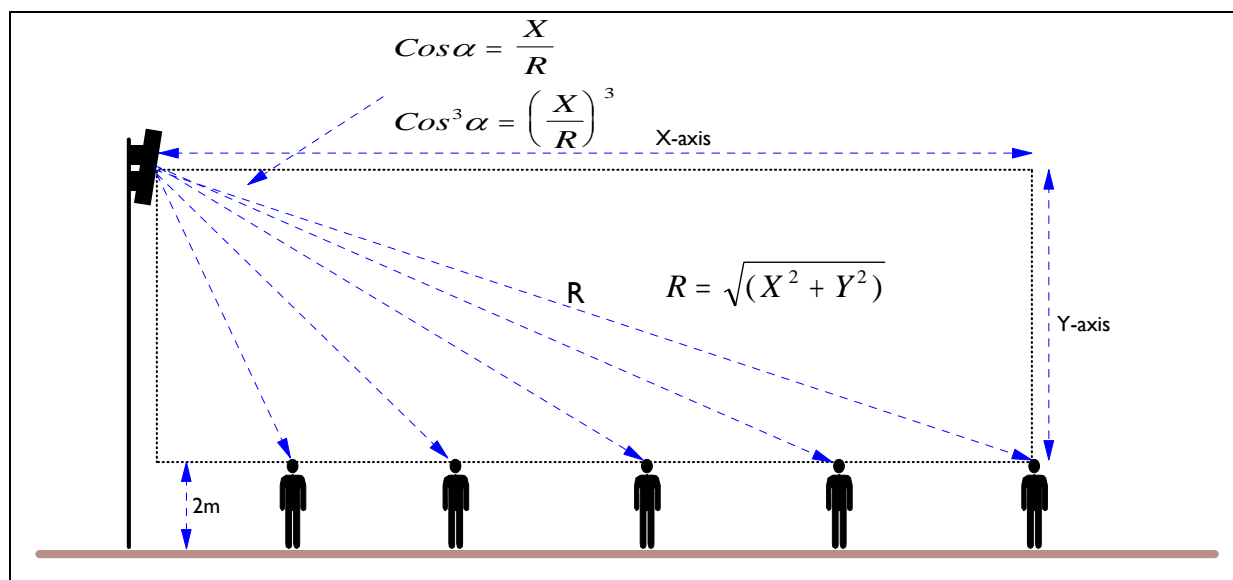


Figure 8 - Antenna gain as a function of cosine

### 3.3 Reflection

Reflection is considered in all cases. In this situation, it is assumed that the observation point is at 2 m above the reference level, that is, the ground level or rooftop level. The ground wave reflection used is based on a survey conducted for the U.S. Federal Communications Commission (FCC), which shows that the indirect waves contribute, on average, an additional 60% to the direct beam. Therefore, reflection is taken as 60%. That is, the field strength of the reflected electric waves is assumed to be 60% of that of the direct waves at any point of observation (Gailey, P.C., and Richard A. Tell, *An Engineering Assessment of the potential Impact of Federal Radiation Protection Guidance on the AM, FM, and TV Broadcast Services*, U.S. Environmental Protection Agency, April 1985).

### 3.4 Single Service/Multiple Services and the Radio Environment

For the single service cases (single frequency band), such as a simple tower or single antenna installation on rooftop, with a land mobile, cellular or PCS antenna, the e.i.r.p. is the summed e.i.r.p. of all the transmitters and/or channels.

For the multiple service cases (multiple frequency bands), such as a combination of land mobile, cellular and PCS antennas, a detailed analysis technique using sound engineering practices that take into consideration the contribution of each antenna present at the site is required. However, for the purpose of this document, a worst-case scenario approach which affords the greatest protection to the public, (for tower sites and some very simple rooftop sites) can be used, employing a conservative approach. For this approach, the e.i.r.p. values can be summed and applied to the centre of the lowest mounted antenna, which is assumed to be the antenna with the greatest far-field distance. The electrical field strength or power density at the point of interest (the observation point) is assessed against the lowest value of SC6 limit of the frequency bands in question.

Nearby transmitting antennas, other than those at the site being studied, can also affect the evaluation, especially if they are high-power. Therefore, it is important to assess the radio environment when analyzing compliance. Mathematical predictions and field measurements have demonstrated that wireless stations beyond 100 m are shown to have a negligible impact on the overall exposure level. For broadcast stations, close attention should be paid to those within 1 km of the proposed site. If it is suspected that there are nearby stations that may impact RF levels at the site being studied, those stations must be taken into account in a detailed analysis (see Section 3.0, Step 3).

#### 4. Non-Exemption Zone

As indicated in Section 3.1, the overall non-exemption zone is derived from a combination of the far-field boundary and the restricted zone. For a given e.i.r.p. and antenna size, the point of interest **must** lie in the far-field **and** outside the restricted zone. If the point of interest falls **inside** the overall non-exemption zone, then more sophisticated methods must be used to evaluate compliance. (see Section 3.0, Step 3).

**Table 1** shows a summary of the formulas used to determine the near-field/far-field boundary. Refer to Section 3.4 before applying to sites with multiple antennas.

**Table 1: Near-field/far-field boundaries**

For electrically small antennas ( $D \leq \lambda$ )	$R_{far-field} = \lambda/2\pi$
For electrically large antennas ( $D > \lambda$ )	$R_{far-field} = 1/2 D^2/\lambda$

Where  $D$  is the largest dimension of the antenna (m) (usually taken as the length)  
 $R_{far-field}$  is the distance from the radiation centre to far-field (m), and  
 $\lambda$  is the wavelength (m) [ $\lambda=c/f$ , where  $c$  is the speed of light ( $3 \times 10^8$  m/s) and  $f$  is the operating frequency (Hz)].

*Example:* For a cellular antenna, with length 1.22 m at 875 MHz:  
 $D=1.22$  m,  $\lambda=0.34$  m,  $D > \lambda$ , therefore  $R_{far-field} = 1/2 D^2/\lambda = 2.17$  m

## 5. Conclusion

This technical note proposes an evaluation tool that can be used to quickly assess radio frequency exposure compliance with Health Canada's SC6 guideline for simple antenna sites. The method applies to single antenna sites, but can also provide a conservative assessment for multiple antennas, simplifying the evaluation process. However, this method is not recommended for detailed radio frequency compliance analysis. For those cases, use techniques that are based on sound engineering practices that take into consideration the contribution of each antenna present.

## References

1. Health Canada. *Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz – Safety Code 6 (2009)*
2. Industry Canada. Client Procedures Circular CPC-2-0-03, *Radiocommunication and Broadcasting Antenna Systems*
3. Industry Canada. GL-01, *Guidelines for the Measurement of Radio Frequency Fields at Frequencies from 3 kHz to 300 GHz*
4. Industry Canada. GL-02, *Guidelines for the Protection of the General Public in Compliance with Safety Code 6*
5. Industry Canada. GL-08, *Guidelines for the Preparation of Radio Frequency (RF) Exposure Compliance Reports for Radiocommunication and Broadcasting Antenna Systems*
6. Industry Canada. TN-329, *Safety Code 6 (SC6) Measurement Procedures (Uncontrolled Environment)*

## Appendix - General Antenna Theory

### Antenna Field Regions:

Antennas are grouped into two categories as defined in Safety Code 6 (SC6), electrically small and electrically large antennas. Electrically small antennas are defined as those where  $D$ , the largest dimension of the antenna (usually taken as the length), is less than the wavelength of the recommended operating frequency ( $D < \lambda$ ). Electrically large antennas are defined as those where the largest dimension is greater than the wavelength of the recommended operating frequency  $D > \lambda$ .

At close proximity to an antenna, the characteristics of electromagnetic fields are unpredictable and the E-field can dominate at one location, while the H-field can dominate just a few centimetres either way. Predictions are very difficult in this region and antenna engineers have defined boundary regions to categorize the behaviour/characteristic of electromagnetic (EM) fields as a function of distance from the radiator. Reflection is another characteristic that adds to the complexity. All waves experience reflections and EM waves are no exception. Further to its research, the U.S. Federal Communications Commission (FCC) recommends that, for the reflected wave, the electric field strength can be assumed to be 60% of that of the direct waves at any point of observation.

In general, the space surrounding an antenna is divided into field regions defined as: near-field region (reactive/evanescent near-field), radiating (Fresnel) near-field, transition zone (intermediate-field region) and the far-field (Fraunhofer) region.

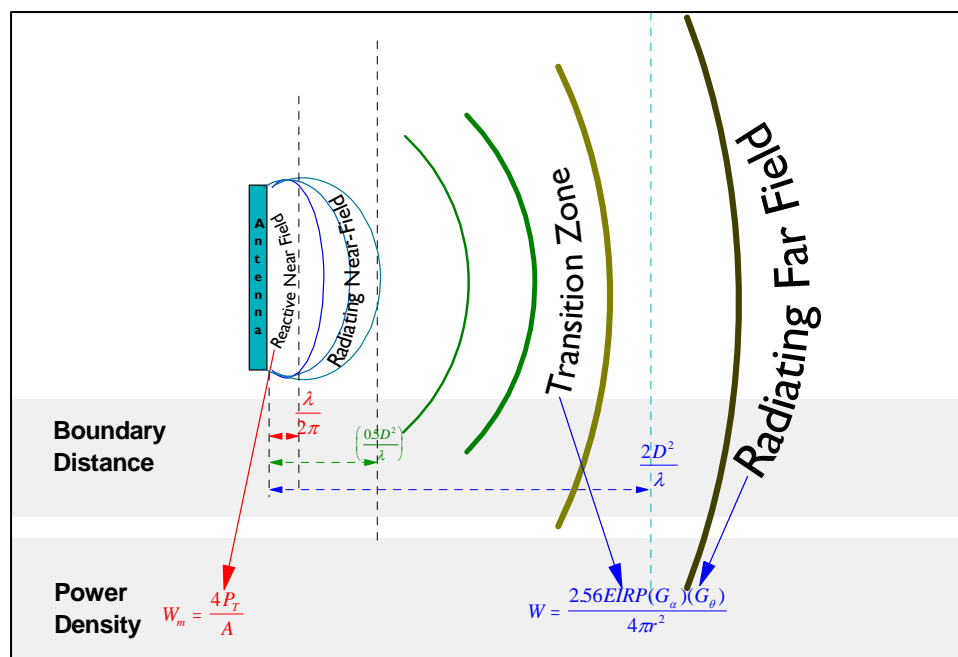


Figure 1 - General antenna field regions

**Reactive Near-field Region** – This is sometimes referred to as the evanescent (fading quickly) region and is the space immediately surrounding the antenna or leakage source, where the reactive (stored energy) components predominate and energy is stored in the field. In this region, the E and H fields are not orthogonal. Therefore, the impedance ( $Z$ ) is not 377 ohms, instead it is a complex impedance. However, the mathematical relationship of  $Z=E/H$  still applies.  $Z$  could be a small fraction of 377 ohms for a predominately magnetic field or many times 377 ohms for a predominately electric field. The region extends up to a distance of  $\lambda/2\pi$  or  $0.159 \lambda$ . For electrically small antennas (where,  $D < \lambda$ ), the end of the reactive near-field region is also the boundary where the far-field region starts. In distance terms, it is: 1.6 m at 30 MHz, 32 cm at 150 MHz, 11 cm at 450 MHz, 5 cm at 875 MHz, and 2.5 cm at 1950 MHz.

**Radiating Near-field Region** – This is sometimes referred to as the Fresnel region. 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 the 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 electrically large antennas ( $D > \lambda$ ), this region extends from  $\lambda/2\pi$  to  $\frac{1}{2}D^2/\lambda$ .

**Transition Region (Intermediate-Field Region)** – For an antenna that is electrically small compared to the wavelength in question, the transition is considered to exist at distances anywhere between 0.1 wavelength and 1.0 wavelength from the antenna, essentially between the radiating near-field and the far-field regions. This region is comprised of a combination of the characteristics found in both the near-field and the far-field, but the far-field characteristics are becoming more evident moving outwards. The E and H fields are almost orthogonal ( $Z$  is almost 377 ohms). This region extends from  $\frac{1}{2}D^2/\lambda$  to  $2D^2/\lambda$  and for the purpose of SC6, is assumed to be the region in which the far-field starts.

**Far-field Region (Fraunhofer Zone)** – This region is also referred to as the Fraunhofer region. This region 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 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, in antenna design and engineering, the far-field region is commonly assumed to begin at a distance of approximately  $2D^2/\lambda$  for electrically large antennas and extends to infinity (“D” being the largest linear aperture dimension and  $\lambda$  the wavelength at the frequency of interest). The E and H fields are orthogonal and  $Z=E/H=377$  ohms. This region extends from  $2D^2/\lambda$  to infinity, but the SC6 guideline recommends that it generally be taken as  $\frac{1}{2}D^2/\lambda$  to infinity because it considers the transition region and the far-field region to be one.



### Establishing the Antenna Boundary Regions:

For electrically small antennas, the near-field/far-field boundary is given as:

$$\text{Wavelength } \lambda = \frac{c}{f}$$

$$\text{Near Field (Reactive)/Far Field} = \frac{\lambda}{2\pi}$$

Where:  $f$  is the operating frequency (MHz),  
 $\lambda$  is the wavelength (m), and  
 $c$  is the speed of light (m/s).

For electrically large antennas, the near-field/far-field boundary is given as:

$$\text{Near Field (Reactive)/Near Field (Radiating)} = \frac{\lambda}{2\pi}$$

$$\text{Near Field (Radiating) = Far Field} = \frac{0.5D^2}{\lambda}$$

Example:

Antenna Type:	Broadband Dipole Array
Antenna Length (D):	1.22 m
Operating Frequency:	875 MHz

$$\text{Wavelength } \lambda = \frac{c}{f} = \frac{3 \times 10^8}{875 \times 10^6} = 0.34 \text{ m}$$

$$\text{Near Field (Reactive)} = \frac{\lambda}{2\pi} = \frac{0.34}{2\pi} = 0.05 \text{ m (or 5 cm)}$$

$$\text{Near Field (Radiating)/Far Field} = \frac{0.5D^2}{\lambda} = \frac{0.5(1.22)^2}{0.34} = 2.17 \text{ m}$$

This is considered a large antenna, since  $D > \lambda$ .

### Power Density Analysis:

Power density predictions are made in both the near-field and the far-field regions of an antenna. The region where the prediction is being made will determine the type of prediction model used. Like field measurements, prediction in the near-field is a complicated undertaking and depends on the type of antenna present. However, in the far-field region, the free-space model used is independent of the type of antenna. For multiple antenna/multiple frequency sites, it may not always be possible to determine where those regions lie. A situation could exist where, although the point of interest may be in the far-field of one antenna, it could also be in the near-field of another antenna present at that same site, making the power density prediction difficult and complicated as the number of antennas increases.

In the near-field region, it is very difficult to determine the true power density. The reactive near-field (stored) energy decays very rapidly with distance and is completely decayed at a distance of several wavelengths from the antenna surface, since this region extends only up to  $\lambda/2\pi$  ( $0.159\lambda$ ). Therefore, the worst-case scenario is assumed (for land mobile (LM) and microwave (MW) application):

$$W_m = 4 \frac{P_T}{A}$$

Where:  $W_m$  is the power density ( $W/m^2$ ),  
 $P_T$  is the transmitter power delivered to the antenna (W), and  
 $A$  is the physical aperture area of the antenna (m).

Power density prediction in the radiating near-field region is possible using several established engineering models. However, the models chosen depend on the type of antenna present.

In the transition and far-field regions, the plane wave/free-space power density formula is commonly used. However, as per an FCC recommendation, a modified free-space power density formula is used to account for ground wave reflection. At the reception point, 2 m above the ground or rooftop level, the equivalent E-field includes both the direct and the reflected E-fields. The reflected portion of the E-field is taken as 60% of the direct E-field as per the FCC recommendation (reflection is not considered from objects surrounding the reception point, e.g. adjacent buildings).

$$\text{Power Density } W = \frac{E_T^2}{Z}$$

*At the reception point*

$$E_t = E_{\text{Direct}} + \Gamma E_{\text{Reflected}} = E + 0.6E = 1.6E$$

$$W_M = \frac{(1.6E)^2}{120\pi} = \frac{1.6^2 \left( \frac{\sqrt{30EIRP}}{r} \right)^2}{120\pi} = \frac{2.56 \left( \frac{30EIRP}{r^2} \right)}{120\pi} = \frac{2.56EIRP}{4\pi r^2}$$

Where:  $W$  is the power density ( $W/m^2$ ),  
 $W_M$  is the modified free-space power density ( $W/m^2$ ),  
 $E$  is the electric field (V/m),  
 $E_T$  is the electric field (V/m),  
 $Z$  is the free-space impedance (ohms), and  
 $\Gamma$  is the reflection coefficient.

In addition to the changes to the free-space power density formula to account for ground wave reflection, a further modification is done to account for both the vertical and horizontal antenna patterns. The normalized numerical vertical and horizontal gains are introduced relative to the observation point as outlined in Figure 2.

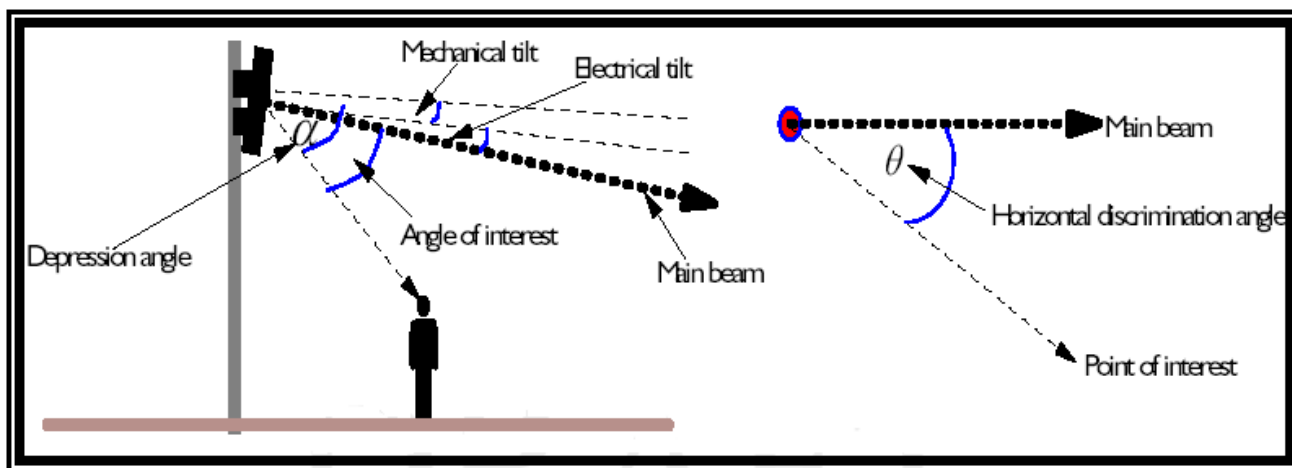
*Free-Space Formula*

$$W = \frac{P_T G}{4\pi r^2} = \frac{EIRP}{4\pi r^2}$$

*Modified Free-Space Formula*

$$W = \frac{2.56 P_T G}{4\pi r^2} = \frac{2.56 EIRP (G_\alpha)(G_\theta)}{4\pi r^2}$$

Where:  $W$  is the power density ( $W/m^2$ ),  
 $P_T$  is the transmitter power fed into the antenna (W),  
 $EIRP$  is the equivalent isotropically radiated power from the antenna (W),  
 $G$  is the numeric gain of the antenna with respect to an isotropic source,  
 $G_\alpha$  is the normalized numerical vertical gain for the angle ( $\alpha$ ) of the point of interest to the main beam,  
 $G_\theta$  is the normalized numerical horizontal gain for the angle ( $\theta$ ) of the point of interest to the main beam, and  
 $r$  is the distance from the centre of radiation of an antenna to the test point (m).



**Figure 2 - Considering the horizontal and vertical discrimination angle**

There are numerous sources of error encountered when predicting field strength. One source is the transmitting antenna installation. This accuracy consists of two parts, the horizontal azimuth (for directional antennas) and the mechanical tilt. The telecommunications industry estimates the level of accuracy to be in the order of approximately  $\pm 3^\circ$  for the azimuth and about  $\pm 1^\circ$  for the mechanical tilt. Essentially, this means that the angle to the point of interest for both the vertical ( $\alpha$ ) and horizontal ( $\theta$ )

angles may be either less than or greater than the calculated angle. It is important to consider these factors when predicting power density levels. To safeguard against this, a conservative approach of using both the horizontal and vertical envelope antenna patterns should be considered.

### **General Considerations:**

It is important to collect as much information as possible about the antenna installation being studied. Analyze the technical parameters of each transmit antenna present, taking into consideration the antenna heights above ground and rooftop level, antenna type(s), mechanical downtilt, electrical tilt, gains and radiation patterns (Both H and V), frequency range and transmit power fed to the antenna (or transmit power and line losses).

### **Calculations:**

Calculations are generally done at 2 m above ground or rooftop level. For rooftop sites, look for the worst-case scenario to use as a test point by analyzing the rooftop layout diagram.

Steps to consider:

- Define the near-field/far-field boundary for the antenna(s) being studied
- Determine if the test point lies in the near-field or far-field for each antenna present
- If test point is in near-field, use appropriate model
- If test point is in far-field, use free-space formula (with Cosine or antenna pattern) + 60% reflection (for electric field) at 2 m above ground or rooftop level only
- Determine the horizontal and vertical angles to the test point
- Factor in the electrical and mechanical downtilt of the antenna
- Using the antenna pattern, estimate the normalized numerical H and V gains
- Factor in the field installation accuracy of antennas (in the horizontal plane  $\pm 3^\circ$ , in the vertical plane  $\pm 1^\circ$ )
- Repeat the previous procedures for each TX antenna for a multiple antenna site
- Calculate power density for each TX antenna at the test point
- Normalize the power density of each TX antenna at the test point using SC6 limits with respect to the operating frequencies (for Uncontrolled Environment or Controlled Environment)
- Sum the normalized power density values from all sources at the test point
- Repeat the procedure for several test points by moving the test point horizontally (in the main beam) away from the antenna under test
- Identify the hot spots, i.e. where the normalized power density = 1 or > 1 (in terms of percentage, power density = 100 or >100)

$$N_{SC6\%} = 100 * W_{Total \ Normalized} = 100 * \sum_{i=1}^n \left( \frac{W_i}{W_{SC6Limit_i}} \right) \text{ where, } W_i = \sum_{j=1}^n (W_1 + W_2 + \dots W_j)$$

$$N_{SC6\%} = 100 * H_{Total \ Normalized} = 100 * \sum_{i=1}^n \left( \frac{H_i}{H_{SC6Limit_i}} \right)^2 \text{ where, } H_i = \sqrt{\sum_{j=1}^n (H_1^2 + H_2^2 + \dots H_j^2)}$$

$$N_{SC6\%} = 100 * E_{Total \ Normalized} = 100 * \sum_{i=1}^n \left( \frac{E_i}{E_{SC6Limit_i}} \right)^2 \text{ where, } E_i = \sqrt{\sum_{j=1}^n (E_1^2 + E_2^2 + \dots E_j^2)}$$