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May 2012

Spectrum Management and Telecommunications

Report

Case Study: Measurements of Radio Frequency Exposure from Wi-Fi Devices

Aussi disponible en français

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Acknowledgement

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Preamble

Radiocommunication, including the technical aspects related to broadcasting, falls under the responsibility of Industry Canada, which has the power to establish standards, rules, policies and procedures. Under this authority, the Department has adopted Health Canada's Safety Code 6 (SC6) guideline for the purpose of protecting the general public from radio frequency (RF) overexposure.

As part of its ongoing monitoring of wireless devices for compliance with regulatory specifications, Industry Canada conducted an extensive series of tests to measure RF exposure from the use of Wi-Fi devices in a simulated classroom setting. This study, performed in late 2011, confirms that the level of RF exposure is considerably below the SC6 limits for uncontrolled environments. The wireless devices that were studied operate at higher power than most Wi-Fi devices currently available in Canada.

The measurements were based on 24 laptops and two wireless access points, or routers, used in a situation designed as a worst-case scenario, which involved downloads of a very large file, such as a video file, as well as the use of interactive applications among several computers, as would be found in a school setting.

Measurements were taken at several points in the room and at various distances from the Wi-Fi access points, including those where higher levels of RF exposure are typically reported. All measurements of RF exposure were well below the SC6 limits for uncontrolled environments.

Executive Summary

Many consumers, businesses, and public and private institutions (such as schools, hospitals and libraries) install Wi-Fi access points on their premises. These Wi-Fi access points typically consist of one or more low-power transmitters installed at ceiling level or on tabletops, which are used by individuals to gain Internet access through standard Wi-Fi-enabled devices, such as laptops. To address the recent public concerns related to the proliferation of Wi-Fi technology, Industry Canada staff performed measurements of radio frequency (RF) field measurements in an Industry Canada boardroom located in Aurora, Ontario. The boardroom contained two Wi-Fi access points and 24 Wi-Fi-enabled devices (laptops). The goal of this study was to obtain measurements of the levels of aggregated RF exposure from multiple Wi-Fi access points and Wi-Fi-enabled devices in an indoor environment.

Health Canada's Safety Code 6 (SC6) specifies maximum exposure limits for RF fields in uncontrolled and controlled environments.¹

Industry Canada has adopted Health Canada's guideline for the purpose of protecting the general public from RF overexposure. All installations and apparatus must comply with the SC6 limits for uncontrolled environments. The maximum exposure limit of SC6 is expressed in terms of field strength (volts per metre, or V/m, and amperes per metre, or A/m) or power density (watts per square metre, or W/m²). This document presents the results more simply as percentage of SC6 limits for uncontrolled environments.

In accordance with the requirements for spatial and time averaging set forth by Industry Canada,^{2, 3} the RF exposure level was measured at 0.19% of the SC6 limits (515 times below the limit). This value includes the measurement equipment uncertainty. In this scenario, the two Wi-Fi access points were operational with the 24 Wi-Fi-enabled devices downloading a large file simultaneously. This measurement was carried out at the location found to exhibit the highest RF exposure level during the initial scanning of the boardroom.

For these measurements, the Wi-Fi access point 1 (AP1) was in a test mode that forced it to transmit continuously, while the Wi-Fi access point 2 (AP2) was in normal communication with all 24 laptops, which were all in downloading mode. With one of the Wi-Fi access points set to transmit continuously while test software was used, the measured RF levels were higher than they would be for the same device in normal operating mode.

Measurements were also conducted at one location with the laptops in different uploading or downloading modes, or both, to determine the variations in RF exposure levels. For these measurements, the laptops were connected to Wi-Fi AP2, operating at 2437 MHz. The highest average RF level obtained from among four different uploading and/or downloading configurations occurred when a

¹ "Limits for uncontrolled environments" and "limits for controlled environments" are the terms used in the current (2009) edition of SC6. The limits for uncontrolled environments typically apply to the general public. In previous versions of SC6, these limits were defined as the "general public limits."

² See GL-01, *Guidelines for the Measurement of Radio Frequency Fields at Frequencies from 3 kHz to 300 GHz* (<http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01451.html>).

³ See TN-329, *Safety Code 6 (SC6) Measurement Procedures (Uncontrolled Environment)* (<http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09977.html>).

single laptop was in downloading mode, as opposed to numerous laptops in uploading mode, downloading mode, or both.

At 20 cm from the Wi-Fi access points, the maximum instantaneous RF exposure levels obtained for Wi-Fi AP1 and Wi-Fi AP2 were 10.59% and 7.73% of the SC6 limits, respectively. For a typical scenario in which a person is located at several metres from the access point and surrounded by other users, the RF exposure level will be thousands of times below the SC6 limits.

Industry Canada found that the aggregated RF exposure levels are well below the SC6 limits at this indoor location. In addition, the Wi-Fi access points selected for this study were operating at higher power compared with most of the Wi-Fi devices currently available on the Canadian market. Therefore, the results of this study are likely higher than would typically be observed in equivalent setups in public and private environments.

1.0 Introduction

Wi-Fi is a trademark of the Wi-Fi Alliance. Manufacturers may use the term “Wi-Fi” to brand certified products that belong to a class of wireless local area network (WLAN) devices based on IEEE 802.11 standards. Because of the close relationship with its underlying standards, the term “Wi-Fi” is often used as a synonym for IEEE 802.11 technology (see Annex A).

Under Industry Canada’s regulations, Wi-Fi devices are licence-exempt if they meet the technical certification requirements of both RSS-210, *Licence-exempt Radio Apparatus (All Frequency Bands): Category I Equipment*,⁴ which includes specifications for power levels, and RSS-102, *Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands)*,⁵ which includes Health Canada’s Safety Code 6 (SC6)⁶ limits for RF exposure (see Annex D of this document). An RF exposure evaluation⁷ must be performed on Wi-Fi access points.⁸ As part of the certification requirements outlined in RSS-102, a specific absorption rate (SAR) evaluation⁹ must be performed on Wi-Fi-enabled devices, such as laptops that contain the Wi-Fi client cards. Under the requirements of RSS-102, the manufacturer is also responsible for providing proper instruction to users of wireless devices and for informing users of any usage restrictions to ensure compliance with the SC6 limits.

In Canada, Wi-Fi systems may operate at 2400-2483.5 MHz (RSS-210, Annex 8), 5150-5350 MHz (RSS-210, Annex 9), 5470-5825 MHz (RSS-210, Annex 9) and 5725-5875 MHz (RSS-210, Annex 8), using either 20- or 40-MHz channels. Wi-Fi devices may operate at different power levels, depending on the band and operating characteristics. Based on the technical requirements of RSS-210, the maximum conducted power (into the antenna) and maximum equivalent isotropically radiated power (e.i.r.p.) must not exceed 1 watt and 4 watts, respectively. However, the majority of Wi-Fi devices currently on the Canadian market operate at lower power (e.g. <1 W e.i.r.p.).

Many consumers, businesses, and public and private institutions install Wi-Fi access points on their premises. These access points typically consist of one or more low-power transmitters installed at ceiling level or on tabletops, which are used by individuals to gain Internet access through standard Wi-Fi-enabled-devices, such as laptops.

⁴ See RSS-210, *Licence-exempt Radio Apparatus (All Frequency Bands): Category I Equipment* (<http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01320.html>).

⁵ See RSS-102, *Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands)* (<http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01904.html>).

⁶ See 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)* (http://www.hc-sc.gc.ca/ewh-semt/pubs/radiation/radio_guide-lignes_direct-eng.php).

⁷ **RF exposure evaluation** is the method used to evaluate the RF field strength levels generated by a device. RF exposure evaluation is required if the separation distance between the user and the device is greater than 20 cm.

⁸ Wi-Fi access points are commonly called “Wi-Fi routers.”

⁹ **SAR evaluation** is the method used to evaluate the SAR levels from a device by physical measurement or computational modeling techniques. SAR evaluation is required if the separation distance between the user or bystanders and the device is less than or equal to 20 cm.

Given the recent public concerns related to the proliferation of Wi-Fi technology, the goal of this case study was to obtain RF exposure levels from multiple access points and Wi-Fi-enabled devices in an indoor environment, and to assess compliance with the SC6 limits. However, the testing of all possible configurations under which these devices are deployed would not be possible. Therefore, specific scenarios were tested to determine the levels of aggregated RF exposure within an indoor environment.

2.0 Materials and Methods

2.1 Equipment for Measuring RF Fields

Table 1 lists the equipment for RF measurement that was used during the Wi-Fi measurement case study, including the equipment used during the laboratory testing for radiated emission levels.

Table 1 – Measurement equipment

Equipment/auxiliary devices	Model	Manufacturer	Serial No.	Calibration date	Calibration due date
Selective Radiation Meter	SRM 3006	Narda	D0154	2011-01-31	2013-01-31
RF-Cable SRM, 9 kHz to 6 GHz, N 50 ohm, 5 m	3602/02	Narda	AA-0096	2011-01-28	2013-01-28
Three-Axis E-field Antenna, 50 MHz to 3 GHz	3501/02	Narda	H-0350	2011-02-28	2013-02-28
Three-Axis E-field Antenna, 420 MHz to 6 GHz	3502/01	Narda	B-0137	2011-01-28	2013-01-28
Spectrum Analyzer	FSL	Rohde & Schwarz	101098	2011-02-01	2012-02-01
RF Chamber Cable	NA	Huber & Suhner	236469 001	2011-10-17	2012-10-17
RF Cable	RD-162	Huber & Suhner	121-42673 001	2011-03-30	2012-03-30
RF Cable	RD-101	Huber & Suhner	160561 001	2011-02-01	2012-02-01
Horn Antenna	3117	ETS-Lindgren	00075938	2011-07-21	2012-07-21

Auxiliary devices, such as non-metallic tripod, measuring tape, digital camera and masking tape, were also used during the study.

The Narda SRM 3006 Selective Radiation Meter was set in the Safety Evaluation mode. It displayed the RF exposure levels as a percentage of the SC6 limits. Between 50 and 70 sweeps¹⁰ of approximately 1.2 second per sweep were performed at each measurement location (except when a time-averaging period of 6 minutes was applied).

2.2 Wi-Fi Access Points and Wi-Fi-Enabled Devices

The Wi-Fi access points and Wi-Fi-enabled laptops used during this case study can be found in Table 2 and Table 3, respectively.

¹⁰ A sweep is defined as the time required for one spectrum (frequency band, or bands, under investigation) to be measured and displayed.

Wi-Fi access point 1 (AP1) was set to transmit continuously¹¹ through the use of the test-mode software. The continuous transmission was selected to provide a worst-case exposure from this Wi-Fi access point. The operating center frequency was set at 5180 MHz (Channel 36). AP1 was installed on the ceiling with the antenna located at approximately 2.05 metres from the floor (see Figure 1). The antenna panel used had a directional gain of 7.5 dBi.



Figure 1 – Setup of Wi-Fi access point 1 (5180 MHz) near the ceiling

For Wi-Fi access point 2 (AP2), the device was transmitting normally at a center frequency of 2437 MHz (Channel 6). Test software was not available for AP2. Therefore, measurements were not performed in continuous mode for this access point. AP2 was installed on top of a computer desktop tower at approximately 1.1 metres from the floor (see Figure 2).

¹¹ Continuous transmission represents a duty cycle of approximately 100%.

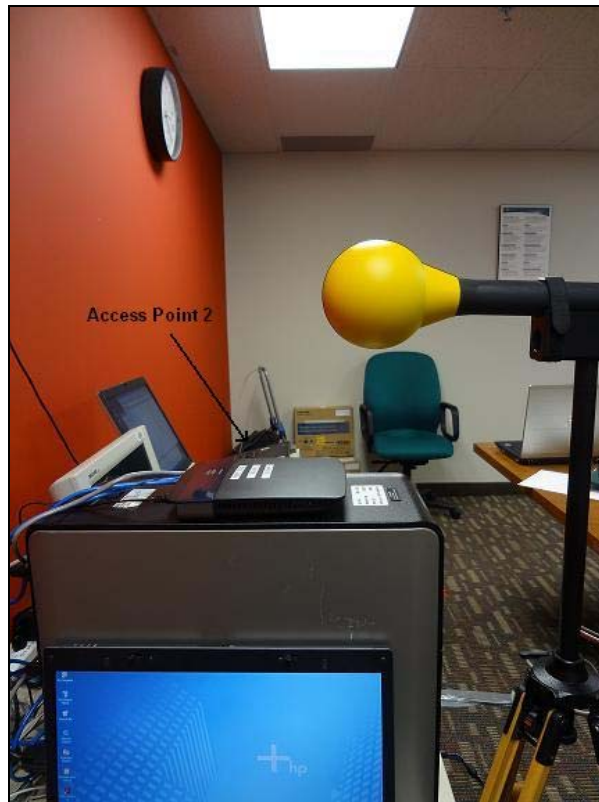


Figure 2 – Setup of Wi-Fi access point 2 (2437 MHz) at 1.1 metres from the floor

The AP1 and AP2 were each set for a conducted power level of 24 dBm (251 mW). AP1 had an e.i.r.p. of 30.3 dBm (1.1 W), and AP2 had an e.i.r.p. of 33.7 dBm (2.3 W).¹²

These two access points were specifically chosen because they had slightly higher e.i.r.p. values than most Wi-Fi access points currently on the Canadian market. With Wi-Fi AP1 set to transmit continuously, the measured RF levels are higher than when the same device is in normal operating mode.¹³ Therefore, the results of this study are likely higher than would typically be observed in equivalent setups in public and private environments.

Table 2 – Wi-Fi access points

Access point No.	Wi-Fi band available	IC certification No.	Model
1	2/5 GHz	4675A-AP134135	Aruba AP-134
2	2/5 GHz	3839A-E3200	Cisco E3200

¹² Determination of the e.i.r.p. was based on radiated emission tests performed in an anechoic chamber at 3 metres from the access points with their conducted power set at 24 dBm.

¹³ Wi-Fi transmitted signals during regular operation (i.e. not in test mode) are pulsed, with a low duty cycle.

Table 3 – Wi-Fi-enabled laptops

Laptop No.	Wi-Fi band available	IC certification No.	Model
1	2/5 GHz	248H-DPA3375W	Toshiba Tecra S2
2	2/5 GHz	248H-DPA3489W	Toshiba Tecra S4
3	2/5 GHz	248H-DPA3795W	Toshiba Tecra S11
4	2 GHz	248H-DPA3362W	Toshiba Portégé M200
5	2 GHz	248H-DPA3272W	Toshiba Tecra S1
6	2 GHz	248H-DPA3362W	Toshiba Tecra S1
7	2 GHz	248H-DPA3272W	Toshiba Tecra S1
8	2/5 GHz	248H-DPA3538W	Toshiba Tecra S9
9	2/5 GHz	248H-DPA3489W	Toshiba Portégé M700/M710
10	2/5 GHz	248H-DPA3489W	Toshiba Portégé M700/M710
11	2/5 GHz	248H-DPA3489W	Toshiba Portégé M700/M710
12	2/5 GHz	248H-DPA3489W	Toshiba Portégé M700/M710
13	2/5 GHz	248H-DPA3375W	Toshiba Tecra S2
14	2/5 GHz	248H-DPA3538W	Toshiba Tecra A9
15	2/5 GHz	248H-DPA3538W	Toshiba Tecra A9
16	2/5 GHz	248H-DPA3538W	Toshiba Tecra A9
17	2/5 GHz	248H-DPA3538W	Toshiba Tecra A9
18	2/5 GHz	248H-DPA3375W	Toshiba Tecra S2
19	2/5 GHz	248H-DPA3375W	Toshiba Tecra S2
20	2/5 GHz	248H-DPA3375W	Toshiba Tecra S2
21	2/5 GHz	248H-DPA3375W	Toshiba Tecra S2
22	2/5 GHz	248H-DPA3375W	Toshiba Tecra S2
23	2/5 GHz	248H-DPA3375W	Toshiba Tecra S2
24	2/5 GHz	248H-DPA3375W	Toshiba Tecra S2

The program NetStumbler¹⁴ was installed on a laptop to identify the Wi-Fi access points in the area. The software provided information on the signal strength of each Wi-Fi access point. On November 8, 2011, NetStumbler detected four additional access points. These Wi-Fi access points had signal strengths that were 45-51 dB lower than the two Wi-Fi access points being tested. On November 9, 2011, NetStumbler detected seven additional Wi-Fi access points. These Wi-Fi access points had signal strengths that were 33-65 dB lower than AP1 and AP2. These additional Wi-Fi access points were all operating in the 2.4 GHz band.

2.3 Measurement Locations and Environmental Conditions

The measurements were performed on November 8-9, 2011, in an Industry Canada office located in Aurora, Ontario (see Figure 3). The temperature within the boardroom was approximately 20°C with low humidity.

¹⁴ Available at <http://www.netstumbler.com>.



Figure 3 – Aerial view of the measurement location in Aurora, Ontario

The measurement locations within the boardroom are represented in Figure 4, and a photo of the boardroom setup is presented in Figure 5.

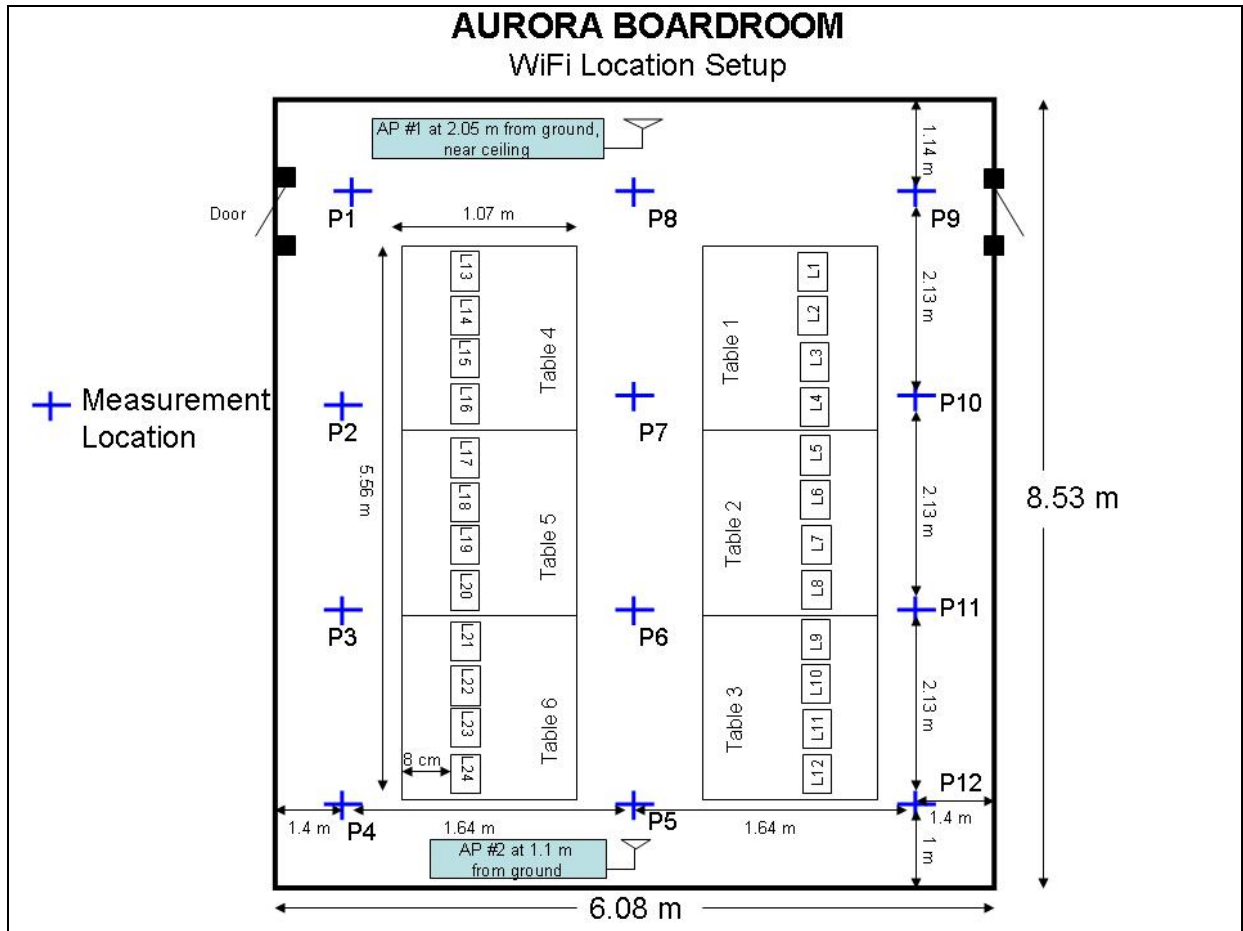


Figure 4 – Schematic of Wi-Fi measurement locations



Figure 5 – Boardroom setup

2.4 Measurement Methodology

The measurement methodology was based on Industry Canada's GL-01, *Guidelines for the Measurement of Radio Frequency Fields at Frequencies from 3 kHz to 300 GHz*,¹⁵ and TN-329, *Safety Code 6 (SC6) Measurement Procedures (Uncontrolled Environment)*.¹⁶

This case study did not include an assessment of near-field exposure, which requires a laboratory test setup to determine compliance with the SAR limits outlined in RSS-102. SAR evaluations of Wi-Fi-enabled devices such as laptop computers are conducted as part of the technical requirements for certification by independent laboratories, so this assessment would already have been performed.

Table 4 and Table 5 present details of the test cases related to the ambient fields and to the Wi-Fi devices in operation, respectively.

Table 4 – Test cases related to the ambient fields

Test case no.	Frequency range	Measurement location	Tri-axis antenna height	Total measurement/scan time	Wi-Fi access points
1a	50 MHz to 6 GHz	At each preselected location ^a	1.75 m	~1 min	Off
2a	50 MHz to 6 GHz	At one location (P11)	1.25 m ^b	~1 min	Off
3a	50 MHz to 6 GHz	At one location (P11)	1.25 m	6 min	Off
4a	50 MHz to 6 GHz	At one location (P11)	Nine-point matrix representing a cross-section of the human body ^c	12 sec at each point	Off

^a See Figure 4 for preselected measurement locations.

^b The height of 1.25 metres is approximately the height of a person in the sitting position.

^c The nine-point matrix is described in Health Canada's *Technical Guide for Interpretation and Compliance Assessment of Health Canada's Radiofrequency Exposure Guidelines* (http://www.hc-sc.gc.ca/ewh-semt/pubs/radiation/radio_guide-lignes_direct-eng.php).

¹⁵ Available at <http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01451.html>.

¹⁶ Available at <http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09977.html>.

Table 5 – Test cases related to Wi-Fi devices in operation

Test case No.	Frequency range	Measurement location	Tri-axis antenna height	Total measurement/scan time	Wi-Fi-enabled devices	Wi-Fi access points
1b	2.4 to 5.825 GHz	At each preselected location	1.75 m	~1 min	All laptops in downloading mode ^a	On
2b	2.4 to 5.825 GHz	At each preselected location	1.25 m	~1 min	All laptops in downloading mode	On
3b	2.4 to 5.825 GHz	At location with highest RF level from results of 1b and 2b (location P5)	Nine-point matrix representing a cross-section of the human body	6 min for each point ^b	All laptops in downloading mode	On
4b	2400 to 2483.5 MHz	At 50 cm from location P7, closer to location P8	1.25 m	6 min	8 laptops in uploading mode; ^c 16 laptops off	On
5b	2400 to 2483.5 MHz	At 50 cm from location P7, closer to location P8	1.25 m	6 min	8 laptops in uploading mode; 16 laptops in downloading mode	On
6b	2400 to 2483.5 MHz	At 50 cm from location P7, closer to location P8	1.25 m	6 min	1 laptop in uploading mode; 23 laptops off	On
7b	2400 to 2483.5 MHz	At 50 cm from location P7, closer to location P8	1.25 m	6 min	1 laptop in downloading mode; 23 laptops off	On
8b	5150 to 5350 MHz	20 cm from AP1	NA	~1 min	All laptops in downloading mode	On
9b	2400 to 2483.5 MHz	20 cm from AP2	NA	~1 min	All laptops in downloading mode	On

^a **Downloading mode:** Wi-Fi-enabled devices are receiving data from a remote network location (from a host server via a Wi-Fi access point).

^b For each point in the nine-point matrix, a measurement of 6 minutes is performed to provide the RF level based on spatial and time averaging.

^c **Uploading mode:** Wi-Fi-enabled devices are sending data to a remote network location (to a host server via a Wi-Fi access point).

3.0 Measurement Results

3.1 Ambient Fields

Measurements were initially performed to determine the RF exposure levels in the ambient environment when the Wi-Fi devices under test, and all other wireless devices in the boardroom, were non-operational. This section summarizes the main findings for test cases 1a through 4a. However, more detailed measurement results are presented in Annex E.

1a) Ambient levels from 50 MHz to 6 GHz at each measurement location with the tri-axis antenna positioned at a height of 1.75 metres

Location P6 had the highest instantaneous (maximum) recorded value, which was 0.013% of the SC6 limits. The average RF exposure level recorded at the same location was 0.003% of the SC6 limits. The average field strength values for the 12 locations were similar, with a standard deviation of 0.0001%.

2a) Ambient levels from 50 MHz to 6 GHz at one measurement location with the tri-axis antenna positioned at a height of 1.25 metres

Because RF exposure levels were similar for all locations, location P11 was arbitrarily chosen, with the tri-axis antenna positioned at a height of 1.25 metres. The RF exposure levels were similar to the levels measured with the tri-axis antenna positioned at a height of 1.75 metres. The average RF exposure level recorded at P11 was 0.003% of the SC6 limits.

3a) Ambient levels from 50 MHz to 6 GHz at one measurement location with the tri-axis antenna positioned at a height of 1.25 metres for a sweep time of 6 minutes

Location P11 was chosen for the 6-minute time-averaging measurement with the tri-axis antenna positioned at a height of 1.25 metres. The average RF exposure level recorded was 0.003% of the SC6 limits.

4a) Ambient levels from 50 MHz to 6 GHz at one measurement location with a nine-point matrix representing a cross-section of the human body

Spatial averaging was performed at location P11 by using a nine-point matrix representing a cross-section of the human body. Because the ambient RF exposure levels were well below the SC6 limits, a quick scan was performed at each point of the nine-point matrix. The value obtained for the spatial averaging was 0.003% of the SC6 limits. The ambient average is the same for all locations.

3.2 Test Results with the Wi-Fi Access Points and Wi-Fi-Enabled Devices Operational

Measurements were performed to determine the RF exposure levels when the Wi-Fi devices under test, and all 24 Wi-Fi-enabled devices, were operational. This section summarizes the main findings for test cases 1b through 9b. However, more detailed measurement results are presented in Annex E.

1b) RF exposure levels from 2.4 to 5.825 GHz at each preselected measurement location with the tri-axis antenna positioned at a height of 1.75 metres

The measurements were performed at each preselected location (see Figure 4) with the tri-axis antenna positioned at a height of 1.75 metres. Information was captured for approximately 50 to 70 sweeps (~1 min) at each location. The Wi-Fi-enabled devices were downloading a large file from a host server via AP2 while AP1 was in continuous-transmission test mode (duty cycle ~100%).

According to the measurement results, location P8 had the highest RF exposure level. Location P8 was the preselected location closest to AP1 (distance ~1.1 m). The average RF exposure level for the Wi-Fi bands at this location was 0.232% of the SC6 limits (431 times below the limits). The 5150-5350 MHz band provided the largest contribution to the average RF level, which was 0.229% of the SC6 limits (436 times below the limits).

2b) RF exposure levels from 2.4 to 5.825 GHz at each preselected measurement location with the tri-axis antenna positioned at a height of 1.25 metres

The measurements were again performed at each preselected location with the tri-axis antenna positioned at a height of 1.25 metres. Information was captured for approximately 50 to 70 sweeps (~1 min) at each location. The Wi-Fi-enabled devices were downloading a large file by connecting to AP2 while AP1 was in continuous-transmission test mode (duty cycle ~100%).

According to the measurement results, location P5 had the highest RF exposure level. Location P5 was the preselected location closest to AP2 (distance ~0.43 m). The average RF exposure level for the Wi-Fi bands at this location was 0.234% of the SC6 limits (427 times below the limits). The 2400-2483.5 MHz band provided the largest contribution to the average RF level, which was 0.221% of the SC6 limits (452 times below the limits).

3b) Spatial- and time-averaged RF exposure levels from 2.4 to 5.825 GHz at the location with the highest levels found from 1b and 2b

Health Canada's Safety Code 6 states that for situations in which the exposure intensity varies significantly with time within a period of 6 minutes, time-averaging values must be calculated from multiple measurements. Safety Code 6 also states that spatial averaging (from a nine-point matrix) over the projected surface area (flat plane) equivalent to the head and the body region of a person shall be measured if the localized values vary by more than 20%.

In compliance with the requirements set forth in Industry Canada's GL-01 and TN-329 (based on SC6), spatial and time averaging were performed at the location with the highest RF exposure value from 1b and 2b. Location P5, the location nearest to AP2, was selected for the spatial- and time-averaging measurements. Measurements were logged for 6 minutes at each point of the nine-point matrix. As in test cases 1b and 2b, both Wi-Fi access points were operational, and all Wi-Fi-enabled devices were in downloading mode.

The percentages of the SC6 limits were measured from 2400 to 5825 MHz. The spatial- and time-averaging value was 0.099% of the SC6 limits (1010 times below the limits).

4b) RF exposure levels for eight laptops connected to AP2 in uploading mode at a preselected measurement location with the tri-axis antenna positioned at a height of 1.25 metres

Test cases 4b through 7b determined the variation in the RF exposure levels when laptops were in uploading or downloading mode, or both, at one selected measurement location. The measurement tri-axis antenna was positioned at a height of 1.25 metres. The measurement location was 50 cm from location P7, closer to location P8. This location was selected because it was centered between the eight uploading laptops (see Figure 6). The measurement location and the tri-axis antenna height remained the same for test cases 4b, 5b, 6b and 7b. Data was captured for 6 minutes for the four uploading and/or downloading scenarios.

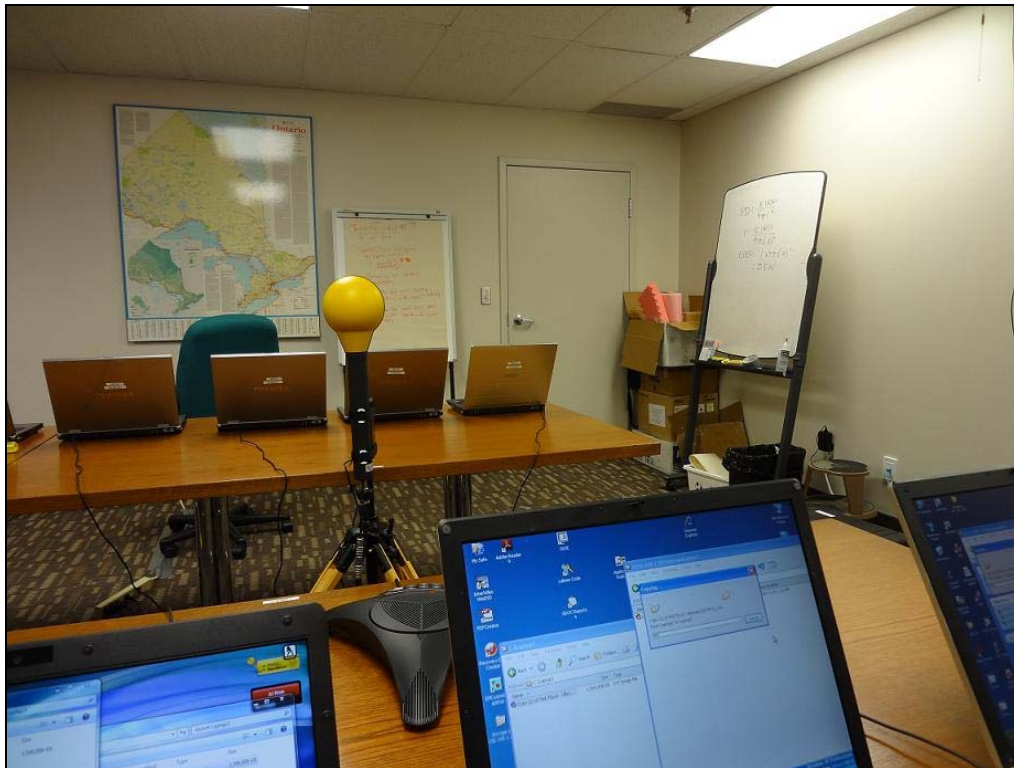


Figure 6 – Tri-axis antenna location for the uploading and/or downloading scenarios

In test case 4b, eight laptops (Nos. 1 to 4 and 13 to 16) were uploading a large file of approximately 3.6 GB to a server connected to AP2 while the remaining 16 laptops were turned off. The average RF exposure level for the 2400-2483.5 MHz band was measured at 0.006% of the SC6 limits.

5b) RF exposure levels for eight laptops connected to AP2 in uploading mode and 16 laptops in downloading mode at a preselected measurement location with the tri-axis antenna positioned at a height of 1.25 metres

In this test case, eight laptops (Nos. 1 to 4 and 13 to 16) were uploading a large file of approximately 3.6 GB to a server connected to AP2 while the remaining laptops were downloading a large file of approximately 14.4 GB from AP2. The average RF exposure level for the 2400-2483.5 MHz band was 0.005% of the SC6 limits.

6b) RF exposure levels for one laptop connected to AP2 in uploading mode at a preselected measurement location with the tri-axis antenna positioned at a height of 1.25 metres

In this test case, one laptop (No. 3) was uploading a large file of approximately 3.6 GB to a server connected to AP2 while the remaining laptops were turned off. Laptop 3 was selected because it was closest to the measurement tri-axis antenna. The average RF exposure level for the 2400-2483.5 MHz band was 0.004% of the SC6 limits.

7b) RF exposure levels for one laptop connected to AP2 in downloading mode at a preselected measurement location with the tri-axis antenna positioned at a height of 1.25 metres

In this test case, laptop 3 was downloading a large file from Wi-Fi AP2 while the remaining laptops were turned off. The average level for the 2400-2483.5 MHz band was 0.007% of the SC6 limits.

8b) RF exposure levels from 5150 to 5350 MHz with the tri-axis antenna positioned at 20 cm from AP1

The tri-axis antenna was positioned at 20 cm¹⁷ from AP1 for a total sweep time of approximately 70 seconds when AP1 was transmitting in the continuous mode. The maximum RF exposure level obtained during this time frame was 10.59% of the SC6 limits.

9b) RF exposure levels from 2400 to 2483.5 MHz with the tri-axis antenna positioned at 20 cm from AP2

The tri-axis antenna was positioned at 20 cm above AP2 (this access point has built-in antennas) for a total sweep time of approximately 70 seconds. All laptops were in downloading mode. The built-in antennas of this access point were small, so the distance of 20 cm was well in the far-field zone of each one (see Annex B). The maximum RF exposure level obtained during this time frame was 7.73% of the SC6 limits.

4.0 Discussion

4.1 Application of Equipment-Related Uncertainty to Spatial- and Time-Averaged Measurements

Industry Canada's GL-01 states that in order to verify compliance with the SC6 limits, measurement equipment uncertainty must be considered. Table 6 represents the spatial- and time-averaged RF exposure levels at location P5 in the configuration of test case 3b, with all Wi-Fi devices active, along with the minimum and maximum expected values,¹⁸ based on a confidence level of 95%. (See Annex C for the expanded uncertainty of the Narda SRM 3006 and its corresponding antennas, which constitute the measurement system.)

¹⁷ At 20 cm, the tri-axis antenna was located in the near field because the antenna of AP1 is considered an electrically large antenna (D = 17 cm). E and H field measurements would be required at 20 cm. However, H field measurements were not performed during this case study.

¹⁸ The highest values for expanded measurement uncertainty, + 2.9 /-4.3 dB, were added to the measured RF exposure value.

Table 6 – Percentage of SC6 limits (uncontrolled environment) including the measurement equipment uncertainty for the spatial- and time-averaged RF exposure value obtained at location P5

Measured Value – Exp. Uncert. (% SC6 limits) ^a	Measured % SC6 limits for the uncontrolled environment	Measured Value + Exp. Uncert. (% SC6 limits) ^a
0.037%	0.099%	0.194%

^a Includes the expanded measurement uncertainty (Exp. Uncert.) of the equipment.

4.2 Impact of Wi-Fi Protocol on RF Exposure

Table 7 summarizes the contribution of the 2400-2483.5 MHz band when Wi-Fi-enabled devices operate in different configurations of uploading or downloading, or both. The highest average RF exposure level obtained from the four configurations was 0.007% of the SC6 limits, for the test case with a single laptop in downloading mode.

Table 7 – Percentage of SC6 limits (uncontrolled environment) for the 2400-2483.5 MHz band between locations P7 and P8 with the tri-axis antenna at a height of 1.25 metres for different configurations

Location ^a	Lower frequency (MHz)	Upper frequency (MHz)	Configuration ^b	Average (% SC6 limits)
50 cm from P7	2400	2483.5	Eight laptops uploading	0.006
	2400	2483.5	Eight laptops uploading; 16 laptops downloading	0.005
	2400	2483.5	One laptop uploading	0.004
	2400	2483.5	One laptop downloading	0.007

^a See Figure 4 for measurement location.

^b All configurations were statistically different (at 95% confidence level), except for the configuration with eight laptops uploading versus the configuration with one laptop downloading.

When numerous devices are uploading and/or downloading at the same time, a collision avoidance (CA) mechanism is used to improve the performance of carrier sense multiple access (CSMA). To avoid a collision when a packet is sent, the node must first “listen” to confirm that a channel is clear. When the full bandwidth (e.g. 20 MHz) of a node is devoted to only one client device, such as a laptop, the node can transmit more often without deferring the transmission. However, when the bandwidth is divided into numerous channels of similar size because the node is connected to many client devices, the node must listen more often before a packet can be transmitted. When a channel is sensed as busy, transmission is deferred and the RF exposure level decreases. A configuration of one laptop uploading produces a lower level of RF exposure than a configuration of one laptop downloading, because the power of the Wi-Fi module in a Wi-Fi-enabled device is typically lower than the power of the Wi-Fi access points.

5.0 Conclusion

In this study, the measured results were expressed as percentages of the SC6 limits (see Section 3.0).

When the Wi-Fi access points and Wi-Fi-enabled devices were operating, the RF exposure levels were higher when the tri-axis antenna was nearer to the Wi-Fi access points (locations P5 and P8). For location P8, which was near AP1, the highest average RF exposure level obtained was 0.232% of the SC6 limits, for a measurement time of approximately 1 minute (see test case 1b in Section 3.2). The largest contribution came from the 5150-5350 MHz band, with a value of 0.229%. For location P5, which was near AP2, the highest average RF exposure level obtained was 0.234% of the SC6 limits, for the same measurement time of approximately 1 minute (see test case 2b in Section 3.2). The largest contribution came from AP2 in the 2400-2483.5 MHz band, with a value of 0.221%.

In compliance with the procedures set forth in Industry Canada's GL-01 and TN-329, spatial- and time-averaging measurements were performed at location P5 near AP2, the location with the highest measured field strength levels (see test case 3b in Section 3.2). The resulting value was 0.1% of the SC6 limits. With the measurement equipment uncertainty added, the measured RF exposure level was 0.19% of the SC6 limits (515 times below the limit).

With the tri-axis antenna positioned at a distance of 20 cm from the Wi-Fi access points,¹⁹ the maximum RF exposure levels obtained for AP1 and AP2 were 10.59% and 7.73% of the SC6 limits, respectively. In a typical scenario in which a person is located several metres from the access point and surrounded by other users, the RF exposure level is thousands of times below the SC6 limits.

Based on the results of this case study, the aggregated RF exposure of multiple Wi-Fi access points and Wi-Fi-enabled devices in this indoor location was well below the SC6 limits. In addition, the Wi-Fi access points selected for this study were operating at higher power compared with the majority of the Wi-Fi devices currently available on the Canadian market. Therefore, the results of this study are likely higher than typical equivalent setups in public and private environments, such as homes, schools and businesses.

¹⁹ A distance of 20 cm represents the distance at which a manufacturer will generally demonstrate compliance with the RF exposure requirements set forth in RSS-102.

Annex A – Wi-Fi Standards, Spectral Allocations and Emissions

The common Wi-Fi standards are summarized in Table A.1.

Table A.1 – 802.11 Network standards

802.11 Protocol	Release date	Frequency (GHz)	Channel bandwidth (MHz)	Channel number	Data rate per stream (Mbits/s)	Allowable MIMO streams	Modulation
-	June 1997	2.4	20	1-14 (2.4 GHz)	1, 2	1	DSSS, FHSS
a	Sept. 1999	3.7/5	20	131-138 (3.7 GHz) 34-165 (5 GHz)	6, 9, 12, 18, 24, 36, 48, 54	1	OFDM
b	Sept. 1999	2.4	20	1-14 (2.4 GHz)	5.5, 11	1	DSSS
g	June 2003	2.4	20	1-14 (2.4 GHz)	7.2, 14.4, 21.7, 28.9, 43.3, 57.8, 65, 72.2	1	OFDM, DSSS
n	Oct.2009	2.4/5	40	1-14 (2.4 GHz) 34-165 (5 GHz)	15, 30, 45, 60, 90, 120, 135, 150	4	OFDM

Abbreviations: DSSS, direct sequence spread spectrum; FHSS, frequency hopping spread spectrum; MIMO, multiple input multiple output; OFDM, orthogonal frequency division multiplexing.

The following figures and tables show the spectral emission and channel allocation for 2.4-GHz Wi-Fi (Figure A.1, Figure A.2 and Table A.2) and for 5-GHz Wi-Fi (Figure A.3, Table A.3, Table A.4 and Table A.5).

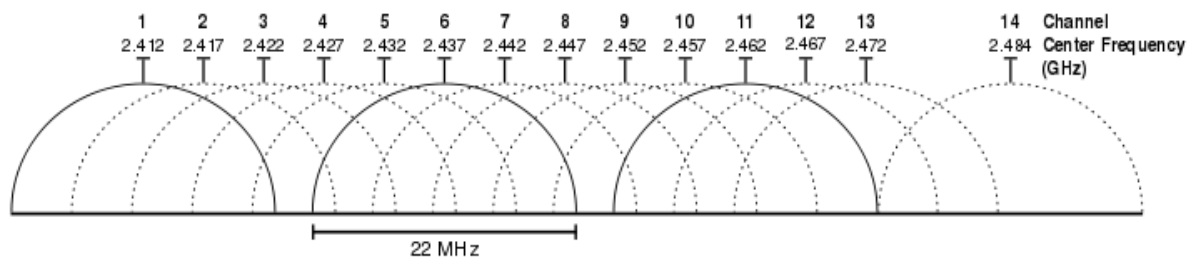


Figure A.1 – 2.4-GHz spectral emission

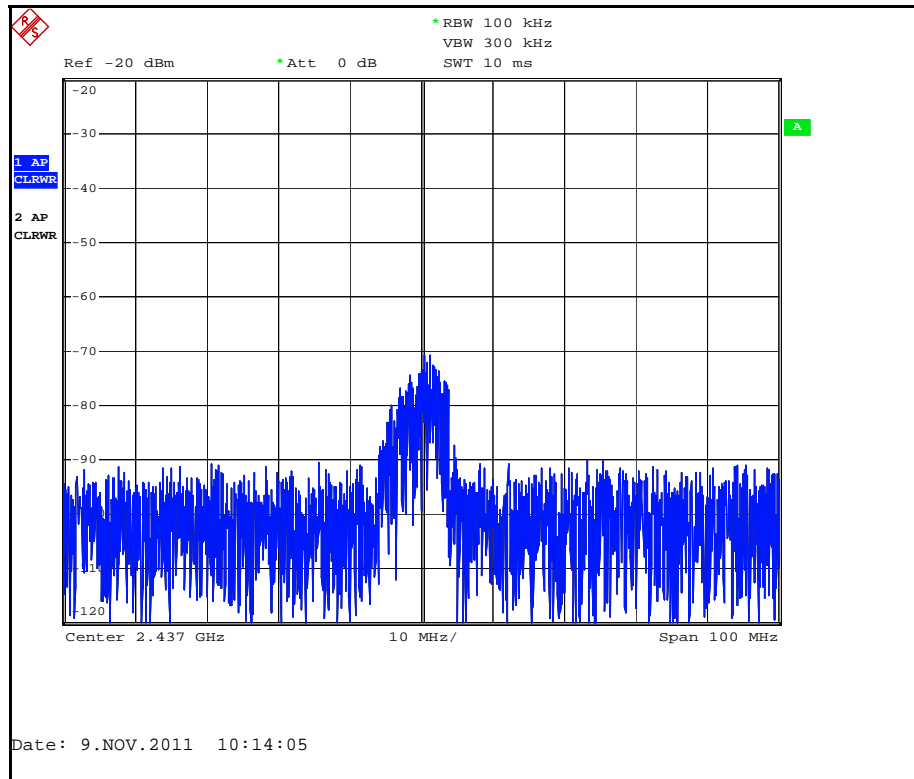


Figure A.2 – Spectral emission of Wi-Fi AP2

Table A.2 – Wi-Fi channels in the 2400-2483.5 MHz band (RSS-210, Annex 8)

Channel	Frequency (MHz)
1	2412
2	2417
3	2422
4	2427
5	2432
6	2437
7	2442
8	2447
9	2452
10	2457
11	2462
12	2467
13	2472
14	2484

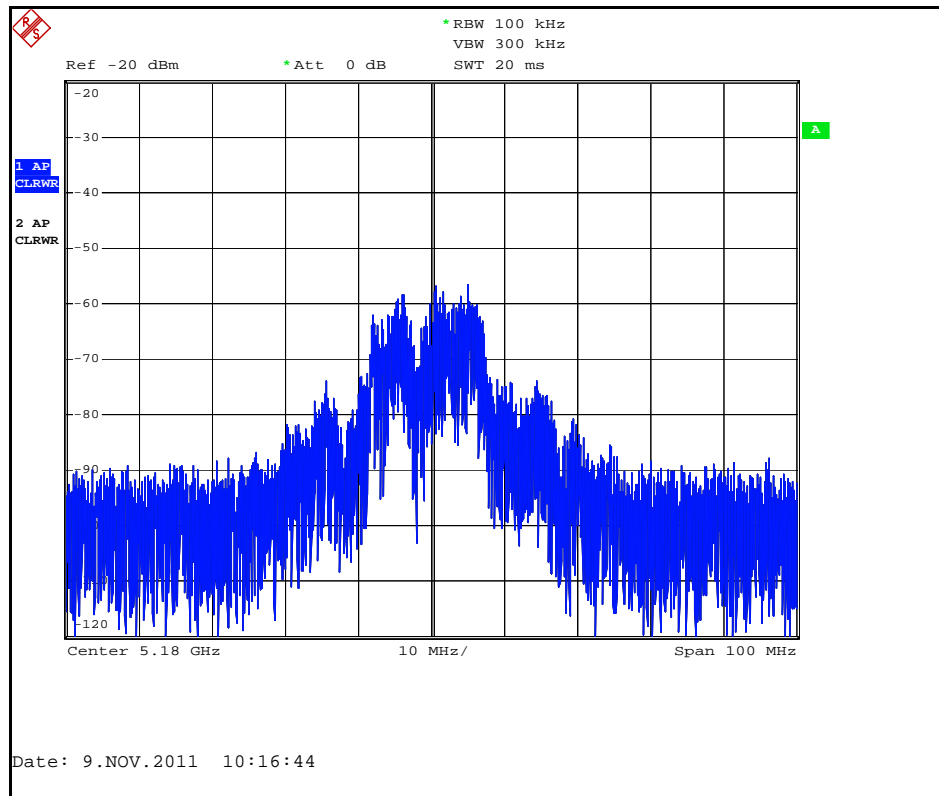


Figure A.3 – Spectral emission of Wi-Fi AP1

Table A.3 – Wi-Fi channels in the 5150-5350 MHz band (RSS-210 Annex 9)

Channel	Frequency (MHz)
34	5170
36	5180
38	5190
40	5200
42	5210
44	5220
46	5230
48	5240
52	5260
56	5280
60	5300
64	5320

Table A.4 – Wi-Fi channels in the 5825 MHz band (RSS-210, Annex 9)

Channel	Frequency (MHz)
100	5500
104	5520
108	5540
112	5560
116	5580
120	5600
124	5620
128	5640
132	5660
136	5680
140	5700
149	5745
153	5765
157	5785
161	5805
165	5825

Table A.5 – Wi-Fi channels in the 5725-5875 MHz band (RSS-210, Annex 8)

Channel	Frequency (MHz)
149	5745
153	5765
157	5785
161	5805
165	5825

Annex B – Near-Field and Far-Field Zones

An antenna whose largest dimension is no greater than the wavelength of its operating frequency is referred to as an electrically small antenna.²⁰ The reactive near field of these antennas extend up to the distance given below:

$$R_{\text{rnf}} = \frac{\lambda}{2\pi}$$

where:

R_{rnf} is the reactive near field, and
 λ is the wavelength of the operating frequency

$$R_{\text{rnf}} \text{ at } 2.437 \text{ GHz} = 0.123/2\pi = 0.020 \text{ m (or 2 cm)}$$

$$R_{\text{rnf}} \text{ at } 5.18 \text{ GHz} = 0.058/2\pi = 0.009 \text{ m (or 0.9 cm)}$$

An antenna whose largest dimension is greater than the wavelength of its operating frequency is referred to as an electrically large antenna.²¹ The far-field region of this type of antenna extends from $2D^2/\lambda$ to infinity, where D is the largest dimension of the antenna. In SC6, however, the transition region and the far-field region are considered to be the same, and the far-field region is therefore considered to extend from $0.5 D^2/\lambda$ to infinity.

$$R_{\text{ff}} = \frac{0.5D^2}{\lambda}$$

where:

R_{ff} is the distance from the antenna to the boundary between the near field and far field
in metres

λ is the wavelength of the operating frequency

D is an electrical dimension in metres

All measurement locations were in the far-field zone of both AP1 and AP2 (except for the measurement at 20 cm from AP1).

²⁰ AP2 was considered an electrically small antenna.

²¹ AP1 was considered an electrically large antenna.

Annex C – Uncertainty due to Measurement Equipment

Table C.1 and Table C.2 list the expanded uncertainty of the measurement system (consisting of the Narda SRM 3006 and its electric field antennas) over its usable frequency range, with a confidence level of 95%.

Table C.1 – Expanded measurement uncertainty for three-axis E-field antenna 3501/02 from 75 MHz to 3 GHz (in conjunction with SRM basic unit and 1.5-m RF cable)

Frequency range (MHz)	Single axis (dB)	Isotropic measurement (dB)
75-900	+2.4 / -3.4	+2.4 / -3.3
>900-1400	+2.3 / -3.1	+2.4 / -3.3
>1400-1600	+2.2 / -3.1	+2.6 / -3.7
>1600-1800	+1.8 / -2.2	+2.2 / -3.0
>1800-2200	+1.8 / -2.2	+2.4 / -3.3
>2200-2700	+1.8 / -2.3	+2.6 / -3.6
>2700-3000	+1.9 / -2.4	+3.2 / -5.3

Table C.2 – Expanded measurement uncertainty for three-axis E-field antenna 3502/01 from 420 MHz to 6 GHz (in conjunction with SRM basic unit and 1.5-m RF cable)

Frequency range (MHz)	Single axis (dB)	Isotropic measurement (dB)
420-750	+2.1 / -2.9	+2.6 / -3.8
>750-1600	+2.0 / -2.7	+2.2 / -2.9
>1600-2000	+1.7 / -2.2	+1.9 / -2.4
>2000-4000	+1.7 / -2.2	+2.0 / -2.6
>4000-4500	+1.8 / -2.3	+2.2 / -3.0
>4500-5000	+1.9 / -2.5	+2.2 / -3.0
>5000-5000	+1.9 / -2.5	+2.5 / -3.5
>5000-6000	+1.9 / -2.5	+2.9 / -4.3

Annex D – Health Canada’s Safety Code 6 Limits for Uncontrolled Environment

Industry Canada has adopted Health Canada’s RF exposure guideline, Safety Code 6, in its regulation for the protection of the general public. The SC6 limits for uncontrolled environments are listed in Table D.1.

Table D.1 – Safety Code 6 limits for uncontrolled environments

Frequency (MHz)	Electric field strength, rms (V/m)	Magnetic field strength, rms (A/m)	Power density (W/m ²)	Averaging time (min)
0.003-1	280	2.19		6
1-10	280/f	2.19/f		6
10-30	28	2.19/f		6
30-300	28	0.073	2 ^a	6
300-1500	1.585f ^{0.5}	0.0042 f ^{0.5}	f/150	6
1500-15,000	61.4	0.163	10	6
15,000-150,000	61.4	0.163	10	616,000/f ^{1.2}
150,000-300,000	0.158 f ^{0.5}	4.21 × 10 ⁻⁴ f ^{0.5}	6.67 × 10 ⁻⁵ f	616,000/f ^{1.2}

^a Power density limit is applicable at frequencies greater than 100 MHz.

Annex E – Detailed Measurement Results

This annex provides the detailed results of each test case performed in this study. The maximum value represents the maximum instantaneous value measured during the measurement time period, and the minimum value represents the minimum instantaneous value measured during the measurement time period. The average value represents the average value measured during the measurement time period.

1a) Ambient levels from 50 MHz to 6 GHz at each measurement location with the tri-axis antenna positioned at a height of 1.75 metres

Table E.1 – Percentage of SC6 limits (uncontrolled environment) at a height of 1.75 metres from 50 MHz to 6 GHz

Location ^a	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
P1	0.002527	0.005386	0.002057
P2	0.002498	0.003360	0.002083
P3	0.002545	0.003978	0.002098
P4	0.002589	0.005431	0.002129
P5	0.002632	0.006384	0.002149
P6	0.002846	0.013032	0.002159
P7	0.002640	0.004001	0.002185
P8	0.002691	0.004851	0.002197
P9	0.002674	0.004687	0.002243
P10	0.002717	0.004865	0.002269
P11	0.002741	0.006172	0.002241
P12	0.002754	0.007066	0.002250

^a See Figure 4 for measurement locations.

2a) Ambient levels from 50 MHz to 6 GHz at one measurement location with the tri-axis antenna positioned at a height of 1.25 metres

Table E.2 – Percentage of SC6 limits (uncontrolled environment) at a height of 1.25 metres from 50 MHz to 6 GHz

Location	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
P11	0.002855	0.011449	0.002276

Table E.3 and Table E.4 list the measured percentages of SC6 limits for each specific service operating in the frequency band from 50 MHz to 6 GHz at location P11.

Table E.3 – Percentage of SC6 limits (uncontrolled environment) for each service in the frequency range from 50 MHz to 3 GHz (ambient environment)

Lower frequency (MHz)	Upper frequency (MHz)	Service name	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
50	54	Mixed L/M	0.000035	0.000077	0.000015
54	72	TV Ch. 2-4	0.000098	0.000134	0.000069
72	76	Mixed LM	0.000017	0.000032	0.000006
76	88	TV CH5 - 6	0.000041	0.000057	0.000027
88	108	FM Broadcast	0.000050	0.000070	0.000032
108	136	Aeronautical	0.000050	0.000070	0.000036
136	174	Land Mobile	0.000056	0.000073	0.000040
174	216	TV Ch. 7-13	0.000046	0.000059	0.000040
216	300	Mixed L/M	0.000062	0.000079	0.000052
300	406	Mixed L/M	0.000050	0.000058	0.000043
406	470	Land Mobile	0.000021	0.000025	0.000018
470	608	TV Ch. 14-36	0.000024	0.000028	0.000022
608	614	Radio Astronomy	0.000001	0.000001	0.000000
614	806	TV CH 38 - 69	0.000026	0.000028	0.000023
806	824	Trunking/Paging	0.000002	0.000003	0.000002
824	849	Cellular Mob TX	0.000003	0.000005	0.000002
849	869	Trunking/Paging	0.000003	0.000004	0.000002
869	894	Cellular BaseTX	0.000003	0.000004	0.000002
894	960	Trunk/Page/Fix	0.000007	0.000009	0.000006
960	1300	AirTrafficRadar	0.000036	0.000039	0.000033
1300	1452	MoSAT / SRS	0.000010	0.000011	0.000008
1452	1492	DAB	0.000002	0.000003	0.000002
1492	1500	MoSat / SRS	0.000001	0.000001	0.000000
1500	1518	MoSat / SRS	0.000001	0.000002	0.000001
1518	1670	MoSAT/Fixed	0.000011	0.000013	0.000010
1670	1675	Fixed / Mobile	0.000000	0.000001	0.000000
1675	1710	Mteorg / Fixed	0.000003	0.000003	0.000002
1710	1755	AWS LwrTX (A-F)	0.000004	0.000005	0.000003
1755	1850	MSS / Fixed	0.000009	0.000010	0.000007
1850	1910	PCS LwrTX	0.000007	0.000008	0.000006
1910	1915	AWS LwrTX (G)	0.000000	0.000001	0.000000
1915	1930	Licence Exempt	0.000002	0.000003	0.000001
1930	1990	PCS UpTX	0.000010	0.000012	0.000008
1990	1995	AWS UpTX (G)	0.000001	0.000001	0.000000
1995	2110	MSS / D-FIX	0.000018	0.000020	0.000015
2110	2155	AWS UpTX(A-F)	0.000009	0.000011	0.000006
2155	2305	Fixed / Mobile	0.000036	0.000041	0.000032
2305	2320	WCS	0.000004	0.000007	0.000003
2320	2345	S-DARS	0.000008	0.000011	0.000005
2345	2360	WCS	0.000005	0.000007	0.000004
2360	2400	MATS	0.000013	0.000017	0.000010
2400	2483.5	LIC EXEMPT	0.000199	0.008268	0.000026
2483.5	2500	MoSAT	0.000006	0.000009	0.000004
2500	2596	MCS	0.000036	0.000041	0.000032
2596	2686	MDS	0.000034	0.000039	0.000029

2686	2690	MDS / MDS (Rtr)	0.000002	0.000003	0.000001
2692	3000	Aeronautical	0.000198	0.000211	0.000178
		Total (%)	0.001225	0.009574	0.000830

Note: **Bold** represents the Wi-Fi bands in Canada.

Table E.4 – Percentage of SC6 limits (uncontrolled environment) for each service in the frequency range from 3 to 6 GHz (ambient environment)

Lower frequency (MHz)	Upper frequency (MHz)	Service name	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
3000	3100	Radionavigation	0.000006	0.000007	0.000005
3100	3300	Radar / Sat	0.000011	0.000012	0.000010
3300	3400	Radar / Amateur	0.000007	0.000008	0.000006
3400	3475	FWA (A-C)	0.000006	0.000008	0.000005
3475	3500	FWA (D)	0.000003	0.000003	0.000002
3500	3525	FWA(E)/C-Band	0.000003	0.000003	0.000002
3525	3550	FWA(F)/C-Band	0.000003	0.000004	0.000002
3550	3575	FWA(G)/C-Band	0.000003	0.000004	0.000002
3575	3600	FWA(H)/C-Band	0.000003	0.000004	0.000002
3600	3625	FWA(J)/C-Band	0.000003	0.000004	0.000002
3625	3650	FWA(K)/C-Band	0.000003	0.000005	0.000002
3650	3700	WBS/C-Band	0.000007	0.000009	0.000005
3700	4200	C-BAND SAT	0.000075	0.000079	0.000070
4200	4400	Aeronautical	0.000049	0.000054	0.000045
4400	5000	Fixed	0.000308	0.000328	0.000285
5000	5150	Aeronautical	0.000090	0.000099	0.000077
5150	5250	ISM / LicEx	0.000060	0.000073	0.000053
5250	5350	Radar / LicEx.	0.000068	0.000077	0.000059
5350	5460	ARNS	0.000095	0.000110	0.000084
5460	5470	Radar	0.000009	0.000015	0.000005
5470	5650	Marit Radar	0.000193	0.000219	0.000176
5650	5725	Amateur	0.000101	0.000134	0.000082
5725	5825	Lic. Exempt	0.000152	0.000173	0.000133
5825	5925	Fixed	0.000180	0.000221	0.000162
5925	6000	C-Band Sat	0.000155	0.000182	0.000136
		Total (%):	0.001594	0.001836	0.001413

Note: **Bold** represents the Wi-Fi bands in Canada.

Figure E.1 and Figure E.2 represent the signals in the ambient environment when all wireless devices were non-operational in the boardroom at location P11. As shown in Figure E.1, the Narda SRM 3006 meter was able to capture licence-exempt devices, such as Wi-Fi access points in the 2.4 GHz band, which were located in the area. In addition, cellular services in the 800 and 1900 MHz bands were prevalent and captured on the meter.

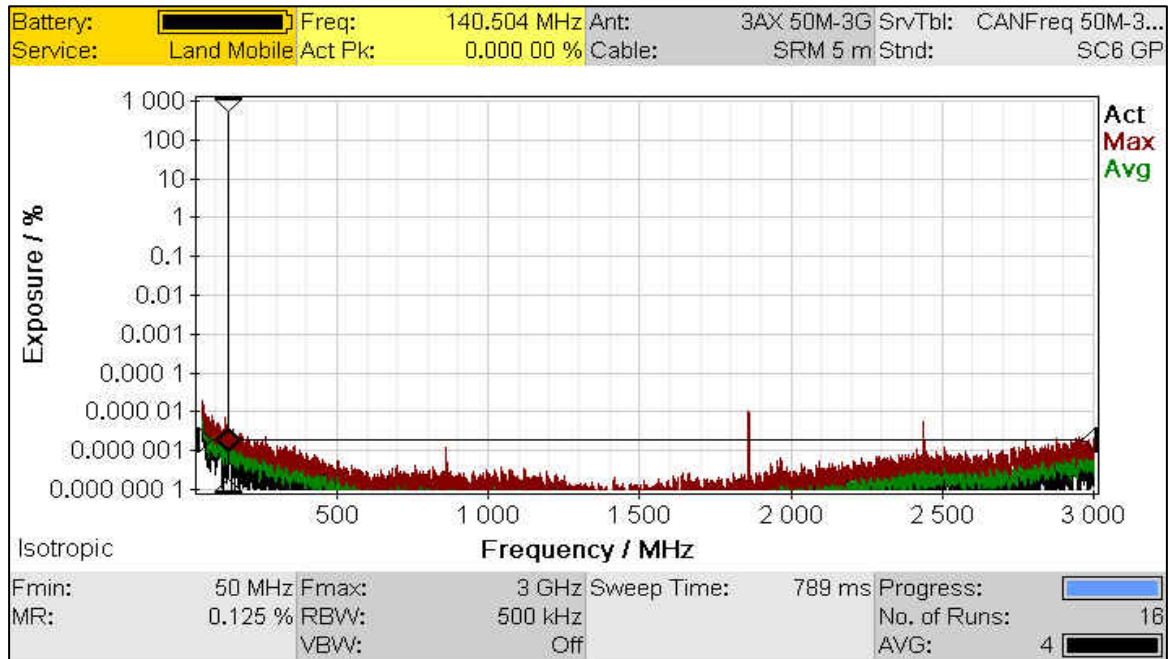


Figure E.1 – Signals in the RF ambient environment for the 50 MHz to 3 GHz frequency band

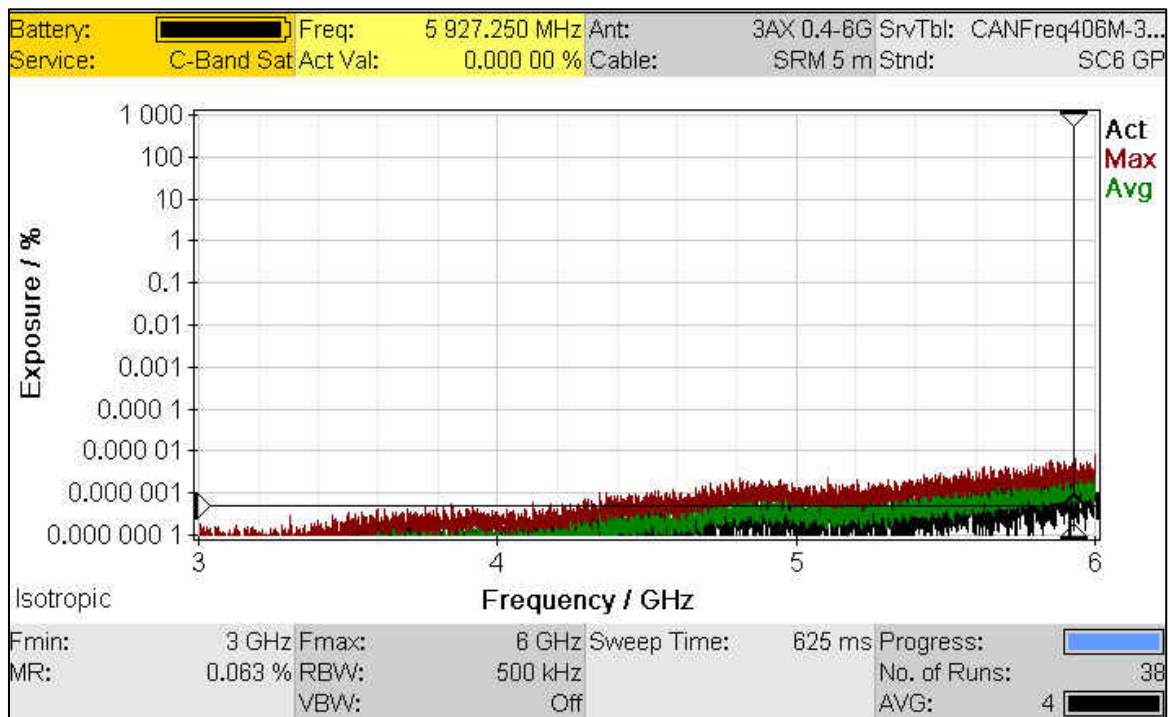


Figure E.2 – Signals in the RF ambient environment for the 3 to 6 GHz frequency band

- 3a) Ambient levels from 50 MHz to 6 GHz at one measurement location with the tri-axis antenna positioned at a height of 1.25 metres for a sweep time of 6 minutes

Table E.5 – Percentage of SC6 limits (uncontrolled environment) at a height of 1.25 metres from 50 MHz to 6 GHz for 6 minutes time averaging

Location	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
P11	0.002735	0.013794	0.002232

- 4a) Ambient levels from 50 MHz to 6 GHz at one measurement location with a nine-point matrix representing a cross-section of the human body

Table E.6 – Percentage of SC6 limits (uncontrolled environment) for each point of the nine-point matrix for spatial averaging of RF ambient field strength values from 50 MHz to 6 GHz (location P11)

	Total width (0.35 m)		
Height (0.5 m to 1.75 m)	0.00285%	0.00275%	0.00269%
	0.00282%	0.00272%	0.00274%
	0.00277%	0.00268%	0.00293%

Spatial averaging of the nine-point matrix (% SC6 limits): 0.00277%

- 1b) RF exposure levels from 2.4 to 5.825 GHz at each preselected measurement location with the tri-axis antenna positioned at a height of 1.75 metres

Table E.7 lists the measured percentages of the SC6 limits when both Wi-Fi APs were operational and all Wi-Fi-enabled devices were in downloading mode. The percentages of the SC6 limits were measured within the Wi-Fi bands from 2400 to 2483.5 MHz, 5150 to 5350 MHz, and 5470 to 5825 MHz. “Other” represents the contribution from other services operating in the frequency bands from 2483.5 to 5150 MHz and from 5350 to 5470 MHz.

Table E.7 – Percentage of SC6 limits (uncontrolled environment) for Wi-Fi bands at each location with the tri-axis antenna at a height of 1.75 metres

Location ^a	Lower frequency (MHz)	Upper frequency (MHz)	Service name	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
P1	2400	2483.5	Wi-Fi 2.4 GHz	0.004735	0.007653	0.000036
	5150	5350	Wi-Fi Low 5 GHz	0.044205	0.072308	0.032271
	5470	5825	Wi-Fi Low 5 GHz	0.001070	0.001078	0.001118
	Subtotal (Wi-Fi)			0.050010	0.081040	0.033749
			Other	0.001759	0.001724	0.001810
	Total			0.051769	0.082764	0.035559
P2	2400	2483.5	Wi-Fi 2.4 GHz	0.008658	0.061424	0.002647
	5150	5350	Wi-Fi Low 5 GHz	0.043953	0.0362364	0.032649
	5470	5825	Wi-Fi Low 5 GHz	0.001084	0.001037	0.001070
	Subtotal (Wi-Fi)			0.053695	0.098697	0.036366
			Other	0.001767	0.001763	0.001725
	Total			0.055462	0.100460	0.038091
P3	2400	2483.5	Wi-Fi 2.4 GHz	0.007164	0.015010	0.000368
	5150	5350	Wi-Fi Low 5 GHz	0.018175	0.027389	0.015431
	5470	5825	Wi-Fi Low 5 GHz	0.001079	0.001096	0.001130
	Subtotal (Wi-Fi)			0.026419	0.043495	0.016929
			Other	0.001775	0.001749	0.001776
	Total			0.028194	0.045244	0.018705
P4	2400	2483.5	Wi-Fi 2.4 GHz	0.028911	0.153082	0.000016
	5150	5350	Wi-Fi Low 5 GHz	0.007905	0.006924	0.006152
	5470	5825	Wi-Fi Low 5 GHz	0.001096	0.001130	0.001121
	Subtotal (Wi-Fi)			0.037912	0.161136	0.000729
			Other	0.001779	0.001787	0.001724
	Total			0.039691	0.162923	0.009014
P5	2400	2483.5	Wi-Fi 2.4 GHz	0.102474	0.403164	0.002500
	5150	5350	Wi-Fi Low 5 GHz	0.014984	0.012339	0.012737
	5470	5825	Wi-Fi Low 5 GHz	0.001102	0.001087	0.001073
	Subtotal (Wi-Fi)			0.118560	0.416590	0.016310
			Other	0.001796	0.001792	0.001760
	Total			0.120356	0.418382	0.018070
P6	2400	2483.5	Wi-Fi 2.4 GHz	0.017882	0.065530	0.006459
	5150	5350	Wi-Fi Low 5 GHz	0.034485	0.029514	0.026282
	5470	5825	Wi-Fi Low 5 GHz	0.001103	0.001141	0.001075
	Subtotal (Wi-Fi)			0.05347	0.096185	0.033816
			Other	0.001801	0.001783	0.001712
	Total			0.055271	0.097968	0.035528

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P7	2400	2483.5	Wi-Fi 2.4 GHz	0.009528	0.063536	0.005327
	5150	5350	Wi-Fi Low 5 GHz	0.026598	0.025371	0.016514
	5470	5825	Wi-Fi Low 5 GHz	0.001100	0.001053	0.001059
	Subtotal (Wi-Fi)			0.037227	0.089960	0.022900
			Other	0.001800	0.001826	0.001847
	Total			0.039027	0.091786	0.024747
P8	2400	2483.5	Wi-Fi 2.4 GHz	0.001924	0.003287	0.000313
	5150	5350	Wi-Fi Low 5 GHz	0.228547	0.291060	0.156598
	5470	5825	Wi-Fi Low 5 GHz	0.001399	0.001424	0.001430
	Subtotal (Wi-Fi)			0.231870	0.295771	0.158341
			Other	0.002299	0.002359	0.002274
	Total			0.234169	0.298130	0.160615
P9	2400	2483.5	Wi-Fi 2.4 GHz	0.001850	0.000543	0.003111
	5150	5350	Wi-Fi Low 5 GHz	0.140841	0.195879	0.104190
	5470	5825	Wi-Fi Low 5 GHz	0.001409	0.001503	0.001454
	Subtotal (Wi-Fi)			0.144100	0.197925	0.108755
			Other	0.002290	0.002296	0.002262
	Total			0.146390	0.200221	0.111017
P10	2400	2483.5	Wi-Fi 2.4 GHz	0.008325	0.035362	0.000014
	5150	5350	Wi-Fi Low 5 GHz	0.028610	0.032092	0.020040
	5470	5825	Wi-Fi Low 5 GHz	0.001397	0.001381	0.001463
	Subtotal (Wi-Fi)			0.038333	0.068835	0.021517
			Other	0.002308	0.002305	0.002279
	Total			0.040641	0.071140	0.023796
P11	2400	2483.5	Wi-Fi 2.4 GHz	0.033791	0.105839	0.000051
	5150	5350	Wi-Fi Low 5 GHz	0.018507	0.017489	0.013263
	5470	5825	Wi-Fi Low 5 GHz	0.001418	0.001392	0.001401
	Subtotal (Wi-Fi)			0.053716	0.124720	0.014715
			Other	0.002302	0.002286	0.002316
	Total			0.056018	0.127006	0.017031
P12	2400	2483.5	Wi-Fi 2.4 GHz	0.046572	0.186518	0.000825
	5150	5350	Wi-Fi Low 5 GHz	0.016836	0.017990	0.013761
	5470	5825	Wi-Fi Low 5 GHz	0.001421	0.001408	0.001386
	Subtotal (Wi-Fi)			0.064829	0.205916	0.015972
			Other	0.002311	0.002253	0.002317
	Total			0.067140	0.208169	0.018289

^a See Figure 4 for measurement locations.

2b) RF exposure levels from 2.4 to 5.825 GHz at each preselected measurement location with the tri-axis antenna positioned at a height of 1.25 metres

Table E.8 – Percentage of SC6 limits (uncontrolled environment) for Wi-Fi bands at each location with the tri-axis antenna at a height of 1.25 metres

Location ^a	Lower frequency (MHz)	Upper frequency (MHz)	Service name	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
P1	2400	2483.5	Wi-Fi 2.4 GHz	0.003580	0.034979	0.000624
	5150	5350	Wi-Fi Low 5 GHz	0.065602	0.072193	0.047365
	5470	5825	Wi-Fi Low 5 GHz	0.000721	0.000706	0.000696
	Subtotal (Wi-Fi)			0.069903	0.107878	0.048685
			Other	0.001178	0.001196	0.00114
Total				0.071081	0.109074	0.049825
P2	2400	2483.5	Wi-Fi 2.4 GHz	0.003151	0.006556	0.003967
	5150	5350	Wi-Fi Low 5 GHz	0.031888	0.041673	0.020565
	5470	5825	Wi-Fi Low 5 GHz	0.004294	0.004189	0.004254
	Subtotal (Wi-Fi)			0.039333	0.052418	0.028786
			Other	0.006982	0.006899	0.006855
Total				0.046315	0.059317	0.035641
P3	2400	2483.5	Wi-Fi 2.4 GHz	0.004380	0.012621	0.000123
	5150	5350	Wi-Fi Low 5 GHz	0.019723	0.024176	0.015182
	5470	5825	Wi-Fi Low 5 GHz	0.004267	0.004282	0.004252
	Subtotal (Wi-Fi)			0.028370	0.041079	0.019557
			Other	0.006949	0.007020	0.006831
Total				0.035319	0.048099	0.026388
P4	2400	2483.5	Wi-Fi 2.4 GHz	0.022426	0.073809	0.000678
	5150	5350	Wi-Fi Low 5 GHz	0.013593	0.016411	0.010180
	5470	5825	Wi-Fi Low 5 GHz	0.004272	0.004240	0.004136
	Subtotal (Wi-Fi)			0.040291	0.094460	0.014994
			Other	0.006994	0.006972	0.006984
Total				0.047285	0.101432	0.021978
P5	2400	2483.5	Wi-Fi 2.4 GHz	0.220791	0.926314	0.000063
	5150	5350	Wi-Fi Low 5 GHz	0.008580	0.009547	0.007806
	5470	5825	Wi-Fi Low 5 GHz	0.004244	0.004231	0.003970
	Subtotal (Wi-Fi)			0.233614	0.940092	0.011839
			Other	0.006977	0.007067	0.007084
Total				0.240591	0.947159	0.018923

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P6	2400	2483.5	Wi-Fi 2.4 GHz	0.020515	0.081288	0.000368
	5150	5350	Wi-Fi Low 5 GHz	0.015473	0.016321	0.011955
	5470	5825	Wi-Fi Low 5 GHz	0.001438	0.001459	0.001493
	Subtotal			0.037426	0.099068	0.013816
			Other	0.002345	0.002320	0.002359
	Total			0.039771	0.101388	0.016175
P7	2400	2483.5	Wi-Fi 2.4 GHz	0.020169	0.060808	0.003015
	5150	5350	Wi-Fi Low 5 GHz	0.029016	0.036393	0.020209
	5470	5825	Wi-Fi Low 5 GHz	0.001428	0.001300	0.001385
	Subtotal (Wi-Fi)			0.050612	0.098501	0.024609
			Other	0.002333	0.002290	0.002378
	Total			0.052945	0.100791	0.026987
P8	2400	2483.5	Wi-Fi 2.4 GHz	0.003571	0.008332	0.000302
	5150	5350	Wi-Fi Low 5 GHz	0.137439	0.216658	0.089318
	5470	5825	Wi-Fi Low 5 GHz	0.001422	0.001330	0.001387
	Subtotal (Wi-Fi)			0.142432	0.226320	0.091007
			Other	0.002331	0.002385	0.002365
	Total			0.144763	0.228705	0.093372
P9	2400	2483.5	Wi-Fi 2.4 GHz	0.005426	0.018015	0.000891
	5150	5350	Wi-Fi Low 5 GHz	0.053570	0.060559	0.041570
	5470	5825	Wi-Fi Low 5 GHz	0.001413	0.001398	0.001310
	Subtotal (Wi-Fi)			0.060410	0.079882	0.043771
			Other	0.002337	0.002354	0.002342
	Total			0.062747	0.082326	0.046113
P10	2400	2483.5	Wi-Fi 2.4 GHz	0.005442	0.013639	0.000066
	5150	5350	Wi-Fi Low 5 GHz	0.024338	0.037097	0.017275
	5470	5825	Wi-Fi Low 5 GHz	0.001408	0.001464	0.001384
	Subtotal (Wi-Fi)			0.031187	0.052200	0.018725
			Other	0.002326	0.002320	0.002326
	Total			0.033513	0.054520	0.021051
P11	2400	2483.5	Wi-Fi 2.4 GHz	0.011916	0.067794	0.000290
	5150	5350	Wi-Fi Low 5 GHz	0.019791	0.018873	0.016421
	5470	5825	Wi-Fi Low 5 GHz	0.001411	0.001354	0.001354
	Subtotal (Wi-Fi)			0.033118	0.088021	0.018065
			Other	0.002321	0.002308	0.002287
	Total			0.035439	0.090329	0.020352

P12	2400	2483.5	Wi-Fi 2.4 GHz	0.047716	0.213234	0.000014
	5150	5350	Wi-Fi Low 5 GHz	0.015246	0.014393	0.010589
	5470	5825	Wi-Fi Low 5 GHz	0.001415	0.001385	0.001425
	Subtotal (Wi-Fi)			0.064605	0.229012	0.012028
			Other	0.002315	0.002315	0.002271
Total				0.066692	0.231327	0.014299

^a See Figure 4 for measurement locations.

3b) Spatial- and time-averaged RF exposure levels from 2.4 to 5.825 GHz at the location with the highest levels found from 1b and 2b

Table E.9 – Spatial- and time-averaged percentage of SC6 limits (uncontrolled environment) from 2400 to 5825 MHz at location P5

	Total width (0.35 m)		
Height (0.5 m to 1.75 m)	Time Avg for 6 min: 0.105392%	Time Avg for 6 min: 0.133299%	Time Avg for 6 min: 0.141245%
	Time Avg for 6 min: 0.053149%	Time Avg for 6 min: 0.154457%	Time Avg for 6 min: 0.141279%
	Time Avg for 6 min: 0.047408%	Time Avg for 6 min: 0.056150%	Time Avg for 6 min: 0.061859%

Time and spatial averaging of the nine-point matrix (% SC6 limits): 0.099360%

4b) RF exposure levels for eight laptops connected to AP2 in uploading mode at a preselected measurement location with the tri-axis antenna positioned at a height of 1.25 metres

Table E.10 – Percentage of SC6 limits (uncontrolled environment) for Wi-Fi bands with eight laptops in uploading mode

Location	Lower frequency (MHz)	Upper frequency (MHz)	Service name	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
50 cm from P7	2400	2483.5	Wi-Fi 2.4 GHz	0.006360	0.031755	0.001070
	5150	5350	Wi-Fi Low 5 GHz	0.056737	0.057610	0.043178
	5470	5825	Wi-Fi Low 5 GHz	0.002684	0.002508	0.002765
	Subtotal (Wi-Fi)			0.065780	0.091873	0.047013
			Other	0.004424	0.004413	0.004427
Total				0.070204	0.096286	0.051440

- 5b) RF exposure levels for eight laptops connected to AP2 in uploading mode and 16 laptops in downloading mode at a preselected measurement location with the tri-axis antenna positioned at a height of 1.25 metres

Table E.11 – Percentage of SC6 limits (uncontrolled environment) for Wi-Fi bands with eight laptops uploading and 16 laptops downloading

Location	Lower frequency (MHz)	Upper frequency (MHz)	Service name	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
50 cm from P7	2400	2483.5	Wi-Fi 2.4 GHz	0.004548	0.045900	0.003339
	5150	5350	Wi-Fi Low 5 GHz	0.051387	0.049386	0.032502
	5470	5825	Wi-Fi Low 5 GHz	0.000672	0.000676	0.000666
	Subtotal (Wi-Fi)			0.056607	0.095962	0.036507
			Other	0.001104	0.001094	0.001113
	Total			0.057711	0.097056	0.037620

- 6b) RF exposure levels for one laptop connected to AP2 in uploading mode at a preselected measurement location with the tri-axis antenna positioned at a height of 1.25 metres

Table E.12 – Percentage of SC6 limits (uncontrolled environment) for Wi-Fi bands with one laptop uploading

Location	Lower frequency (MHz)	Upper frequency (MHz)	Service name	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
50 cm from P7	2400	2483.5	Wi-Fi 2.4 GHz	0.003791	0.008447	0.001496
	5150	5350	Wi-Fi Low 5 GHz	0.052724	0.064955	0.036069
	5470	5825	Wi-Fi Low 5 GHz	0.000603	0.000625	0.000596
	Subtotal (Wi-Fi)			0.057118	0.074027	0.038161
			Other	0.000990	0.000985	0.000974
	Total			0.058108	0.075012	0.039135

- 7b) RF exposure levels for one laptop connected to AP2 in downloading mode at a preselected measurement location with the tri-axis antenna positioned at a height of 1.25 metres

Table E.13 – Percentage of SC6 limits (uncontrolled environment) for Wi-Fi bands with one laptop downloading

Location	Lower frequency (MHz)	Upper frequency (MHz)	Service name	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
50 cm from P7	2400	2483.5	Wi-Fi 2.4 GHz	0.007008	0.023605	0.003691
	5150	5350	Wi-Fi Low 5 GHz	0.068841	0.090550	0.039203
	5470	5825	Wi-Fi Low 5 GHz	0.000413	0.000399	0.000396
	Subtotal (Wi-Fi)			0.076263	0.114554	0.043290
			Other	0.000670	0.000673	0.000668
Total			0.076933	0.115227	0.043958	

- 8b) RF exposure levels from 5150 to 5350 MHz with the tri-axis antenna positioned at 20 cm from AP1

Table E.14 – Percentage of SC6 limits (uncontrolled environment) at 20 cm from Wi-Fi AP1 antenna

Location	Lower frequency (MHz)	Upper frequency (MHz)	Service name	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
20 cm from AP1	5150	5350	Wi-Fi Low 5 GHz	6.679538	10.585600	4.221111

- 9b) RF exposure levels from 2400 to 2483.5 MHz with the tri-axis antenna positioned at 20 cm from AP2

Table E.15 – Percentage of SC6 limits (uncontrolled environment) at 20 cm from Wi-Fi AP2

Location	Lower frequency (MHz)	Upper frequency (MHz)	Service name	Average (% SC6 limits)	Maximum (% SC6 limits)	Minimum (% SC6 limits)
20 cm from AP2	2400	2483.5	Wi-Fi 2.4 GHz	1.824045	7.733128	0.000897

References

- (1) Industry Canada, GL-01, *Guidelines for the Measurement of Radio Frequency Fields at Frequencies from 3 kHz to 300 GHz*
- (2) Industry Canada, GL-08, *Guidelines for the Preparation of Radio Frequency (RF) Exposure Compliance Reports for Radiocommunication and Broadcasting Antenna Systems*
- (3) Industry Canada, RSS-102 *Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands)*
- (4) Industry Canada, RSS-210 *Low-power Licence-exempt Radiocommunication Devices (All Frequency Bands): Category I Equipment*
- (5) Industry Canada, TN-329 *Safety Code 6 (SC6) Measurement Procedures (Uncontrolled Environment)*
- (6) Health Canada, *Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz – Safety Code 6 (2009)*
- (7) Health Canada, *Technical Guide for the Interpretation and Compliance Assessment of Health Canada's Radiofrequency Exposure Guidelines*