8. RF EXPOSURE

8.1. RULES AND LIMITS

FCC RULES

§1.1310 The criteria listed in Table 1 shall be used to evaluate the environmental impact of human exposure to radio-frequency (RF) radiation as specified in §1.1307(b), except in the case of portable devices which shall be evaluated according to the provisions of §2.1093 of this chapter.

TABLE 1—LIMITS FOR MAXIMUM PERMISSIBLE EXPOSURE (MPE)

Frequency range (MHz)	Electric field strength (V/m)	Magnetic field strength (A/m)	Power density (mW/cm^2)	Averaging time (minutes)
(A) Limits for Occupational/Controlled Exposures				
0.3–3.0	614	1.63	*(100)	6
3.0–30	1842/f	4.89/f	*(900/f^2)	6
30–300	61.4	0.163	1.0	6
300–1500			f/300	6
1500–100,000			5	6
(B) Limits for General Population/Uncontrolled Exposure				
0.3–1.34	614	1.63	*(100)	30
1.34–30	824/f	2.19/f	*(180/f^2)	30

TABLE 1—LIMITS FOR MAXIMUM PERMISSIBLE EXPOSURE (MPE)—Continued

Frequency range (MHz)	Electric field strength (V/m)	Magnetic field strength (A/m)	Power density (mW/cm^2)	Averaging time (minutes)
30–300	27.5	0.073	0.2	30
300–1500			f/1500	30
1500–100,000			1.0	30

f = frequency in MHz
* = Plane-wave equivalent power density

NOTE 1 TO TABLE 1: Occupational/controlled limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Limits for occupational/controlled exposure also apply in situations when an individual is transient through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure.

NOTE 2 TO TABLE 1: General population/uncontrolled exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or can not exercise control over their exposure.

IC RULES

IC Safety Code 6, Section 2.2.1 (a) A person other than an RF and microwave exposed worker shall not be exposed to electromagnetic radiation in a frequency band listed in Column 1 of Table 5, if the field strength exceeds the value given in Column 2 or 3 of Table 5, when averaged spatially and over time, or if the power density exceeds the value given in Column 4 of Table 5, when averaged spatially and over time.

Table 5
Exposure Limits for Persons Not Classed As RF and Microwave Exposed Workers (Including the General Public)

1 Frequency (MHz)	2 Electric Field Strength; rms (V/m)	3 Magnetic Field Strength; rms (A/m)	4 Power Density (W/m^2)	5 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*	6
300–1 500	$1.585f^{0.5}$	$0.0042f^{0.5}$	$f/150$	6
1 500–15 000	61.4	0.163	10	6
15 000–150 000	61.4	0.163	10	$616\,000/f^{1.2}$
150 000–300 000	$0.158f^{0.5}$	$4.21 \times 10^{-4}f^{0.5}$	$6.67 \times 10^{-5}f$	$616\,000/f^{1.2}$

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

Notes: 1. Frequency, f, is in MHz.
2. A power density of 10 W/m^2 is equivalent to 1 mW/cm^2.
3. A magnetic field strength of 1 A/m corresponds to 1.257 microtesla (μT) or 12.57 milligauss (mG).

8.2. INTRODUCTORY INFORMATION

8.2.1. OPERATING MODES

The setup phase (LRP) and normal operation (MRP/HRP) do not occur simultaneously; therefore it is appropriate to consider the RF exposure during these two operating modes independently.

8.2.2. LAPTOP CONFIGURATIONS

The EUT may be installed in one of three laptop configurations. The EUT is installed in the display section of the laptop, with the bottom of the transmitting antenna located one of three distances from the base of the laptop.

Configuration	Distance from bottom of TX antenna to base of laptop
#1	3.9 cm
#2	4.5 cm
#3	4.9 cm

8.2.3. SMALL APERTURE PROBE

The required measurements at a distance no closer than 5 cm were made using a small aperture rectangular waveguide probe antenna as specified in IEEE C95.3.

The measurement probe consists of an 8-inch long straight section of WR-15 rectangular waveguide. One end of this waveguide is equipped with a standard UG-385/U flange. The other end of this waveguide is open. The inside dimensions of the WR-15 are 0.00376 by 0.00188 m.

The probe gain was measured using two probes spaced at a 5 cm distance, and the Friis equation assuming the gain of the two probes is identical.

(Friis equation)

$$G^2 = G_R G_T = \frac{P_R}{P_T}\left(\frac{4\pi D}{\lambda}\right)^2$$

where

G = G_R = G_T = Gain of small aperture probe antennas
P_T = Power Transmitted
P_R = Power Received
D = Measurement distance
λ = wavelength

8.3. SETUP PHASE (LRP) EVALUATION

8.3.1. SETUP PHASE (LRP) PROCEDURE

The maximum power of the Setup Phase (LRP) emission is measured on-axis at a 5 cm distance using the small aperture waveguide probe antenna.

The RF Exposure calculations for LRP assume that the off-axis power density in all possible beam orientations is equal to the maximum on-axis power density, and the separation distance is the height of the lowest TX antenna element.

The probe antenna is connected to a spectrum analyzer via a downconverter. The spectrum analyzer is set to measure channel power using peak detection with the Max Hold mode activated, to capture the maximum peak emission level as the LRP beam is scanned over the normal range of beam orientations. The source-based duty cycle is applied to this peak measurement to yield the maximum average emission level.

The power density is calculated using the Friis equation and OET 65 Equation 18:

(Friis equation)

$$(P_T G_T)_{eff} = \frac{P_R}{G_R}\left(\frac{4\pi D}{\lambda}\right)^2$$

where

$(P_T G_T)$eff = effective radiated power at measurement distance
P_R = Power Received
G_R = Gain of small aperture Receive probe antenna
D = Measurement distance
λ = wavelength

(OET 65 Equation 18)

$$S = (P_T G_T)_{eff} / (4\pi D^2)$$

where

S = Power Density
$(P_T G_T)$eff = effective radiated power at measurement distance
D = Separation Distance

8.3.2. SETUP PHASE (LRP) DUTY CYCLE

The Worst-case Source-based Duty Cycle = 100 * (0.3 ms / 20 ms) = 1.5%.

The Worst-case Source-based Duty Cycle Factor = 10 * Log (0.3 ms / 20 ms) = -18.2 dB.

The Worst-case Source-based Duty Cycle Factor is applied to all peak measured values of the LRP transmission to derive average measured LRP values.

8.3.3. SETUP PHASE (LRP) RESULTS

For reference the Average Far Field EIRP is included in the table below and denoted as Far Field EIRP.

Average Far Field EIRP = Peak Far Field EIRP + Worst-case Source-based Duty Dycle Factor.

Where Peak Far Field EIRP is based on RF Regulatory measurements of the LRP transmission.

Far Field EIRP = Average Far Field EIRP = 33.2 dBm – 21.8 dB = 15 dBm.

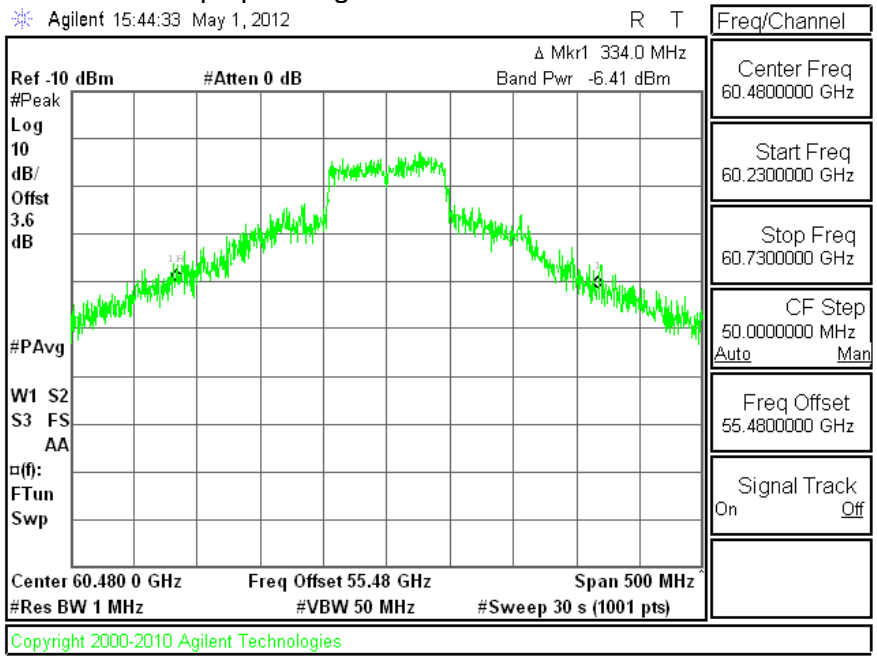
All other measurements in table below are based on small aperture probe measurements.

LRP POWER DENSITY

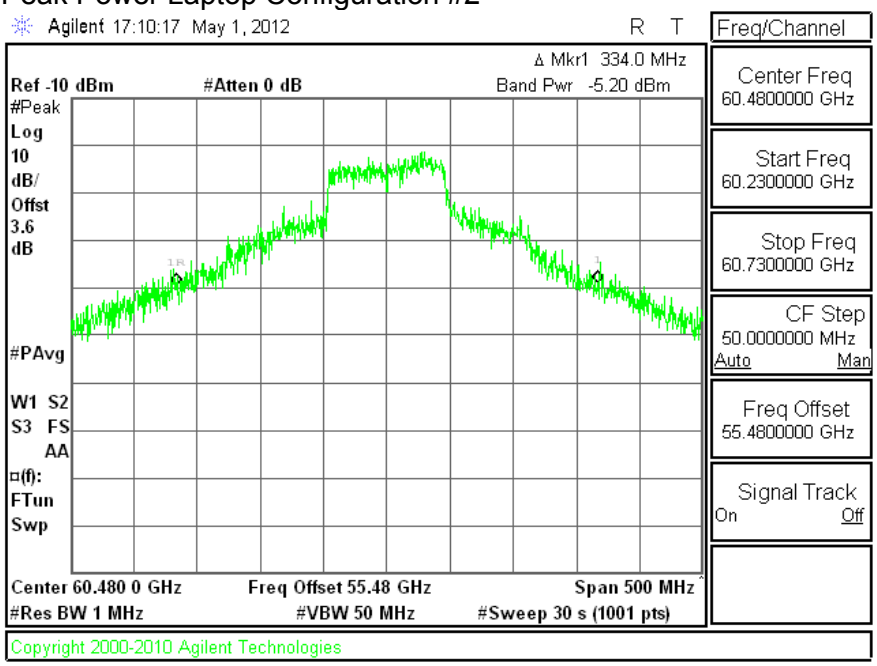
Freq	Far Field EIRP	Meas Dist	Meas Peak Power	Duty Cycle Factor	Probe Gain	Average (Pt*Gt)	Average (Pt*Gt)	Separation Distance	Power Density	FCC Pwr Density Limit
(GHz)	(dBm)	(cm)	(dBm)	(dB)	(dBi)	(dBm)	(mw)	(cm)	(mW/cm^2)	(mW/cm^2)
Worst-case LRP Channel for Laptop Configuration #1										
60.480	15.0	5.0	-6.41	-18.20	6.53	10.9	12.3	3.9	0.0645	1.0
Worst-case LRP Channel for Laptop Configuration #2										
60.480	15.0	5.0	-5.20	-18.20	6.53	12.1	16.3	4.5	0.0640	1.0
Worst-case LRP Channel for Laptop Configuration #3										
60.639	15.0	5.0	-8.21	-18.20	6.53	9.1	8.2	4.9	0.0272	1.0

8.3.4. PEAK ON-AXIS LRP POWER

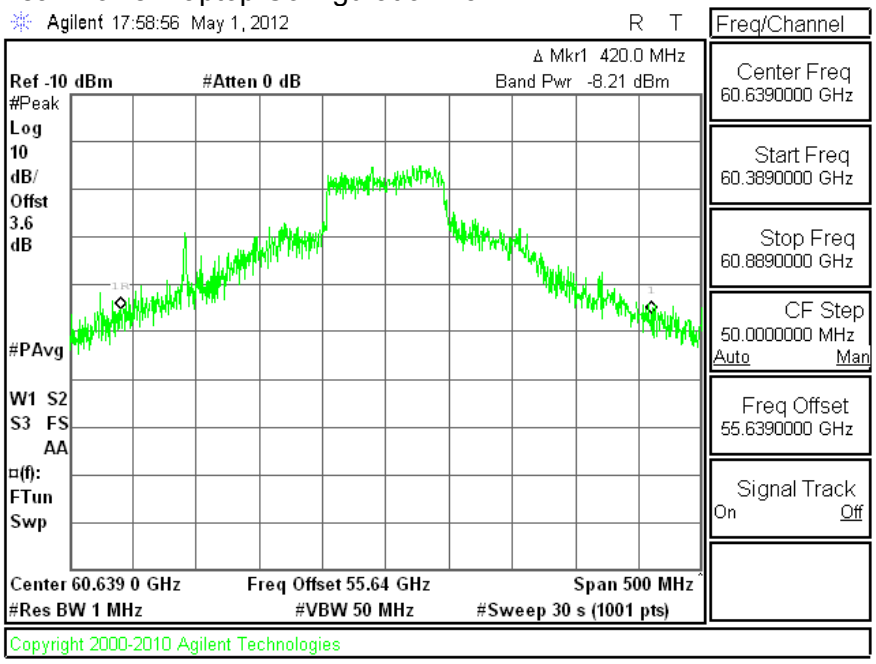
Peak Power Laptop Configuration #1



Peak Power Laptop Configuration #2



Peak Power Laptop Configuration #3



8.4. NORMAL OPERATION (MRP/HRP) EVALUATION

8.4.1. NORMAL OPERATION (MRP/HRP) PROCEDURE

The worst-case average power of the Normal Operation Phase (MRPHRP) emission is measured directly using the small aperture waveguide probe antenna.

The probe antenna is connected to an average power sensor. Since the transmitting antenna beam is locked during the measurement and the sensor responds across ON and OFF times of the EUT, the inherent source-based duty cycle is included in the measurement and no duty cycle factor is applied to subsequent calculations.

The measurement is made with the EUT TX beam angle oriented in the worst-case direction, with the measurement probe bore-sighted to this beam, and with the aperture of the probe in the plane of the base of the host laptop. The measurement distance is equal to the separation distance corresponding to the location of this worst-case power density.

The power density is calculated using the Friis equation and OET 65 Equation 18:

(Friis equation)

$$(P_T G_T)_{eff} = \frac{P_R}{G_R}\left(\frac{4\pi D}{\lambda}\right)^2$$

Where

$(P_T G_T)$eff = effective radiated power at measurement distance
P_R = Power Received
G_R = Gain of small aperture Receive probe antenna
D = Measurement distance
λ = wavelength

(OET 65 Equation 18)

$$S = (P_T G_T)_{eff} / (4\pi D^2)$$

Where

S = Power Density
$(P_T G_T)$eff = effective radiated power at measurement distance
D = Separation Distance

8.4.2. NORMAL OPERATION (MRP/HRP) RESULTS

For reference the Average Far Field EIRP is included in the table below and denoted as Far Field EIRP. The Average Far Field EIRP is based on RF Regulatory measurements of the MRP and HRP emissions.

All other measurements in table below are based on small aperture probe measurements.

Freq	Far Field EIRP	Meas Dist	Meas Avg Power	Probe Gain	Boresight (Pt*Gt)	Boresight (Pt*Gt)	Separation Distance	Power Density	FCC Pwr Density Limit
(GHz)	(dBm)	(cm)	(dBm)	(dBi)	(dBm)	(mw)	(cm)	(mW/cm^2)	(mW/cm^2)
MRP for Laptop Configuration #1									
60.480	28.6	5.5	-13.70	6.53	22.6	184.0	5.5	0.4842	1.0
62.640	27.7	5.5	-12.99	6.49	23.7	234.5	5.5	0.6173	1.0
HRP for Laptop Configuration #1									
60.480	26.1	5.5	-14.50	6.53	21.8	153.0	5.5	0.4027	1.0
62.640	25.0	5.5	-15.21	6.49	21.5	140.7	5.5	0.3702	1.0
MRP for Laptop Configuration #2									
60.480	28.6	6.4	-14.84	6.53	22.8	191.6	6.4	0.3724	1.0
62.640	27.7	6.4	-15.03	6.49	23.0	198.5	6.4	0.3859	1.0
HRP for Laptop Configuration #2									
60.480	26.1	6.4	-15.31	6.53	22.4	171.9	6.4	0.3342	1.0
62.640	25.0	6.4	-16.22	6.49	21.8	150.9	6.4	0.2934	1.0
MRP for Laptop Configuration #3									
60.480	28.6	6.9	-16.79	6.53	21.5	142.1	6.9	0.2377	1.0
62.640	27.7	6.9	-18.22	6.49	20.4	110.7	6.9	0.1851	1.0
HRP for Laptop Configuration #3									
60.480	26.1	6.9	-17.95	6.53	20.4	108.8	6.9	0.1820	1.0
62.640	25.0	6.9	-19.55	6.49	19.1	81.5	6.9	0.1363	1.0

8.5. RESULTS BASED ON WORST-CASE POWER SCALING

8.5.1. POWER SCALING

The HRP mode is the reference mode for device output power.
The output power of the LRP mode and the MRP mode tracks the output power of the HRP mode.
The maximum output power is limited by the maximum specified tolerance limit for HRP power.

Therefore the maximum upward scaling of the output power in all transmitting modes (LRP, HRP and MRP) is determined by the difference between the maximum HRP tolerance limit and the highest measured HRP EIRP on the sample tested. These parameters are average values.

The maximum HRP tolerance limit is 28 dBm EIRP.
The highest measured Average HRP EIRP on the sample tested was 26.1 dBm.
The maximum upward power scaling for the sample tested is 28 dBm EIRP – 26.1 dBm EIRP = 1.9 dB.

8.5.2. SETUP PHASE (LRP) RESULTS WITH POWER SCALING

The Far Field EIRP of the LRP mode is scaled upward by 1.9 dB.
All other measurements in table below are based on small aperture probe measurements, scaled upward by 1.9 dB.

LRP POWER DENSITY SCALED UPWARD BY 1.9 dB

Freq	Scaled Far-field EIRP	Meas Dist	Scaled Peak Power	Duty Cycle Factor	Probe Gain	Average (Pt*Gt)	Average (Pt*Gt)	Separation Distance	Power Density	FCC Pwr Density Limit
(GHz)	(dBm)	(cm)	(dBm)	(dB)	(dBi)	(dBm)	(mw)	(cm)	(mW/cm^2)	(mW/cm^2)
Worst-case LRP Channel for Laptop Configuration #1										
60.480	16.9	5.0	-4.51	-18.20	6.53	12.8	19.1	3.9	0.1000	1.0
Worst-case LRP Channel for Laptop Configuration #2										
60.480	16.9	5.0	-3.30	-18.20	6.53	14.0	25.2	4.5	0.0992	1.0
Worst-case LRP Channel for Laptop Configuration #3										
60.639	16.9	5.0	-6.28	-18.20	6.53	11.1	12.8	4.9	0.0423	1.0

8.5.3. NORMAL OPERATION (MRP/HRP) RESULTS WITH POWER SCALING

The Far Field EIRP of each of the HRP and MRP modes is scaled upward by 1.9 dB.

All other measurements in table below are based on small aperture probe measurements, scaled up by 1.9 dB.

Freq	Scaled Far-field EIRP	Meas Dist	Scaled Avg Power	Probe Gain	Boresight (Pt*Gt)	Boresight (Pt*Gt)	Separation Distance	Power Density	FCC Pwr Density Limit
(GHz)	(dBm)	(cm)	(dBm)	(dBi)	(dBm)	(mw)	(cm)	(mW/cm^2)	(mW/cm^2)
MRP for Laptop Configuration #1									
60.480	30.5	5.5	-11.80	6.53	24.5	284.9	5.5	0.7499	1.0
62.640	29.6	5.5	-11.09	6.49	25.6	363.2	5.5	0.9560	1.0
HRP for Laptop Configuration #1									
60.480	28.0	5.5	-12.60	6.53	23.7	237.0	5.5	0.6237	1.0
62.640	26.9	5.5	-13.31	6.49	23.4	217.9	5.5	0.5734	1.0
MRP for Laptop Configuration #2									
60.480	30.5	6.4	-12.94	6.53	24.7	296.7	6.4	0.5768	1.0
62.640	29.6	6.4	-13.13	6.49	24.9	307.5	6.4	0.5977	1.0
HRP for Laptop Configuration #2									
60.480	28.0	6.4	-13.41	6.53	24.3	266.3	6.4	0.5176	1.0
62.640	26.9	6.4	-14.32	6.49	23.7	233.8	6.4	0.4544	1.0
MRP for Laptop Configuration #3									
60.480	30.5	6.9	-14.89	6.53	23.4	220.1	6.9	0.3681	1.0
62.640	29.6	6.9	-16.32	6.49	22.3	171.5	6.9	0.2867	1.0
HRP for Laptop Configuration #3									
60.480	28.0	6.9	-16.05	6.53	22.3	168.5	6.9	0.2818	1.0
62.640	26.9	6.9	-17.65	6.49	21.0	126.2	6.9	0.2111	1.0