8. MAXIMUM PERMISSIBLE EXPOSURE

8.1. RULES

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/cm²)	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/f²)	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/f²)	30
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. EQUATIONS FROM OET BULLETIN 65

NEAR-FIELD BOUNDARY

For the high-gain aperature antenna used with the EUT the extent of the near-field can be described by the following equation (D and λ in same units):

(OET 65 equation 12) $Rnf = (D^2) / (4 * \lambda)$

where

Rnf = extent of near-field
D = maximum dimension of antenna (diameter if circular)
λ = wavelength

MAXIMUM NEAR-FIELD POWER DENSITY

The magnitude of the on-axis (main beam) power density varies according to location in the near-field. However, the maximum value of the near-field, on-axis, power density can be expressed by the following equation:

(OET 65 equation 13) $Snf = (16 * \eta * P) / (\pi * D^2)$

where

Snf = maximum near-field power density
η = aperture efficiency
P = power fed to the antenna
D = antenna diameter

The antenna for the EUT is rectangular rather than circular. Substituting the formula for the area of a retangle in place of the area of a circle yields:

(modified equation 13) $Snf = (4 * \eta * P) / (L * W)$

where

Snf = maximum near-field power density
η = aperture efficiency
P = power fed to the antenna
L = antenna length
W = antenna width

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APERTURE EFFICIENCY

Aperture efficiency can be estimated, or a reasonable approximation for circular apertures can be obtained from the ratio of the effective aperture area to the physical area as follows:

(OET 65 equation 14) $\eta = ((G * \lambda^2) / (4 * \pi)) / ((\pi * D^2) / 4)$

where

η = aperture efficiency for circular apertures
G = power gain in the direction of interest relative to an isotropic radiator
λ = wavelength
D = antenna diameter

Substituting the formula for the area of a retangle in place of the area of a circle yields:

(modified equation 14) $\eta = ((G * \lambda^2) / (4 * \pi)) / (L * W)$

η = aperture efficiency for rectangular apertures
G = power gain in the direction of interest relative to an isotropic radiator
λ = wavelength
L = antenna length
W = antenna width

FAR-FIELD BOUNDARY

For purposes of evaluating RF exposure, the distance to the beginning of the far-field region (farthest extent of the transition region) can be approximated by the following equation:

(OET 65 equation 16) $Rff = (0.6 * (D^2)) / \lambda$

where

Rff = extent of near-field
D = antenna diameter
λ = wavelength

TRANSITION REGION

Power density in the transition region decreases inversely with distance from the antenna, while power density in the far-field (Fraunhofer region) of the antenna decreases inversely with the square of the distance.

The transition region will then be the region extending from Rnf, calculated from Equation (12), to Rff. If the location of interest falls within this transition region, the on axis power density can be determined from the following equation:

(OET 65 equation 17) St = Snf * Rnf / R

where

St = power density in the transition region
Snf = maximum power density for near-field calculated above
Rnf = extent of near-field calculated aboveS
R = distance to point of interest

FAR-FIELD REGION

The power density in the far-field or Fraunhofer region of the antenna pattern decreases inversely as the square of the distance. The power density in the far-field region of the radiation pattern can be estimated by the general equation discussed earlier:

(OET 65 equation 18) Sff = P * G / (4 * π * (R^2))

where

Sff = power density (on axis)
P = power fed to the antenna
G = power gain of the antenna in the direction of interest relative to an isotropic radiator
R = distance to the point of interest

8.3. CALCULATIONS

ANTENNA SPECIFICATIONS

The transmitting antenna specifications are as follows:
length = 0.07 m
width = 0.02 m
maximum dimension = .073 m
gain = 25 dBi

NEAR-FIELD BOUNDARY

Frequency (GHz)	Lambda (m)	Maximum Antenna Dimension (m)	Near-field Boundary (m)	Near-field Boundary (cm)
76.5	0.003922	0.073	0.34	34

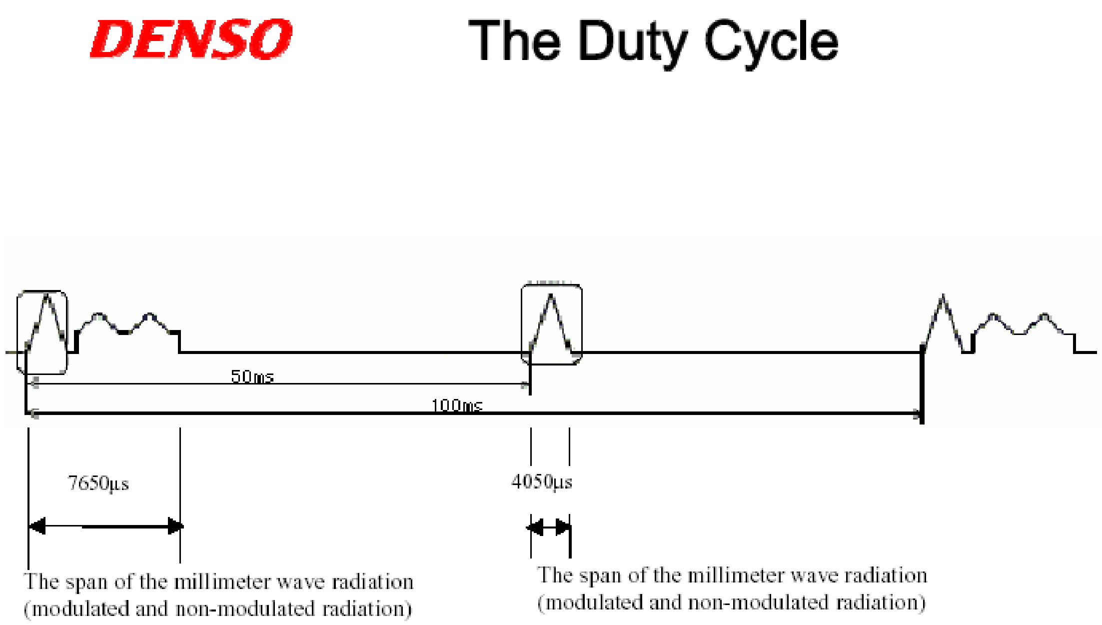
FAR-FIELD BOUNDARY

Frequency (GHz)	Lambda (m)	Maximum Antenna Dimension (m)	Far-field Boundary (m)	Far-field Boundary (cm)
76.5	0.003922	0.073	0.82	82

APERTURE EFFICIENCY

Frequency (GHz)	Gain (dBi)	Gain (numeric)	Lambda (m)	Antenna Length (m)	Antenna Width (m)	Aperture Efficiency (η)
76.5	25	316	0.003922	0.070	0.020	0.277

DUTY CYCLE



The total ON time is 11.7 msec within a 100 msec period. This yields a duty cycle of 11.7% and a correction factor of -9.32 dB.

POWER FED TO THE ANTENNA

Field Strength at 3 meters (dBuV/m)	F.S. to EIRP Conversion Factor	Peak EIRP (dBm)	Duty Cycle Factor (dB)	Average EIRP (dBm)
134	-95.2	38.8	-9.32	29.5

Antenna Gain (dBi)	Power Fed To Antenna (dBm)	Power Fed To Antenna (W)
25.00	4.5	0.002805

8.4. MAXIMUM POWER DENSITY AT A DISTANCE OF 20 cm

MAXIMUM NEAR-FIELD POWER DENSITY

The minimum allowable declared MPE distance for mobile devices is 20 cm, which is within the 34 cm boundary of the near-field Fresnel region of the antenna. Therefore the near-field power density is applicable to a separation distance of 20 cm.

MPE Distance (cm)	Aperture Efficiency (η)	Output Power (W)	Antenna Diameter (m)	FCC Power Density (mW/cm^2)	IC Power Density (W/m^2)
20.0	0.277	0.002805	0.073	0.074	0.743

From §1.1310 Table 1 (B), S = 1.0 mW/cm^2

From IC Safety Code 6, Section 2.2 Table 5 Column 4, S = 10 W/m^2

These calculations indicate that the power density at 20 cm is less than the applicable limits.

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8.5. VALIDATION OF APPLICABILITY OF OET 65 EQUATIONS

The OET 65 equations cited above are based on parabolic aperture antennas with circular cross sections. The EUT antenna is a slotted waveguide array with a rectangular shape.

The modifications to the original equations to accomodate the actual antenna shape, as well as the applicability of the equations to the actual antenna design, can be validated by extrapolating the near-field power density through the transition region to the far-field boundary. This extrapolated value is compared to the direct calculation of the far-field power density at the far-field boundary.

EXTRAPOLATION OF NEAR-FIELD POWER DENSITY TO THE FAR-FIELD BOUNDARY

For the particular value of R = Rff, combining equations 12, 16 and 17 yields:

Sffboundary / Snf = Rnf / Rff = ((D^2) / (4 * λ)) / ((0.6 * (D^2)) / λ) = 1 / 2.4 = 0.417

Near-field Power Density (W/m^2)	Extrapolation Factor (linear)	Power Density at Far-field Boundary	
		FCC (mW/cm^2)	IC (W/m^2)
0.743	0.417	0.031	0.310

DIRECT CALCULATION OF POWER DENSITY AT THE FAR-FIELD BOUNDARY

Far-field Boundary (cm)	Output Power (dBm)	Antenna Gain (dBi)	Power Density at Far-field Boundary	
			FCC (mW/cm^2)	IC (W/m^2)
82.0	4.5	25.0	0.011	0.106

RESULTS

The extrapolated value of the near-field power density is greater than the direct calculation, therefore the near-field calculations provide a worst-case, upper bound of the actual maximum power density.