“Assessing RF Levels for Compliance with FCC Human Exposure Standards”

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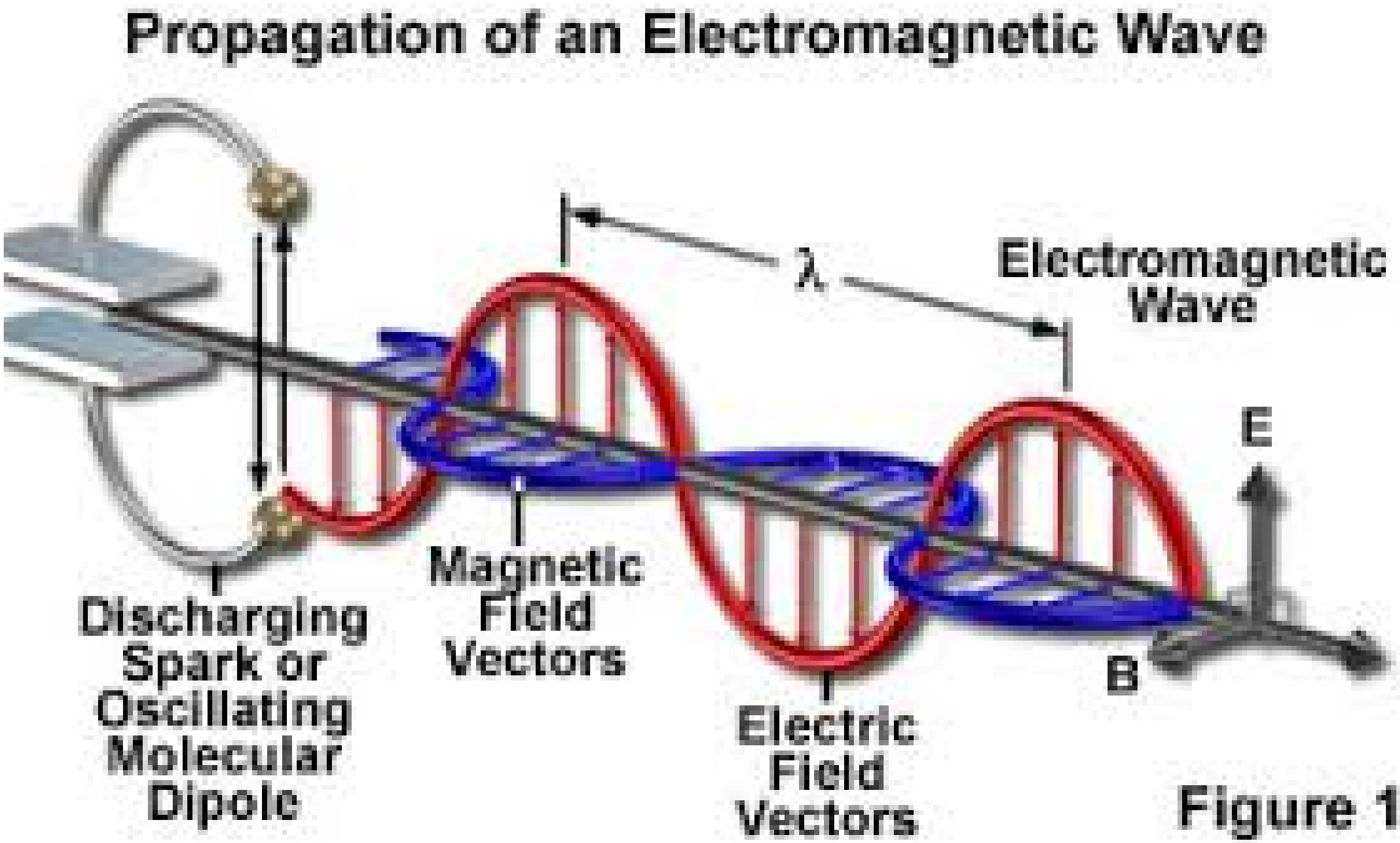
What we'll cover…

- A little bit of EMF wave theory
- FCC Maximum Permitted Exposure Standards (MPE) and Underlying Data
- Methods for calculating RF Exposure Levels for FM Transmitting Stations
- Measuring RF Exposure Levels with an RF Survey Meter
- Various ways to protect oneself from excessive RF Radiation



Source: Spring, Kenneth R.; Inoué, Shinya; Flynn, Brian O.; Sutter, Robert T.; Davidson, Michael W., "Electromagnetic Wave Propagation", May 19, 2016, Florida State University, Molecular Expressions Microscopy, https://micro.magnet.fsu.edu/primer/java/polarizedlight/emwave/, accessed February 14, 2018.

An electric current through a conductor that changes polarity over repeating cycles creates a composite wave of electric and magnetic fields.

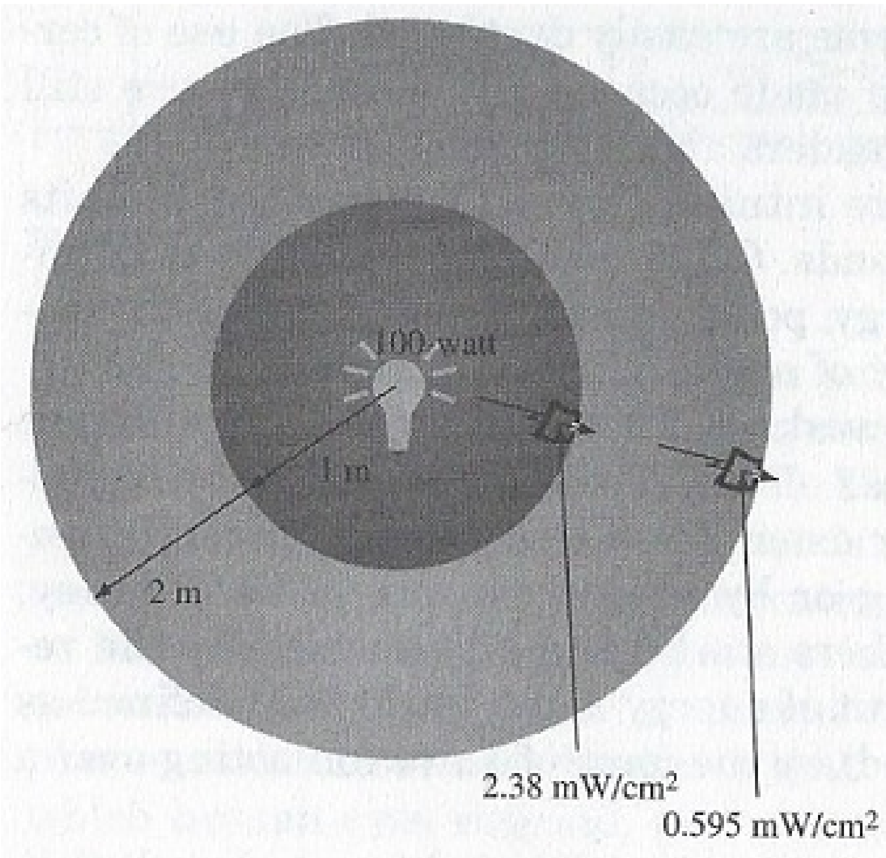
Electric field (E) expressed in volts per meter (V/m)
Magnetic field (H) expressed in amps per meter (A/m)

In free space: $E = H \times 377$
(in the far-field only, >10λ or 10 x antenna height)

Similar to Ohm's Law: $E = I \times R$

In the near-field, the relationship between E and H is complex, thus the above simple formula can't be used in this region.

Power Density (S)



Source: Hammett, William F., *Radio Frequency Radiation: Issues & Standards,* McGraw-Hill, 1997.

Emitted power from an isotropic source in free space is distributed evenly over the surface area of a sphere of a given radial distance.

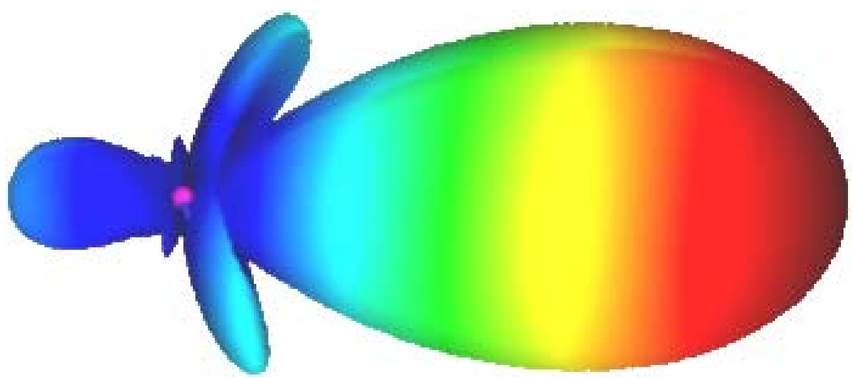
$S = P/(4\pi R^2)$

S = power density in mW/cm^2

P = Input Power in mW

R = distance from radiation center of source in cm

Power Density due to Antenna with Gain (Directionality)



$$S = (P \times G)/(4\pi R^2)$$

$$\text{or } S = EIRP/(4\pi R^2)$$

G = Power Gain in the direction of interest relative to an isotropic radiator

EIRP = Effective Isotropic Radiated Power

Power Density S can also be calculated in terms of Electric Field Strength or Magnetic Field Strength.

$$S = E^2/3770 = 37.7H^2$$

where: S = Power Density in mW/cm^2

E^2 = Electric Field Strength squared (V^2/m^2)

H^2 = Magnetic Field Strength squared (A^2/m^2)

Again, similar to Ohm's Law:

$$P = V^2/R = R \times I^2$$

Establishment of an Exposure Threshold

Based on animal experiments involving RF exposure, the NCRP in 1986 recommended a threshold Specific Absorption Rate* (SAR) of 4 W/kg for human exposure, a level at which behavioral impairment was found in primates.

*Specific Absorption Rate is the rate of energy absorbed by a unit of mass of biological tissue.

Adoption of NCRP-86 & ANSI/IEEE C95.1-1992 as Standards for RF Exposure

- Established a two-tier set of standards: "Controlled" or Occupational Exposure and "Uncontrolled" or Public Exposure.
- Standards for "Controlled" and "Uncontrolled" Exposure based on <u>whole-body exposure</u>.
- Safety factors applied to 4 W/kg SAR threshold.
  - "Controlled": 4 W/kg ---10x---> 0.4 W/kg
  - "Uncontrolled: 4 W/kg ---50x---> 0.08 W/kg
- Standard for <u>localized exposure</u> to public derived by scaling up by a factor of 20 to 1.6 W/kg (This is the standard for cell phones.)
- In August 1996 the FCC issued a ruling that all stations not categorically excluded from exposure evaluation must comply with the new standards.

Table 1. LIMITS FOR MAXIMUM PERMISSIBLE EXPOSURE (MPE)

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
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

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	$(180/f^2)$*	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

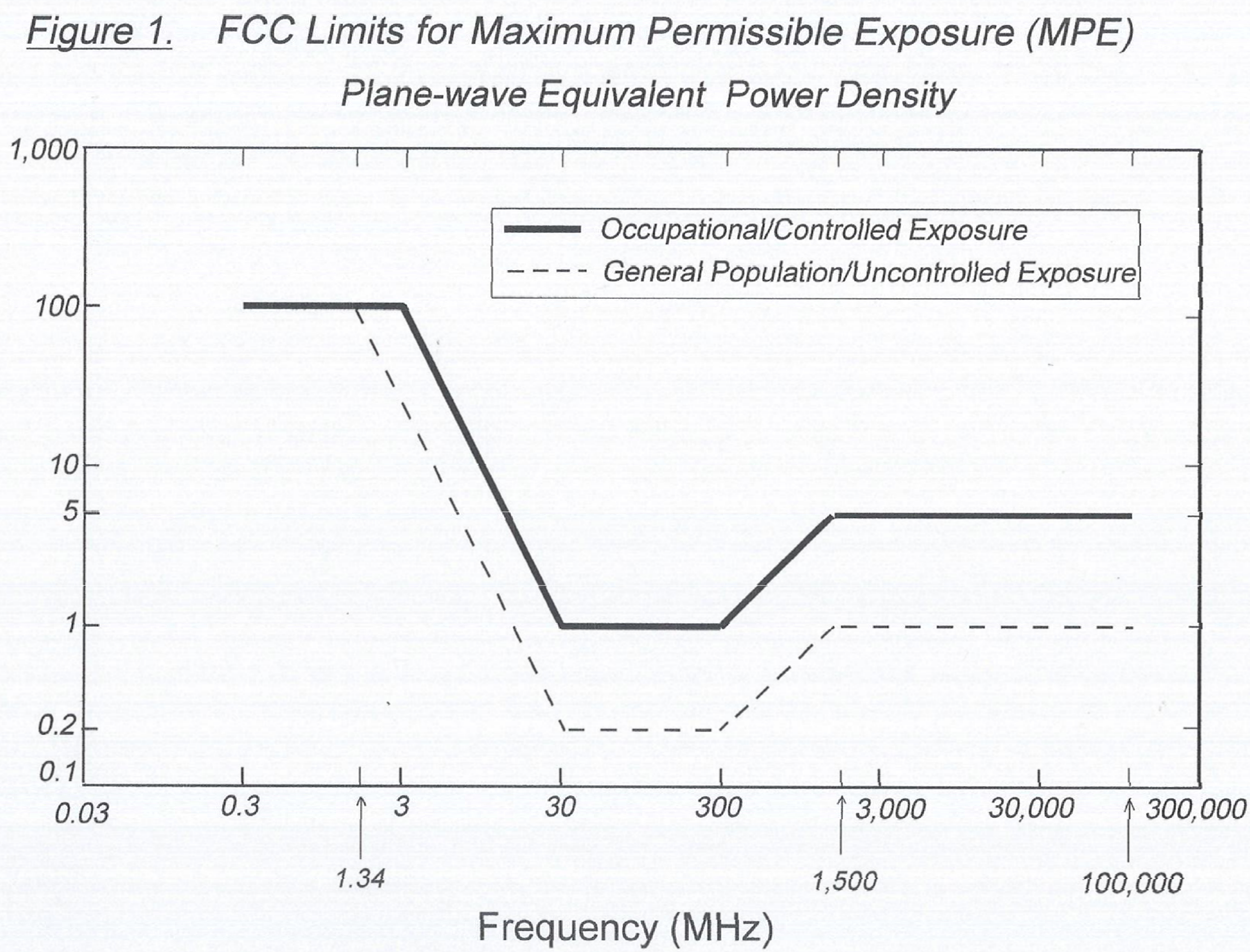


Figure 1. FCC Limits for Maximum Permissible Exposure (MPE)
Plane-wave Equivalent Power Density
1,000
100
10
5
1
0.2
0.1
Occupational/Controlled Exposure
General Population/Uncontrolled Exposure
0.03
0.3
3
30
300
3,000
30,000
300,000
1.34
1,500
100,000
Frequency (MHz)

Calculating Predicted RF Exposure Levels of FM Broadcast Stations

Remember the equation: $S = EIRP/(4\pi R^2)$

Taking into account:
Assume a 1.6-fold increase in field strength caused by ground reflection, and that FM power is expressed in ERP (Effective Radiated Power relative to a half-wave dipole rather than an isotropic radiator), this equation becomes:

$$S = 33.4 \times ERP/R^2$$

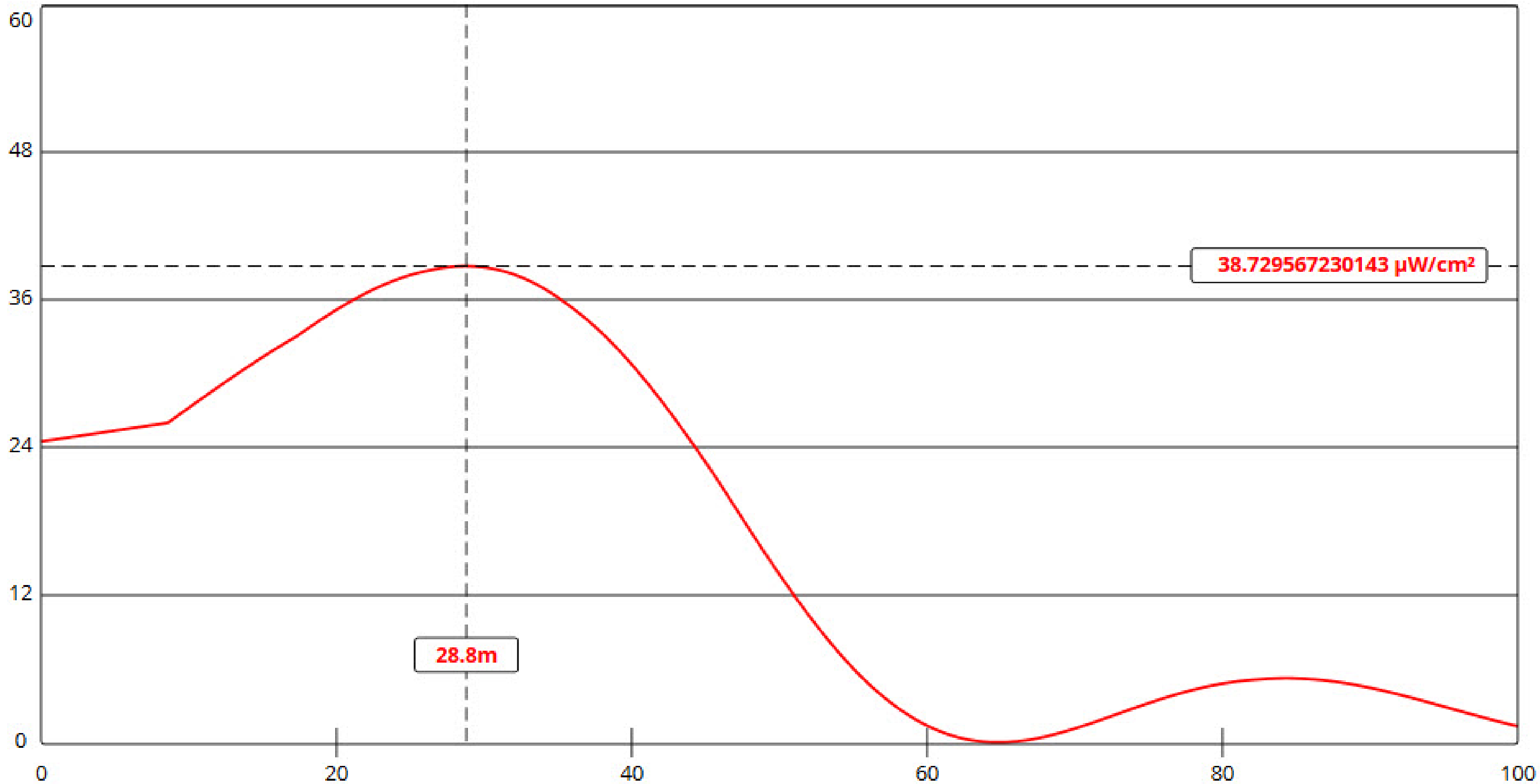
where: S = power density in mW/cm
ERP = power in KW in both horiz. plus vert. polarizations
R = distance in meters

Example of a Calculation for an FM Station

A station is transmitting at a frequency of 100 MHz with an ERP of 5 KW in both the horizontal and vertical polarizations (10 KW total) from a tower-mounted antenna. The height to the antenna's center of radiation is 50 meters above ground. Using the previous formula, what would be the calculated "worst-case" power density at a point 2 meters above ground (head level) and at a distance of 20 meters from the base of the tower?

Answer: Assuming fairly flat terrain, the distance R is the square root of $(48)^2 + (20)^2 = 52$ meters. Thus, using the formula, the calculated conservative "worst case" power density is: $S = 33.4\ (10)/52^2 = 0.124$ mW/cm. From Table 1 of MPE limits, the General Population/Uncontrolled MPE Limit is 0.2 mW/cm^2. Therefore, at this location the station would comply with the General Population MPE Limit.

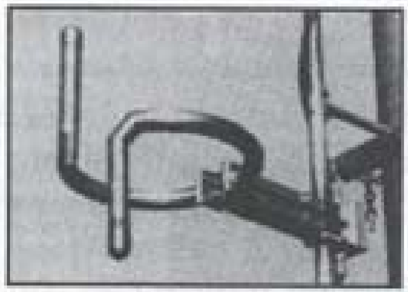
FCC's "FM Model" Program for more accurate predictions
Available at www.fcc.gov/general/fm-model



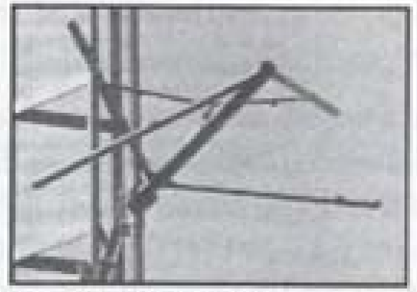
Channel 250 (97.9 MHz)   Antenna EPA Type 2 – Opposed V Dipole   50,000 W (H & V)   100 m Height
6 Elements, 1.0 λ spaced

This model takes into account the physical characteristics of the antenna and the vertical plane radiation pattern to get a more accurate prediction of power density.

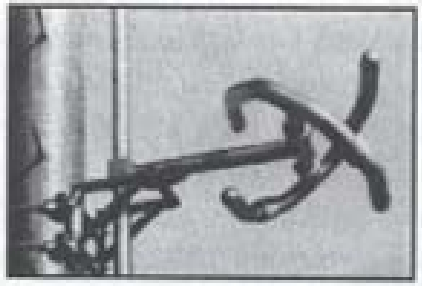
Types of FM Antennas used in FM Model



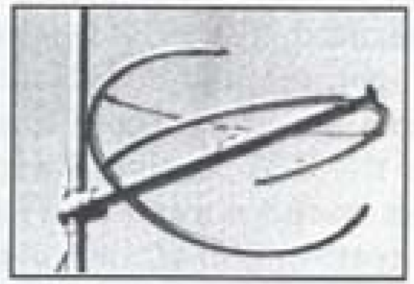
Type 1: "Ring & Stub"



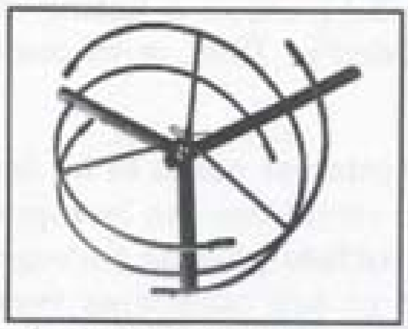
Type 2: "Mix-Master"



Type 3: "Roto-Tiller"



Type 4: "2-Piece Spiral"



Type 5: "3-Piece Spiral"

Source: Hammett, William F., *Radio Frequency Radiation: Issues & Standards,* McGraw-Hill, 1997.

ARRL Bulletin – Requirements for Amateur Radio

FCC Rules and RF Safety Bulletin

FCC Section 97.13(c) reads: *Before causing or allowing an amateur station to transmit from any place where the operation of the station could cause human exposure to RF electromagnetic field levels in excess of those allowed under §1.1310 of this chapter, the licensee is required to take certain actions.*

1. *The licensee must perform the routine RF environmental evaluation prescribed by §1.1307(b) of this chapter, if the power of the licensee's station exceeds the limits given in the following table:*

Wavelength Band & Evaluation Required if Power* (watts) Exceeds		
MF/HF	***VHF***	***SHF***
160m - 40m = 500 watts	*all bands = 50 watts*	*all bands = 250 watts*
30m = 425 watts		
20m = 225 watts	***UHF***	***EHF***
17m = 125 watts	*70cm = 70 watts*	*all bands = 250 watts*
15m = 100 watts	*33cm = 150 watts*	
12m = 75 watts	*23cm = 200 watts*	
10m = 50 watts	*13cm = 250 watts*	

- Repeater stations (all bands) non-building-mounted antennas:

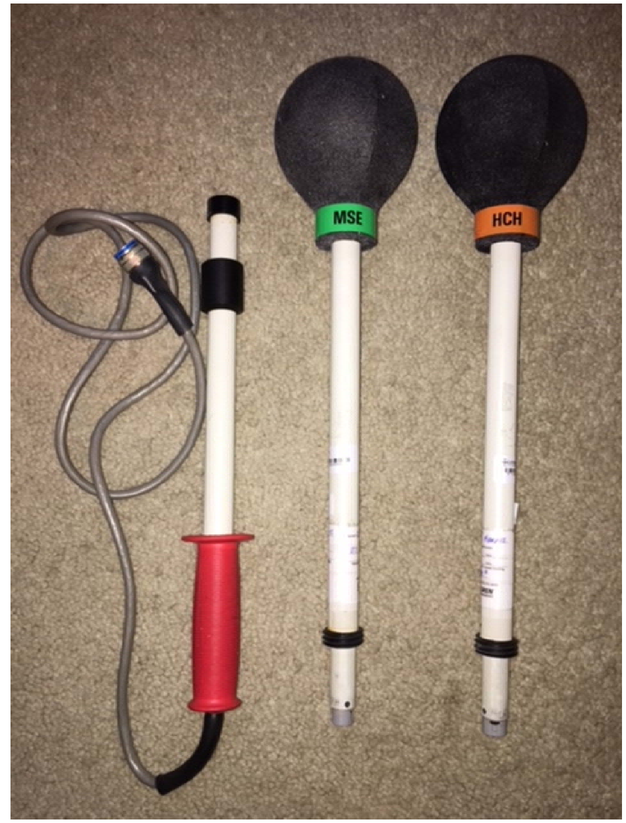
height above ground level to lowest point of antenna < 10 m and power > 500 W ERP

- Building-mounted antennas: power > 500 W ERP

** Power = PEP input to antenna except, for repeater stations only, power exclusion is based on ERP (effective radiated power).*

2. *If the routine environmental evaluation indicates that the RF electromagnetic fields could exceed the limits contained in §1.1310 of this chapter in accessible areas, the licensee must take action to prevent human exposure to such RF electromagnetic fields. Further information on evaluating compliance with these limits can be found in the FCC's OET Bulletin 65, "Evaluating Compliance with FCC-Specified Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields."*

Measuring RF Fields with a Broadband RF Survey Meter



This is the Holaday Industries HI-3012 RF Survey Meter. Comes with E-field and H-field probes. Simple to use, no tuning required. I also have an H-probe for MF and HF frequencies (not pictured), which can be used to measure H-fields from AM broadcast antennas.

Frequency Responses for Field Probes

- MSE Probe (for E-field measured in V^2/m^2): 0.5 MHz – 5000 MHz
- HCH Probe (for H-field measured in A^2/m^2): 5 MHz – 300 MHz
- LFH Probe (for H-field measured in A^2/m^2*): 0.3 – 10 MHz

<u>The probes are essentially isotropic receiving antennas.</u>

If you're measuring in the near-field of the antenna(s), you <u>must</u> measure both the E- and H-fields. For example, AM station transmitter properties, including the transmitter building and equipment shelters, are generally in the near-field.

If the area you're measuring is in the far-field, only the E-field is usually measured. Antennas operating above 300 MHz and mounted on a structure at least 10 meters above ground should not have any near-field areas at ground level.

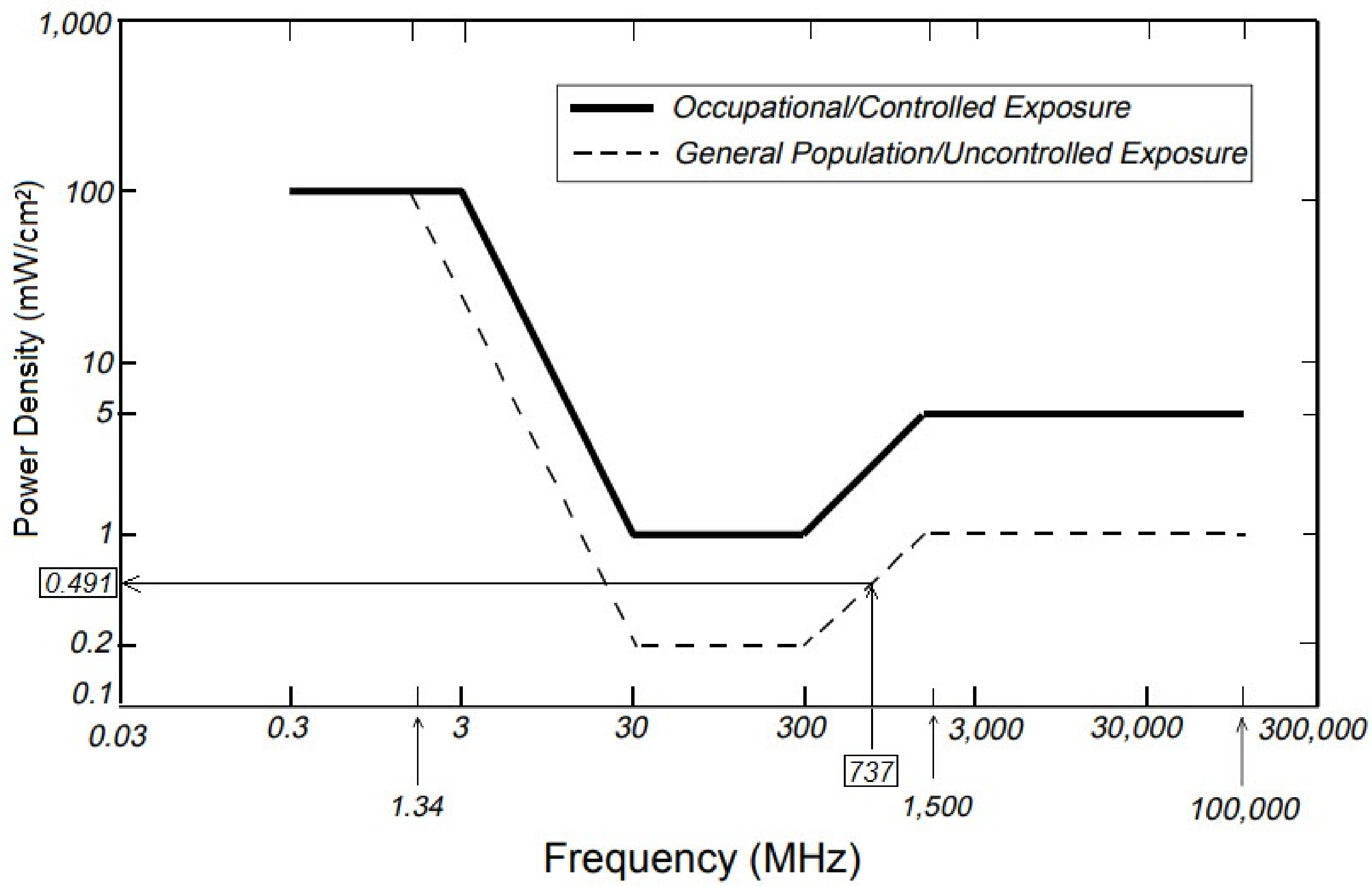
** The LFH probe has a correction multiplier factor that's applied to the direct reading on the meter to provide the actual H-field value. (The correction factor on my LFH probe is 38.)*

Measuring RF Fields – A Case Study

Lakeview Hills Water Tower in Madison, WI, the antenna support structure for three cell carriers and county & city government two-way radio. Multi- and omni-directional antennas range in frequency from 737 MHz to 2637.5 MHz; thus, ground level areas to measured are in the far-field, and we measure only the E-field.

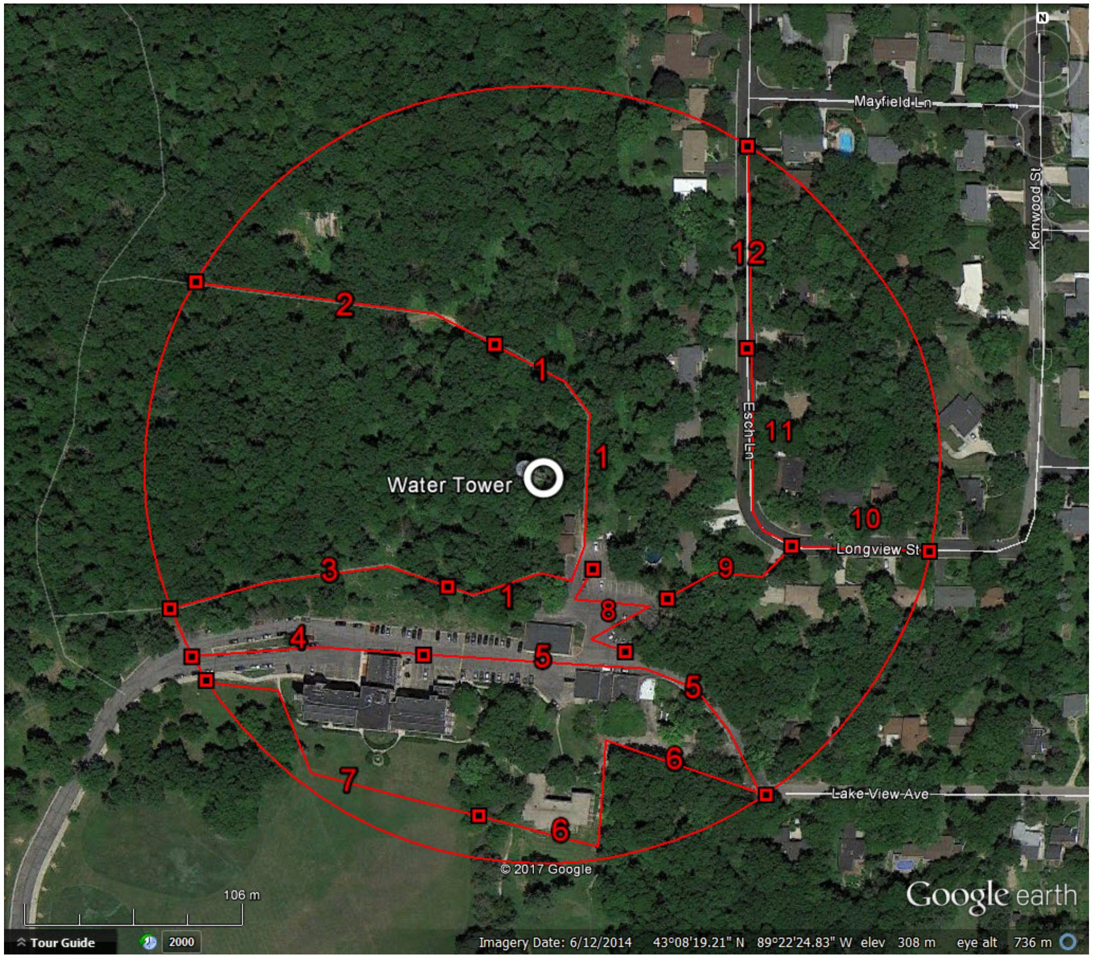
Figure 1. *FCC Limits for Maximum Permissible Exposure (MPE)*

Plane-wave Equivalent Power Density



We need a threshold value for S and then calculate the corresponding value for E^2. We pick the frequency with the lowest (most restrictive) general population MPE (in this case 737 MHz), then calculate according to the MPE Limits Table: S = f/1500 = 737/1500 = 0.491 mW/cm^2. Then using the $S = E^2/3770$, solving for E^2, we get E^2 = 1852 A^2/m^2.

Walking measurements were made along the segmented paths shown below. (Cell phone must be turned off as it may affect the readings!)



The result was that there were no RF fields that measured greater than 1.35% of the power density MPE level.

Marking an RF Exposure “Hotspot”

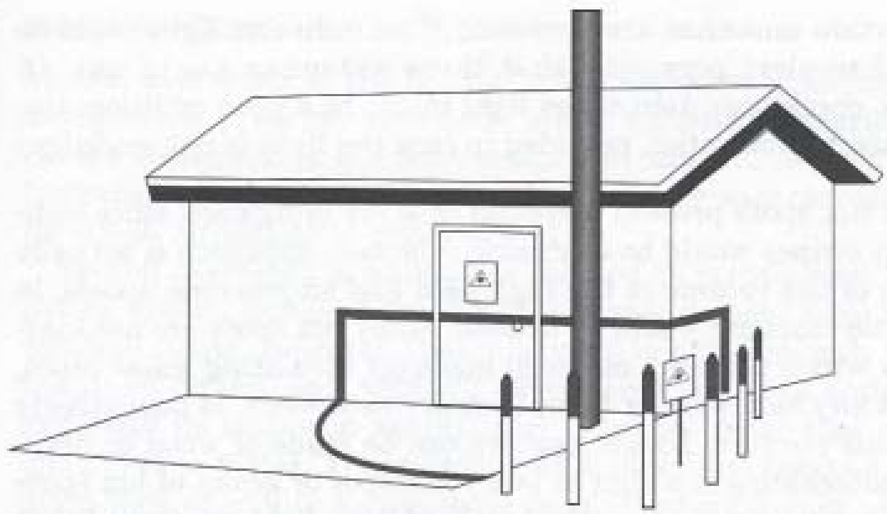


Figure 3.16 Example of high RF field identification.

Source: Hammett, William F., *Radio Frequency Radiation: Issues & Standards,* McGraw-Hill, 1997.

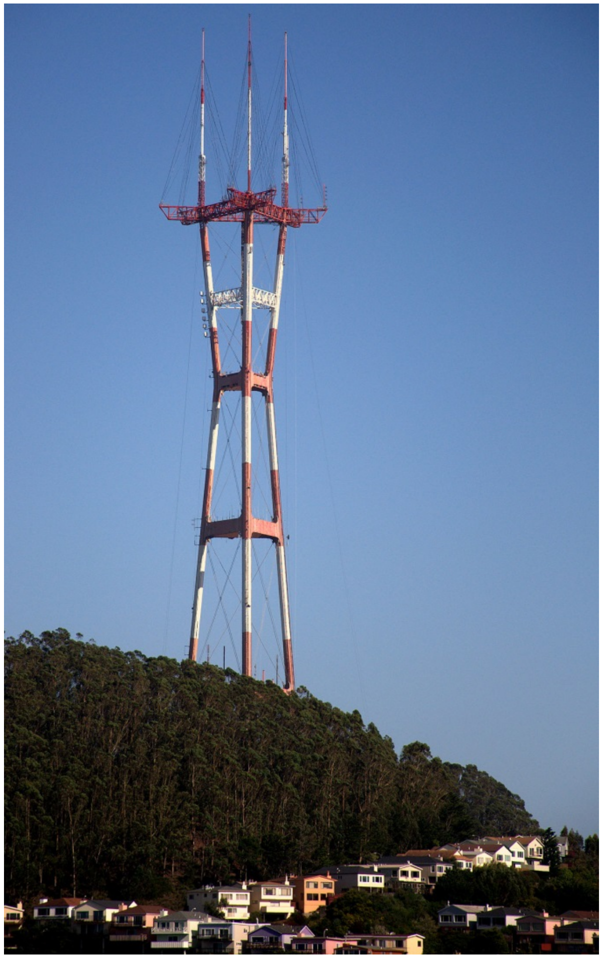
If RF measurements reveal a “hotspot” at a transmitting facility, i.e. an area where the occupational MPE level is exceeded, FCC rules require the area to be marked in a manner to communicate the danger to workers. Fences should be used to keep the public away from the tower.

Devices to Protect Tower Climbers from High RF Fields (PPE)

Metal mesh in fireproof fabric attenuates RF, protects from up to 10 times the MPE level.

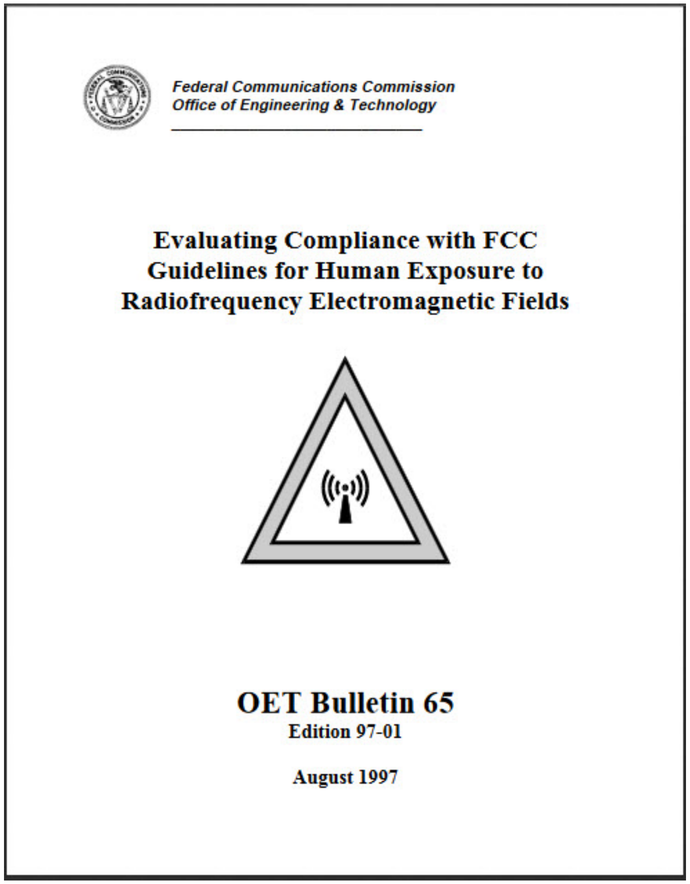
Nardalert XT RF personal monitor, shown here with pocket clip attached. Two yellow and three red LED lights flash in sequence to indicate the strength of the RF field. A similar high power model is available for when an RF suit is worn.

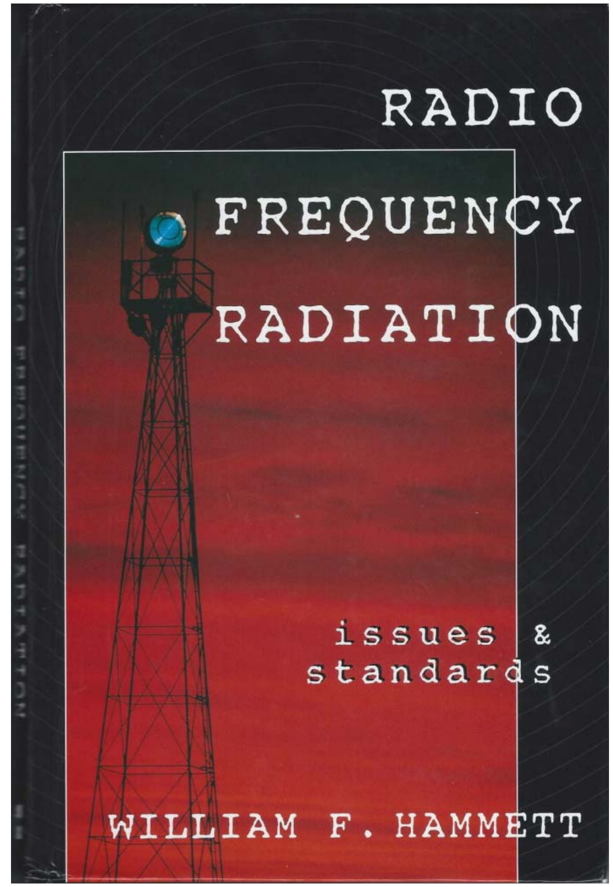
Tower owners must have a plan in the event of new installations and maintenance.



To protect tower workers from excessive RF radiation, the tower owner should have in place a shutdown or power-reduction plan. Especially important when there are many tenants on the tower. Options include complete shutoff, reduction of power or moving to a standby antenna either on the tower or off-site.

Recommended Reading





Available at:
www.fcc.gov/bureaus/oet/info/documents/bulletins/oet65/oet65.pdf

Available on Amazon

Thank you!

Thanks for listening!!

Questions?