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RF Power Density and RF Electric Field:[1] Conversions among Units, plus RF Exposure Limits

RF Electric Field	RF Power Density					RF Exposure Limits and Promulgating Organizations for Specific RF Sources, Frequencies, and Populations
volts per meter	milliwatts per square meter	milliwatts per square centimeter	microwatts per square meter	microwatts per square centimeter	watts per square meter	
V/m	mW/m^2	mW/cm^2	$\mu W/m^2$	$\mu W/cm^2$	W/m^2	
61	10,000	1.0	10,000,000	1,000	→ 10	← • FCC MPE[2] 1.5-100 GHz: 10 W/m^2
55	8,000	0.80	8,000,000	800	→ 8.0	← • FCC MPE[2] 1200 MHz: 8 W/m^2
48	6,000	0.60	6,000,000	600	→ 6.0	← • FCC MPE[2] 900 MHz: 6 W/m^2
39	4,000	0.40	4,000,000	400	→ 4.0	← • FCC MPE[2] 600 MHz: 4 W/m^2
27	2,000	0.20	2,000,000	200	→ 2.0	← • FCC MPE[2] 30-300 MHz: 2 W/m^2
19	1,000	0.10	1,000,000	100	1.0	FCC MPE are 30 minute averages, permitting high peaks.[2]
17	800	0.080	800,000	80	0.80	
15	600	0.060	600,000	60	0.60	
12	400	0.040	400,000	40	0.40	
8.7	200	0.020	200,000	20	0.20	
6.1	100	0.010	100,000	10	0.10	
5.5	80	0.0080	80,000	8.0	0.080	
4.8	60	0.0060	60,000	6.0	0.060	
3.9	40	0.0040	40,000	4.0	0.040	
2.7	20	0.0020	20,000	2.0	0.020	• EUROPAEM[3]: 10,000 $\mu W/m^2$ for
1.9	10	0.0010	→ 10,000	1.0	0.010	← ○ Daytime Exposure for Radio Broadcast (FM)
1.7	8.0	0.00080	8,000	0.80	0.0080	
1.5	6.0	0.00060	6,000	0.60	0.0060	
1.2	4.0	0.00040	4,000	0.40	0.0040	• Building Biology[4] "Extreme" concern: >1000 $\mu W/m^2$
0.87	R3 2.0	0.00020	2,000	0.20	0.0020	• EUROPAEM[3]: 1000 $\mu W/m^2$ for ○ Nighttime Exposure for Radio Broadcast (FM)
0.61	1.0	0.00010	→ 1,000	0.10	0.0010	← ○ Daytime Exposure for TETRA and DVBT (TV)
0.55	0.80	0.000080	800	0.080	0.0008	
0.48	R2 0.60	0.000060	600	0.060	0.0006	• EUROPAEM[3]: 100 $\mu W/m^2$ for ○ Sensitive Populations for Radio Broadcast (FM)
0.39	0.40	0.000040	400	0.040	0.0004	○ Nighttime Exposure for TETRA and DVBT (TV)
0.27	R1 0.20	0.000020	200	0.020	0.0002	○ Daytime Exposure for LTE(4G), UMTS(3G),
0.19	0.10	0.000010	→ 100	0.010	0.0001	← GSM(2G) 900/1800 MHz DECT (cordless phone)
0.17	0.080	0.0000080	80	0.0080	0.000080	• Building Biology[4] "Severe" concern: 10-1000 $\mu W/m^2$
0.15	Y3 0.060	0.0000060	60	0.0060	0.000060	• EUROPAEM[3]: 10 $\mu W/m^2$ for
0.12	0.040	0.0000040	40	0.0040	0.000040	○ Sensitive Populations for TETRA and DVBT (TV)
0.087	Y2 0.020	0.0000020	20	0.0020	0.000020	○ Nighttime Exposure for LTE(4G), UMTS(3G), GSM(2G), 900/1800 MHz DECT (cordless phone)
0.061	0.010	0.0000010	→ 10	0.0010	0.000010	← ○ Daytime Exposure for Wi-Fi 2.4/5.6 GHz
0.055	0.0080	0.00000080	8.0	0.00080	0.0000080	
0.048	Y1 0.0060	0.00000060	6.0	0.00060	0.0000060	• EUROPAEM[3]: 1 $\mu W/m^2$ for
0.039	0.0040	0.00000040	4.0	0.00040	0.0000040	○ Sensitive Populations for LTE(4G) UMTS(3G), GSM(2G), 900/1800 MHz DECT (cordless phone)
0.027	G3 0.0020	0.00000020	2.0	0.00020	0.0000020	
0.019	0.0010	0.00000010	→ 1.0	0.00010	0.0000010	← ○ Nighttime Exposure for Wi-Fi 2.4/5.6 GHz
0.017	0.00080	0.000000080	0.80	0.000080	0.00000080	
0.015	G2 0.00060	0.000000060	0.60	0.000060	0.00000060	• Building Biology[4] "Slight" concern: 0.1-10 $\mu W/m^2$
0.012	0.00040	0.000000040	0.40	0.000040	0.00000040	• EUROPAEM[3]: 0.1 $\mu W/m^2$ for
0.0087	0.00020	0.000000020	0.20	0.000020	0.00000020	○ Sensitive Populations for Wi-Fi 2.4/5.6 GHz
0.0061	0.00010	0.000000010	→ 0.10	0.000010	0.00000010	← • Building Biology[4] "No" concern: <0.1 $\mu W/m^2$

ENDNOTES

[1] This conversion from the RF Electric Field to RF Power Density, and the reverse, is applicable only in the "far field", that is, at distances greater than 2 to 3 wavelengths from the source where these quantities gradually assume a known relationship. That relationship is shown in the following equation:

$$P_D = \frac{E^2}{Z_o}$$

where

P_D is the RF Power Density in watts per square meter (W/m^2).
E is the RF Electric Field in volts per meter (V/m).
Z_o is the impedance of free space 377 ohms (Ω).

[2] Robert F. Cleveland, Jr., David M. Sylvar, Jerry L. Ulcek, Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields, FCC OET Bulletin 65, Edition 97-01, August 1997, Table 1(B) "Limits for the General Population/Uncontrolled Exposure", p. 67-68. MPE means "Maximum Permissible Exposure", an FCC guideline. The FCC MPE limits are thermally based. Specifically, they are based on the amount of power per unit mass delivered to, and thus on the amount of heating caused in, a liquid simulation of the head and the body. The FCC MPE limits are time-average values, with an averaging time of 30 minutes. There is no FCC limit on peak values, so they are permitted to be many orders of magnitude (many factors of 10) higher, provided only that the time-average limits are not exceeded. Thus, the gap between the unstated peak values permitted by the FCC MPE limits, and the exposure limits from EUROPEAM and Building Biology, which are peak values, can be far greater than shown in the table. (https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet65/oet65.pdf)

[3] Igor Belyaev, Amy Dean, Horst Eger, Gerhard Hubmann, Reinhold Jandrisovits, Markus Kern, Michael Kundi, Hanns Moshammer, Piero Lercher, Kurt Müller, Gerd Oberfeld, Peter Ohnsorge, Peter Pelzmann, Claus Scheingraber, and Roby Thill, EUROPAEM EMF Guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses, Reviews of Environmental Health 2016, Vol. 31, No. 3, pages 363-397. Specifically, see "Table 3: Precautionary guidance values for radio-frequency radiation." on page 381. (https://www.degruyter.com/downloadpdf/j/reveh.2016.31.issue-3/reveh-2016-0011/reveh-2016-0011.pdf)

All EUROPAEM Precautionary Guidance Values are peak levels, not time-average levels. They are based on biological effects, not on thermal effects; but they are keyed to likely induced current levels in the body. Those current levels reflect both rise time and periodic low frequency (ELF) "pulsing". Table 3 in the reference explains: "Rectangular signals show short rise times and consist of a broad spectrum of frequencies. The current density induced in the human body increases with increasing frequency in an approximately linear relationship."

The EUROPAEM Precautionary Guidance provides three levels of RF Power Density for each source, each of which is progressively more restrictive: Daytime Exposure, Nighttime Exposure, and Sensitive Populations. Nighttime Exposure is more restrictive than Daytime Exposure, presumably because individuals need time to heal at night from their daytime exposure. Sensitive Populations is the most restrictive category because sensitive people are either already adversely affected, or are known to be especially vulnerable to harm, and thus have little to no tolerance for exposure.

[4] International Institute for Building-Biology & Ecology, Inc., Building Biology Evaluation Guidelines for Sleeping Areas, Supplement to the Standard of Building Biology Testing Methods SBM-2015, page 1. The Evaluation Guidelines represent peak levels, not time-average levels. (https://buildingbiology.com/site/wp-content/uploads/richtwerte-2015-englisch.pdf)

Notes on the Cornet Microsystems ED88TPlus

Dynamic Range

The specifications for the "RF Mode" of the ED88TPlus indicate that it can report the peak RF Power Density within a range from 0.0005 mW/m^2 to 1800 mW/m^2 and over a frequency range from 100 MHz to 8 GHz. The rectangular boxes (purple) in the "mW/m^2" column in the table on page 1 mark the approximate limits of the measurement range for RF Power Density.

Sensitivity of LEDs

The red, yellow, and green LEDs of the ED88TPlus can be adjusted for sensitivity, as a group. That sensitivity has been set to its maximum value so that the LEDs track better with the biologically based exposure limits provided EUROPAEM and Building Biology. The red, yellow, and green indicators in the table on page 1 show the RF Power Density levels at which these color LEDs are illuminated when set for maximum sensitivity. That setting has been made in the "System Setup" menu by changing the setting for the "LED Level" from its

default value of "OFF" to "-20". This change increased the sensitivity of the LEDs to the RF Power Density by 20 dB, which is a factor of 100. This change does not alter any of the numerical values reported by the meter. Only the LEDs are affected.

For clarity, the levels associated with the LEDs when the meter's "LED Level" is set to the default value of "OFF" are shown in Table A below. Both the RF Power Input to the meter's RF circuitry, and the translation of that input to RF Power Density, are shown. These default levels appear in a table on the back of the meter, but should be ignored. The levels now associated with the LEDs, after the meter's "LED level" have been set for "-20", are shown in Table B below. The color indicators in the "mW/m^2" column of the table on page 1 are those from Table B.

Table A: "LED Level" set to "OFF"

LED	RF Power Input	RF Power Density
R3	-5 dBm	180 mW/m^2
R2	-10 dBm	58 mW/m^2
R1	-15 dBm	18 mW/m^2
Y3	-20 dBm	5.8 mW/m^2
Y2	-25 dBm	1.8 mW/m^2
Y1	-30 dBm	0.58 mW/m^2
G3	-35 dBm	0.18 mW/m^2
G2	-40 dBm	0.06 mW/m^2

Table B: "LED Level" set to "-20"

LED	RF Power Input	RF Power Density
R3	-25 dBm	1.8 mW/m^2
R2	-30 dBm	0.58 mW/m^2
R1	-35 dBm	0.18 mW/m^2
Y3	-40 dBm	0.058 mW/m^2
Y2	-45 dBm	0.018 mW/m^2
Y1	-50 dBm	0.0058 mW/m^2
G3	-55 dBm	0.0018 mW/m^2
G2	-60 dBm	0.0006 mW/m^2

With the "LED level" set as in Table B, the lowest green LED, labelled "G2", will be illuminated when the detected level is *at or below* 0.0006 mW/m^2. And the highest red LED, labelled "R3", will be illuminated when the detected level is *at or above* 1.8 mW/m^2 (that is, about 2.0 mW/m^2 in the table on page 1). The observed "noise floor" of the ED88TPlus, that is, the lowest level that the meter can report, no matter what the level of the ambient RF radiation, varies a bit from one copy of the ED88TPlus to another but is close to 0.0006 mW/m^2; so "G2" will be illuminated often. That level is well into the "Slight" concern category of the Building Biology Evaluation Guidelines. And that level is higher than the EUROPAEM Precautionary Guidance Value for "Sensitive Populations" for Wi-Fi. So, while the "-20" setting for the "LED level" makes the LEDs more useful as indicators of risk, there can be risk at any level of illumination of the LEDs.

Note that there is only one biologically based exposure limit that exceeds "R3": the EUROPAEM Precautionary Guidance Value for "Daytime Exposure" to "Radio Broadcast (FM)" is 10,000 µW/m^2. "Radio Broadcast (FM)", as referenced here, is presumed to be the traditional analog source which has constant amplitude and varying frequency. That source does not generate the rise times characteristic of digital sources with their constant ON/OFF behavior.

Display of Frequency Readings

The ED88TPlus meter can report the frequency when both of the following conditions are met:

- the detected RF Power Density reaches or exceeds the level of the red "R1" LED, which represents -35 dBm RF Power Input to the meter's RF circuitry, AND
- the frequency is within the frequency range of 100 MHz to 2.7 GHz.

The frequency readings for the ED88TPlus appear in the format "0000 MHz" at the top of the LCD display. So, for example, in the presence of a strong Wi-Fi signal, a frequency reading of about "2400 MHz", which is Wi-Fi's lower frequency, will be reported. Because the meter cannot measure frequencies above 2.7 GHz (equivalent to 2700 MHz), the meter will not be able to report Wi-Fi's upper frequency, which is 5000 MHz or greater.

The frequency reading at the top of the display will appear for only 0.5 seconds unless subsequent pulses are strong enough to trigger additional readings of frequency. Such a short presence can easily be missed, but the meter has been set to retain the frequency associated with its maximum ("MAX") RF Power Density reading by using the "System Setup Menu" to set "Avg/F" to "MAXFreq". That retained frequency reading will appear near the bottom of the display in the format "F0000M" or F0000MH", depending on the particular copy of the ED88TPlus, where the "F" is in reverse video. This reading will be located just to the right of the associated maximum RF Power Density reading in the format "MAX 0.0000" where "MAX" is in reverse video and "0.0000" is in mW/m^2, just as in the main display. For example, in the presence of a strong Wi-Fi signal, that line of the LCD display will have this format: "MAX1.0000 F2400MH", where both "MAX" and "F" are in reverse video.

The “MAX” reading, and the associated frequency reading, can be cleared at any time by pressing the HOLD button twice. The first press causes the meter to enter the HOLD mode, which temporarily freezes the data on the display. The second press exits the HOLD mode and simultaneously clears the “MAX” reading and the frequency reading. Then a new “MAX” value will quickly appear; and, if its level and frequency meet the two requirements stated above, a new frequency value, associated with that particular “MAX” value, will also appear.

Who am I?

I am a retired U.S. Government career scientist (Ph.D. in Applied Physics from Harvard University). During my Government career, I worked for the Executive Office of the President, the National Science Foundation, and the National Institute of Standards and Technology. I currently interact with other scientists, with physicians, and with aware individuals worldwide about the impact of radiofrequency radiation on human health.