∂/∂t TimeDerivative

TimeDerivative, Inc.
10988 NW 14th Street
Coral Springs, FL 33071

UWB Emission Mask Characteristics Compared with Natural Radiating Phenomena

Report: 2005-04-031.r2

12 April 2005

Abstract:

The report provides a comparison of UWB emissions masks with black-body radiation from emitters that are the same size, temperature and in the same ambient temperature as human bodies.

Revision History

Date	*Description*
12 Apr 2005	r0 Initial draft.
21 Apr 2005	r1 add detail in -75dBm section
15 Aug 2005	r2 ITU ref added

UWB Emissions Mask Characteristics Compared with Natural Radiating Phenomena

Kazimierz "Kai" Siwiak, Ph.D., P.E.
TimeDerivative, Inc

Abstract

This study relates to emission characteristics of various masks compared with naturally occurring emissions. Specifically, masks are compared with black-body radiation from human beings to provide a reference level that is within our physical experience. A comparisons is shown between the FCC hand held and vehicular radar emissions masks, and the CEPT outdoor slope emission mask, and natural occurring radiation from human beings. The limit levels proposed by the RAS are very stringent, and commensurate with natural radiation from people.

Introduction

The FCC hand-held mask and the Outdoor Slope mask are compared with a black-body radiator operating at the same power level, the same temperature, and immersed in the same ambient condition as a human body. This material was presented in ITU-R Task Group 1/8 on UWB [ITU-R/329 2005]. The comparisons provide guidance in relating UWB emissions mask levels to the aggregate radiation of one or several human beings.

Discussion

The human body radiates like a "black body" emitter across all frequencies, including the RF spectrum in which UWB devices operate. The body radiates at T_{body} and absorbs radiation at $T_{ambient}$ and Stephan's Law shows that the total power radiated by a human body is thus

$$P_{total} = sA\varepsilon(T^4_{body} - T^4_{ambient}) \tag{1}$$

where s=5.57x10^{-8} W/m^{2}K^4 and A=1 m^2 for the combined torso and head emitting surface area. The emissivity of the human body is known to be at least ε=0.98 [Dziuban 2002]. At an ambient temperature of 15°C ($T_{ambient}$= 283.15 Kelvin) and a body temperature of 37°C (T_{body}= 310.15 Kelvin) the net total body emission is about P_{total} = 131 watts. While different values may be obtained for different body surface areas and for different ambient temperatures, the value of 131 W (or approximately 2,700k calories per day) serves as a useful reference level for further discussion.

Measurements of human body temperatures using RF thermography techniques at decimeter frequencies, see [Obukhova 1992], show that the human body radiation follows the black body emissions curve even at radio frequencies. The curve is given by

$$P(T) = \frac{2\pi h f^3}{c^2\,(e^{hf/kT} - 1)} \quad \text{W/m}^2\text{/Hz} \tag{2}$$

where h=6.63x10^{-34} J sec, k=1.38x10^{-23} J/K, c=299,792,458 m/s and f is in Hz. The peak radiation occurs near 24,000 GHz. The radiated power spectral density (PSD) from one human body is

$$P_{humanPSD} = A[P(T_{body}) - P(T_{ambient})] \quad \text{W/Hz} \tag{3}$$

When integrated over all frequencies, and with the body emissivity factor and body area, Eq (3) gives the same 131 W as Eq (1). At frequencies below about 20,000 GHz human body radiation can be closely approximated by

$$P_{body} = 20\log(f_{GHz}) - 106.7 \ \text{dBm/MHz} \tag{4}$$

We can now consider a human body as an " equivalent black-body radiator" operating at the same power level, the same temperature, and immersed in the same ambient condition as a human body. Figure 1 shows the exact single body radiation Eq (2) curve, and the Eq (3) approximation.

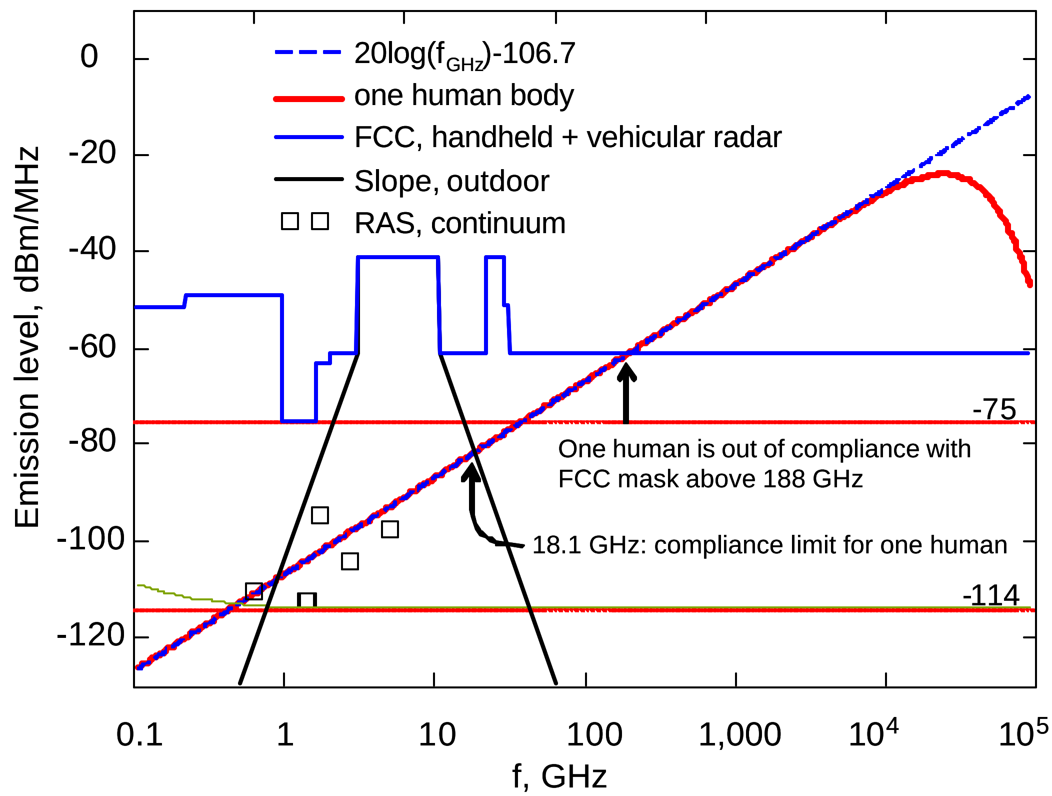

Figure 1. Human radiation and RAS-desired levels compared with UWB Masks.

The Figure also depicts the RAS (Radio Astronomy Service) desired limits for continuum observations, see Table A7-4 from [RAS 2005], by the square symbols in Figure 1.

The RAS requirements are indeed quite severe, with several points occurring below human-like black-body radiation at the same frequencies. Figure AA1 shows the FCC hand-held and vehicular radar (22-29 GHz) UWB masks, and the Indoor Slope mask. Radiation from one human radiator is "out of compliance" with the FCC mask at frequencies above 188 GHz. This same human emits more than the Indoor Slope Mask would permit at frequencies above 18.1 GHz.

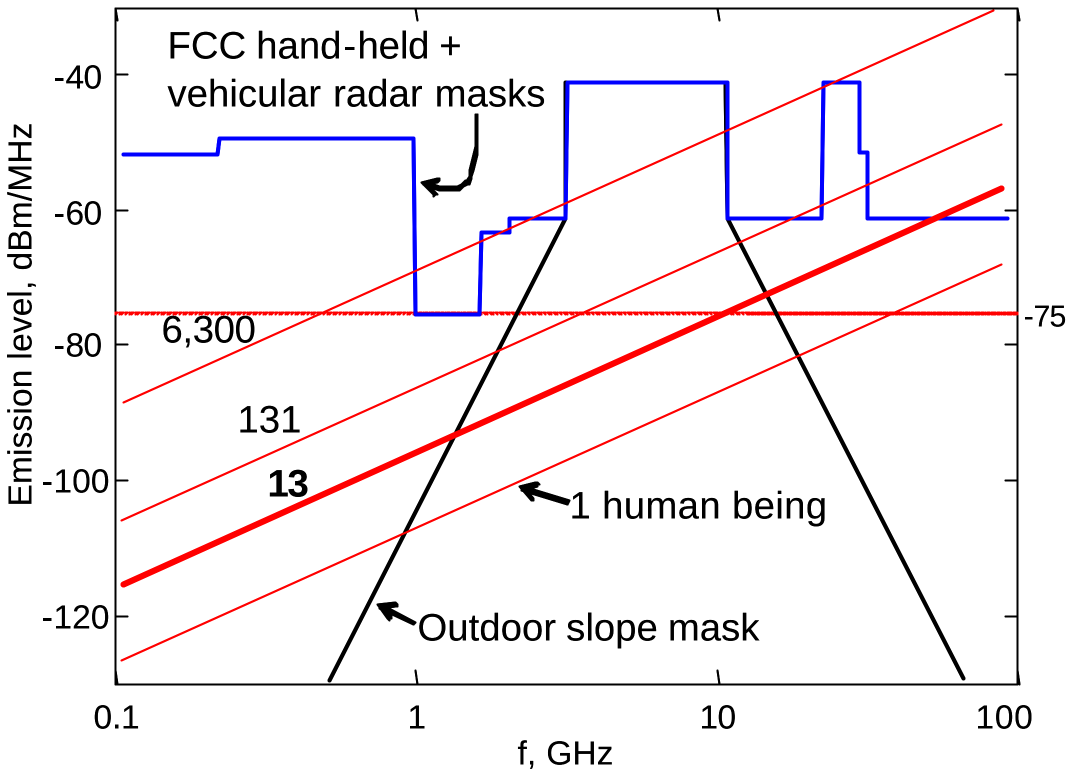

Figure 2. Human radiation compared with UWB Masks.

The world human population densities, see [Wikipedia 2005], vary from one person per km^2 on Pitcairn Island, to 31 per km^2 in the US; 131 per km^2 in the European Union; 6,300 per km^2 in Singapore and Hong Kong; and as high as 17,700 per km^2 in Macao. The average density of human beings on Earth (including oceans) is 13 beings per km^2. These human body densities suggest natural aggregation values for a physical reference when comparing with UWB emissions mask levels. The human radiation is given by

$$P_{limit} = 20\log(f_{GHz}) - 106.7 + 10\log(N)\ \text{dBm/MHz} \tag{5}$$

Figure 2 portrays the FCC handheld mask and the Outdoor Slope mask along with the aggregate characteristic radiation from N=1, 13, 131, and 6,300 human beings. These values of N correspond to population densities discussed earlier.

The -75 dBm/MHz Reference Level

A reference value of -75 dBm/MHz is also depicted in Figure 2. A -75 dBm/MHz emitter at 1 GHz (lowest point in FCC mask) encounters 42.0 dB propagation attenuation at 3 meters distance, thus develops -110.1 dBm/MHz in the input of a test receiver having a measurement antenna gain of 6.91 dBi (for example, an AH Systems SAS-571 double ridge guide horn), see the sample calibration values in Table 1.

Table 1. Gain calibration of SAS-571 test antenna at 1 and 3 m measuring distance.

Frequency, GHz	*Gain at 1 m, dBi*	*Gain at 3 m, dBi*
1	6.90	6.91
3	9.67	9.76
5.5	9.91	11.56
10.5	11.54	12.32

The calibrated test set receiver might comprise an Agilent A4440E spectrum analyzer which has a specification sheet noise figure of about 26 dB at 1 GHz. This results in a noise floor that is [-174+10log(1 MHz)+26]= -88 dBm, thus the -75 dBm/MHz EIRP signal would be 22.1 dB below the spectrum analyzer noise floor. The noise figure of the receiver system can be coaxed down by using a pair of low noise amplifiers between the antenna and the spectrum analyzer. Assuming a cable loss of 0.2 dB between the horn antenna and the amplifiers, amplifier noise figures of 2.2 dB, and gain per amplifier of 21 dB, the system noise figure becomes

$$NF=10\log[10^{2.2/10} + (10^{2.2/10}-1)/10^{21/10} + (10^{26/10}-1)/10^{21/10}10^{21/10}] + 0.2\text{ dB} = 2.5\text{ dB} \qquad (2)$$

This improves test receiver system sensitivity by 26-2.5 = 23.5 dB, and the -75dBm/MHz EIRP signal at 1 GHz would have a 1.4 dB signal to noise ratio, so would show as a discernable 3.8 dB noise rise in the spectrum analyzer. Moving the test antenna to a 1 m measurement distance would increase the field strength by 20log(3/1)=9.5 dB, improving the signal to noise ratio to about 11 dB. At a 1 m distance this is a near field measurement, but the result is discernable using only slightly heroic means.

Summary and Conclusions

A comparison has been made been the emission levels of natural black-body radiators and Several UWB emissions masks. The natural Black-body radiators are the same size, and are at the same temperature as human beings, and are immersed in a room temperature ambient level. The human-like black body radiators emit at levels above the limits sought by the RAS, and exceed the CEPT outdoor mask above 18 GHz, and exceed the US limits above 188 GHz. The level of -75 dBm/MHz EIRP is an emitter that is close to the limit of measurement capability of current test equipment.

References

[Dziuban 2002] Ewa Dziuban, "Human Body Temperature Measurement Class Program, Joint IMEKO TC-1 and XXXIV MKM Conference 2002, Wroclaw PL, 8-12 September 2002.

[ITU-R/329 2005] ITU-R Document 1-8/329-E 11, "Emissions Masks Characteristics Compared with Natural Radiating Phenomena", May 2005, Online: <http://www.itu.int/md/meetingdoc.asp?type=sitems&lang=e&parent=R03-TG1.8-C-0329>

[Obukhova 1992] Obukhova A. A., Baturina T. D., "Measurement of thermal radiation of the human body in the radiofrequency band," Fiziologia Cheloveka [Human Physiology]. 1992 Mar-Apr;18(2):93-9, (in Russian).

[RAS 2005] R03-TG1.8-C-0178!!MSW-E.doc, ITU Temp Document, November, 2004.

[Wikipedia 2005] List of Countries by Population Density, (Online): 28 March 2005, <http://en.wikipedia.org/wiki/List_of_countries_by_population_density>