SATEL-TR4+ RF Exposure Limits and Approximation of Safety Distances Applicable to Radio Modem Systems

RF Exposure Limits on VHF/UHF Frequency Range

On VHF/UHF frequency range the most significant mechanism of action of RF exposure is tissue warming. Other physiological mechanisms have not yet been proven by scientific research.

Basic restrictions for RF exposure on VHF/UHF band are based on SAR (Specific Absorption Rate) limits. Basic restrictions are set in a way that a person is well protected against all verified adverse effects.

ICNIRP (International Commission on Non-Ionizing Radiation, www.icnirp.de) has 1998 set the following limits for SAR on VHF/UHF frequency range (actually covering 10 MHz – 10 GHz), based on 6-minute exposure average per 10 g tissue mass. However, local legislation and standards are to be respected always when preparing an RF exposure analysis. European Council has set the recommendation 1999/519/EC on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz).

ICNIRP Basic Restrictions on VHF/UHF for SAR	SAR, work-related exposure [W/kg]	SAR, population exposure [W/kg]
whole body average	0.4	0.08
head and torso	10	2
extremities	20	4

Due to the practical difficulties of measuring SAR inside a body, equivalent reference levels are used for RF power density or electric or magnetic field strength outside the body. The reference levels have been set so that the basic restrictions are not exceeded at any circumstances.

ICNIRP has 1998 set the following reference limits for RF power density [W/m2] on VHF/UHF frequency range (10-400 MHz or 400-2000 MHz), based on 6-minute exposure average.

ICNIRP Reference Values on VHF/UHF for RF Power Density	Equivalent RF power density, work-related exposure [W/m^2]	Equivalent RF power density, population exposure [W/m^2]
10 – 400 MHz	10	2
400 – 2000 MHz	2.5E-8 x f	0.5E-8 x f

f is given in [Hz]

Approximation of Safety Distances in Order to Meet ICNIRP Reference Values for RF Exposure

Electro-magnetic wave carries energy, which is expressed as power density *S*. It depends on electric and magnetic field strength according to their vector product.

$$\vec{S} = \vec{E} \times \vec{H} \quad (1)$$

The direction of *S* vector gives the direction of propagation of power. The amplitude of *S* vector defines the power per unit area carried by the wave.

In case of a sinusoidal TEM (Transverse Electro-Magnetic) wave, the amplitude of the power density *S* at a distance *r* from the radiator antenna can be calculated by the formula below

$$S = \frac{PG}{4\,\pi r^2} \quad (2)$$

where:

P = RF signal power fed to the antenna, [W], in this case 6-minute average
G = isotropic gain of the antenna, [numeric]
r = observation distance from the transmitter antenna, [m]
$\pi \approx 3.14$

The formula (2) is not valid in the near field conditions when $r < 2D^2/\lambda$ (Rayleigh's criteria). *D* is the maximum dimension of an antenna and λ is the wavelength of the RF signal. In free space $\lambda = c/f$, where *c* = velocity of light and *f* = frequency.

The signal power fed to the antenna can be determined by starting with transmitter output power (in this case 6-minute average value is used), and then subtracting insertion loss or adding gain of each RF component on the feeder line up to the antenna.

The formula (2) we can solve for the distance *r*, in order to find out the minimum distance to meet the limit set for maximum RF power density.

$$r = \sqrt{PG/4\pi S} \quad (3)$$

Calculation

- Transmitter output power of radio modem is max 1.0 W
- Transmit frequency = 403 MHz
- Antenna gain = 0 dBi including all signal losses of cables, attenuators etc. The radio specification states that the effective radiated power from the antenna must not be more than 1 W.

Antenna gain can be converted to a numeric gain with the formula below.

$$G = 10^{\frac{G[dBi]}{10}} \quad (4)$$

By substituting the above values to the formula (3) we can determine minimum safety distances acc. to ICNIRP reference values...

...for work-related Exposure

a)

$$r = \sqrt{PG/4\pi S}$$

Work-related Exposure (400-2000 MHz)						
f/Hz	P/W	G[dBi]	G	S [W/m²]	r/m	r/cm
403000000	1	0	1.0	10.075	0.089	8.9
		4	2.5	10.075	0.141	14.1
		6	4.0	10.075	0.177	17.7
		8	6.3	10.075	0.223	22.3
		10	10.0	10.075	0.281	28.1
		12	15.8	10.075	0.354	35.4

...and for population Exposure

b)

$$r = \sqrt{PG/4\pi S}$$

Population Exposure (400-2000 MHz)						
f/Hz	P/W	G[dBi]	G	S [W/m²]	r/m	r/cm
403000000	1	0	1.0	2.015	0.199	19.9
		4	2.5	2.015	0.315	31.5
		6	4.0	2.015	0.397	39.7
		8	6.3	2.015	0.499	49.9
		10	10.0	2.015	0.628	62.8
		12	15.8	2.015	0.791	79.1

CFR Part 47, §1.1310

In accordance to CFR Part 47, §1.1310

Frequency Range /MHz	RF power density, occupational/controlled [mW/cm^2]	RF power density, general population/uncontrolled [mW/cm^2]
300 – 1500 MHz	f/300	f/1500

f = frequency in MHz

Limits for power density according to table above:

Frequency Range /MHz	RF power density, occupational/controlled [W/m^2]	RF power density, general population/uncontrolled [W/m^2]
300 – 1500 MHz	13.4	2.7

Calculations

Occupational/Controlled						
f/Hz	P/W	G[dBi]	G	S [W/m^2]	r/m	r/cm
403000000	1	0	1.0	13.400	0.077	7.7
		4	2.5	13.400	0.122	12.2
		6	4.0	13.400	0.154	15.4
		8	6.3	13.400	0.194	19.4
		10	10.0	13.400	0.244	24.4
		12	15.8	13.400	0.307	30.7
		14	25.1	13.400	0.386	38.6

Population/Uncontrolled						
f/Hz	P/W	G[dBi]	G	S [W/m^2]	r/m	r/cm
403000000	1	0	1.0	2.700	0.172	17.2
		4	2.5	2.700	0.272	27.2
		6	4.0	2.700	0.343	34.3
		8	6.3	2.700	0.431	43.1
		10	10.0	2.700	0.543	54.3
		12	15.8	2.700	0.683	68.3

		14	25.1	2.700	0.860	86.0

RSS-102 Issue 5

In accordance to RSS-102 Issue 5

Frequency Range /MHz	RF power density, controlled environment [W/m^2]	RF power density, general public/uncontrolled environment [W/m^2]
300 – 6000 MHz	$0.6455*f^{0.5}$ (1	$0.02619*f^{0.6834}$

f = frequency in MHz

(1 100 – 6000 MHz

Limits for power density according to table above:

Frequency Range /MHz	RF power density, controlled environment [W/m^2]	RF power density, general public/uncontrolled environment [W/m^2]
300 – 6000 MHz	15.8	1.6

Calculations

Controlled Environment						
f/Hz	P/W	G[dBi]	G	S [W/m^2]	r/m	r/cm
403000000	1	0	1.0	15.800	0.071	7.1
		4	2.5	15.800	0.112	11.2
		6	4.0	15.800	0.142	14.2
		8	6.3	15.800	0.178	17.8
		10	10.0	15.800	0.224	22.4
		12	15.8	15.800	0.283	28.3
		14	25.1	15.800	0.356	35.6

Uncontrolled Environment						
f/Hz	P/W	G[dBi]	G	S [W/m^2]	r/m	r/cm
403000000	1	0	1.0	1.600	0.223	22.3
		4	2.5	1.600	0.353	35.3
		6	4.0	1.600	0.445	44.5
		8	6.3	1.600	0.560	56.0

		10	10.0	1.600	0.705	70.5
		12	15.8	1.600	0.888	88.8
		14	25.1	1.600	1.118	111.8

Approximation of RF Exposure near to the antenna

Under near-field conditions of the antenna ($r < 2D^2/\lambda$), electric and magnetic field vectors are not perpendicular to each other and power density is then not equal to the scalar product of their amplitudes. A separate analysis is required for electric and magnetic field strength.

ICNIRP has set reference levels for electric and magnetic field strength, as well. They are listed in the tables below.

ICNIRP Reference Values on VHF/UHF for Electric Field Strength	Electric Field Strength, work-related exposure [V/m]	Electric Field Strength, population exposure [V/m]
10 – 400 MHz	61	2
400 – 2000 MHz	3E-3 x $f^{1/2}$	1.38E-3 x $f^{1/2}$

f is given in [Hz]

ICNIRP Reference Values on VHF/UHF for Magnetic Field Strength	Magnetic Field Strength, work-related exposure [A/m]	Magnetic Field Strength, population exposure [A/m]
10 – 400 MHz	0.16	0.073
400 – 2000 MHz	8.0E-6 x $f^{1/2}$	3.7E-6 x $f^{1/2}$

f is given in [Hz]

In the case the antenna is less than 20 cm from the body, safety analysis must be based on a direct examination of SAR inside the body. The examination can be performed, either by laboratory SAR measurements with a standardized physical body model, or by computer analysis with a numerical body model. As an example, IEC 62209-1 specifies the methods for SAR analysis in the case a mobile phone is kept near to ear.

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SUMMARY

- In conclusion the separation distance of at least 50 cm must be maintained between the antenna of radio modem and all persons.
- According to CFR part 47 $1.1310 the separation distance of at least 0.86 m must be maintained between the 14 dBi antenna of radio modem and all persons.
- According to RSS-102 Issue 5 the separation distance of at least 1.1 m must be maintained between the 14 dBi antenna of radio modem and all persons.