Appendix E: MOTOTRBO Repeater EME Assessment

NOTICE: The example in this Appendix applies for a UHF band system. For different frequency bands, applicable band-specific parameters should be employed to carry out the computations yielding band-specific compliance boundaries.

Executive Summary

Compliance is established with respect to the U.S. FCC regulations [11] in a typical system configuration of the MOTOTRBO SLR 1000 Repeater described in the following as derived.

A computational assessment was carried out to provide an estimation of the EME exposure and compliance distances relative to the FCC ID ABZ99FT4100, Model AAR11SDGANQ1AN with HKAE4003_, HKAE4004_, and HKAE4005_ antennas.

The following table provides the compliance distances for *general public* and *occupational-type* exposure, for the UHF frequency band, antenna, and parameters considered in this analysis, based on a typical system configuration:

Table 28: Indoor EME Compliance Distances Based on Example UHF Evaluation

Compliance distances	Peak 1-g Average SAR	Whole-Body SAR
General public exposure	40 cm	40 cm
Occupational-type exposure	40 cm (*)	40 cm (*)

Table 29: Outdoor EME Compliance Distances Based on Example UHF Evaluation

Compliance distances	Peak 1-g Average SAR	Whole-Body SAR
General public exposure	67 cm	67 cm
Occupational-type exposure	14 cm (*)	14 cm (*)

(*) This distance is very conservative and may be reduced significantly by carrying out a specific occupational exposure analysis. The present analysis comprises a single distance suitable for both exposure conditions.

Device Power Characteristics

The technical characteristics of the FCC ID ABZ99FT4100 Model AAR11SDGANQ1AN are as follows:

- Transmit Frequency Range: 400–527 MHz
- Maximum Power: 10 W
- Maximum Duty Cycle: 100%
- Antenna Information:
  - Frequency Range: 400–530 MHz
  - Monopole (17 cm)
  - Peak Gain: 4.1 dBi

Outdoor Exposure Prediction Model

This section describes how to determine the outdoor exposure model prediction of an antenna.

Whole-Body SAR Compliance

Full-wave and half-wave simulations are represented to show the exposure conditions.

The full-wave simulations based on the FDTD method were performed at 400 MHz and 470 MHz which includes the operating band of the evaluated antenna. The simulation code employed was XFDTD, version 7.3 by Remcom Inc., State College, PA. The exposed subject was modeled by a heterogeneous full body model standardized for SAR evaluation according to the IEC/IEEE 62704-2 draft standard [12].

The half-wave dipole antenna and maximum radiated power were used to represent the exposure condition. At each frequency, two individual simulations representing the exposure from the front and back at 40 cm distance from the dipole were conducted. No losses other than dissipation of RF energy inside the human body were assumed in the FDTD modeling, which provides an extra degree of overestimation.

Figure 42: H-Field and SAR Distributions for Exposure from a Dipole Antenna

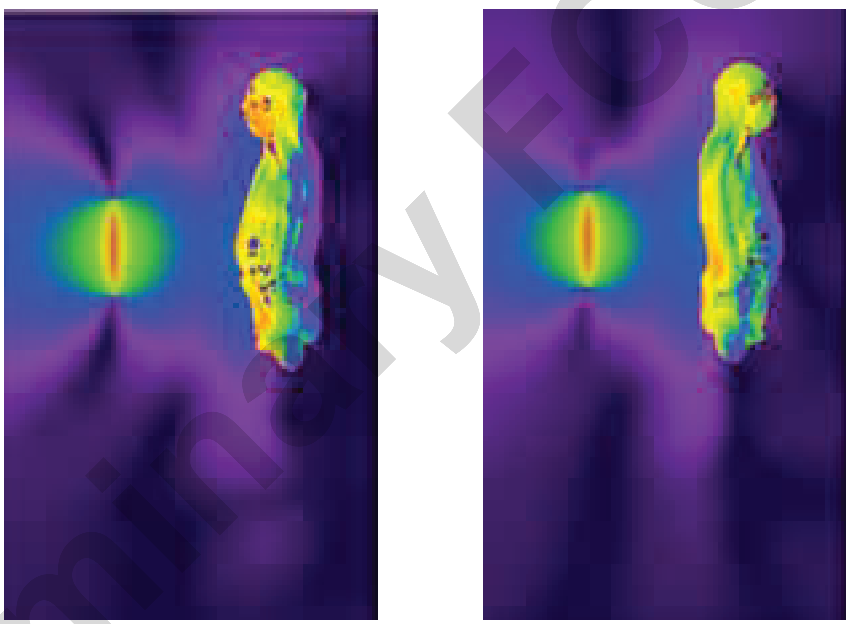


Table 30: Whole-Body Average SAR Results on page 100 presents the whole-body average SAR results for the simulated conditions at. To account for the actual measured antenna gain of 4.1 dBi which is higher than the half -wave dipole gain by factor of 1.57 the whole-body average results were scaled by that factor and are present in a separate column as adjusted whole-body SAR values alongside.

Table 30: Whole-Body Average SAR Results

Table Number	Frequency MHz	Antenna Position	Whole-Body SAR W/kg	Adjusted Whole-Body SAR, W/kg
1	400	Front	0.010	0.016

Table continued…

Table Number	Frequency MHz	Antenna Position	Whole-Body SAR W/kg	Adjusted Whole-Body SAR, W/kg
2	400	Back	0.012	0.019
5	470	Front	0.010	0.016
6	470	Back	0.012	0.019

The highest adjusted whole-body average SAR value from these simulations is 0.019 W/kg. This value is below the US FCC whole-body SAR limits for both controlled (occupational) and general public exposure environments, 0.4 W/kg and 0.08 W/kg, respectively.

Peak 1-g Average SAR Compliance

The maximum measured gain of the antenna is used in this assessment to produce the conservative evaluation of exposure in the operating condition of the radio.

The compliance relative to the US FCC limits for the peak 1-g average SAR [11] is evaluated at *p*=40 cm from the antenna by estimating an upper bound for said quantity. Evaluation of the peak power density at 40 cm distance is performed based on maxim radiated power *P* =10 W and maximum antenna gain G_{ant} = 4.1 dBi:

$$S_{40cm} \leq \left. \frac{P \cdot G_{ant}}{4\pi \cdot r^2} \right|_{\substack{P=10.7W \\ G_{ant}=10^{\wedge}(4.1/10) \\ r=0.4m}} = \frac{10 \cdot 10^{\frac{4.1}{10}}}{4\pi(0.4)^2} \frac{W}{m^2} < 12.8 \frac{W}{m^2} = 1.28 \frac{mW}{cm^2} \qquad (4)$$

Making the further conservative assumption that, at the point of maximum exposure, the whole impinging power over a cross-section equal to one face of a 1-g cube of tissue (an area equal to $1cm^2$ assuming that the tissue density is $1g/cm^3$) is absorbed by the body inside that cube, the following upper bound for the peak 1-g average SAR is derived.

$$SAR_{1-g} < \frac{S_{40cm} \cdot A_{cube}}{M_{cube}} = \frac{1.28 \frac{mW}{cm^2} \cdot 1cm^2}{1g} = 1.28 \frac{mW}{g} . \qquad (5)$$

This value is below the US FCC peak 1-g average SAR limits [11] for both controlled (occupational) and uncontrolled (general public) environments, 8 W/kg and 1.6 W/kg, respectively.

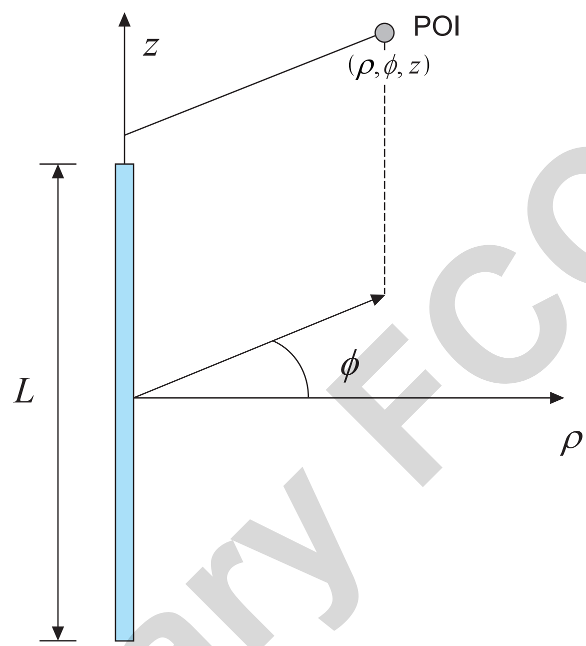
Indoor Exposure Prediction Model

This section describes how to determine the indoor exposure model prediction of an antenna or at ground level.

Exposure in Front of the Antenna

The cylindrical-wave model defined in Clause 8.3.4 of the EN50383:2010 standard is applied to determine the compliance boundaries for workers and general public for a typical system configuration of the SLR 1000 Repeater.

Figure 43: Reference Frame for the Point of Interest (POI) Cylindrical Co-Ordinates



Per the reference frame in Figure 43: Reference Frame for the Point of Interest (POI) Cylindrical Co-Ordinates on page 102, the cylindrical-wave model is applicable in the volume described in cylindrical co-ordinates (ρ, ϕ, z) for omni-directional array antennas as follows:

$$\hat{S}(r,\phi)=\frac{P}{\pi r L\cos^2\gamma\sqrt{1+\left(2\frac{r}{r_0}\right)^2}},\quad r_0=\frac{1}{2}D_A L\cos^2\gamma \qquad (1)$$

where

P
available power at the antenna port (W);

L
physical antenna length (metres);

D_A
peak antenna directivity (unit-less), assumed equal to the peak gain G_A;

γ
electrical down-tilt angle of the antenna main beam (radians), and

$$r=\frac{\rho}{\cos\gamma}$$

is the distance from the antenna center (metres). Spatial power density averaging may be required by some regulations. As the formula (1) predicts the peak power density, it represents a conservative estimate of the average power density. Thus there is no need to compute the latter.

Exposure at Ground Level

Several methods can be employed to determine the EME exposure at ground level.

Such an assessment is not necessary if the mounting height of the antenna is larger than the compliance distance in front of the antenna, computed using the EN50383:2010 methodology outlined in
Exposure in Front of the Antenna on page 102. If this is not feasible, then the following approach can be employed.

At ground level exposure occurs in the antenna far-field. The antenna phase center is assumed to be the mounting height. The resulting predictive equation for the power density is:

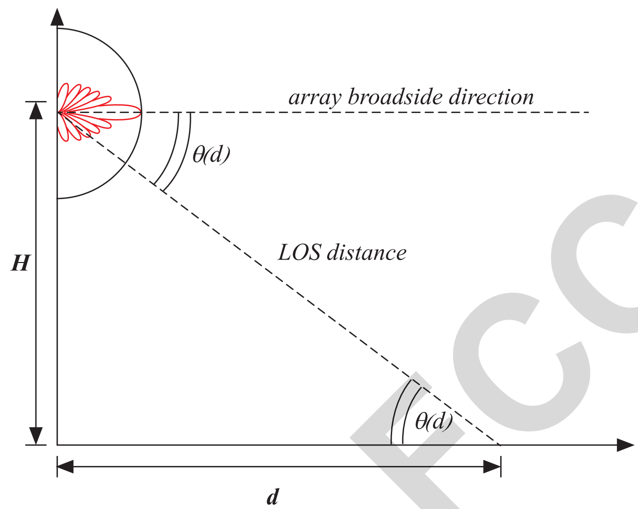
$$S(d)=(2.56)\frac{P\cdot G(\theta)}{4\pi(H^2+d^2)}$$

where $G(\theta)$ is the elevation gain pattern, which is approximated by the following expression:

$$G(\theta)=G_A\left|\frac{\sin\left(\frac{k_0L}{2}\sin\theta\right)}{\frac{k_0L}{2}\sin\theta}\right|^2$$

where $k_0 = 2\pi/\lambda$ is the free-space wavenumber and L is the effective antenna length yielding the appropriate vertical beamwidth, while H is the antenna height above ground and d is the point of interest (POI) distance from the vertical antenna projection to ground (see the following figure). The multiplicative factor 2.56 is introduced to enforce near-perfect, in-phase ground reflection as recommended in [2]. In this case, spatial averaging is not carried out to make the EME exposure assessment more conservative.

Figure 44: Schematic of the Ground-Level Exposure Model Adopted for the Assessment



Typical System Configuration

The SLR 1000 Repeater operates in different frequency ranges with different channels transmitting 10 W radio frequency (RF) power.

The typical system configuration comprises an omnidirectional array antenna featuring 6–10 dBd gain, installed at or above 20 m from ground level, and fed by the repeater through a combiner characterized by a typical 3 dB transmission loss, and a 30 m 7/8" coaxial cable characterized by a typical 2.7 dB/100m loss, resulting in a total 3.9 dB transmission loss. Based on these characteristics, the RF power at the antenna input is about 20 W.

Since shorter antennas provide a conservative EME exposure assessment from equation (1), when $r < r_0$, the parameters of a typical 6.6 dBd antennas are employed (it has to be verified that the resulting compliance distances are indeed smaller than r_0). Such an antenna (such as, Andrew DB408) would exhibit a typical elevation beamwidth of about 14 degrees.

Exposure Limits

Guidelines are used for the EME exposure assessment.

Based on the operating frequency range, the most conservative power density limits are those defined in the ICNIRP guidelines [1]. The guidelines are 10.1 W/m^2 for occupational exposure, and 2.02 W/m^2 for general public exposure.

EME Exposure Evaluation

This section describes how to evaluate the EME exposure of an antenna or at ground level.

Exposure in Front of the Antenna

The assessment is based on the following characteristics of the Andrew DB408 antenna:

$$G_A = 10^{\frac{6.6+2.15}{10}} = 7.5 \qquad P = 22.9\, W \qquad \gamma = 0 \qquad L = 2.7\, m$$

The parameter r_0 is thus $r_0 = 10.1m$. Upon inserting the power density limits established in Exposure Limits on page 104 into formula (1), the following distances for occupational and general public exposure compliance are respectively determined:

$$r_{occupational} = 14cm$$

and

$$r_{general\ public} = 67cm$$

As both these distances are less than r_0, the aforementioned choice (Typical System Configuration on page 104) of considering the shorter, lower gain antenna to perform the assessment is deemed valid. Longer, higher gain antennas would yield shorter compliance distances, for the same input antenna power and operating frequency range.

Exposure at Ground Level

Since the antenna installation height above ground level in the typical system configuration (20 m) is larger than either of the compliance distances determined in Exposure in Front of the Antenna, the EME exposure at ground level is always compliant with the exposure limits defined in the ICNIRP guidelines.

Compliance Boundary Description

Based on the analysis in EME Exposure Evaluation on page 105, the compliance boundaries for occupational and general public exposure are defined as cylinders enclosing the antenna (see Figure 45: Compliance Boundary for General Public (GP) and Ocupational (OCC) Exposure on page 106), extending 75 cm (one wavelength) above and below the physical antenna, with radii:

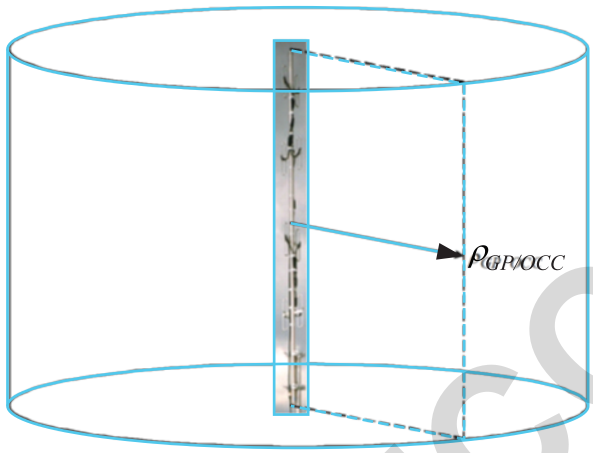
Occupational exposure:

$$\rho_{OCC} = 2.15\, m$$

General Public exposure:

$$\rho_{GP} = 6.9\ m$$

Figure 45: Compliance Boundary for General Public (GP) and Ocupational (OCC) Exposure



Product Put In Service

Some regulations require that additional exposure assessments be performed when putting the product in service, to account for antenna site-specific circumstances such as the environment (such as, electromagnetic scatterers) and other antennas. In such cases, certain standards [7]–[10] may need to be considered to determine the most suitable compliance assessment methodology.

References

1 International Commission on Non-Ionizing Radiation Protection (ICNIRP), "Guideline for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields", Health Physics, vol. 74, no. 4, pp. 494-522, April 1998.

2 United States Federal Communication Commission, "Evaluating compliance with FCC guidelines for human exposure to radio frequency electromagnetic fields", OET Bulletin 65, Ed. 97-01, Section 2 (Prediction Methods), August 1997.

3 US Code of Federal Regulations, Title 47, Volume 1, Sec. 1.1310 Radio frequency radiation exposure limits (Revised as of October 1, 2003). http://edocket.access.gpo.gov/cfr_2003/octqtr/47cfr1.1310.htm.

4 EN 50383:2010. Basic standard for the calculation and measurement of electromagnetic field strength and SAR related to human exposure from radio base stations and fixed terminal stations for wireless telecommunication systems (110 MHz–40 GHz). CENELEC (European Committee for Electrotechnical Standardization).

5 EN 50384:2002. Product standard to demonstrate the compliance of radio base stations and fixed terminal stations for wireless telecommunication systems with the basic restrictions or the reference levels related to human exposure to radio frequency electromagnetic fields

(110 MHz–40 GHz). Occupational. CENELEC (European Committee for Electrotechnical Standardization).

6 EN 50385:2002. Product standard to demonstrate the compliance of radio base stations and fixed terminal stations for wireless telecommunication systems with the basic restrictions or the reference levels related to human exposure to radio frequency electromagnetic fields (110 MHz–40 GHz). General public. CENELEC (European Committee for Electrotechnical Standardization).

7 EN 50401:2006. Product standard to demonstrate the compliance of fixed equipment for radio transmission (110 MHz–40 GHz) intended for use in wireless telecommunication networks with the basic restrictions or the reference levels related to general public exposure to radio frequency electromagnetic fields, when put into service. CENELEC (European Committee for Electrotechnical Standardization).

8 EN 50400:2006. Basic standard to demonstrate the compliance of fixed equipment for radio transmission (110 MHz–40 GHz) intended for use in wireless telecommunication networks with the basic restrictions or the reference levels related to general public exposure to radio frequency electromagnetic fields, when put into service. CENELEC (European Committee for Electrotechnical Standardization).

9 EN 50492:2008. Basic standard for the in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations. CENELEC (European Committee for Electrotechnical Standardization).

10 IEC 62232:2011. Determination of RF field strength and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure. IEC (International Electrotechnical Commission).

11 United States Federal Communication Commission, “Evaluating compliance with FCC guidelines for human exposure to radio frequency electromagnetic fields,” OET Bulletin 65 (Ed. 97-01), August 1997. Supplement C (Edition 01-01) to US FCC OET Bulletin 65 (Edition 97-01), “Additional Information for Evaluating Compliance of Mobile and Portable Devices with FCC Limits for Human Exposure to Radio frequency Emissions,” June 2001.

12 IEC/IEEE 62704-2, Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz – Part 2: Specific requirements for finite difference time domain (FDTD) modeling of exposure from vehicle mounted antennas. Draft, Dec 11, 2015.