Appendix E

MOTOTRBO Repeater EME Assessment

NOTE: The examples in this Appendix apply to a UHF band system configuration. For different frequency bands, applicable band-specific parameters should be employed to carry out the computations yielding band-specific compliance boundaries.

E.1

Executive Summary

Compliance versus EME (Electromagnetic Energy Exposure) limits is established with respect to the ICNIRP guidelines [1] and U.S. FCC regulations [2-3] in a typical system configuration of the MOTOTRBO SLR 1000 Repeater described in the following.

A computational assessment was carried out to provide an estimation of the EME exposure and compliance distances relative to the SLR 1000 Repeater Model FCC ID ABZ99FT3096 AAR11JDGANQ1AN and FCC ID ABZ99FT4100, Model AAR11SDGANQ1AN) equipped with HKAD4003, HKAD4004, HKAD4005, HKAE4003, HKAE4004, or HKAE4005 antennas for indoor installation and with the Andrew DB408-B antenna for outdoor installations.

The following tables provide the compliance distances for *general public* and *occupational-type* exposure, for the UHF frequency band, antennas, and other relevant parameters considered in this analysis of typical system configurations:

Table 27: Indoor EME Compliance Distances Based on the UHF Evaluation Example (applicable antennas: HKAE4003, HKAE4004, and HKAE4005)

Exposure Condition	Based on the Peak 1-g SAR FCC Limit	Based on the Peak 10-g SAR ICNIRP Limit	Based on the Whole-Body SAR Limit
General public exposure	46 cm	20 cm	20 cm
Occupational-type exposure	20 cm	20 cm	20 cm

Table 28: Outdoor EME Compliance Distances Based on the UHF Evaluation Example (applicable antenna: DB408-B)

Exposure Condition	Based on the Peak 1-g SAR FCC Limit	Based on the Peak 10-g SAR ICNIRP Limit	Based on the Whole-Body SAR Limit
General public exposure	20 cm	20 cm	20 cm
Occupational-type exposure	20 cm	20 cm	20 cm

The compliance distances in the preceding tables were derived based on the applicable IEC 62232:2017 standard [10] Specific Absorption Rate (SAR) prediction formulas. In several cases, the derived distance of 20 cm is very conservative because it is a minimum distance for the validity of the mentioned SAR formulas [10]. This distance may be reduced significantly for occupational-type exposure conditions by carrying out an analysis based on SAR measurements.

Table 29: Indoor EME Compliance Distances Based on the VHF Evaluation Example (applicable antenna:HKAD4003, HKAD4004 and HKAD4005)

Exposure Condition	Based on the ICNIRP reference Levels and FCC MPE Limits
General public exposure	59 cm
Occupational-type exposure	27 cm

The compliance distances in the table above were derived based on the applicable IEC 62232:2017 standard [10] and U.S. FCC OET Bulletin [2[power density prediction formulas. These formulas are conservative and the distance may be reduced by carrying out analysis based on SAR measurements.

E.2

Device Characteristics

The technical characteristics of the Model FCC ID ABZ99FT3096 AAR11JDGANQ1AN and FCC ID ABZ99FT4100 AAR11SDGANQ1AN are as follows:

- Transmit Frequency Range: 136-174 MHz and 400–512 MHz
- Maximum Power: 10 W
- Maximum Duty Cycle: 100%
- Antenna Information is summarized in the following table:

Table 30: Antenna Characteristics

Kit or Model Number	Frequency MHz	Type	Peak Gain dBi	Length m	3 dB Elevation Beamwidth, deg	3 dB Azimuth Beamwidth, deg
HKAD4003	136-154	monopole	-1.8	0.49*	100	Omni
HKAD4004	146-164	monopole	-1.3	0.49*	100	Omni
HKAD4005	160-174	monopole	-0.6	0.49*	100	Omni
HKAE4003	400-460	monopole	3.4	0.40*	60	Omni
HKAE4004	440-495	monopole	3.2	0.40*	60	Omni
HKAE4005	490-530	monopole	3.4	0.40*	60	Omni
DB408-B	450-470	linear array	8.7	2.70	14	Omni

* This length represents the overall length of the MOTOTRBO SLR 1000 Repeater with the attached monopole antenna.

E.3
Exposure Prediction Model

This section describes the EME exposure prediction model based on a SAR evaluation. In the UHF band and based on reference levels and FCC Maximum Permissible Exposure (MPE) limits in the VHF band.

E.3.1
SAR Evaluation Formulas

The EME exposure prediction model is based on Clause B.4.2.2 of the IEC 62232:2017 standard, which defines a computational method for evaluating the whole-body average and localized SAR values to establish a conservative compliance distance from an antenna. Specifically, the formulas B.28, B.29, and B.30 from this standard were employed in the evaluation of typical system configurations of the SLR 1000 Repeater.

$$SAR_{\mathrm{wb}}^{\mathrm{a,ch}} = C(f) \cdot \frac{H_{\mathrm{eff}}}{\tilde{A}^{\mathrm{a,ch}}\ \tilde{B}^{\mathrm{a,ch}}} \cdot \frac{\overline{P}_{\mathrm{avg}}}{\phi_{\mathrm{3dB}} \cdot L \cdot d} \cdot \left[1 + \left(\frac{4 \cdot \pi \cdot d}{\phi_{\mathrm{3dB}} \cdot D \cdot L}\right)^2\right]^{-1/2} \qquad \text{(B.28)}$$

$$SAR_{\mathrm{10g}} = 25 \cdot SAR_{\mathrm{wb}}^{\mathrm{a}} \cdot \frac{\tilde{B}}{H_{\mathrm{eff}}} \cdot \frac{1}{R_{\mathrm{wb/10g}}} \qquad \text{(B.29)}$$

$$SAR_{\mathrm{1g}} = 20 \cdot SAR_{\mathrm{wb}}^{\mathrm{a}} \cdot \frac{\tilde{B}}{H_{\mathrm{eff}}} \cdot \frac{1}{R_{\mathrm{wb/1g}}} \qquad \text{(B.30)}$$

where

$SAR_{\mathrm{wb}}^{\mathrm{a,ch}}$ denotes the whole-body SAR evaluated for adults, $SAR_{\mathrm{wb}}^{\mathrm{a}}$, or children, $SAR_{\mathrm{wb}}^{\mathrm{ch}}$;

$\tilde{A}^{\mathrm{a,ch}}$ equals $\tilde{A}^{\mathrm{a}}$ = 0,089 m for adults and $\tilde{A}^{\mathrm{ch}}$ = 0,06 m for children;

$\tilde{B}^{\mathrm{a,ch}}$ equals $\tilde{B}^{\mathrm{a}}$ = 1,54 m for adults and $\tilde{B}^{\mathrm{ch}}$ = 0,96 m for children;

d is the closest distance measured in metres from the antenna element to the evaluation point. If the distance to the antenna elements is not known, d may be taken consercatively as the distance to the antenna radome;

H_{eff} is the effective height of the body measured in metres;

L is the physical antenna array length measured in metres. The individual antenna lengths for each band shall be used for antennas covering more than one band;

$$R_{\mathrm{wb/10g}} = \begin{cases} 1{,}5 & 300\,\mathrm{MHz} < f \le 2{,}5\,\mathrm{GHz} \\ 1 & 2{,}5\,\mathrm{GHz} < f < 5\,\mathrm{GHz} \end{cases}$$

$$R_{\mathrm{wb/1g}} = \begin{cases} 0{,}6 & 300\,\mathrm{MHz} < f \le 2{,}5\,\mathrm{GHz} \\ 0{,}3 & 2{,}5\,\mathrm{GHz} < f < 5\,\mathrm{GHz} \end{cases}$$

H_{eff} shall be ecaluated using

$$H_{\mathrm{eff}} = \begin{cases} L & H_{\mathrm{beam}} < L \text{ AND } H_{\mathrm{beam}} < \tilde{B} \\ H_{\mathrm{beam}} & L \le H_{\mathrm{beam}} < \tilde{B} \\ \tilde{B} & \tilde{B} \le H_{\mathrm{beam}} \\ \tilde{B} & \tilde{B} \le L \end{cases}$$

where

$H_{\mathrm{beam}} = 2 \cdot d \cdot \tan(\theta_{3\mathrm{dB}} / 2)$

Table B.17 – Definition of $C(f)$

f MHz	$C(f,d)$ 10^{-4} m³/kg	
300 to 900	$\left(3{,}5 + \frac{f - 300}{600}\right)\left(1 + \frac{0{,}8d}{400}\right)$	for 200mm $\le d \le$ 400mm
	$6{,}3 + \left(\frac{f - 300}{600}\right)1{,}8$	for d > 400mm
900 to 5 000	$4{,}5\left(1 + \frac{0{,}8d}{400}\right)$	for $d \le$ 400mm
	8,1	for d > 400mm

As shown, the formulas are valid for a specific frequency range and distances. Based on the device and antenna characteristics the formulas are valid for evaluation of the upper bounds of localized and whole-body average SAR for exposures within the main beam of the antenna (front direction). Since this represents the most conservative exposure condition, the front direction compliance distance is also applied for all other directions to define conservative compliance boundaries in those directions.

E.3.2
Implementation and Validation of SAR Formulas

Formulas B.28, B.29, and B.30 from the IEC 62232:2017 standard were implemented in Mathcad 15.0 software as shown in the following formula with highlighted items being the input antenna parameters.

$$\text{Pavg} := 10 \qquad \varphi\_3dB := 360\frac{\pi}{180} \qquad \theta\_3dB := 60\frac{\pi}{180} \qquad D := 10^{\frac{3.4}{10}} \qquad Aa := 0.089$$

$$f := 530 \qquad Ach := 0.06$$

$$d := 0.46 \qquad L := 0.4 \qquad Ba := 1.54$$

$$Bch := 0.96$$

$$A := Aa \qquad \text{Hbeam} := 2\cdot d\cdot \tan\left(\frac{\theta\_3dB}{2}\right)$$

$$B := Ba$$

$$\text{Rwb10g} := \begin{cases} 1.5 & \text{if } (300 < f) \wedge (f \le 2500) \\ 1 & \text{if } (2500 < f) \wedge (f < 5000) \end{cases} \qquad \text{Rwb1g} := \begin{cases} 0.6 & \text{if } (300 < f) \wedge (f \le 2500) \\ 0.3 & \text{if } (2500 < f) \wedge (f < 5000) \end{cases}$$

$$\text{Heff} := \begin{cases} L & \text{if } (\text{Hbeam} < L) \wedge (\text{Hbeam} < B) \\ \text{Hbeam} & \text{if } (L \le \text{Hbeam}) \wedge (\text{Hbeam} < B) \\ B & \text{if } B \le \text{Hbeam} \\ B & \text{if } B \le L \end{cases}$$

$$C := \begin{cases} \left[3.5 + \frac{(f-300)}{600}\right]\left(1 + \frac{0.8d}{0.400}\right)\cdot 10^{-4} & \text{if } (0.2 \le d) \wedge (d \le 0.4) \wedge (300 \le f) \wedge (f < 900) \\ \left[6.3 + \frac{(f-300)}{600}\cdot 1.8\right]\cdot 10^{-4} & \text{if } (d > 0.4) \wedge (300 \le f) \wedge (f < 900) \\ \left[4.5\left(1 + \frac{0.8d}{0.400}\right)\right]\cdot 10^{-4} & \text{if } (0.2 \le d) \wedge (d \le 0.4) \wedge (900 \le f) \wedge (f \le 5000) \\ 8.1\cdot 10^{-4} & \text{if } (d > 0.4) \wedge (900 \le f) \wedge (f \le 5000) \end{cases}$$

$$SAR\_WB := C \cdot \frac{Heff}{Aa \cdot Ba} \cdot \frac{Pavg}{\varphi\_3dB \cdot L \cdot d} \cdot \left[1 + \left(4 \cdot \pi \cdot \frac{d}{\varphi\_3dB \cdot D \cdot L}\right)^2\right]^{-0.5}$$

$$SAR1g := 20 \cdot SAR\_WB \cdot \frac{B}{Heff} \cdot \frac{1}{Rwb1g}$$

$$SAR10g := 25 \cdot SAR\_WB \cdot \frac{B}{Heff} \cdot \frac{1}{Rwb10g}$$

The validation of this implementation was performed according to IEC 62232:2017 standard using the test input parameters from the following table of the standard:

- RF Power: 1 W
- Antenna Length: 1.3 m
- Gain: 18 dBi
- 3 dB elevation beamwidth: 6.5 deg
- 3 dB azimuth beamwidth: 65 deg
- Frequency: 2140 MHz

The SAR results computed using this implementation of the IEC 62232:2017 standard formulas B.28, B.29, and B.30, and a body mass of 46 kg agree with all the applicable reference results from the IEC 62232:2017 standard and are summarized in the following table. Therefore according to the standard, the implementation passes the validation test.

Table 31: Reference and Validation Results

Front Exposure (within main beam)		Separation Distance from the Antenna					
		0.2 m	**1 m**	**5 m**	**10 m**	**15 m**	**20 m**
SAR_{10g} [W/kg/W]	IEC 62232:2017 reference	0.40	0.10	0.017	0.0061	0.003	0.0018
	As implemented	*0.400*	*0.102*	*0.0170*	*0.00612*	*0.0030*	*0.00179*
SAR_{WB} [W/kg/W]	IEC 62232:2017 reference	0.020	0.0052	0.00086	0.00031	0.00018	0.00011
	As implemented	*0.0200*	*0.00516*	*0.000863*	*0.000310*	*0.000182*	*0.000107*

E.3.3
Equivalent Plane Wave Power Density Evaluation

Compliance evaluation with respect to the ICNIRP reference levels and U.S. FCC MPE limits in the VHF band is based on the IEC 62232:2017 standard clause B.4.2.1 for estimating the spatial-peak equivalent plane wave power density. Similar approach is also described in US FCC OET Bulletin [2]. Specifically the spherical formula B.15 from IEC 62232:2017 standard is used to calculate the spatial-peak equivalent power density:

$$S = \frac{P_{avg}\,G}{4\,\pi r^2}$$

where,

P_{avg} is power input to the antenna

G is peak power gain of the antena

R is the distance to the antenna

It should be noted that this formula is generally accurate in the far field region, however, as explained in section "Equations for Predicting RF Fields" in [2], it tends to over-predict power density in the near field and therefore can be used for making a conservative prediction.

E.4

Exposure Limits

Applicable guidelines and regulations are referenced for the EME exposure assessment. The SAR limits are those defined in the ICNIRP guidelines [1] and U.S. FCC regulations [2-3].

The ICNIRP guidelines are 10 W/kg for the peak spatially averaged SAR over 10 g and 0.4 W/kg for the whole-body average SAR in occupational-type exposure conditions, and 2.0 W/kg for the peak spatially averaged SAR over 10 g and 0.08 W/kg for the whole-body average SAR in general public exposure conditions.

The U.S. FCC regulations feature 8 W/kg for the peak spatially averaged SAR over 1 g and 0.4 W/kg for the whole-body average SAR in occupational-type exposure conditions, and 1.6 W/kg for the peak spatially averaged SAR over 1 g and 0.08 W/kg for the whole-body average SAR in general public exposure conditions.

The ICNRIP guidelines also define the reference levels and U.S. FCC regulations define the MPE limits in terms of equivalent plane wave power density. In the applicable VHF frequency range (136-174 MHz) it is $10 W/m^2$ in occupational-type exposure conditions and $2 W/m^2$ in general public exposure conditions.

E.5

EME Exposure Evaluation

The employed exposure evaluation method and results are equally applicable to both indoor and outdoor exposure conditions even though particular antenna models are meant specifically for only indoor (HKAD4003, HKAD4004, HKAD4005, HKAE4003, HKAE4004, and HKAE4005) or only outdoor (Andrew DB408-B) installation.

For each antenna models the maximum operating frequency and maximum RF power was used in SAR evaluation to produce the most conservative estimate of exposure within the respectively applicable frequency band. The distance from the antenna was minimized to arrive at the maximum exposure condition where SAR is still below the compliance limit. In many instances, however, even at the minimum formula validity distance of 20 cm, the SAR values are very small, especially for the occupational-type exposure limits. In those cases, this minimum distance of 20 cm was used to define the conservative compliance boundary.

Table 32: Compliance Distance in General Public Exposure (UHF) on page 125 shows the compliance distance for each evaluated UHF antenna in general public exposure condition alongside

the corresponding peak 1-g average and whole-body average SAR values derived from the IEC 62232:2017 formulas and applicable to evaluation of EME compliance with U.S. FCC regulations.

Table 32: Compliance Distance in General Public Exposure (UHF)

Antenna Kit or Model Number	Evaluation Frequency (MHz)	Compliance Distance (m)	Peak 1-g Average SAR (W/kg)	Whole-Body Average SAR (W/kg)
HKAE4003	460	0.45	1.57	0.016
HKAE4004	495	0.45	1.55	0.016
HKAE4005	530	0.46	1.56	0.016
Andrew DB408-B	470	0.20	0.59	0.018

Table 33: Compliance Distance in Occupational-Type Exposure (UHF) on page 125 shows the corresponding distances for occupational-type exposure conditions in UHF band.

Table 33: Compliance Distance in Occupational-Type Exposure (UHF)

Antenna Kit or Model Number	Evaluation Frequency (MHz)	Compliance Distance (m)	Peak 1-g Average SAR (W/kg)	Whole-Body Average SAR (W/kg)
HKAE4003	460	0.20	3.57	0.028
HKAE4004	495	0.20	3.60	0.028
HKAE4005	530	0.20	3.68	0.029
Andrew DB408-B	470	0.20	0.59	0.018

Table 34: Compliance Distance in General Public Exposure and Occupational-Type Exposure (UHF) on page 125 shows the compliance distance for each evaluated UHF antenna applicable to general public exposure and occupational-type exposure conditions and evaluated against the ICNIRP limits alongside the corresponding peak 10-g average and whole-body average SAR values.

Table 34: Compliance Distance in General Public Exposure and Occupational-Type Exposure (UHF)

Antenna Kit or Model Number	Evaluation Frequency (MHz)	Compliance Distance (m)	Peak 10-g Average SAR (W/kg)	Whole-Body Average SAR (W/kg)
HKAE4003	460	0.20	1.79	0.028
HKAE4004	495	0.20	1.80	0.028
HKAE4005	530	0.20	1.84	0.029
Andrew DB408-B	470	0.20	0.28	0.018

Table 35: Compliance Distance in General Public Exposure (VHF) on page 126 shows the compliance distance for each evaluated VHF antenna applicable to general public exposure conditions and evaluated against the ICNIRP reference levels and FCC MPE limits alongside the corresponding peak equivalent plane wave power density values.

Table 35: Compliance Distance in General Public Exposure (VHF)

Antenna Kit or Model Number	Evaluation Frequency (MHz)	Compliance Distance (m)	Equivalent plane wave power density (W/m^2)
HKAD4003	136-154	0.52	1.94
HKAD4004	146-164	0.55	1.95
HKAD4005	160-174	0.59	1.99

Table 36: Compliance Distance in Occupational-Type Exposure (VHF) on page 126shows the compliance distance for each evaluated VHF antenna applicable to occupational-type exposure conditions and evaluated against the ICNIRP reference levels and FCC MPE limits alongside the corresponding peak equivalent plane wave power density values.

Table 36: Compliance Distance in Occupational-Type Exposure (VHF)

Antenna Kit or Model Number	Evaluation Frequency (MHz)	Compliance Distance (m)	Equivalent plane wave power density (W/m^2)
HKAD4003	136-154	0.23	9.9
HKAD4004	146-164	0.25	9.4
HKAD4005	160-174	0.27	9.5

E.6

Compliance Boundary Description

The compliance boundary is defined as all surfaces of a cylinder surrounding the antenna with the minimum separation distance from the antenna established by the compliance distance from the proceeding tables in EME Exposure Evaluation on page 124. If there is an antenna attached to the repeater (indoor installation), the repeater enclosure is considered as part of the antenna.

For EME Exposure Evaluation in UHF band performed with respect to the U.S. FCC Regulation, this compliance distance for indoor installation is 46 cm for General Public exposure conditions and 20 cm for occupational-type exposure conditions. For the outdoor installations, the compliance distance is 20 cm for both general public and occupational-type exposure conditions.

For EME Exposure Evaluation in UHF band performed with respect to the ICNIRP guidelines, the compliance distance is 20 cm for indoor and outdoor installations and is applicable to both general public and occupational-type exposure conditions.

It should be noted that based on the foregoing analysis, the 20 cm distance is conservative for occupational exposure and may be reduced significantly by carrying out SAR measurements.

For the EME Exposure Evaluation in VHF performed with respect to both the ICNIRP guidelines and U.S. FCC Regulation, this compliance distance is 59 cm for General Public exposure conditions and 27 cm for occupational-type exposure conditions.

E.7

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 (for example, 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.

E.8
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 50385:2017. 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 62232:2017. Determination of RF field strength and SAR in the vicinity of radio communication 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.