Research and Technical Services

Core-Transport Technology

CTT-0024 Core-TT Pallet tag RF emissions measurements

Final Deliverable Report

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Revision history

Date	Version	Notes
27 Mar 19	1.0	Initial release

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Executive summary

This report presents RF emissions measurements of a Core-TT pallet tag. During the measurements the RTCA/DO-160G [1] methodology and test set up conditions were followed where possible.

The EUT is a battery operated BLE tag programmed to act as a BLE central device. It turns on its radio receiver for a short amount of time. If no BLE advertisements of a reader (BLE peripheral) are received the receiver is turned off again. This is called the ‘passive’ mode in this report. If BLE advertisements of the reader are received, then the tag will start a connection by transmitting on the BLE frequencies. This is called the ‘active’ mode in this report.

RTCA/DO-160G requirements only concern unintended RF emissions. It explicitly excludes intentional transmissions.

Measurement methodology, setup and results are presented and compared to RTCA/DO-160G section 21 Category H maximum allowed emission levels.

In passive mode, for which RTCA/DO-160G is applicable, the RF emissions of the EUT remain below Section 21 category H levels.

In active mode the measured RF emissions do not exceed the RTCA/DO-160G section 21 Category H levels because RTCA/DO-160G is not applicable in that mode. In this mode, measurements could only be done while both EUT and reader were present. The measurement graphs presented show excursions around 2.45 GHz which are caused by the intentional reader and EUT BLE transmissions.

1 Project and report details

1.1 Project Name
SOW11 Task 108 Pallet tag emissions measurement.

1.2 Project Manager
Marco Meijer.

1.3 Deliverable
This report is the deliverable report under SOW11 Task 108 Pallet tag emissions measurement.

1.4 Author
Marco Meijer

2 Introduction

Core-TT has designed an asset tracking system using readers and tags based on Bluetooth Low Energy (BLE). A tag only transmits when it receives a BLE advertisement that is transmitted by a reader. When the tag cannot detect this advertisement, i.e. when it is too far from the reader or shielded from the reader, it will not transmit, it will only receive. This behaviour is defined by the software that runs in the tag. Core-TT developed two tag models; a standard tag and a pallet tag.

The RTCA/DO-160 standard [1] sets out a procedure for measuring the unintended RF emissions of a device. Core-TT has contracted Callaghan Innovation to measure the RF emissions from a pallet tag when it is near a reader and when it is not near a reader, according to the conditions and test procedures for airborne equipment that are set out in RTCA/DO-160.

Section 3 describes the Equipment under Test, followed by section 4 which presents the methodology and section 5 describing the test setup. Sections 6 and 7 present the results and conclusions respectively. Where possible the DO-160 methodology and test set up conditions have been followed.

3 Equipment under Test (EUT) description

The EUT is a small (approximately 11x4x2 cm) battery-operated device with no connectors or cables in a plastic enclosure with clip-on metal brackets (Figure 1). The device is also called ‘pallet tag’. The pallet tag is programmed to be a Bluetooth Low Energy (BLE) Central device. It periodically turns its BLE radio receiver on for a short amount of time. If it receives a valid BLE advertisement transmission from a reader (a BLE peripheral which will be introduced shortly), then it will transmit to connect to the reader and exchange data.

BLE transmissions are between 2400 and 2483.5 MHz using a frequency hopping scheme.

The reader is a device that normally has a fixed location in e.g. a warehouse. The reader contains a BLE radio programmed to be a peripheral and to transmit advertisements very often. The reader also contains a cellular modem.

After a connection between tag (EUT) and reader is established and the data exchange is completed, the tag then goes to sleep and doesn’t respond to advertisements for a period.

The maximum distance between reader and tag for a connection to be established has been experimentally determined to be up to approximately 100 metres.

Figure 1 Photograph of the pallet tag (EUT).

4 Methodology

All measurements were done in an RF anechoic chamber with measurement antennas and a spectrum analyser.

4.1 Active and Passive EUT

In this report, the measured RF emissions from the EUT are presented where the EUT is in one of two different states:

1. Passive: the measurement setup emulates the situation where a tag cannot receive transmissions from a reader, e.g. when it is in an aircraft hold or out of range of a reader.
2. Active: the measurement setup emulates the situation where a tag receives transmissions from a reader and subsequently transmits itself.

4.1.1 Passive

For this measurement, only the EUT was put onto a wooden pedestal.

A measurement antenna was set up on a wooden tripod at a distance of 1 metre from the EUT. The antenna was aligned to be horizontal at the same height as the EUT and aiming at the EUT.

The RF anechoic room was closed to ensure that the EUT would not receive any transmissions from the reader and to prevent recording external RF radiation.

The emissions were then measured and stored using a spectrum analyser.

To determine any background RF emissions, another measurement was done in the room with the same measurement antenna while it was empty, i.e. no EUT or reader was present in the room. The background RF emissions were subtracted from the recorded EUT in passive mode measurements.

4.1.2 Active

To determine the RF emissions of the EUT when it is active both EUT and reader need to be placed in the RF anechoic chamber because the EUT will only transmit if it can receive BLE advertisements from a reader.

To determine only the emissions from the EUT (and suppress the emissions from the reader) a reader-only measurement was done first. Then the reader and tag were placed in the room and the emissions from both reader and tag were measured. The reader-only emissions were then subtracted from the reader-and-tag emissions.

The EUT was set up as described under ‘passive’ above. The reader was placed behind the measurement antenna to use the front to back ratio (> 15 dB) of the antennas to suppress the reader emissions as much as possible.

5 Measurement setup

5.1 Equipment setup

Figure 2, Figure 3 and Figure 4 show the equipment setup for the measurements. The EUT, antenna and, where used, the reader were placed in an RF anechoic chamber. The spectrum analyser is placed outside the room and is connected to the measurement antenna through a cable.

The EUT is a battery-operated device and has no connectors. It operates autonomously, hence, no connections are needed from the EUT.

The antenna is placed 1 metre from the EUT. The EUT is placed upon a wooden pedestal. The antenna is placed on a wooden tripod and levelled[1]. The antenna height is adjusted so that it is pointing at the centre of the EUT.

For the measurements, a Rohde & Schwarz FSW-13 spectrum analyser and two measurement antennas were used:

- Rohde & Schwarz HL223 Log periodic dipole antenna which is calibrated from 200 MHz to 1.3 GHz
- EMCO 3115 Double Ridged waveguide horn which is calibrated from 1 GHz to 18 GHz.

The reader is placed behind the antenna, to make use of the high front to back ratios (> 15 dB) of the measurement antennas

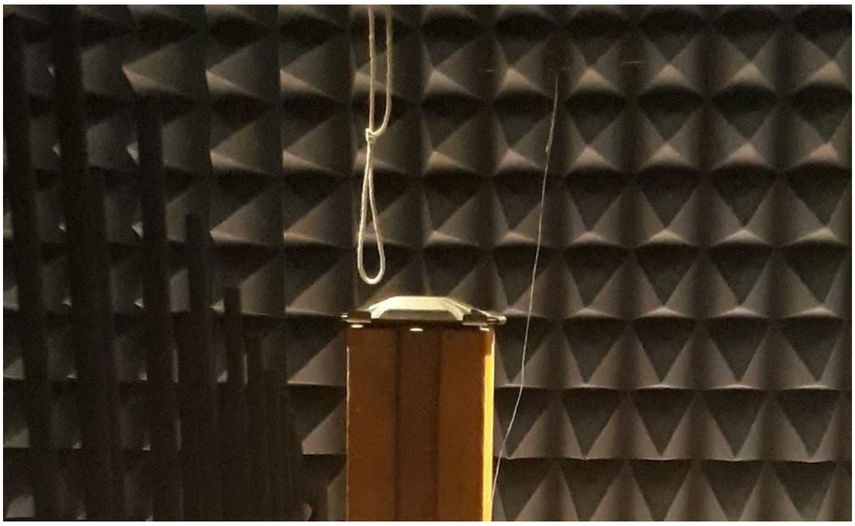

Figure 2 Photograph illustrating the measurement setup. The EUT can be seen in the middle of the picture on top of the wooden pedestal.

[1] This setup differs from [1] where a $2m^2$ ground plane is prescribed.

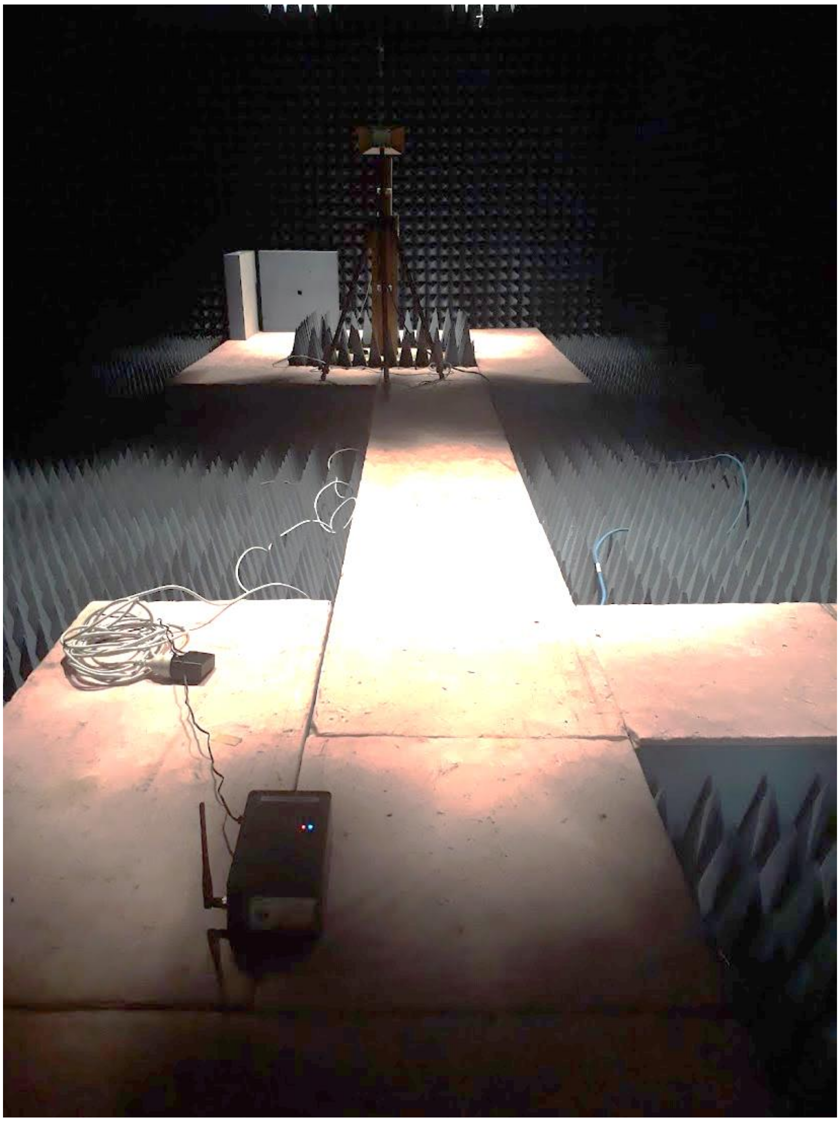

Figure 3 Photograph illustrating the measurement setup. The EUT is at the end of the room on top of the wooden pedestal. The tripod with measurement antenna is just visible. The reader is 4.2 m behind the measurement antenna.

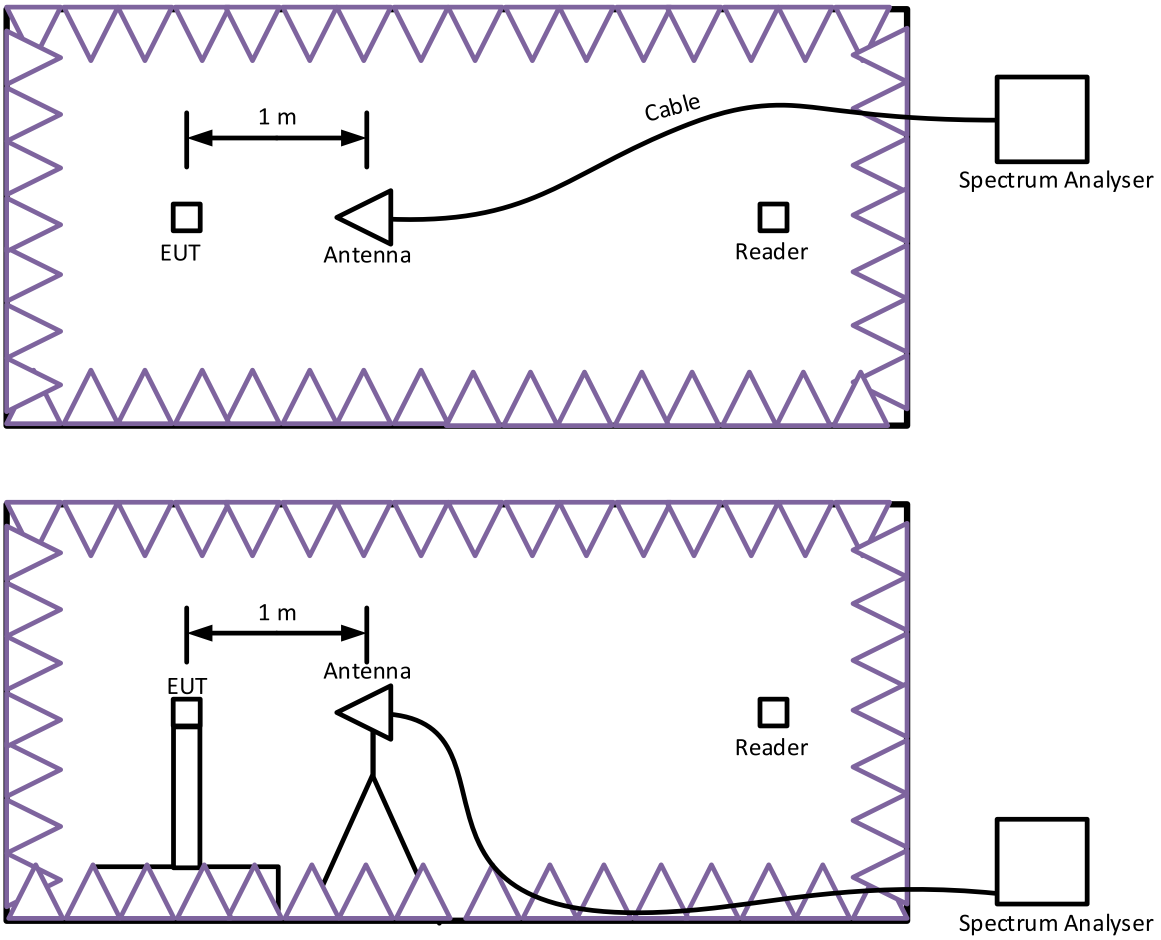

Figure 4 Test setup. Top diagram shows top view and the bottom diagram shows side view.

5.2 Measurements

For the measurements [1] was followed where possible.

No conducted RF emissions ([1], section 21.4) were measured as there are no cables connected to the EUT.

Radiated RF emissions ([1], section 21.5) were measured from 100 MHz to 6000 MHz for the following situations:

- No EUT and no reader in the room: this establishes a background RF measurement.
- Only the EUT in the room: in this situation the EUT is passive; it does not transmit.
- Only the reader in the room: this establishes an RF measurement of the radiation of the reader only. This includes BLE advertisements and reader attempts to connect to the cellular network.
- Both EUT and reader in the room: in this situation the EUT is active but also the reader transmits.

Radiated RF emissions were measured using the two antennas described above, for the appropriate frequency ranges:

- HL223 was used for the frequency range 100 MHz 960 MHz[2]
- EMCO 3115 was used for the frequency range 960 MHz to 6 GHz[3]

All measurements were done for both horizontal and vertical polarisation.

Cable attenuation was measured (see also Appendix C and VSWR of cable with antenna was verified.

5.3 Spectrum analyser settings

[1] section 21.3 was followed to determine the FSW-13 Spectrum Analyser (SA) settings. The settings are summarised in the table below.

Table 1 Requirements and actual SA settings

	Frequency band		
	100 to 400 MHz	400 to 960 MHz	960 MHz to 6 GHz
[1] parameters			
6 dB bandwidth	10 kHz	100 kHz	1 MHz
Minimum dwell time	0.015 s	0.015 s	0.015 s
Freq step	0.5 BW	0.5 BW	0.5 BW
SA settings			
RBW	10 kHz	100 kHz	1 MHz
VBW	10 kHz (auto)	100 kHz (auto)	1 MHz (auto)
Detector	Autopeak	Autopeak	Autopeak
Trace setting	Maxhold	Maxhold	Maxhold
Total band width	300 MHz	560 MHz	5.04 GHz
Num of points per sweep[4]	60,000	60,000	60,000
Num sweeps[5]	3,000	4,500	3,200
Preamp	Off	Off	30 dB
Attenuator	0 dB	0 dB	0 dB
Vertical unit	dBµV	dBµV	dBµV
Start Freq	100 MHz	400 MHz	960 MHz
Stop Freq	400 MHz	960 MHz	6 GHz
Antenna used	HL223	HL223	EMCO 3115

[2] The HL223 is calibrated from 200 MHz to 1.3 GHz
[3] The 3115 is calibrated from 1 GHz to 18 GHz
[4] Total bandwidth divided by 0.5 the resolution bandwidth. The number of points was calculated once for the worst case and kept constant during all measurements.
[5] Using the required dwell time and the number of points per sweep the required total sweep time becomes 900 seconds. The number of sweeps was calculated to achieve the required total sweep time. This long total sweep time also ensures that sporadic emissions of the EUT turning on only every 3 or 4 seconds are captured.

6 Results

The following sections show the measurement results for the measurements described above. The measurements were corrected for cable loss. The measurements were not corrected for background emissions.

Only measurement data for which the antennas were calibrated are shown, i.e. no data is shown for the frequencies between 100-200 MHz and between 960 MHz and 1000 MHz.

6.1 EUT passive emissions

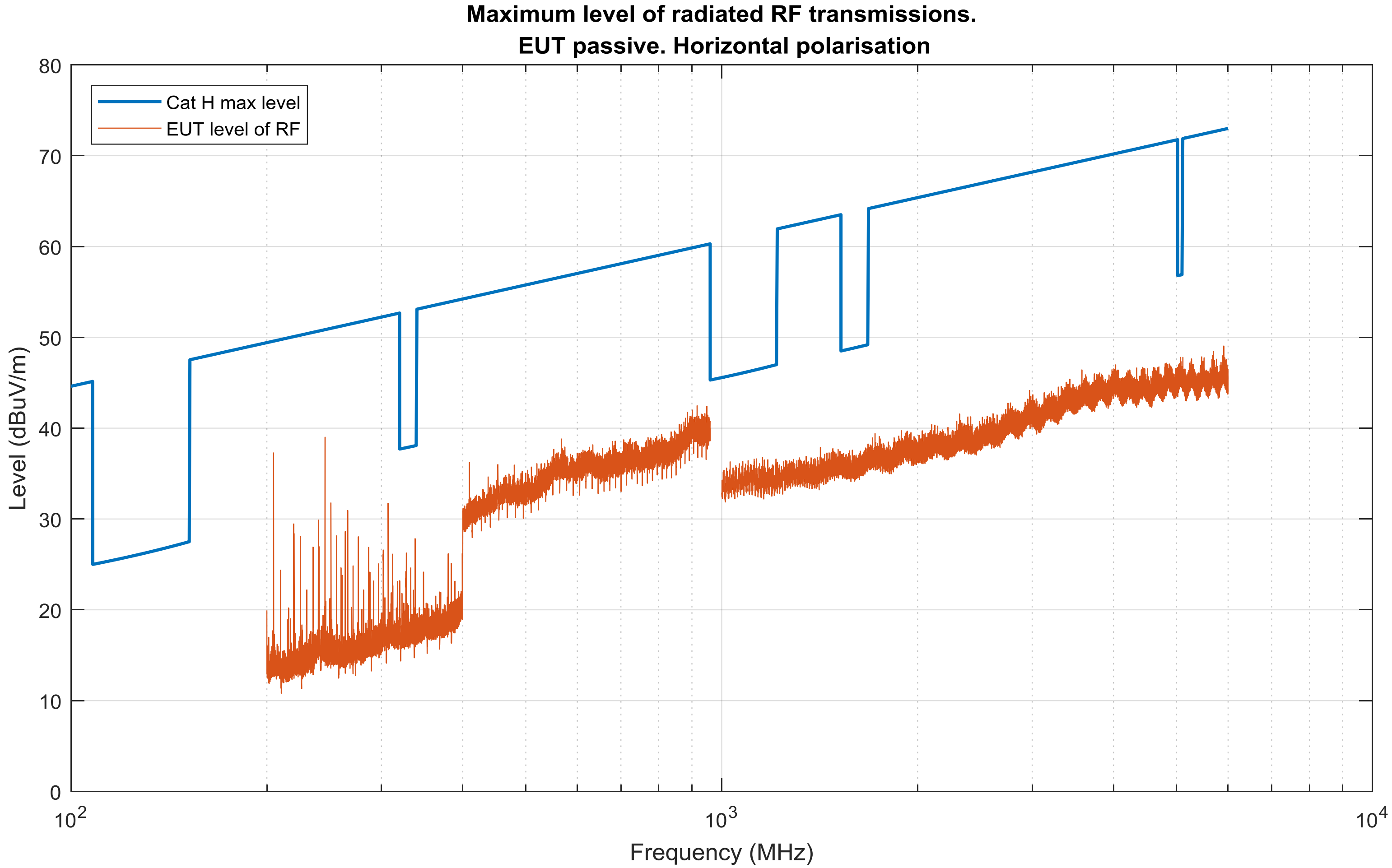

Figure 5 Measured radiated RF emissions of EUT while passive. Horizontal polarisation. Also shown is the DO-160 Section 21 Cat H mask.

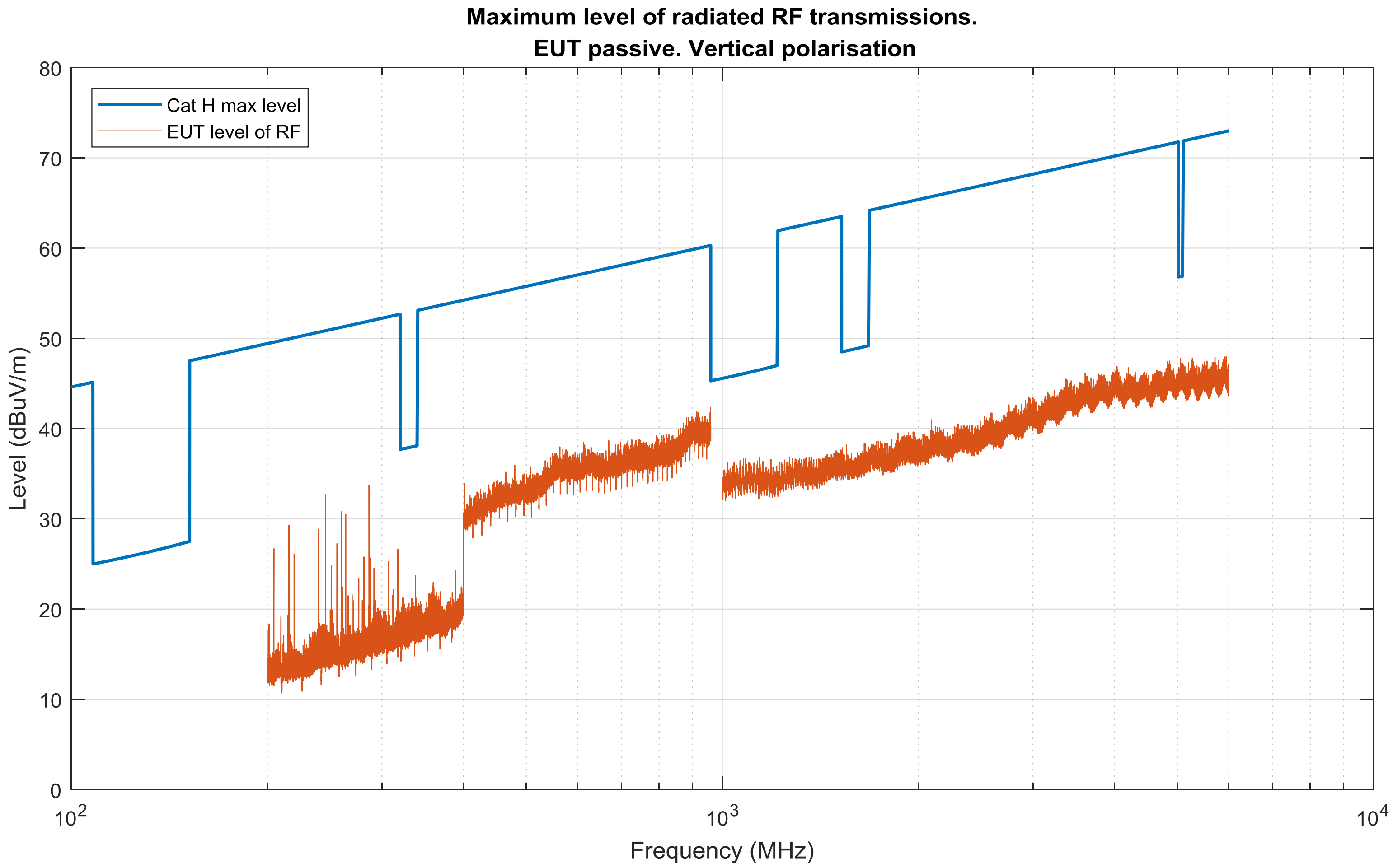

Figure 6 Measured radiated RF emissions of EUT while passive. Vertical polarisation. Also shown is the DO-160 Section 21 Cat H mask.

6.2 EUT active emissions

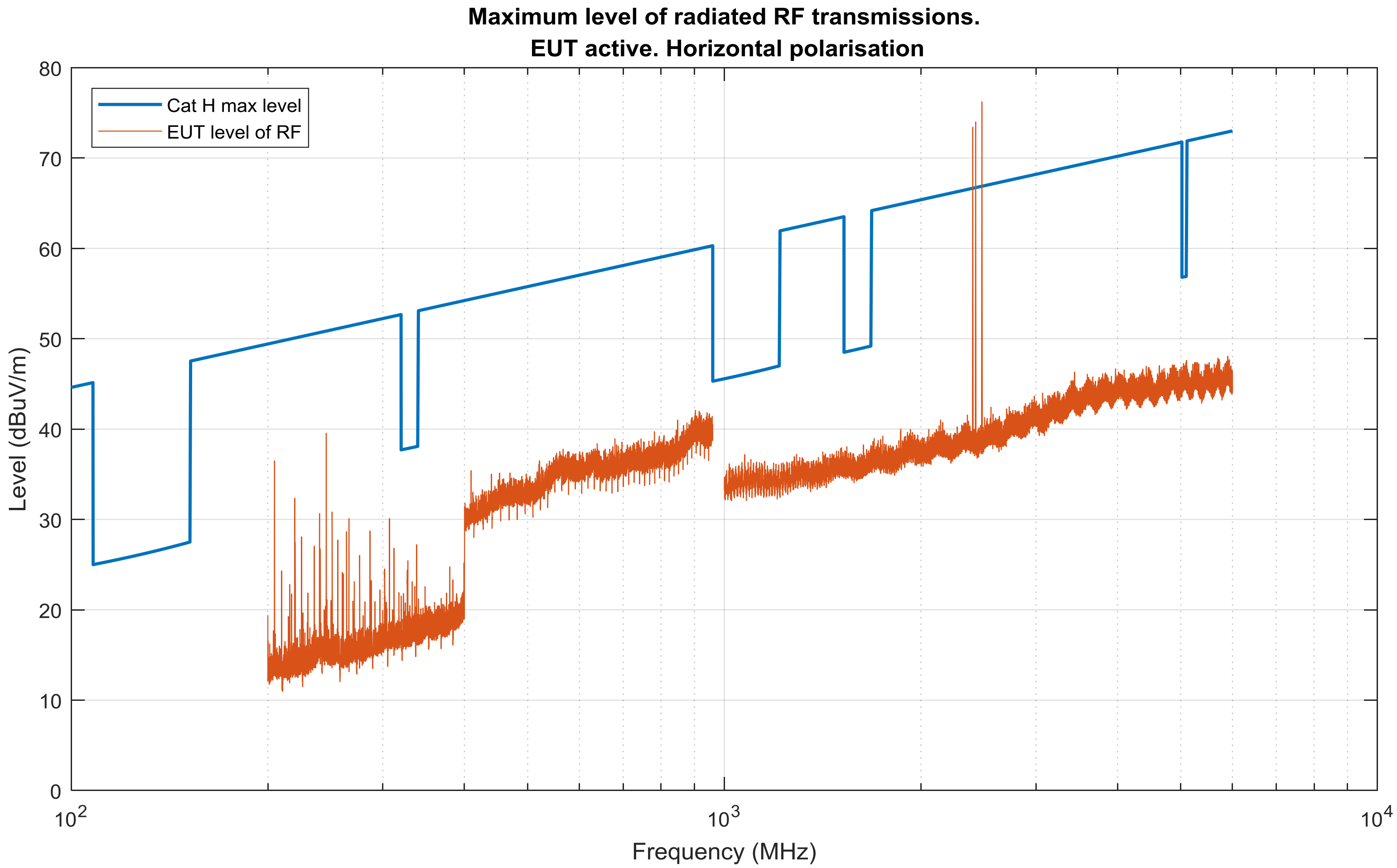

Figure 7 Measured radiated RF emission of EUT while active including reader emissions. Horizontal polarisation. Also shown is the DO-160 Section 21 Cat H mask. Note that these measurements include emissions from the reader. The peak around 2.45 GHz is due to both EUT and reader transmitting using BLE.

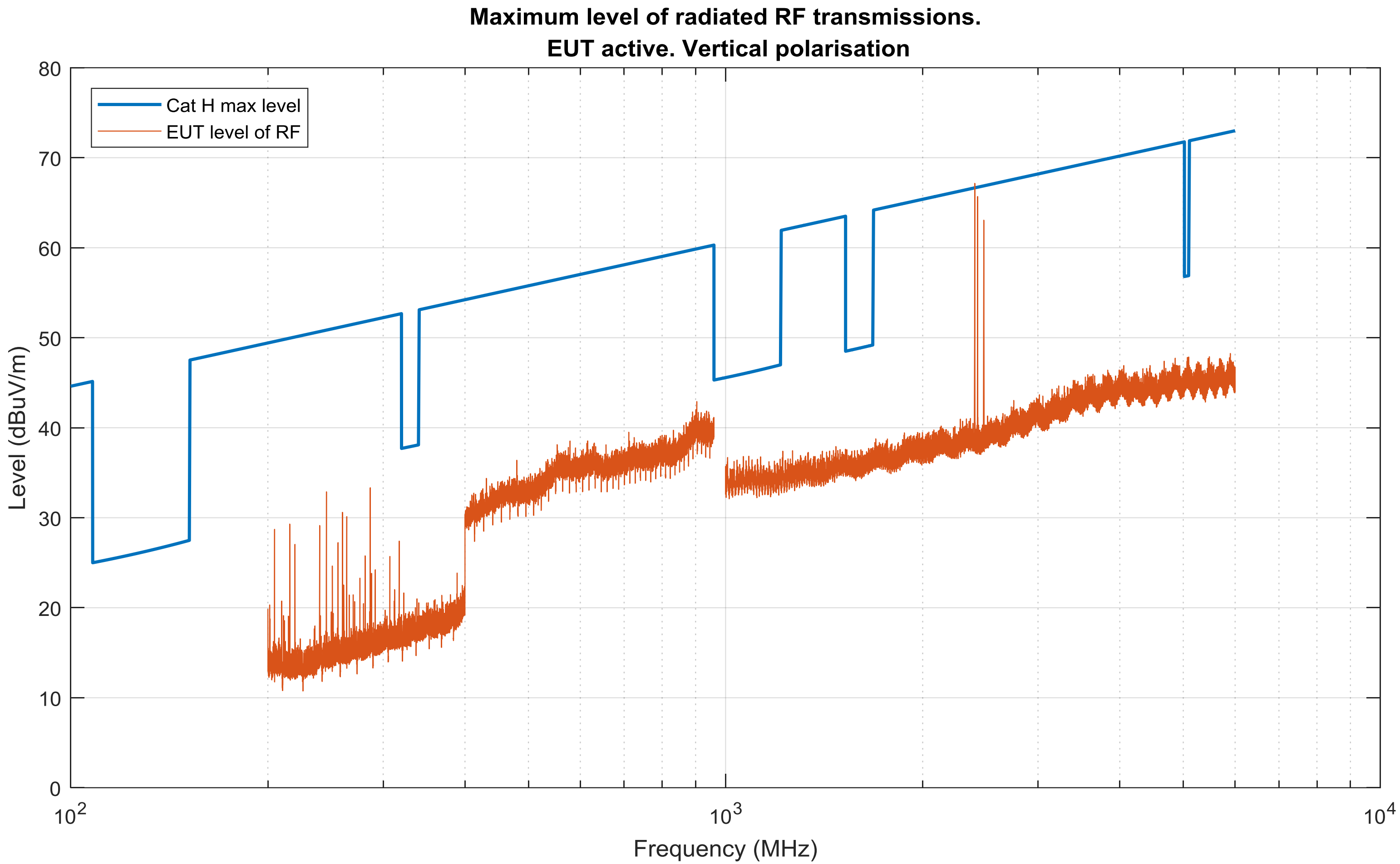

Figure 8 Measured radiated RF emission of EUT while active including reader emissions. Vertical polarisation. Also shown is the DO-160 Section 21 Cat H mask. Note that these measurements include emissions from the reader. The peak around 2.45 GHz is due to both EUT and reader transmitting using BLE.

6.3 Reader-only emissions compared to Reader-and-tag emissions

The figures below show the RF emissions for the situation where only a reader was in the RF anechoic chamber. No EUT was in the chamber.

The graphs can be compared to Figure 7 and Figure 8 in section 6.2. The graphs below show that the reader's BLE transmissions cause significant emissions around 2.45 GHz. The reader was positioned 4.2 m behind the measurement antenna. When the tag is added to the room (in front of the antenna) no significant increase of emissions around 2.45 GHz is observed as shown in the graphs in section 6.2.

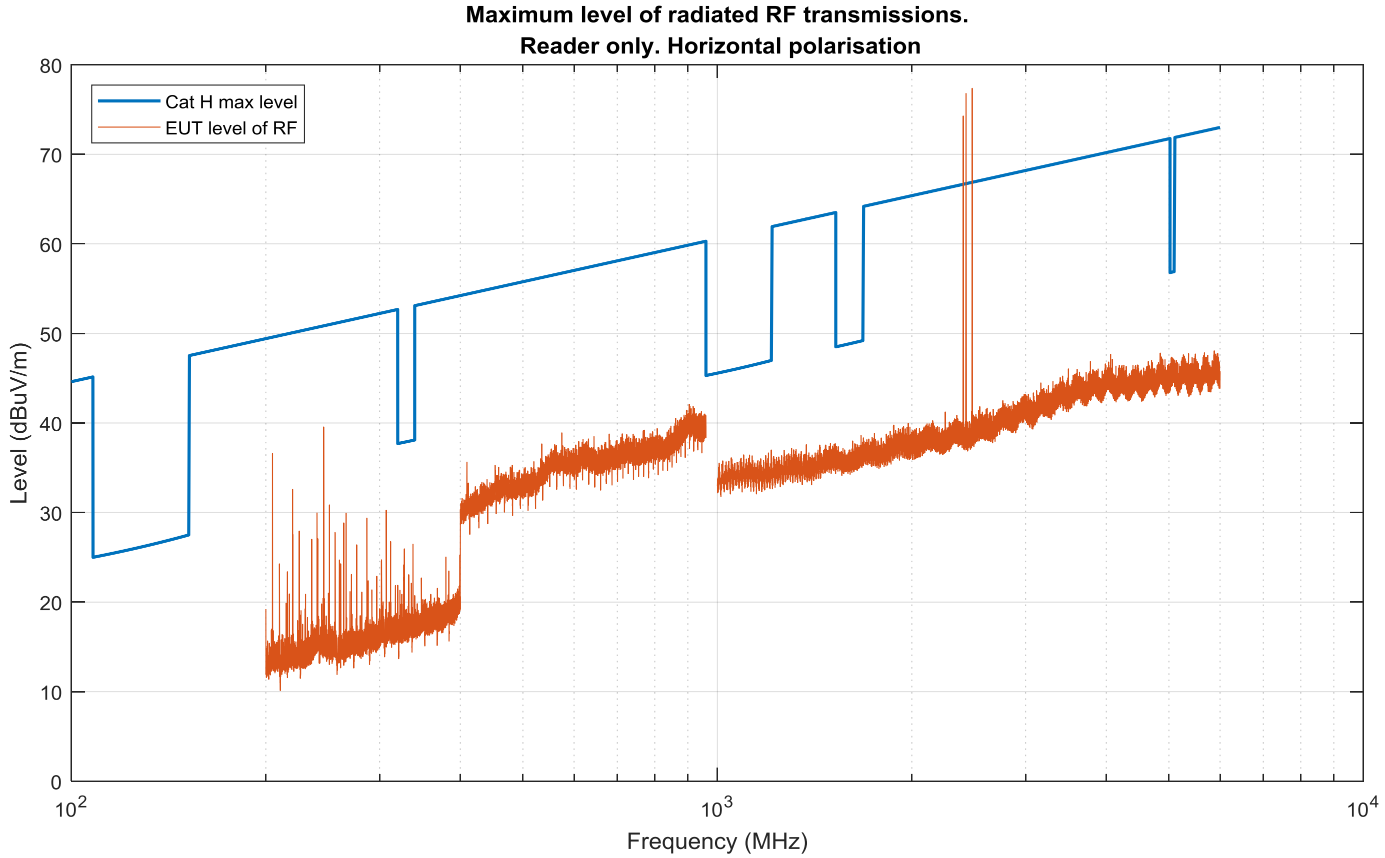

Figure 9 Measured radiated RF emission of reader only. Horizontal polarisation.

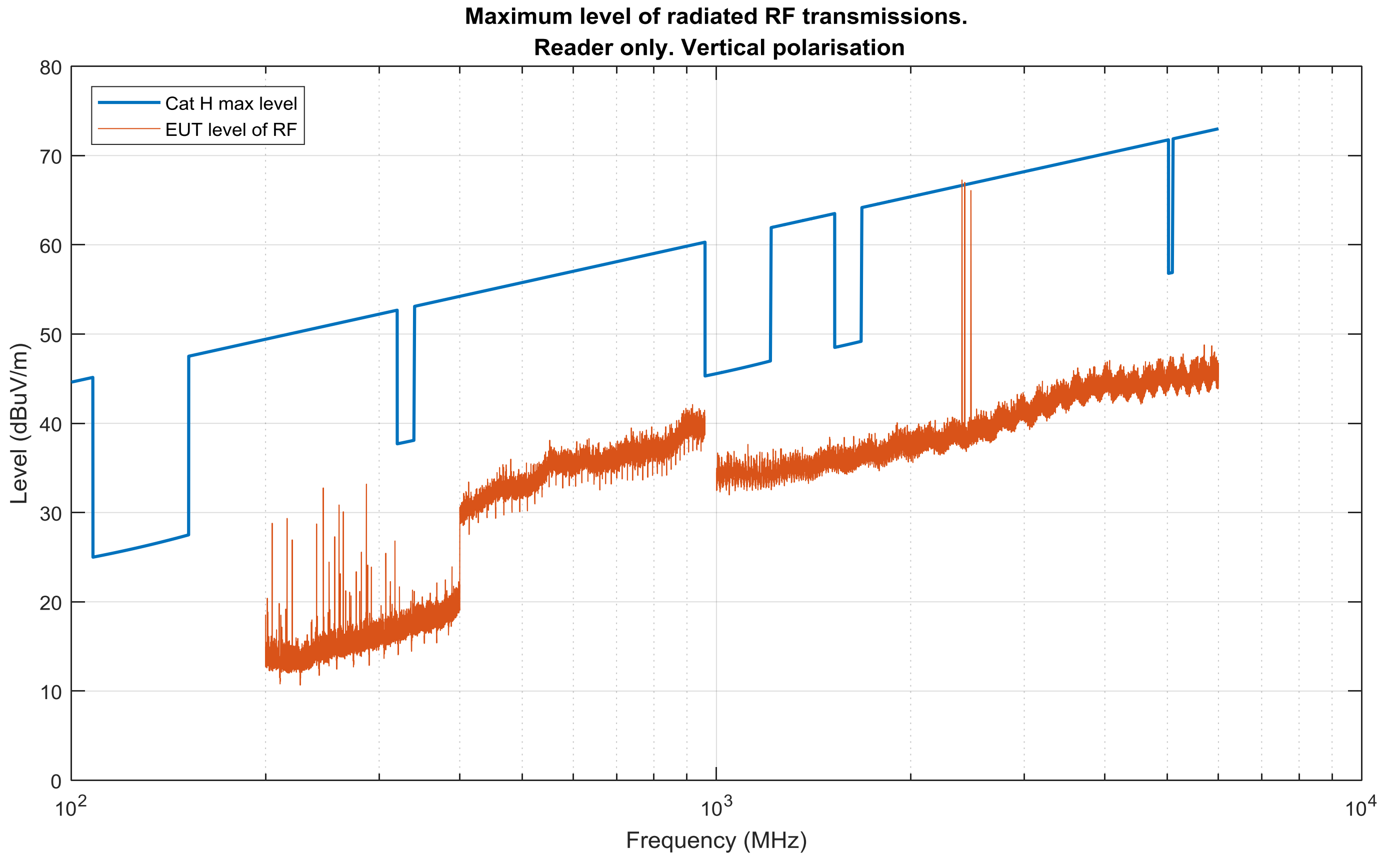

Figure 10 Measured radiated RF emissions of reader only. Vertical polarisation.

7 Conclusions

In passive mode, for which RTCA/DO-160G is applicable, the RF emissions of the EUT remain below DO-160G section 21 Category H levels.

In active mode the measured RF emissions do not exceed the RTCA/DO-160G section 21 Category H levels because RTCA/DO-160G is not applicable in that mode. In this mode, measurements could only be done while both EUT and reader were present. The measurement graphs presented show excursions around 2.45 GHz which are caused by the intentional reader and EUT BLE transmissions.

8 References

[1] "Environmental Conditions and Test Procedures for Airborne Equipment," *RTCA/DO-160G*. RTCA Special Committee SC-35, 2010.

Appendix A Log-Periodic Dipole Antenna HL223 calibration data

The HL223 is a Rohde & Schwarz linearly polarised Log-Periodic Dipole Antenna designed for general broadband transmitting and receiving application in the frequency range 200 to 1300 MHz.

The antenna was calibrated according to DIN 45003 on 21 June 1993. The calibrated antenna factor data were copied from the calibration report and are shown below in tabular and graphical form below. The calibration is within +/- 1 dB.

The SWR is smaller than 1.8 over the frequency range. The polarization decoupling is > 20 dB. The front to back ratio > 15 dB and > 20 dB from 400 MHz upward. The gain > 6 dBi.

Table 2 HL223 sn 832727/003 calibrated antenna factor

Frequency (MHz)	Antenna Factor (dB)
200	9.7
225	10.3
250	11.5
275	12.3
300	12.8
325	13.3
350	14.2
375	14.6
400	15.7
425	16.2
450	16.8
475	16.9
500	17.3
525	17.5
550	18.0
575	18.9
600	18.7
625	19.9
650	19.7
675	20.4
700	20.5
725	21.0
750	20.8
775	21.0
800	21.5
825	21.2
850	21.8
875	22.5
900	23.1
925	22.5
950	22.2
975	22.9
1000	22.6
1025	23.3
1050	23.6
1075	24.6
1100	25.5
1125	24.5
1150	23.5
1175	24.0
1200	24.3
1225	25.4
1250	26.4
1275	25.5
1300	25.0

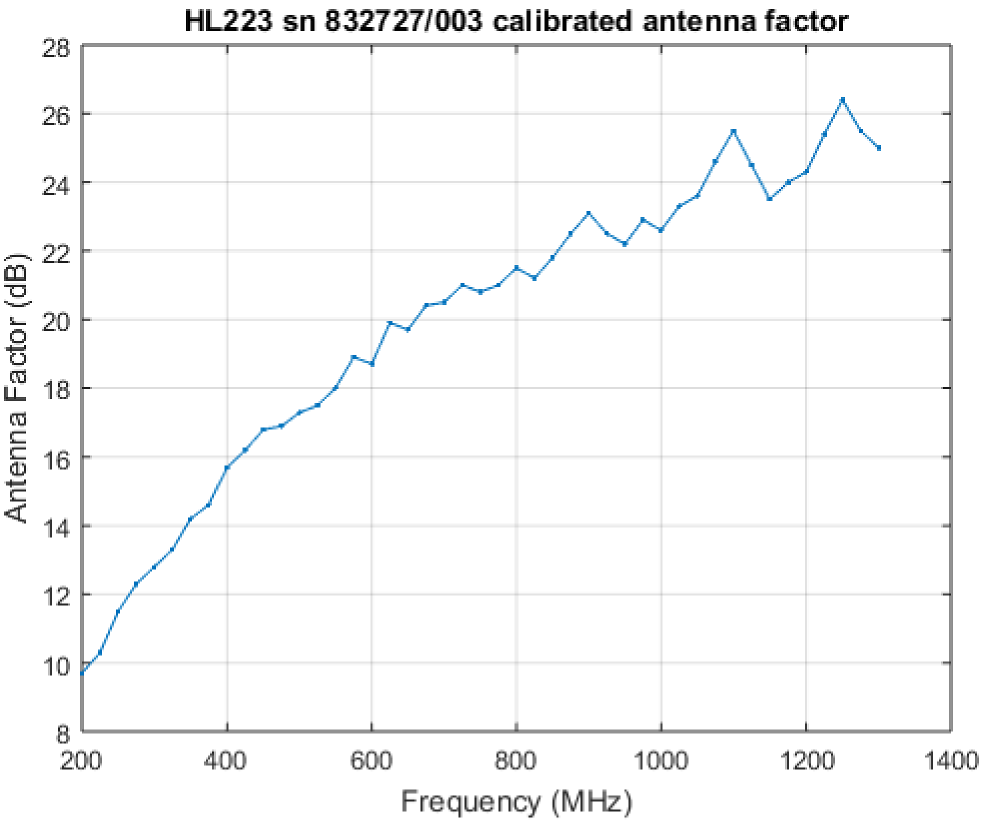

Figure 11 HL223 sn 832727/003 calibrated antenna factor

Appendix B Double Ridged Waveguide Horn 3115 calibration data

The 3115 is an EMCO double-ridged waveguide antenna designed for EMI measurements and specification compliance testing in the frequency range 1 to 18 GHz.

The antenna was calibrated according to SAE, ARP-958 – 1997 on 1 June 2001. The calibrated antenna factor data were copied from the calibration report and are shown below in tabular and graphical form. The calibration is within +/- 0.3 dB.

The VSWR is less than 3:1 over the frequency range and less than 2:1 from 2 GHz to 17 GHz. The polarization decoupling is > 20 dB.

Table 3 3115 sn 6454 calibrated antenna factor

1000	24.2
1500	25.6
2000	27.8
2500	28.6
3000	30.4
3500	31.7
4000	32.8
4500	32.7
5000	34.1
5500	34.4
6000	34.8
6500	35.1
7000	36.3
7500	37.4
8000	37.4
8500	37.8
9000	38.0
9500	37.9
10000	38.3
10500	38.3
11000	38.4
11500	39.1
12000	38.8
12500	38.5
13000	39.7
13500	40.4
14000	41.0
14500	40.5
15000	39.2
15500	37.8
16000	37.7
16500	39.4
17000	41.8
17500	45.4
18000	47.9

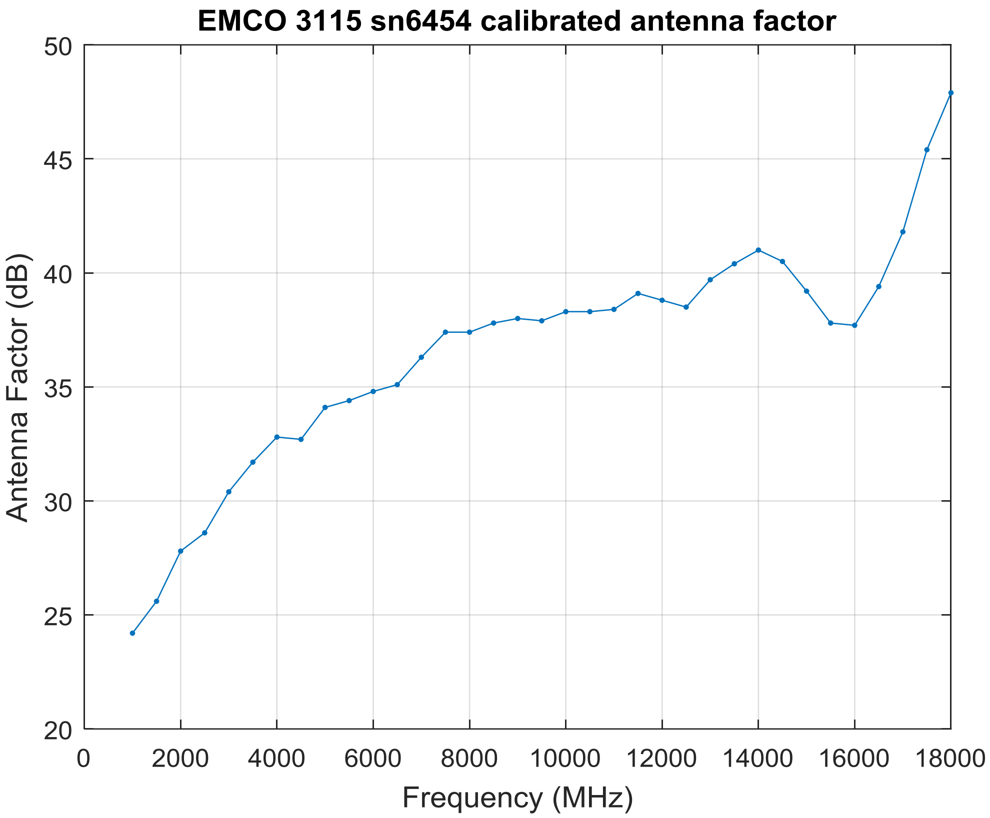

Figure 12 EMCO 3115 sn 6454 calibrated antenna factor

Appendix C Cable loss

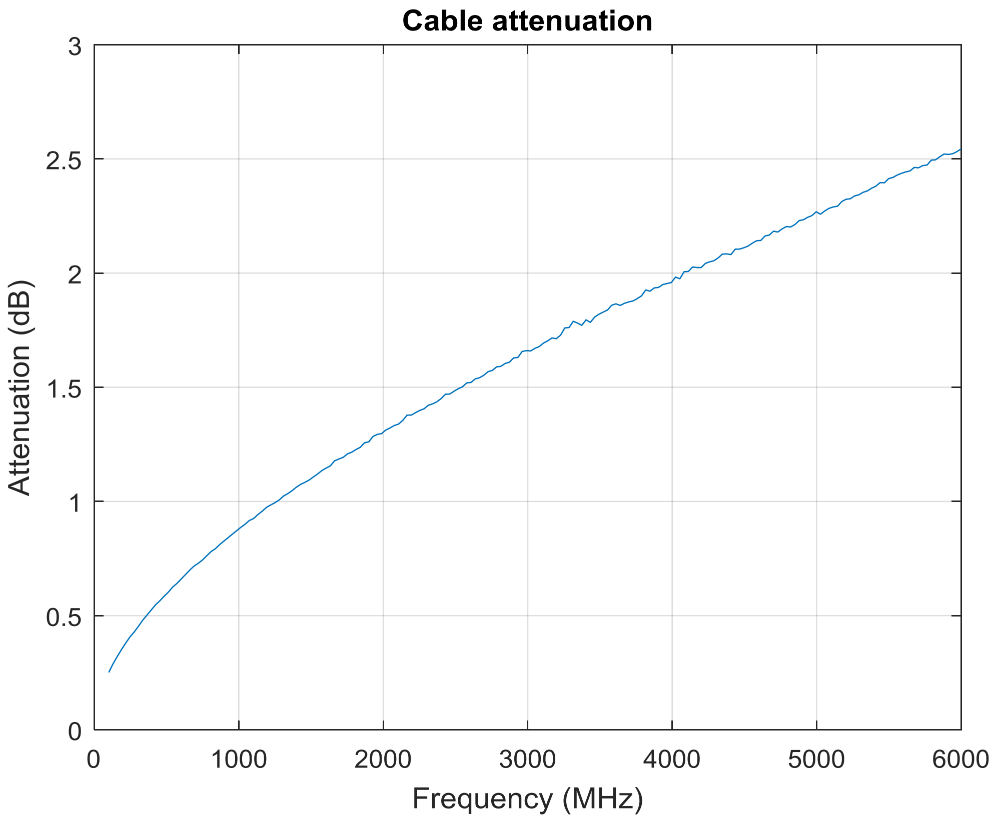

Figure 13 Cable attenuation (loss)

Appendix D Calculations

The EUT RF emissions produce an electric field at the measurement antenna which in turn produces a voltage at the input of the spectrum analyser. (The contributing background RF emissions and spectrum analyser noise also produce a voltage at the spectrum analyser input.) Hence, the voltage caused by the EUT emissions at the spectrum analyser is:

$$V_{SA} = V_{EUTatSA}$$

where the units are Volt.

As indicated above, the field strength at the antenna E_{Ant} $(\frac{V}{m})$ is converted into a voltage at the output terminals of the antenna. The conversion factor is the antenna factor of the antenna.

$$E_{Ant} = V_{Ant} \cdot AF$$

where V_{Ant} is the antenna voltage in V and AF is the antenna factor in $\frac{1}{m}$.

Expressed in logarithmic form:

$$E_{AntdB} = V_{AntdB} + AF_{dB}$$

with

$$E_{dB} = 20 \cdot log_{10}(E)$$

Note that if the antenna is at a distance from the EUT other than 1 metre, the field strength at 1 metre can be calculated as follows[6]:

$$E_{EUT} = E_{EUT_{Ant}} \cdot r$$

The voltage measured at the spectrum analyser is the antenna voltage attenuated by the cable.

$$V_{SAdB} = V_{AntdB} - L_{cabledB}$$

Combining the above we arrive at:

$$V_{EUTatSA} = V_{SA}$$

$$E_{EUTatAntdB} = V_{EUTatSAdB} + L_{cabledB} + AF_{dB}$$

$$E_{EUTdB} = E_{EUTAntdB} + 20 \cdot log_{10}(r)$$

[6] Using spherical expansion, the field strength decreases inversely proportionally with distance; a doubling in distance will cause the field strength to half.