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Document
Test Report
Date
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Prepared
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Page
1(25)

Title
EMC Test of Raptor 45

Summary:

The object of the test is to show compliance with the emission requirements of Federal Communications Commission (FCC) Part 15 Subpart F for ground penetrating radars (GPR) using ultra wideband (UWB) technology.

The EUT complied with the requirement of radiated emissions given in FCC Part 15 Subpart F, measured in the frequency range 30 MHz – 18 GHz.

The tests have been performed at an Open Area Test Site (OATS). The test site is 2.948 registered at FCC with the registration number 389317.

Approved:

[The original is signed]

Fredrik Danielsson
Technical Manager

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1 General information

| | |
|-----------------------|--|
| Date of test: | 20 and 21 March 2017 |
| Location of the test: | Saab AB Storlienvägen 56 SE-831 52 Östersund Sweden |
| Test performed by: | Björn Olsson, Saab AB |
| Client: | ImpulseRadar AB Storgatan 78 SE-930 70, Malå Sweden |
| Client's observer: | Bernth Johansson, ImpulseRadar AB |

2 Test methods and results

2.1 Results

The test results in this report apply only for the tested EUT.

| Emission requirements according to FCC Part 15 Subpart F | | | | | |
|--|-------------|--------------------------|-------------|---|------------|
| Environmental phenomena | Test method | Requirement | Result | Comments | Test order |
| Radiated emission 30-960 MHz | ANSI C63.4 | FCC 15.209 | PASS | | 5 |
| Radiated emission 960 MHz - 18 GHz | FCC 02-48 | FCC 15.509 (d) | PASS | | 1 |
| Radiated emission 1164-1240 MHz 1559-1610 MHz | FCC 02-48 | FCC 15.509 (e) | PASS | | 2 |
| UWB definition | | FCC 15.503 (a) 15.509(a) | PASS | $f_M = 967$ MHz $f_L = 302$ MHz $f_H = 1\,136$ MHz $f_C = 719$ MHz UWB BW = 834 MHz Fractional BW = 1.16 | 3 |
| Peak emission at f_M | FCC 02-48 | FCC 15.509 (f) | PASS | | 4 |

2.2 Applicable documents

| Measurements | | |
|--------------------|----------------|---|
| ANSI C63.4 | 2014 | American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the range of 9 kHz to 40 GHz |
| FCC CFR 47 Part 15 | March 28, 2017 | Radio Frequency Devices |
| FCC 02-48 | April 22, 2002 | Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems |

3 Equipment under test (EUT)

3.1 Identification of equipment under test

| | |
|---------------|---|
| Description: | Ground penetrating radar antenna |
| UWB subclass: | Ground Penetrating Radar (GPR) |
| Manufacturer: | ImpulseRadar AB |
| Model name: | Raptor 45 |
| Part No: | AO00083 |
| Serial No: | 16100801 |
| Build state: | Production sample modified with a 5 pF capacitor soldered in between the antenna flares |



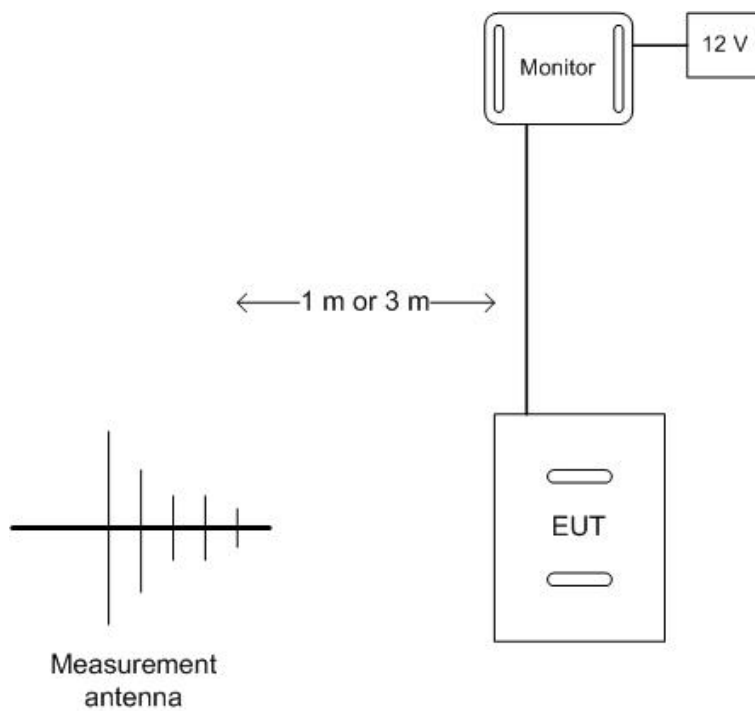
Picture 1. Identification of the EUT.

3.2 General configuration of EUT

The EUT was connected to a receiver positioned approximately 2 m away from the EUT. The receiver unit was powered by a battery. See Pictures 2 and 3 for a description of the setup.



Picture 2. Set-up of the EUT.



Picture 3. Schematic illustration of the EUT and the auxiliary equipment.

3.3 Operation of EUT during tests

The EUT was switched on and transmitting like in normal operation.

4 Test site

4.1 Description

The measurements were all performed on a weather protected open area test site (OATS) that was modified with a flat sand bed located in the ground plane. The depth of the sand bed was more than 0.5 m. The EUT was positioned on the sand bed with no ground plane beneath.

At frequencies below 960 MHz the measurement distance from the antenna to the EUT was 3 m. The measurement receiver and related equipment, such as a PC and equipment for remote control, were placed next to the test site approximately 10 m from the antenna.

At frequencies above 960 MHz the measurement distance from the antenna to the EUT was 1 m. The measurement receiver and a preamplifier were placed next to the measurement antenna while other related equipment was placed next to the site.

4.2 Ambient signals

A number of ambient signals were frequently detected in the different frequency ranges where measurements were made, see table below. Additionally, some signals of short-term duration were found. Each measurement signal close to or above the limit was examined if ambient or related to the EUT.

| Frequency | Service |
|--------------|-----------------------------------|
| 87-108 MHz | FM Broadcast |
| 390-395 MHz | Mobile radio (TETRA) |
| 460-790 MHz | Television |
| 876-960 MHz | Mobile phones (GSM) |
| 960-1164 MHz | Aeronautical radio |
| 1.3 GHz | Radar system |
| 1.7-2.2 GHz | Mobile phones (DECT, GSM, W-CDMA) |
| 2.4-2.5 GHz | Wireless-LAN |

5 Results

5.1 Measurement of radiated emission, 30 MHz – 960 MHz

5.1.1 Requirements according to FCC 15.209 and 15.509 (d)

Radiated emission from the EUT in the frequency range 30 MHz to 960 MHz shall not exceed the limit as specified below.

| Frequency range | Limit |
|-----------------|-------------------|
| 30 – 88 MHz | 40 dB μ V/m |
| 88 – 216 MHz | 43.5 dB μ V/m |
| 216 – 960 MHz | 46 dB μ V/m |

5.1.2 Procedures

The radiated emission was measured on an Open Area Test Site (OATS) with 3 meters measuring distance as described in section 4.1. See also picture 4.

The EUT was configured and the test was performed in accordance with ANSI C63.4. A resolution bandwidth of 120 kHz was used.

The test was initiated with a pre-scan with peak detector in the frequency range 30 MHz to 960 MHz. The emission level was measured in 32 different combinations of 16 EUT angle positions plus vertical and horizontal polarisation at one meter antenna height. For each position the EUT was turned manually.

A measurement software was used to add antenna factors and cable attenuation and to form a composite trace of the peak field strength.

EUT positions and frequencies with the highest emission were selected based on the pre-scan. The EUT angle, antenna height and antenna polarisation were thereafter adjusted in order to find the highest emission level. The antenna height was changed between 1 m and 4 m. At these maximized positions quasi peak values were measured.



Picture 4. Measurement setup.

5.1.3 Deviations from ANSI C63.4

The test site was arranged according to FCC 02-48 with a flat sand bed located in the ground plane.

5.1.4 Environmental conditions

Temperature (inside test facility): 16 to 20°C

5.1.5 Results

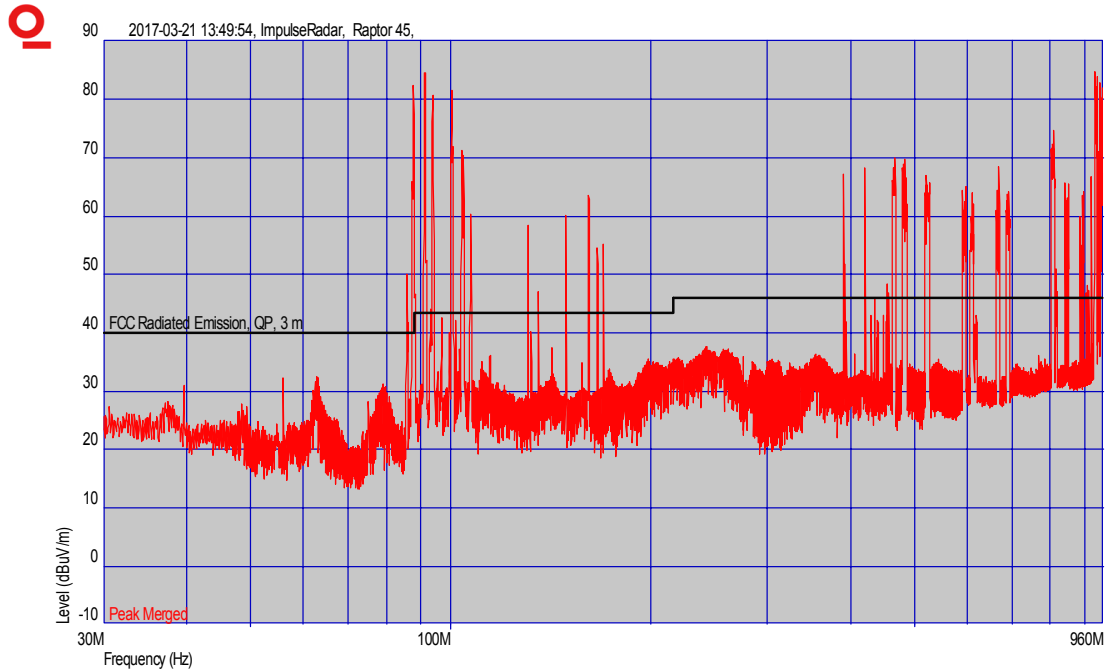
Results are valid for the described arrangement and operation of the tested EUT.

The EUT complied with the requirement of radiated emission specified in FCC 15.209 in the frequency range 30-960 MHz. No narrowband signals above the limit line were related to the EUT.

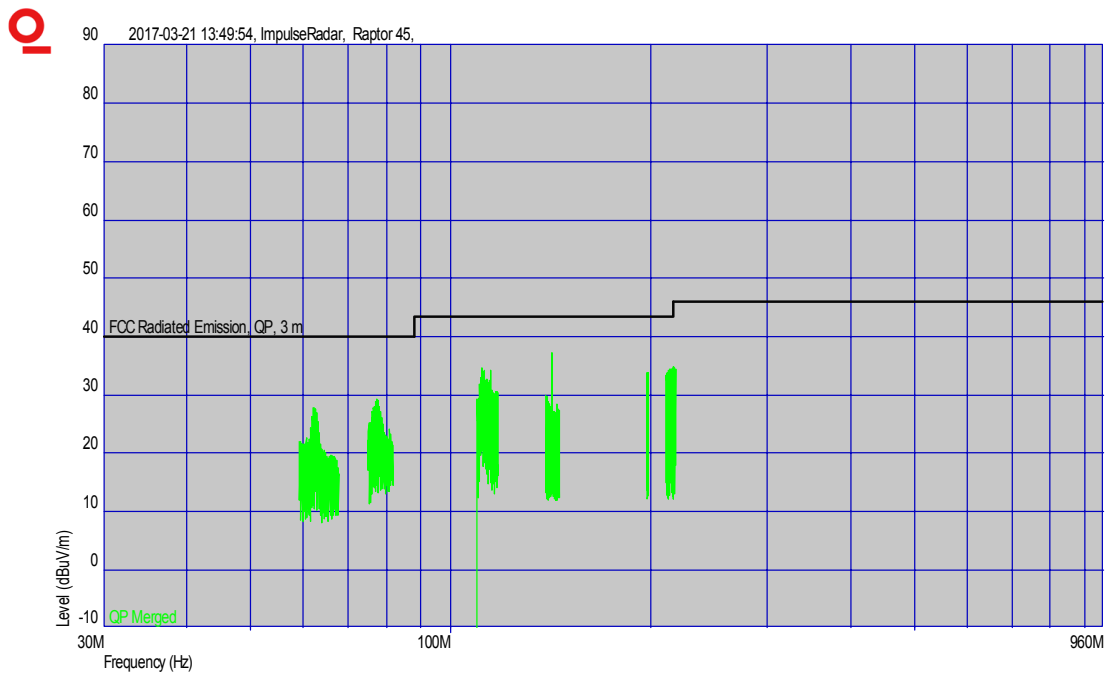
Emission levels measured with peak detector and with the quasi peak limit according to FCC 15.209 are shown in the diagrams below. Emission levels measured with quasi-peak detector at maximized positions are shown in the table below.

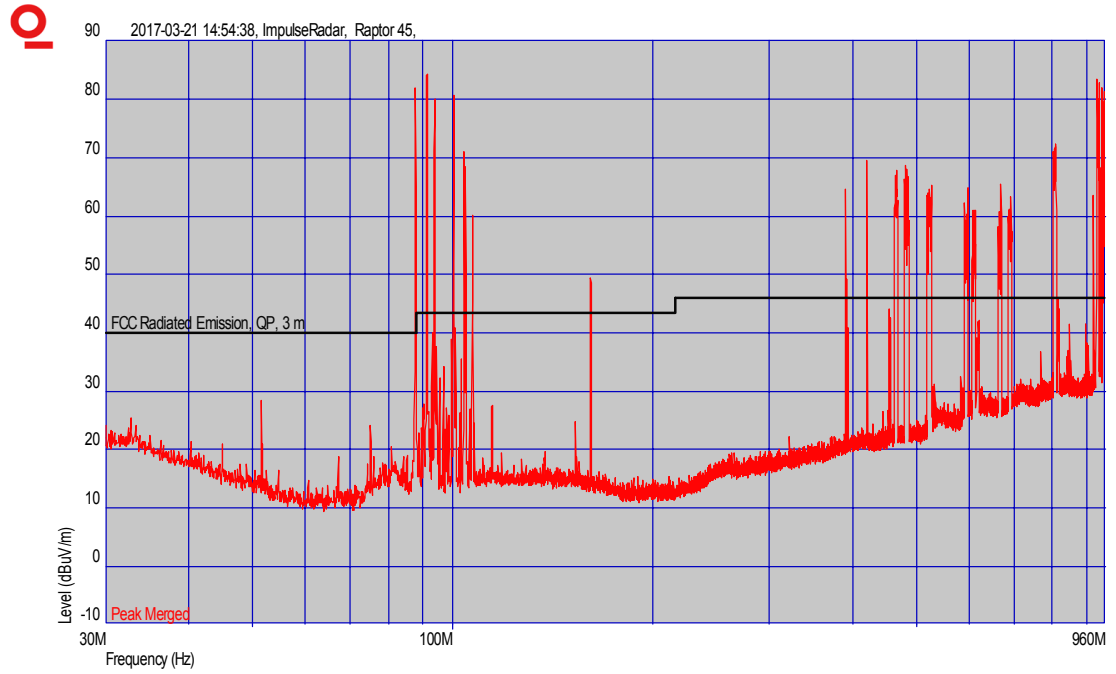
| Frequency (MHz) | Limit (dB μ V/m) | Quasi peak Result (dB μ V/m) | Margin (dB) | Notes |
|-----------------|----------------------|----------------------------------|-------------|-------|
| 62.2 | 40.0 | 27.7 | 12.3 | Pass |
| 77.5 | 40.0 | 29.3 | 10.7 | Pass |
| 112 | 43.5 | 34.6 | 8.9 | Pass |
| 142 | 43.5 | 37.3 | 6.2 | Pass |
| 198 | 43.5 | 33.9 | 9.6 | Pass |
| 213 | 43.5 | 34.5 | 9.0 | Pass |
| 217 | 46.0 | 34.8 | 11.2 | Pass |

Composite trace of emissions, peak detector, 30-960 MHz



Composite trace of emissions, quasi-peak detector, 30-960 MHz



Ambient measurement, peak detector, 30-960 MHz

5.1.6 Instrumentation

| Manufacturer | Model | Range | S/N | Cal. Interval | Cal. Date |
|---------------------------------|----------|------------------|---------|----------------|------------|
| Rohde & Schwarz EMI-receiver | ESU26 | 20 Hz – 26.5 GHz | 100019 | 24 month | 21/09/2016 |
| Chase Bilog antenna | CBL6111A | 30 - 1000 MHz | 1164 | 36 month | 07/01/2015 |
| EMISYS Antenna tower | 140K | | | Not applicable | |
| Heinrich Diesel Controller | HD100 | | 100/391 | Not applicable | |

5.2 Measurement of radiated emission, 960 MHz – 18 GHz

5.2.1 Requirements according to FCC 15.509 (d, e)

Radiated emission from the EUT shall not exceed the limit as specified below. Measurements are performed up to 18 GHz, which include the 10th harmonic of the center UWB frequency, see 5.3.3.

| Frequency range | Limit | Limit* | Limit** |
|------------------|----------------|-------------------|-------------------|
| 960 – 1610 MHz | -65.3 dBm EIRP | 29.9 dB μ V/m | 39.4 dB μ V/m |
| 1610 – 1990 MHz | -53.3 dBm EIRP | 41.9 dB μ V/m | 51.4 dB μ V/m |
| 1990 – 3100 MHz | -51.3 dBm EIRP | 43.9 dB μ V/m | 53.4 dB μ V/m |
| 3100 – 10600 MHz | -41.3 dBm EIRP | 53.9 dB μ V/m | 63.4 dB μ V/m |
| > 10600 MHz | -51.3 dBm EIRP | 43.9 dB μ V/m | 53.4 dB μ V/m |

| Frequency range | Limit | Limit* | Limit** |
|-----------------|----------------|-------------------|-------------------|
| 1164 – 1240 MHz | -75.3 dBm EIRP | 19.9 dB μ V/m | 29.4 dB μ V/m |
| 1559 – 1610 MHz | -75.3 dBm EIRP | 19.9 dB μ V/m | 29.4 dB μ V/m |

* Converted to field strength level at 3 meters according to FCC 15.521 (g)

** Converted to field strength level at 1 m according to $E_{1m} = E_{3m} + 9.5$ dB μ V/m

5.2.2 Procedures

Radiated emission was measured on an Open Area Test Site (OATS) with 1 m measuring distance between the EUT and the measurement antenna, see picture 5. The antenna height was fixed at 1 m and the antenna was slightly tilted and pointed towards the EUT.

The emission was measured with an RMS detector in the frequency range 960 MHz to 18 GHz. The number of sweep points for the whole frequency range was 34 080 and the total sweep time was 34 s. Thus the dwell time was 1 ms.

The following resolution bandwidths, video bandwidths and sweep times were used during the measurements.

| Frequency range | RBW | VBW | Sweep points | Total sweep time |
|------------------|-------|--------|--------------|------------------|
| 960 MHz – 10 GHz | 1 MHz | 10 MHz | 34 080 | 34 s |
| 1164-1240 MHz | 1 kHz | 10 MHz | 152 000 | 152 s |
| 1559-1610 MHz | 1 kHz | 10 MHz | 102 000 | 102 s |



Picture 5. Measurement setup.

Measurements were performed with the EUT rotated in 16 different positions on the sand bed and with two antenna polarizations resulting in a total of 32 sweeps.

Measurement software was used to add antenna factors and cable attenuation and the resulting maximum field strength level were plotted.

After the sweeps field strength levels above the limit were checked manually due to the high number of ambient signals.

5.2.3 Results

Results are valid for the described arrangement and operation of the tested EUT.

The EUT complied with the requirement of radiated emission specified in FCC 15.509 (d) and (e) in the frequency range 960 MHz – 18 GHz. Emissions above the limit were not related to the EUT.

Measured emission levels are shown in the diagrams below. Results are also tabulated including the six highest peaks, where peaks were found, originating from the EUT.

960 MHz - 18 GHz, RMS detector, 1 MHz bandwidth

| Frequency (MHz) | Limit * (dB μ V/m) | RMS level (dB μ V/m) | Margin (dB) | Notes |
|-----------------|------------------------|--------------------------|-------------|-------|
| 965 | 39.4 | 37.2 | 2.2 | Pass |
| 971 | 39.4 | 37.1 | 2.3 | Pass |
| 1 073 | 39.4 | 34.1 | 5.3 | Pass |

* Converted to field strength limit at 1 m according to $E_{1m} = E_{3m} + 9.5$ dB μ V/m

1164-1240 MHz, RMS detector, 1 kHz bandwidth

| Frequency (MHz) | Limit * (dB μ V/m) | RMS level (dB μ V/m) | Margin (dB) | Notes |
|-----------------|------------------------|--------------------------|-------------|-------|
| 1167 | 29.4 | 17.4 | 12.0 | Pass |
| 1168 | 29.4 | 16.9 | 12.5 | Pass |

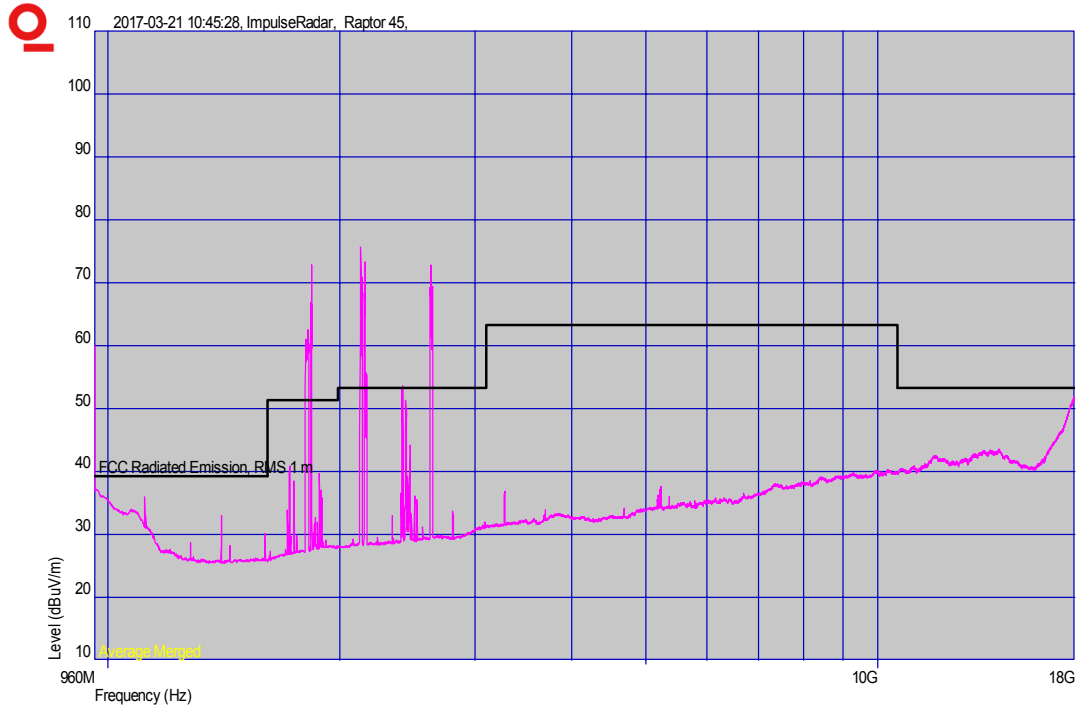
* Converted to field strength limit at 1 m according to $E_{1m} = E_{3m} + 9.5$ dB μ V/m

1559-1610 MHz, RMS detector, 1 kHz bandwidth

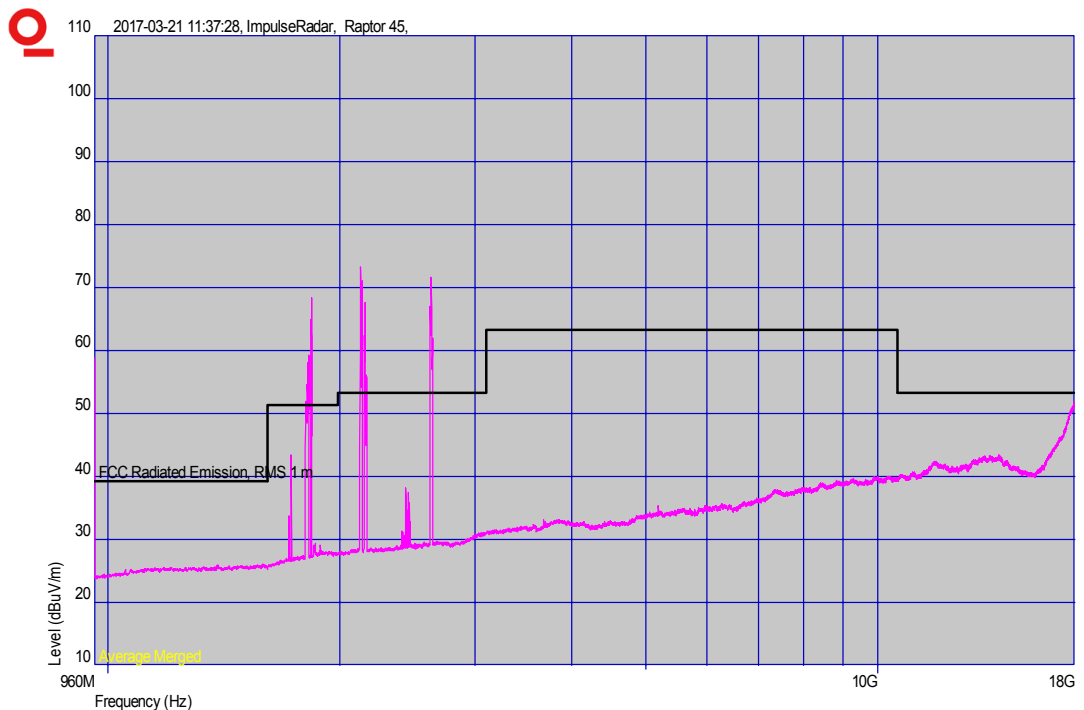
| Frequency (MHz) | Limit * (dB μ V/m) | RMS level (dB μ V/m) | Margin (dB) | Notes |
|-----------------|------------------------|--------------------------|-------------|-------|
| 1579 | 29.4 | 4.3 | 25.1 | Pass |
| 1600 | 29.4 | 29.0 | 0.4 | Pass |

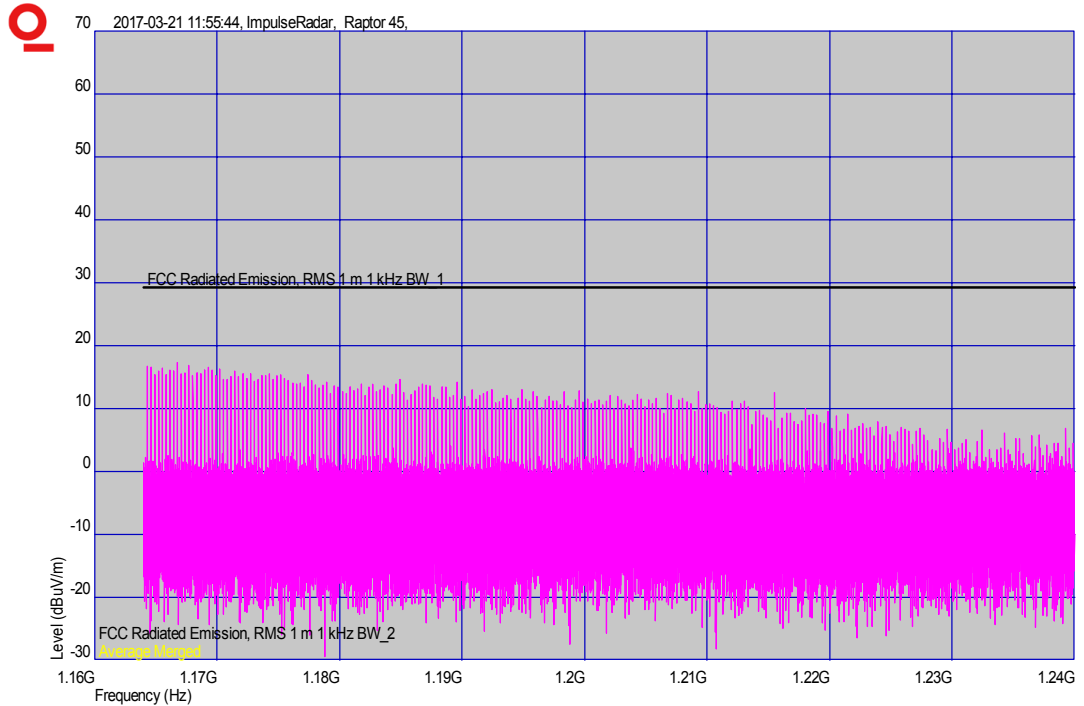
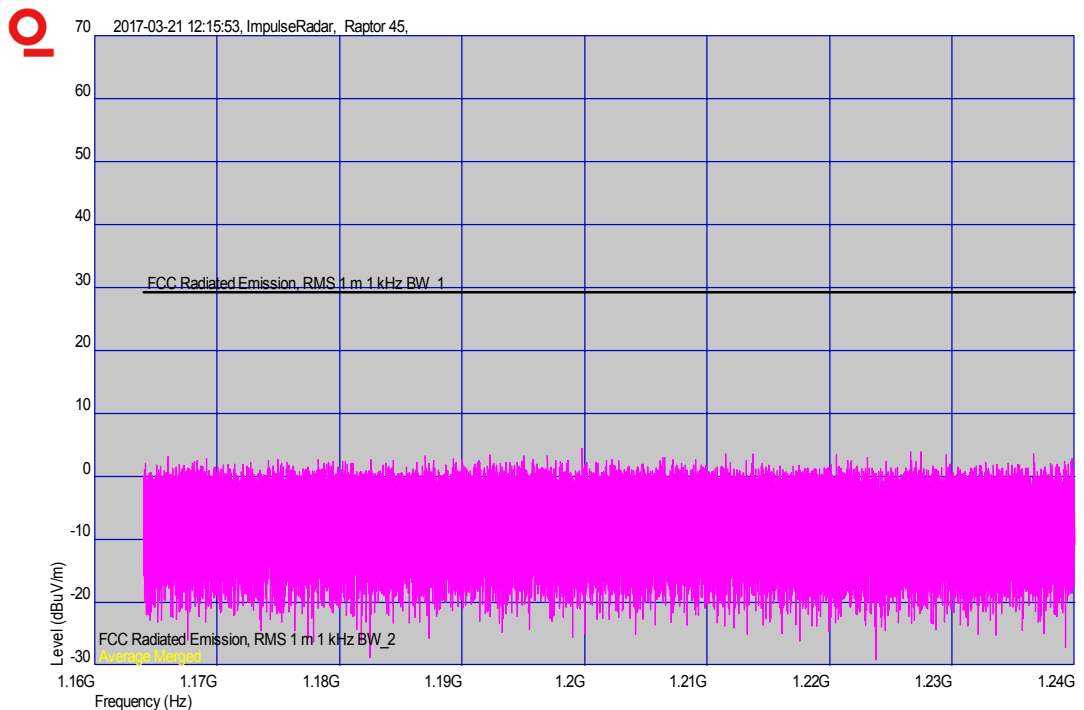
* Converted to field strength limit at 1 m according to $E_{1m} = E_{3m} + 9.5$ dB μ V/m

Composite trace emissions, RMS detector, 1 MHz BW, 960 MHz - 18 GHz

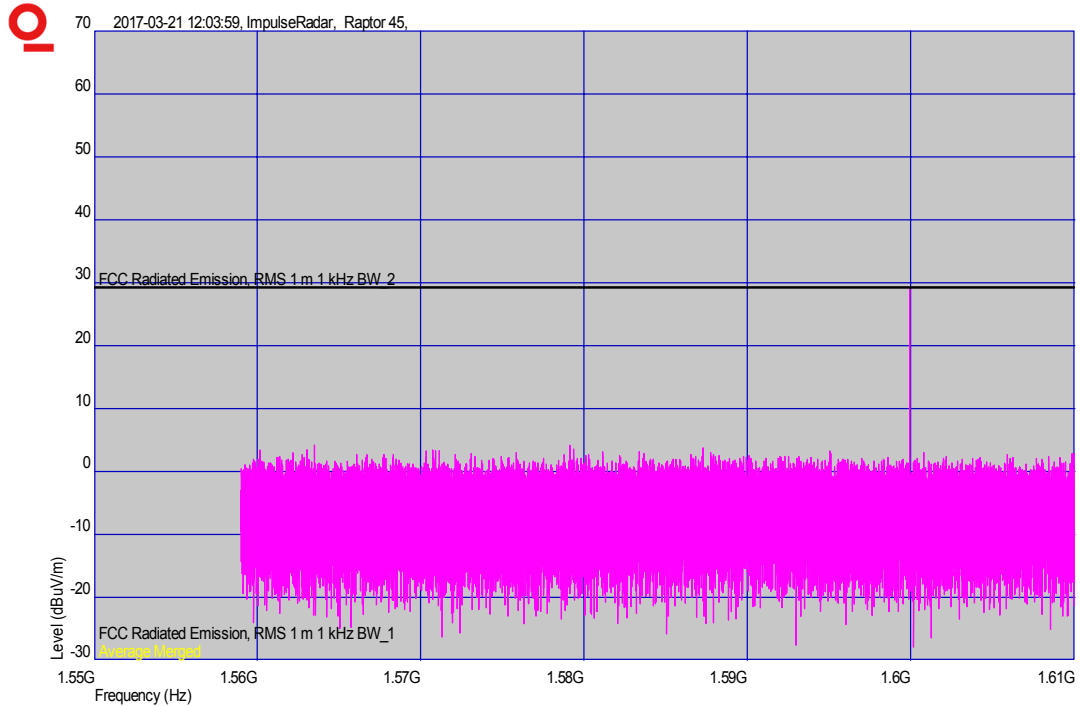


Ambient emissions, RMS detector, 1 MHz BW, 960 MHz - 10 GHz

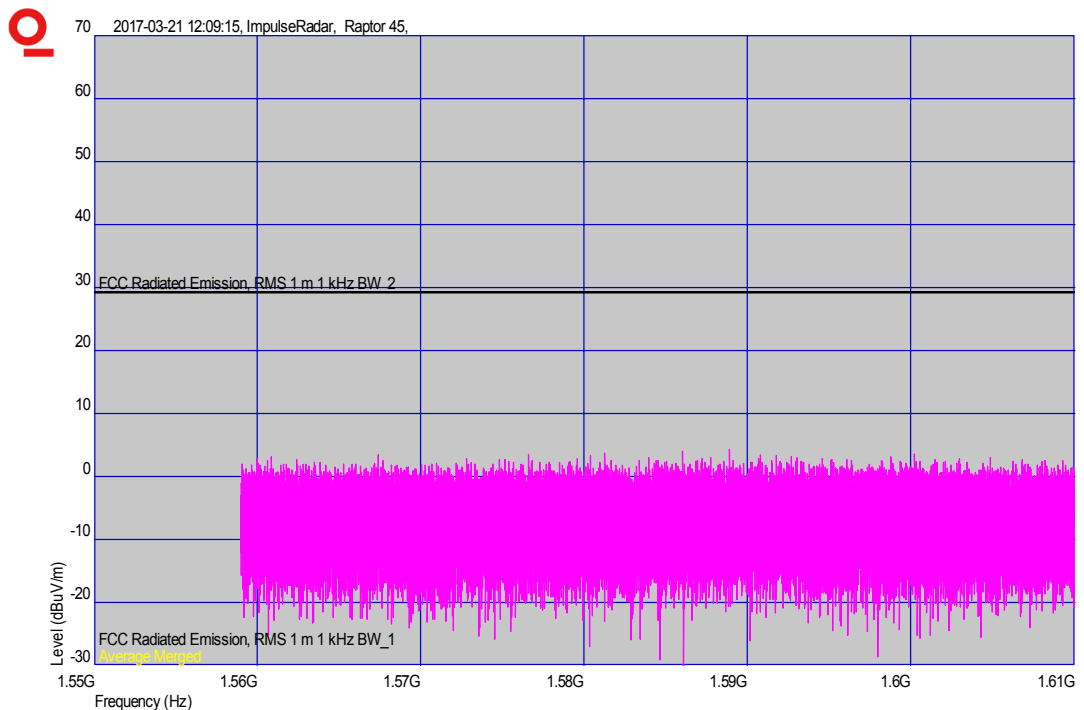


Composite trace of emissions, RMS detector, 1 kHz BW, 1164-1240 MHz**Ambient emissions, RMS detector, 1 kHz BW, 1164-1240 MHz**

Composite trace of emissions, RMS detector, 1 kHz BW, 1559-1610 MHz



Ambient emissions, RMS detector, 1 kHz BW, 1559-1610 MHz



5.2.4 Instrumentation

| Manufacturer | Model | Range | S/N | Cal. Interval | Cal. Date |
|---------------------------------|------------------------------|------------------|--------|---------------|------------|
| Rohde & Schwarz EMI-receiver | ESU26 | 20 Hz – 26.5 GHz | 100019 | 24 month | 21/09/2016 |
| Miteq Pre-amplifier | AFS44- 00101800-25-10P-44 | 0.96-18 GHz | 1127 | 12 month | 13/03/2017 |
| Huber/Suhner Attenuator | 6806.19A | DC-18 GHz | 1115 | 12 month | 09/09/2016 |
| Emco Double Ridge Waveguide | 3115 | 0.96-18 GHz | 2800 | 36 month | 14/11/2014 |

5.3 Measurement of UWB bandwidth and peak emissions

5.3.1 Requirements and definitions according to FCC

5.3.1.1 Definitions according to FCC 15.503 (d)

UWB bandwidth: The frequency band bounded by the points that are 10 dB below the highest radiated emission, as based on the complete transmission system including the antenna. The upper boundary is designated f_H and the lower boundary is designated f_L . The frequency at which the highest radiated emission occurs is designated f_M .

Center frequency (f_C): Equals $(f_H + f_L)/2$.

Fractional bandwidth: Equals $2(f_H - f_L) / (f_H + f_L)$.

Ultra-wideband (UWB) transmitter/device: An intentional radiator that, at any point in time, has a fractional bandwidth equal to or greater than 0.20 or has a UWB bandwidth equal to or greater than 500 MHz, regardless of the fractional bandwidth.

5.3.1.2 Requirements according to FCC 15.509 (a)

The UWB bandwidth of an imaging system operating under the provisions of this section must be below 10.6 GHz.

5.3.1.3 Requirements according to FCC 15.509 (f)

For UWB devices where the frequency at which the highest radiated emission occurs, f_M is above 960 MHz, there is a limit on the peak level of the emissions contained within a 50 MHz bandwidth centered on f_M . The limit is 0 dBm EIRP. It is acceptable to employ a different resolution bandwidth and a correspondingly different peak emission limit, following the procedures described in FCC 15.521.

5.3.2 Procedures

5.3.2.1 UWB bandwidth parameters

To determine the UWB bandwidth separate measurements were made with the EUT tilted and pointing towards the receiving antennas. Separate measurements were performed below 1 GHz and above 1 GHz. A resolution bandwidth of 1 MHz and a measuring distance of 3 m were used in both cases.

5.3.2.2 Peak emissions

To determine the highest emission at f_M for frequencies above 960 MHz an additional peak detector was used during the emission measurements described in Section 5.2. The measurements were performed at 1 m distance and with a measurement bandwidth of 1 MHz. The limit (0 dBm EIRP at 3 m and 50 MHz measurement bandwidth) was recalculated according to:

$$E \text{ (dB}\mu\text{V/m)} = 0 + 95.2 + 20\log(1\text{MHz}/50\text{MHz}) + 9.5 = 70.7$$

Measurement software added antenna factors and cable attenuation.

5.3.3 Results

Results are valid for the described arrangement and operation of the tested EUT.

The EUT fulfilled the definition of an UWB transmitter according to FCC 15.503 (d). The EUT complied with the requirement in FCC 15.509 (a, f).

Measurement data is presented in diagrams below. From the diagrams data regarding the UWB definition was gathered and calculated.

| | |
|-------------------------------------|-----------|
| Frequency of highest emission f_M | 967 MHz |
| Lower boundary f_L | 302 MHz |
| Upper boundary f_H | 1 136 MHz |
| Centre frequency f_C | 719 MHz |
| UWB bandwidth | 834 MHz |
| Fractional bandwidth | 1.16 |

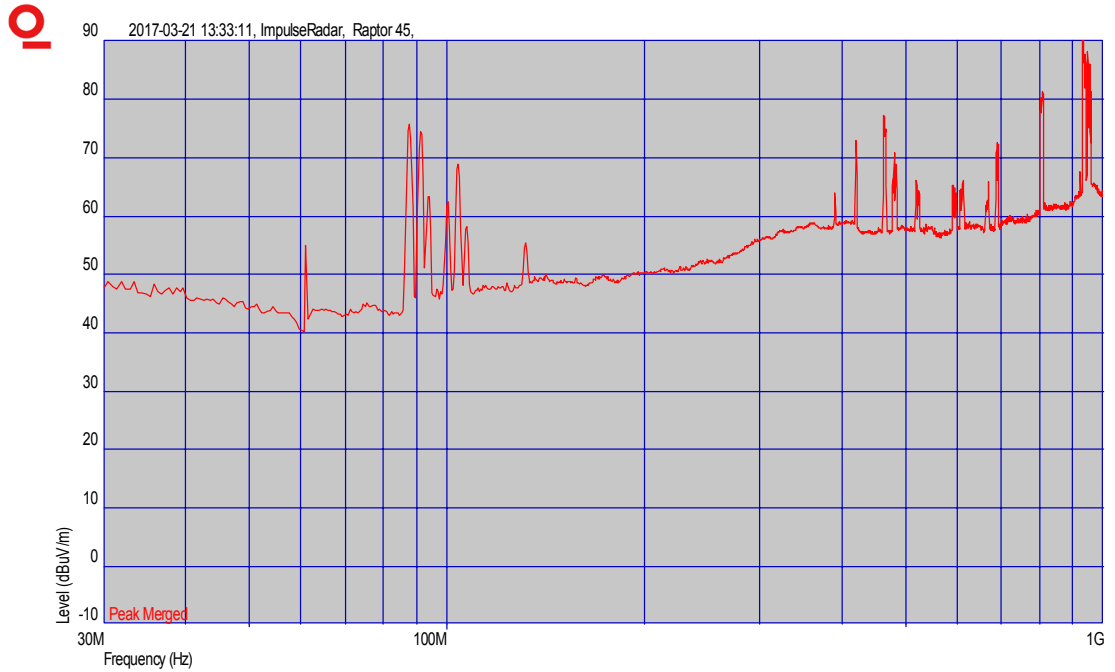
Emission at f_M (peak emissions)

The frequency of highest emission (f_M) was 967 MHz, which is above 960 MHz.

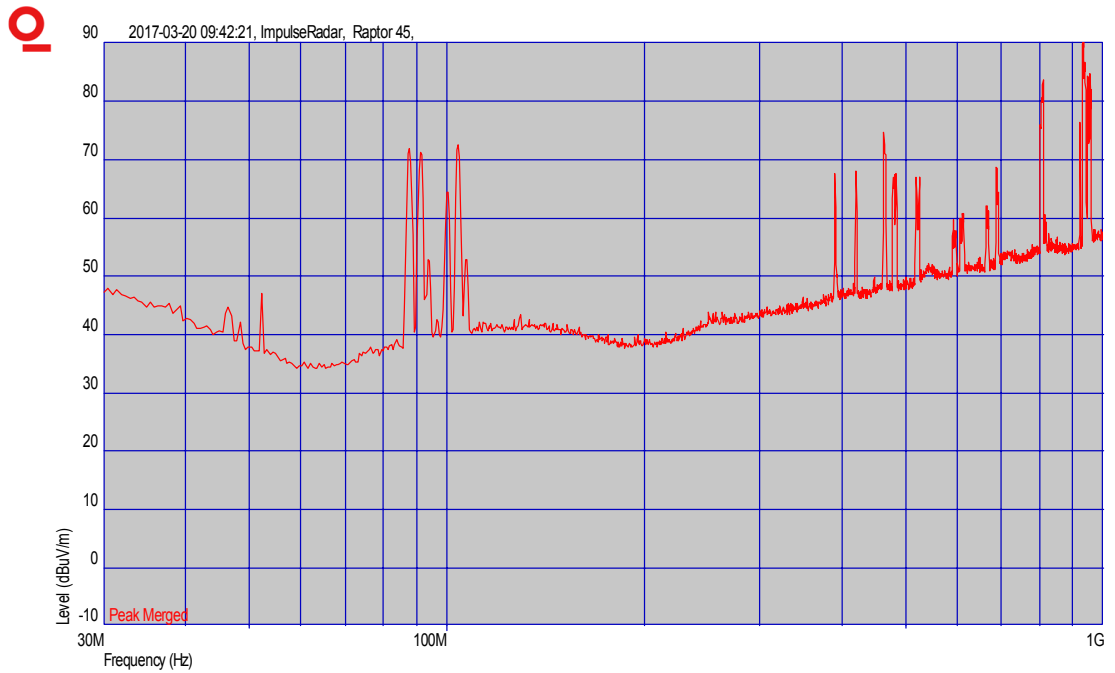
The level at 967 MHz was 65.8 dB μ V/m measured with 1 MHz bandwidth, compared with the requirement of 70.7 dB μ V/m. The requirement of peak emissions was fulfilled with a margin of 4.9 dB.



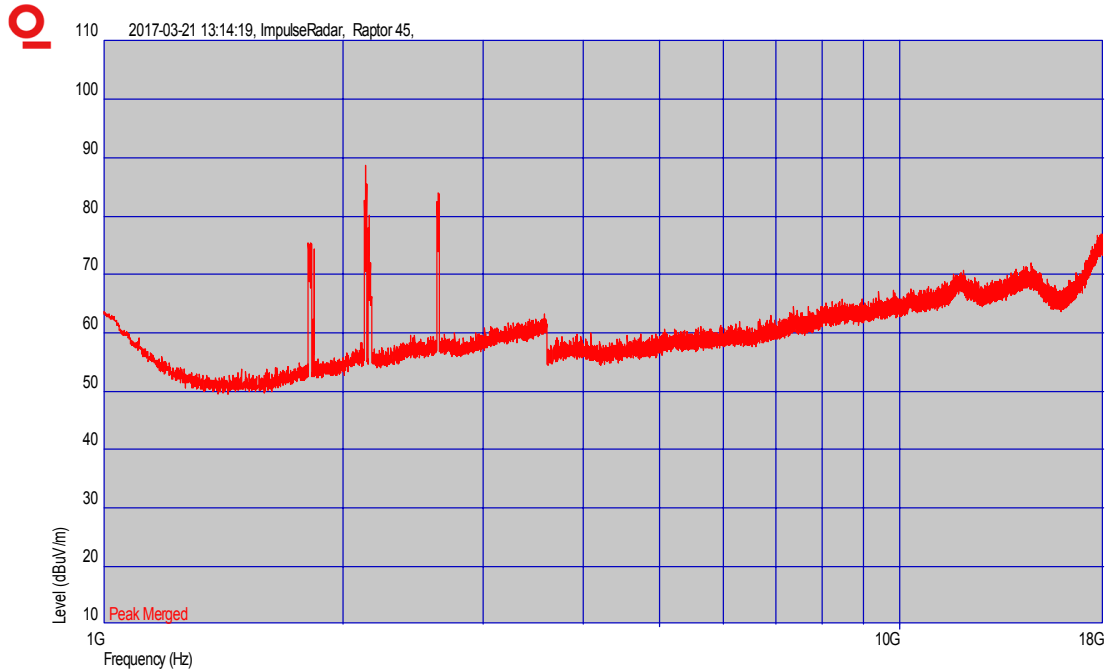
UWB bandwidth, peak detector, 1 MHz BW, 30 MHz - 1 GHz, EUT tilted



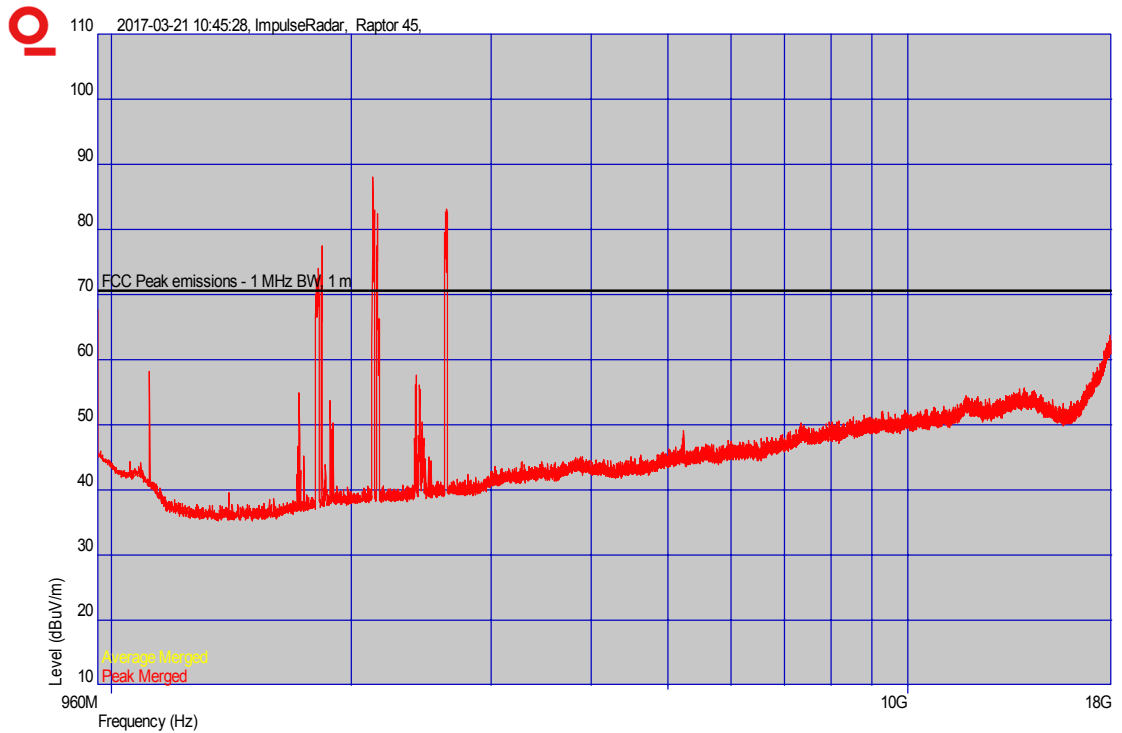
Ambient emissions, peak detector, 1 MHz BW, 30 MHz - 1 GHz



UWB bandwidth, peak detector, 1 MHz BW, 1-18 GHz, EUT tilted



Peak emissions, peak detector, 1 MHz BW, 960 MHz - 18 GHz



5.3.4 Instrumentation

| Manufacturer | Model | Range | S/N | Cal. Interval | Cal. Date |
|---------------------------------|--------------|------------------|------------|----------------------|------------------|
| Rohde & Schwarz EMI-receiver | ESU26 | 20 Hz – 26.5 GHz | 100019 | 24 month | 21/09/2016 |
| Emco Double Ridge Waveguide | 3115 | 0.96-18 GHz | 2800 | 36 month | 14/11/2014 |
| Chase Bilog antenna | CBL6111A | 30 - 1000 MHz | 1164 | 36 month | 07/01/2015 |