

TEST REPORT

Test report no.: 1-0764/20-01-02



Testing laboratory

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Accredited Testing Laboratory:

The testing laboratory (area of testing) is accredited according to DIN EN ISO/IEC 17025 (2018-03) by the Deutsche Akkreditierungsstelle GmbH (DAkkS)

The accreditation is valid for the scope of testing procedures as stated in the accreditation certificate starting with the registration number: D-PL-12076-01.

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Test standard/s

CFR 47 Part 95,
Subpart M

The 76-81 GHz Band Radar Service

CFR 47 Part 2,
Subpart J

Frequency allocations and radio treaty matters; general rules and regulations

For further applied test standards please refer to section 3 of this test report.

Test Item

Kind of test item: 76 GHz Automotive Radar

Type: MRGEN21

FCC ID: S9I-MRGEN21

Frequency: 76.0 GHz – 77.0 GHz

Antenna: Integrated antenna

Power supply: 8.0 to 16.0 V DC by external power supply

Temperature range: -40°C to +85°C



This test report is electronically signed and valid without handwritten signature. For verification of the electronic signatures, the public keys can be requested at the testing laboratory.

Test report authorized:



Meheza Walla
Lab Manager
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Test performed:



Frank Heussner
Testing Manager
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2 General information

2.1 Notes and disclaimer

The test results of this test report relate exclusively to the test item specified in this test report. CTC advanced GmbH does not assume responsibility for any conclusions and generalizations drawn from the test results with regard to other specimens or samples of the type of the equipment represented by the test item.

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2.2 Application details

| | |
|------------------------------------|------------|
| Date of receipt of order: | 2020-09-30 |
| Date of receipt of test item: | 2021-10-01 |
| Start of test:* | 2021-10-18 |
| End of test:* | 2021-11-17 |
| Person(s) present during the test: | -/- |

*Date of each measurement, if not shown in the plot, can be requested. Dates are stored in the measurement software.

2.3 Test laboratories sub-contracted

None

3 Test standard/s and references

| Test standard | Date | Description |
|---------------------------|------|---|
| CFR 47 Part 95, Subpart M | -/- | The 76-81 GHz Band Radar Service |
| CFR 47 Part 2, Subpart J | -/- | Frequency allocations and radio treaty matters; general rules and regulations |

| Guidance | Version | Description |
|------------------|-------------------|---|
| 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 |
| ANSI C63.10-2013 | -/- | American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices |
| ANSI C63.26-2015 | -/- | American National Standard for Compliance Testing of Transmitters Used in Licensed Radio Services |
| KDB 653005 D01 | v01r01 2019-04 | Equipment Authorization Guidance for 76-81 GHz Radar Devices |

| Accreditation | Description |
|---------------|-------------|
|---------------|-------------|

D-PL-12076-01-05

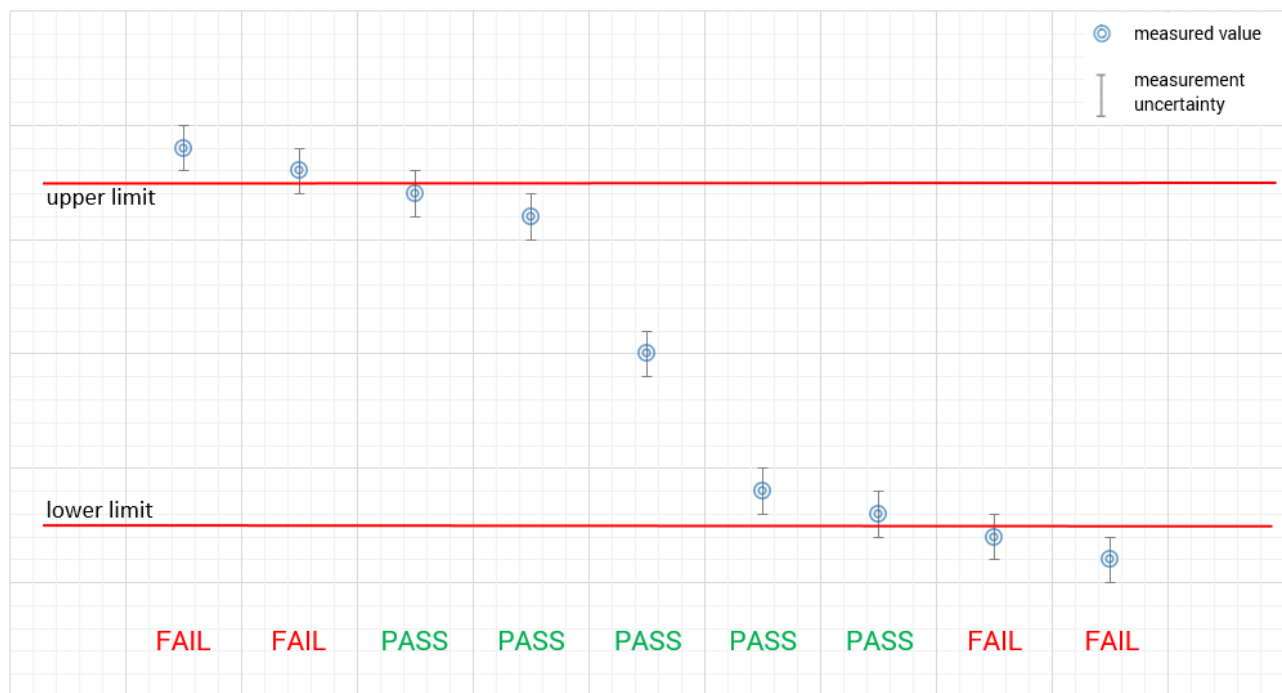
 Telecommunication FCC requirements
<https://www.dakks.de/as/ast/d/D-PL-12076-01-05e.pdf>


4 Reporting statements of conformity – decision rule

Only the measured values related to their corresponding limits will be used to decide whether the equipment under test meets the requirements of the test standards listed in chapter 3.

The measurement uncertainty is mentioned in this test report, see chapter 9, but is not taken into account - neither to the limits nor to the measurement results. Measurement results with a smaller margin to the corresponding limits than the measurement uncertainty have a potential risk of more than 5% that the decision might be wrong."

measured value, measurement uncertainty, verdict



5 Test environment

| | | |
|---------------------------|---|---|
| Temperature | : | T_{nom} +22 °C during room temperature tests T_{max} +85 °C during high temperature tests T_{min} -40 °C during low temperature tests |
| Relative humidity content | : | 55 % |
| Barometric pressure | : | not relevant for this kind of testing |
| Power supply | : | V_{nom} 12.0 V DC by external power supply V_{max} 16.0 V V_{min} 8.0 V |

6 Test item

6.1 General description

| | | |
|---------------------------|---|---|
| Kind of test item | : | 76 GHz Automotive Radar |
| Type | : | MRGEN21 |
| S/N serial number | : | TOY21175BRT20010 |
| Hardware status | : | BD3.0 |
| Software status | : | T2_R11 |
| Frequency band | : | 76.0 GHz – 77.0 GHz |
| Type of modulation | : | FMCW |
| Number of modes | : | 3 |
| Antenna | : | Integrated antenna |
| Power supply | : | 8.0 to 16.0 V DC by external power supply |
| Temperature range | : | -40°C to +85°C |

6.2 Additional information

Operating modes as declared by manufacturer:

| Modulation mode | Detection Range | Accuracy | Bandwidth [MHz] |
|--------------------------|-----------------|----------|-------------------------------------|
| Long Range High Speed | 220 m | ≤ 0.1 m | 150MHz (eff)* ≈ 210MHz (chirp)** |
| Mid-Range Mid. Speed | 154 m | ≤ 0.07 m | 215MHz (eff)* ≈ 300MHz (chirp)** |
| Short Range Low Speed | 90 m | ≤ 0.04 m | 375MHz (eff)* ≈ 520MHz (chirp)** |

* refers to the bandwidth used by the radar ADC; ** is referred to the bandwidth of the modulated RF signal

The operating modes were set with the help of special software and according to the document "PRO_MEM_2165_A.pdf".

The 3 modulations were tested.

The content of the following annexes is defined in the QA. It may be that not all of the listed annexes are necessary for this report, thus some values in between may be missing.

Test setup and EUT photos are included in test report:

- 1-0764/20-01-01_AnnexA
- 1-0764/20-01-01_AnnexB
- 1-0764/20-01-01_AnnexD

7 Description of the test setup

Typically, the calibrations of the test apparatus are commissioned to and performed by an accredited calibration laboratory. The calibration intervals are determined in accordance with the DIN EN ISO/IEC 17025. In addition to the external calibrations, the laboratory executes comparison measurements with other calibrated test systems or effective verifications. Weekly chamber inspections and range calibrations are performed. Where possible, RF generating and signaling equipment as well as measuring receivers and analyzers are connected to an external high-precision 10 MHz reference (GPS-based or rubidium frequency standard).

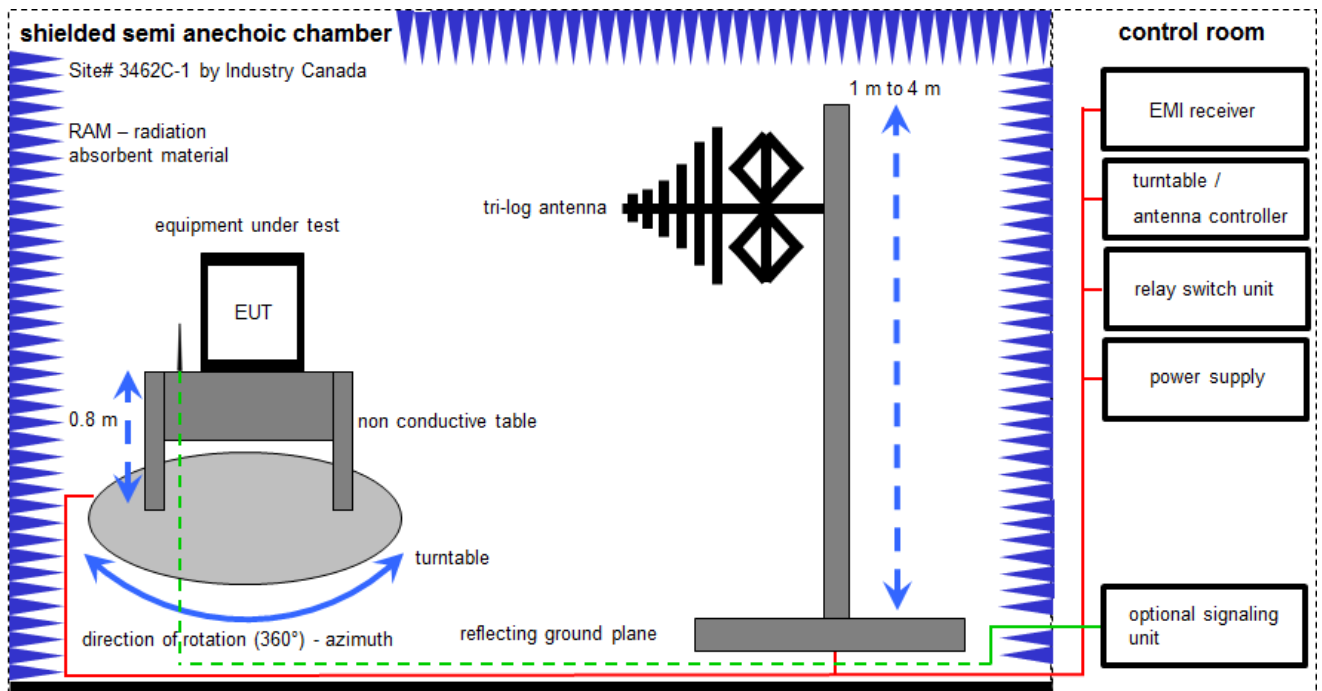
In order to simplify the identification of the equipment used at some special tests, some items of test equipment and ancillaries can be provided with an identifier or number in the equipment list below (Lab/Item).

Agenda: Kind of Calibration

| | | | | |
|------|--|--|-----|--|
| k | calibration / calibrated | | EK | limited calibration |
| ne | not required (k, ev, izw, zw not required) | | zw | cyclical maintenance (external cyclical maintenance) |
| ev | periodic self verification | | izw | internal cyclical maintenance |
| Ve | long-term stability recognized | | g | blocked for accredited testing |
| vkl! | Attention: extended calibration interval | | | |
| NK! | Attention: not calibrated | | *) | next calibration ordered / currently in progress |

7.1 Shielded semi anechoic chamber

The radiated measurements are performed in vertical and horizontal plane in the frequency range from 30 MHz to 1 GHz in semi-anechoic chambers. The EUT is positioned on a non-conductive support with a height of 0.80 m above a conductive ground plane that covers the whole chamber. The receiving antennas are conform to specifications ANSI C63. These antennas can be moved over the height range between 1.0 m and 4.0 m in order to search for maximum field strength emitted from EUT. The measurement distances between EUT and receiving antennas are indicated in the test setups for the various frequency ranges. For each measurement, the EUT is rotated in all three axes until the maximum field strength is received. The wanted and unwanted emissions are received by spectrum analyzers where the detector modes and resolution bandwidths over various frequency ranges are set according to requirement ANSI C63.



Measurement distance: tri-log antenna 10 meter

$$FS = UR + CL + AF$$

(FS-field strength; UR-voltage at the receiver; CL-loss of the cable; AF-antenna factor)

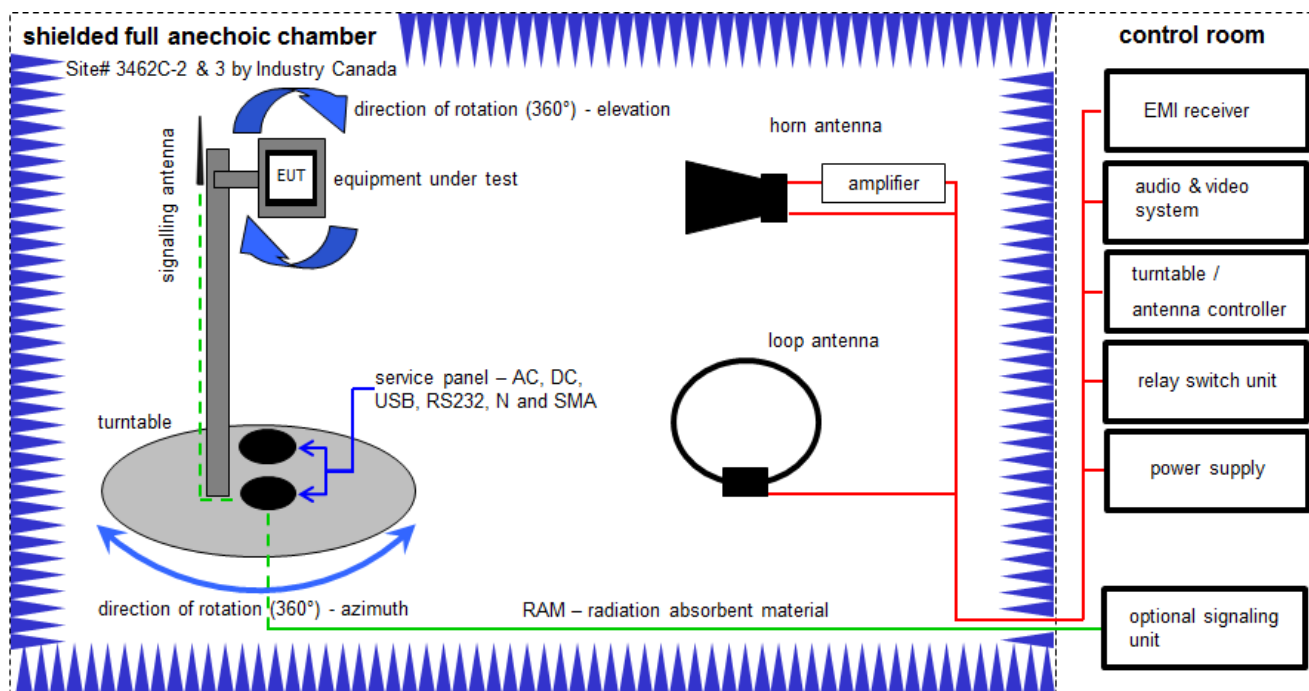
Example calculation:

$$FS [dB\mu V/m] = 12.35 [dB\mu V/m] + 1.90 [dB] + 16.80 [dB/m] = 31.05 [dB\mu V/m] (35.69 \mu V/m)$$

Equipment table:

| No. | Lab / Item | Equipment | Type | Manufacturer | Serial No. | INV. No. | Kind of Calibration | Last Calibration | Next Calibration |
|-----|------------|--|--------------|-------------------------------|------------|-----------|---------------------|------------------|------------------|
| 1 | n. a. | Switch-Unit | 3488A | HP | 2719A14505 | 300000368 | ev | -/- | -/- |
| 2 | n. a. | DC power supply, 60Vdc, 50A, 1200 W | 6032A | HP | 2920A04466 | 300000580 | ne | -/- | -/- |
| 3 | n. a. | Semi anechoic chamber | 300023 | MWB AG | -/- | 300000551 | ne | -/- | -/- |
| 4 | n. a. | Antenna Tower | Model 2175 | ETS-Lindgren | 64762 | 300003745 | izw | -/- | -/- |
| 5 | n. a. | Positioning Controller | Model 2090 | ETS-Lindgren | 64672 | 300003746 | izw | -/- | -/- |
| 6 | n. a. | Turntable Interface-Box | Model 105637 | ETS-Lindgren | 44583 | 300003747 | izw | -/- | -/- |
| 7 | n. a. | TRILOG Broadband Test-Antenna 30 MHz - 3 GHz | VULB9163 | Schwarzbeck Mess - Elektronik | 318 | 300003696 | vKI! | 30.09.2021 | 29.09.2023 |
| 8 | n. a. | EMI Test Receiver | ESR3 | Rohde & Schwarz | 102587 | 300005771 | k | 10.12.2020 | 09.12.2021 |
| 9 | n. a. | PC | TecLine | F+W | -/- | 300004388 | ne | -/- | -/- |

7.2 Shielded fully anechoic chamber



Measurement distance: horn antenna 3 meter; loop antenna 3 meter / 1 meter

$$FS = UR + CA + AF$$

(FS-field strength; UR-voltage at the receiver; CA-loss of the signal path; AF-antenna factor)

Example calculation:

$$FS [dB\mu V/m] = 40.0 [dB\mu V/m] + (-35.8) [dB] + 32.9 [dB/m] = 37.1 [dB\mu V/m] (71.61 \mu V/m)$$

$$OP = AV + D - G + CA$$

(OP-radiated output power; AV-analyzer value; D-free field attenuation of measurement distance; G-antenna gain+amplifier gain; CA-loss signal path)

Example calculation:

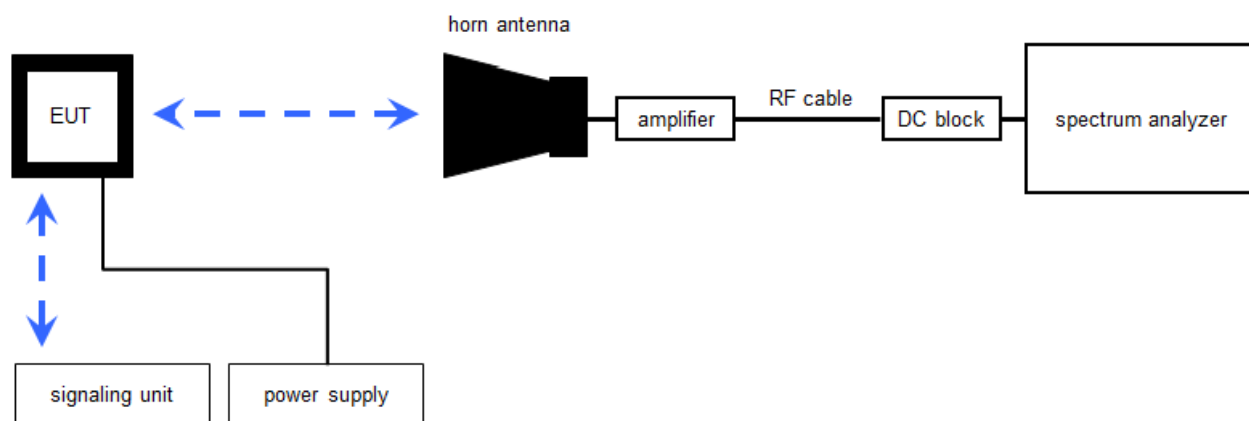
$$OP [dBm] = -39.0 [dBm] + 57.0 [dB] - 12.0 [dBi] + (-36.0) [dB] = -30 [dBm] (1 \mu W)$$

Equipment table:

| No. | Lab / Item | Equipment | Type | Manufacturer | Serial No. | INV. No. | Kind of Calibration | Last Calibration | Next Calibration |
|-----|------------|--|---|-------------------------------|------------|-----------|---------------------|------------------|------------------|
| 1 | n. a. | DC power supply, 60Vdc, 50A, 1200 W | 6032A | HP | 2818A03450 | 300001040 | vKI! | 09.12.2020 | 08.12.2023 |
| 2 | n. a. | Active Loop Antenna 9 kHz to 30 MHz | 6502 | EMCO | 2210 | 300001015 | vKI! | 13.06.2019 | 12.06.2022 |
| 3 | n. a. | Anechoic chamber | FAC 3/5m | MWB / TDK | 87400/02 | 300000996 | ev | -/- | -/- |
| 4 | n. a. | TRILOG Broadband Test-Antenna 30 MHz - 3 GHz | VULB9163 | Schwarzbeck Mess - Elektronik | 371 | 300003854 | vKI! | 14.01.2020 | 13.01.2022 |
| 5 | n. a. | Double-Ridged Waveguide Horn Antenna 1-18.0GHz | 3115 | EMCO | 9107-3697 | 300001605 | vKI! | 12.03.2021 | 11.03.2023 |
| 6 | n. a. | Switch / Control Unit | 3488A | HP | * | 300000199 | ne | -/- | -/- |
| 7 | n. a. | Variable isolating transformer | MPL IEC625 Bus Variable isolating transformer | Erfi | 91350 | 300001155 | ne | -/- | -/- |
| 8 | n. a. | EMI Test Receiver 20Hz- 26,5GHz | ESU26 | R&S | 100037 | 300003555 | k | 11.12.2020 | 10.12.2021 |
| 9 | n. a. | Highpass Filter | WHKX7.0/18G-8SS | Wainwright | 19 | 300003790 | ne | -/- | -/- |
| 10 | n. a. | Broadband Amplifier 0.5-18 GHz | CBLU5184540 | CERNEX | 22049 | 300004481 | ev | -/- | -/- |
| 11 | n. a. | Broadband Amplifier 5-13 GHz | CBLU5135235 | CERNEX | 22010 | 300004491 | ev | -/- | -/- |
| 12 | n. a. | 4U RF Switch Platform | L4491A | Agilent Technologies | MY50000037 | 300004509 | ne | -/- | -/- |
| 13 | n. a. | NEXIO EMV-Software | BAT EMC V3.16.0.49 | EMCO | | 300004682 | ne | -/- | -/- |
| 14 | n. a. | PC | ExOne | F+W | | 300004703 | ne | -/- | -/- |
| 15 | n. a. | RF-Amplifier | AMF-6F06001800-30-10P-R | NARDA-MITEQ Inc | 2011572 | 300005241 | ev | -/- | -/- |

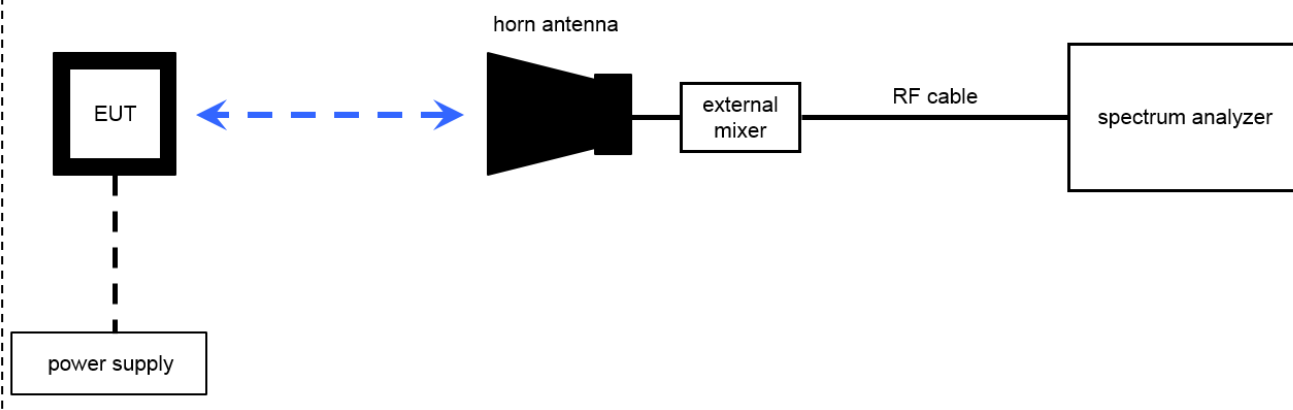
7.3 Radiated measurements > 18 GHz

Radiated measurements > 18 GHz



7.4 Radiated measurements > 50/85 GHz

Radiated measurements RF laboratory



$$OP = AV + D - G$$

(OP-rad. output power; AV-analyzer value; D-free field attenuation of measurement distance; G-antenna gain)

Example calculation:

$$OP \text{ [dBm]} = -54.0 \text{ [dBm]} + 64.0 \text{ [dB]} - 20.0 \text{ [dBi]} = -10 \text{ [dBm]} \text{ (100 } \mu\text{W)}$$

Note: conversion loss of mixer is already included in analyzer value.

Equipment table:

| No. | Lab / Item | Equipment | Type | Manufacturer | Serial No. | INV. No. | Kind of Calibration | Last Calibration | Next Calibration |
|-----|------------|--------------------------------------|---------------|-------------------------|---------------|-----------|---------------------|------------------|------------------|
| 1 | n.a. | Horn Antenna 18.0-40.0 GHz | LHAF180 | Microw.Devel | 39180-103-021 | 300001747 | vKI! | 18.02.2019 | 17.02.2022 |
| 2 | n. a. | Std. Gain Horn Antenna 18.0-26.5 GHz | 638 | Narda | | 300000486 | vKI! | 21.01.2020 | 20.01.2022 |
| 3 | n. a. | Std. Gain Horn Antenna 26.5-40.0 GHz | V637 | Narda | 82-16 | 300000510 | vKI! | 23.01.2020 | 22.01.2022 |
| 4 | n.a. | Std. Gain Horn Antenna 33.0-50.1 GHz | 2324-20 | Flann | 57 | 400000683 | ne | -/- | -/- |
| 5 | n. a. | Std. Gain Horn Antenna 49.9-75.8 GHz | 2524-20 | Flann | * | 300001983 | ne | -/- | -/- |
| 6 | n. a. | Std. Gain Horn Antenna 60-90 GHz | COR 60_90 | Thomson CSF | | 300000814 | ev | -/- | -/- |
| 7 | n. a. | Std. Gain Horn Antenna 73.8-112 GHz | 2724-20 | Flann | * | 300001988 | ne | -/- | -/- |
| 8 | n.a. | Std. Gain Horn Antenna 92.3-140 GHz | 2824-20 | Flann | | 300001993 | ne | -/- | -/- |
| 9 | n. a. | Std. Gain Horn Antenna 114-173 GHz | 2924-20 | Flann | * | 300001999 | ne | -/- | -/- |
| 10 | n. a. | Std. Gain Horn Antenna 145-220 GHz | 3024-20 | Flann | * | 300002000 | ne | -/- | -/- |
| 11 | n. a. | Std. Gain Horn Antenna 217-330 GHz | 32240-20 | Flann | 233278 | 300004960 | ne | -/- | -/- |
| 12 | n. a. | Broadband LNA 18-50 GHz | CBL18503070PN | CERNEX | 25240 | 300004948 | ev | 09.03.2020 | 08.03.2022 |
| 13 | n. a. | Harmonic Mixer 3-Port, 60-90 GHz | FS-Z90 | R&S | 102152 | 300006202 | k | 21.01.2021 | 20.01.2022 |
| 14 | n.a. | Harmonic Mixer 3-port, 90-140 GHz | FS-Z140 | Rohde & Schwarz | 101119 | 300005581 | k | 22.07.2021 | 21.07.2022 |
| 15 | n.a. | Harmonic Mixer 3-port, 75-110 GHz | FS-Z110 | Rohde & Schwarz | 101411 | 300004959 | k | 15.06.2021 | 14.06.2022 |
| 16 | n.a. | Harmonic Mixer 3-port, 110-170 GHz | FS-Z170 | Rohde & Schwarz | 100014 | 300004156 | k | 11.06.2021 | 10.06.2022 |
| 17 | n. a. | Harmonic Mixer 3-Port, 140-220 GHz | SAM-220 | Radiometer Physics GmbH | 200001 | 300004157 | k | 22.07.2021 | 21.07.2022 |
| 18 | n. a. | Harmonic Mixer 3-Port, 220-325 GHz | SAM-325 | Radiometer Physics GmbH | 100002 | 300004158 | k | 22.07.2021 | 21.07.2022 |
| 19 | n. a. | Spectrum Analyzer 2 Hz - 50 GHz | FSW50 | R&S | 101332 | 300005935 | k | 05.03.2021 | 04.03.2022 |
| 20 | n.a. | Spectrum Analyzer 2 Hz - 85 GHz | FSW85 | R&S | 101333 | 300005568 | k | 30.06.2021 | 29.06.2022 |
| 21 | n. a. | Temperature Test Chamber | T-40/50 | CTS GmbH | 064023 | 300003540 | ev | 08.05.2020 | 07.05.2022 |

8 Sequence of testing

8.1 Sequence of testing radiated spurious 9 kHz to 30 MHz

Setup

- The equipment is set up to simulate normal operation mode as described in the user manual or defined by the manufacturer.
- If the EUT is a tabletop system, it is placed on a table with 0.8 m height.
- If the EUT is a floor standing device, it is placed directly on the turn table.
- Auxiliary equipment and cables are positioned to simulate normal operation conditions as described in ANSI C 63.4.
- The AC power port of the EUT (if available) is connected to a power outlet below the turntable.
- Measurement distance is 3 m (see ANSI C 63.4) – see test details.
- EUT is set into operation.

Premeasurement*

- The turntable rotates from 0° to 315° using 45° steps.
- The antenna height is 1 m.
- At each turntable position the analyzer sweeps with positive-peak detector to find the maximum of all emissions.

Final measurement

- Identified emissions during the pre-measurement are maximized by the software by rotating the turntable from 0° to 360°.
- Loop antenna is rotated about its vertical axis for maximum response at each azimuth about the EUT. (For certain applications, the loop antenna plane may also need to be positioned horizontally at the specified distance from the EUT)
- The final measurement is done in the position (turntable and elevation) causing the highest emissions with quasi-peak (as described in ANSI C 63.4).
- Final levels, frequency, measuring time, bandwidth, turntable position, correction factor, margin to the limit and limit will be recorded. A plot with the graph of the premeasurement and the limit is stored.

*)Note: The sequence will be repeated three times with different EUT orientations.

8.2 Sequence of testing radiated spurious 30 MHz to 1 GHz

Setup

- The equipment is set up to simulate normal operation mode as described in the user manual or defined by the manufacturer.
- If the EUT is a tabletop system, a table with 0.8 m height is used, which is placed on the ground plane.
- If the EUT is a floor standing device, it is placed on the ground plane with insulation between both.
- Auxiliary equipment and cables are positioned to simulate normal operation conditions as described in ANSI C 63.4.
- The AC power port of the EUT (if available) is connected to a power outlet below the turntable.
- Measurement distance is 10 m or 3 m (see ANSI C 63.4) – see test details.
- EUT is set into operation.

Premeasurement

- The turntable rotates from 0° to 315° using 45° steps.
- The antenna is polarized vertical and horizontal.
- The antenna height changes from 1 m to 3 m.
- At each turntable position, antenna polarization and height the analyzer sweeps three times in peak to find the maximum of all emissions.

Final measurement

- The final measurement is performed for at least six highest peaks according to the requirements of the ANSI C63.4.
- Based on antenna and turntable positions at which the peak values are measured the software maximize the peaks by changing turntable position $\pm 45^\circ$ and antenna height between 1 and 4 m.
- The final measurement is done with quasi-peak detector (as described in ANSI C 63.4).
- Final levels, frequency, measuring time, bandwidth, antenna height, antenna polarization, turntable angle, correction factor, margin to the limit and limit are recorded. A plot with the graph of the premeasurement with marked maximum final results and the limit is stored.

8.3 Sequence of testing radiated spurious 1 GHz to 18 GHz

Setup

- The equipment is set up to simulate normal operation mode as described in the user manual or defined by the manufacturer.
- If the EUT is a tabletop system, a 2-axis positioner with 1.5 m height is used.
- If the EUT is a floor standing device, it is placed directly on the turn table.
- Auxiliary equipment and cables are positioned to simulate normal operation conditions as described in ANSI C 63.4.
- The AC power port of the EUT (if available) is connected to a power outlet below the turntable.
- Measurement distance is 3 m (see ANSI C 63.4) – see test details.
- EUT is set into operation.

Premeasurement

- The turntable rotates from 0° to 315° using 45° steps.
- The antenna is polarized vertical and horizontal.
- The antenna height is 1.5 m.
- At each turntable position and antenna polarization the analyzer sweeps with positive peak detector to find the maximum of all emissions.

Final measurement

- The final measurement is performed for at least six highest peaks according to the requirements of the ANSI C63.4.
- Based on antenna and turntable positions at which the peak values are measured the software maximizes the peaks by rotating the turntable from 0° to 360°. This measurement is repeated for different EUT-table positions (0° to 150° in 30°-steps) and for both antenna polarizations.
- The final measurement is done in the position (turntable, EUT-table and antenna polarization) causing the highest emissions with Peak and RMS detector (as described in ANSI C 63.4).
- Final levels, frequency, measuring time, bandwidth, turntable position, EUT-table position, antenna polarization, correction factor, margin to the limit and limit are recorded. A plot with the graph of the premeasurement with marked maximum final results and the limit is stored.

8.4 Sequence of testing radiated spurious above 18 GHz

Setup

- The equipment is set up to simulate normal operation mode as described in the user manual or defined by the manufacturer.
- Auxiliary equipment and cables are positioned to simulate normal operation conditions as described in ANSI C 63.4.
- The AC power port of the EUT (if available) is connected to a power outlet.
- The measurement distance is as appropriate (e.g. 0.5 m).
- The EUT is set into operation.

Premeasurement

- The test antenna is handheld and moved carefully over the EUT to cover the EUT's whole sphere and different polarizations of the antenna.

Final measurement

- The final measurement is performed at the position and antenna orientation causing the highest emissions with Peak and RMS detector (as described in ANSI C 63.4).
- Final levels, frequency, measuring time, bandwidth, correction factor, margin to the limit and limit are recorded. A plot with the graph of the premeasurement and the limit is stored.

8.5 Sequence of testing radiated spurious above 50/85 GHz with external mixers

Setup

- The equipment is set up to simulate normal operation mode as described in the user manual or defined by the manufacturer.
- Auxiliary equipment and cables are positioned to simulate normal operation conditions as described in ANSI C 63.4.
- The AC power port of the EUT (if available) is connected to a power outlet.
- The measurement distance is as appropriate for far field (e.g. 0.25 m).
- The EUT is set into operation.

Premeasurement

- The test antenna with external mixer is handheld and moved carefully over the EUT to cover the EUT's whole sphere and different polarizations of the antenna.
- Caution is taken to reduce the possible overloading of the external mixer.

Final measurement

- The final measurement is performed at the position and antenna orientation causing the highest emissions with Peak and RMS detector (as described in ANSI C 63.4).
- As external mixers may generate false images care is taken to ensure that any emission measured by the spectrum analyzer does indeed originate in the EUT. Signal identification feature of spectrum analyzer is used to eliminate false mixer images (i.e., it is not the fundamental emission or a harmonic falling precisely at the measured frequency).
- Final levels, frequency, measuring time, bandwidth, correction factor, margin to the limit and limit are recorded. A plot with the graph of the premeasurement and the limit is stored.

9 Measurement uncertainty

| Test case | Uncertainty |
|---|---|
| Equivalent isotropically radiated power (e.i.r.p.) | Conducted value ± 1 dB Radiated value ± 3 dB |
| Permitted range of operating frequencies | ± 100 kHz |
| Conducted unwanted emissions in the spurious domain (up to 40 GHz) | ± 1 dB |
| Radiated unwanted emissions in the spurious domain (up to 40 GHz) | ± 3 dB |
| Conducted unwanted emissions in the spurious domain (40 to 50 GHz) | ± 4 dB |
| Radiated unwanted emissions in the spurious domain (40 to 50 GHz) | ± 4 dB |
| Conducted unwanted emissions in the spurious domain (50 to 300 GHz) | ± 5 dB |
| Radiated unwanted emissions in the spurious domain (50 to 300 GHz) | ± 5 dB |
| DC and low frequency voltages | ± 3 % |
| Temperature | ± 1 °C |
| Humidity | ± 3 % |

10 Summary of measurement results

| | |
|-------------------------------------|--|
| <input checked="" type="checkbox"/> | No deviations from the technical specifications were ascertained |
| <input type="checkbox"/> | There were deviations from the technical specifications ascertained |
| <input type="checkbox"/> | This test report is only a partial test report. The content and verdict of the performed test cases are listed below. |

| TC Identifier | Description | Verdict | Date | Remark |
|---------------|--------------------------|-----------|------------|--------|
| RF-Testing | 47 CFR Part 95 Subpart M | see below | 2021-12-09 | -/- |

| Test specification clause | Test case | Temperature conditions | Power source voltages | C | NC | NA | NP | Results (max.) |
|--|---|------------------------|-----------------------|-------------------------------------|--------------------------|-------------------------------------|--------------------------|----------------|
| §2.1046 §95.3367 (a) / (b) | Radiated power | Nominal | Nominal | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | -/- |
| §2.1047 | Modulation characteristics | -/- | -/- | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | -/- |
| §2.1049 | Occupied bandwidth (99% bandwidth) | Nominal | Nominal | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | -/- |
| §2.1051 | Spurious emissions at antenna terminals | Nominal | Nominal | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/> | see note |
| §2.1053 §95.3379 (a)(1) §95.3379 (a)(2) §95.3379 (a)(3) | Field strength of emissions (radiated spurious) | Nominal | Nominal | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | -/- |
| §2.1055 §95.3379 (b) | Frequency stability | Nominal and Extreme | Nominal and Extreme | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | -/- |

Note: C = Compliant; NC = Not compliant; NA = Not applicable; NP = Not performed

See FCC's Millimeter Wave Test Procedures:

I. A radiated method of measurements in order to demonstrate compliance with the various regulatory requirements has been chosen in consideration of test equipment availability and the limitations of many external harmonic mixers. A conducted method of measurement could be employed if EUT and mixer waveguides both are accessible and of the same type (WG number) and if waveguide sections and transitions can be found. Another potential problem is that the peak power output of devices operating under Sections 15.253 and 15.255 may exceed the +20 dBm input power limit of many commercially available mixers. For these reasons a radiated method is preferred.

11 Measurement results

11.1 Radiated power

Description:

The fundamental radiated emission limits within the 76-81 GHz band are expressed in terms of Equivalent Isotropically Radiated Power (EIRP) and are as shown below.

Measurement:

| Parameters | |
|-----------------------|----------------|
| Detector: | RMS / Pos-Peak |
| Sweep time: | 72.5 s |
| Resolution bandwidth: | 1 MHz |
| Video bandwidth: | 3 MHz |
| Trace-Mode: | Max Hold |

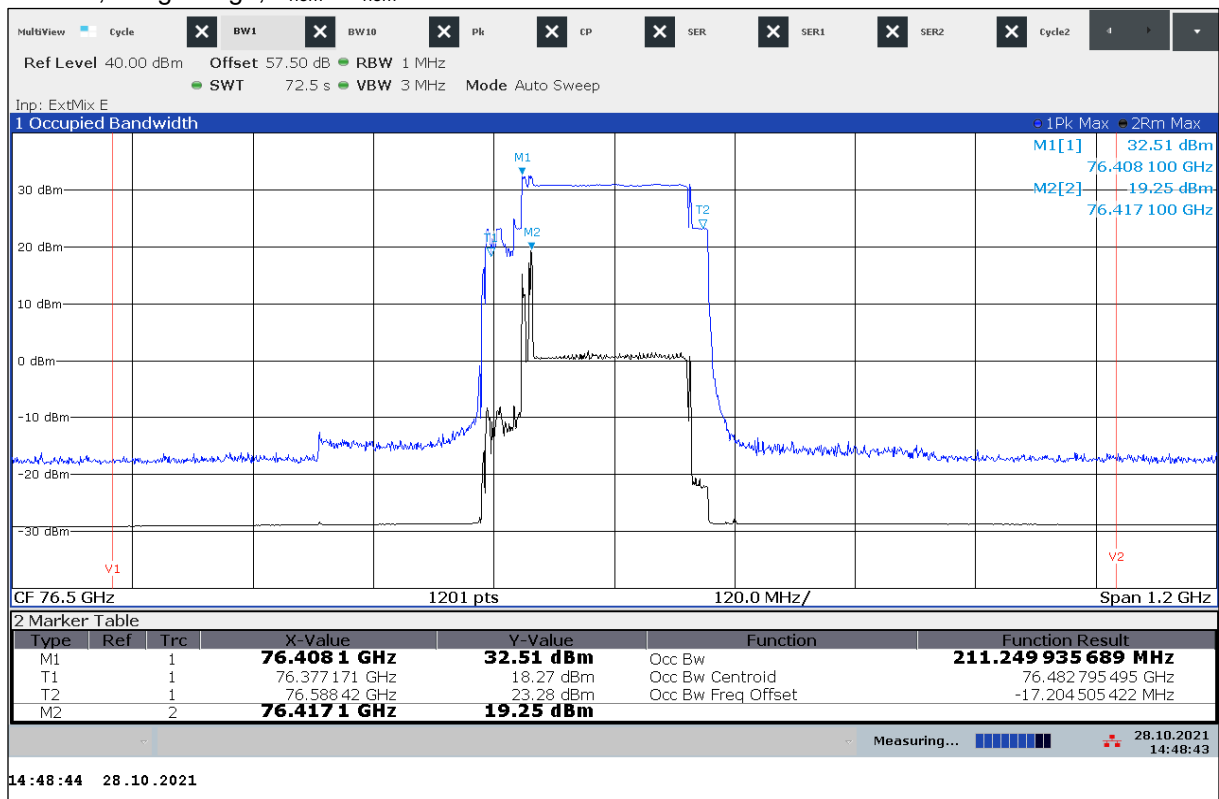
Limits:

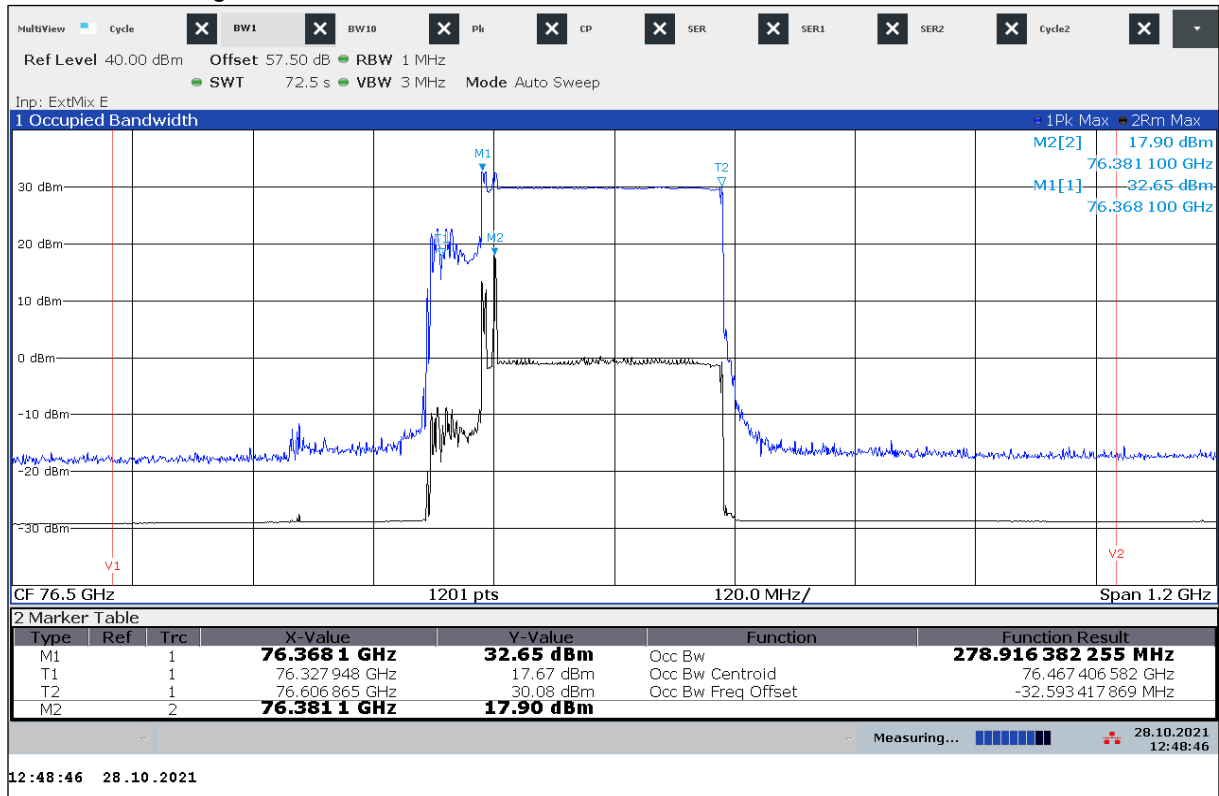
FCC §95.3367 (a) (b)

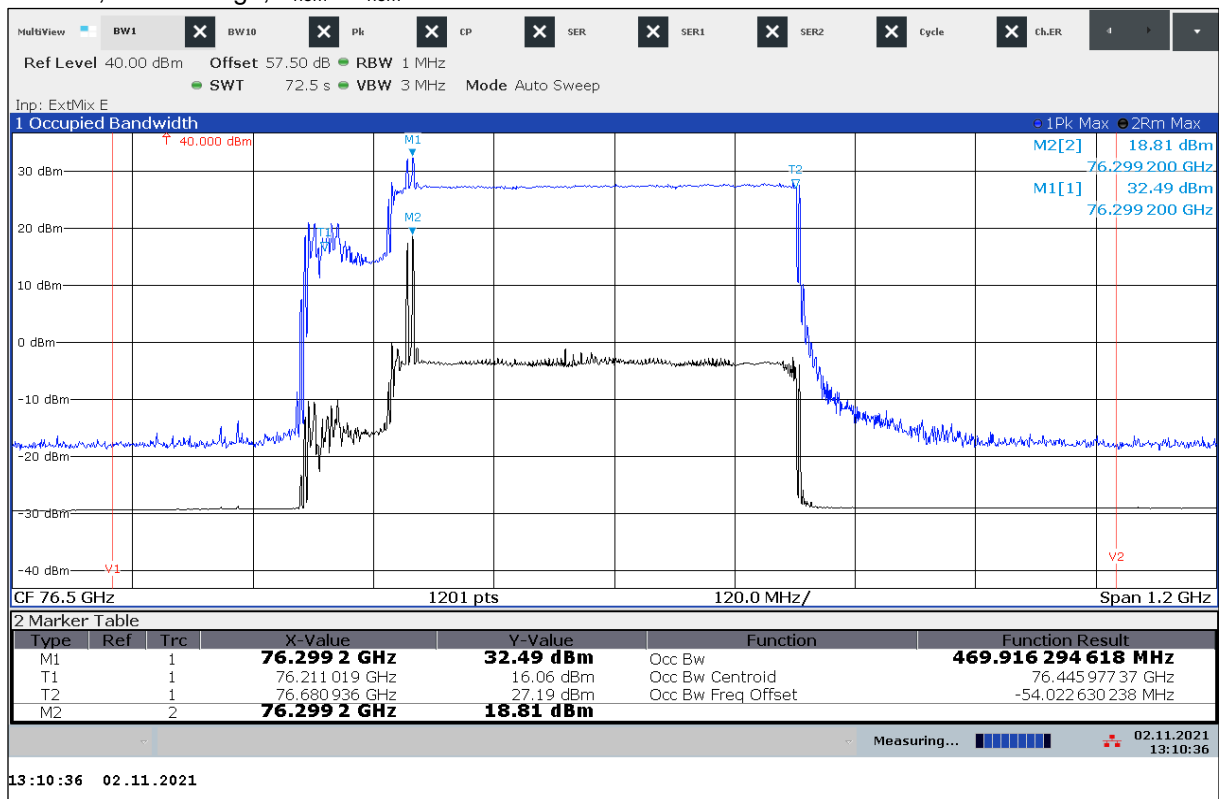
| Frequency | Measurement distance | EIRP |
|-----------------|----------------------|--|
| 76.0 - 81.0 GHz | 3.0 m | $88 \mu\text{W}/\text{cm}^2 \rightarrow 50 \text{ dBm (Average)}$ $279 \mu\text{W}/\text{cm}^2 \rightarrow 55 \text{ dBm (PEAK)}$ |

Measurement results:

| Modulation / Test conditions | | Channel power Radiated mean power (eirp) [dBm] | Radiated peak power (eirp) [dBm] | Radiated power spectral density [dBm] |
|---------------------------------------|-----------------------------------|---|--|---|
| Long Range High Speed (150 MHz) | $T_{\text{nom}} / V_{\text{nom}}$ | 25.98 | 32.51 | 19.25 |
| Mid-Range Mid. Speed (215 MHz) | $T_{\text{nom}} / V_{\text{nom}}$ | 24.72 | 32.65 | 17.90 |
| Short Range Low Speed (375 MHz) | $T_{\text{nom}} / V_{\text{nom}}$ | 24.69 | 32.49 | 18.81 |

Plot 1: EIRP Mean Power (Channel Power), Long Range, T_{nom} / V_{nom} Plot 2: OBW, Long Range, T_{nom} / V_{nom} 

Plot 3: EIRP Mean Power (Channel Power), Mid Range, T_{nom} / V_{nom} Plot 4: OBW, Mid Range, T_{nom} / V_{nom} 

Plot 5: EIRP Mean Power (Channel Power), Short Range, T_{nom} / V_{nom} Plot 6: OBW, Short Range, T_{nom} / V_{nom} 

11.2 Modulation characteristics

Description:

§2.1047 (d) *Other types of equipment.* A curve or equivalent data which shows that the equipment will meet the modulation requirements of the rules under which the equipment is to be licensed.

Comments from manufacturer on modulation characteristics according to KDB:


Referenced document: ZF_MRGen21_Product_data_sheet.pdf

4.4.2 Modulation

Main radar modulation parameters:

| | |
|-----------------------------|-----------------------|
| Bandwidth Min | 150MHz (eff) => 1 m |
| Bandwidth Max | 365MHz (eff) => 0.4 m |
| Cycle time | 60 ms |
| RF Frequency | 77 GHz |
| Number of Rx channels | 4 |
| Number of Tx | 3 |
| Sampling rate | 5 Msamples/s IQ |
| Number of chirps | 256 |
| Number of samples per chirp | 256 IQ |
| Chirp repetition time | 66 – 94 us |
| Speed ambiguity (+/-) | 37.5 – 53.5 kph |
| Speed resolution | 0.4 km/h |

The proposed parameters contain 3 variants for the Bandwidth, i.e., range resolution of 0.4, 0.7, or 1 m. This will depend on the host vehicle speed, to have more resolution at lower speeds, and increase the maximum detection range at higher speeds.

| | | |
|--|--|---|
| DATE: 27/10/2021 REVISION: 0.1 1,10 DOC# Confidential PAGE: 8 of 19 | MRGen21 Core Project Product Data Sheet |  |
|--|--|---|

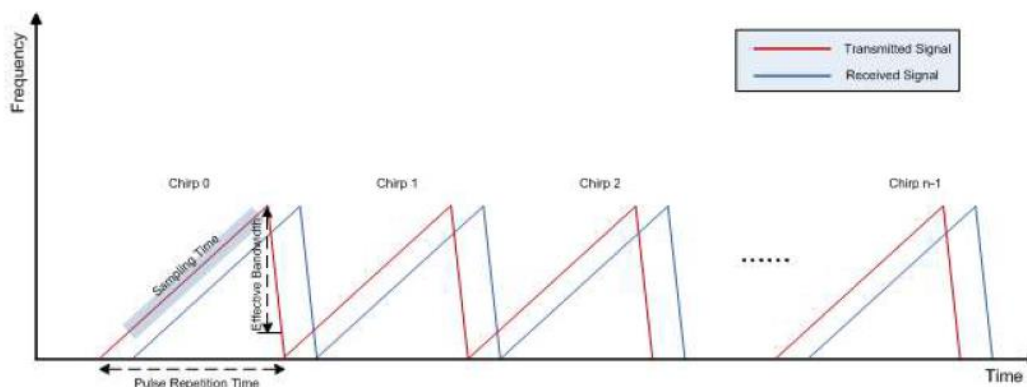


Figure 4: Single Chirp Timing

We use a modulation scheme based on a coherent train of linearly frequency modulated pulses which is also known as fast chirp-sequence modulation as shown in Figure 4.

11.3 Occupied bandwidth

Description:

§2.1049 The occupied bandwidth, that is the frequency bandwidth such that, below its lower and above its upper frequency limits, the mean powers radiated are each equal to 0.5 percent of the total mean power radiated by a given emission.

Measurement:

| Parameters | |
|--------------------------|-----------|
| Detector: | Pos. Peak |
| Sweep time: | 72.5 s |
| Resolution bandwidth: | 1 MHz |
| Video bandwidth: | 3 MHz |
| Trace-Mode: | Max Hold |
| Measurement uncertainty: | Span/1000 |

Limits:

FCC §95.3379 (b)

| | | |
|-----------------|----------------------|-----------------------|
| Frequency range | f(lowest) > 76.0 GHz | f(highest) < 81.0 GHz |
|-----------------|----------------------|-----------------------|

Measurement results:

| Modulations / Test conditions | | 99% Occupied Bandwidth | | OBW [MHz] |
|---------------------------------------|-------------------------------------|------------------------|----------------------|-----------|
| | | f _L [GHz] | f _H [GHz] | |
| Long Range High Speed (150 MHz) | T _{nom} / V _{nom} | 76.377 171 | 76.588 420 | 211.2 |
| Mid-Range Mid. Speed (215 MHz) | T _{nom} / V _{nom} | 76.327 948 | 76.606 865 | 278.9 |
| Short Range Low Speed (375 MHz) | T _{nom} / V _{nom} | 76.211 019 | 76.680 936 | 469.9 |

Refer to plot 2, 4, 6

11.4 Field strength of spurious emissions

Description:

The power density of any emissions outside the 76-81 GHz band shall consist solely of spurious emissions and shall not exceed the following:

Limits:

FCC §95.3379

| FCC | | |
|--|-------------------------|----------------------|
| CFR Part 95.3379 (a) (1) / CFR Part 95.3379 (a) (3) | | |
| Radiated Spurious Emissions | | |
| Emissions radiated outside of the specified frequency bands, except for harmonics, shall be attenuated by at least 50 dB below the level of the fundamental or to the general radiated emission limits in § 15.209, whichever is the lesser attenuation. | | |
| Frequency [MHz] | Field Strength [dBµV/m] | Measurement distance |
| 0.009 – 0.490 | 2400/F[kHz] | 300 |
| 0.490 – 1.705 | 24000/F[kHz] | 30 |
| 1.705 – 30.0 | 30 | 30 |
| 30 – 88 | 30.0 | 10 |
| 88 – 216 | 33.5 | 10 |
| 216 – 960 | 36.0 | 10 |
| 960 – 40 000 | 54.0 | 3 |

Limits:

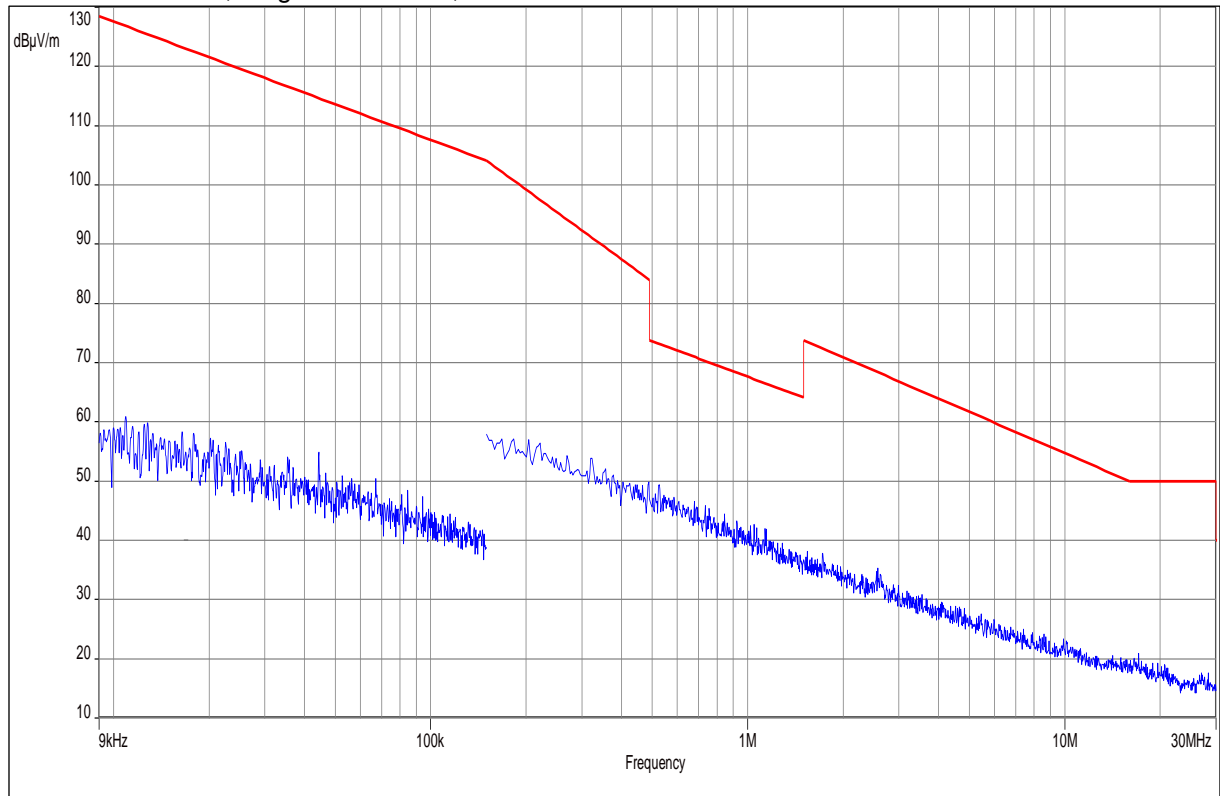
FCC §95.3379 (a) (2) (i) + (ii)

| Frequency Range [GHz] | Measurement distance | Power Density |
|-----------------------|----------------------|------------------------------------|
| 40 – 200 | 3.0 m | 600 pW/cm ² → -1.7 dBm |
| 200 – 231 | 3.0 m | 1000 pW/cm ² → +0.5 dBm |

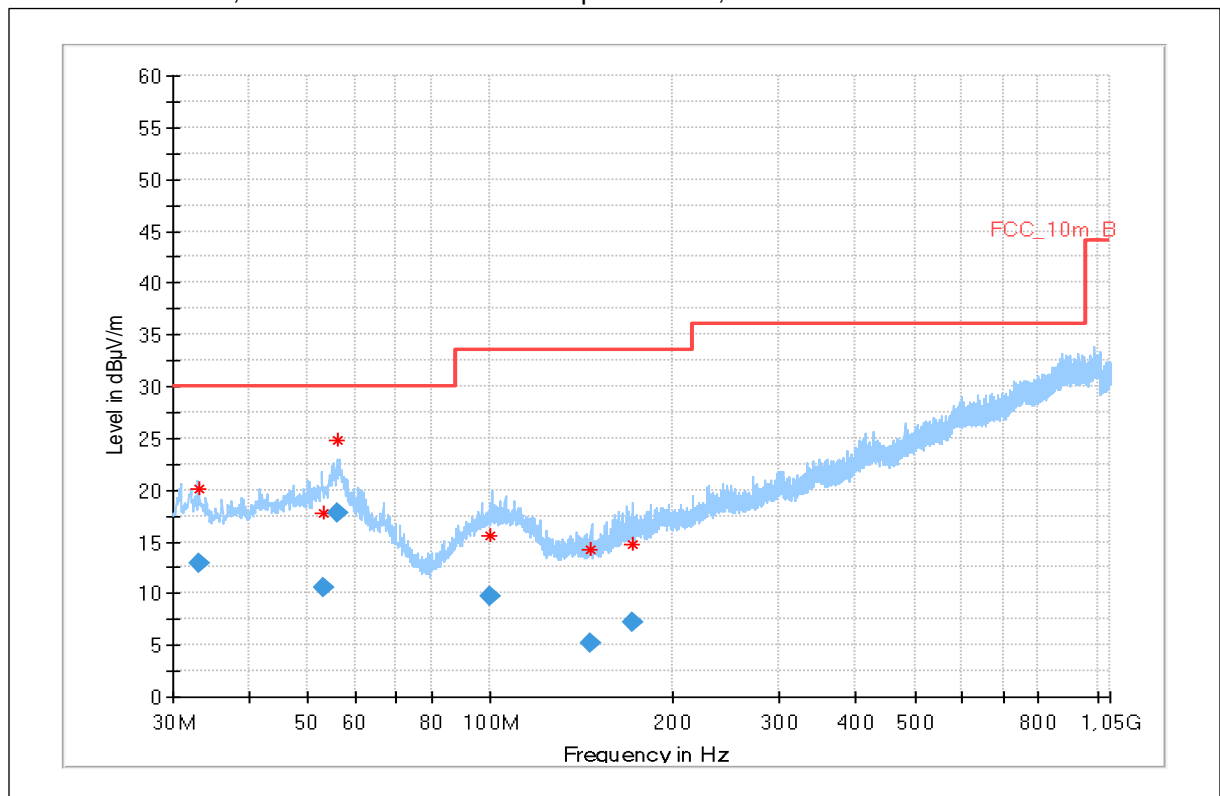
Measurement results:

| Frequency in [GHz] | Detector | Bandwidth [kHz] | Level [dBµV] | Distance [m] | Limit [dBµV] | Margin [dB] |
|-------------------------|----------|-----------------|--------------|--------------|--------------|-------------|
| No critical peak found! | | | | | | |

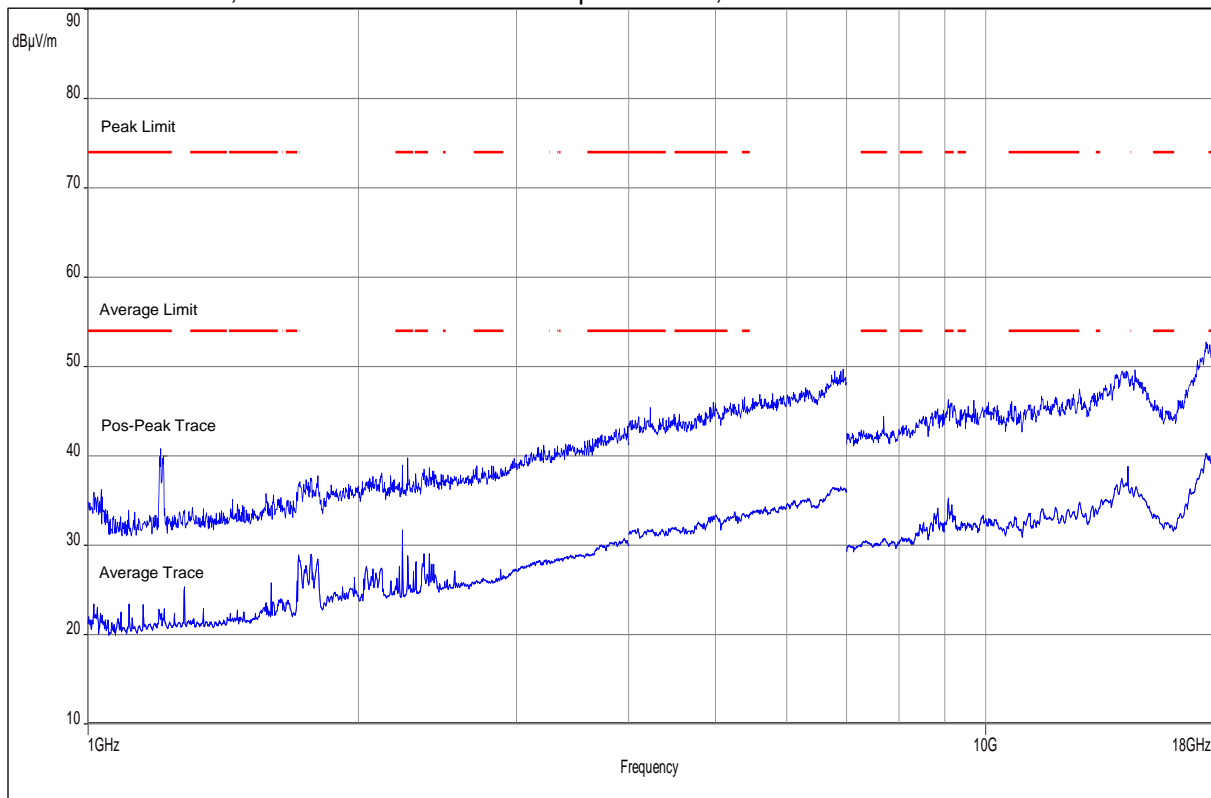
Plot 7: 9 kHz – 30 MHz, Magnetic antenna, valid for all modulations



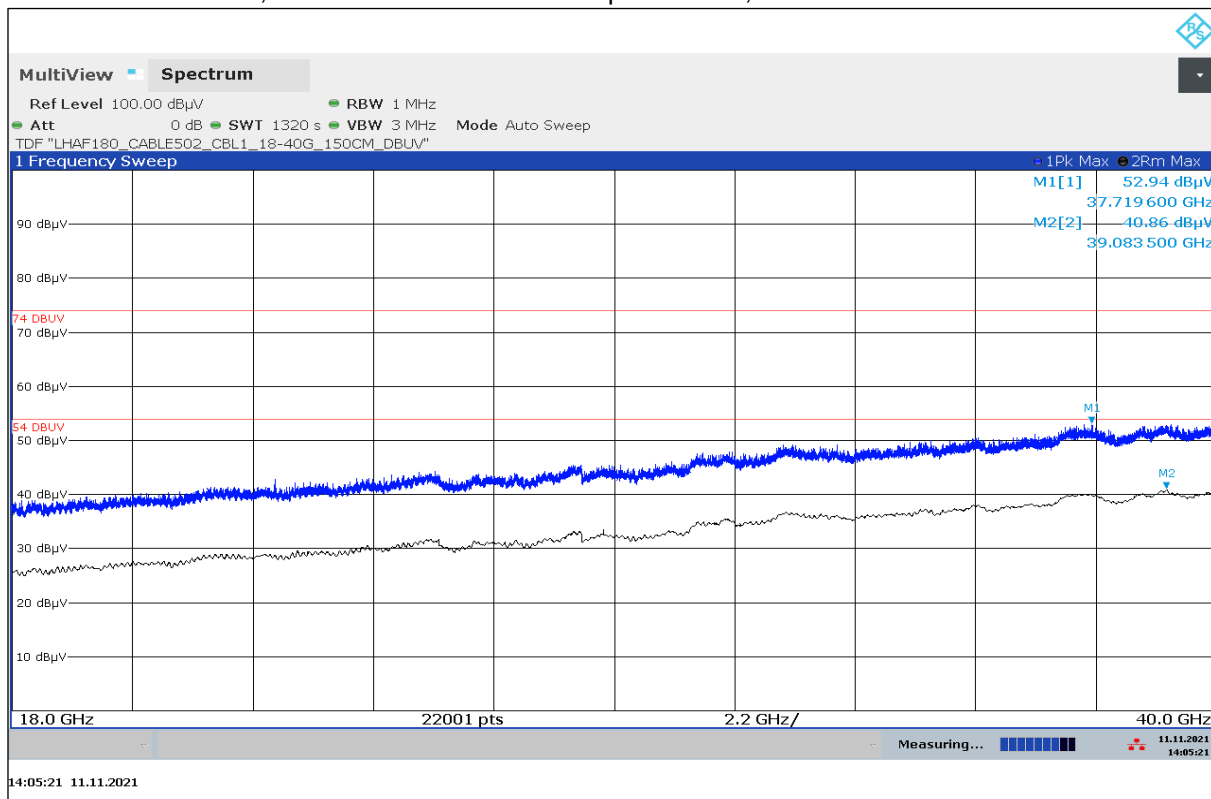
Plot 8: 30 MHz – 1 GHz, antenna vertical / horizontal polarization, valid for all modulations



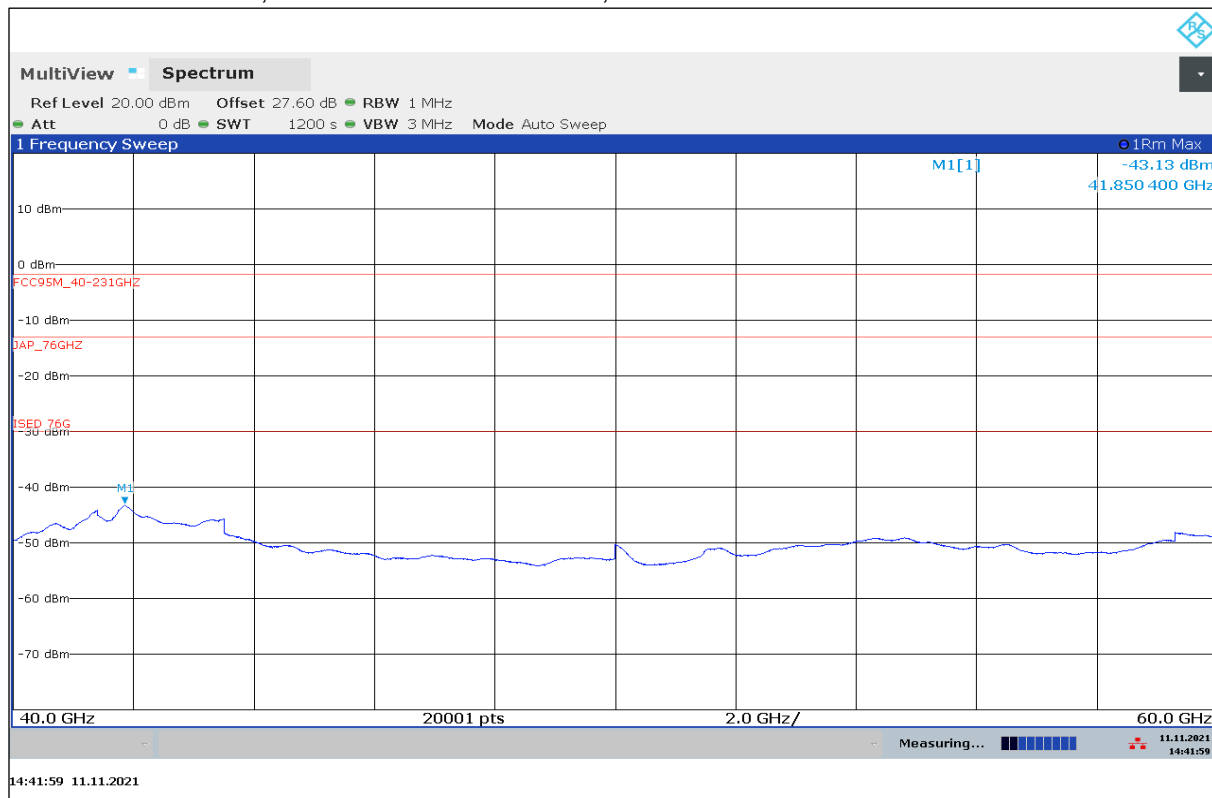
Plot 9: 1 GHz – 18 GHz, antenna vertical / horizontal polarization, valid for all modulations



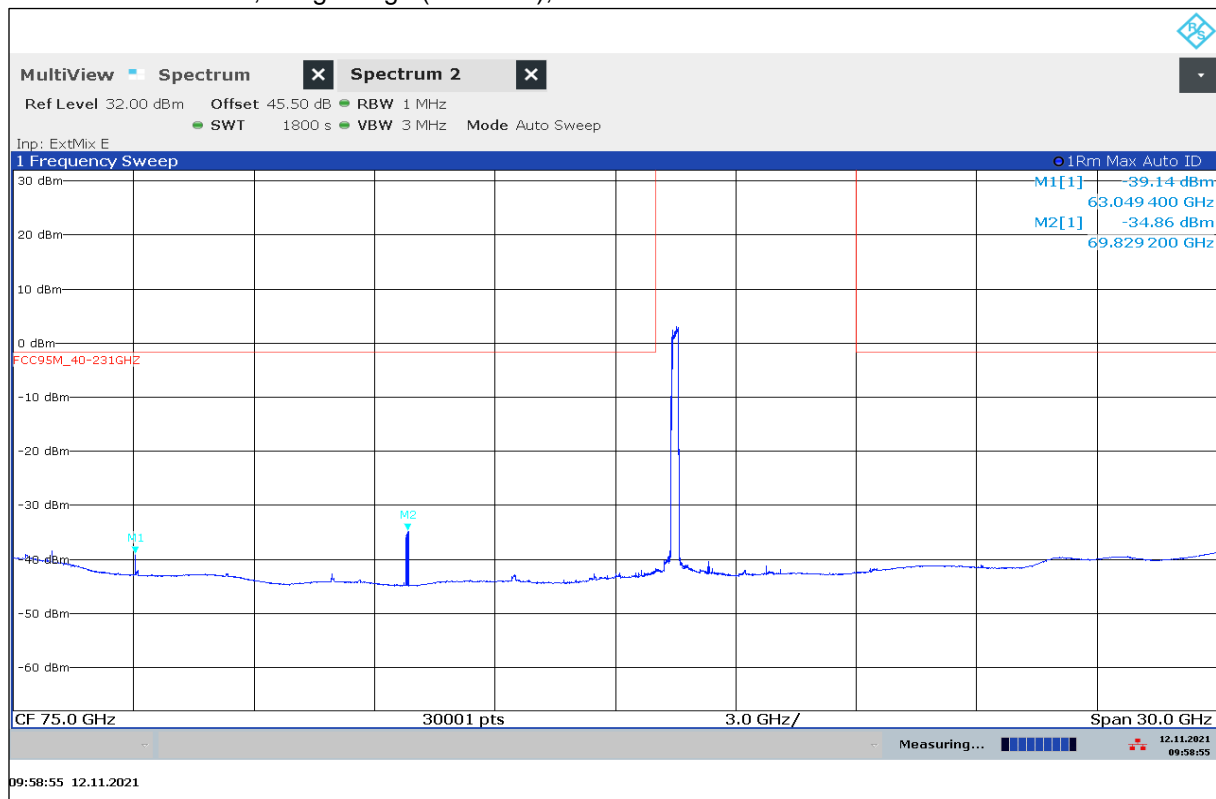
Plot 10: 18 GHz – 40 GHz, antenna vertical / horizontal polarization, valid for all modulations



Plot 11: 40 GHz – 60 GHz, antenna vertical / horizontal, valid for all modulations



Plot 12: 60 GHz – 90GHz, Long Range (150 MHz), antenna vertical / horizontal



Marker show mixer products produced by harmonic mixer.

MultiView ■ Spectrum X Spectrum 2 X

Ref Level 32.00 dBm Offset 45.50 dB RBW 1 MHz
SWT 1800 s VBW 3 MHz Mode Auto Sweep

Imp: ExtMix E

1 Frequency Sweep

30 dBm
20 dBm
10 dBm
0 dBm
-10 dBm
-20 dBm
-30 dBm
-40 dBm
-50 dBm
-60 dBm

FCC95M_40-231GHZ

M1
M2

01Rm Max Auto ID
M1[1] -36.35 dBm 69.855 200 GHz
M2[1] -34.00 dBm 81.362 800 GHz

CF 75.0 GHz 30001 pts 3.0 GHz/ Span 30.0 GHz

Measuring... 12.11.2021 11:17:29

MultiView ☒ Spectrum ☒ Spectrum 2 ☒

Ref Level 32.00 dBm Offset 45.50 dB RBW 1 MHz
 ● SWT 1800 s ● VBW 3 MHz Mode Auto Sweep

Imp: ExtMix E

1 Frequency Sweep

30 dBm
 20 dBm
 10 dBm
 0 dBm
 -10 dBm
 -20 dBm
 -30 dBm
 -40 dBm
 -50 dBm
 -60 dBm

60.0 GHz 30001 pts 3.0 GHz/ 90.0 GHz

M1 [1] -38.30 dBm
 69.924 200 GHz
 M2 [1] -31.68 dBm
 84.019 700 GHz

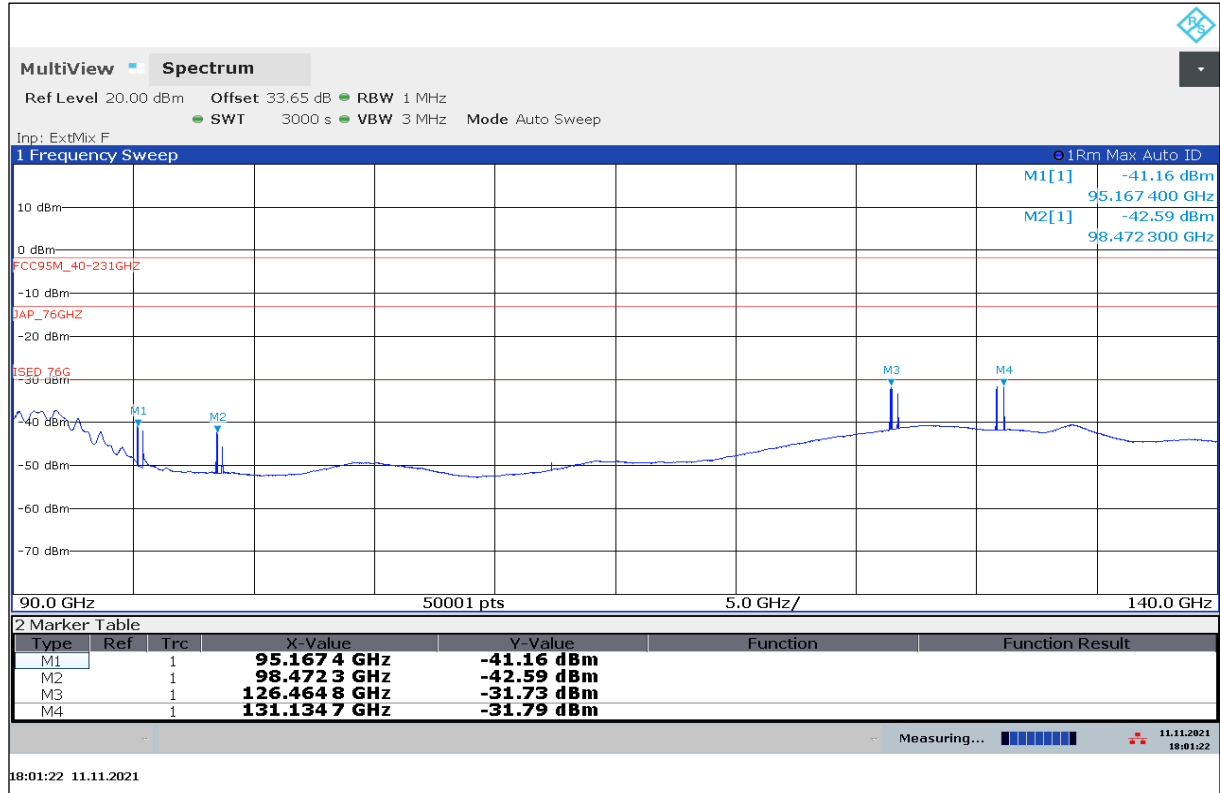
FCC95M_40-231GHz

Measuring... 12.11.2021 15:32:32

15:32:32 12.11.2021

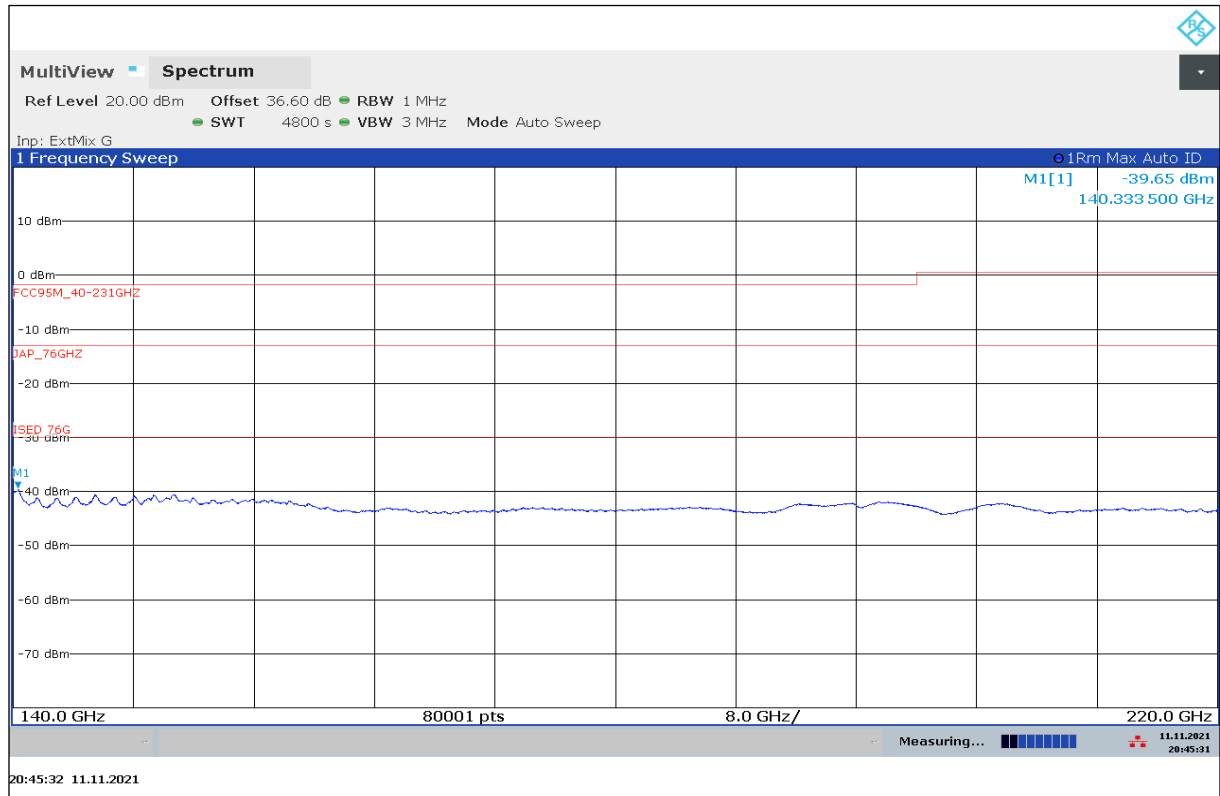
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Plot 15: 90 GHz – 140 GHz, antenna vertical / horizontal, valid for all modulations

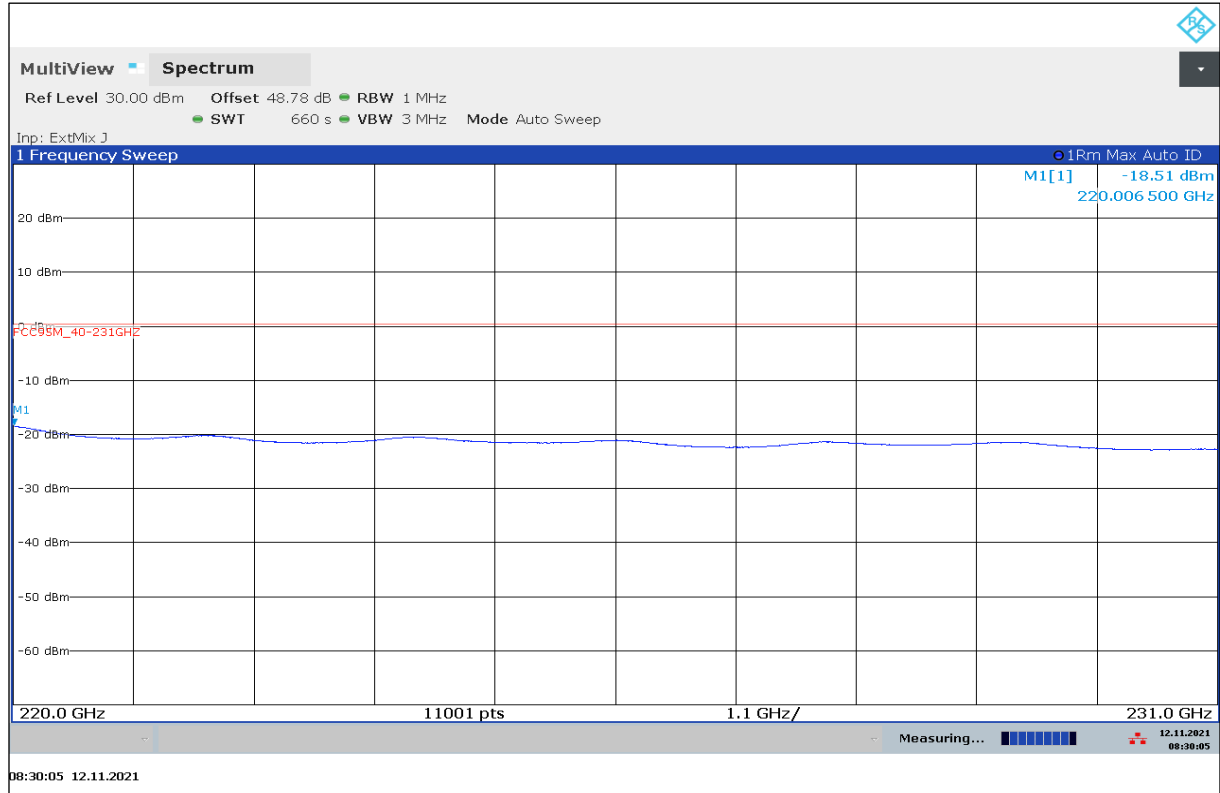


Marker show mixer products produced by harmonic mixer.

Plot 16: 140 GHz – 220 GHz, antenna vertical / horizontal, valid for all modulations



Plot 17: 220 GHz to 231 GHz, horizontal / vertical polarization, valid for all modulations



11.5 Frequency stability

Description:

§95.3379 (b) Fundamental emissions must be contained within the frequency bands specified in this section during all conditions of operation. Equipment is presumed to operate over the temperature range -20 to +50 degrees Celsius with an input voltage variation of 85% to 115% of rated input voltage, unless justification is presented to demonstrate otherwise.

Limits:

FCC §95.3379 (b)

| | | |
|-----------------|----------------------|-----------------------|
| Frequency range | f(lowest) > 76.0 GHz | f(highest) < 81.0 GHz |
|-----------------|----------------------|-----------------------|

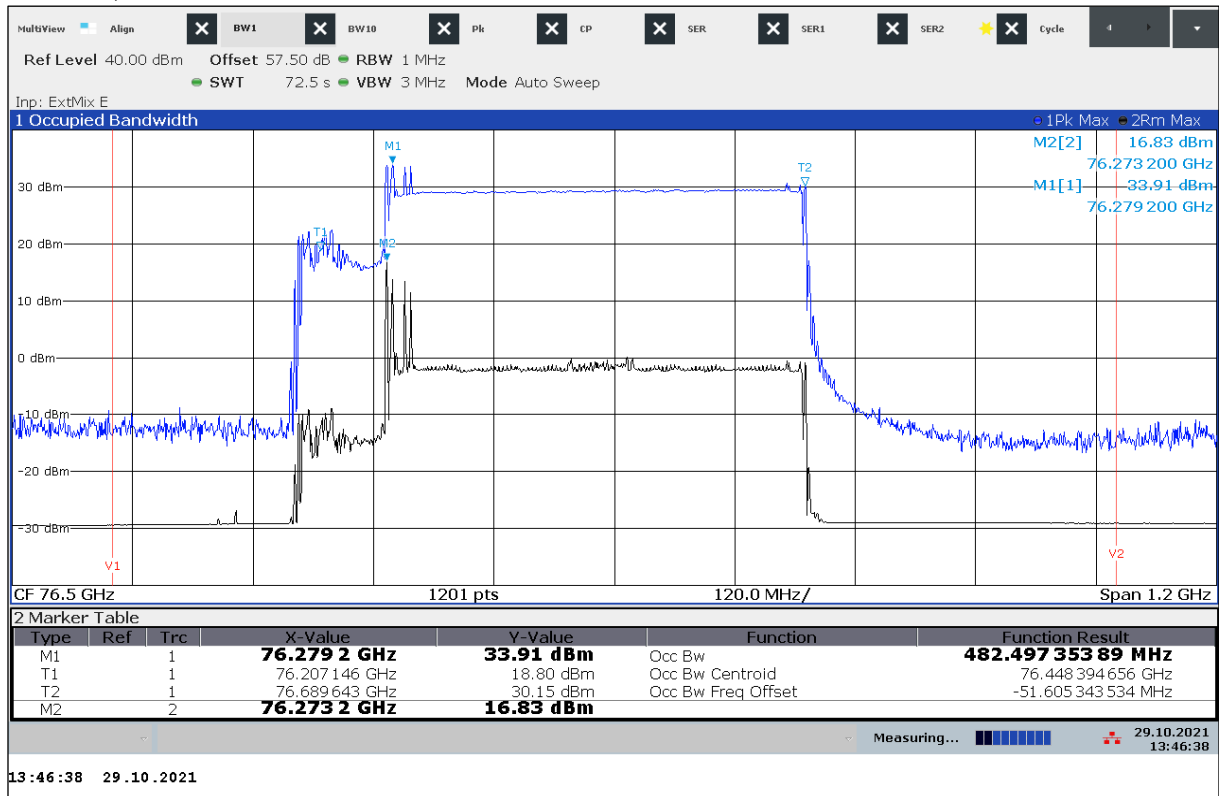
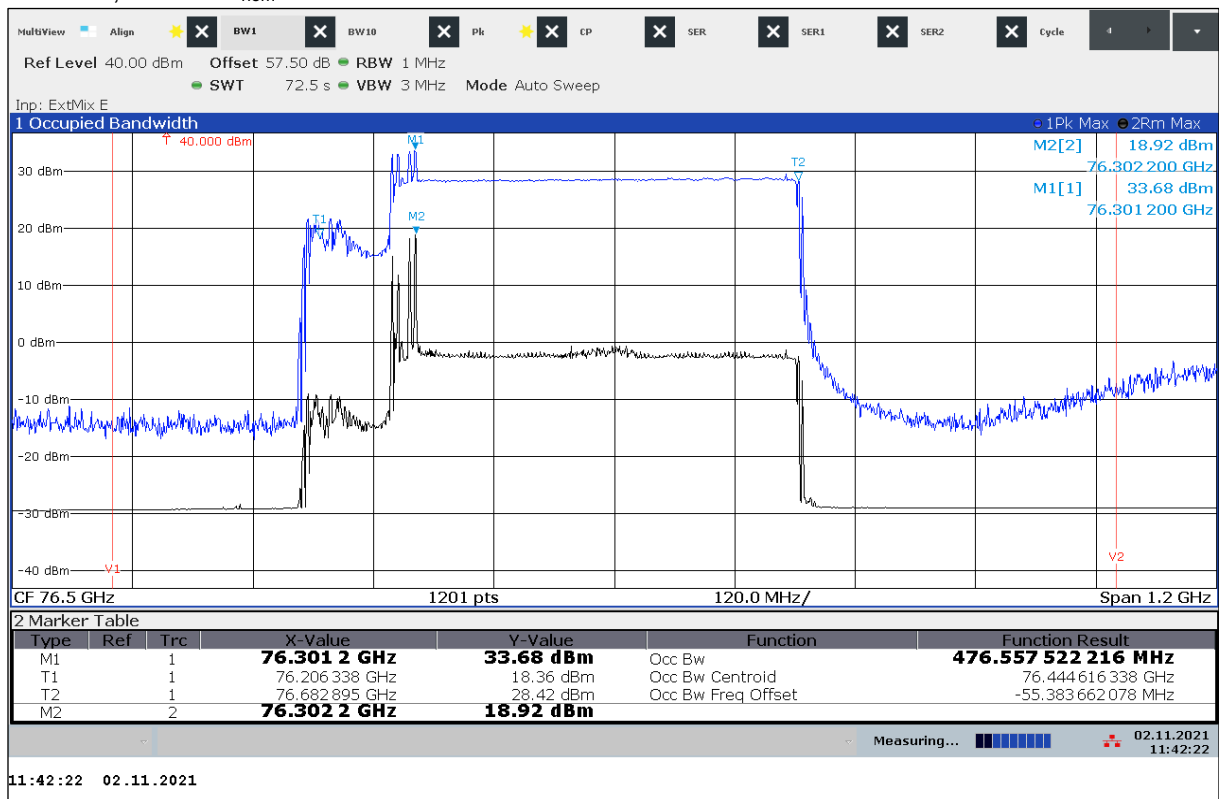
Measurement results:

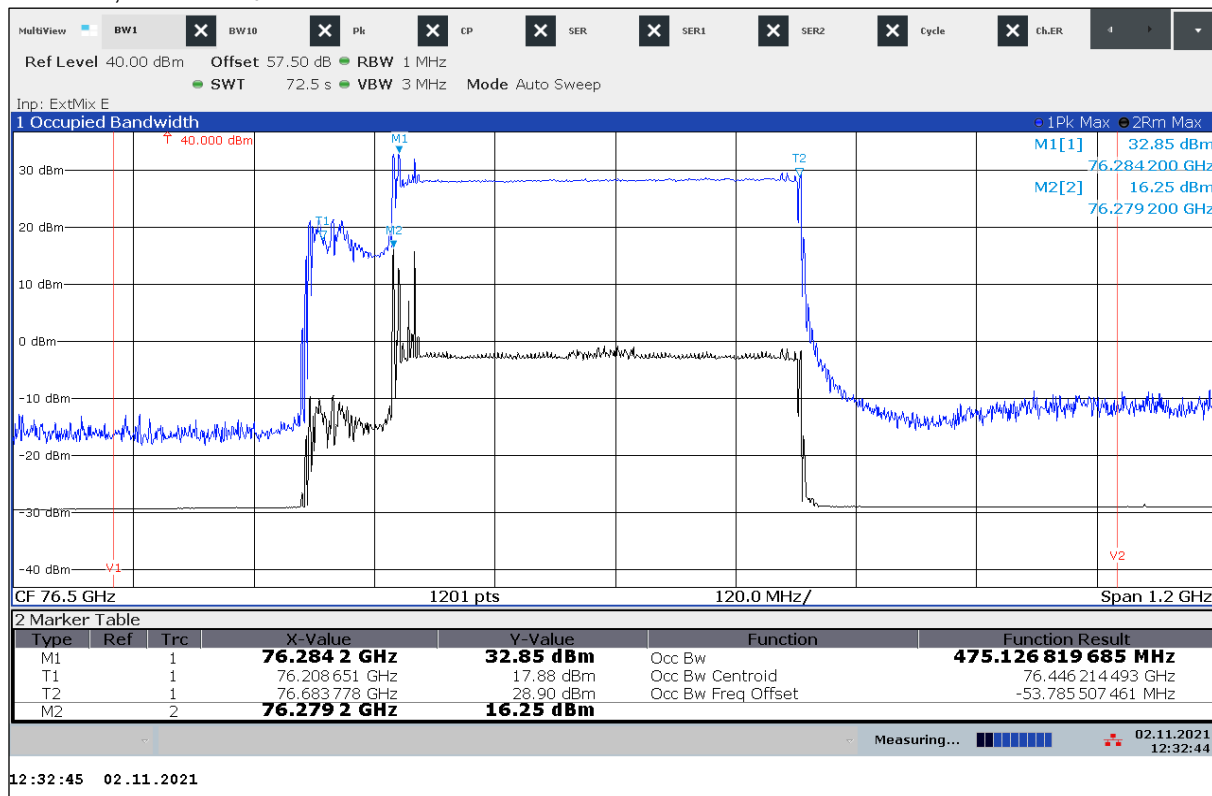
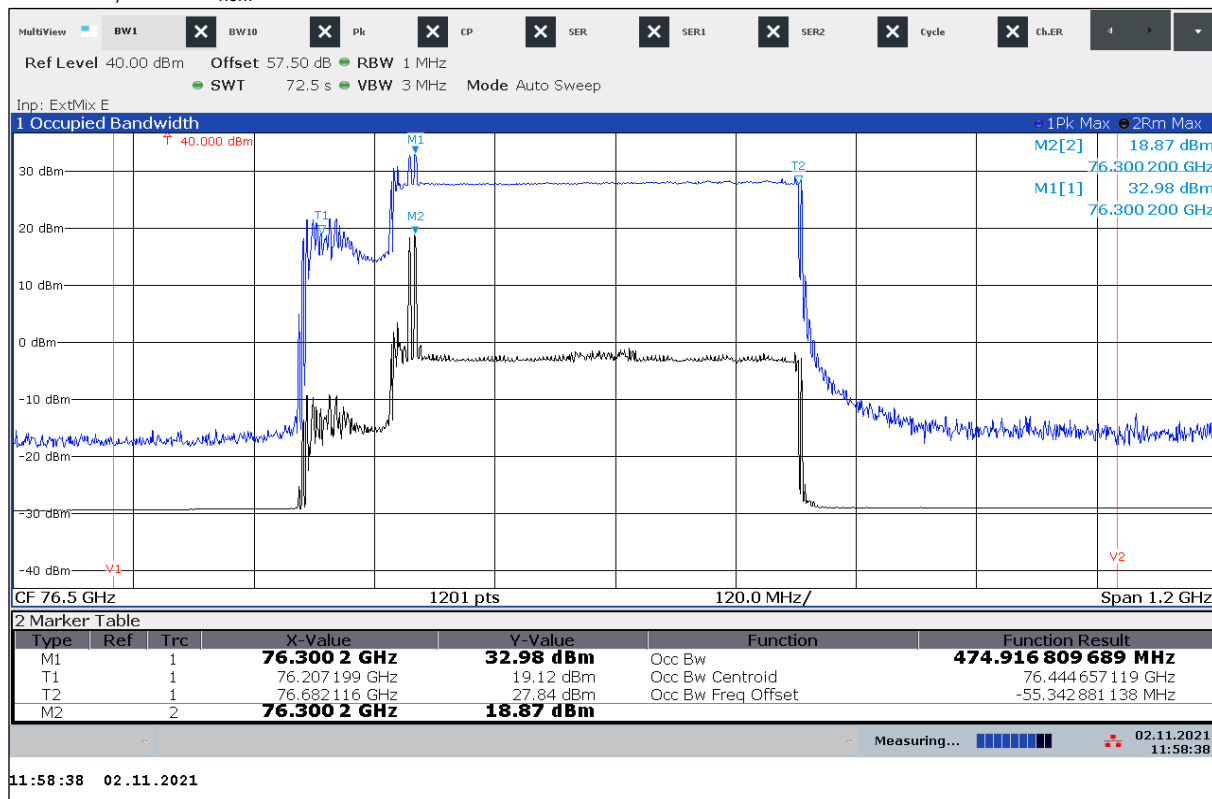
Temperature variation:

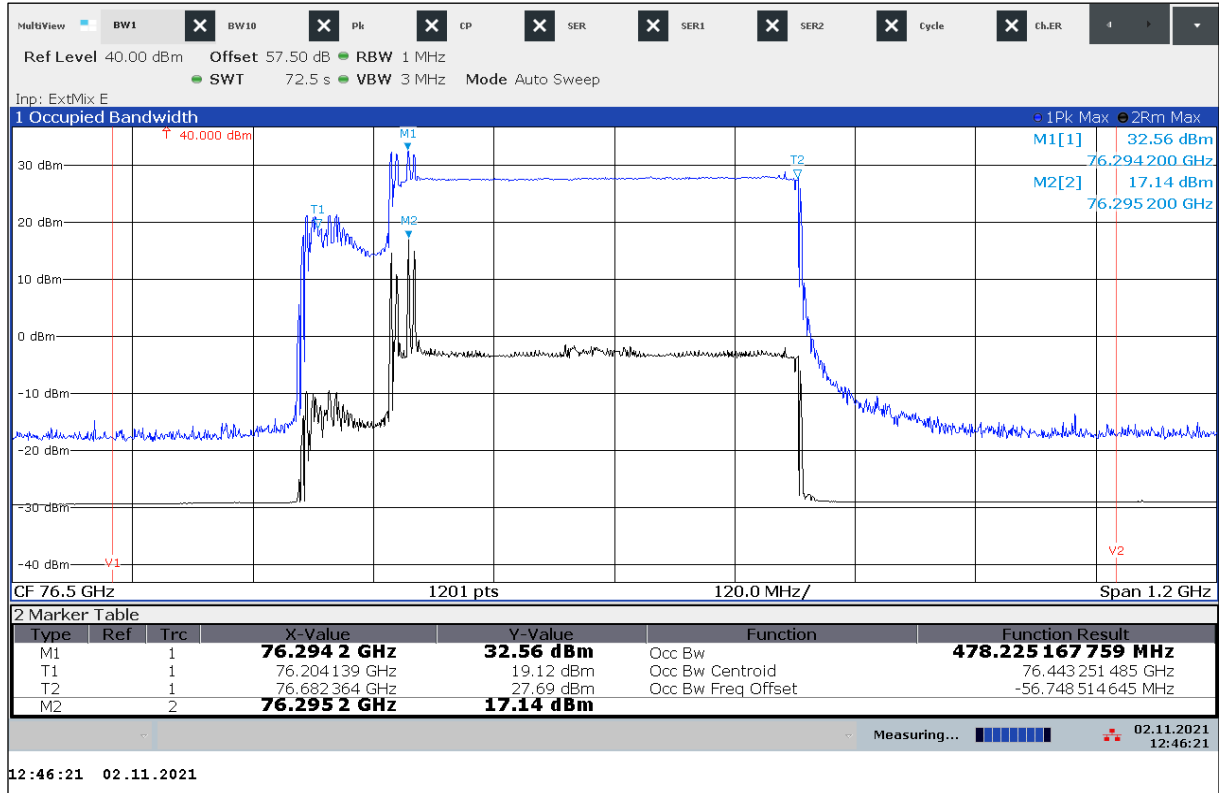
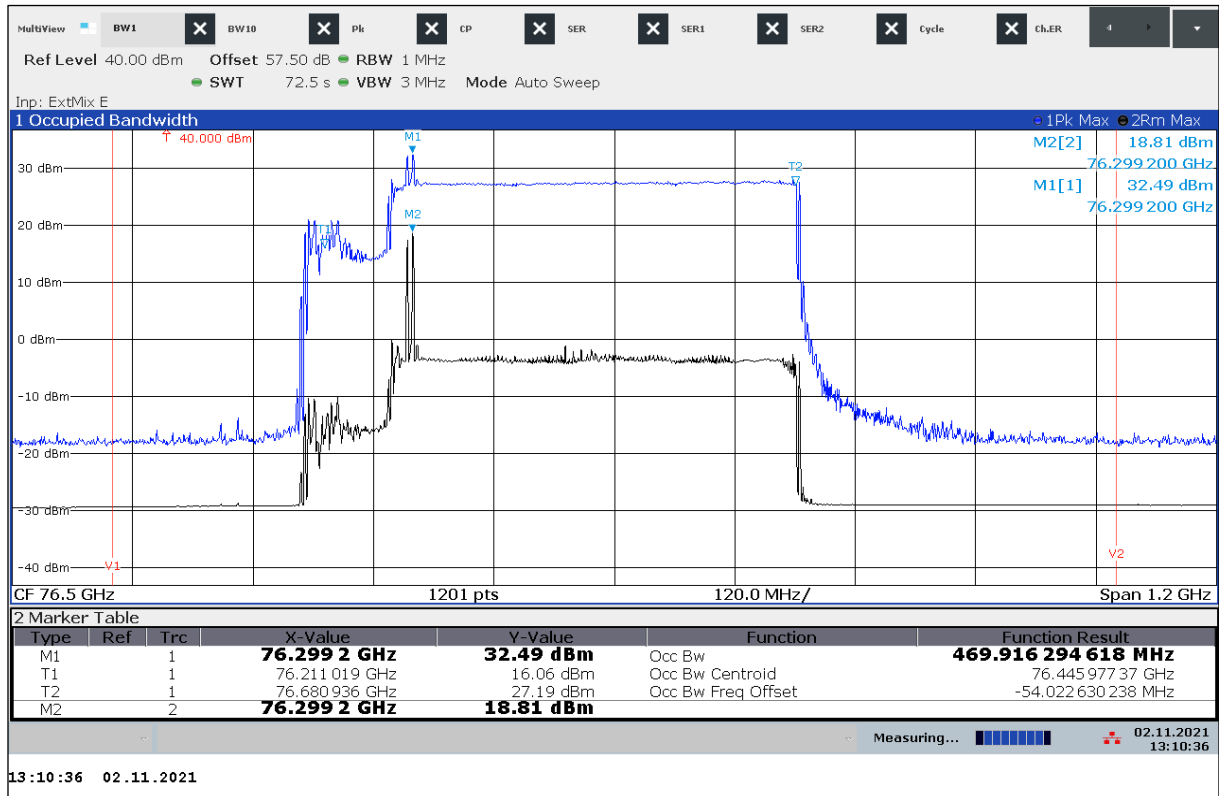
| Modulation | Temperature in °C | f _L in GHz | f _H in GHz |
|---------------------------------------|-------------------|-----------------------|-----------------------|
| Short Range Low Speed (375 MHz) | -40 | 76.207 146 | 76.689 643 |
| | -20 | 76.206 338 | 76.682 895 |
| | -10 | 76.208 651 | 76.683 778 |
| | 0 | 76.207 199 | 76.682 116 |
| | 10 | 76.204 139 | 76.682 364 |
| | 20 | 76.211 019 | 76.680 936 |
| | 30 | 76.212 069 | 76.680 638 |
| | 40 | 76.204 297 | 76.679 413 |
| | 50 | 76.202 606 | 76.679 614 |
| | 85 | 76.202 452 | 76.680 671 |

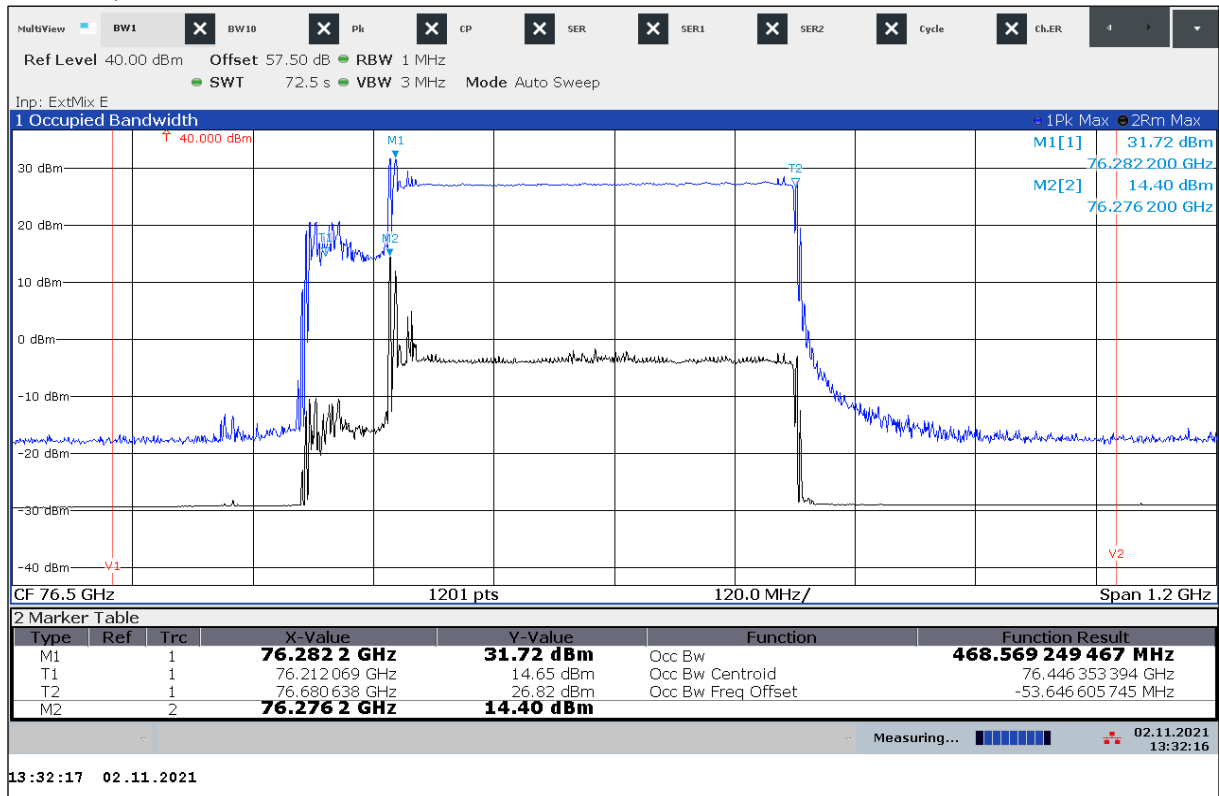
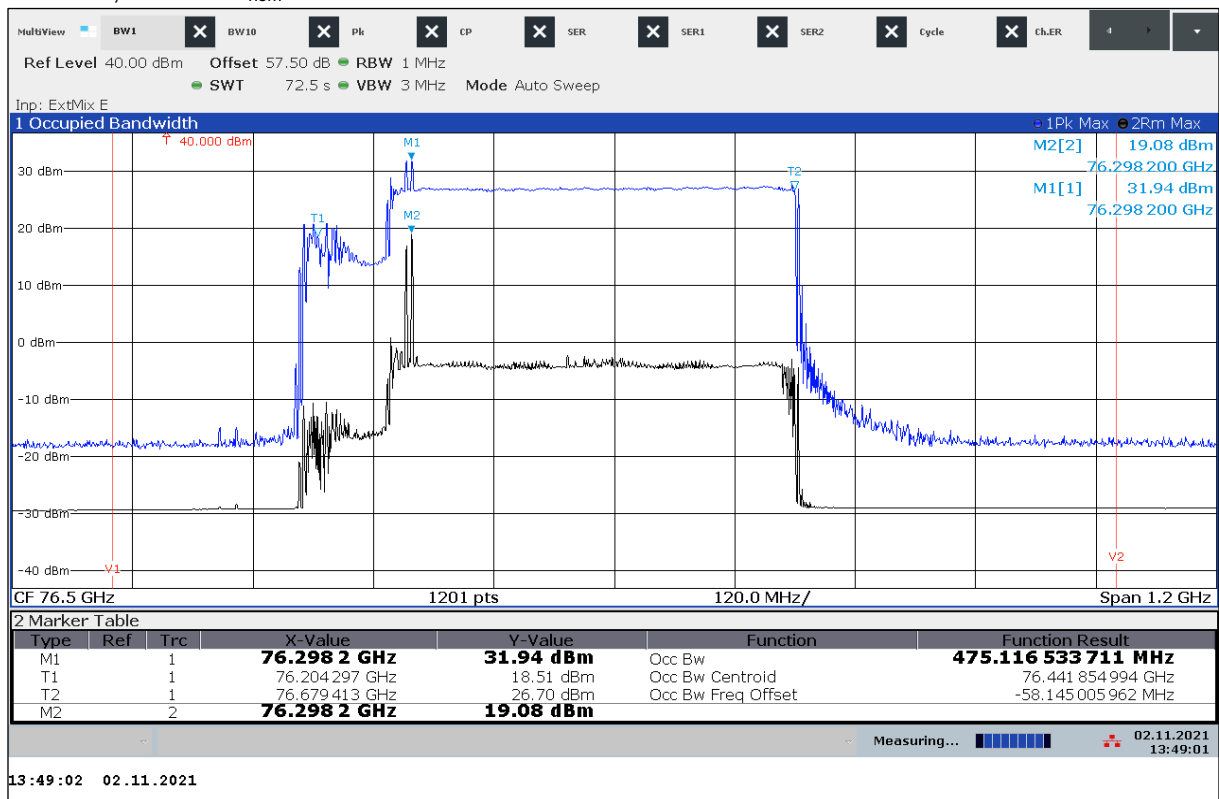
Voltage variation:

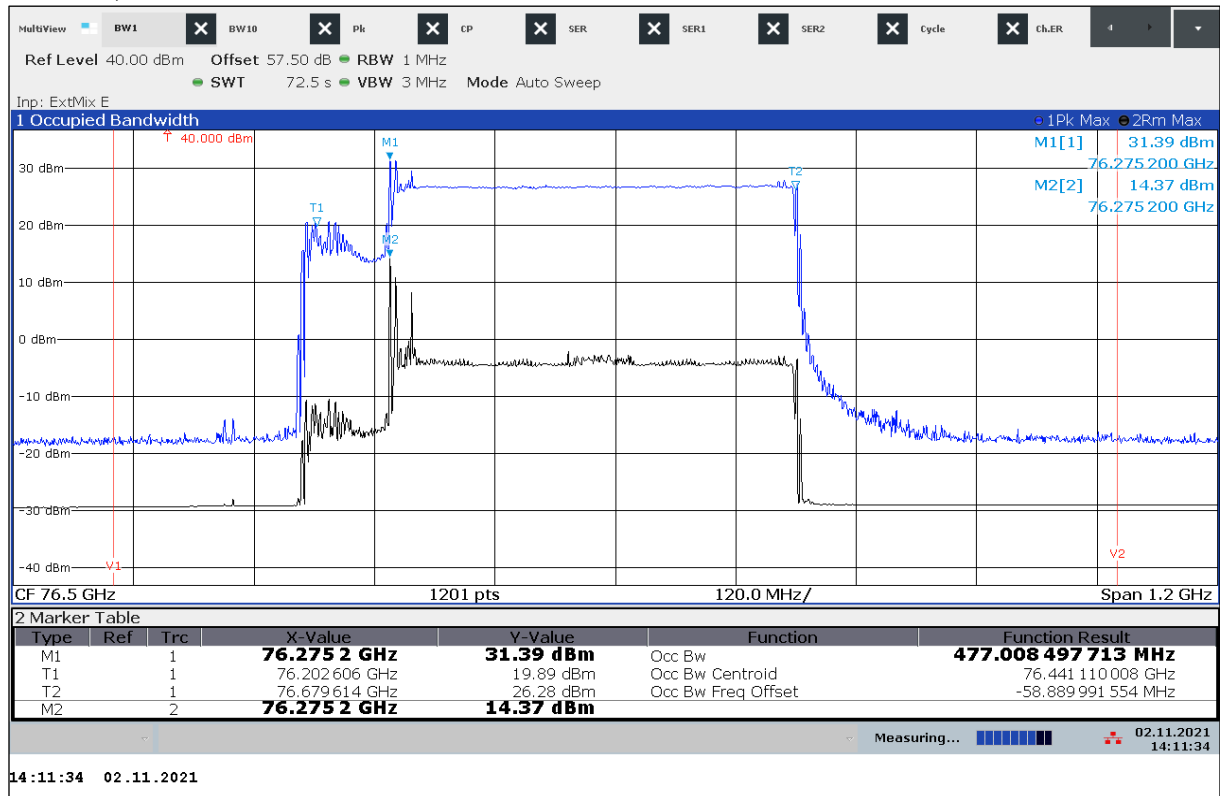
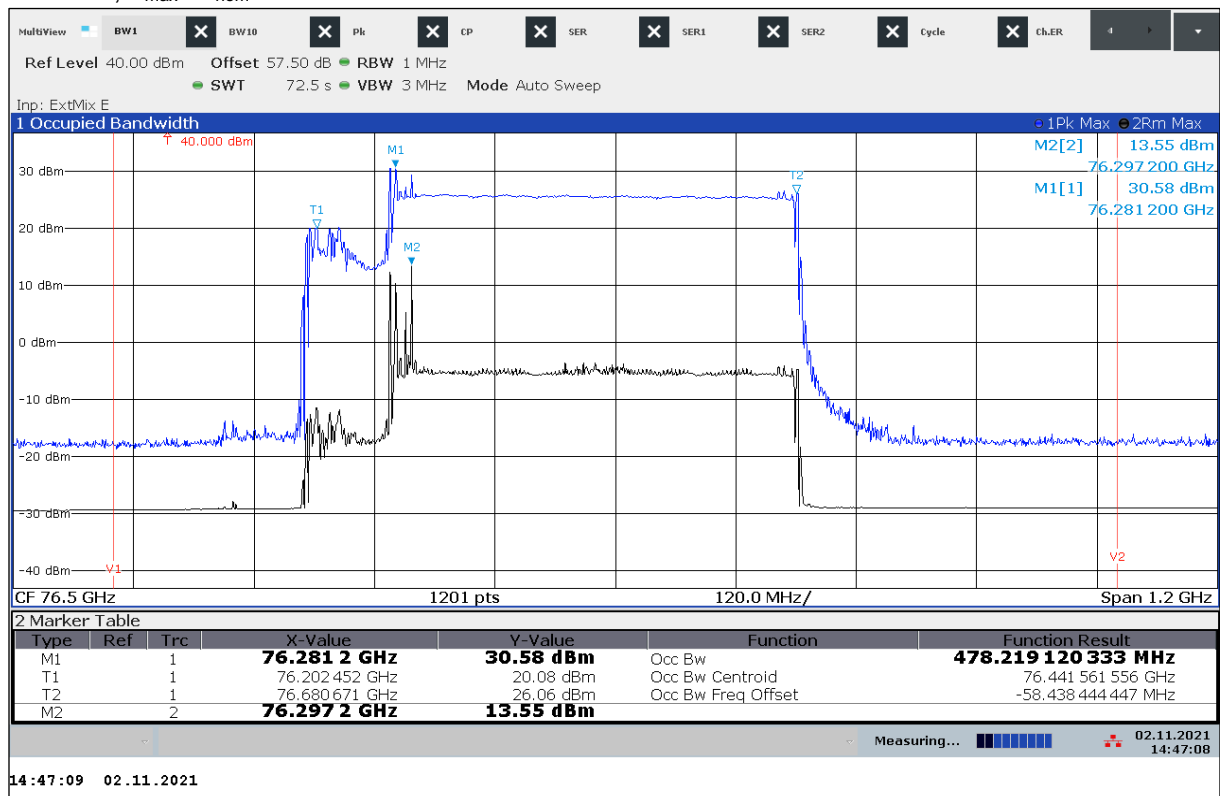
| Voltage variation of rated input voltage | f _L in GHz | f _H in GHz |
|---|---|-----------------------|
| < 85 % of U | Voltage variation does not affect the radiated signal | |
| > 115 % of U | | |

Plot 18: OBW, T_{min} / V_{nom} Plot 19: OBW, -20 °C / V_{nom} 

Plot 20: OBW, -10 °C / V_{nom}Plot 21: OBW, 0 °C / V_{nom}

Plot 22: OBW, +10 °C / V_{nom} Plot 23: OBW, +20 °C / V_{nom} 

Plot 24: OBW, +30 °C / V_{nom} Plot 25: OBW, +40 °C / V_{nom} 

Plot 26: OBW, +50 °C / V_{nom} Plot 27: OBW, T_{max} / V_{nom} 

12 Glossary

| | |
|------------------------|--|
| EUT | Equipment under test |
| DUT | Device under test |
| UUT | Unit under test |
| GUE | GNSS User Equipment |
| ETSI | European Telecommunications Standards Institute |
| EN | European Standard |
| FCC | Federal Communications Commission |
| FCC ID | Company Identifier at FCC |
| IC | Industry Canada |
| PMN | Product marketing name |
| HMN | Host marketing name |
| HVIN | Hardware version identification number |
| FVIN | Firmware version identification number |
| EMC | Electromagnetic Compatibility |
| HW | Hardware |
| SW | Software |
| Inv. No. | Inventory number |
| S/N or SN | Serial number |
| C | Compliant |
| NC | Not compliant |
| NA | Not applicable |
| NP | Not performed |
| PP | Positive peak |
| QP | Quasi peak |
| AVG | Average |
| OC | Operating channel |
| OCW | Operating channel bandwidth |
| OBW | Occupied bandwidth |
| OOB | Out of band |
| DFS | Dynamic frequency selection |
| CAC | Channel availability check |
| OP | Occupancy period |
| NOP | Non occupancy period |
| DC | Duty cycle |
| PER | Packet error rate |
| CW | Clean wave |
| MC | Modulated carrier |
| WLAN | Wireless local area network |
| RLAN | Radio local area network |
| DSSS | Dynamic sequence spread spectrum |
| OFDM | Orthogonal frequency division multiplexing |
| FHSS | Frequency hopping spread spectrum |
| GNSS | Global Navigation Satellite System |
| C/N₀ | Carrier to noise-density ratio, expressed in dB-Hz |

13 Document history

| Version | Applied changes | Date of release |
|---------|-----------------|-----------------|
| -/- | Initial release | 2021-12-09 |

14 Accreditation Certificate – D-PL-12076-01-05

| first page | last page |
|--|--|
|  <p>Deutsche Akkreditierungsstelle GmbH</p> <p>Entrusted according to Section 8 subsection 1 AkkStelleG in connection with Section 1 subsection 1 AkkStelleGBV Signatory to the Multilateral Agreements of EA, ILAC and IAF for Mutual Recognition</p> <p>Accreditation </p> <p>The Deutsche Akkreditierungsstelle GmbH attests that the testing laboratory</p> <p>CTC advanced GmbH Untertürkheimer Straße 6-10, 66117 Saarbrücken</p> <p>is competent under the terms of DIN EN ISO/IEC 17025:2018 to carry out tests in the following fields:</p> <p>Telecommunication (FCC Requirements)</p> <p>The accreditation certificate shall only apply in connection with the notice of accreditation of 09.06.2020 with the accreditation number D-PL-12076-01. It comprises the cover sheet, the reverse side of the cover sheet and the following annex with a total of 05 pages.</p> <p>Registration number of the certificate: D-PL-12076-01-05</p> <p>Frankfurt am Main, 09.06.2020</p> <p>by order: Dipl.-Ing. (FH) Ralf Egner Head of Division</p> <p><small>The certificate together with its annex reflects the status at the time of the date of issue. The current status of the scope of accreditation can be found in the database of accredited bodies of Deutsche Akkreditierungsstelle GmbH. https://www.dakks.de/en/content/accredited-bodies-dakks See notes attached.</small></p> | <p>Deutsche Akkreditierungsstelle GmbH</p> <p>Office Berlin Spittelmarkt 10 10117 Berlin</p> <p>Office Frankfurt am Main Europa-Allee 52 60327 Frankfurt am Main</p> <p>Office Braunschweig Bundesallee 100 38116 Braunschweig</p> <p>The publication of extracts of the accreditation certificate is subject to the prior written approval by Deutsche Akkreditierungsstelle GmbH (DAKKS). Exempted is the unchanged form of separate disseminations of the cover sheet by the conformity assessment body mentioned overleaf.</p> <p>No impression shall be made that the accreditation also extends to fields beyond the scope of accreditation attested by DAKKS.</p> <p>The accreditation was granted pursuant to the Act on the Accreditation Body (AkkStelleG) of 31 July 2009 (Federal Law Gazette I p. 2625) and the Regulation (EC) No 765/2008 of the European Parliament and of the Council of 9 July 2008 setting out the requirements for accreditation and market surveillance relating to the marketing of products (Official Journal of the European Union L 218 of 9 July 2008, p. 30). DAKKS is a signatory to the Multilateral Agreements for Mutual Recognition of the European co-operation for Accreditation (EA), International Accreditation Forum (IAF) and International Laboratory Accreditation Cooperation (ILAC). The signatories to these agreements recognise each other's accreditations.</p> <p>The up-to-date state of membership can be retrieved from the following websites: EA: www.european-accreditation.org ILAC: www.ilac.org IAF: www.iaf.nu</p> |

Note: The current certificate annex is published on the websites (link see below).

<https://www.dakks.de/files/data/as/pdf/D-PL-12076-01-05e.pdf>

or

https://ctcadvanced.com/app/uploads/2020/06/D-PL-12076-01-05_TCB_USA.pdf

END OF TEST REPORT