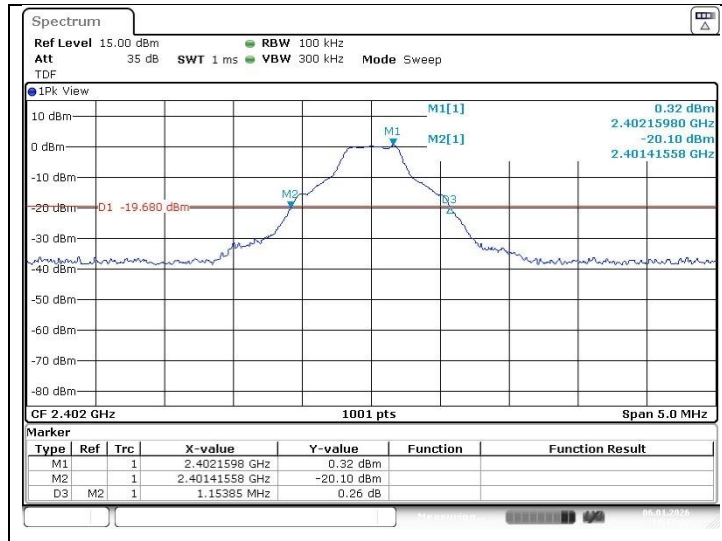


Ant. 2

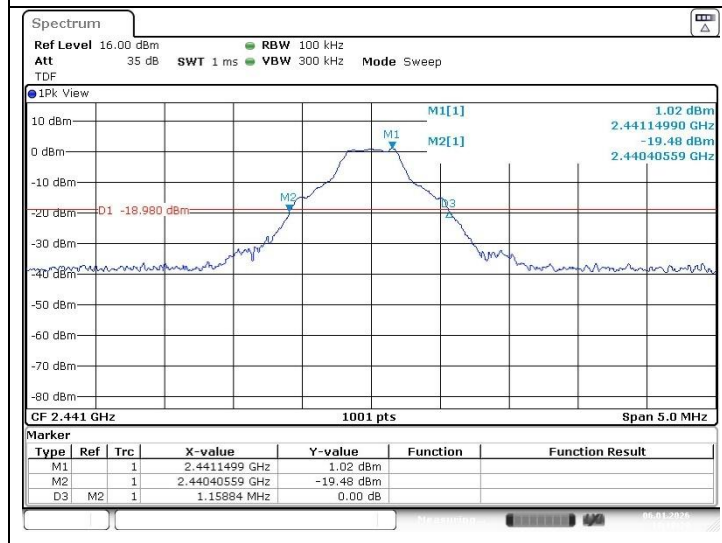
20 dB Bandwidth

Mode: GFSK

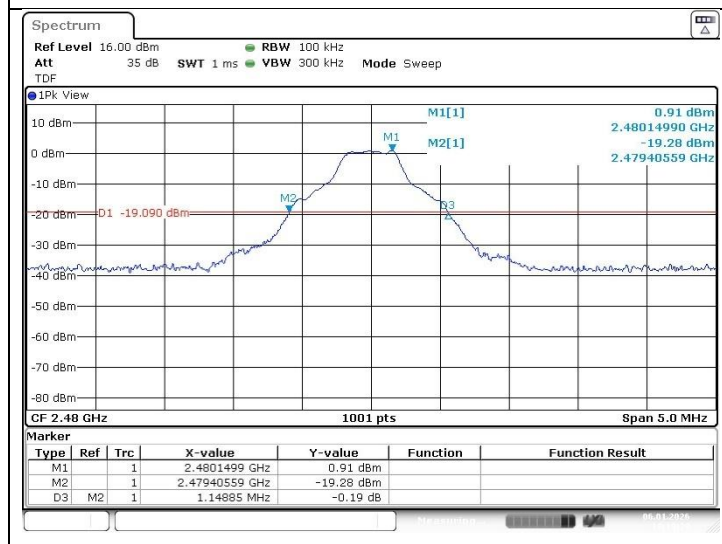
Low Channel



Middle Channel

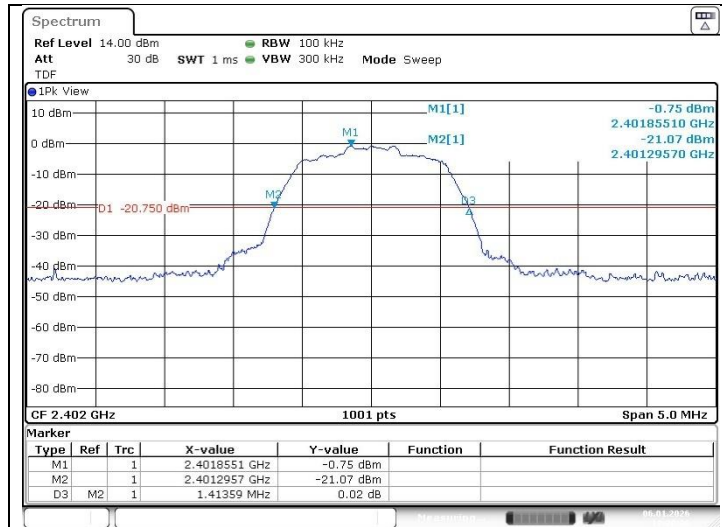


High Channel

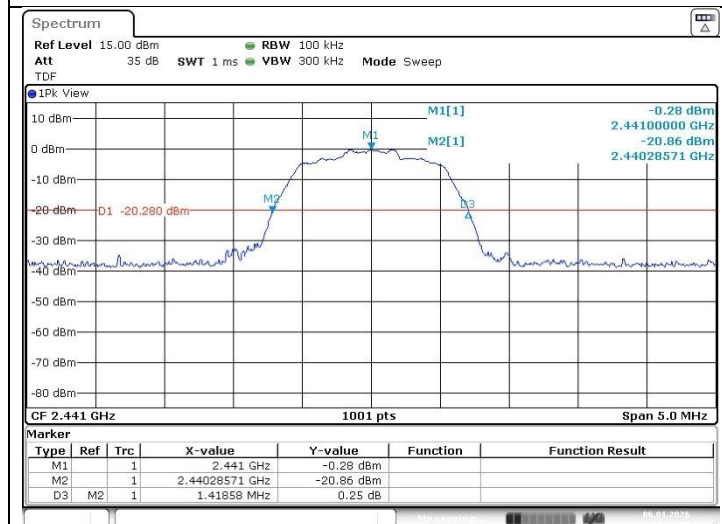


Mode: $\pi/4$ DQPSK

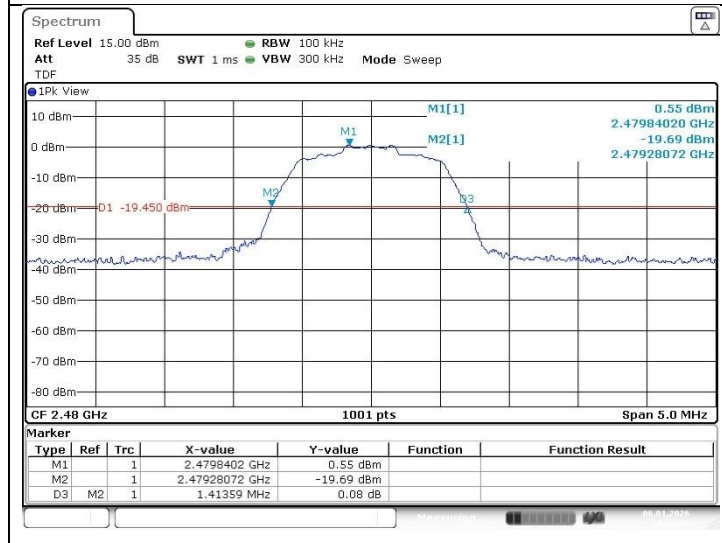
Low Channel



Middle Channel

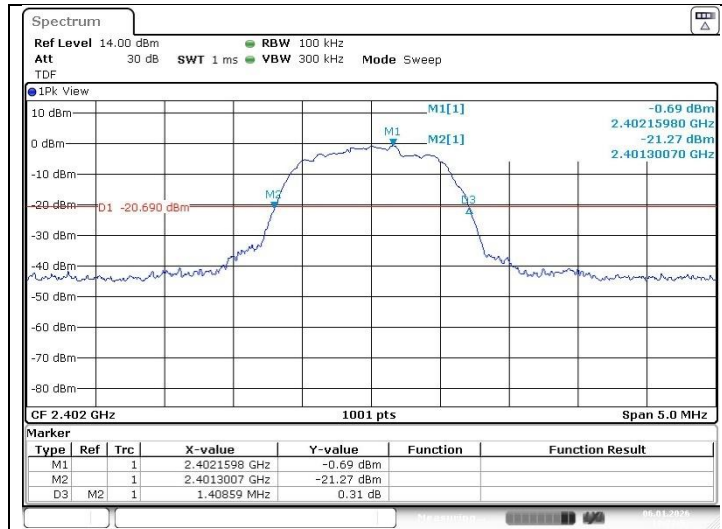


High Channel

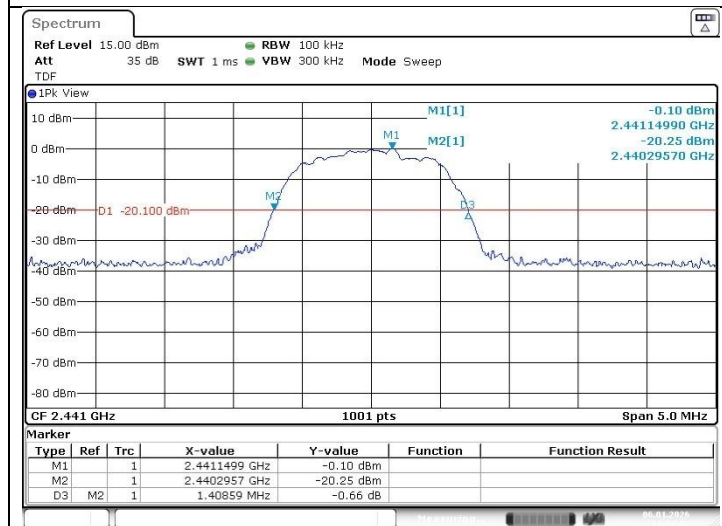


Mode: 8DPSK

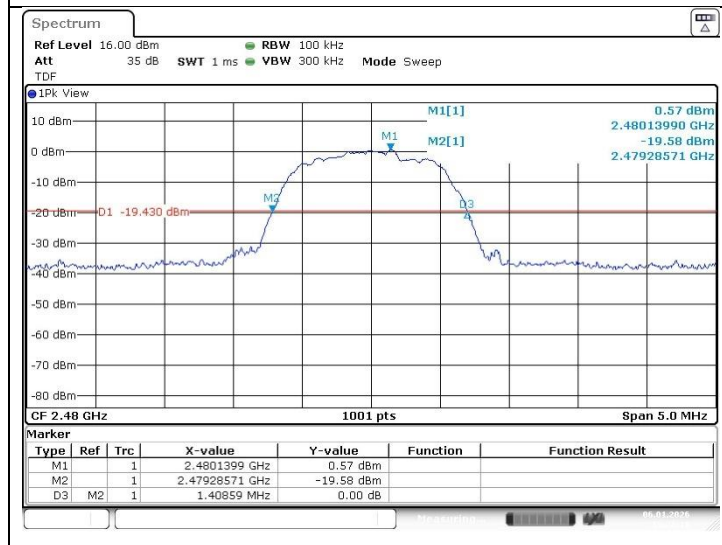
Low Channel



Middle Channel



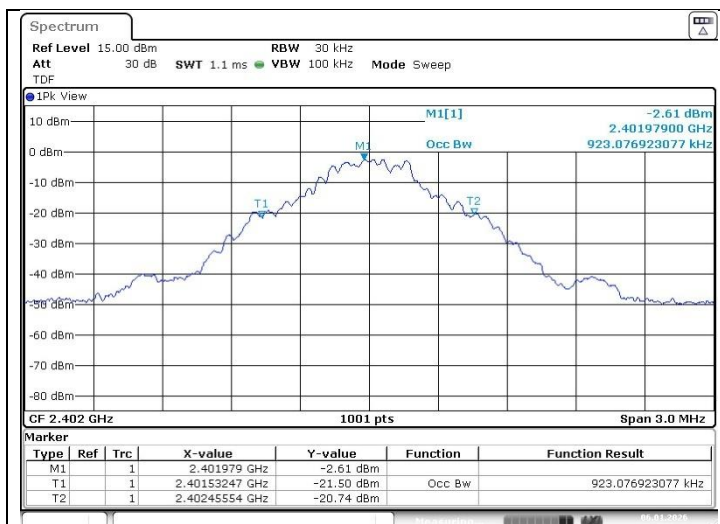
High Channel



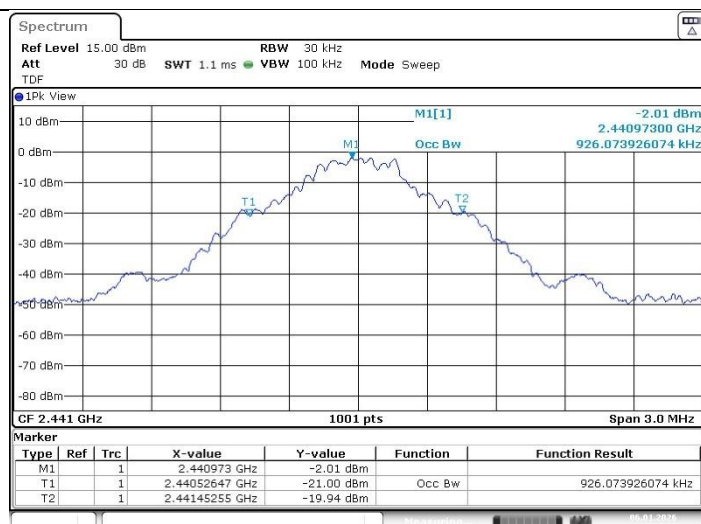
99 % Bandwidth

Mode: GFSK

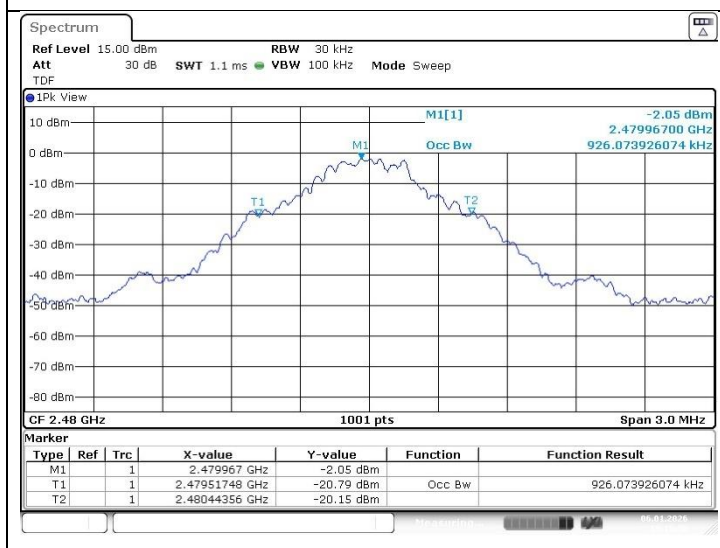
Low Channel



Middle Channel

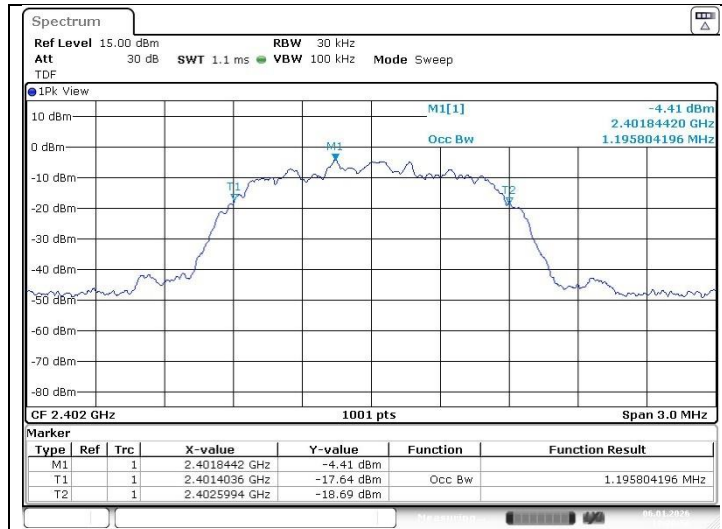


High Channel



Mode: $\pi/4$ DQPSK

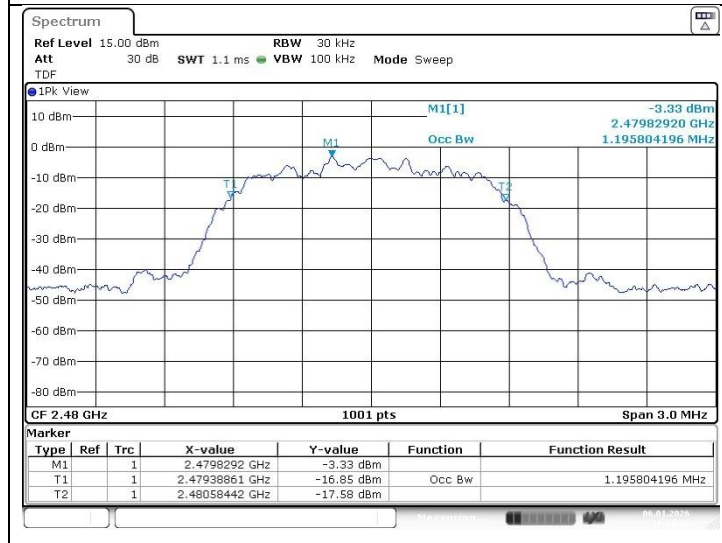
Low Channel



Middle Channel



High Channel

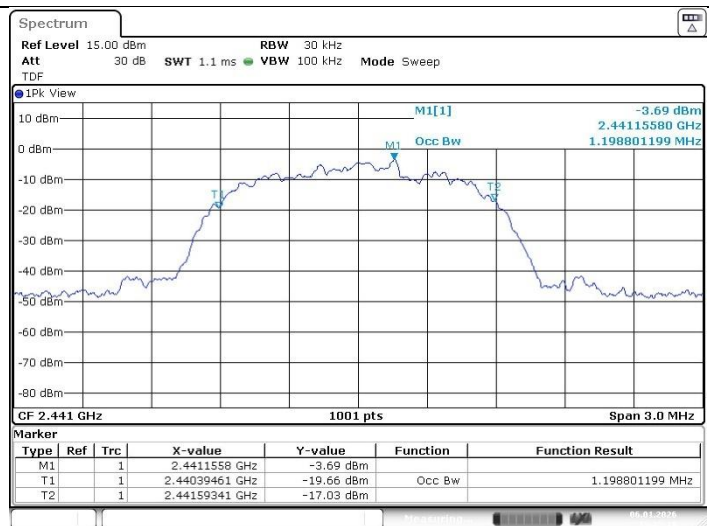


Mode: 8DPSK

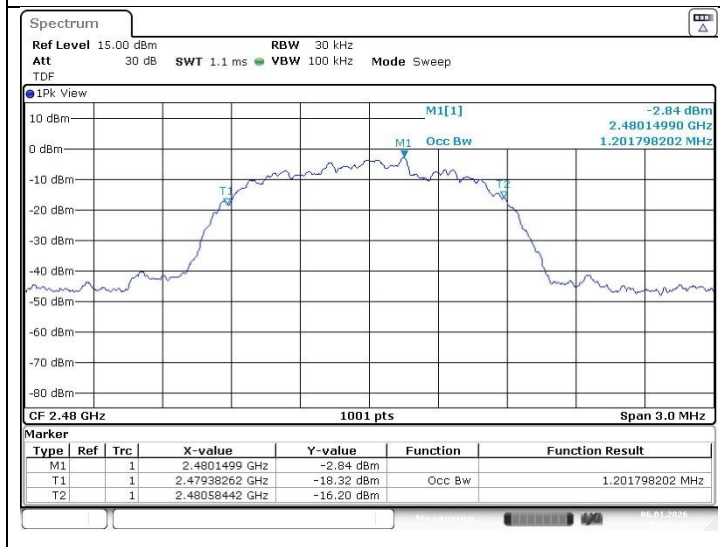
Low Channel



Middle Channel

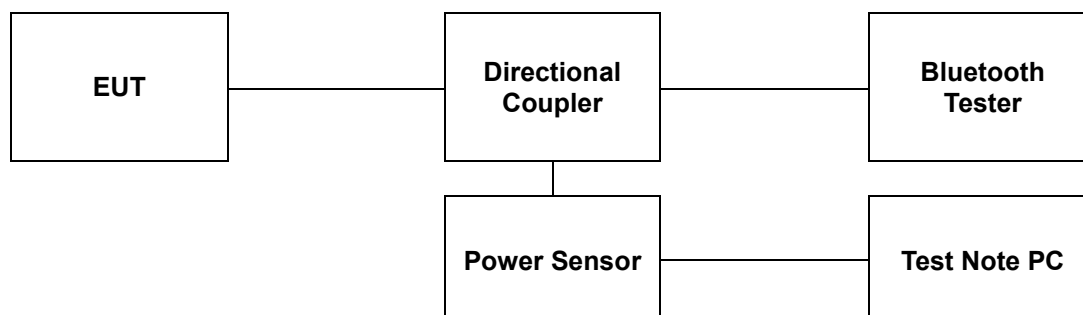


High Channel



4. Maximum Peak Conducted Output Power

4.1. Test Setup



4.2. Limit

1. §15.247(a)(1), Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater. Alternatively, frequency hopping systems operating in the 2 400-2 483.5 MHz band may have hopping channel carrier frequencies that are separated by 25 kHz or two-thirds of the 20 dB bandwidth of the hopping channel, whichever is greater, provided the systems operate with an output power no greater than 125 mW.
2. §15.247(b)(1), For frequency hopping systems operating in the 2 400-2 483.5 MHz band employing at least 75 non-overlapping hopping channels, and all frequency hopping systems in the 5 725-5 850 MHz band: 1 watt. For all other frequency hopping systems in the 2 400-2 483.5 MHz band: 0.125 watts.

4.3. Test Procedure

The test follows ANSI C63.10-2020. Using the power sensor instead of a spectrum analyzer.

1. Initially overall offset for directional coupler and cable loss is measured per frequencies.
2. Place the EUT on the table and set it in the transmitting mode.
3. Remove the antenna from the EUT and then connect a low loss RF cable from the antenna port to the Power sensor.
4. Test program: (S/W name: R&S Power Viewer, Version: 3.2.0)
5. Measure each channel.

4.4. Test Results

Ambient temperature : (23 ± 1) °C
Relative humidity : 47 %

Ant. 1

Mode	Data Rate (Mbps)	Channel	Frequency (MHz)	Average Power Result (dB m)	Peak Power Result (dB m)	Limit (dB m)
GFSK	1	Low	2 402	0.13	1.12	20.97
		Middle	2 441	0.48	1.49	
		High	2 480	1.01	1.91	
π/4DQPSK	2	Low	2 402	-0.28	2.68	
		Middle	2 441	-0.21	2.62	
		High	2 480	0.13	2.89	
8DPSK	3	Low	2 402	-0.17	3.17	
		Middle	2 441	-0.14	3.17	
		High	2 480	0.18	3.36	

Ant. 2

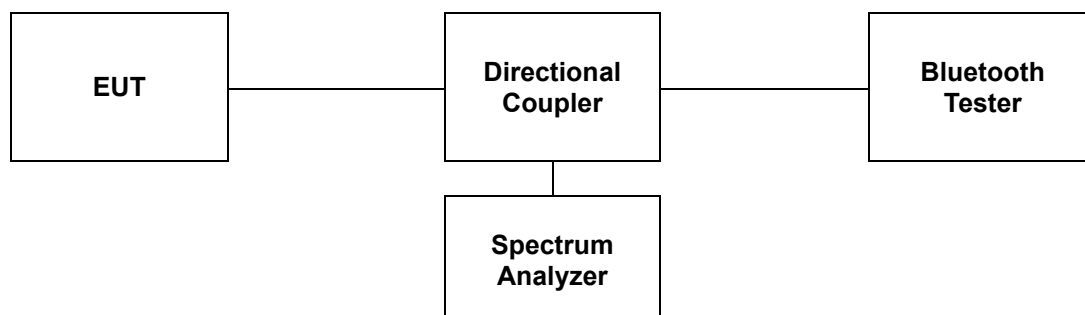
Mode	Data Rate (Mbps)	Channel	Frequency (MHz)	Average Power Result (dB m)	Peak Power Result (dB m)	Limit (dB m)
GFSK	1	Low	2 402	0.70	1.81	20.97
		Middle	2 441	1.54	2.28	
		High	2 480	1.29	2.34	
π/4DQPSK	2	Low	2 402	0.20	3.02	
		Middle	2 441	0.56	3.44	
		High	2 480	1.30	4.09	
8DPSK	3	Low	2 402	0.20	3.18	
		Middle	2 441	0.61	3.63	
		High	2 480	1.35	4.38	

Remark;

In the case of AFH, the limit for peak power is 0.125 W.

5. Carrier Frequency Separation

5.1. Test Setup



5.2. Limit

§15.247(a)(1), Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater. Alternatively, frequency hopping systems operating in the 2 400-2 483.5 MHz band may have hopping channel carrier frequencies that are separated by 25 kHz or two-thirds of the 20 dB bandwidth of the hopping channel, whichever is greater, provided the systems operate with an output power no greater than 125 mW.

5.3. Test Procedure

The test follows ANSI C63.10-2020.

The device is operating in hopping mode between 79 channels and also supporting Adaptive Frequency Hopping with hopping between 20 channels. As compared with each operating mode, 79 channels are chosen as a representative for test.

Use the following spectrum analyzer settings:

1. Span: Wide enough to capture the peaks of two adjacent channels
2. RBW: Start with the RBW set to approximately 30 % of the channel spacing; adjust as necessary to best identify the center of each individual channel.
3. VBW $\geq$ RBW.
4. Sweep: No faster than coupled (auto) time
5. Detector: Peak
6. Trace: Max hold
7. Allow the trace to stabilize.

Use the marker-delta function to determine the separation between the peaks of the adjacent channels. Compliance of an EUT with the appropriate regulatory limit shall be determined. A spectral plot of the data shall be included in the test report.

Where the device shares the same channel plan (carrier frequencies and number of channels) across multiple data rates or modulation schemes then the carrier separation need only be measured for one of those modulation schemes or data rates.

5.4. Test Results

Ambient temperature : (23 ± 1) °C
 Relative humidity : 47 %

Ant. 1

Mode	Frequency (MHz)	Adjacent Hopping Channel Separation (kHz)	Two-third of 20 dB Bandwidth (kHz)
GFSK	2 441	1 000	759
8DPSK	2 441	1 000	939

Ant. 2

Mode	Frequency (MHz)	Adjacent Hopping Channel Separation (kHz)	Two-third of 20 dB Bandwidth (MHz)
GFSK	2 441	1 000	773
8DPSK	2 441	1 000	939

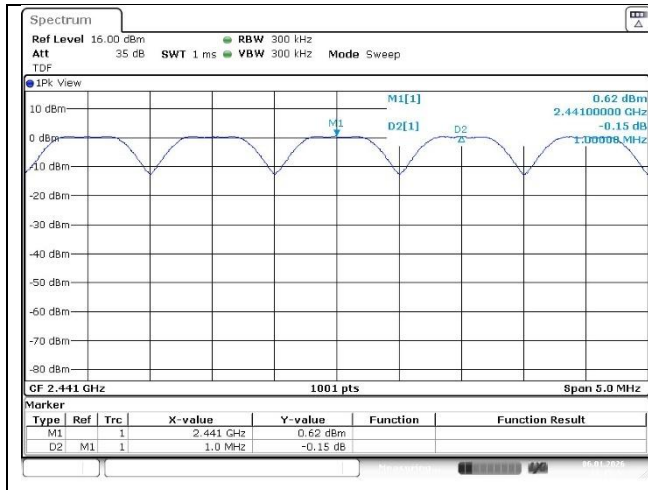
Remark;

Measurement is made with EUT operating in hopping mode between 79 channels providing a worst case scenario as compared to AFH mode hopping between 20 channels.

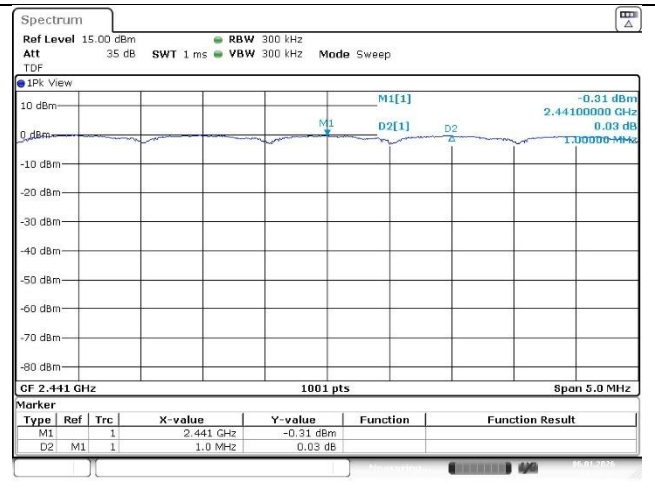
- Test plots

Ant. 1

GFSK

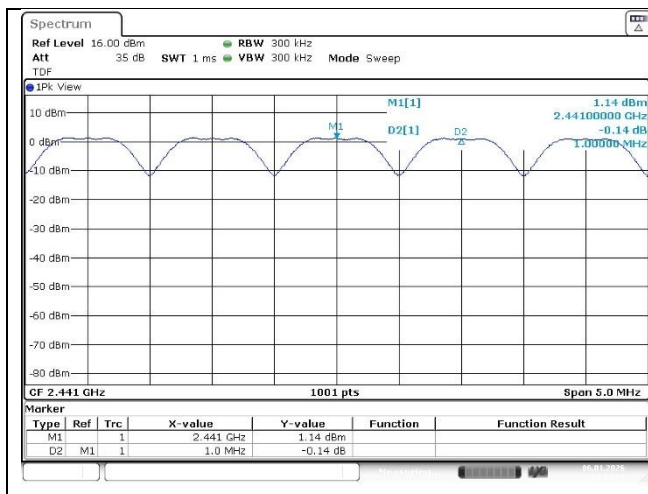


8DPSK

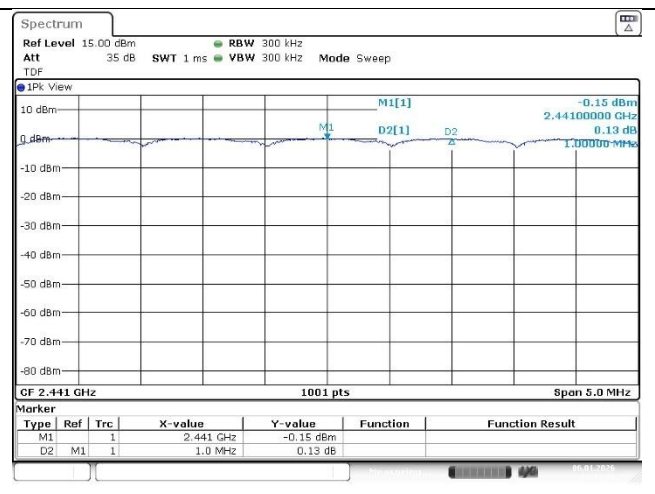


Ant. 2

GFSK

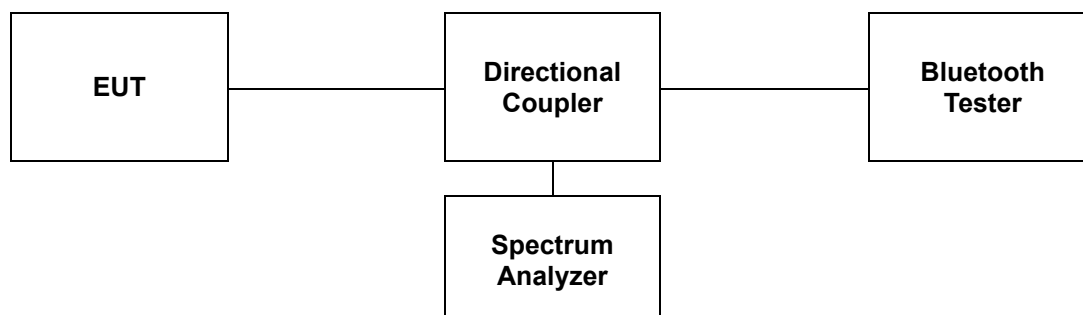


8DPSK



6. Number of Hopping Frequencies

6.1. Test Setup



6.2. Limit

§15.247(a)(1)(iii), Frequency hopping systems in the 2 400-2 483.5 MHz band shall use at least 15 channels. The average time of occupancy on any channel shall not be greater than 0.4 seconds within a period of 0.4 seconds multiplied by the number of hopping channels employed. Frequency hopping systems may avoid or suppress transmissions on a particular hopping frequency provided that a minimum of 15 channels are used.

6.3. Test Procedure

The test follows ANSI C63.10-2020

The device supports Adaptive Frequency Hopping and will use a minimum of 20 channels of the 79 available channels.

The EUT shall have its hopping function enabled. Use the following spectrum analyzer settings:

1. Span: The frequency band of operation. Depending on the number of channels the device supports, it could be necessary to divide the frequency range of operation across multiple spans, to allow the individual channels to be clearly seen.
2. RBW: To identify clearly the individual channels, set the RBW to less than 30 % of the channel spacing or the 20 dB bandwidth, whichever is smaller.
3. VBW $\geq$ RBW.
4. Sweep: No faster than coupled (auto) time.
5. Detector function: Peak
6. Trace: Max hold
7. Allow the trace to stabilize.

It might prove necessary to break the span up into subranges to show clearly all of the hopping frequencies. Compliance of an EUT with the appropriate regulatory limit shall be determined for the number of hopping channels. A spectral plot of the data shall be included in the test report.

Where the device shares the same channel plan (carrier frequencies and number of channels) across multiple data rates or modulation schemes then the number of channels need only be measured for one of those modulation schemes or data rates.

6.4. Test Results

Ambient temperature : $(23 \pm 1) ^\circ\text{C}$
 Relative humidity : 47 %

Ant.1

Mode	Number of Hopping Frequency	Limit
GFSK	79	≥ 15
8DPSK	79	≥ 15

Ant.2

Mode	Number of Hopping Frequency	Limit
GFSK	79	≥ 15
8DPSK	79	≥ 15

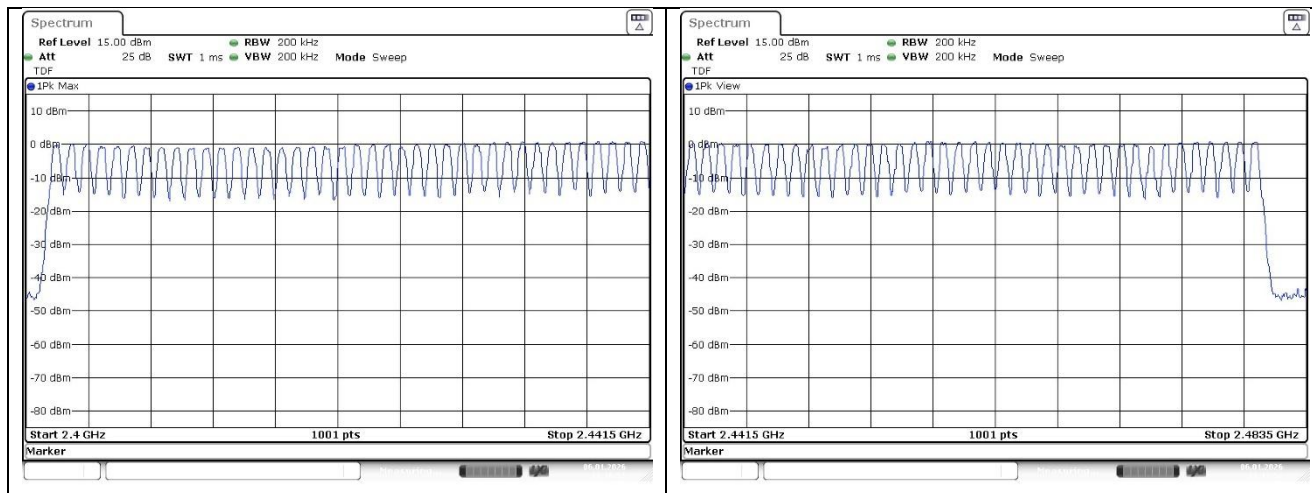
Remark;

Measurement is made with EUT operating in hopping mode between 79 channels providing a worst case scenario as compared to AFH mode hopping between 20 channels.

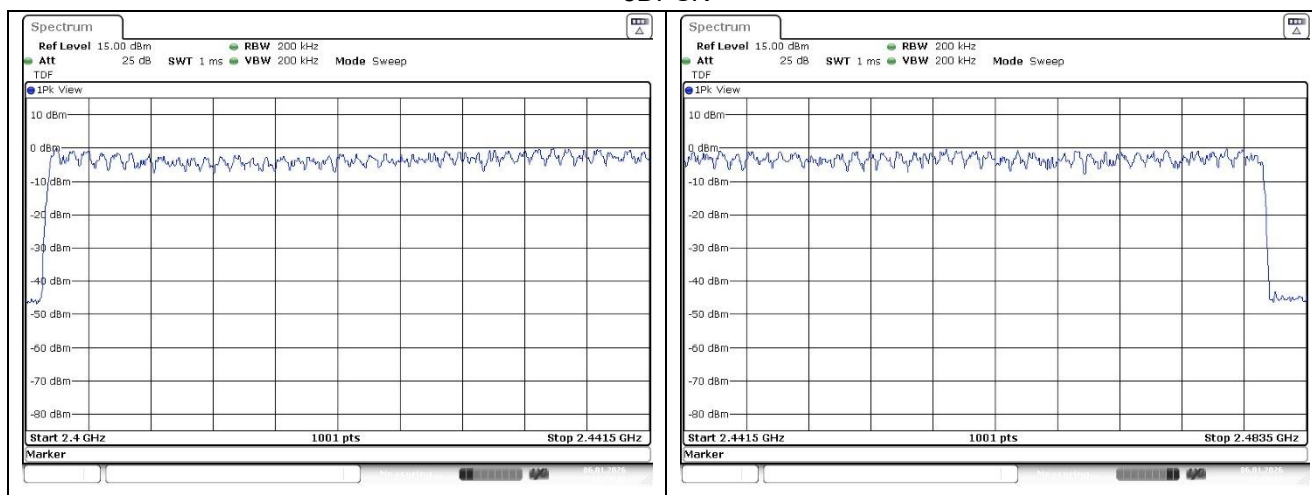
- Test plots

Ant. 1

GFSK

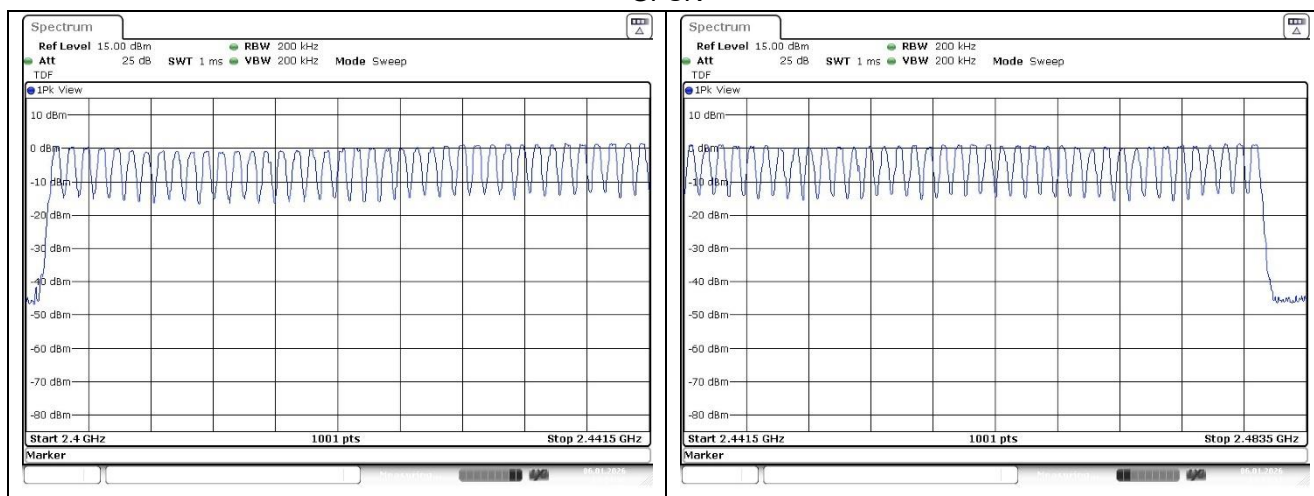


8DPSK

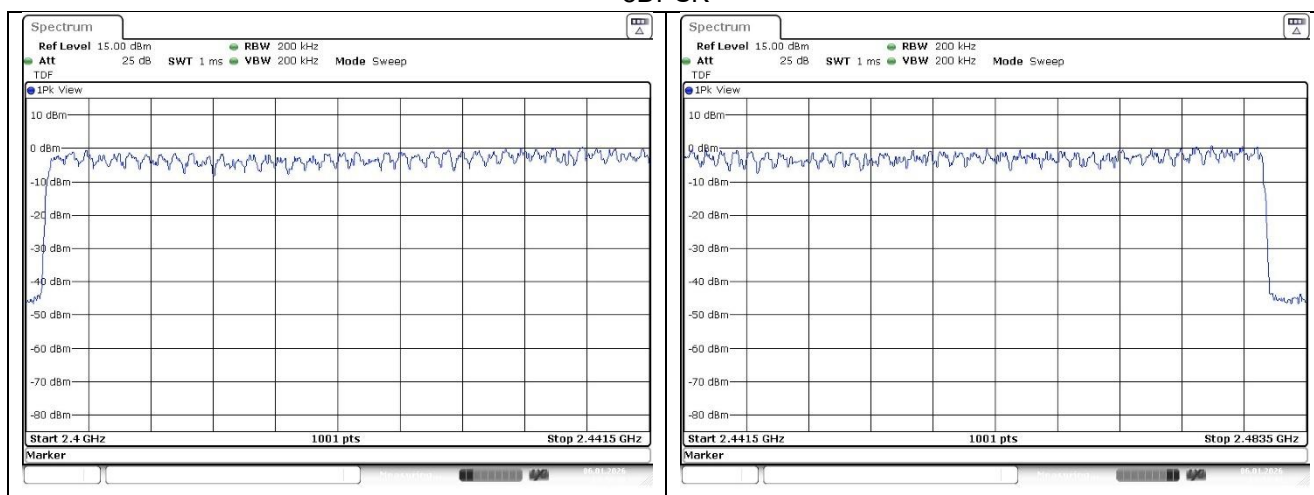


Ant. 2

GFSK

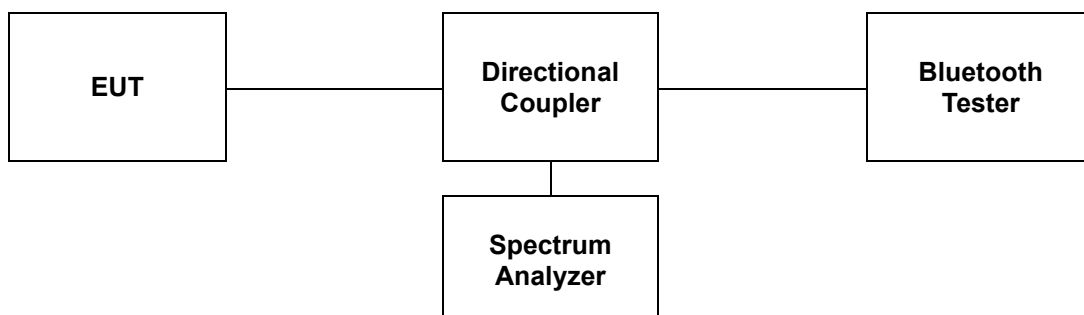


8DPSK



7. Time of Occupancy (Dwell Time)

7.1. Test Set up



7.2. Limit

§15.247(a)(1)(iii), Frequency hopping systems in the 2 400-2 483.5 MHz band, the average time of occupancy on any frequency shall not be greater than 0.4 second within a 31.6 second period.

A period time = 0.4 (s) * 79 = 31.6 (s)

*Adaptive Frequency Hopping

A period time = 0.4 (s) * 20 = 8 (s)

7.3. Test Procedure

The test follows ANSI C63.10-2020.

1. The dwell time per hop on a channel is the time from the start of the first transmission to the end of the last transmission for that hop. If the device has a single transmission per hop then the dwell time is the duration of that transmission. If the device has a multiple transmissions per hop then the dwell time is measured from the start of the first transmission to the end of the last transmission.
2. The time of occupancy is the total time that the device dwells on a channel over an observation period specified in the regulatory requirement. To determine the time of occupancy the spectrum analyzer will be configured to measure both the dwell time per hop and the number of times the device transmits on a specific channel in a given period.
3. The EUT shall have its hopping function enabled. Compliance with the requirements shall be made with the minimum and with the maximum number of channels enabled. If the dwell time per channel does not vary with the number of channels then compliance with the requirements may be based on the minimum number of channels. If the device supports different dwell times per channel (example Bluetooth devices can dwell on a channel for 1, 3 or 5 time slots) then measurements can be limited to the longest dwell time with the minimum number of channels.

Use the following spectrum analyzer settings to determine the dwell time per hop

1. Span = Zero span, centered on a hopping channel.
2. RBW shall be $\leq$ channel spacing and where possible RBW should be set $\gg 1/T$, where T is the expected transmission time per hop.
3. Sweep = Set so that the start of the first transmission and end of the last transmission for the hop are clearly captured. Setting the sweep time to be slightly longer than the hopping period per channel (hopping period = $1/\text{hopping rate}$) should achieve this.
4. Use a video trigger, where possible with a trigger delay, so that the start of the transmission is clearly observed. The trigger level might need adjustment to reduce the chance of triggering when the system hops on an adjacent channel.
5. Detector = Peak.
6. Trace = Clear-write, Single sweep
7. Place markers at the start of the first transmission on the channel and at the end of the last transmission. The dwell time per hop is the time between these two markers.

7.4. Test Results

Ambient temperature : (23 ± 1) °C
 Relative humidity : 47 %

7.4.1. Packet Type: DH5,3DH5

Ant. 1

Mode	Frequency (MHz)	Dwell Time (ms)	Time of occupancy on the Tx Channel in 31.6 sec (ms)	Limit for time of occupancy on the Tx Channel in 31.6 sec (ms)
GFSK	2 441	2.88	364.03	400
8DPSK	2 441	2.88	364.03	400

Remark;

In case of GFSK:

The number of hops in 0.5 sec = 2

Time of occupancy on the Tx Channel in 31.6 sec = $(2 / 0.5) \times 31.6 \times 2.88 \text{ ms} = 364.03 \text{ ms}$

In case of 8DPSK:

The number of hops in 0.5 sec = 2

Time of occupancy on the Tx Channel in 31.6 sec = $(2 / 0.5) \times 31.6 \times 2.88 \text{ ms} = 364.03 \text{ ms}$

Ant. 2

Mode	Frequency (MHz)	Dwell Time (ms)	Time of occupancy on the Tx Channel in 31.6 sec (ms)	Limit for time of occupancy on the Tx Channel in 31.6 sec (ms)
GFSK	2 441	2.88	182.02	400
8DPSK	2 441	2.88	364.03	400

Remark;

In case of GFSK:

The number of hops in 0.5 sec = 1

Time of occupancy on the Tx Channel in 31.6 sec = $(1 / 0.5) \times 31.6 \times 2.88 \text{ ms} = 182.02 \text{ ms}$

In case of 8DPSK:

The number of hops in 0.5 sec = 2

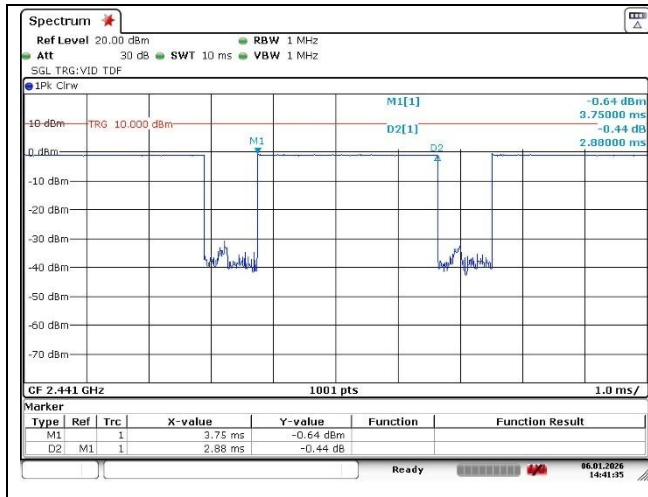
Time of occupancy on the Tx Channel in 31.6 sec = $(2 / 0.5) \times 31.6 \times 2.88 \text{ ms} = 364.03 \text{ ms}$

- Test plots

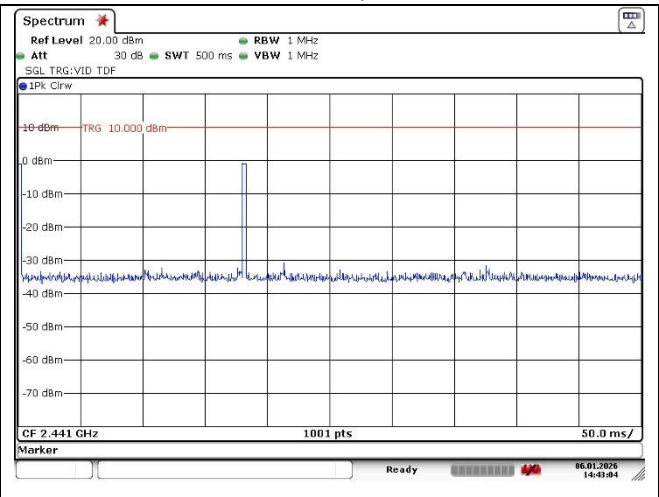
Ant. 1

Operation Mode: GFSK

Dwell time

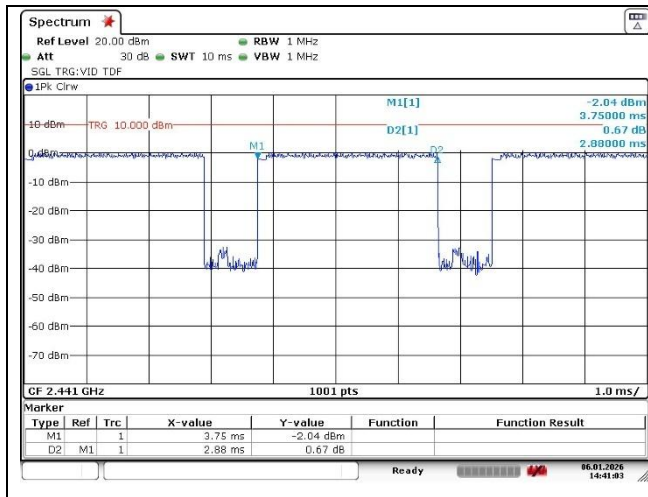


The number of hops in 0.5 sec

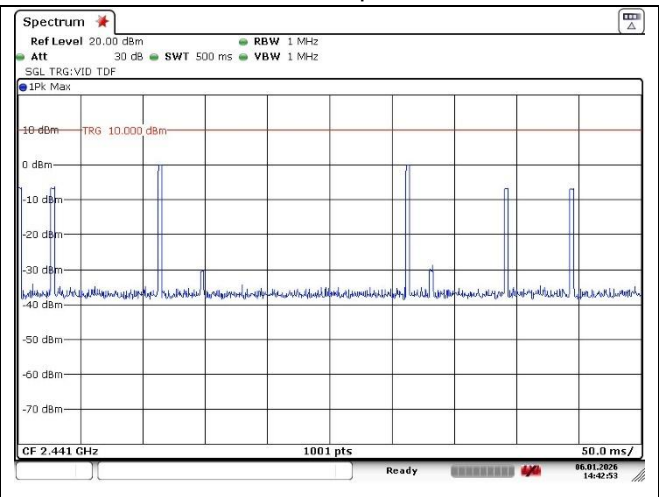


Operation Mode: 8DPSK

Dwell time



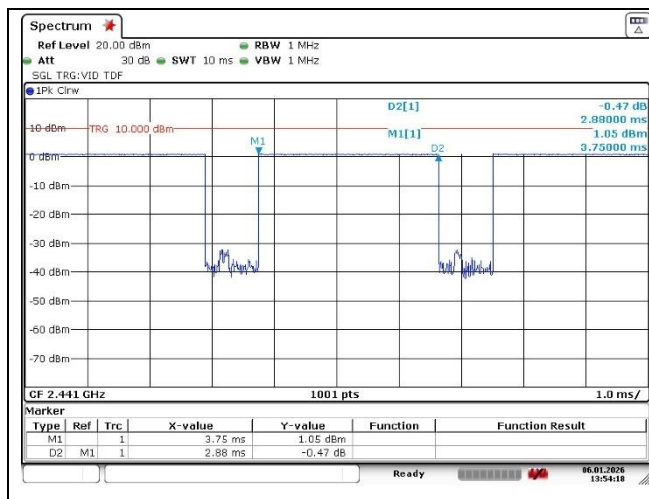
The number of hops in 0.5 sec



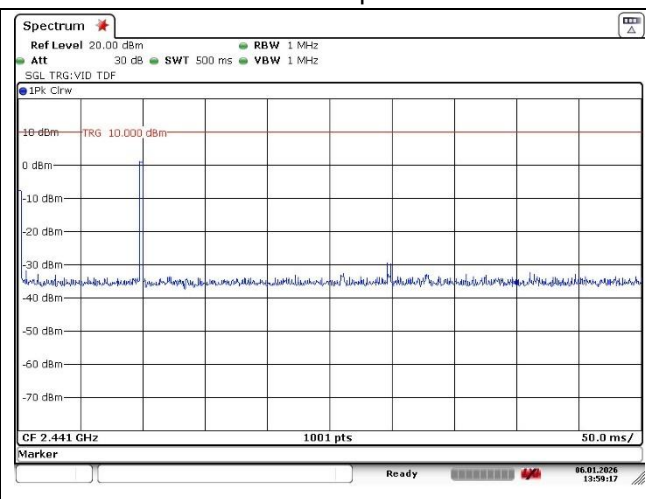
Ant. 2

Operation Mode: GFSK

Dwell time

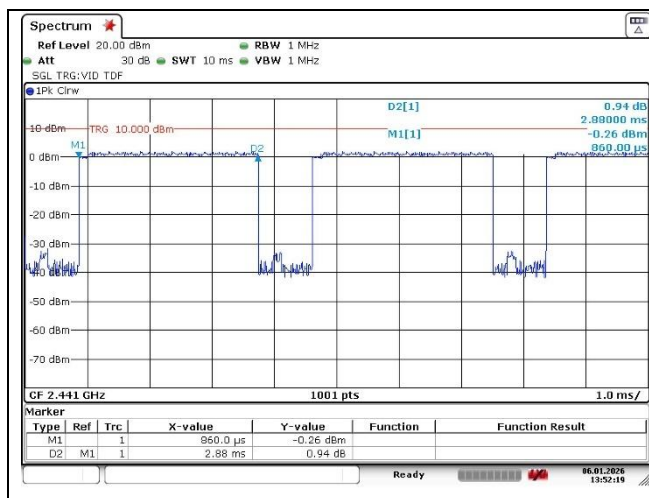


The number of hops in 0.5 sec

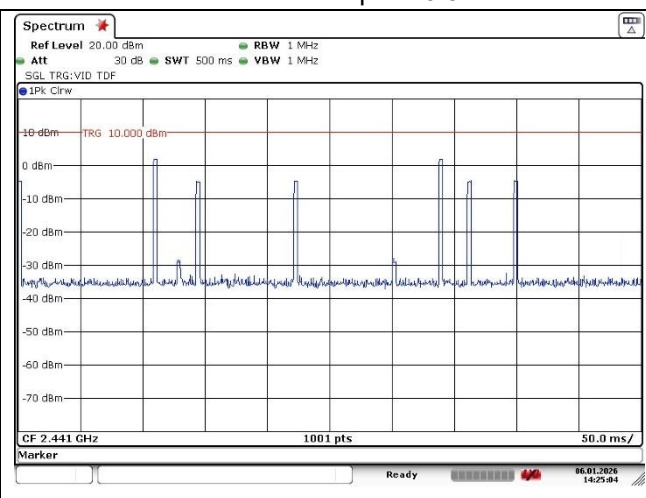


Operation Mode: 8DPSK

Dwell time



The number of hops in 0.5 sec



7.4.2. Packet Type: DH5, 3DH5 (Adaptive Frequency Hopping)

Ant. 1

Operation Mode	Frequency (MHz)	Dwell Time (ms)	Time of occupancy on the Tx Channel in 8 sec (ms)	Limit for time of occupancy on the Tx Channel in 8 sec (ms)
GFSK	2 441	2.88	92.16	400
8DPSK	2 441	2.88	368.64	400

Remark;

In case of GFSK:

The number of hops in 0.5 sec = 2

Time of occupancy on the Tx Channel in 8 sec = $(2 / 0.5) \times 8 \times 2.88 \text{ ms} = 92.16 \text{ ms}$

In case of 8DPSK:

The number of hops in 0.5 sec = 8

Time of occupancy on the Tx Channel in 8 sec = $(8 / 0.5) \times 8 \times 2.88 \text{ ms} = 368.64 \text{ ms}$

Ant. 2

Operation Mode	Frequency (MHz)	Dwell Time (ms)	Time of occupancy on the Tx Channel in 8 sec (ms)	Limit for time of occupancy on the Tx Channel in 8 sec (ms)
GFSK	2 441	2.88	92.16	400
8DPSK	2 441	2.88	368.64	400

Remark;

In case of GFSK:

The number of hops in 0.5 sec = 2

Time of occupancy on the Tx Channel in 8 sec = $(2 / 0.5) \times 8 \times 2.88 \text{ ms} = 92.16 \text{ ms}$

In case of 8DPSK:

The number of hops in 0.5 sec = 8

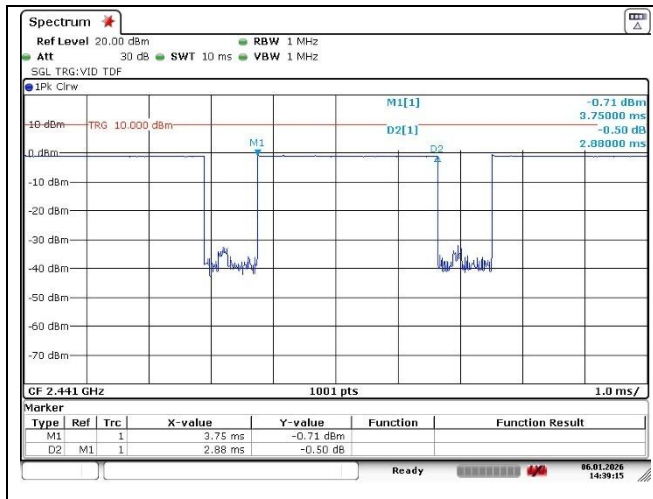
Time of occupancy on the Tx Channel in 8 sec = $(8 / 0.5) \times 8 \times 2.88 \text{ ms} = 368.64 \text{ ms}$

- Test plots

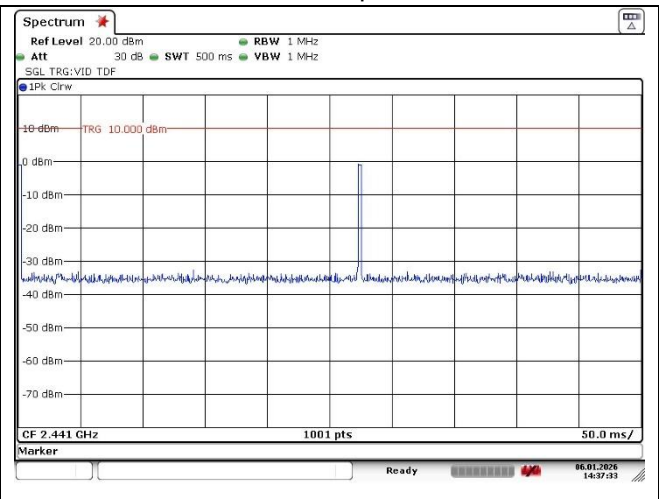
Ant. 1

Operation Mode: GFSK

Dwell time

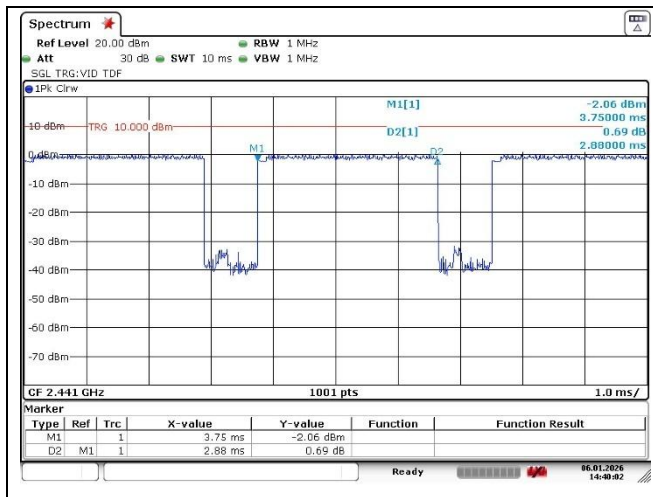


The number of hops in 0.5 sec

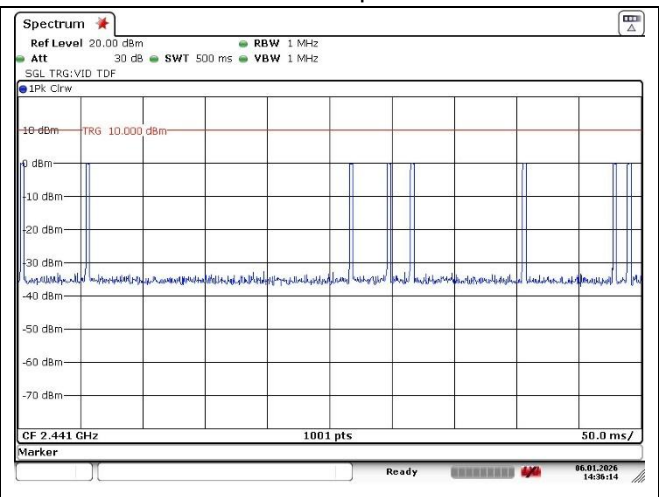


Operation Mode: 8DPSK

Dwell time



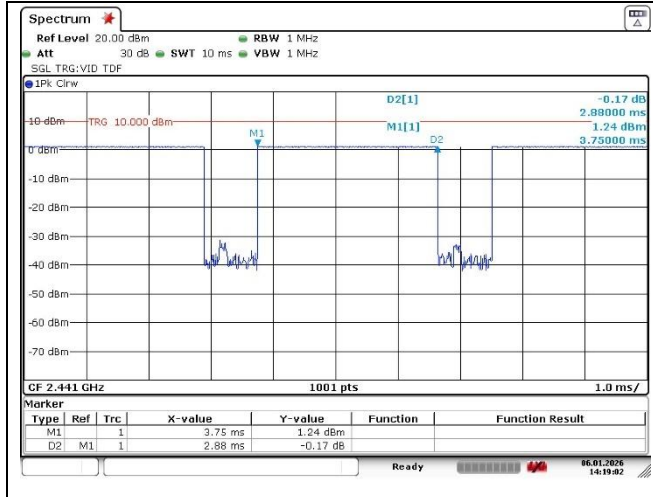
The number of hops in 0.5 sec



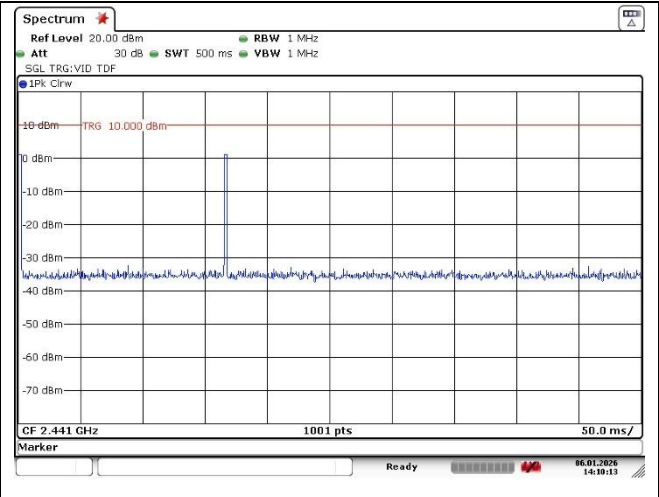
Ant. 2

Operation Mode: GFSK

Dwell time

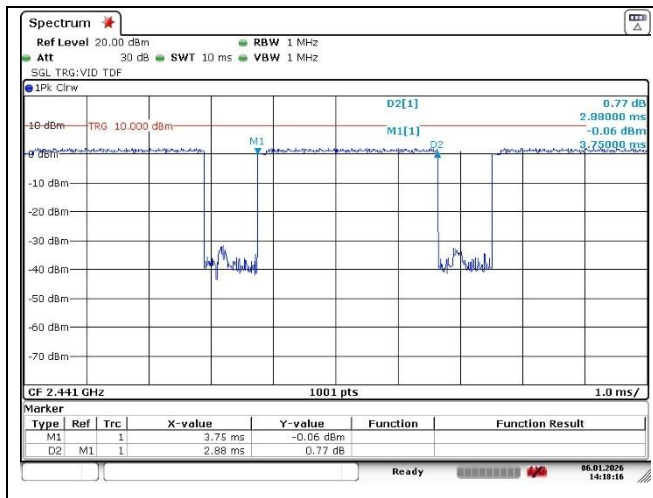


The number of hops in 0.5 sec

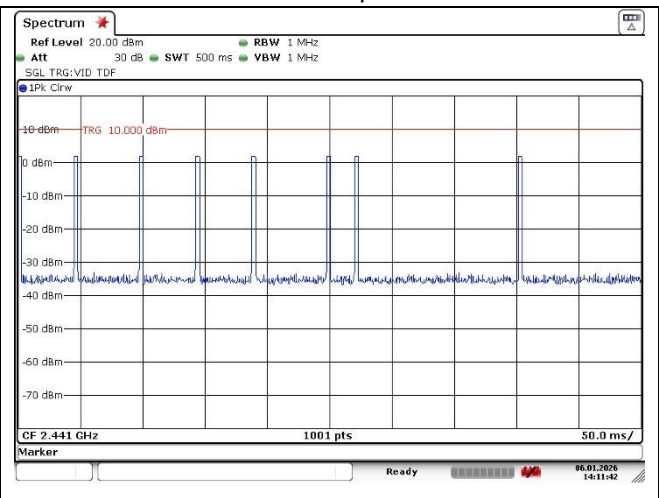


Operation Mode: 8DPSK

Dwell time



The number of hops in 0.5 sec



8. Antenna Requirement

8.1. Standard Applicable

For intentional device, according to FCC 47 CFR Section §15.203, an intentional radiator shall be designed to ensure that no antenna other than that furnished by the responsible party shall be used with the device. The use of a permanently attached antenna or of an antenna that uses a unique coupling to the intentional radiator shall be considered sufficient to comply with the provisions of this section. The manufacturer may design the unit so that a broken antenna can be replaced by the user, but the use of a standard antenna jack or electrical connector is prohibited. And according to FCC 47 CFR Section §15.247(b) if transmitting antennas of directional gain greater than 6 dB i are used, the conducted output power shall be reduced appropriate, by the amount in dB that the directional gain of the antenna exceeds 6 dB i.

8.2. Antenna Connected Construction

Antenna	Type	Frequency Band	Max Peak Gain
Ant. 1	PCB Pattern Antenna	2.4 GHz	3.90 dB i
Ant. 2	PCB Pattern Antenna	2.4 GHz	2.70 dB i

- End of the Test Report -