How to perform BLE RF-PHY and telecommunication regulatory tests on Apollo-based wireless products

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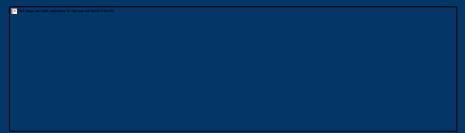


Table of Contents

Table of Contents

Preparation before Testing

- Lead the VDD, GND, SWD interface, 2-wire UART test interface and RF port out from EUT board.
- Burn test program (test_bridge.bin) over J-link to make MCU enter into Direct Test Mode (Frequency hopping off, fixed frequency).
- The general J-Flash programming parameters shall be set as follows:

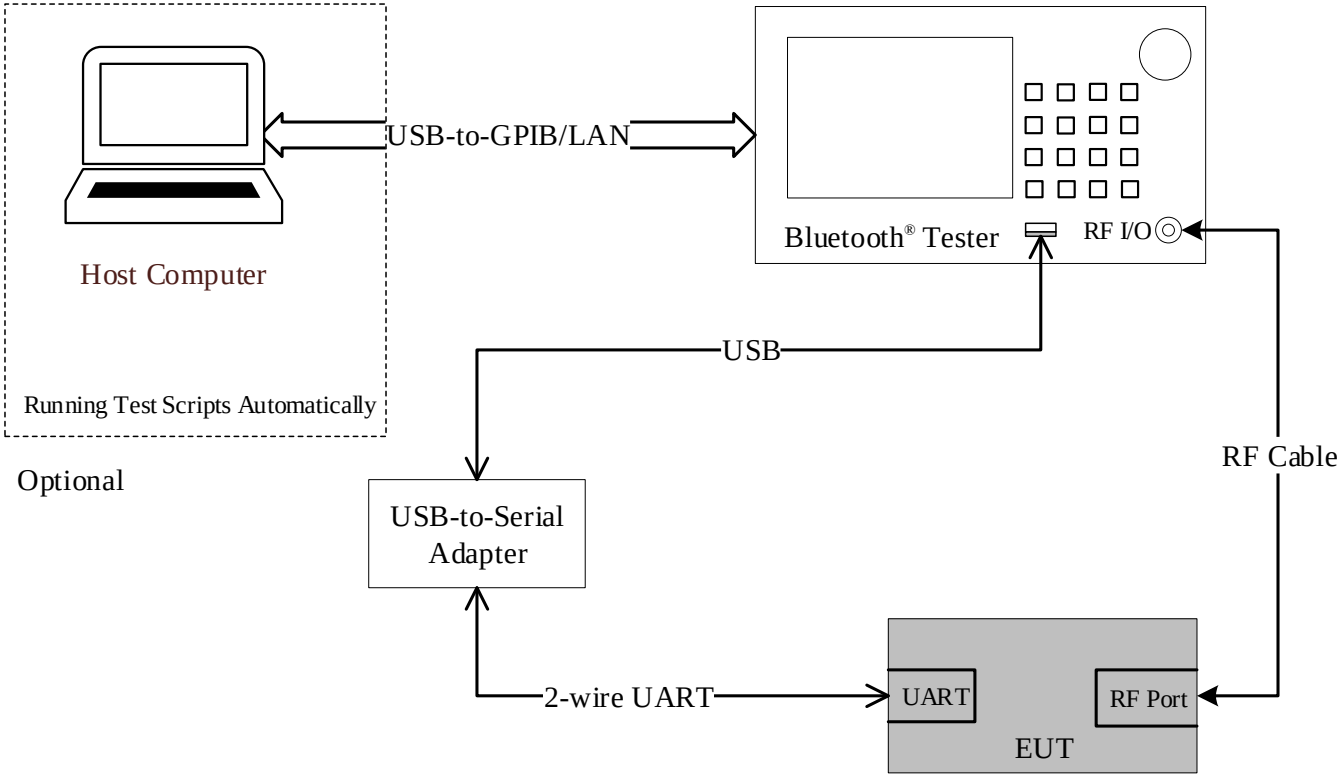
MCU Type	Target Device Type	Debug Interface	Speed	Burning Start Address
Apollo2-Blue	AMAPH1KK-KBR	SWD	1000	0x00000000
Apollo3-Blue	AMAPH1KK-KBR	SWD	1000	0x0000C000

- Connect 2-wire UART test interface of EUT and USB interface of PC or BLE tester with one USB-to-Serial adapter (driver must be installed at first).
  - *Note: Apollo series MCU family has two power supply schemes: 3.3V or 1.8V. The interface level of USB-to-Serial adapter must be compatible with EUT power supply.*
- Connect antenna port of EUT to the tester via a 50Ω connector by using an RF coaxial cable or soldering a pig-tail from feed point pad on PCBA.

Table of Contents

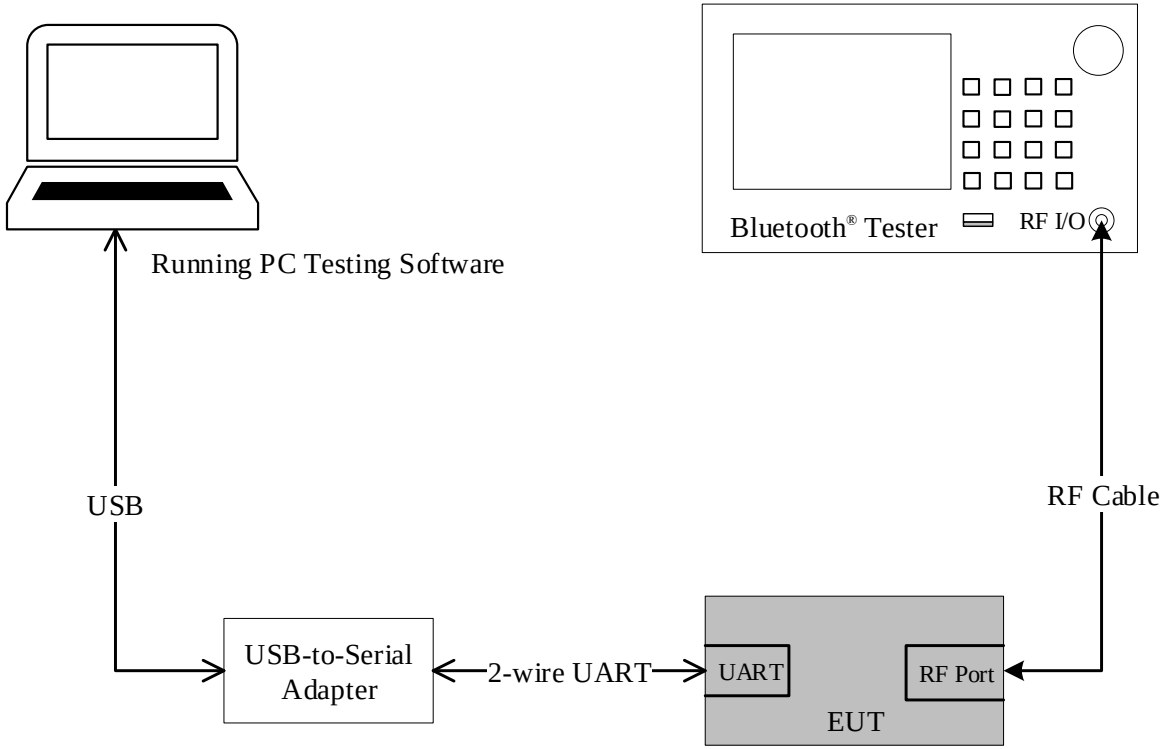
BLE RF-PHY Test Setup 1

- There are two main test methods: Bluetooth signaling and non-signaling. And two common models of Bluetooth testers: R&S CMW series and Anritsu MT8852B.
- For Bluetooth signaling test method, RF testing commands are generated by tester automatically to control EUT and the test setup is shown as follows:



BLE RF-PHY Test Setup 2

- For non-signaling test method, RF testing commands are sent by PC software manually to control EUT and the test setup is shown as follows:



- There are two kinds of commonly used PC testing software: SSCOM tool and BLE Connector tool .
- Only R&S CMW series testers can support Bluetooth non-signaling test method.

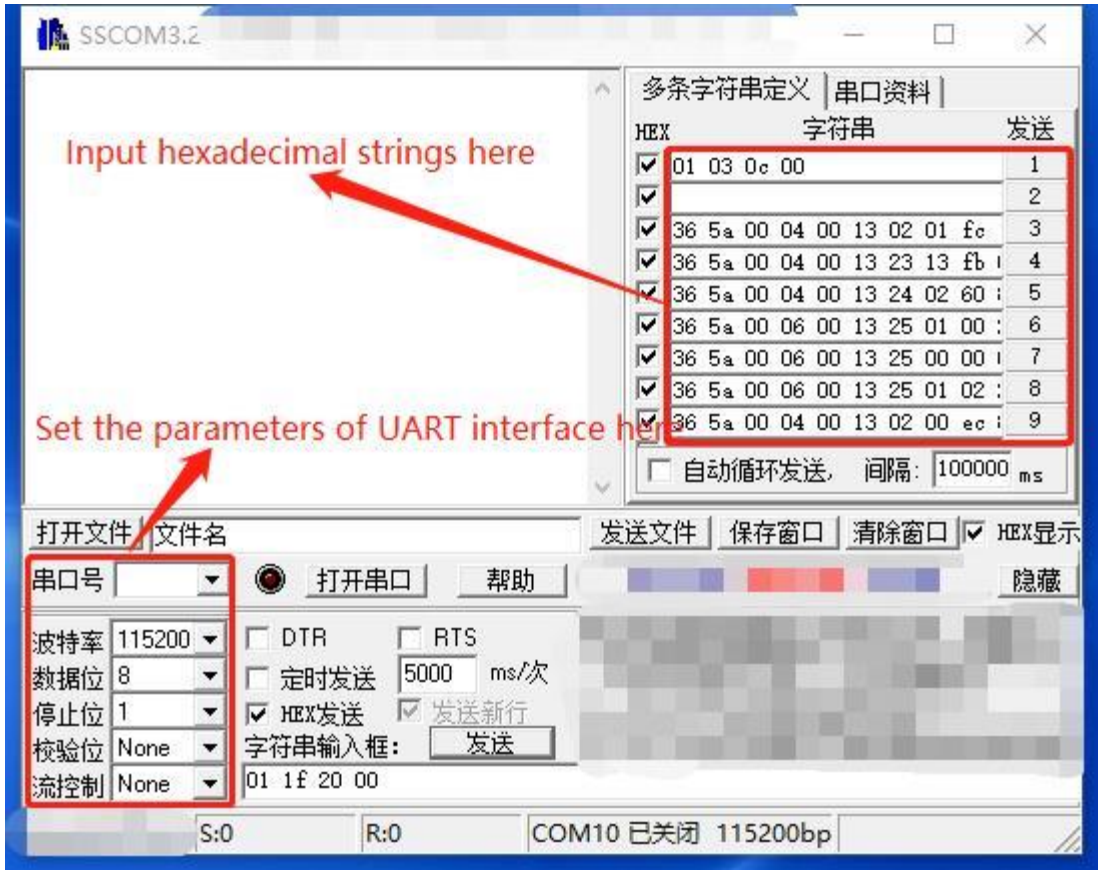
HCI Testing Commands

- For both of Apollo2-Blue and Apollo3-Blue, HCI testing commands used in RF-PHY non-signaling test mode are defined as follows:

Packaged HCI Commands	SSCOM Strings	Description
HCI_RESET	01 03 0C 00	Reset EUT before testing
HCI_LE_TRANSMITTER_TEST	01 1E 20 03 XX 25 00	'00': sending LE test packets with PRBS9 in payload
	01 1E 20 03 XX 25 01	'01': sending LE test packets with repeated '11110000' sequence in payload
	01 1E 20 03 XX 25 02	'02': sending LE test packets with repeated '10101010' sequence in payload
HCI_LE_RECEIVER_TEST	01 1D 20 01 XX	Set EUT in direct RX mode
HCI_LE_TEST_END	01 1F 20 00	End current test and be ready for next one

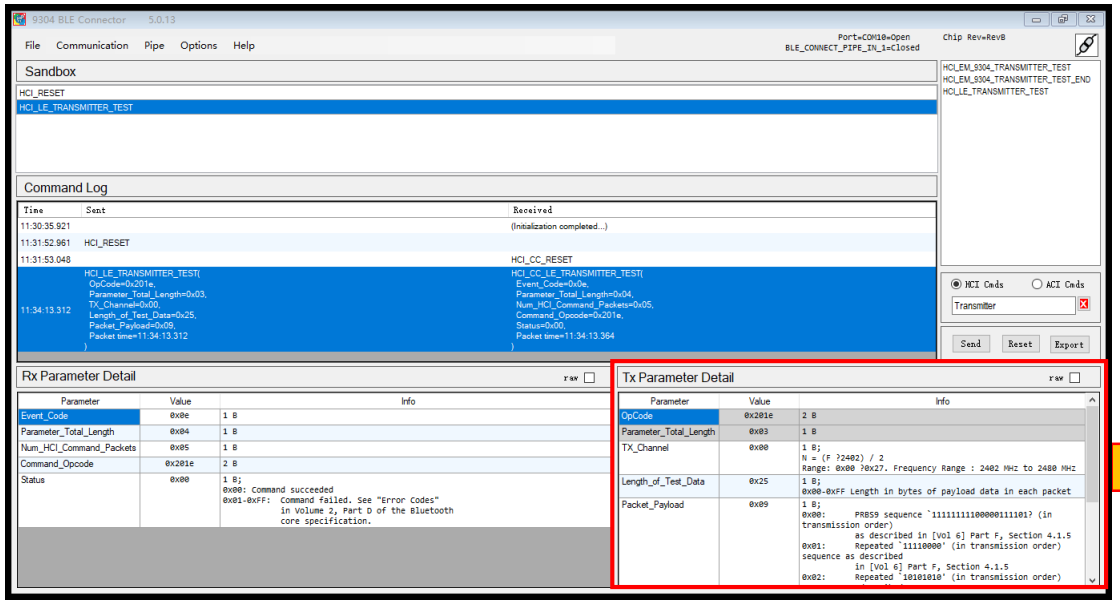
- 'XX' in all transmitter and receiver testing commands above means channel to be tested (within range: 0x00~0x27).
- Note that If each command processed successfully, the last octet of LE_STATUS packet returned by EUT will be 0x00.

PC Testing Software – SSCOM



- The UART test Interface characteristics of Bluetooth tester or PC testing software shall be set to use following parameters:
  - Baud rate: 115200
  - Number of data bits: 8
  - Number of stop bits: 1
  - No parity
  - No flow control

PC Testing Software – BLE Connector



Parameter	Value
TX_Channel	Channel for testing
Length_of_Test_Data	0x25 (37 octets)
Packet_Payload	As specific

Tx Parameter Detail raw

Parameter	Value	Info
Parameter_Total_Length	0x03	1 B
TX_Channel	0x00	1 B; N = (F ?2402) / 2 Range: 0x00 ?0x27. Frequency Range : 2402 MHz to 2480 MHz
Length_of_Test_Data	0x25	1 B; 0x00-0xFF Length in bytes of payload data in each packet
Packet_Payload	0x09	1 B; 0x00: PRBS9 sequence `11111111100000111101? (in transmission order) as described in [Vol 6] Part F, Section 4.1.5 0x01: Repeated `11110000' (in transmission order) sequence as described in [Vol 6] Part F, Section 4.1.5 0x02: Repeated `10101010' (in transmission order) sequence as described in [Vol 6] Part F, Section 4.1.5

Transmitter Tests (TRM-LE)

No.	Test Case	Requirement	Channels for Testing
1	Output Power	$-20 \le P_{AVG} \le +10$ dBm $P_{PEAK} - P_{AVG} \le 3$ dB	Ch0, 12, 19, 39
2	In-band emissions	$P_{TX} \le -20$ dBm for ($f_{TX} \pm 2$ MHz); $P_{TX} \le -30$ dBm for ($f_{TX} \pm n$ MHz]); where $n \ge 3$	Ch0, 2, 12, 19, 37,39
3	Modulation Characteristics	225 kHz ≤ Δf1avg ≤ 275 kHz 99.9% Δf2max > 185 kHz Δf2avg / Δf1avg ≥ 0.8	Ch0, 12, 19, 39
4	Carrier frequency offset and drift	Freq Offset (Accuracy) ≤ ±150 kHz Freq Drift ≤ ±50 kHz Initial frequency drift ≤ ±23 kHz Maximum drift rate ≤ 20kHz/50µs	Ch0, 12, 19, 39

Receiver Tests (RCV-LE)

No.	Test Case	Requirement	Channels for Testing
1	Receiver sensitivity	PER ≤ 30.8% when input power level = -70 dBm in dirty TX mode	Ch0, 12, 19, 39
2	Maximum input signal level	PER ≤ 30.8% when input power level = -10 dBm	Ch0, 12, 19, 39
3	PER Report Integrity	50% ≤ PER ≤ 65.4% when input power level = -30 dBm and every test packet has an intentionally corrupted CRC value	Ch12, 19
4	Blocking Performance	See RF-PHY.TS.4.2.2 for details	Ch12
5	C/I and Receiver Selectivity Performance	See RF-PHY.TS.4.2.2 for details	Ch0, 2, 12, 19, 37,39
6	Intermodulation Performance	See RF-PHY.TS.4.2.2 for details	Ch0, 12, 19, 39

Declarations in RCV-LE

- Due to different receiver design inside chip, below two values shall be declared to test facility by manufacturer when performing receiver tests:

No.	Identifier	Channel	Apollo2-Blue	Apollo3-Blue	Unit
1	In-band image frequency for C/I and receiver selectivity test	Low	78	-4	MHz
		Middle			
		High			
2	Value n for intermodulation test	Low	3	5	integer
		Middle			
		High			

Tips for Tester Model Selection

- Generally, R&S CMW series Bluetooth testers, such as CMW270/500, are recommended for R&D use since they could be operated more flexibly.
- While Anritsu MT8852B series are more suitable for production tests since they can run testing scripts and generate test results automatically.

Table of Contents

Overview

- Telecommunication regulatory tests indicate mandatory regional radio type approval for where those radio products intend to be sold.
- The primary approval standards include SRRC, FCC and CE corresponding to marketplace in China, North America and Europe respectively.
- Some test cases in FCC and CE certification require radiated measurement in SAR or FAR similar as EMC tests, in this case conducted measurement may be used instead for reference.

SRRC FC CE

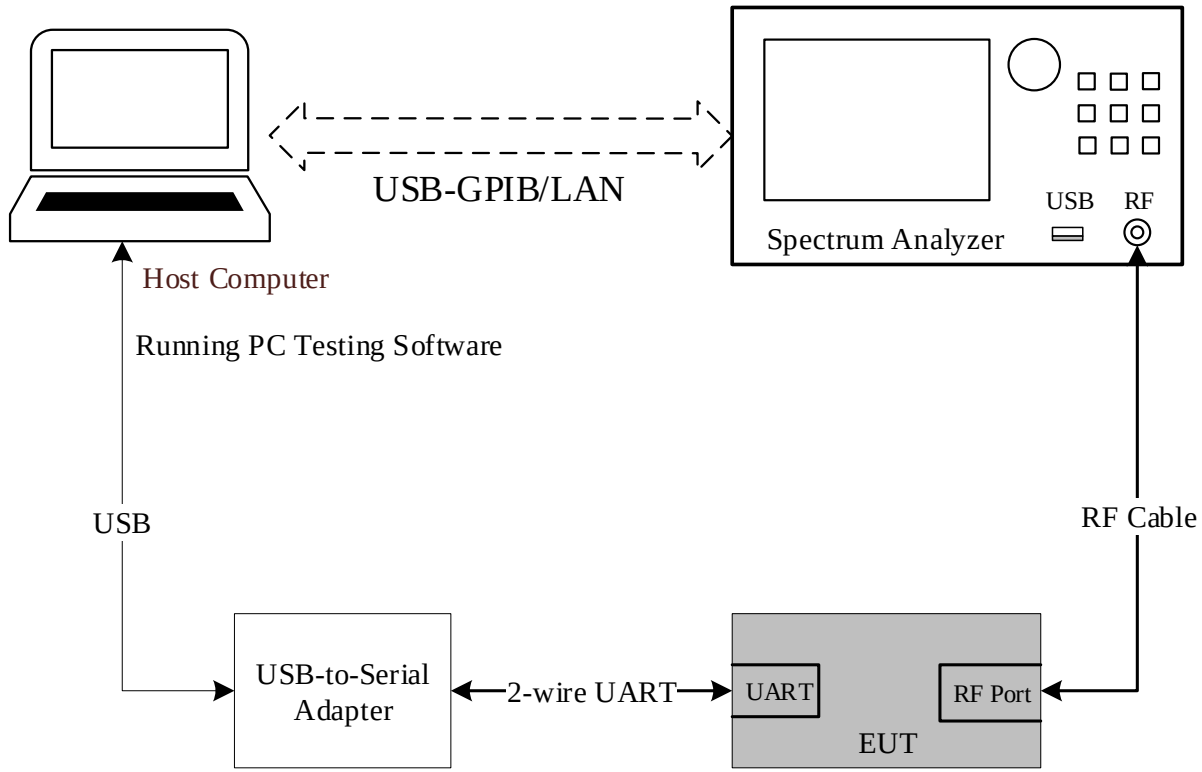
Applicable Standards

- All telecommunication regulatory tests shall follow these standards listed as below respectively:

Category	Standard Code	Document Title
SRRC	MIIT regulation [2002]353	微功率（短距离）无线电发射设备技术要求
FCC	47 CFR Part 15 Subpart C	Miscellaneous Wireless Communication Services
	ANSI C63.10-2013	American National Standard for Testing Unlicensed Wireless Devices
CE	ETSI EN 300 328 V2.1.1	Wideband transmission systems; Data transmission equipment operating in the 2.4 GHz ISM band and using wideband modulation techniques
	ETSI EN 300 440 V2.1.1	Short Range Devices (SRD); Radio equipment to be used in the 1 GHz to 40 GHz frequency range
	ETSI EN 301 489-17 V2.1.1	Electromagnetic compatibility and Radio spectrum Matters (ERM); ElectroMagnetic Compatibility (EMC) standard for radio equipment

Regulatory Test Setup

- The regulatory test configuration is similar as BLE RF-PHY non-signaling test, the only difference is spectrum analyzer used instead of Bluetooth tester.
- All RF testing commands are sent by upper host computer to control EUT and the brief test setup is shown as follows:



RF Testing Commands

- As provided in ANSI C63.10, the EUT shall be set to operate in the worst case transmission situation i.e. continuous transmit mode with 100% duty cycle no matter carrier wave or modulated data during testing.
- For Apollo3-Blue, RF testing commands to be used in regulatory tests are defined as follows:

Packaged HCI Commands	SSCOM Strings	Description
HCI_RESET	01 03 0C 00	Reset EUT before testing
HCI_LE_TRANSMITTER_TEST	01 1E 20 03 XX 25 08	'08': Set EUT in continuous carrier wave mode at center frequency
	01 1E 20 03 XX 25 09	'09': Set EUT in continuous modulation transmit mode with duty cycle = 100%
HCI_LE_RECEIVER_TEST	01 1D 20 01 XX	Set EUT in direct RX mode
HCI_LE_TEST_END	01 1F 20 00	End current test and be ready for next one

RF Testing Commands (continued)

- For Apollo2-Blue, RF testing commands to be used in regulatory tests are defined as follows:

Packaged HCI Commands	SSCOM Strings	Description
HCI_RESET	01 03 0C 00	Reset EUT before testing
HCI_EM_9304_TRANSMITTER_TEST	01 11 fc 04 01 XX 25 00	'01': Set EUT in continuous modulation transmit mode with duty cycle = 100%
	01 11 fc 04 04 XX 25 00	'04': Set EUT in continuous carrier wave transmit mode at center frequency
HCI_LE_RECEIVER_TEST	01 1D 20 01 XX	Set EUT in direct RX mode
HCI_LE_TEST_END	01 1F 20 00	End current test and be ready for next one

- Note:
  - The frequency tolerance test item in SRRC requires to configure EUT in carrier wave transmit mode.
  - The receiver spurious emission and receiver blocking test items in SRRC and CE require to configure EUT in direct receiver mode.
  - All other test items are performed in continuous transmit mode (PRBS9, 100% duty cycle) of EUT.

SRRC Requirements

No.	Test Items	Requirement	Channel for Testing	EUT Status
1	Peak Output Power	EIRP ≤ 20 dBm	Low/Mid/High	Continuous transmit mode
2	Frequency Tolerance	±20 ppm	Low/Mid/High	Carrier wave transmit mode
3	Out-of-band Emissions (Band Edge)	EIRP≤-80 dBm/Hz out of 2.4-2.4835 GHz band	Low/High	Continuous transmit mode
4	Spurious emissions of transmitter	See table on next page	Low/Mid/High	Continuous transmit mode
5	Spurious emissions of receiver	Same as above	Low/Mid/High	Receiver mode

- *Note:*
  - The frequency tolerance mainly depends on the frequency accuracy of external HF crystal (32 or 48 MHz), so be careful of crystal selection.

Limitation of Spurious Emission

Frequency Range	Measurement BW	Detector	Limit
30 - 1000 MHz	100 kHz	Peak	-36 dBm
2.4 – 2.4835 GHz	100 kHz	Peak	-33 dBm
3.4 - 3.53 GHz	1 MHz	Peak	-40 dBm
5.725 - 5.85 GHz	1 MHz	Peak	-40 dBm
Others within 1 - 12.75GHz	1MHz	Peak	-30 dBm

✓ **Note:**

- The frequency range should be set outside 2.5 times channel bandwidth of the center frequency to be tested.
  - e.g., when measuring at 2402MHz (lowest channel), the lower stop frequency should be set to 2397MHz and the upper start frequency should be set to 2407MHz.
  - However, when measuring at 2480MHz (highest channel), the upper start frequency should be set to 2483.5MHz.

FCC Requirements

No.	Test Items	Requirement	Channel for Testing	EUT Status
1	Output Power	EIRP ≤ 30 dBm	Low/Mid/High	Continuous transmit mode
2	Occupied Bandwidth	6 dB Bandwidth ≥ 500 kHz	Low/Mid/High	Continuous transmit mode
3	Conducted Spurious Emission	-20 dBc (Peak) -30 dBc (Average)	Low/Mid/High	Continuous transmit mode
4	Band Edge	-20 dBc relative to desired power	Low/High	Continuous transmit mode
5	Power Spectral Density	≤ 8 dBm/3kHz	Low/Mid/High	Continuous transmit mode
6	Radiated Spurious Emission	See table on next page	Low/Mid/High	Continuous transmit mode

Limitation of Radiated Emission

Frequency Range	RBW	Detector	Distance	Field Strength	Calculated EIRP
30 – 88 MHz	100 kHz	Quasi-Peak	3 m	40 dBuV/m	-55 dBm
88 – 216 MHz				43.5 dBuV/m	-52 dBm
216 – 960 MHz				46 dBuV/m	-49 dBm
960 – 1000 MHz				54 dBuV/m	-41 dBm
1 – 18 GHz	1MHz	Average		54 dBuV/m	-41 dBm

- *Note:*

- The relationship between field strength [dBuV/m] and EIRP [dBm]:
  - EIRP = E + 20log d –104.8 = Conducted Power + Antenna Gain
- where
  - EIRP is the equivalent isotropically radiated power, in dBm
  - E is the field strength of the emission at the measurement distance, in dBµV/m
  - d is the measurement distance, in m

CE Requirements

No.	Test Items	Requirement	Channel for Testing	EUT Status
1	RF Output Power	EIRP ≤ 20 dBm	Low/Mid/High	Continuous transmit mode
2	Power Spectral Density	≤ 10 dBm/MHz	Low/Mid/High	Continuous transmit mode
2	Occupied Channel Bandwidth (similar as band edge)	99% power BW fall within 2.4 – 2.4835 GHz completely	Low/High	Continuous transmit mode
3	Unwanted Emissions in out-of-band domain	-10 dBc at 2399 or 2484.5 MHz -20 dBc at 2398 or 2485.5 MHz	Low/High	Continuous transmit mode
4	Unwanted Emissions in spurious domain	See table on next two pages	Low/High	Continuous transmit mode
5	Receiver Spurious Emissions		Low/High	Receiver mode
6	Receiver Blocking		Low/High	Receiver mode

Transmitter Spurious Emissions

Frequency Range	Maximum Power (dBm)	Measurement BW	Detector
30 – 47 MHz	-36	100 kHz	Peak
47 – 74 MHz	-54		
74 – 87.5 MHz	-36		
87.5 – 118 MHz	-54		
118 – 174 MHz	-36		
174 – 230 MHz	-54		
230 – 470 MHz	-36		
470 – 862 MHz	-54		
862 – 1000 MHz	-36		
1 – 12.75 GHz	-30	1MHz	

Receiver Measurement

- Receiver Spurious Emissions

Frequency Range	Emission Limits (dBm)	Measurement BW	Detector
30 – 1000 MHz	-57	100 kHz	Peak
1 – 12.75 GHz	-47	1 MHz	

- Receiver Blocking Parameters (2 vector signal generators required)

Wanted signal mean power (dBm)	Blocking signal frequency (MHz)	Blocking signal power (dBm)	PER Limit	Blocking signal type
Pmin + 6 dB	2380	-57	10%	Continuous Wave
	2503.5			
Pmin + 6 dB	2300	-47		
	2583.5			

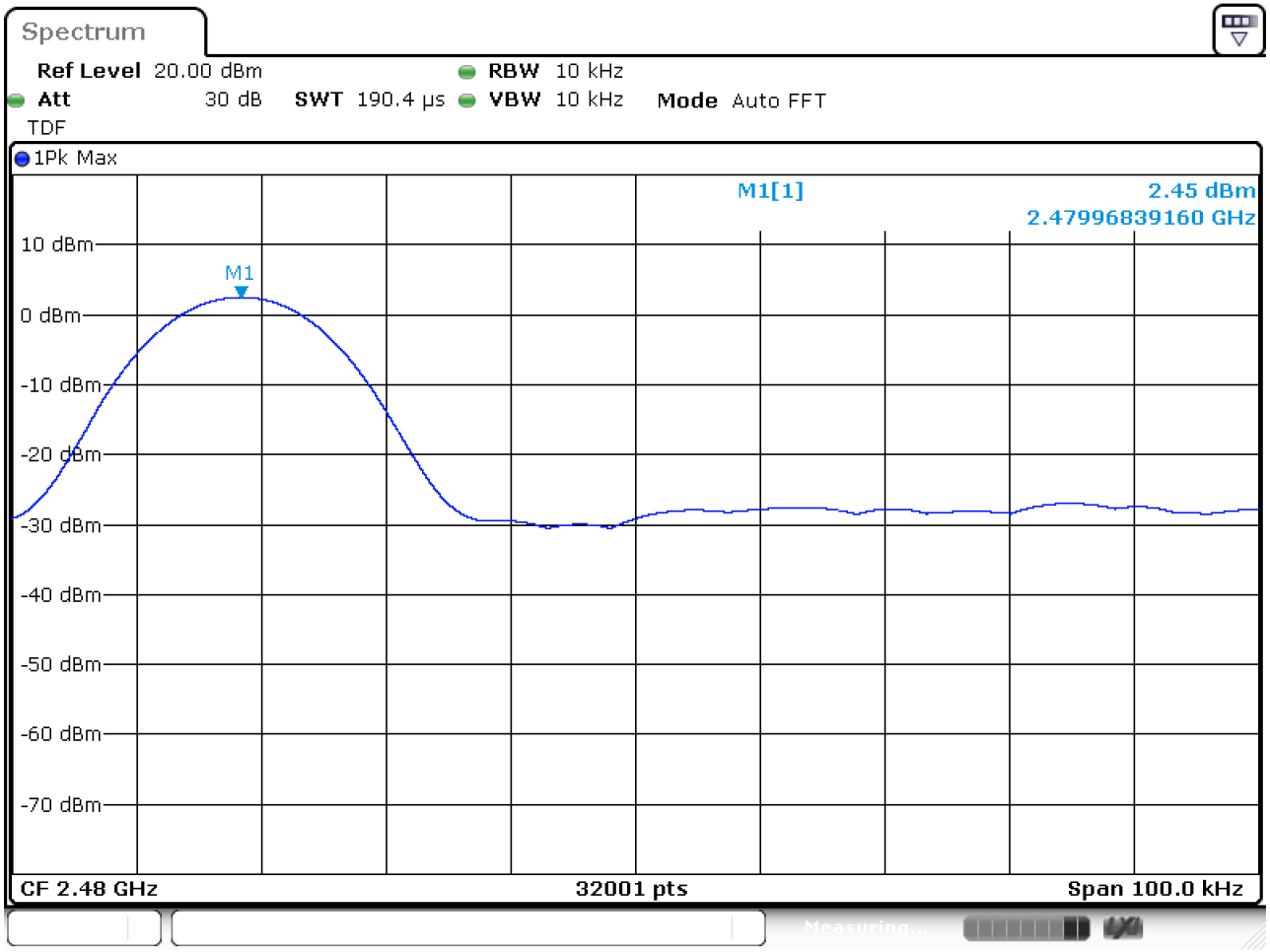
- Note: Pmin is the minimum level of the wanted signal power (in dBm) at PER less than or equal to 10%.

Table of Contents

Precautions

- Proper impedance matching between chip and antenna is necessary for decreasing mismatch loss.
- If possible, shield box is recommended for placing EUT to eliminate uncertain coupling interference.
- The conducted RF path loss between EUT and tester must be set appropriately to acquire more meaningful data.
- All RF measurement instruments shall be calibrated every 1 year or less to guarantee testing accuracy.

Example–CW Frequency Tolerance



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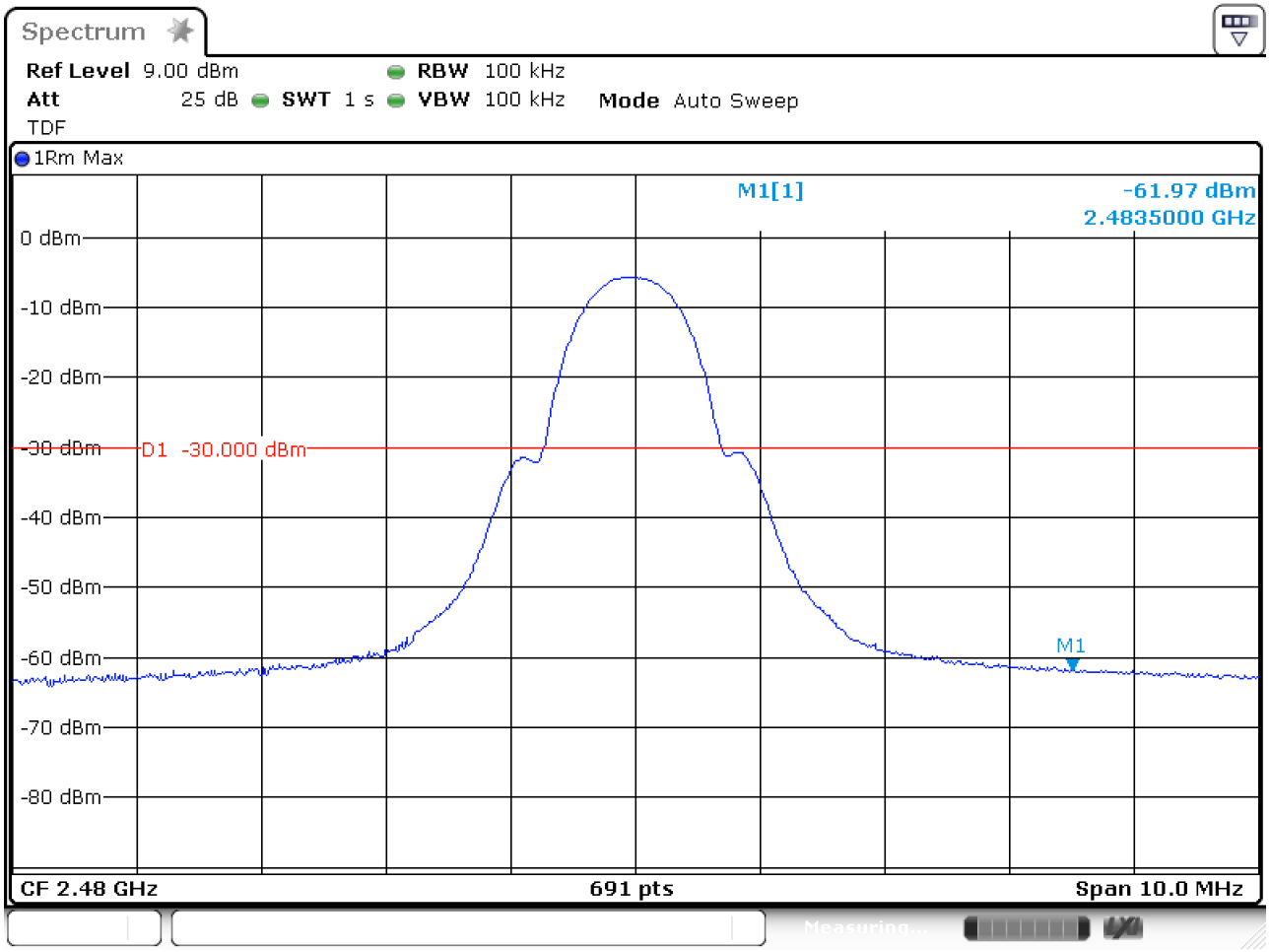
Example–Band Edge Emission



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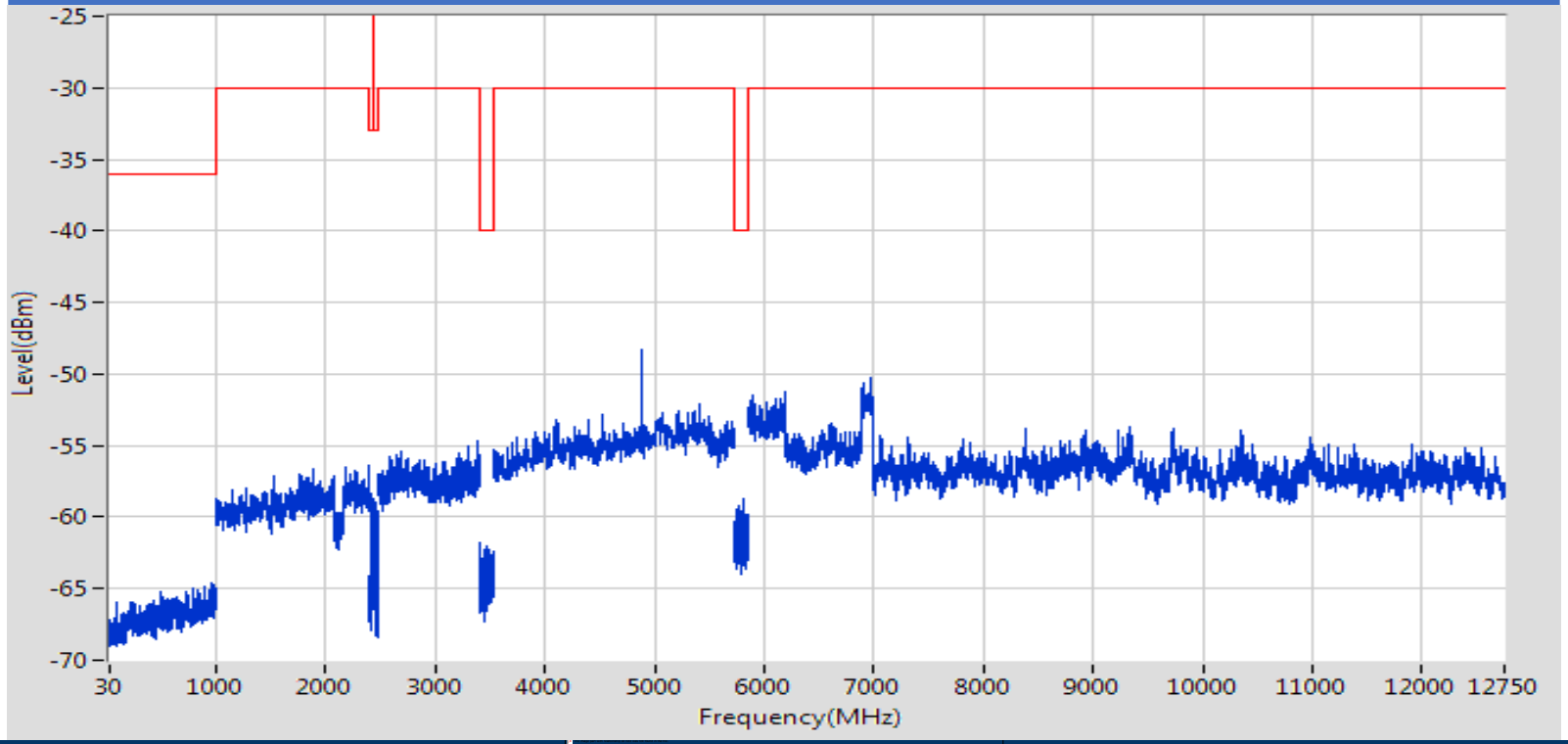
Example–Spurious Emissions

Start Frequency (MHz)	Stop Frequency (MHz)	RBW (MHz)	Detector	Frequency (MHz)	Power (dBm)	Limit (dBm)	Verdict	Sweep Point
30	1000	0.1	Peak	953.609	-64.56	-36	Pass	691
1000	2400	1	Peak	2400	-56.42	-30	Pass	691
2400	2435	0.1	Peak	2408.217	-58.36	-33	Pass	691
2445	2483.5	0.1	Peak	2445.112	-58.73	-33	Pass	691
2483.5	3400	1	Peak	3389.374	-54.69	-30	Pass	691
3400	3530	1	Peak	3408.478	-61.8	-40	Pass	691
3530	5725	1	Peak	4881.993	-48.36	-30	Pass	691
5725	5850	1	Peak	5811.775	-58.73	-40	Pass	691
5850	12750	1	Peak	6974.7	-50.27	-30	Pass	4001



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Thanks and best regards.