GigaDevice Semiconductor Inc.

GD32VW553 RF Calibration Flow

Application Note
AN147

Revision 1.2

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1. Introduction

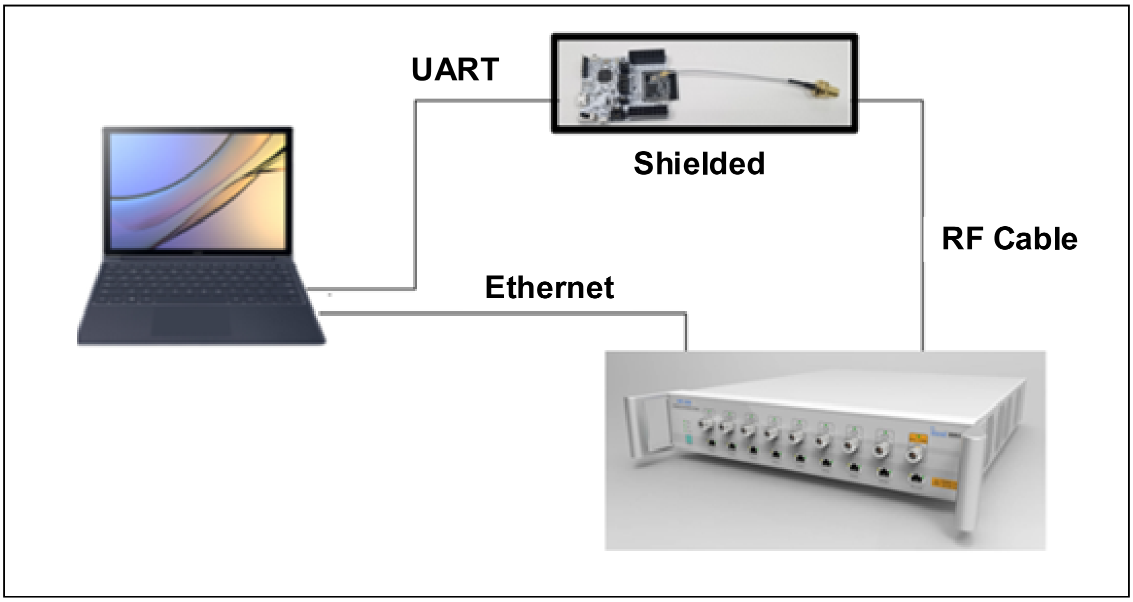
This document is mainly used to give instructions to clients on production line RF calibration and testing of PCB of GD32VW553 series. Chapter 2 introduces methods of building a test environment. Chapter 3 introduces preparation before tests. Chapter 4 gives instructions on chip Efuse. Chapter 5 introduces test procedures and detailed test steps. Chapter 6 is version history.

2. Test Environment

RF calibration test environment of GD32VW553 series is:

Upper computer (Host) is connected to a wireless test instrument (RF Tester, like iTest WT328 from Itenest) by a network cable, meanwhile is connected to DUT (GD32VW553 PCB board) through a serial port, and controls DUT by using CMD line through the serial port. The RF port of DUT is connected to RF Tester using an RF cable. DUT must be placed in the shielded environment, as shown in ***Figure 2-1. Test environment***.

Figure 2-1. Test environment



3. Test preparation

3.1. Software and Hardware Configuration

Before RF calibration, confirm the following configurations:

- Firmware version: "image-all-rf-test.bin"
- Power supply capacity: 3.3 V, at least 500 mA
- Communication method: serial port communication by connecting to GD32VW553 serial port (the default firmware is GPIO_PA6 & GPIO_PA7, but it can also be changed according to actual requirements).
- Boot configuration: pull down BOOT0; pull up PU and NRST
- Test environment: shielded environment at room temperature

3.2. Description on Summary of Serial Port Commands

Following is the summary of serial port commands involved in the document and their description. Settings of the following commands (except **rf_efuse <operation> [item] [size][value]**) are not saved after power-down. In the command format, <> means mandatory, [] means optional. The value is 0 by default if an optional parameter is not filled in. Usage of commands will be introduced in ***Test Flow*** in details.

rf_mp_mode <mode>

Set MP test mode of the chip, in a range of 0 to 3. Generally, select mode 1 for RF calibration and test of the production line.

<mode>: MP mode selection, 0: normal mode (non-MP mode); 1: MP test mode (required in this document); 2: rf normal test mode; 3: rf temp test mode

wifi_set_mp_targetpwr <para1> <para2> <para3>

Set the target power in decimal for power calibration. Detailed description is shown in ***Table 3-1. CMD wifi_set_mp_targetpwr parameter description***.

<para1>: 11B 11M target power

<para2>: 11AX MCS7 target power

<para3>: 11G 54M and 11AX MCS7 target power difference

Table 3-1. CMD wifi_set_mp_targetpwr parameter description

<Para> Parameters	**para1**	**para2**	**para3**
Parameter Meaning	11B 11M target power	11AX SU MCS7 target power	11G 54M and 11AX MCS7 target power difference
Recommended Value	**17 dBm**	**14 dBm**	**1 dB**

Maximum Value	20 dBm	15 dBm	2 dB
Minimum Value	13 dBm	10 dBm	0 dB
Step	0.5 dB	0.5 dB	0.5 dB

wifi_set_ch <channel>

Set WiFi channel in in decimal.

<channel>: channel value in a range of 1 to 14;

wifi_tx_duty <percentage> <rate> [add_power]

The chip starts to execute non-signal packet Tx. It will continue to execute Tx until it receives the wifi_tx_stop command.

<percentage>: tx duty cycle (%). Only 10% is supported at present.

<rate>: rate value of Tx in hexadecimal. Details are shown in ***Table 3-2. CMD wifi_tx_duty <rate> parameter description***.

[add_power]: power adjustment value in decimal in a range of -16.0 dB to 16.0 dB，with a step of 0.25 dB. This value should be empty or set to the default value of 0 during the power calibration.

Table 3-2. CMD wifi_tx_duty <rate> parameter description

11B Rate		11G Rate		11N Rate		11AX SU Rate	
1M	0x0	6M	0x4	MCS0	0x200	MCS0	0x500
2M	0x1	9M	0x5	MCS1	0x201	MCS1	0x501
5.5M	0x2	12M	0x6	MCS2	0x202	MCS2	0x502
11M	0x3	18M	0x7	MCS3	0x203	MCS3	0x503
		24M	0x8	MCS4	0x204	MCS4	0x504
		36M	0x9	MCS5	0x205	MCS5	0x505
		48M	0xa	MCS6	0x206	MCS6	0x506
		54M	0xb	MCS7	0x207	MCS7	0x507
						MCS8	0x508
						MCS9	0x509

rf_set_crystal_cap <tune>

Modify the hexadecimal capacitance of the load capacitor in the chip corresponding to the external crystal (40 MHz by default).

<tune>: Adjust the hexadecimal capacitance of the load capacitor in the chip in a range of 0x0 ~ 0x3F & 0x40 ~ 0x7F (0 ~ 63 & -64 ~ -1), with a step of 1. By using this definition, the valid value is only 7-bit. When finally writing efuse, it should be supplemented to 8-bit, but the highest bit makes no sense. In this case, the constant “0” is recommended to be written.

0x00 ~ 0x3F (0 ~ 63): As the capacitance gradually increases, the frequency offset gradually goes in the negative direction.

0x7F ~ 0x40 (-1 ~ -64): As the capacitance gradually decreases, the frequency offset gradually goes in the positive direction.

wifi_tx_stop

Stop WiFi Tx

wifi_set_mp_pcom <para1> <para2> <para3> <para4> <para5> <para6>

Temporarily save the WiFi power calibration value in decimal to the chip.

<para1>: Not enabled, recommend to use same value of <para4>

<para2>: Not enabled, recommend to use same value of <para5>

<para3>: Not enabled, recommend to use same value of <para6>

<para4>: 11AX MCS7 Channel1 power offset compensation value

<para5>: 11 AX MCS7 Channel7 power offset compensation value

<para6>: 11 AX MCS7 Channel13 power offset compensation value

Range: -4 dB to 4 dB; step: 0.25 dB

wifi_reset_trxc

Reset WiFi T/Rx counter

wifi_phy_rxc

View the return value of WiFi Rx (packets received) counter.

Such as printed return value: FCS OK: 0x000003df, ERR: 0x00000021, RX END: 0x00000400", only pay attention to FCS OK (decimal). 0x000003df means Rx successfully received 991 packets.

ble_test_tx <channel> <data length> <pkt payload> <phy> <tx power level>

Conduct BLE Tx. It will continue to execute Tx until it receives the ble_test_stop command.

<channel>: channel of BLE Tx, in hexadecimal system

<data length>: length of packet, in hexadecimal system, in units of bytes. During the power calibration, it is recommended to use 37 bytes, namely 0x25

<pkt payload>: payload type in hexadecimal. During the power calibration, it is recommended to use PRBS9, namely 0x0.

<phy>: BLE Tx rate in hexadecimal. During the power calibration, it is recommended to use 1M, namely 0x1.

<tx power level>: BLE Tx target power in hexadecimal. During the power calibration, it is recommended to use 0 dBm, namely 0x0.

Definition of parameters are shown in ***Table 3-3. CMD ble_test_tx parameter description***.

Table 3-3. CMD ble_test_tx parameter description

Parameter Name	Value and Meaning
channel	0x0-0x27=ch0-39
data length	0x0-0xFF=0B-255B
pkt payload	0x00/01/02/03/04/05/06/07=PRBS9/0xF0F0/0xAAAA /PRBS15/0xFFFF/0x0000/0x0F0F/0x5555
phy	0x01/02/03/04 = 1M/2M/Coded S=8/ Coded S=2
tx power level	0x7E/7F=min/max, 0x00=0dbm/ 0xFF=-1dbm...

ble_set_mp_pcom <offset value>

Temporarily save the BLE power calibration value in decimal to the chip

Range: -4 dB to 4 dB; step: 0.25 dB

ble_test_rx <channel> <phy> <modulation idx>

Start the BLE Rx test. It will continue to execute Rx until it receives the **ble_test_stop** command.

All parameters are hexadecimal. For detailed parameter meanings, please refer to ***Table 3-4. CMD ble_test_rx parameter description***.

Table 3-4. CMD ble_test_rx parameter description

Parameter Name	Value and Meaning
channel	0x0-0x27=ch0-39
phy	0x01/02/03 = 1M/2M/Coded
modulation idx	0x00/01=standard/ stable modulation index

ble_test_stop

Stop the BLE Tx or Rx test. If BLE Rx is stopped, then obtain the number of received packets of BLE Rx in hexadecimal.

rf_efuse <operation> [item] [size] [value]

Perform operation on chip efuse.

<operation>: show/read/write/check_bytes/total_space/available_space

[item]: the type of item, 1, 2, 4, 6, 7, 8

1: AX20 & BLE power offset;

2: power level control;

4: freq tuning;

6: WiFi MAC address low;

7: MAC address high;

8: BLE MAC address low.

[size]: the size to rf efuse item, 1- 4

[value]: the hex value to set

4. Efuse Description

Efuse is mainly used to save some necessary parameters set before RF calibration and calibration values obtained after calibration. In case of chip power-down, efuse data will not be lost and can be enabled when the chip is powered on again. Efuse map can be viewed with CMD ***rf_efuse show***. For complete map, please see ***Table 4-1. Efuse Map***. Default value of all bytes is 0x00.

Table 4-1. Efuse Map

Efuse Address	Byte0	Byte1	Byte2	Byte3
0x00	0x00	0x00	0x00	0x00
0x10	0x00	0x00	0x00	0x00
0x20	0x00	0x00	0x00	0x00
0x30	0x00	0x00	0x00	0x00
0x40	0x00	0x00	0x00	0x00
0x50	0x00	0x00	0x00	0x00
0x60	0x00	0x00	0x00	0x00
0x70	0x00	0x00	0x00	0x00
0x80	0x00	0x00	0x00	0x00
Defined by calibration				
Defined by user, before calibration				
Defined by user, before efuse writing				
Not Defined				

In ***Table 4-1. Efuse Map***, the contents highlighted in red can only be determined after actual calibration. The contents highlighted in green should be worked out by users before calibration according to their actual needs and may influence the calibration results. The contents highlighted in yellow should be determined by users before they write Efuse. The contents highlighted in gray are not defined yet.

Table 4-2. Efuse definition shows the description of items and their default value meanings in Efuse.

Table 4-2. Efuse definition

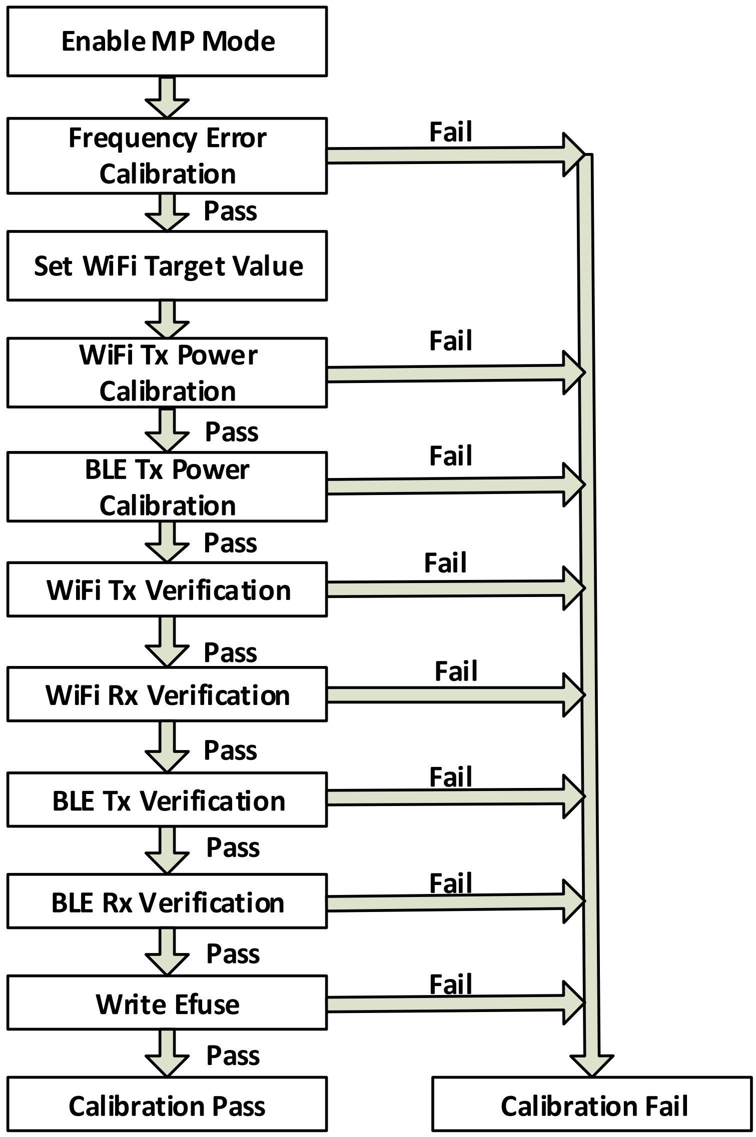
Item Name	Efuse Location	Description	Default Value	Meaning of Default Value	Determination Time
11AX Offset_ BasedOnTargetPower	0x10- 12	Compensate the difference between the measured power and target power in low, medium and high channels of 11AX SU MCS7.	0x00	0dB	After calibration

BLE Offset_ BasedOnTargetPower	0x13	Compensate the difference between the measured power and target power in BLE channel19 (2,440 MHz).	0x00	0dB	After calibration
TargetPower_1	0x20 [7:4]	Set the 11B 11M target power	0x00	17dBm	Before calibration
	0x20 [3:0]	Set the 11AX SU MCS7 target power	0x00	14dBm	Before calibration
TargetPower_2	0x21 [7:4]	Set the 11G 54M and 11AX SU MCS7 target power difference	0x00	1dB	Before calibration
TXPowerLimit_byMode	0x22 [7:4]	Limit the 11B maximum power value	0x00	18dBm	Before writing Efuse
	0x22 [3:0]	Limit the 11G/ N/ AX maximum power value	0x00	18dBm	Before writing Efuse
TargetPower_3	0x23 [7:4]	Set the BLE target power	0x00	0dBm	Before calibration
	0x23 [3:0]	Set the BLE maximum power	0x00	8dBm	Before writing Efuse
FreqTuning	0x40	Calibrate the capacitance in the chip used to adjust the crystal frequency offset.	0x00	0	After calibration
MAC_Address	0x60- 62- 72- 82	MAC address	0x00	/	Before writing Efuse

5. Test Flow

The flow chart of the GD32VW553 RF calibration test is as shown in ***Figure 5-1. RF calibration flow***:

Figure 5-1. RF calibration flow



Description of steps:

- Enable MP Mode: Enter the MP mode
- Frequency Error Calibration: Calibrate the frequency offset of the chip, usually through WiFi Tx.
- Set WiFi Target Value: Set WiFi target power in different rates for calibration.
- WiFi Tx Power Calibration: Calibrate the WiFi Tx power in three channels, so three parameters in total.
- BLE Tx Power Calibration: Calibrate the BLE Tx power.

- WiFi Tx Verification: After the WiFi Tx frequency offset and power are calibrated as mentioned above, conduct complete verification on WiFi Tx performance.
- WiFi Rx Verification: Verify WiFi Rx PER performance.
- BLE Tx Verification: After the BLE Tx power is calibrated as mentioned above, conduct complete verification on BLE Tx performance.
- BLE Rx Verification: Verify BLE Rx PER performance.
- Write Efuse: When all above items pass, write the calibration values to the chip's Efuse.

5.1. Enable MP Mode

After DUT is started normally, entering the MP (Mass Production) mode before related calibration tests is needed， which can be achieved with CMD ***rf_mp_mode.***

- CMD example:
  - ***rf_mp_mode 1*** //Enter the RF calibration mode

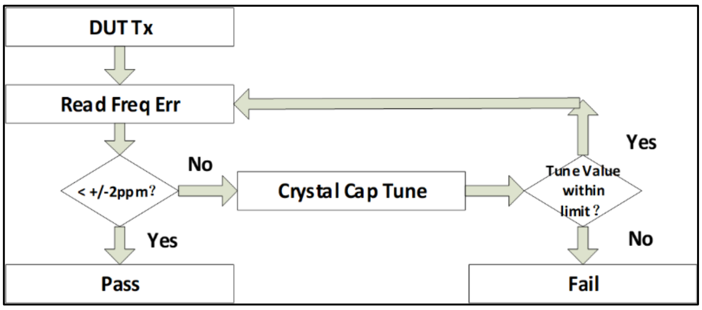
5.2. Frequency Error Calibration

The frequency error of DUT Tx must be calibrated firstly during the production line calibration.

5.2.1. Flow Chart

The frequency error calibration flow chart is as shown in ***Figure 5-2. Frequency error calibration flow***:

Figure 5-2. Frequency error calibration flow



5.2.2. Detailed Flow

1. In MCS7 Channel7, execute DUT Tx with CMD ***wifi_set_ch*** and ***wifi_tx_tudy***.

- CMD example:
  - ***wifi_set_ch 7*** // Set channel to 7
  - ***wifi_tx_duty 10 0x507***
    //Duty cycle = 10%, rate = 11AX MCS7, use the default power (For non-calibrated chips, only the default power can be used), and conduct Tx

2. The tester works as VSA in the corresponding channel. Check the DUT Tx frequency error.
3. Adjust the DUT Tx frequency error with CMD ***rf_set_crystal_cap*** until it meets the requirements

■ CMD example:
  - ***rf_set_crystal_cap 0x3*** //Increase the capacitance by three steps based on the default value
  - ***rf_set_crystal_cap 0x7C*** //Decrease the capacitance by four steps based on the default value

■ If the frequency error is positive --> increase the tune value —> the capacitance value increases -> The frequency error moves in the negative direction until it is close to the target; vice versa.

■ Tune calculation formula:

  tune = Freq_err_current / step, step ≈ 1.3 kHz per step

■ End target:

  Freq_err_current ≤ +/-5 kHz or 2 ppm

4. When the target is met, DUT stops Tx with CMD ***wifi_tx_stop***.

■ CMD example:
  - ***wifi_tx_stop***

5. Record the final tune value. (Note: This value is 7-bit valid data. bit7 is recommended to be the constant 0. A negative number is expressed by a complement.) Save this value to Efuse 0x40, as described in ***Write Efuse***. For detailed definitions, please see ***Table 5-1. FreqTuning definition***.

Table 5-1. FreqTuning definition

Efuse 0x40			Internal Capacity value
Bit[7:6]	Bit[5:0]	Hex	
00	111111	0x3F	Capacity increases linearly (frequency error moves in negative direction)
…			
00	000001	0x01	
00	**000000**	**0x00**	Capacity value is at the middle position.
01	111111	0x7F	Capacity decreases linearly (frequency error moves in positive direction)
…			
01	000000	0x40	

■ The items in **bold** in the table are default values. The same as below.

5.3. Set WiFi Target Value

Before RF calibration, confirm target power of each mode (highlighted in green in ***Efuse Description***). Definition of power and its range are shown in ***Table 5-2. Description of setting the WiFi target power.*** Target power can be transmitted to DUT with CMD ***wifi_set_mp_targetpwr***. Finally, save this value to Efuse 0x20 and 0x21, as described in

Write Efuse.

- CMD example:
  - ***wifi_set_mp_targetpwr 17 13.5 0.5***

  //Set target power 11B 11M to 17dBm; 11AX SU MCS7 to 13.5dBm; 11G 54M to 13.5+0.5=14dBm. These are only examples. It is recommended to set the three parameters to 17, 14 and 1 respectively.
- Target power can be set by the users, but should be within the range.

Table 5-2. Description of setting the WiFi target power

<table>
<tr><th>Para NO.</th><th>Efuse Location</th><th>Description of Item</th><th>Bit Value</th><th>Power Level</th></tr>
<tr><td rowspan="9">1</td><td rowspan="9">0x20 [7:4]</td><td rowspan="9">11B 11M target power (dBm)</td><td>0110</td><td>20</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>0010</td><td>18</td></tr>
<tr><td>0001</td><td>17.5</td></tr>
<tr><td>0000</td><td>17</td></tr>
<tr><td>1111</td><td>16.5</td></tr>
<tr><td>1110</td><td>16</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>1000</td><td>13</td></tr>
<tr><td rowspan="7">2</td><td rowspan="7">0x20 [3:0]</td><td rowspan="7">11AX SU MCS7 target power (dBm)</td><td>0010</td><td>15</td></tr>
<tr><td>0001</td><td>14.5</td></tr>
<tr><td>0000</td><td>14</td></tr>
<tr><td>1111</td><td>13.5</td></tr>
<tr><td>1110</td><td>13</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>1000</td><td>10</td></tr>
<tr><td rowspan="5">3</td><td rowspan="5">0x21 [7:4]</td><td rowspan="5">Difference in target power between 11G 54M and 11AX SU MCS7 (dB)</td><td>0010</td><td>2</td></tr>
<tr><td>0001</td><td>1.5</td></tr>
<tr><td>0000</td><td>1</td></tr>
<tr><td>1111</td><td>0.5</td></tr>
<tr><td>1110</td><td>0</td></tr>
</table>

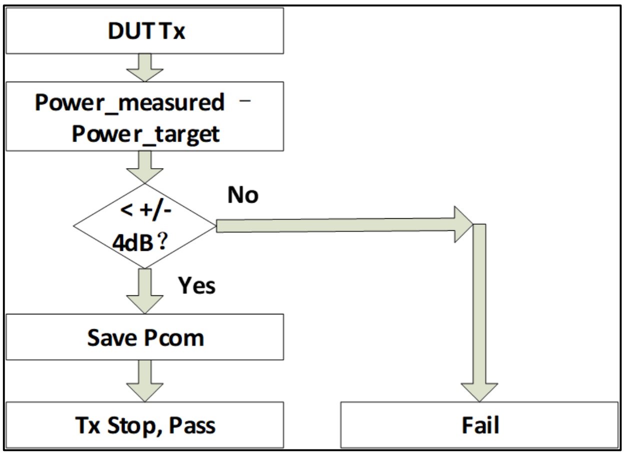
5.4. WiFi Tx Power Calibration

Due to differences in PCB manufacture, SMT manufacture and components themselves, initial WiFi Tx power of each PCB may vary and the power of different channels may vary as well, so WiFi Tx power must be calibrated for higher consistency of PCB board.

5.4.1. Flow Chart

WiFi Tx power calibration flow chart is as shown in *Figure 5-3. Tx power calibration flow*:

Figure 5-3. Tx power calibration flow



5.4.2. Detailed Flow

1. Based on the target power set as specified in ***Set WiFi Target Value***, three specific channels are set at DUT. There is a total of 3 parameters to be calibrated as follows:

- Channel to be calibrated = 1/7/13
- Rate to be calibrated = 11AX MSC7
- There are 3 parameters to be calibrated in total: 11AX MCS7 Channel1, 11AX MCS7 Channel7, and 11AX MCS7 Channel13

2. DUT conducts packet Tx in a specific channel and rate with CMD ***wifi_set_ch*** and ***wifi_tx_duty***.

- CMD example:
  - ***wifi_set_ch 7*** // Set channel to 7
  - ***wifi_tx_duty 10 0x507***
    // Set the duty cycle to 10% and the rate to 11AX MCS7. The third parameter [add power] must be 0, which indicates using the default power. Therefore, here the parameter will use default value 0 instead of being set to other values.

3. The RF tester as VSA receives packets at a specific channel and rate. When the actual power value is obtained, DUT stops Tx with CMD ***wifi_tx_stop***.
4. Record the difference between the measured power and the target power in ***Set WiFi Target Value*** (Power Offset). When the difference is within +/-4.125 dB, obtain the corresponding power compensation value Pcom according to ***Table 5-3. Relationship between WiFi calibration power offset and power compensation value***. If the difference is over +/-4.125dB, the test fails.

Table 5-3. Relationship between WiFi calibration power offset and power compensation value

Power Offset		Pcom	Efuse 0x00-02 & 0x10-12		
Lower Limit	Upper Limit		Bit[7]	Bit[6:0]	Dec
-4.125	-3.875	4	0	0100000	32
-3.875	-3.625	3.75	0	0011110	30

				…	
-0.875	-0.625	0.75	0	0000110	6
-0.625	-0.375	0.5	0	0000100	4
-0.375	-0.125	0.25	0	0000010	2
-0.125	**0.125**	**0**	**0**	**0000000**	**0**
0.125	0.375	-0.25	1	1111110	-2
0.375	0.625	-0.5	1	1111100	-4
-0.126	0.875	-0.75	1	1111010	-6
				…	
3.625	3.875	-3.75	1	1100010	-30
3.875	4.125	-4	1	1100000	-32

5. Temporarily save Pcom to the chip for subsequent verification with CMD ***wifi_set_mp_pcom***. Finally save it to Efuse 0x10-0x12, as described in ***Write Efuse***.

- Power Offset = Measured_Power – Target_Power
- Pcom is the actual compensated power.
- Compensation precision is 0.25 dB.
- For example, actual measured value of 11AX ch1 power is 13.2 dbm. Target power is 14 dbm. Therefore, the difference is 13.2 - 14 = -0.8 dB. With reference to the table, the compensated power Pcom = 0.75 dB.
- For the specific correspondence of 3 parameters to be calibrated and Efuse location, please see ***Table 5-4. CMD wifi_set_mp_pcom parameter description***.
- CMD example:
  - ***wifi_set_mp_pcom 0 -1.25 -1.75 0 -1.25 -1.75***
    // Set 11AX_MCS7 power compensation at low, medium and high channels to 0dB, -1.25 dB and -1.75 dB respectively. (Only last three items are defined)

Table 5-4. CMD wifi_set_mp_pcom parameter description

Pcom Parameter	Efuse Location	Channel	Rate
para1(**Not enabled, recommend to use same value of <para4>**)	/	/	/
para2(**Not enabled, recommend to use same value of <para5>**)	/	/	/
para3(**Not enabled, recommend to use same value of <para6>**)	/	/	/
para4	0x10	1	11AX MCS7
para5	0x11	7	11AX MCS7
para6	0x12	13	11AX MCS7

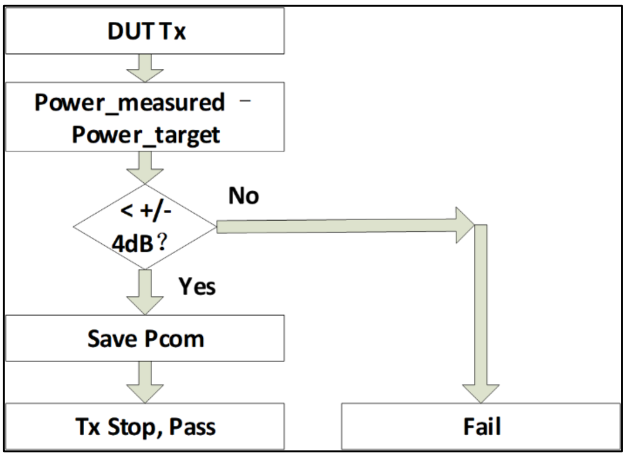
5.5. BLE Tx Power Calibration

Similar to WiFi, BLE also requires Tx Power calibration.

5.5.1. Flow Chart

BLE Tx power calibration flow chart is as shown in ***Figure 5-4. BLE Tx power calibration flow***:

Figure 5-4. BLE Tx power calibration flow



5.5.2. Detailed Flow

1. Firstly confirm Target Power and Max Power of BLE, and use Target Power as the calibration power value, as well as verification power value in the subsequent ***BLE Tx Verification***. According to Efuse definitions, Target Power of BLE is 0 dBm by default with a range of -24 to15 dBm. There are 16 optional values in total, as shown in ***Table 5-5. BLE target power***. Default Max Power of BLE is 8 dBm with a range of -12 to 15 dBm. There are 7 optional values in total, as shown in ***Table 5-6. BLE max power***.

Table 5-5. BLE target power

Efuse0x23	Power Level (dBm)
Bit[7:4]	**BLE Target Power**
0111	15
0110	12
0101	10
…	…
0010	4
0001	2
0000	**0**
1111	-3
1110	-6
…	…
1001	-21
1000	-24

Table 5-6. BLE max power

Efuse0x23	Power Level (dBm)
Bit[3:0]	**BLE Max Power Limit**
0010	15
0001	12
0000	**8**
1111	4
1110	0
1101	-6
1100	-12

2. Use CMD ***ble_test_tx*** for BLE Tx test

- CMD example:
  - ***ble_test_tx 0x13 0x25 0x0 0x1 0x0***

    //Channel = 0x13 (recommended value) = 19 (2,440 MHz); it is recommended to use the middle channel19 (2,440 MHz) during the power calibration

    //Data length = 37 bytes (recommended value)

    //Payload = PRBS9 (recommended value)

    //Rate = 1M (recommended value)

    //Target Power =0 dBm (recommended value); range: -24 to 15 dBm (according to Efuse definitions)

3. The RF tester as VSA receives packets at a specific channel. When the actual power value is obtained, DUT stops Tx with CMD ***ble_test_stop***

- CMD example:
  - ***ble_test_stop***

4. Record the difference (Power Offset) between the measured power and the <target power> in CMD ***ble_test_tx***. When the difference is within +/-4.125 dB, obtain the corresponding power compensation value Ble Pcom according to ***Table 5-7. Relationship between BLE calibration power and power compensation value***. If the difference is over +/-4.125 dB, the test fails.

Table 5-7. Relationship between BLE calibration power and power compensation value

BLE Power Offset		BLE Pcom	Efuse 0x13		
Lower Limit	**Upper Limit**		**Bit[7]**	**bit[6:0]**	**Dec**
-4.125	-3.875	4	0	0100000	32
-3.875	-3.625	3.75	0	0011110	30
				…	
-0.875	-0.625	0.75	0	0000110	6
-0.625	-0.375	0.5	0	0000100	4
-0.375	-0.125	0.25	0	0000010	2
-0.125	**0.125**	**0**	**0**	**0000000**	**0**
0.125	0.375	-0.25	1	1111110	-2
0.375	0.625	-0.5	1	1111100	-4

-0.126	0.875	-0.75	1	1111010	-6
				…	
3.625	3.875	-3.75	1	1100010	-30
3.875	4.125	-4	1	1100000	-32

5. Temporarily save Pcom to the chip for subsequent verification with CMD ***ble_set_mp_pcom***. Finally, save it to Efuse 0x23, as described in ***Write Efuse***.

- Power Offset = Measured_Power – Target_Power
- Pcom is the actual compensated power.
- Compensation precision is 0.25 dB.
- For example, actual measured value of BLE Tx power is 0.6 dbm. Target power is 0 dbm. Therefore, the difference is 0.6 - 0 = 0.6 dB. With reference to the table, the compensated power Pcom = -0.5 dB.
- CMD example:
  - ***ble_set_mp_pcom -0.5***
    // Set BLE power compensation to -0.5 dB

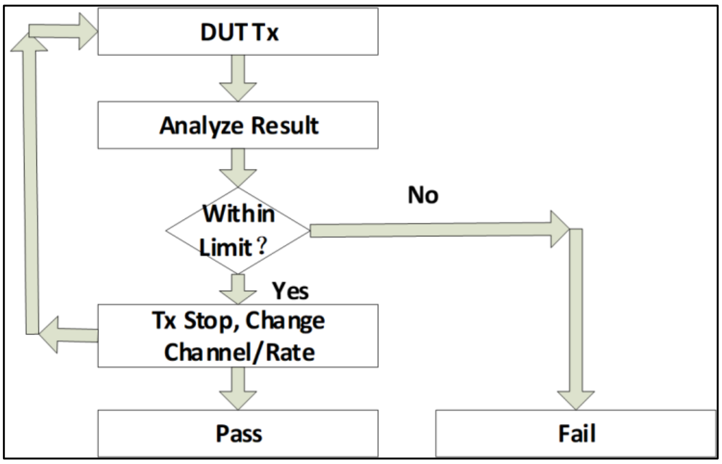
5.6. WiFi Tx Verification

After WiFi Tx power calibration, conduct more comprehensive verification on the calibrated Tx performance.

5.6.1. Flow Chart

WiFi Tx verification flow chart is as shown in ***Figure 5-5. WiFi Tx verification flow***:

Figure 5-5. WiFi Tx verification flow



5.6.2. Detailed Flow

1. A specific channel is set at DUT and DUT conducts Tx with CMD ***wifi_set_ch*** and

wifi_tx_duty.

- Channel can be selected by users and the range of 1-14 is supported.
- In terms of rate, it is recommended to use the maximum rate for each mode, namely 11B 11M, 11G 54M, 11N MCS7, and 11AX MCS9, 4 rates in total.
- Usually, only one channel needs to be tested for each rate. Recommended combination of channel and rate is as shown in ***Table 5-8. Recommended Specifications for WiFi Tx verification***.
- Users can also modify all Pass Criterion.

2. RF tester receives packets in the corresponding channel and rate and analyzes and judges the test result.
3. DUT stops Tx with CMD ***wifi_tx_stop***.

5.6.3. Test Items and Test Specifications

After the RF tester receives packets, it is recommended to judge according to ***Table 5-8. Recommended Specifications for WiFi Tx verification***.

Table 5-8. Recommended Specifications for WiFi Tx verification

Rate	Channel	Results from Tester	Pass Criterion
11B 11M	1	Power	Target+/-2db
		EVM	<10%
		Freq error	<±20ppm
		LO Leakage	<-20dbc
		MASK	Passed
11G 54M	4	Power	Target+/-2db
		EVM	<-26db
		Freq error	<±20ppm
		LO Leakage	<-20dbc
		MASK	Passed
11N MCS7	13	Power	Target+/-2db
		EVM	<-28db
		Freq error	<±20ppm
		LO Leakage	<-20dbc
		MASK	Passed
11AX MCS9	9	Power	Target+/-2db
		EVM	<-33db
		Freq error	<±20ppm
		LO Leakage	<-20dbc
		MASK	Passed

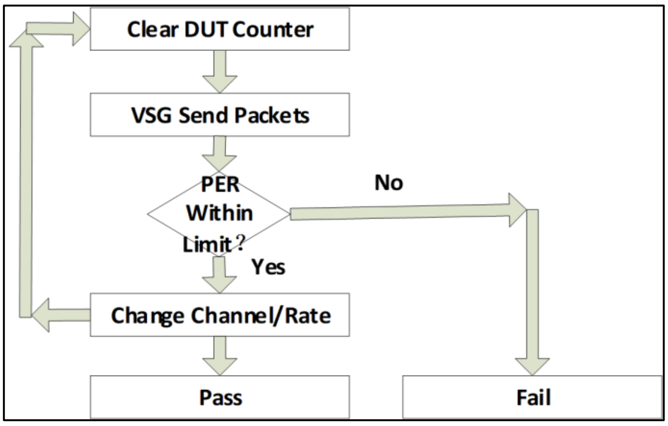
5.7. WiFi Rx Verification

After WiFi Rx verification, verify WiFi Rx PER performance of DUT.

5.7.1. Flow Chart

WiFi Rx verification flow chart is as shown in ***Figure 5-6. WiFi Rx verification flow***:

Figure 5-6. WiFi Rx verification flow



5.7.2. Detailed Flow

1. Ensure that the environment where DUT is placed in a **shielded environment.** Set the channel and clear the Rx counter with CMD ***wifi_set_ch*** and ***wifi_reset_trxc.***

- Channel can be selected by users and the range of 1-14 is supported.
- CMD example:
  - ***wifi_set_ch 3*** ***// Set channel to 3***
  - ***wifi_reset_trxc*** ***//Clear the counter***
- Rate can be selected by users. It is recommended to use the maximum rate for each mode, namely 11B 11M, 11G 54M, 11N MCS7, or 11AX MCS9.
- Usually, only one channel needs to be tested for each rate. Recommended combination of channel and rate is as shown in ***Table 5-9. Recommended Specifications for WiFi Rx verification***.

2. The RF tester as VSG sends a fixed number of packets (usually 1,000) at the corresponding channel and rate, according to the input power of following table (sensitivity+6 dB). The recommended length of packet is 1,024 bytes.
3. After the RF tester finishes sending packets, check the return value of the counter and calculate PER.

- CMD example:
  - ***wifi_phy_rxc***

    // View the return value of the phy counter, such as printed return value: "FCS OK:

0x000003df, ERR: 0x00000021, RX END: 0x00000400". Pay attention to only FCS OK. 0x000003df means RX OK = 991. The process is passed as PER = (1000 – 991)/1000 = 0.9%.

5.7.3. Test Items and Test Specifications

The recommended power settings and specifications at the RF tester during the Rx verification are as shown in ***Table 5-9. Recommended Specifications for WiFi Rx verification***:

Table 5-9. Recommended Specifications for WiFi Rx verification

Rate	Channel	Input Power	PER Criterion
11B 11M	13	Psen + 6db	≤8%
11G 54M	10	Psen + 6db	≤10%
11N MCS7	1	Psen + 6db	≤10%
11AX MCS9	5	Psen + 6db	≤10%

- PER = (number of packets sent - MAC OK quantity) / number of packets sent* 100%
- Psen is the actual sensitivity power of DUT at the laboratory

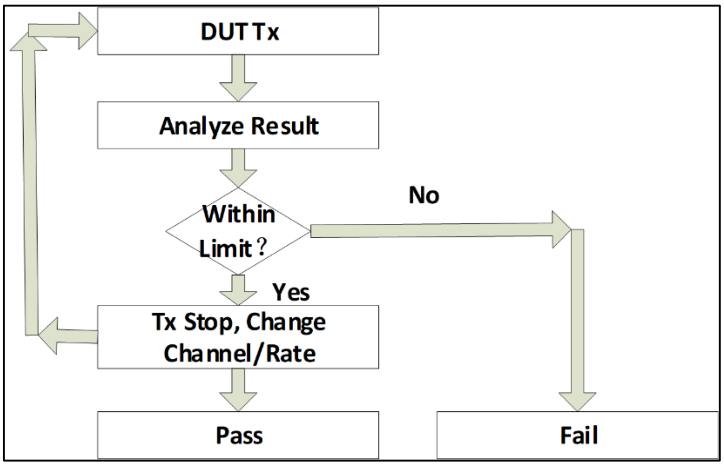
5.8. BLE Tx Verification

After BLE Tx power calibration, conduct more comprehensive verification on the calibrated Tx performance.

5.8.1. Flow Chart

Tx verification flow chart is as shown in ***Figure 5-7. BLE Tx verification flow***:

Figure 5-7. BLE Tx verification flow



5.8.2. Detailed Flow

1. Parameters are set at DUT and DUT conducts Tx with CMD ***ble_test_tx***. It is recommended to select Max Power for testing.
2. RF tester receives packets at the corresponding channel and rate and analyzes and judge the test result.
3. DUT stops Tx with CMD ***ble_test_stop***.

5.8.3. Test Items and Test Specifications

For recommended test items and specifications of BLE Tx verification, please refer to ***Table 5-10. Recommended Specifications for BLE Tx verification***.

Table 5-10. Recommended Specifications for BLE Tx verification

Rate	Channel	Length	Payload	Results from Tester	Pass Criterion
1M	0	37B	0xF0&0xAA	Power	Set Power+/-2db
				Modulation Characteristics	Follow spec
				Initial Carrier Frequency Tolerance	Follow spec
				Carrier Frequency Drift	Follow spec
2M	39	37B	0xF0&0xAA	Power	Set Power+/-2db
				Modulation Characteristics	Follow spec
				Initial Carrier Frequency Tolerance	Follow spec
				Carrier Frequency Drift	Follow spec

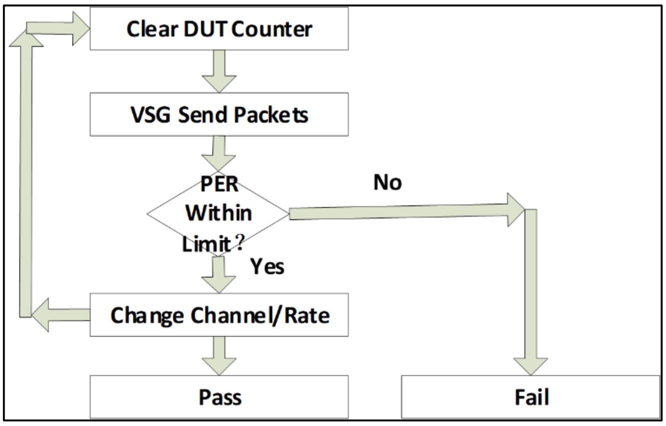
5.9. BLE Rx Verification

Similar to WiFi, BLE also requires RX PER verification.

5.9.1. Flow Chart

BLE Rx verification flow chart is as shown in ***Figure 5-8. BLE Rx verification flow***:

Figure 5-8. BLE Rx verification flow



5.9.2. Detailed Flow

1. Ensure that the environment where DUT is placed in a **shielded environment**. Tests can be done with CMD ***ble_test_rx.***

■ CMD example:

- ***ble_test_rx 0x0 0x1 0x0*** //Set channel to 0, rate to 1M, and payload to PRBS9

2. The RF tester as VSG sends a fixed number of packets (usually 1,500) at the corresponding channel and rate, according to the input power of following table (sensitivity+6 dB). The recommended length of packet is 37 bytes and the recommended payload is PRBS9.
3. After the RF tester finishes sending packets, use CMD ***ble_test_stop*** to stop Tx, check the return value of the counter and calculate PER.

■ CMD example:

- ***ble_test_stop*** //Stop BLE test, and check the return value of the counter, such as “le test end, status 0x0, received pkt num: 1316”, PER = (1500-1316)/1500 = 12.3%. PASS

5.9.3. Test Items and Test Specifications

The recommended power settings and specifications at the RF tester during the BLE Rx verification are as shown in ***Table 5-11 Recommended Specifications for BLE Rx verification***:

Table 5-11 Recommended Specifications for BLE Rx verification

Rate	Channel	Length	Payload	Input Power	PER Criterion
1M	0	37B	PRBS9	Psen + 6db	≤30.8%
2M	39	37B	PRBS9	Psen + 6db	≤30.8%

■ PER = (number of packets sent - MAC OK quantity) / number of packets sent* 100%

- Psen is the actual sensitivity power of DUT at the laboratory

5.10. Write Efuse

After all the above-mentioned flows pass, thermal value, power calibration values and other set values should be written into Efuse of DUT. These parameters will be imported to the chip when it is rebooted. Users may use CMD ***rf_efuse*** to read and write Efuse.

5.10.1. Check Written Contents

As mentioned in ***Efuse Description*** in this document, contents highlighted in green are confirmed before WiFi or BLE calibration, and contents highlighted in red are confirmed after calibration. Contents highlighted in yellow need to be confirmed before writing Efuse. For detailed definition of 0x22 TXPowerLimit_byMode, please see ***Table 5-12. TXPowerLimit_byMode definition***.

Table 5-12. TXPowerLimit_byMode definition

Efuse 0x22	MAX Power Level (dBm)
Bit[7:4]	**11B**
0110	21
…	…
0010	19
0001	18.5
0000	**18**
1111	17.5
1110	17
…	…
1000	14
Bit[3:0]	**11G, 11N & 11AX**
0010	19
0001	18.5
0000	**18**
1111	17.5
1110	17
…	…
1000	14

MAC addresses of WiFi and BLE are in Efuse 0x60-62, 0x70-72 and 0x80-82. For detailed definitions, please see ***Table 5-13. MAC address definition***. Specific contents are defined by users.

Table 5-13. MAC address definition

Efuse Location	Description	Default Value	Meaning

0x60	MAC_Address_Byte3	0x00	WIFI MAC address bit[23:16]
0x61	MAC_Address_Byte2	0x00	WIFI MAC address bit[15:8]
0x62	MAC_Address_Byte1	0x00	WIFI MAC address bit[7:0]
0x70	MAC_Address_Byte6	0x00	WIFI/BLE MAC address bit[47:40]
0x71	MAC_Address_Byte5	0x00	WIFI/BLE MAC address bit[39:32]
0x72	MAC_Address_Byte4	0x00	WIFI/BLE MAC address bit[31:24]
0x80	MAC_Address_Byte9	0x00	BLE MAC address bit[23:16]
0x81	MAC_Address_Byte8	0x00	BLE MAC address bit[15:8]
0x82	MAC_Address_Byte7	0x00	BLE MAC address bit[7:0]

5.10.2. Example of Completely Writing Efuse

Example of CMD for completely writing efuse:

- ***rf_efuse write 1 4 FEFCFA02***
  Set power compensation of WiFi 11AX MCS7 at low, medium, and high channels to -0.25 dB, -0.5 dB, and -0.75dB respectively. Set BLE power compensation to 0.25 dB.
- ***rf_efuse write 2 4 0DF00E21***
  //0x0d: Set target power of 11B 11M to 17 dBm. Set target power of 11AX MCS7 to 12.5 dBm.
  //0xF0: Set target power of 11G 54M to 12.5 + 0.5 = 13 dBm
  //0x0E: Set maximum power of 11B to 18 dBm, 11G, 11N&11AX to 17 dBm
  //0x21: Set BLE target power to 4 dBm and maximum power to 12 dBm
  //NOTE: Here, the set power value must be the same as the value set by CMD in ***Set WiFi Target Value*** and ***BLE Tx Power Calibration***.(Here, this is used for an example only and might not be consistent with the target power mentioned above). Otherwise, it may lead to power calibration deviation.
- ***rf_efuse write 4 1 7A***
  // Set frequency calibration to -6 steps. Bit7 is a constant 0
- ***rf_efuse write 6 3 000102***
- ***rf_efuse write 7 3 76baed***
- ***rf_efuse write 8 3 030405***
  //Set WiFi MAC address to 0x76baed000102 and BLE MAC to 0x76baed030405

5.10.3. Description of Efuse Available Space

For completely empty Efuse, there is a space of 64 bytes in total and the default value of each byte is 0x00. If the written value is the same as the current value, it does not actually consume any Efuse space. Completely writing Efuse once (all values are non 0x00) requires 24 bytes, so each chip allows complete calibration (all calibration values are non 0x00) more than twice.

6. Revision History

Table 6-1. Revision history is the version update history of this document.

Table 6-1. Revision history

Revision No.	Description	Date
1.0	Initial release	Nov.17, 2023
1.1	Based on efuse alternation of definition, modify efuse usage accordingly	Jul.19, 2024
1.2	Modify Important Notice page content.	Mar.28, 2025

Important Notice