Ameba D

WiFi MP FLOW

V10

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USING THIS DOCUMENT

This document is intended for the software engineer's reference and provides detailed programming information. Though every effort has been made to ensure that this document is current and accurate, more information may have become available subsequent to the production of this guide.

Revision History

Revision	Date	Changes	Author
Ver 01	2018/08/14	First release	*Winnita*
Ver 02	2018/10/31	1. Add ADC Test and GPIO Test 2. Define target power	*Winnita*
Ver 03	2019/01/03	Revise 5G target power	*Alan*
Ver 04	2019/03/01	Add mac address content	*Alan*
Ver 05	2019/03/29	Revise target power	*Alan*
Ver 06	2019/06/26	Modify Calibrated Crystal Cap. Flow	*Winnita*
Ver 07	2019/07/19	Add WiFi/BT Interface Switch	*Winnita*
Ver 08	2019/09/09	Revise 5G target power	*Winnita*
Ver 09	2020/03/13	Add a note in 3.5 Write Data…	*Winnita*
Ver 10	2024/11/13	Modify WL TX CCK calibration method	*Winnita*

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1. Overview

This document is used to introduce WiFi calibration Flow of AmebaD series chip for Mass Production. Customers can build up their own MP software easily with just following step-by-step guidance of this document. Realtek also cooperates with instrument vendors during chip development stage, so customers can inquire MP software support from instrument vendors.

AmebaD series chip includes following IC part numbers and here lists its relative connectivity interface and its memory type,

1. RTL8720D/RTL8721D/RTL8722D: Support basic peripheral interface with external flash.

In order to correctly design your hardware and properly apply AmebaD series chip on your platform, please do provide following information to your Realtek local sales and Technical Support Team,

1. Memory requirements, such as PSRAM or flash size are required.
2. Connectivity interface requirement, such as USB/SDIO interface.
3. Special GPIO requirement, such as wake trigger pin from deep sleep state, ADC, etc.
4. Antenna configuration, such as one or two antenna and diversity required or not.

Realtek Technical Support Team will depend on above information, and then provide following document or design kit to assist customers on hardware design,

1. IC Datasheet
2. Hard Design Kit (HDK) or suitable recommendation
3. Calibration Data Content (flash/ non-volatile memory) Specification
4. Calibration Data Content (flash/ non-volatile memory) MAP file
5. MP API (customer can use this API to develop their own software tool for mass production)
6. MP calibration Flow

Emphasize again, different hardware configurations have to match up different MAP file, so customers do have to contact Realtek Technical Support team to obtain correct MAP file to match up your hardware design.

2. Test Platform

The calibration flow described in following section is based on WiFi one-box tester, such as Agilent N4010A or LitePoint IQFlex, etc.

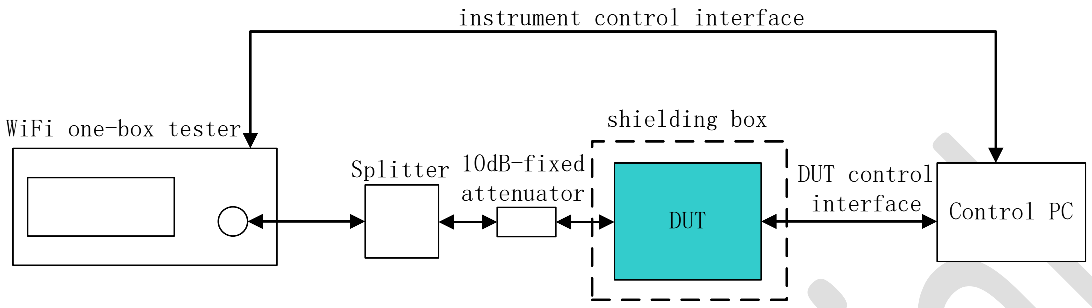

Figure 1: Brief diagram about test environment setup of DUT

Note the 10dB-fixed attenuator has to set as close as possible to DUT since it will reduce the mismatch effect between DUT and the environment.

3. WiFi MP Flow

Below diagram shows a global view of mass production flow, please refer to following sub-section to get detailed description for each step.

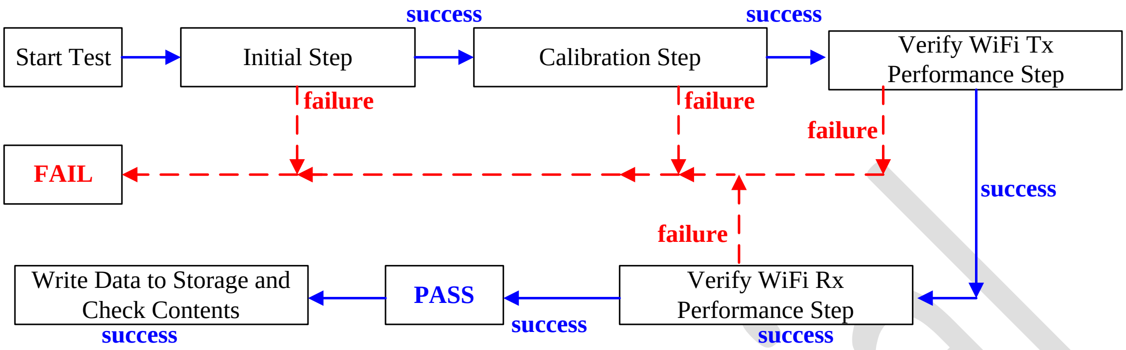

Figure 2: Brief diagram about MP flow

Note: Customers are suggested to read image file and program it to flash of the Ameba-D module before MP flow. Relevant application program is illustrated in

RTL8721D_AN_PART4_image_tool_20180801_1536.docx

3.1 Environment Setup

First you need to check comport show up.
COM port number is based on your environment.

3.2 WiFi Initial Step

The relative control commands about initializing WiFi DUT is in the released UI sample code.

The AT command “**ATWP=1**” can enable WiFi, and use “**ATWP=0”** to disable.

Please check the following message. The message “The driver is for MP” indicates this is a MP driver. MP driver is used to calibrate WiFi data.

```
#ATWP=1
[ATWP]: _AT_WLAN_POWER_[ON]

Initializing WIFI ...
RTL8195A[Driver]: The driver is for MP

WIFI initialized

[MEM] After do cmd, available heap 25968
```

And below commands controls WiFi DUT enter or exit MP(Mass Production) test mode.

iwpriv mp_start

iwpriv mp_stop

```
#iwpriv mp_start

[MEM] After do cmd, available heap 69776
```

This command is recommended before calibration:

iwpriv mp_pwrctldm stop

The reason is that if the DUT has already been PG, the dynamic mechanism will be activated, this may lead to the calibration with unexpected results.

3.3 I/O Test Step

Ameba MP API supports IO connection tests for module fabrication. All the peripheral functions are well tested in Realtek mass production testing procedure.

If customers have specified test requirement for GPIO function used for your module or system design, please contact Realtek Support Team.

3.3.1 ADC Test

For the Ameba-D module, the ADC_CH0 ~ ADC_CH7 are fed with 0 ~ 3.3V voltage level and read the sample value. The sample value should be within tolerated error. When fed with GND, the value should be approach 0x100. When fed with 3.3V, CH0~CH6 would return a value approach 0xFFF, and CH7(VBAT) would return a value approach 0x0B20.

The AT command “**ATSA=1**” can read ADC_CH1 value, use “**ATSA=2**” to read ADC_CH2, and use “**ATSA=3**” to read ADC_CH3.

The following output is the ADC value.

```
#ATSA=1

[ATSA]: _AT_SYSTEM_ADC_TEST_
[ATSA] A1 = 0x0827
[MEM] After do cmd, available heap 37432
```

```
#ATSA=2

[ATSA]: _AT_SYSTEM_ADC_TEST_
[ATSA] A2 = 0x0827
[MEM] After do cmd, available heap 37432
```

Note:
For RTL8721D module, test ADC_CH0~ADC_CH7.

3.3.2 GPIO Test

For the RTK module Ameba-D, module pin PA0 ~ PA31, PB0~PB11 and PB24~PB31 are fed with 0V and 3.3V from the testing equipment. These GPIOs are configured as input mode and read the input value. Check the input logic values are same as the equipment output levels.

The AT command "**ATSG=xy**" can read the number y of GPIO port x.

For example, the command "**ATSG=C1**" can read GPIOC_1, and use "**ATSG=B2**" to read GPIOB_2.

The following output is the testing equipment voltage level.

```
#ATSG=C1

[ATSG]: _AT_SYSTEM_GPIO_TEST_
[ATSG] C1 = 1
[MEM] After do cmd, available heap 37432
```

```
# ATSG=B2

[ATSG]: _AT_SYSTEM_GPIO_TEST_
[ATSG] B2 = 0
[MEM] After do cmd, available heap 37432
```

Note:

For Ameba-D module, PB_12~PB_17 or PB_18~PB_23 are not allowed to be tested when code running on flash.

3.4 Calibration Step

This step includes 2 sub-steps as shown in Figure 3.

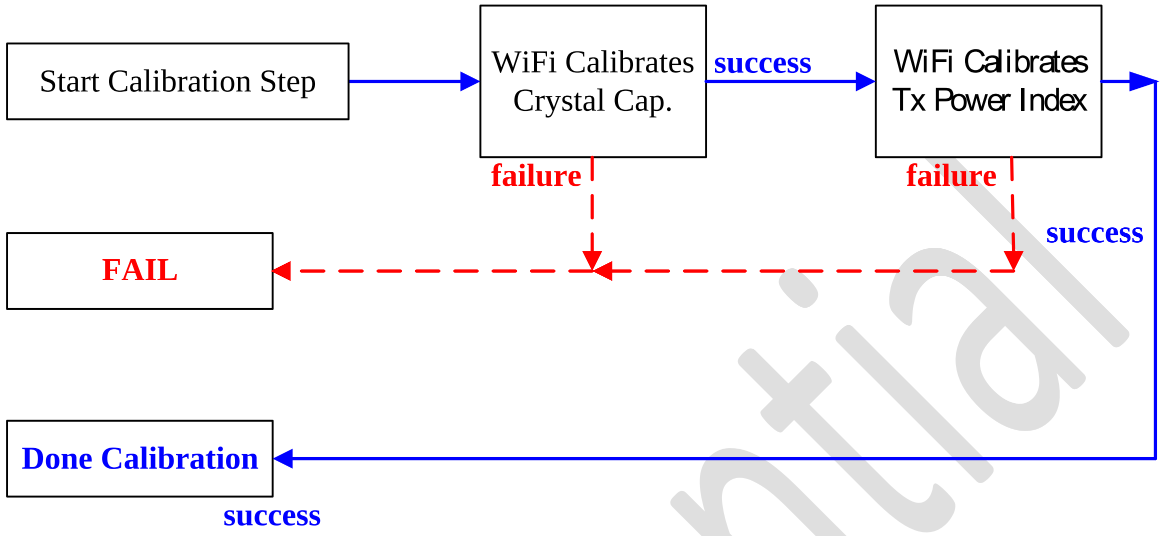

Figure 3: Brief diagram about calibration step

3.3.1 WiFi Calibrates Crystal Cap

3.3.1.1 EFuse definition about Crystal Cap

First, take a look at calibration data content about setting of Crystal Cap. Normal driver will load this value in initial step. So this value must be well-calibrated and filled on correct calibration data location.

Crystal Calibration	0xC9[7:0] & 0x0B[7:0]

Table 1: Crystal calibration offset in eFuse

3.3.1.2 Calibrated Crystal Cap. Flow

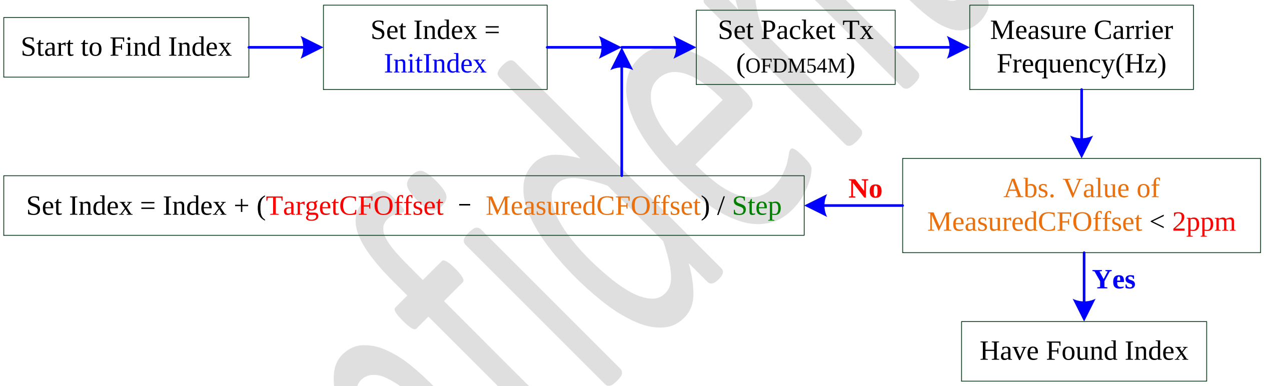

Figure 4: Finding Crystal Cap. Index Flow

Measurement environment : room temperature 25 degree
InitIndex: the default value is 0x40. Index range is 0x0 to 0x7F.
MeasuredCFOffset: Carrier frequency measured by instrument - Ideal Carrier Frequency Target range Abs. Value of 2ppm in 2.4GHz band is about 10KHz(±5KHz).
**TargetCFOffset*: generally is 0~-5ppm ppm, The reason for minus ppm was the frequency deviation could be under 15ppm at high temperature 80 degree environment.
Step: This value is dependent of different module dominated by external capacitor beside the crystal, so it needs to modify easily in initial file of test program. Usually, the value is about -2 ~ -3 KHz by experience. The minus symbol means that the crystal cap. index and carrier frequency is negative-dependent (The larger index is relative to minor carrier frequency).
The command is shown as below:

Step 1:

iwpriv mp_ant_tx a

iwpriv mp_bandwidth 40M=0,shortGI=0

iwpriv mp_channel 7

iwpriv mp_rate 108

iwpriv mp_txpower patha=42,pathb=0

iwpriv mp_phypara xcap=64

iwpriv mp_ctx background,pkt

Step 2:

You can measure Frequency Error(ppm) Freq_Err. If Freq_Erris is between ±2ppm， you found this value (index_cry_ok) correctly. If Freq_Erris is not between ±2ppm, you caught use algorithm as below to find next index_cry_next until you find Freq_Err between ±2ppm.

$$\text{index\_cry\_next= Index\_cry -} \frac{Freq\_Err \times 2442}{2500}$$

ex: We set Index_cry =64, measure Freq_Err = -23.49ppm,

$$\text{The next index is index\_cry\_next= 32-} \frac{(-23.49) \times 2442}{2500} \fallingdotseq 87$$

step3: The index_cry_next must be **rounded the number to the integer**, and use command to update index as follows:

iwpriv mp_phypara xcap=index_cry_next

ex: iwpriv mp_phypara xcap=87

Repeat Step2, Step3 until find Freq_Erris correctly and note down Index_cry_ok.

Stop Tx command is as below:

iwpriv mp_ctx stop

3.3.2 WiFi Calibrates Tx Power Index

3.3.2.1 EFuse definition about Tx power index and thermal meter

First, take a look at eFuse content about setting of RF Tx gain index. Normal driver will load bellow Tx gain setting for each channel group or each PHY data rate. So these Tx gain setting must be well-calibrated and filled on correct eFuse location.

The 0x2B default value was 0x02 for all channels. But the customer also can measured OFDM&HT20 to calculate diff value on CH7 (recommend).

Power Index Location in EFuse of Antenna A						
2G Band						
	Group 1 CH1 – CH2	Group 2 CH3 – CH5	Group 3 CH6 – CH8	Group 4 CH9 – CH11	Group 5 CH12– CH13	Group 6 CH14
MCS7 B40	0x26[7:0]	0x27[7:0]	0x28[7:0]	0x29[7:0]	0x2A[7:0]	
CCK	0x20[7:0]	0x21[7:0]	0x22[7:0]	0x23[7:0]	0x24[7:0]	0x25[7:0]
5G Band						
	Group 7 CH36-40	Group 8 CH44-48	Group 9 CH52-56	Group 10 CH60-64		
MCS7 B40	0x32[7:0]	0x33[7:0]	0x34[7:0]	0x35[7:0]		
	Group 11 CH100-104	Group 12 CH108-112	Group 13 CH116–120	Group 14 CH124–128	Group 15 CH132–136	Group 16 CH140–144
MCS7 B40	0x36[7:0]	0x37[7:0]	0x38[7:0]	0x39[7:0]	0x3A[7:0]	0x3B[7:0]
	Group 17 CH149–153	Group 18 CH157 -161	Group 19 CH165–169	Group 20 CH173–177		
MCS7 B40	0x3C[7:0]	0x3D[7:0]	0x3E[7:0]	0x3F[7:0]		

Power Difference Location in EFuse of Path A		
2G Band	54M-1T to MCS7-B40	0x2B[3:0]
	MCS7-B20 to MCS7-B40	0x2B[7:4]
5G Band	54M-1T to MCS7-B40	0x40[3:0]
	MCS7-B20 to MCS7-B40	0x40[7:4]

Thermal meter	0xCA[7:0]

Table 2: Tx gain index and thermal meter offset in eFuse

3.3.2.2 Define target power

According to
(1) EMI/EMC regulatory
(2) IEEE TX EVM / Spectrum Mask requirement
(3) The method was interpolation power index for un-calibration channel group.

Then you can define your target power for each channel group and also each PHY data rate. The recommended target power is listed below and assumes all channel have the same target power for each PHY data rate.

Data Rate		MCS7-B40	MCS7-B20	54M	CCK
Target Power 2G	3.3V power supply	16dBm	16dBm	17dBm	18dBm
	1.8V power supply	10dBm	10dBm	11dBm	12dBm
Target Power 5G	3.3V power supply	13dBm	13dBm	14dBm	
	1.8V power supply	8dBm	8dBm	9dBm	

Table 3: The recommended target power (DPD on)

3.3.2.3 Tx calibration flow

Theoretically, we need to measure all value defined above in OTP to calibrate the Tx power level. But since it needs too much time, we only measure several channels with MCS7-B40 signal and CCK-11M signal, and figure out the other non-measured value by some easy mathematics method.

Usually, the recommended measured channels are listed below:

2G Band (CCK)			2G Band(MCS7)		5G Band1		5G Band2		5G Band3		5G Band4	
CH4	CH10	CH14	CH4	CH10	CH38	CH46	CH54	CH62	CH102	CH142	CH151	CH175

Table 4: The recommended measured channel for Tx power calibration

The flow is shown as below:

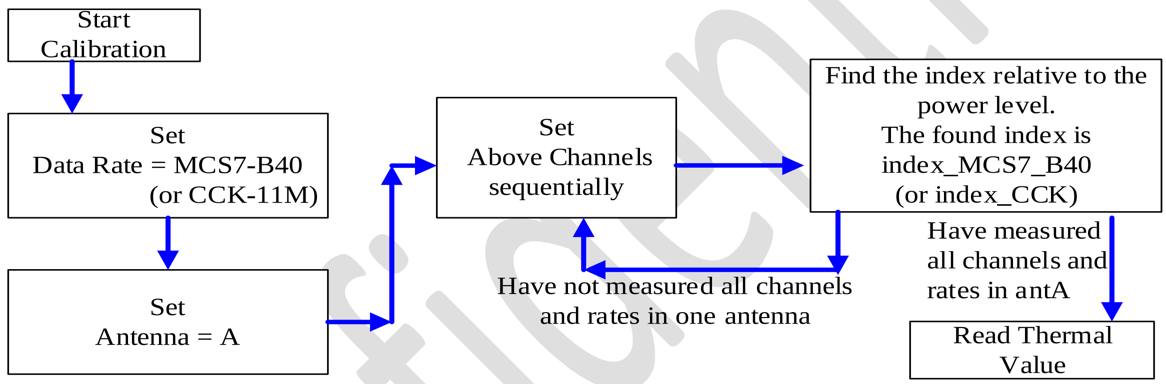

Figure 5: Tx calibration flow

Each finding index flow is shown as below:

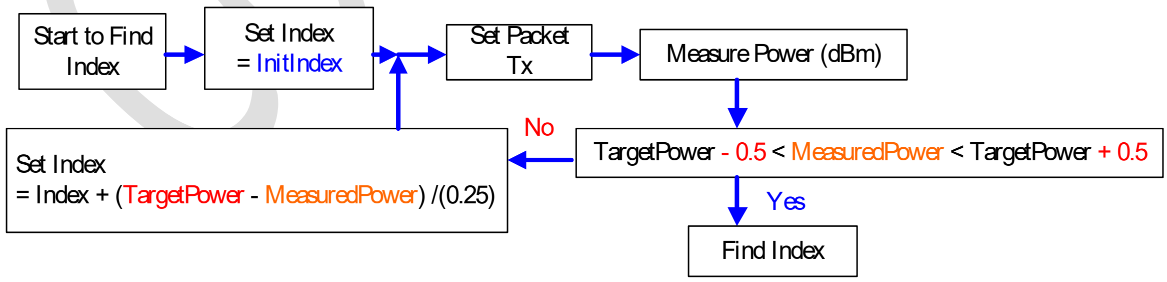

Figure 6: Finding index flow

While finding Index_MCS7_B40, the Init Index is defined by user or programmer and target power is MCS7-B40 target power level defined before.

After finding all Index_MCS7_B40, use these values to get all Tx gain index in each channel set by interpolation. As 2G channels for example, if the measured index in CH4 is 41 and the measured index in CH10 is 43, all 2G group MCS7-B40 index is shown as below:

Group 1	Group 2	Group 3	Group 4	Group 5
40 (Calculated by Interpolation)	41 (Measured)	42 (Calculated by Interpolation)	43 (Measured)	44 (Calculated by Interpolation)

Table 5: The example of finding MCS7 index in 2G band by interpolation

We have measured all groups of 5G band 1 and 5G band 2, so just only use the interpolation for 5G band 3 and 5G band4.
Similarly, all group CCK index is shown as below:

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
44 (Calculated by Interpolation)	45 (Measured)	46 (Calculated by Interpolation)	47 (Measured)	48 (Calculated by Interpolation)	49 (Measured)

Table 6: The example of finding index in 2G band by interpolation

The all power difference values are between +7 and -8. The value 0x0 ~ 0x7 in eFuse means 0 ~ +7 and the value 0x8 ~ 0xF in eFuse means -8 ~ -1. The +1 power difference will plus 0.5dB power theoretically, so we calculate all power difference by the defined target power. We take Table 7 as an example, the 2G power difference is shown as below:

MCS7-B20 to MCS7-B40	(MCS7-B20_Tatget_Power - MCS7-B40_Tatget_Power)x2 = ((13 – 13) x2) = 0
54M-1T to MCS7-B40	(54M_Tatget_Power - MCS7-B40_Tatget_Power)x2 = ((14 – 13) x2) = 2

Table 7: The example of finding power difference

3.3.2.4 Read Thermal Meter

Normal driver will load thermal meter to do power tracking. So this value must be filled on correct calibration data location. Use MP command as below to get thermal meter value:

iwpriv mp_ther

```
#iwpriv mp_ther

Private Message: 24
[MEM] After do cmd, available heap 25968
```

3.5 Write Data to Storage and Check Contents

Allocate 512 bytes of memory space on your local PC and then load default map file to this memory space. (UCHAR calibration_data[512]) Write board-dependent information into respective calibration data offset, this information include MAC address, calibrated Tx index, Thermal Meter, and so on.

The eFuse content about setting of WiFi MAC address is as following table.

WiFi MAC address	**11Ah~11Fh**

Table 8: WiFi MAC address offset in eFuse

Use the MP command:

"iwpriv config_set wmap,offset,data"

Note: Please reference document AN0004 Realtek mp user guide.pdf

to send 16 bytes calibration data content to on-chip Calibration data area, therefore 512 bytes contents need to do above command 512/16=32 times. If you want rewrite new contents, you can use above command again.

Note:

This command is only effective above 2.5V power supply. So if you want to write the "1.8V" efuse data, please storage them first and then write them into efuse at 3.3V power supply.

After above step, you should use below MP command to read partial contents,

"iwpriv config_get rmap,offset,count"

or use below MP command to get full contents

"iwpriv config_get realmap"

Note: Please reference document AN0004 Realtek mp user guide.pdf

to check the written contents are all correct or not.

3.6 Verify Tx Performance Step

This step includes 1 sub-step as shown in **Figure 7**:

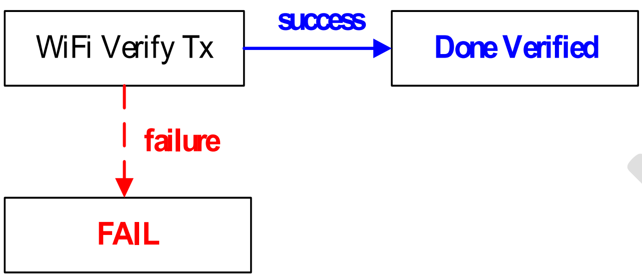

Figure 7: Verify Tx Performance Flow

3.6.1 WiFi Verify Tx Performance

Use the calibrated index in previous step and measure Tx power, EVM, frequency offset and LO leakage to check Tx performance is ok or not. The recommended test items are listed below:

<table>
<tr><th>Data Rate</th><th>Antenna</th><th>Channel</th><th>Item</th><th colspan="3">Criterion</th></tr>
<tr><td rowspan="7">MCS7-B40</td><td rowspan="7">Antenna A</td><td rowspan="7">CH6</td><td rowspan="2">Power</td><td>3.3V</td><td>Typical: 16dBm</td><td rowspan="2">Acceptable Range: +1/-1.5dB</td></tr>
<tr><td>1.8V</td><td>Typical: 10dBm</td></tr>
<tr><td>EVM</td><td colspan="3">< -28dB</td></tr>
<tr><td>Freq. Err.</td><td colspan="3">±15ppm</td></tr>
<tr><td>Leakage</td><td colspan="3">< -20dBtotal</td></tr>
<tr><td>Mask</td><td colspan="3">IEEE spec. defined</td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="6">MCS7-B20</td><td rowspan="6">Antenna A</td><td rowspan="6">CH1</td><td rowspan="2">Power</td><td>3.3V</td><td>Typical: 16dBm</td><td rowspan="2">Acceptable Range: +1/-1.5dB</td></tr>
<tr><td>1.8V</td><td>Typical: 10dBm</td></tr>
<tr><td>EVM</td><td colspan="3">< -28dB</td></tr>
<tr><td>Freq. Err.</td><td colspan="3">±15ppm</td></tr>
<tr><td>Leakage</td><td colspan="3">< -20dBtotal</td></tr>
<tr><td>Mask</td><td colspan="3">IEEE spec. defined</td></tr>
<tr><td rowspan="3">OFDM 54M</td><td rowspan="3">Antenna A</td><td rowspan="3">CH7</td><td rowspan="2">Power</td><td>3.3V</td><td>Typical: 17dBm</td><td rowspan="2">Acceptable Range: +1/-1.5dB</td></tr>
<tr><td>1.8V</td><td>Typical: 11dBm</td></tr>
<tr><td>EVM</td><td colspan="3">< -25dB</td></tr>
</table>

			Freq. Err.	±15ppm		
			Leakage	< -15dBtotal		
			Mask	IEEE spec. defined		
CCK 11M	Antenna A	CH13	Power	3.3V	Typical: 18dBm	Acceptable Range: +1/-1.5dB
				1.8V	Typical: 12dBm	
			EVM	< 8%		
			Freq. Err.	±15ppm		
			Mask	IEEE spec. defined		

MCS7-B40	Antenna A	CH38 CH54 CH102 CH151	Power	3.3V	Typical: 13dBm	Acceptable Range: +1/-1.5dB
				1.8V	Typical: 8dBm	
			EVM	< -28dB		
			Freq. Err.	±15ppm		
			Leakage	< -20dBtotal		
			Mask	IEEE spec. defined		
MCS7-B20	Antenna A	CH48 CH64 CH144 CH177	Power	3.3V	Typical: 13dBm	Acceptable Range: +1/-1.5dB
				1.8V	Typical: 8dBm	
			EVM	< -28dB		
			Freq. Err.	±15ppm		
			Leakage	< -20dBtotal		
			Mask	IEEE spec. defined		
OFDM 54M	Antenna A	CH44 CH60 CH120 CH165	Power	3.3V	Typical: 14dBm	Acceptable Range: +1/-1.5dB
				1.8V	Typical: 9dBm	
			EVM	< -25dB		
			Freq. Err.	±15ppm		
			Leakage	< -15dBtotal		
			Mask	IEEE spec. defined		

Table 9: The recommended test items of WiFi Tx

3.7 Verify Rx Performance Step

This step includes 1 sub-step as shown in **Figure 8**:

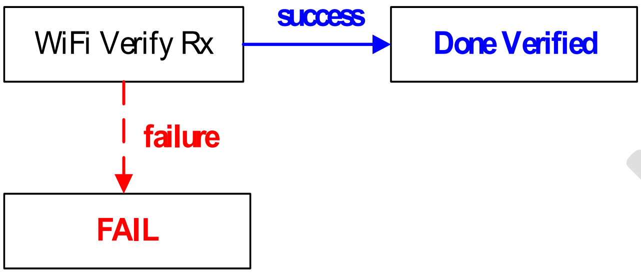

Figure 8: Verify Rx Performance Flow

3.7.1 iFi Verify Rx Performance

Measure the DUT Rx sensitivity to check Rx performance is ok or not. The recommended test items are listed below:

Data Rate	Channel	Item	Sensitivity Criteria
MCS7-B40	CH6	Sensitivity	< -64dBm
MCS7-B20	CH1		< -67dBm
OFDM 54M	CH7		< -71dBm
CCK 11M	CH13		< -82dBm

Data Rate	Channel	Item	Sensitivity Criteria
MCS7-B40	CH118	Sensitivity	< -64dBm
MCS7-B20	CH44		< -67dBm
OFDM 54M	CH100		< -71dBm

Table 10: The recommended test items of WiFi Rx

4. WiFi/BT Interface Switch

The ATM2 series command can switch WiFi or BT MP test mode. Customers should follow this list by steps to do WiFi & BT Mass Production.

<table>
<tr><th>No</th><th>Steps</th><th>Commands/Descriptions</th><th>Remark</th></tr>
<tr><td>1</td><td>MP start</td><td>iwpriv mp_start</td><td></td></tr>
<tr><td>2</td><td>WiFi Calibration & Verification</td><td>iwpriv commands</td><td>Reference doc:
AN0004 Realtek low power wi-fi mp user guide.</td></tr>
<tr><td>3</td><td>Switch to Bluetooth</td><td>ATM2=bt_power,on
ATM2=gnt_bt,bt
ATM2=bridge</td><td></td></tr>
<tr><td>4</td><td>Open BT Uart interface</td><td rowspan="5">Refer to the sample codes in Realtek Bluetooth MP Kit Setup Package</td><td rowspan="5">Reference doc: MP tool User guide for Realtek.

Sample code path:
RealeasePackage\NewBTMP\Realtek Bluetooth MP Kit Setup Package\RTLBTAPP\SampleCode\MPRtlBluetoothSample

Note : keep the tx gain k value and thermal value</td></tr>
<tr><td>5</td><td>BLE- Tx calibration (gain k)</td></tr>
<tr><td>6</td><td>Read BT thermal meter value</td></tr>
<tr><td>7</td><td>BLE- Tx verification</td></tr>
<tr><td>8</td><td>Close BT Uart interface</td></tr>
<tr><td>9</td><td>Switch to Wifi</td><td>ATM2=bridge,close
ATM2=gnt_bt,wifi</td><td></td></tr>
<tr><td>10</td><td>Write efuse</td><td>iwpriv commands</td><td>Reference doc: Realtek Ameba-D calibration data spec.
* Write WiFi calibration data+MAC address
* Write BT calibration data+MAC address.</td></tr>
<tr><td>11</td><td>MP stop</td><td>iwpriv mp_stop</td><td></td></tr>
</table>

Table 11: WiFi & BT Mass Production flow