Bluetooth® Low Energy Over-The-Air Advertiser Testing

Application Note

Products:

- R&S®CMW270
- R&S®CMW100

This document describes Bluetooth* Low Energy RF over-the-air RX and TX measurements using advertising channels for communication with Bluetooth Low Energy devices.

With the R&S®CMW-KD611 software option, the R&S CMW tester is able to perform a large number of Bluetooth Low Energy RF tests without operating in the Direct Test Mode.

Note:

Please find the most up-to-date document on our homepage https://www.rohde-schwarz.com/appnote/1C109.

This document is complemented by software. The software may be updated even if the version of the document remains unchanged.

Application Note
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ROHDE&SCHWARZ

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1 Introduction

Direct Test Mode (DTM) is the mandatory method for RF qualification of Bluetooth Low Energy (LE) devices defined by the Bluetooth Special Interest Group (SIG). DTM is described in the Bluetooth Core Specification, volume 6, part F [1]. The Bluetooth LE RF PHY test specification uses DTM for all transmitter (TX) and receiver (RX) tests [2]. DTM uses a "direct" physical communication channel as a control plane between CMW[1] and Bluetooth LE Equipment Under Test (EUT) to control the EUT. The connection between CMW and EUT depends on the communication method used for DTM:

- Over the Host Controller Interface (HCI) for EUTs with accessible HCI
- Via a 2-wire UART with non-accessible HCI

For setting up the DTM at the CMW, see the 1C105 application note "Configuration of the R&S CMW for Bluetooth Low Energy Direct Test Mode" [4].

For encapsulated and/or small footprint devices, support for a DTM interface is not suitable, or even possible. The DTM method is not well suited for radiated measurements, for example regulatory, TRP/TIS, and CTIA test plans. Moreover, the control cable could fundamentally change the RF characteristics of the EUT. It would therefore be convenient to have an alternative test method to the DTM approach available.

A solution offers the use of Bluetooth LE advertiser communication. This implies a "pseudo-active" signaling type test method approach for Bluetooth LE advertiser measurements. The CMW-KD611[2] option "Bluetooth Low Energy Version 4.2 Advertiser Measurement with ARB Generator" enables non-signaling RX measurements on advertising packets LE 1M PHY.

In the following chapters background information about advertiser communication between EUT and CMW is given. Thereafter Bluetooth LE Over-the-air (OTA) measurements at the CMW are introduced. A detailed description of OTA RX measurements, provided with the CMW-KD611 option, is given. Finally, benefits of CMW OTA measurements are illustrated by a typical manufacturing sequence.

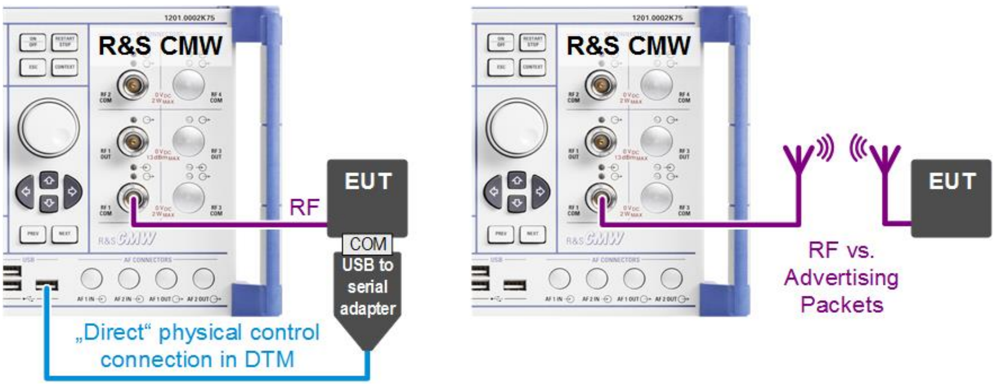

Fig. 1-1: CMW - EUT communication in DTM and via Bluetooth LE advertising packets

[1] The R&S®CMW270 or R&S®CMW100 is referred to as CMW in this document.

[2] R&S soft- and hardware options R&S®CMW-xxx are referred to as CMW-xxx in this document.

2 Basic Ideas

The Bluetooth SIG offers no signaling test type alternative to DTM for Bluetooth LE EUT. The requirements stated in the following are necessary to perform a pseudo-active signaling test approach. Pseudo-active means, that the CMW operates in a pseudo-active scanning mode forcing the EUT to respond with advertising packets. The CMW analyses the received advertising packets.

Note, that RX and TX measurements performed in this way do not conform with the ones specified for Bluetooth LE EUT using DTM [2]. However, they are similar and in addition more flexible, because they do not require a fixed physical connection. Moreover, this approach may satisfy the demand for simple and fast Bluetooth LE EUT testing procedures performed in engineering and production.

2.1 Bluetooth LE Advertiser Communication Requirements

2.1.1 R&S Software Requirements

With the CMW-KD611 option, there is no requirement for using a LE protocol stack on the CMW in order to perform such measurements. The option is specifically required for LE advertiser RX measurements. TX measurements are covered by the CMW-KM611 option "Bluetooth Low Energy Version 4.2 Tx Measurement". Advertiser receiver measurements utilize both Bluetooth and GPRF generator firmware applications, which are both covered by the CMW-KD611 option.

2.1.2 EUT and Test Setup Requirements

Prerequisites for Bluetooth LE advertiser communication are:

- The EUT must be configured to an Advertising state.
- The EUT should utilize all primary advertising channel indexes (for better test coverage).
- The advertising EUT is required to be located in an RF shielded chamber for the duration of testing to avoid the measurement being performed on an unintended LE advertising device or external interference effecting the validity of the measurement results.

2.1.3 Advertiser Measurement Requirements

It is necessary to consider the repeatability and accuracy of advertiser measurements in comparison to the DTM method.

Advertiser packet measurement requirements:

Advertiser packet measurements must be performed in a "pattern independent" mode. The pattern type is undefined unlike the DTM method, which specifically utilizes certain pattern types, for instance:

- The Delta F1 Modulation measurement specifies the use of a ‘11110000’ pattern type.
- The Delta F2 Modulation measurement specifies the use of a ‘10101010’ pattern type.

The modified measurement parameters are discussed in chapter 3.3.

Radiated measurement requirements:

Using a wireless RF connection radiated measurements have a far greater relative uncertainty compared to cabled measurements. Thus, a lower accuracy of the measurement result parameters is inevitable.

- An accuracy of ± 1.2 dB for conducted absolute in-band RF power measurements is required.
- An accuracy of ± 6 dB for radiated absolute in-band RF power measurements is required.

Additionally, a fixed postion of the EUT during the measurement is crucial because slight position changes may alter the EUT radiation characteristics. Take also trigger and expected nominal power level readjustments into account.

We must also consider the measurement time durations in comparison to the DTM method:

- Long advertising event durations up to 10.24 s are possible, this will lead to significantly longer measurement durations.
- Measurement time is critical for manufacturing purposes, long advertising event durations may lead to unacceptably long test times.

Therefore, it is recommended to minimize the advertising event time during the production process.

2.2 Bluetooth LE Basics

2.2.1 Channel Distribution

There are 40 Bluetooth LE RF channels allocated in the ISM Band, each with 2 MHz bandwidth. The relation between the center frequency f_c of the channel and the channel number k can be summarized to:

$$f_c = 2402\text{ MHz} + k \cdot 2\text{ MHz} \;;\; k = 0, 1, .., 39$$

Three of these RF channels, which are used for LE primary advertising purposes, are located between the most commonly used WLAN channels (1, 6, 11) to reduce interference effects. This channel allocation ensures good coverage for advertiser measurements on Bluetooth LE low, mid and top channels.

Note the difference between the RF channel number and the channel index of the advertising channel (37, 38 and 39) and the data channel respectively (0, ..., 36). The RF channel to channel index mapping is also valid for the Bluetooth firmware applications on the CMW.

Further note, that the CMW-KD611 option currently supports primary advertising channels indices 37, 38 and 39 only. For testing RX and TX characteristics of top, middle and bottom channels, it is recommended that the EUT supports all three advertising channel but not recommended by Bluetooth SIG to draw conclusions about the performance inside the whole ISM band.

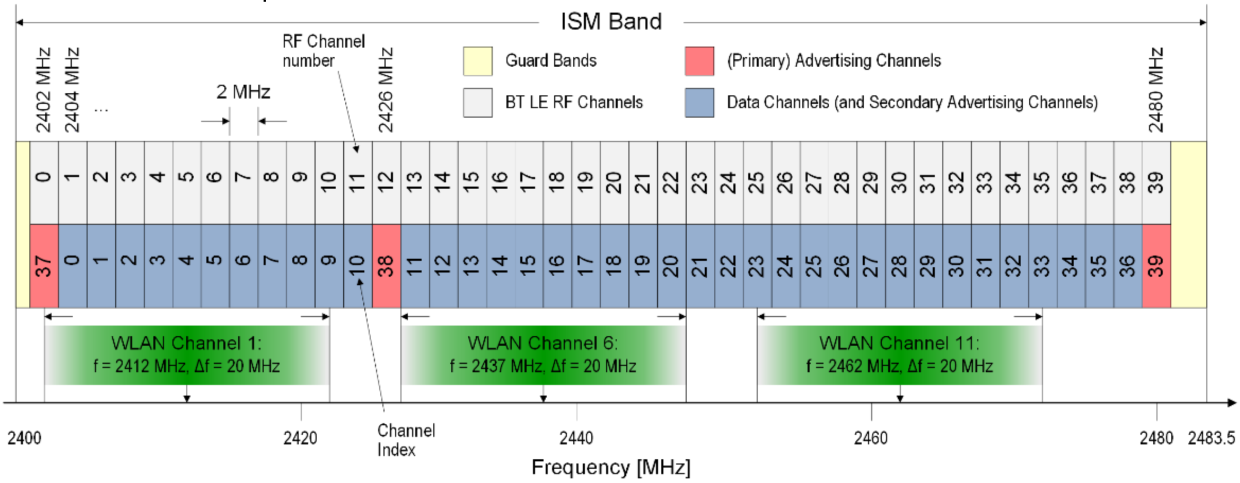

Fig. 2-1: Bluetooth LE channels in the presence of WLAN channels 1, 6, 11

2.2.2 Power Classes

The output power range for Bluetooth LE devices is -20 dBm til +20 dBm. Regulatory compliance based on the geographic location (FFC, ETSI, etc.) can reduce the maximum output power. An optional power control implemented locally in the device can significantly reduce power consumption and interference effects.

There are power classes defined to further specify the operating range of the device (Table 2-1). The devices' power class will depend on the application, power constraints and the required link budget.

Note, that the maximum output power increased for Bluetooth LE v5. In Bluetooth LE v4.x compliant devices the maximum output power is 10 mW (+10 dBm) at most.

Power class	**Maximum output power**	**Minimum output power**[1)]
1	100 mW (+20 dBm)[2)]	10 mW (+10 dBm)
1.5	10 mW (+10 dBm)	0.01 mW (-20 dBm)
2	2.5 mW (+4 dBm)	0.01 mW (-20 dBm)
3	1 mW (0 dBm)	0.01 mW (-20 dBm)

[1)] Minimum output power at maximum power setting
[2)] For Bluetooth LE v5 compliant devices only

Table 2-1: Bluetooth LE power classes as in [1]

2.2.3 Address Types

LE advertising device addresses can be either:

- Public - IEEE 802-2001 standard using an Organizationally Unique Identifier (OUI) obtained from the IEEE Registration Authority, or,
- Random - random addresses can directly be generated by the device and can be of three different types: static, non-resolvable private and resolvable private. The random address is a privacy feature that prevents tracking of a specific device.

Bluetooth LE device address					**CMW-KD611 option**
Address type	Public	Random			Supported
Random address subtype		Static	Private		Supported
Random private address subtype			Resolvable	Non-resolvable	Not supported

Table 2-2: Bluetooth LE device addresses as in [1]

Typically, a Bluetooth LE device uses the random address type in the development phase. Public addresses are assigned to devices on the market. If you don't know the address type, you may have to change it to receive results during an RX measurement.

2.2.4 Operation States

Bluetooth LE devices operate in five separate states:

- **Standby**: This is the device's default state. No packets are received or transmitted. A transition to each of the other four states is possible.
- **Advertising**: The device is transmitting advertising channel packets and possibly listening to and responding to responses triggered by these advertising channel packets. Transmission is mostly performed on the three primary advertising channels. This is a transmitting state only.
- **Scanning**: The device listens to the three advertising channels for advertising events. There are two types of scanning modes:
  - **Passive scanning** – only data reception, no transmission
  - **Active scanning** – on receipt of an advertising PDU the scanner can transmit a scan request (advertiser PDU type dependant)
- **Initiating**: A scanner can send a connection request to an advertiser if the advertiser signals a connection opportunity. This connection request is sent to the advertiser on the advertising channels.
- **Connection**: If the connection setup (initiating) was successful then both devices enter the connection state and can exchange date within the piconet. The initiator (scanner) will become assume the master role, and the advertiser the slave role within the connection.

Note that LE devices can perform multiple roles simultaneously.

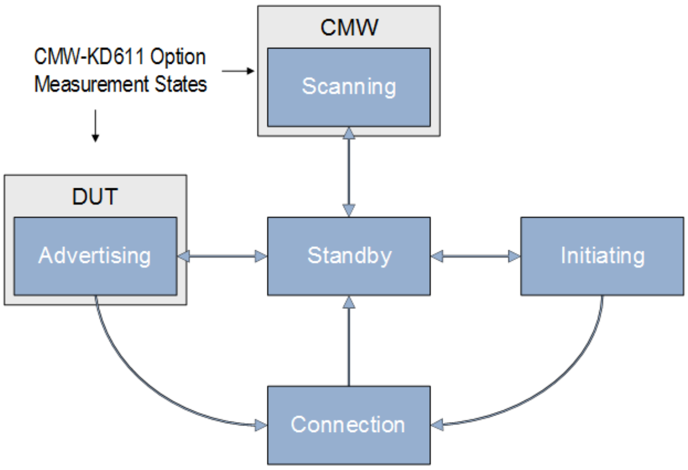

Fig. 2-2: Bluetooth LE states as in [1] and CMW-KD611 measurement states

2.3 Bluetooth LE Advertising

In the following, only primary advertising is considered because this type is relevant for the CMW-KD611 option.

2.3.1 Packet structure

The Bluetooth LE link layer has a single generic packet structure used for both advertising channel and Data channel packets shown in Fig. 2-3:

- **Preamble**: An eight bit alternating bit pattern used by the receiving device to perform frequency synchronization, symbol timing estimation, and Automatic Gain Control (AGC) training.
- **Access Address**: A common access address is used for all advertising channel packets (0x8E89BED6). This is the default access address for advertising TX measurements configured within the CMW platform when the advertising packet type is selected.
- **PDU**: The PDU contains a 16-bit header field, and a variable size payload.
- **CRC**: At the end of every link layer packet there is a three byte CRC calculated over the PDU.

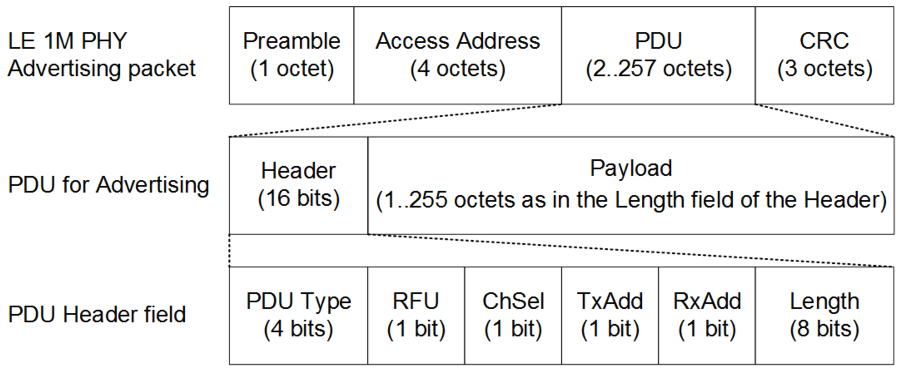

Fig. 2-3: Bluetooth LE 1M PHY / advertising packet structure as in [1]

The PDU's payload length depends on the PDU type and is defined in the length field of the PDU header.

2.3.2 Events and PDU types

The advertiser can broadcast four different advertising events.

Advertising event	Purpose	Application
Connectable undirected	General advertising	Multidirectional non-addressed advertising
Connectable directed	Direct advertising	Rapid connection setup for directly addressed devices
Non-connectable undirected	Non-connectable advertising	Broadcast only, e.g. beacon-like transmission
Scannable Unidirected	Discoverable advertising	Dynamic user data broadcast

Table 2-3: Advertising events on primary advertising channels

Each advertising event is associated with a certain advertiser PDU type. The scanning device responds to each advertising event with a defined response PDU type:

- SCAN_REQ: The scanner requests user data of the advertiser via advertising channels.
- CONNECT_REQ: The scanner requests to setup a connection with the advertiser, thus forcing the advertiser to transit into the Connection state.

Advertising event	Advertiser PDU type	Scanner PDU type and compatibility	
		SCAN_REQ	CONNECT_REQ
Connectable undirected	ADV_IND	Yes	Yes
Connectable directed	ADV_DIRECT_IND	No	Yes
Non-connectable undirected	ADV_NONCONN_IND	No	No
Scannable Unidirected	ADV_SCAN_IND	Yes	No

Table 2-4: Advertiser PDU and Scanner PDU

2.3.3 PDU Payload

ADV_IND

The ADV_IND PDU is used in both the connectable and scannable undirected advertising events and is supported with the CMW-KD611 option. The payload field for the ADV_IND PDU consists of the AdvA and AdvData fields. The TxAdd bit in the advertising channel PDU header (Fig. 2-3) indicates whether the AdvA field is public (TxAdd = 0) or random (TxAdd = 1). The AdvData field may contain advertising data from the advertiser's host.

SCAN_REQ

The payload field for the SCAN_REQ PDU consists of the ScanA and AdvA fields. The TxAdd bit in the advertising channel PDU header indicates whether the scanners address in the ScanA field is public or random. The RxAdd bit in the advertising channel PDU header indicates whether the advertiser's address in the AdvA field is public or random. The payload is fixed to 12 bytes – an important aspect for receiver

PER measurements (see chapter 3.2.1). The payload field for the SCAN_REQ PDU consists of the ScanA and AdvA fields.

SCAN_RSP

The payload field for the SCAN_RSP PDU consists of AdvA and ScanRspData fields. The TXAdd bit in the advertising channel PDU header indicates whether the AdvA field is public or random. The ScanRspData field may contain advertising data from the advertiser's host.

PDU Type	ADV_IND		SCAN_REQ		SCAN_RSP	
Payload Fields	AdvA 6 octets	AdvData 0 - 31 octets	ScanA 6 octets	AdvA 6 octets	AdvA 6 octets	ScanRspData 0 - 31 octets
PDU Payload	6 - 37 octets		12 octets		6 - 37 octets	

Table 2-5: PDU content and payload as in [1]

2.3.4 Advertising Event Timing

All initial communication between two devices takes place via advertising channels contained within advertising events. Advertising events are defined as one or more advertising PDUs sent on the primary advertising channel starting with the first used advertising channel index (typically 37), and ending with the last used advertising channel index (typically 39).

An advertising event can be closed early after a CONNECT_IND is received or a SCAN_RSP PDU is sent. Advertising packets sent on the secondary channel indices are not part of the advertising event. The advertising event period T_advEvent between two consecutive events is given by: T_advEvent = advInterval + advDelay.

The advInterval period is an integer multiple of the slot period (625 µs) in the range 20 ms to 10.24 s. The advDelay parameter generated by the Link Layer for each Event, is a pseudo-random value with range 0 ms to 10 ms. This is done to improve robustness by moving the advInterval relative to other piconets.

Accordingly, the advertising measurement time duration depends on the total number of required advertising events. Longer event periods will inevitably lead to a longer measurement time as illustrated for the PER measurement in chapter 2.3.3, Table 3-1.

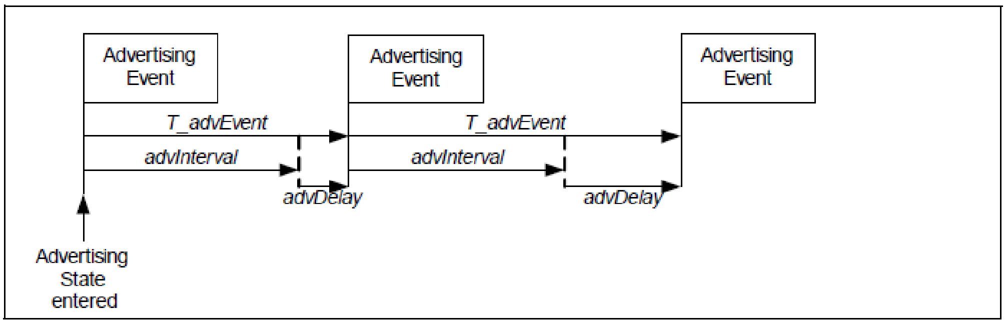

Fig. 2-4: Advertising event timing in the presence of a scanner [1]

No scanner interaction

The time between the beginning of two consecutive ADV_IND PDUs within an advertising event is specified ≤ 10ms. No lower bound is defined for the separation, the limitation will be defined by the EUT's PLL channel switching speed. Lower durations are preferred to conserve the advertising device's energy by shortening the transmit window requirements. Typically devices will implement a consecutive ADV_IND PDU period < 1ms.

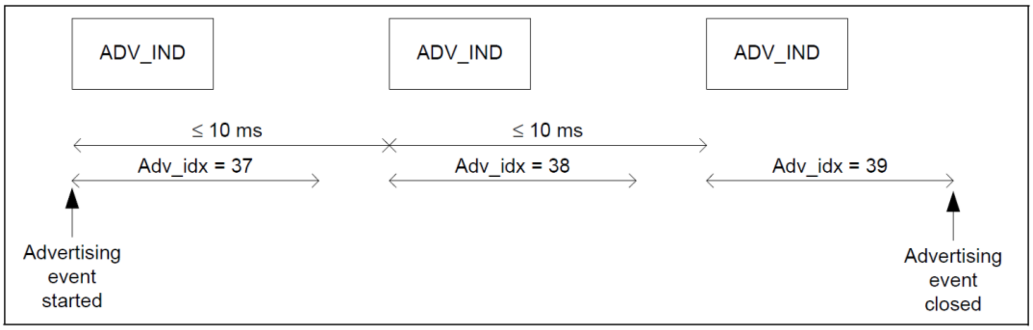

Fig. 2-5: Advertising event timing without scanner interaction [1]

Scanner interaction

The time between the beginning of two consecutive ADV_IND PDUs within an advertising event with scanner interaction (scanner replies with a SCAN_REQ PDU) is also defined as being ≤ 10 ms.

The period T_IFS is specified as the time from the end of the last bit of the previous packet to the start bit of the following packet. The so-called Inter Frame Space (IFS) period T_IFS is defined as 150 ± 2 µs.

The below diagram (Fig. 2-6) shows the advertiser and scanner interaction occuring on channel index 38. This also applies to channel indices 37 and 39, though not shown here.

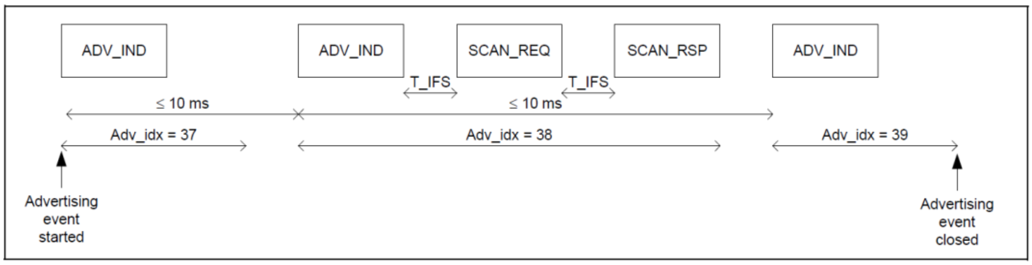

Fig. 2-6: Advertising event timing with scanner interaction [1]

3 OTA Measurements

This chapter introduces Bluetooth LE OTA measurements based on a single RF connection between the CMW and the EUT (Fig. 3-1). No Direct Test Mode (DTM) is used, the CMW and the EUT solely communicate via one of the three advertising channels. For RX and TX measurement results, the CMW analyses data from advertising PDUs sent by the EUT.

3.1 Test Setup

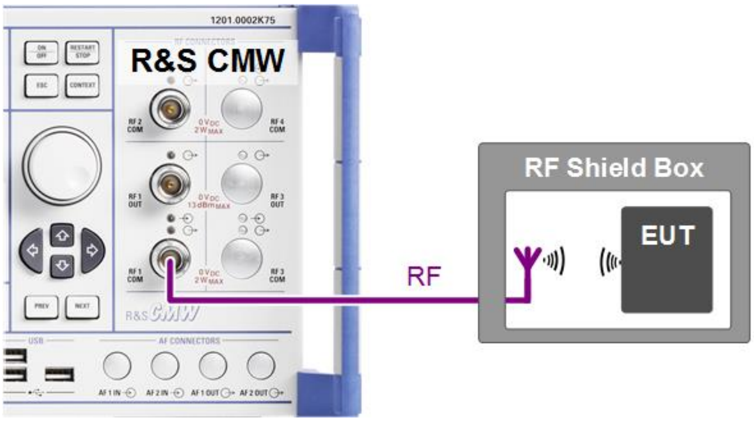

Fig. 3-1: Test setup for Bluetooth OTA measurements, exemplary with the R&S®CMW270

- The RF signal of the CMW is fed to the antenna port of the EUT.
- The EUT is placed in an RF shield box, e.g. the R&S®CMW-Z10.
- The RF shield box is connected to one of the bidirectional RF connectors on the front panel of the CMW.
- The CMW measures the EUT's reaction.

3.2 RX Measurements

3.2.1 Overview

The CMW-KD611 option supports three receiver measurement operational modes using only one advertising channel.

Spot Check

The CMW transmits one SCAN_REQ packet at a single specified power level. The CMW acknowledges the EUT's reaction by a simple PASS or FAIL receiver spot check corresponding to a packet count = 1 or 0 (Fig. 3-2).

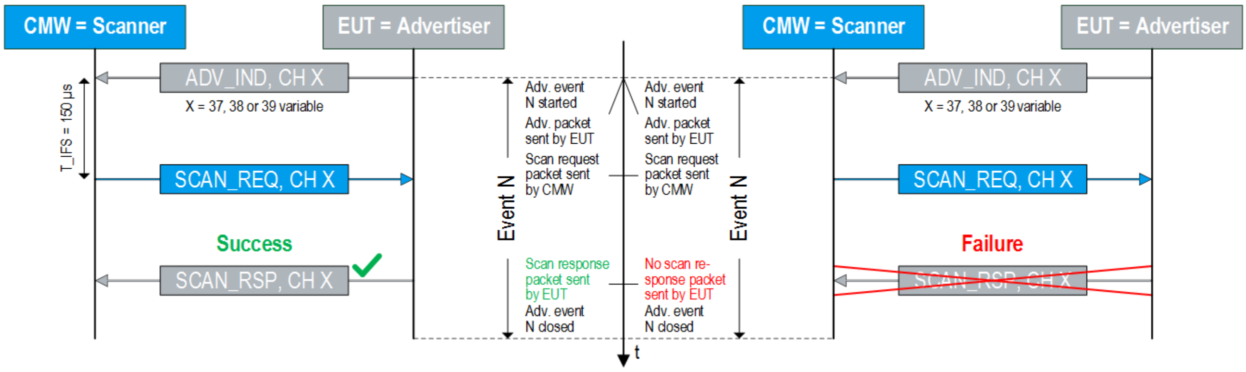

Fig. 3-2: Spot check measurement principle

PER Measurement

The CMW transmits the specified number of SCAN_REQ packets at constant power level and calculates packet error ratio (PER) statistics. In Fig. 3-3 below, the total number of SCAN_REQ packets is M. The method is similar to the DTM PER method but a packet count higher than one already provides PER statistics. The PER statistics are calculated as specified in the Bluetooth LE RF PHY specification [2].

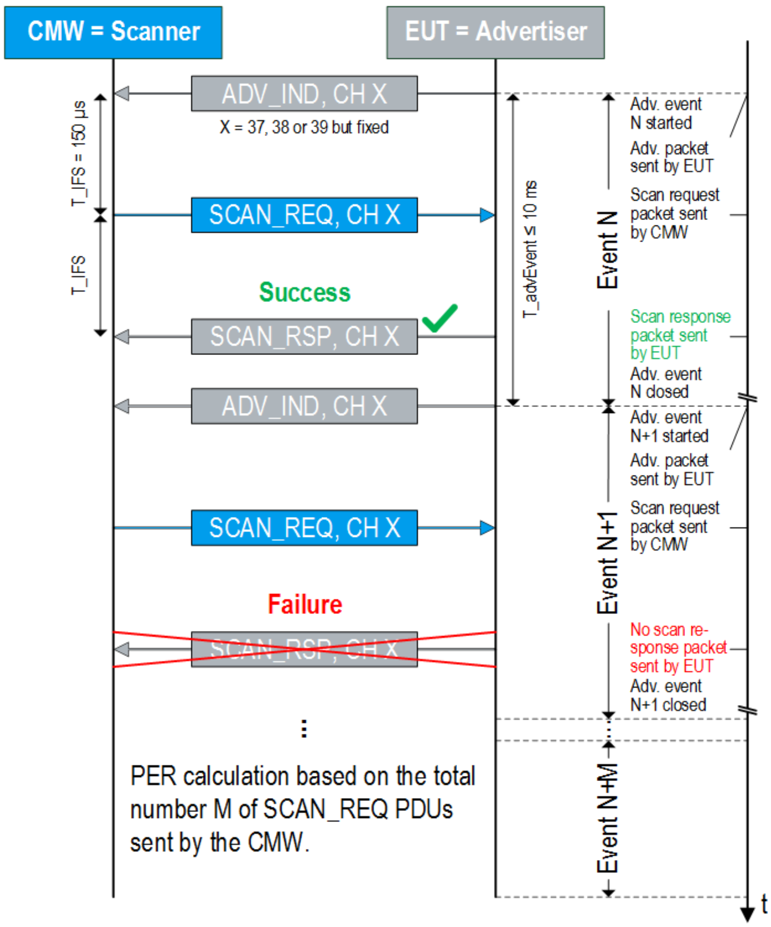

Fig. 3-3: PER measurement principle

Note, that the PER result is calculated assuming a 12 byte payload as specified for SCAN_REQ PDUs and does not conform with the minimum 37 byte payload mandatory for Bluetooth SIG qualification [1, 2]. Using Equation 3-1, the upper threshold PER value is 15.5 %.

$$\text{PER [\%]} = \left(1 - X^{[MAX_{LENGTH} * 8) + 72]}\right) * 100\ \%$$

Equation 3-1: PER upper threshold calculation

For SCAN_REQ PDUs: $X = 1 - \text{BER} = 0.999, MAX_{LENGTH} = 12$ => PER ≤ 15.5 %.

Sensitivity Search Measurement

The CMW transmits SCAN_REQ packets at decreasing power level and searches for the minimum power level sufficient for SCAN_RSP reception (Fig. 3-4). The initial CMW TX level is configured along with a step size. The CMW TX level is then iteratively reduced until the EUT does not respond any more. The level prior to the level with no response is documented in the search results section, namely the sensitivity level of the EUT.

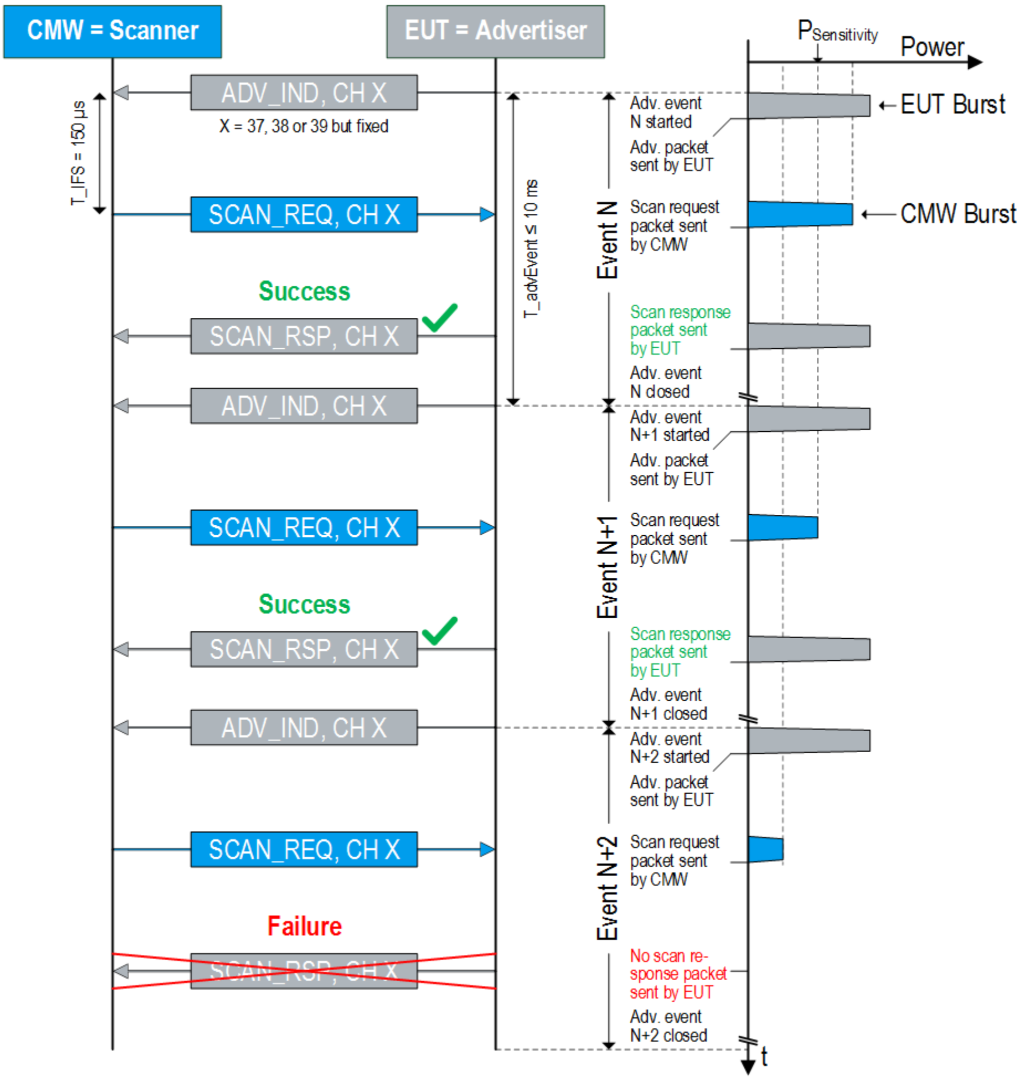

Fig. 3-4: Sensitivity search measurement principle

3.2.2 Procedures

To execute an RX measurement, proceed as follows:

1. Connect your EUT to the CMW (see Test Setup).
2. In the Bluetooth measurement, set scenario to "Standalone" for non-signaling mode.
3. Set Detection Mode to "Auto".
4. Set Burst Type to "Low Energy" and PHY (LE) to "LE1M".
5. Set Packet Type to "Advertiser".
6. Specify the RF center frequency of advertising channel.

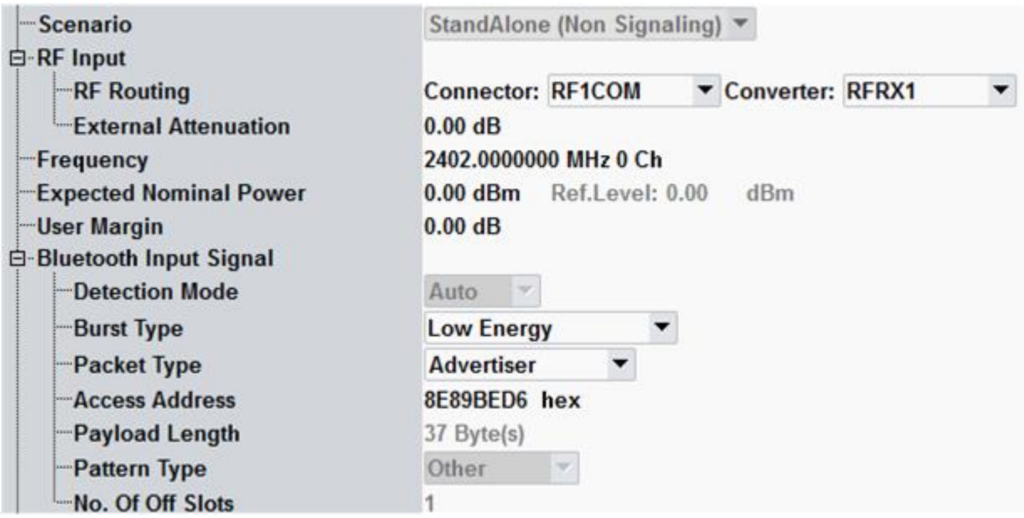

Fig. 3-5: Bluetooth RX measurement scenario and input signal settings

7. Set Trigger Source to 'Bluetooth Meas:Power'.

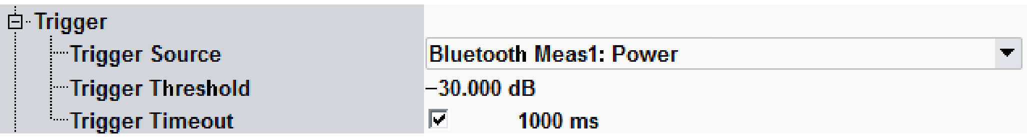

Fig. 3-6: Bluetooth RX measurement trigger settings

8. Configure output path for waveform signal transmission.
9. Specify Rx Measurement Control Settings (Fig. 3-7).
10. In particular, specify CMW Scanner Address and CMW Address Type.

    Note: You may have to change the address type, when you do not receive RX results.

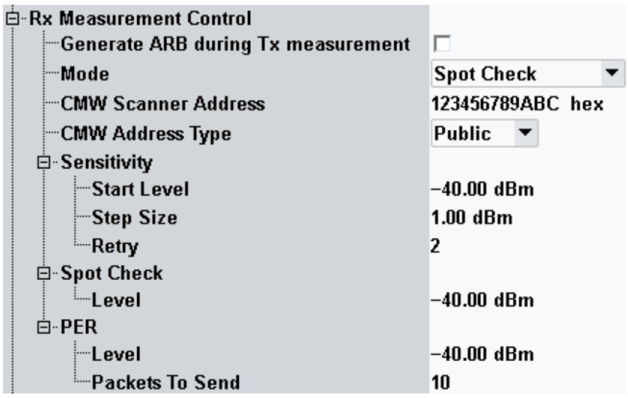

Fig. 3-7: Bluetooth RX measurement control settings

11. Select the softkey "Rx Meas" and switch on the signal generator and measurement:
    a) Press ON | OFF, or
    b) Right-click the softkey "Rx Meas" > "ON".
12. Evaluate the results.

3.2.3 Measurement Results

Spot Check

The spot check measurement presents three statistical result parameters in the "Rx Meas" tab:

- "Detected Address": device address of EUT. Both public and random address types are supported.
- "Level (CMW) [dBm]": TX level of the CMW for SCAN_REQ transmission
- "Spot Check": pass / fail test verdict

Additionally Fig. 3-8 illustrates the most important setting procedures for performing a spot check measurement as stated in chapter 3.2.2.

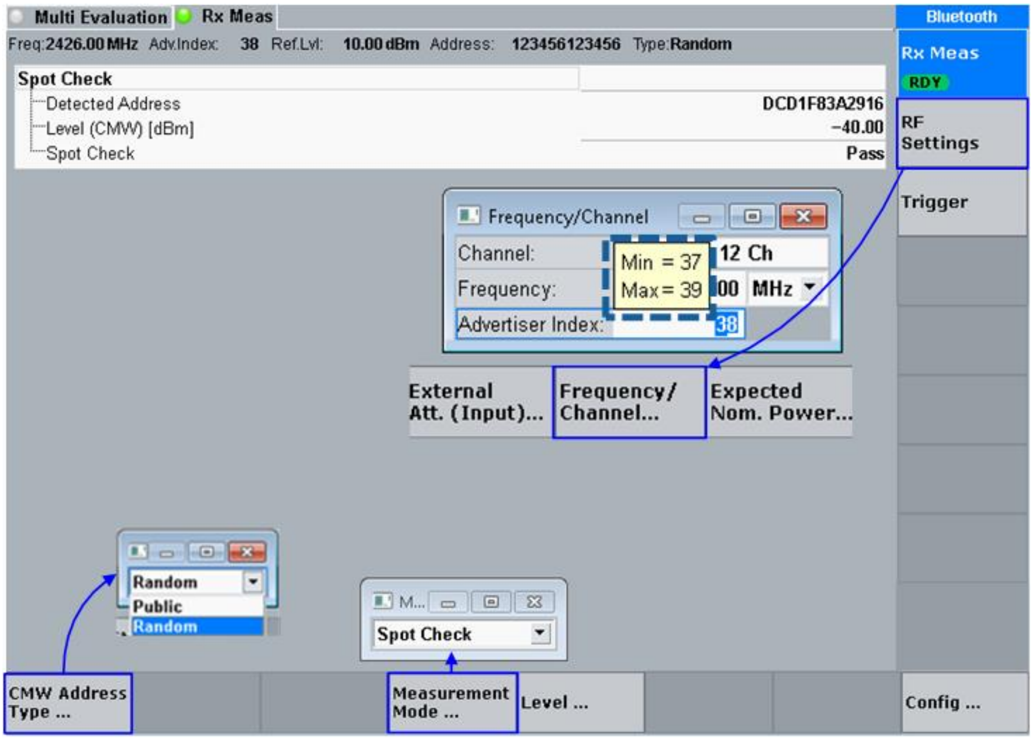

Fig. 3-8: Spot check measurement results

PER Measurement

The PER measurement presents four statistical result parameters in the "Rx Meas" tab:

- "Detected Address" and "Level (CMW) [dBm]": same as in spot check results above.
- "Number of Packets Received": number of SCAN_RSP packets received by the CMW since the start of a measurement.
- "PER": packet error rate, the ratio of corrupted and missing SCAN_RSP packets to the total number of transmitted SCAN_REQ packets in percent.
- "Packets Sent": number of SCAN_REQ packets transmitted by the R&S CMW, which are the reference value for PER calculation. After measurement start, this value indicates the number of transmitted packets and the total number of packets to be transmitted. Two equal numbers indicate that the measurement is finished.

Additionally Fig. 3-9 illustrates the most important setting procedures for performing a PER measurement as stated in chapter 3.2.2.

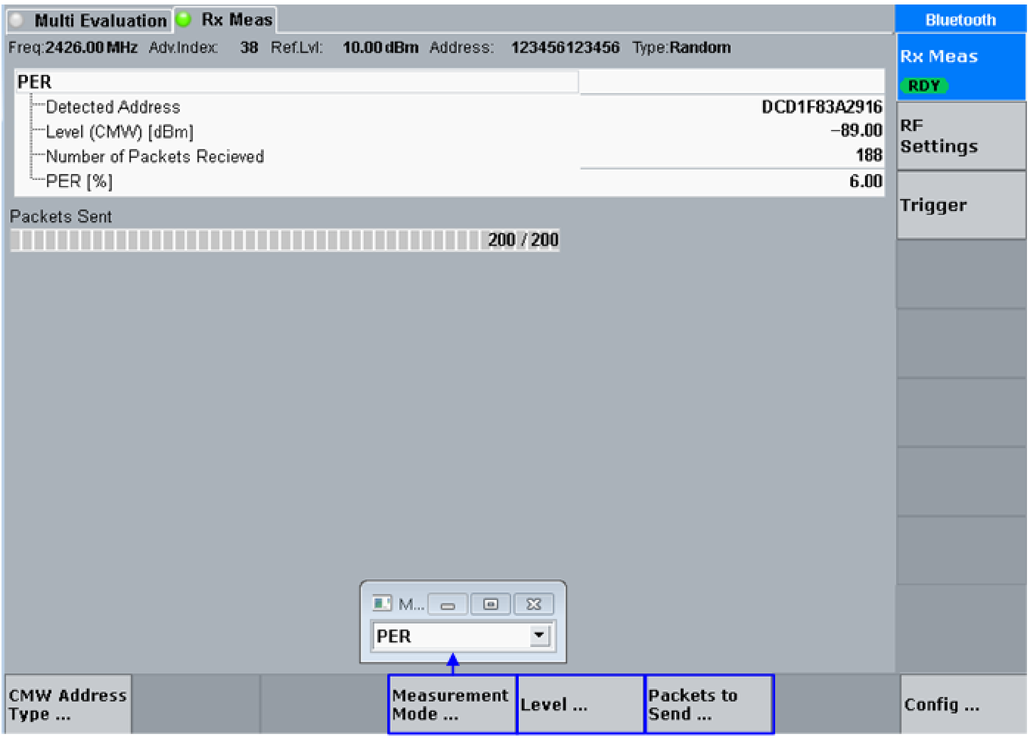

Fig. 3-9: PER measurement results

Note, that the PER measurement time crucially depends on the length of the advertising event interval period *advInterval*. As stated in chapter 2.3.4, this length has a range of 20 ms ≤ *advInterval* ≤ 10.24 s. Assuming a device advertising at maximum length, the PER measurement time for 1500 packets to send is more than four hours (Table 3-1).

Number of packets for PER measurement	Measurement time for *advInterval* = 20 ms	Measurement time for *advInterval* = 10 s
50 packets	1 s	500 s = 8.33 min
200 packets	4 s	2000 s = 33 min
1500 packets [2]	30 s	15000 s = 250 min = 4.16 h

Table 3-1: PER measurement time dependencies

In comparison, the measurement time of 1500 packets using DTM is about one second [2]. Thus, the measurement time using the OTA method with long advertising event periods is not acceptable for manufacturing testing purposes.

Senstivity Search Measurement

The sensitivity search measurement presents three statistical result and two configurable parameters in the "Rx Meas" tab:

- "Detected Address": same as in spot check results above.
- "Start Level (CMW) [dBm]": configurable initial TX level of CMW for SCAN_REQ transmission.

- "Step Size [dB]": configurable power step to decrease the level of SCAN_REQ transmission.
- "Current Level (CMW) [dBm]": actual TX level of the CMW.
- "Search Result [dBm]": the last TX level of the SCAN_REQ transmission, for which the SCAN_RSP packet was detected.

Additionally Fig. 3-10 illustrates the most important setting procedures for performing a spot check measurement as stated in chapter 3.2.2.

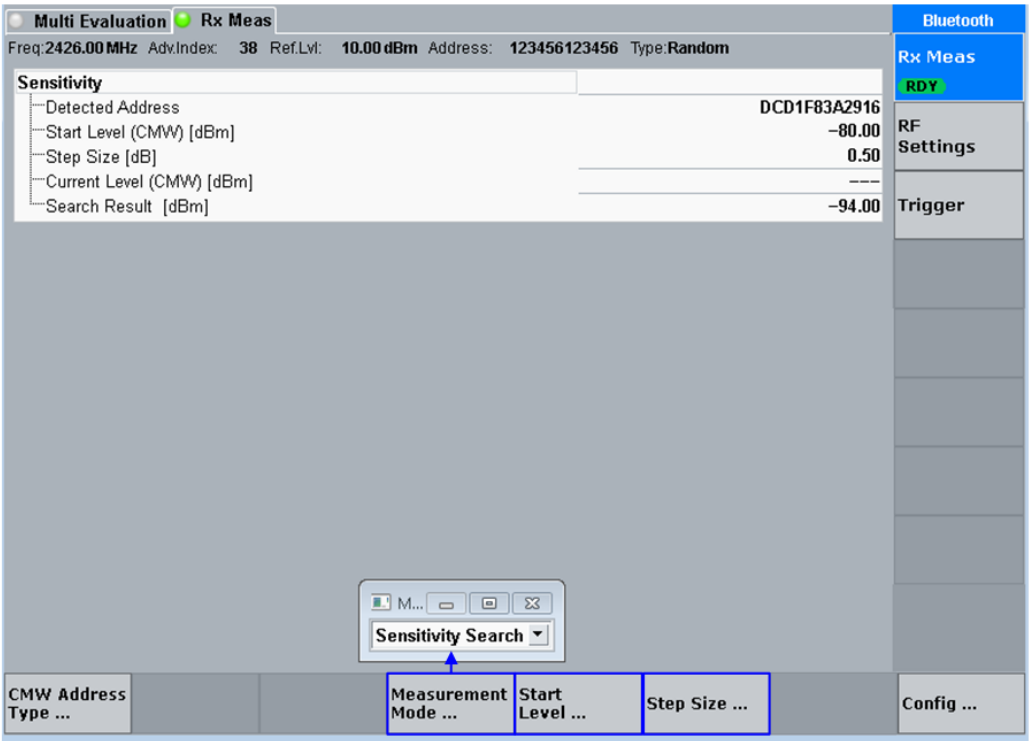

Fig. 3-10: Sensitivity search measurement

3.3 TX Measurements

3.3.1 Overview

Bluetooth LE v.4.2 TX measurements require the software options CMW-KM611. When using the option additional to the CMW-KD611 option, TX measurements can run in parralel to RX measurements. Addressing the same advertising PDUs this combination significantly reduces the total number of required advertising events, thus saving valuable manufacturing testing time.

TX measurements are performed on advertising PDUs with a variable payload length (6 to 37 bytes). No CMW interaction with the EUT required – the CMW is purely measuring advertising PDUs. Table 3-2 shows supported TX measurements.

Note, that the TX measurements do not conform with the Bluetooth LE RF test specification [2] as they do not use specified modulation patterns (see chapter 2.1.3). Moreover, the GFSK modulation measurements results are based on a mathematical search algorithm, which is different from the evaluation method specified in the Bluetooth LE RF test specification.

Power measurements	GFSK modulation measurements	Spectrum measurements
Nominal Power [dBm]	Frequency Accuracy* [kHz]	ACP [dBm] measurement ± 5 channels
Peak Power [dBm]	Frequency Offset* [kHz]	
Leakage Power [dBm]	Frequency Drift* [kHz]	
	Maximum Drift Rate* [kHz/50µs]	
	Freq. Deviation Δf_1* [kHz] avg, min, max	
	Freq. Deviation Δf_2* [kHz] avg, min, max	
	Δf_2 99%* [kHz]	
	Δf_1 avg / Δf_2 avg*	
* GFSK modulation measurements do not conform with the Bluetooth SIG specification.		

Table 3-2: TX measurements on advertising PDUs

A comprehensive summary of Bluetooth LE TX measurements using DTM is given in the 1MA282 application note "Bluetooth® Low Energy (V5.0) RF-Test for Internet of Things Applications" [3].

3.3.2 ARB Waveform Generation

Before evaluating RX characteristics during an OTA manufacturing measurement sequence, it is useful to identify advertiser data from a preceding TX measurement. Thus, RX measurements do not require training phase (more measurements) in order to be performed correctly. Training events are used to determine advertising PDU characteristics such as address and PDU payload.

The CMW-KD611 option allows for auto-detection of the advertiser's address and PDU payload length in TX multi evaluation measurement (MEV) mode. An ARB waveform file can be generated during this measurement containing all information needed to perform the RX measurements in chapter 3.2.1.

Open the "Rx Measurement Control" settings to enable this feature. Ticking the checkbox "Generate ARB during Tx measurement" will generate three SCAN_Req ARB waveforms, one for each advertising channel 37, 38, and 39, during a TX MEV measurement (Fig. 3-11).

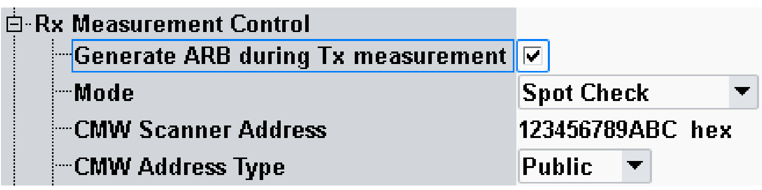

Fig. 3-11: Enabling ARB waveform generation

Generating one waveform per channel is needed because the waveforms are generated with whitening enabled. All subsequent RX measurements performed on an EUT with the same advertiser address can reuse these waveforms. The waveform files are stored in a temporary folder and available for later use.

3.4 Manufacturing Sequence Overview

This chapter gives an overview of a typical manufacturing sequence using the CMW-KD611 option. Manufacturing testing time can be saved by reducing the ADV_IND event periods and the total number of needed advertising events.

For shorter consecutive ADV_IND periods (≤ 1.5ms), an additional advertising event period is required. TX measurements using TX Multi Evalutaion List Mode (MELM) will result in the same number of needed advertising events, or one less, than TX measurements using TX multi evaluation measurement (MEV) mode.

The overall testing time can be minimized, when the TX measurements on the advertising channel indices 37, 38 and 39 are performed before the RX measurements. RX Spot Check measurements are considered here only.

Start therefore with the TX measurements as described in Table 3-3 and proceed with the RX measurements as described in Table 3-4.

Parameter	ADV Event	ADV Event	ADV Event	Comments
Channel (CH) Index	CH 37	CH 38	CH 39	3 channels available
TX Measurement	TX MEV	TX MELM	TX MELM	
	Training	Segment #1	Segment #2	
Generate ARB waveform state	ON	OFF	OFF	Generate 3 waveforms during training phase for RX spot check measurements
Consecutive ADV_IND Period < 1.5ms	1	1 (1 Segment)	1 (1 Segment)	3 ADV events needed (worst case)
Consecutive ADV_IND Period > 1.5ms	1	1 (2 Segments)	-	2 ADV events needed (best case)

Table 3-3: Initial TX measurements during a manufacturing sequence

Parameter	ADV Event	ADV Event	ADV Event	Comments
Channel (CH) Index	CH 37	CH 38	CH 39	3 channels available
RX Measurement	Spot Check	Spot Check	Spot Check	
Generate ARB waveform state	ON	ON	ON	Use pregenerated waveforms to avoid the necessity of additional training events before each RX spot check measurement
Consecutive ADV_IND Period < 1.5ms	1	1	1	In total (3 TX and 3 RX) 6 ADV events needed (worst case)
Consecutive ADV_IND Period > 1.5ms	1	1	1	In total (2 TX and 3 RX) 5 ADV events needed (best case)

Table 3-4: Subsequent RX measurements during a manufacturing sequence

The tables above further illustrate, how many advertising events are required for sufficient evaluation of the EUT's RX and TX characteristics during a manufacturing sequence. Accordingly, the length of the average manufacturing sequence time T_{SEQ_AVG} can be estimated:

- $T_{SEQ\_AVG} = [T_{advEvent} \times 5] + [T_{advEvent} / 2]$ for a consecutive ADV_IND period ≥ 1.5 ms
- $T_{SEQ\_AVG} = [T_{advEvent} \times 6] + [T_{advEvent} / 2]$ for a consecutive ADV_IND period < 1.5 ms

4 Literature

[1] **Bluetooth SIG** Bluetooth Core Specification [Online]. - 12 2, 2014. - 4.2. - https://www.bluetooth.com/specifications.

[2] **Bluetooth SIG** Bluetooth RF PHY Test Specification RF-PHY.TS 4.x.x [Online]. - July 2016. - 4.2.3. - https://www.bluetooth.com/specifications.

[3] **Rohde & Schwarz** Bluetooth® Low Energy (V5.0) RF-Test for Internet of Things Applications [Online] // Application Note. - 2017. - https:\\www.rohde-schwarz.com/appnote/1MA282.

[4] **Rohde & Schwarz** Configuration of the R&S CMW for Bluetooth Low Energy Direct Test Mode [Online] // Application Note. - 2017. - https://www.rohde-schwarz.com/appnote/1C105.

[5] **Rohde & Schwarz** R&S®CMW-KM61x/-KM721/-KD611/-KS60x/-KS61x/-KS721 Bluetooth® Firmware Applications // User Manual. - 2017.

5 Ordering Information

Mandatory hardware		
Designation	**Type**	**Order No.**
Radio Communication Tester	CMW270 CMW100	1201.0002K75 1201.0002K06
Basic Assembly	CMW-PS272 (CMW270) CMW-PS16 (CMW100)	1202.9303.02 1210.7629.03
Baseband Measurement Unit	CMW-S/B100A[1)]	1202.8607.02
Measurement Unit Advanced (MUA)	CMW-S/B100H (for CMW270 only)	1202.4701.09
Optional hardware		
Designation	**Type**	**Order No.**
Baseband RF Generator Module	CMW-S/B110A	1202.5508.02
Signaling Unit Advanced (SUA)	CMW-S/B500I	1208.7954.10
Signaling Unit Universal (SUU)	CMW-S/B200A	1202.6104.02
[1)] A CMW-Sxxx option refers to a single component solely used, a CMW-Bxxx option refers to a component additionally used to the already used CMW-Sxxx option.		

Table 5-1: CMW hardware requirements

Mandatory software		
Designation	**Type**	**Order No.**
Bluetooth Low Energy Version 4.2 Advertiser Measurement with ARB Generator	CMW-KD611[1)]	1211.1582.xx
Bluetooth Low Energy Version 4.2 Tx Measurement	CMW-KM611	1203.9307.xx
[1)] The CMW270 requires an additional measurement unit advanced (see Table 5-1).		
Optional software		
Designation	**Type**	**Order No.**
Bluetooth Low Energy Version 4.2 Signaling	CMW-KS611	1207.8805.xx
Bluetooth Tx Measurement Multi-Evaluation List Mode	CMW-KM012	1203.4457.xx

Table 5-2: CMW software requirements

Appendix

In the following programming examples, the remote command mnemonics are given in short form only. For the long form and more RX measurement examples, please refer to the Bluetooth firmware applications user manual [4].

Example 1: RX Measurement Initial Configuration

```
// Set the RX Port & Convertor.
ROUT:BLU:MEAS:SCEN:SAL <Port, Convertor>
// Set the external attenuation to specify input losses.
CONF:BLU:MEAS:RFS:EATT <Attenuation>
// Define the expected nominal power level.
CONF:BLU:MEAS:RFS:ENP <ENP>
// Set the measurement frequency.
CONF:BLU:MEAS:RFS:FREQ <Frequency>
// Set LE for the measured burst type.
CONF:BLU:MEAS:ISIG:BluetoothYP LE
// Set the Bluetooth LE physical layer packet type 1 Msymbols/s.
CONF:BLU:MEAS:ISIG:LEN:PHY LE1M
// Set the advertising mode.
CONF:BLU:MEAS:ISIG:PTYP:LEN ADV
// Set the access address of the advertiser.
CONF:BLU:MEAS:ISIG:ACC:LEN H8E89BED6
// Select the single shot repetition mode.
CONF:BLU:MEAS:MEV:REP SING
// Set the trigger threshold.
TRIG:BLU:MEAS:MEV:THR <Trigger Threshold>
// Set the measurement timeout.
CONF:BLU:MEAS:MEV:TOUT 0
// Set the trigger timeout.
TRIG:BLU:MEAS:MEV:TOUT <Trigger Timeout>
// Specify no measurement stop condition.
CONF:BLU:MEAS:MEV:SCON NONE
// Disable measuring on exception.
CONF:BLU:MEAS:MEV:MOEX OFF
// Specify the measurement results for power versus time and
// modulation only.
CONF:BLU:MEAS:MEV:RES
OFF,OFF,ON,OFF,OFF,OFF,OFF,OFF,ON,OFF,OFF,OFF,OFF,OFF
// Specify the measurement statistic count for TX MEV
// measurements.
CONF:BLU:MEAS:MEV:SCO:MOD 1
CONF:BLU:MEAS:MEV:SCO:PVT 1
// Specify the CMW address and type prior to enabling TX ARB
// waveform generation. This chronological order is crucial.
CONF:BLU:MEAS:RXQ:SADD <#Hxxxxxxxxxx>
CONF:BLU:MEAS:RXQ:SATY <Address Type>
// Enable ARB waveform generation from the TX measurement.
CONF:BLU:MEAS:RXQ:GARB ON
```

```
*OPC?
SYST:ERR?
```

Example 2a: Performing a Training Phase on a Single Channel (TX MEV)

```
// Execute training phase: Start TX Measurement, return PvT
// and modulation current results, payload length (0 to 31),
// advertiser address, packet and pattern type. Disable ARB
// waveform generation.
FETC:BLU:MEAS:MEV:PVT:LEN:LE1M:CURR?
FETC:BLU:MEAS:MEV:MOD:LEN:LE1M:CURR?
FETC:BLU:MEAS:ISIG:ADET:PLEN:LEN:LE1M?
FETC:BLU:MEAS:ISIG:ADET:AADD:LEN:LE1M?
FETC:BLU:MEAS:ISIG:ADET:PTYP:LEN:LE1M?
FETC:BLU:MEAS:ISIG:ADET:PATT:LEN:LE1M?
CONF:BLU:MEAS:RXQ:GARB OFF
*OPC?
SYST:ERR?
```

Example 2b: Performing a Training Phase on Multiple Channels (TX MELM)

```
// Alternatively to measure at multiple channels, use list mode:
// enable list mode, set the number of segments to two, enable
// only modulation and PvT measurements, set statistic count to
// 1. Start the TX Measurement, return PvT and modulation
// current results. Disable list mode. Disable ARB waveform
// generation.
CONF:BLU:MEAS:MEV:LIST ON
CONF:BLU:MEAS:MEV:LIST:COUN 2
CONF:BLUetooth:MEAS:MEV:LIST:SEGM1:SET
LE,ADV,OTH,27,1,1,OFF,7,2426E+6,NARR,ON
CONF:BLUetooth:MEAS:MEV:LIST:SEGM2:SET
LE,ADV,OTH,27,1,1,OFF,7,2480E+6,NARR,ON
CONFigure:BLUetooth:MEAS:MEValuation:LIST:SEGM1:RESult
ON,ON,OFF,OFF,OFF
CONFigure:BLUetooth:MEAS:MEValuation:LIST:SEGM2:RESult
ON,ON,OFF,OFF,OFF
CONFigure:BLUetooth:MEAS:MEValuation:LIST:SEGM1:SCOunt 1,1,1,1,1
CONFigure:BLUetooth:MEAS:MEValuation:LIST:SEGM2:SCOunt 1,1,1,1,1
INITiate:BLUetooth:MEAS:MEValuation
FETCh:BLUetooth:MEAS:MEValuation:LIST:SEGM1:MODulation:CURRent?
FETCh:BLUetooth:MEAS:MEValuation:LIST:SEGM2:MODulation:CURRent?
FETCh:BLUetooth:MEAS:MEValuation:LIST:SEGM1:PVTime:CURRent?
FETCh:BLUetooth:MEAS:MEValuation:LIST:SEGM2:PVTime:CURRent?
CONFigure:BLUetooth:MEAS:RXQ:GARB OFF
*OPC?
SYST:ERR?
```

Example 3: Performing an RX Spot Check

```
// Select the spot check measurement mode, specify the TX Level,
// enable ARB waveform generation.

CONF:BLU:MEAS:RXQ:MMOD SPOT
CONF:BLU:MEAS:RXQ:SPOT:LEV <Level>
CONF:BLU:MEAS:RXQ:GARB ON
*OPC?
SYST:ERR?

// Specify the frequency of channel 37, start the RX measurement
// and return spot check measurement results of channel 37.
CONF:BLU:MEAS:RFS:FREQ 2402E+6
*OPC?
INIT:BLU:MEAS:RXQ
FETC:BLU:MEAS:RXQ:SPOT?

// Specify the frequency of channel 38, start the RX measurement
// and return spot check measurement results of channel 38.
CONF:BLU:MEAS:RFS:FREQ 2426E+6
*OPC?
INIT:BLU:MEAS:RXQ
FETC:BLU:MEAS:RXQ:SPOT?

// Specify the frequency of channel 39, start the RX measurement
// and return spot check measurement results of channel 39.
CONF:BLU:MEAS:RFS:FREQ 2480E+6
*OPC?
INIT:BLU:MEAS:RXQ
FETC:BLU:MEAS:RXQ:SPOT?
```

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