Advanced Bluetooth RF Tests with R&S CMWrun

Application Note

Products:

- R&S®CMW500
- R&S®CMW290
- R&S®CMW270
- R&S®CMW100
- R&S®SGS100A
- R&S®SGT100A
- R&S®SMA100A
- R&S®SMBV100A
- R&S®SMC100A
- R&S®SMF100A
- R&S®SMW200A

The Rohde & Schwarz Bluetooth RF test solution with the R&S®CMW and R&S®CMWrun is closely aligned to the Bluetooth RF Test Suite. Most of the tests can be performed with the equipment under test connected to a single R&S®CMW which is remotely controlled via R&S®CMWrun running on an external computer. Some of the tests require an additional signal generator. This document describes common setups for these tests and the required configurations.

Note:

Please find the most up-to-date document on our homepage http:\\www.rohde-schwarz.com/appnote/1MA261.

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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The following abbreviations are used in this application note for Rohde & Schwarz test equipment:

The R&S®CMW500, the R&S®CMW290, the R&S®CMW270 and the R&S®CMW100 are referred to as the CMW.

The R&S®CMWrun Sequencer Software Tool is referred to as CMWrun.

The R&S®SGS100A, the R&S®SGT100A, the R&S®SMA100A, the R&S®SMBV100A, the R&S®SMC100A, the R&S®SMF100A and the R&S®SMW200A are referred to as the SGS, the SGT, the SMA, the SMBV, the SMC, the SMF and the SMW respectively.

1 Introduction

The Rohde & Schwarz testing solution for the Bluetooth RF tests is closely aligned with the Bluetooth RF Test Suite 4.2.3 which comprises sets of transmission (TRM) and receiver (RCV) tests. Most of the tests can be performed with the equipment under test connected to a single CMW which is remotely controlled via CMWrun running on an external computer. Some of the tests require an additional signal generator or a specially equipped CMW. Rohde & Schwarz calls these tests “advanced”.

The group of advanced Bluetooth RF tests consists of the following tests (test purposes in terms of the RF Test Suite):

For the burst types Basic Rate (BR) and Enhanced Data Rate (EDR), both also known as Bluetooth® Classic:

- TRM/CA/02/C: Power density
- RCV/CA/03/C: C/I performance
- RCV/CA/04/C: Blocking performance
- RCV/CA/05/C: Intermodulation performance
- RCV/CA/09/C: EDR C/I performance

TRM/CA/02/C requires a spectrum analyzer. The listed RCV tests require interferer signals in addition to the usual Bluetooth RF signals. In RCV/CA/03/C, RCV/CA/05/C and RCV/CA/09/C a Bluetooth interferer is added to the wanted Bluetooth RF signal. In RCV/CA/04/C the interferer is a pure sine wave (CW) covering a range up to 12.75 GHz. RCV/CA/05/C uses a sine wave interferer in addition to the Bluetooth interferer.

For Bluetooth Low Energy (LE), which is also known as Bluetooth® Smart:

- RCV-LE/CA/03/C: C/I and receiver selectivity performance
- RCV-LE/CA/04/C: Blocking performance
- RCV-LE/CA/05/C: Intermodulation performance

The hardware and interferer requirements for these low energy tests are the same as for the corresponding BR/EDR tests.

This document describes the characteristics of the advanced tests, the test setups and the necessary configurations.

2 General

2.1 Test Setup

There are two main setups which allow to carry out all advanced tests: a setup for a CMW with one or two advanced frontends and a setup for a CMW with two basic frontends. Only these cases are described here, though some of the advanced tests could be realized with alternative setups.

General characteristics:

- The RF continuous wave interferer is provided by an additional signal generator, e.g. the SGS.
- The Bluetooth interferer is realized by playing appropriate waveform files from the CMW’s general purpose generator. The waveform files are provided by CMWrun.
- The RF signals from/to the CMW and the RF continuous wave interferer from the signal generator are combined/split via a power combiner/splitter device up to 12.75 GHz (e.g. Weinschel 1515 1 or Minicircuits ZFRSC-183+, resistive combiner).
- Both the CMW and the continuous wave signal generator are controlled by CMWrun on an external control computer.
- The spectrum analyzer measurements for the TRM/CA/02/C test are carried out by the CMW-internal spectrum analyzer.
- For Bluetooth Low Energy tests in direct test mode the Equipment Under Test (EUT) is controlled via an additional connection between CMW and EUT.
- An optional filter (e.g. 2.4 GHz ISM band reject filter) suppresses any harmonics of the signal generator falling in-band.

Fig. 2-1 shows which test needs which instruments.

Tests	Instruments and options			
	CMW			CW Generator
	Channel 1	Channel 2		CW
	wanted signal	BT Interferer	Spectrum Analyzer	up to 12.75 GHz
Basic / EDR				
Power Density	☑	---	☑	---
C/I Performance	☑	☑	---	---
Blocking	☑	---	---	☑
Intermodulation	☑	☑	---	☑
EDR C/I	☑	☑	---	---
Low Energy				
C/I LE	☑	☑	---	---
Blocking LE	☑	---	---	☑
Intermodulation LE	☑	☑	---	☑

needed for the measurement (exact this one)	☑
not used	---

Fig. 2-1: Tests and instruments

CMW with one Advanced Frontend (R&S CMW-S590D)

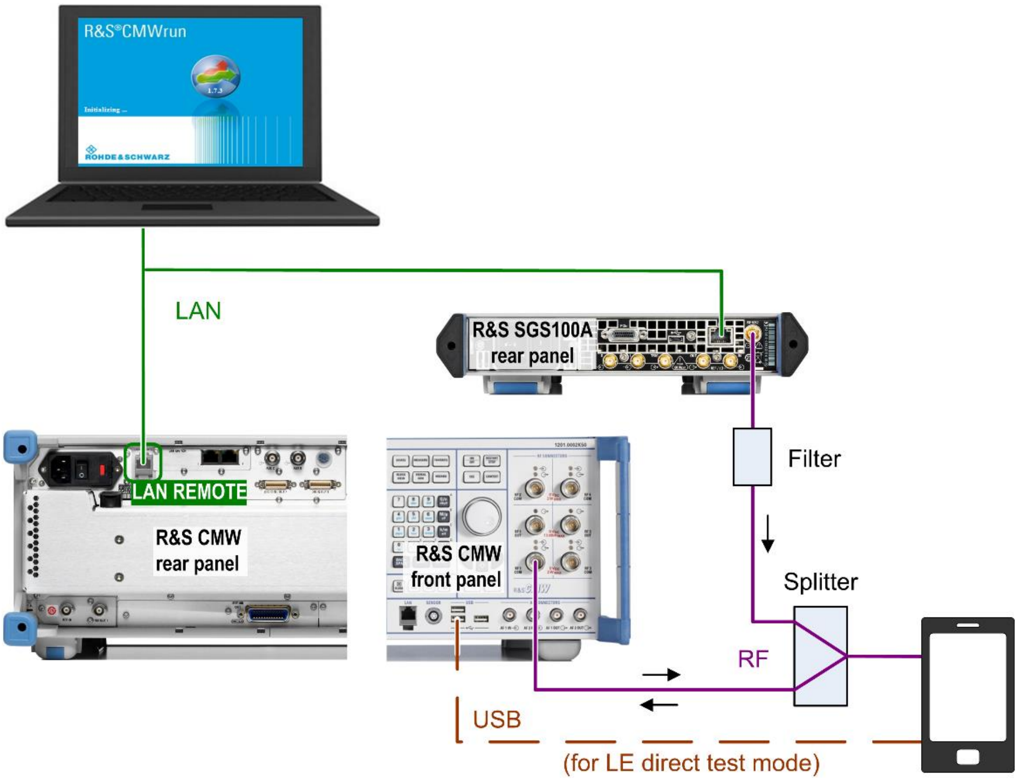


Fig. 2-2: Test setup for a CMW with 1 advanced frontend

Connections:

- The CMW and the SGS are LAN-connected with the CMWrun PC.
- The RF port of the EUT is connected with the combiner/splitter.
- The Bluetooth uplink/downlink signals are routed to RF 1 COM or RF 2 COM. This connection also carries the Bluetooth interferer signal and the signal to be measured by the CMW's spectrum analyzer.
- The RF Out port of the SGS is connected with the splitter.
- For Bluetooth Low Energy tests in direct test mode, the EUT is USB-connected with the CMW. If the EUT only provides a serial RS-232 port for the direct test mode connection, a USB to RS232 adapter is required.

R&S CMW with two Basic Frontends (2 x R&S CMW-B590A)

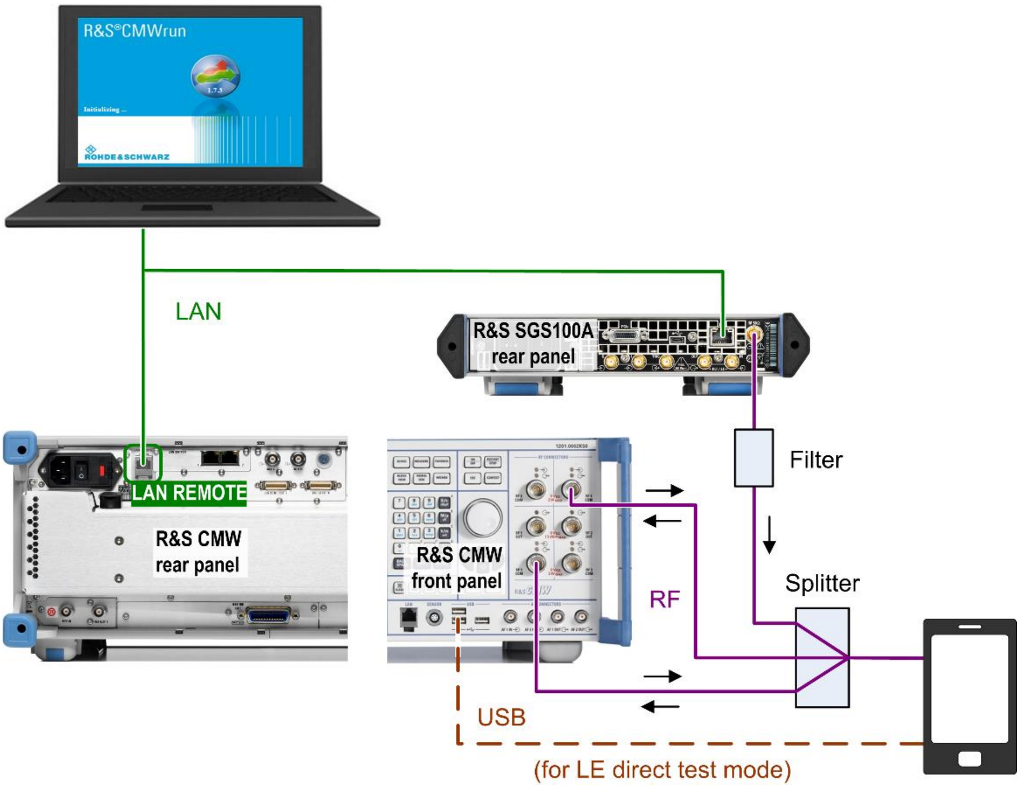


Fig. 2-3: Test setup for a CMW with 2 basic frontends

The test setup in Fig. 2-3 with two basic frontends provides a greater isolation between the RF COM ports. This test setup is preferred to the test setup with one advanced frontend in Fig. 2-2.

Connections:

- The CMW and the SGS are LAN-connected with the CMWrun PC.
- The RF port of the EUT is connected with the combiner/splitter.
- The Bluetooth uplink/downlink signal is routed to RF 1 COM or RF 2 COM (resp. RF 3 COM or RF 4 COM).
- The Bluetooth interferer signal is routed to connector RF 3 COM or RF 4 COM (resp. RF 1 COM or RF 2 COM). This connection also carries the EUT's RF signals to be measured by the CMW's spectrum analyzer.
- The RF Out port of the SGS is connected with the splitter.
- For Bluetooth Low Energy tests in direct test mode, the EUT is USB-connected with the CMW. If the EUT only provides a serial RS-232 port for the direct test mode connection, a USB to RS232 adapter is required.

2.2 Hardware and Software Requirements

2.2.1 CMW

The advanced Bluetooth RF tests are performed on one CMW500 or CMW270. Additionally, a signal generator like the SGS100A is required for generating the continuous wave interference signals. The following table shows the required CMW hardware configuration in terms of hardware options. Different CMW configurations are possible.

Radio Communication Tester

- CMW500 or CMW270
- Basic Assembly up to 3.3 GHz: PS503 (CMW500) or PS272 (CMW270)
- Baseband Measurement Unit: B100A
- Baseband Measurement Generator: B110A
- Baseband Interconnection Board: S550B
- RF Converter Module: S570B
- Extra RF Converter Module: B570B
- Signaling Unit Universal (SUU): B200A
- Advanced RF Frontend (S590D) or 2 Basic RF Frontends (S590A + B590A)
- Software Options:
  - Bluetooth Basic Signaling (KS600)
  - Bluetooth BR/EDR Signaling (KS610)
  - Bluetooth, BR/EDR, TX Measurement (KM610)
  - Bluetooth Low Energy Signaling (KS611)
  - Bluetooth, Low Energy, TX Measurement (KM611)
  - Spectrum Analyzer (KM010)

Note: An extended frequency range 3.3 GHz to 6 GHz (CMW-KB036) is not required on the CMW. For blocking tests a frequency operation range up to 12.75 GHz is required. This is handled with an additional signal generator operating at frequencies above 2561 MHz.

CW Generator

A CW signal generator provides the additional CW signal required for blocking tests. Table 2-1 shows the operational frequency range of CW signal generators supported in CMWrun. CW signal generators capable of operating up to 12.75 GHz are mandatory in order to completely meet the requirements for blocking tests.

CW signal generators for blocking tests		
CW signal generator	**Frequency range**	**Option for f > 3 GHz**
SMA	9 kHz – 6 GHz	required
SMBV	9 kHz – 6 GHz	required
SMC	9 kHz – 3.2 GHz	not provided
SMF	1 GHz – 22 GHz	not required
SMW	100 kHz – 12.75 GHz	required
SGS	1 MHz – 12.75 GHz	required
SGT	1 MHz – 6 GHz	required

Table 2-1: Operational frequency range of CW signal generators for blocking tests

Note: The SGS CW signal generator is used throughout this application note to illustrate the requirements for blocking tests. Any of the signal generators in the table above can be used in the same way, though some of them do not cover the mandatory frequency range up to 12.75 GHz.

2.2.2 PC

The CMWrun sequencer software requires at least the following computer hardware and software:

- Processor: 1300 MHz (x86)
- Memory: 1 Gbyte minimum
- HDD space: 80 Mbyte minimum
- Operating system: Windows XP (32-bit edition with SP3) or Windows 7 (32-bit or 64-bit version)
- Software: Microsoft .Net Framework 4.0 or higher
- VISA

You need administration rights on the computer to perform the installation.

2.3 CMWrun

2.3.1 Basics

CMWrun is a ready-to-use automation software for configuring test sequences by remote control for all supported standards in the CMW family. The software engine is based on the execution of test DLLs (plug-in assemblies). This architecture not only allows easy and straightforward configuration of test sequences without knowledge of specific remote programming of the instrument. It also provides full flexibility in configuring parameters and limits of the test items provided in the CMWrun package options for the different standards. At the end of the test, an easy to read test report with limits, test results and verdict is generated and available in several formats, csv, txt, xml and pdf as well.

The option KT057 (Wireless connectivity standards: WiMAX, WLAN, Bluetooth) for CMWrun remote controls the entire setup for Bluetooth as ready-to-go solution for testing in line with the specification [1] and [2]. It is the right choice for configuring test sequences by remote control, and creating complete pass/ fail test protocols.

Four pre-configured testplans are delivered as examples:

- Bluetooth BR and EDR
  - BTH_RF_TS_4_2_3_Advanced_FE-Advanced
  - BTH_RF_TS_4_2_3_Advanced_2_FE-Basic
- Bluetooth Low Energy
  - BLE_PHY_4_2_3_Advanced_FE-Advanced
  - BLE_PHY_4_2_3_Advanced_2_FE-Basic

2.3.2 Configuration

CMWrun controls the CMW as well as the additional signal generator via SCPI commands over LAN connections. All configurations are done at CMWrun. There is a test plan for the Bluetooth BR/EDR tests and another one for the Bluetooth Low Energy tests. The configurations are done separately for both test plans.

The configurations include the following main steps:

- The SCPI connections between CMWrun and the CMW and the additional signal generator are established.
- The connections with the EUT are configured in test modules. This includes:
  - CMW RF connection(s) taking into account the CMW equipment
  - Connection with the additional signal generator
  - Bluetooth Low Energy: Connection for direct test mode
- The individual tests are configured.

The following sections provide details for these configuration tasks. For more information about configuration please refer to the CMWrun User Manual.

2.3.2.1 SCPI Connections

The SCPI connections to the CMW and the additional signal generator are based on the VXI-11 protocol. CMWrun addresses the instruments either by IP address or by instrument name and serial number. This address information is contained in the “Resource Name”.

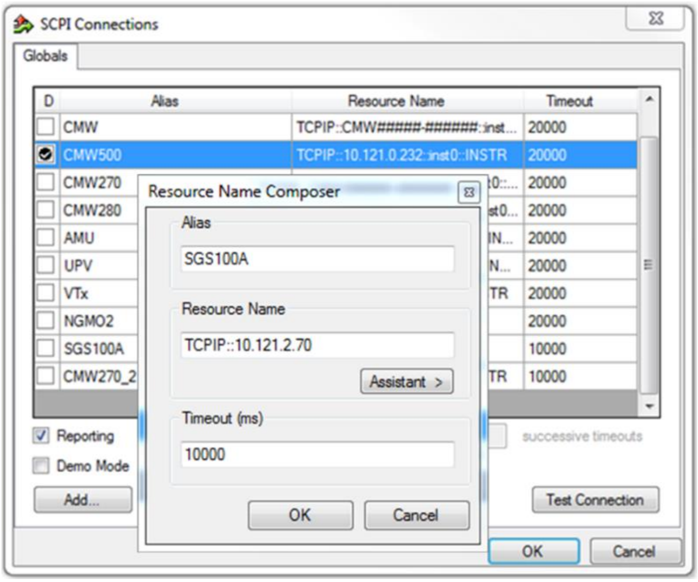


Fig. 2-4: SCPI connection setup

Establishing the SCPI connection with the CMW

1. From the CMWrun menu bar select "Resources", then select "SCPI Connections".
2. In the “SCPI Connections” window, click “Add”.
3. In the "Resource Name Composer" window, enter an "Alias", i.e. an arbitrary name that you choose to identify the connection.
4. Enter the "Resource Name".
   - If you know the resource name, enter it directly. For the CMW, you can find the resource names on the CMW in the "Setup" dialog: "Setup" > "Remote".
   - Otherwise, click "Assistant >" to open the interface configuration section, enter “VXI-11” as “Interface Type” and the IP address of the instrument.

Establishing the SCPI connection with the additional generator

1. Proceed in a similar way as described above with the CMW.
2. In addition, select the additional signal generator in the advanced test module in the “External Interferer Setup” drop-down menu for remote connections (Fig. 2-5).

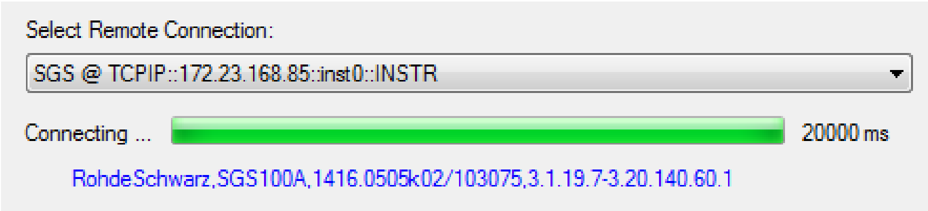


Fig. 2-5: SCPI connection establishment with the additional signal generator

2.3.2.2 Connections with the EUT

Concept for the configuration of the RF connections:

- The configuration of the RF connection (connector, converter, external attenuation) carrying the wanted Bluetooth signal is done in the "BT_Connect" test module.
- In case of two basic frontends, there is a second RF connection (for an interferer signal) which is configured in the advanced test configuration module.
- The configuration of the additional signal generator connection is also done in the advanced test configuration module.

Note that settings in the connection setup module such as Burst Type, Test Mode, RF frequency and RF Power are overwritten by the advanced test configuration module as far as required for the tests. In these cases the parameter values of the connection setup module are just used for an initial establishment of a Bluetooth connection before the actual test.

Note also that an attenuation introduced by the splitter/cables has to be entered in CMWrun separately for each RF path (at 3 locations in case of 2 basic frontends).

2.3.2.3 Compensation for external RF Path losses

The compensation for external RF losses is important in order to ensure that the correct RF levels are presented to the DUT and the CMW to conform to specified Bluetooth test cases. This especially applies for blocking tests operating until up to 12.75 GHz. Significantly higher losses are exhibited by the cables and the splitter in the upper frequency range. For all other tests only Bluetooth channel frequencies are used in the 2.4 GHz ISM band, where the bandwidth is limited to 78 MHz.

A measurement of the cable and splitter assembly for each RF path using vector network analysis is therefore recommended. The losses set in CMWrun should be at the band center frequency (2441MHz for Bluetooth) in order to determine a best fit value per sub-band. For BR/EDR and LE tests the losses can be set in the modules “BT_Connect” and “BTLE_Connect” respectively.

Note that for typical cables and splitters (specified to the upper frequency of interest) the rise in RF losses is expected to be gradual, i.e. the error factor introduced is minimal.

3 Advanced Measurements

3.1 Tests for Basic Rate and Enhanced Data Rate

Fig. 3-1 shows a typical test plan for Bluetooth Basic Rate (BR) and Enhanced Data Rate (EDR).

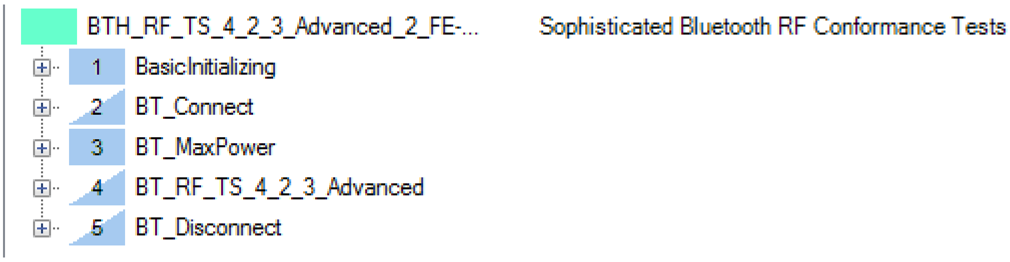


Fig. 3-1: Test plan for Bluetooth BR and EDR

It consists of the basic modules:

- BasicInitializing
- BT_Connect
- BT_MaxPower

and the advanced Bluetooth test cases in

- BTH_RF_TS_4_2_3_Advanced

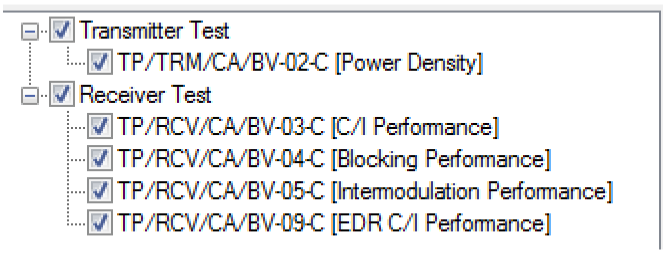


Fig. 3-2: Bluetooth test case details: BTH_RF_TS_4_2_3_Advanced

and is closed by

- BT_Disconnect

For Bluetooth, the signaling is handled via the RF, this connection is established in BT_Connect. BT_MaxPower controls the EUT to transmit at maximum power and BT_Disconnect terminates the connection.

3.1.1 TRM/CA/02/C: Power Density

This measurement determines the maximum transmit power density of the device under test. The CMW causes the DUT to send the wanted signal in hopping mode (i.e.

on all 79 channels) and measures the DUT output power versus a specific frequency range (Fig. 3-3).

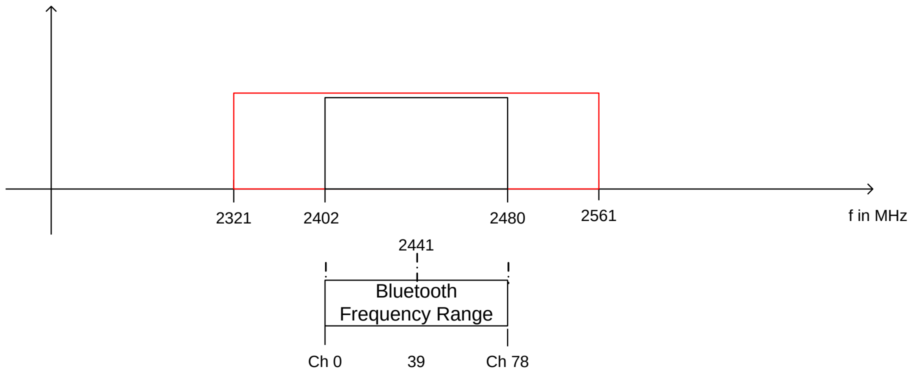


Fig. 3-3: Power density

The Bluetooth test specification defines the following **settings**:

- Loopback or TX mode
- Hopping on
- TX at maximum power
- Longest possible packet type
- PRBS9
- Spectrum analyzer:
  - Center frequency: 2441 MHz
  - Span: 240 MHz
  - RBW: 100 kHz
  - Video BW: 100 kHz
  - Peak detector
  - Max Hold
  - Sweep time: 1 s per 100 kHz

Results:

- 1st test run: The frequency with maximum power is determined.
- 2nd test run: The center frequency is set to the frequency found during the 1st test run. Another measurement is performed with zero span with a sweep time of 60 s. The transmit power density must not exceed 20 dBm (100 mW) per 100 kHz.

Setup and CMWrun

In case of the advanced FE the coupling is handled internally in the CMW, for two basic FE’s the internal spectrum analyzer is coupled in via a splitter.

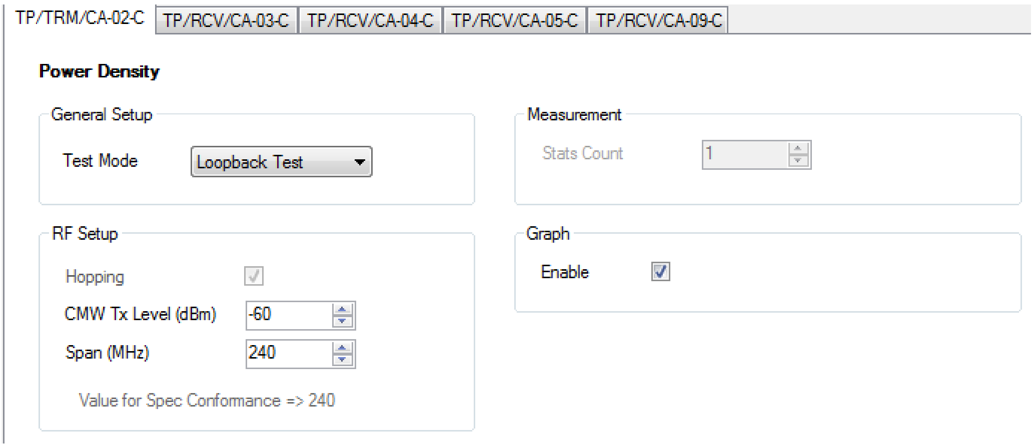
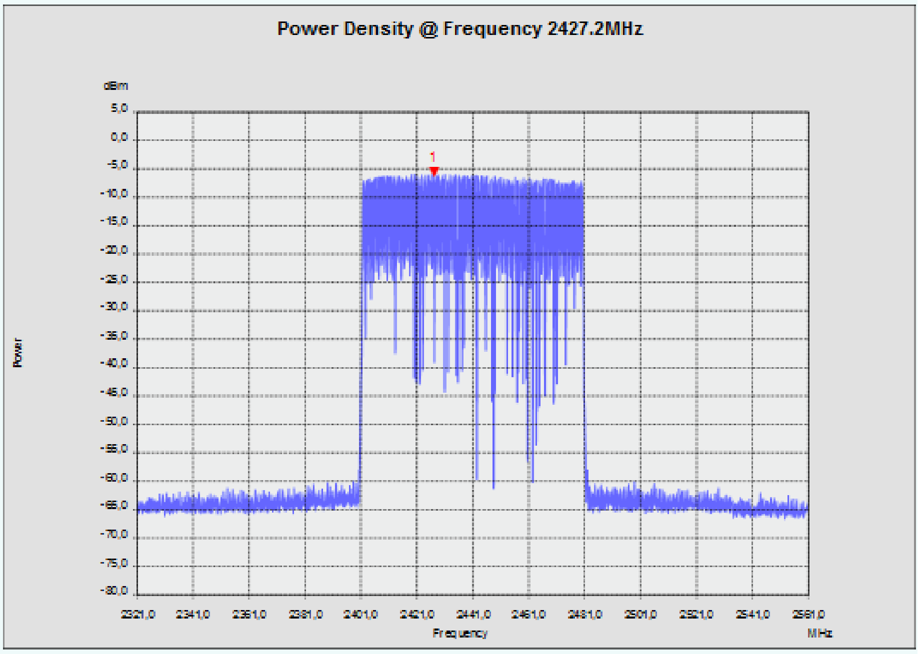


Fig. 3-4: Configuration: Power Density (TP/TRM/CA-02-C)

Fig. 3-5 shows a typical report with graphical output.

TP/TRM/CA-02-C [Power Density]	Lower Limit	Upper Limit	Measured	Unit	Status
Loopback Test, Hopping: ON, DH5, Statistic Count: 1					
Power Density @ Frequency 2427.2MHz	---	20.00	-9.28	dBm	Passed



Traces:

Marker 1: 2427.200 / -6.510;

Peak Freq.: 2427.2 MHz, Peak Power: -6.51 dBm, Zero Span Power Density: -9.28 dBm.

Maximum

Fig. 3-5: Report: Power Density

3.1.2 RCV/CA/03/C: C/I Performance

This measurement determines the receiver quality of the DUT if a Bluetooth interferer is present within the Bluetooth band. The result is obtained by means of a bit error rate (BER) measurement.

The wanted signal is transmitted on a single frequency channel in non-hopping mode. A Bluetooth interferer is likewise generated on a single frequency, coupled in, and the BER is determined. In the next step, the Bluetooth interferer is generated on all channels one after the other, and the BER is determined for each interferer channel. The complete test sequence is repeated twice, i.e. the BER measurement is performed with the wanted signal on three channels in total (Fig. 3-6).

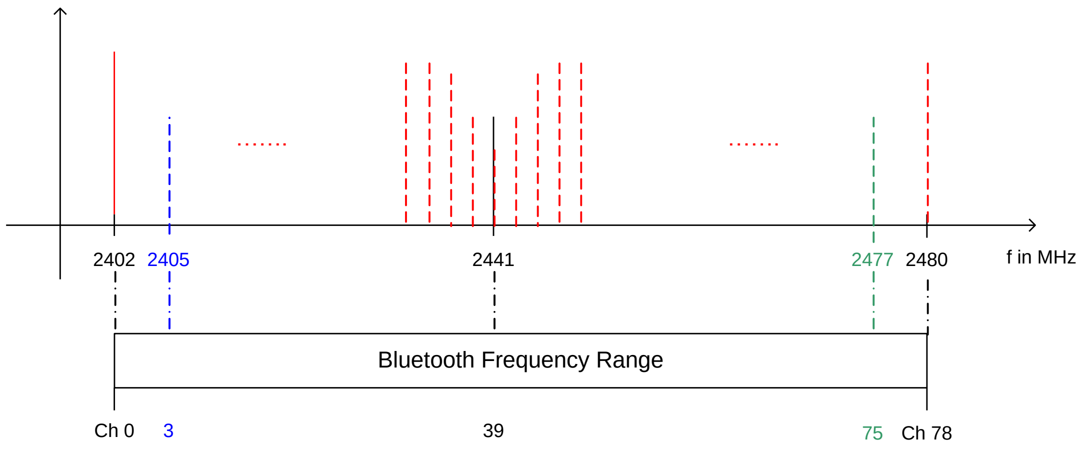


Fig. 3-6: C/I performance

The Bluetooth test specification defines the following **settings**:

- Loopback mode
- Hopping off (RX/TX on single channel)
- Three channels (3, 39, 75)
- TX at maximum power
- DH1
- PRBS9
- Interferer: GFSK with PRBS15 on all Bluetooth channels in consecutive order
- 1,600,000 payload bits for analysis
- Reference level –70 dBm
- For levels see Table 3-1.

C/I level settings			
Interference signal frequency	**Interferer level (abs)**	**C/I level**	**Wanted signal (abs)**
Co-channel $(f_{RX} = f_{Interference})$	–71 dBm	11 dB	–60 dBm
Adjacent channel $(f_{Interference} = f_{RX} \pm 1\ \mathrm{MHz})$	–60 dBm	0 dB	–60 dBm
Adjacent channel $(f_{Interference} = f_{RX} \pm 2\ \mathrm{MHz})$	–30 dBm	–30 dB	–60 dBm
Adjacent channel $(f_{Interference} = f_{RX} \pm (3 + n)\ \mathrm{MHz})$	–27 dBm	– 40 dB	–67 dBm
Image frequency $(f_{Interference} = f_{Image})$	–58 dBm	–9 dB	–67 dBm
Adjacent channel to image frequency $(f_{Interference} = f_{Image} \pm 1\ \mathrm{MHz})$	–47 dBm	–20 dB	–67 dBm

Table 3-1: C/I and receiver selectivity test parameter settings.

Note: The in-band image frequency is specified by the DUT's manufacturer.

Results:

- For each of the three wanted channels, the BER may exceed 0.1 % for five interferer frequencies spaced ≥ 2 MHz from the carrier (test specification: "Spurious").
- For the interferer frequencies (max. five) at which the BER limit is exceeded, the BER is measured in a second test run with a C/I of –17 dB. The BER limit is again 0.1 %.

Setup and CMWrun

For this test the CMW creates the wanted signal and the interferer. CMWrun provides the interferer via an ARB file which is transferred to the CMW.

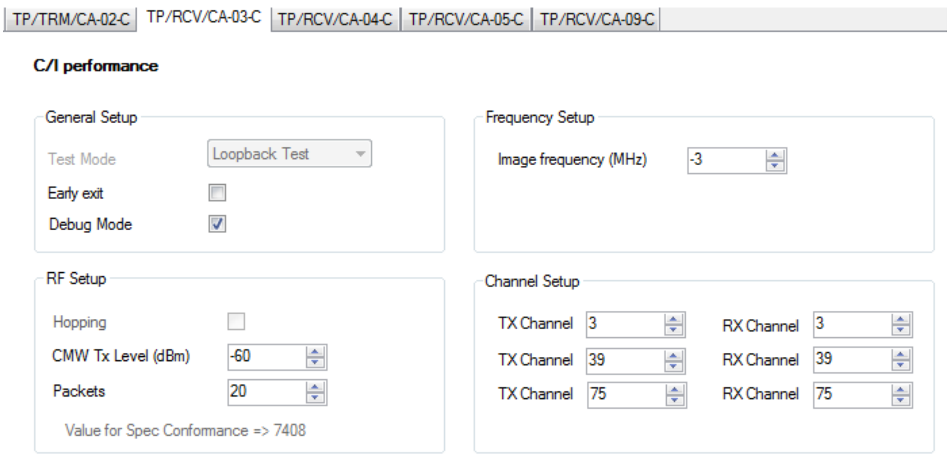


Fig. 3-7: Configuration: C/I performance (TP/RCV/CA-03-C)

If **Debug Mode** is ticked, the report shows every measurement. If **Early Exit** is enabled, the measurement is exited if more than five spurious frequencies are detected.

TP/RCV/CA-03-C [C/I Performance]	Lower Limit	Upper Limit	Measured	Unit	Status
Loopback Test, Hopping: OFF, DH1, Debug Mode					
First run: Channel 3					
BER, Interferer TX Level: -58.0 dBm, Interferer Frequency: 2402 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -47.0 dBm, Interferer Frequency: 2403 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -60.0 dBm, Interferer Frequency: 2404 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -71.0 dBm, Interferer Frequency: 2405 MHz	---	0.1	0.00000	%	Passed

Fig. 3-8: Report: C/I performance

3.1.3 RCV/CA/04/C: Blocking Performance

This measurement determines the receiver quality of the DUT if a CW interferer is present outside the Bluetooth band. The result is obtained by means of a bit error rate (BER) measurement.

The wanted signal is transmitted on a single frequency channel in non-hopping mode. A CW interferer is likewise generated on a single frequency, coupled in, and the BER is determined. In the next step, the CW interferer is generated at intervals of 1 MHz in consecutive order over a specific frequency range, and the BER is determined for each interferer frequency (Fig. 3-9).

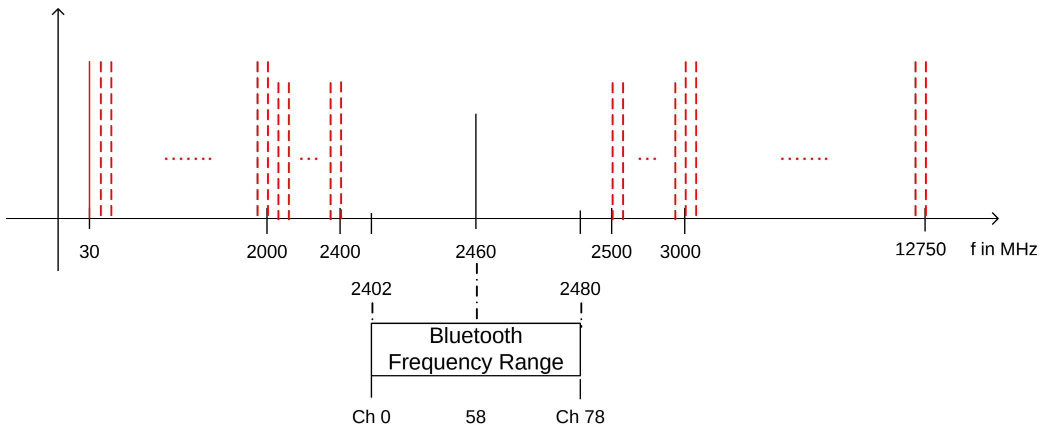


Fig. 3-9: Blocking performance

The Bluetooth test specification defines the following **settings**:

- Loopback mode
- Hopping off (RX/TX on single channel)
- Single wanted channel (58)
- DUT TX at maximum power
- DH1

- PRBS9
- Wanted signal level 3 dB above reference level (–70 dBm), absolute level: –67 dBm
- Interferer: CW in 1 MHz steps, for levels and frequency ranges see Table 3-2.
- 1st test run: At each interferer frequency, 100,000 bits are measured. The frequencies at which a BER > 0.1 % is obtained are recorded.
- 2nd test run: At each frequency recorded during the 1st test run, 1,600,000 bits are measured at reduced levels. The frequencies at which a BER > 0.1 % is obtained are again
- 3rd test run: At each frequency recorded during the 2nd test run (max. 24), 1,600,000 bits are measured at an absolute interference level of –50 dBm. The BER limit of 0.1 % may be exceeded for a maximum of five frequencies.

Blocking levels

Interferer Frequency range	Interferer Absolute level		
	1st run	**2nd run**	**3rd run**
30 MHz to 2000 MHz	–8 dBm	–10 dBm	–50 dBm
2000 MHz to 2400 MHz	–25 dBm	–27 dBm	
2500 MHz to 3000 MHz	–25 dBm	–27 dBm	
3000 MHz to 12.75 GHz	–8 dBm	–10 dBm	

Table 3-2: Blocking performance: Interferer levels

Setup and CMWrun

For this test the CMW creates the wanted signal. An external generator provides the CW interferer up to 12.75 GHz which is coupled via a combiner. As the ratio between the level of the wanted signal and the level of the interferer is very large, a filter can be used to suppress any harmonics of the signal generator falling in-band.

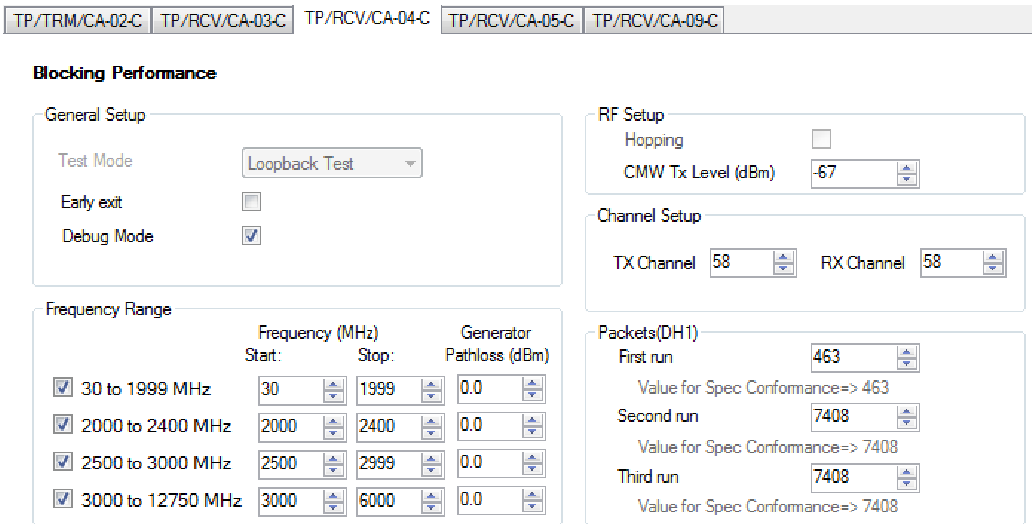


Fig. 3-10: Configuration: Blocking Performance (TP/RCV/CA-04-C)

If **Debug Mode** is ticked, the report shows every measurement. If **Early Exit** is enabled, the measurement is exited if more than five spurious frequencies are detected.

TP/RCV/CA-04-C [Blocking Performance]	Lower Limit	Upper Limit	Measured	Unit	Status
Loopback Test, Hopping: OFF, DH1, Debug Mode					
First run: Interferer Frequency from 30MHz to 2000MHz					
BER, Interferer TX Level: -8 dBm, Interferer Frequency: 30 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -8 dBm, Interferer Frequency: 31 MHz	---	0.1	0.00100	%	Passed
BER, Interferer TX Level: -8 dBm, Interferer Frequency: 32 MHz	---	0.1	0.00400	%	Passed
BER, Interferer TX Level: -8 dBm, Interferer Frequency: 33 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -8 dBm, Interferer Frequency: 34 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -8 dBm, Interferer Frequency: 35 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -8 dBm, Interferer Frequency: 36 MHz	---	0.1	0.00100	%	Passed
BER, Interferer TX Level: -8 dBm, Interferer Frequency: 37 MHz	---	0.1	0.00100	%	Passed
BER, Interferer TX Level: -8 dBm, Interferer Frequency: 38 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -8 dBm, Interferer Frequency: 39 MHz	---	0.1	0.00100	%	Passed

Fig. 3-11: Report: Blocking (in debug mode, all single measurements are listed).

3.1.4 RCV/CA/05/C: Intermodulation Performance

This measurement determines the intermodulation characteristic of the DUT's receiver. A BER measurement is performed with two interferers that cause intermodulation at the DUT's receive frequency.

The wanted signal is transmitted on a single frequency channel in non-hopping mode. A CW interferer spaced +n MHz and a Bluetooth interferer spaced +2n MHz from the wanted signal are generated, coupled in, and the BER is determined. The measurement is then performed with the interferers at –n MHz and –2n MHz. The two measurements are repeated on two more wanted channels (Fig. 3-12).

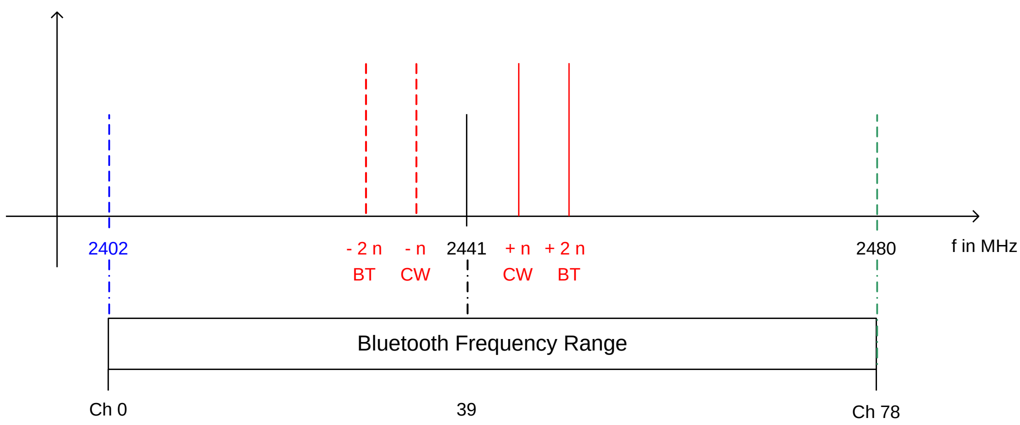


Fig. 3-12: Intermodulation performance

The Bluetooth test specification defines the following **settings**:

- Loopback mode
- Hopping off (RX/TX on single channel)
- Three channels (0, 39, 78)
- DUT TX at maximum power
- DH1
- PRBS9
- Wanted signal level 6 dB above reference level (–70 dBm), absolute level: –64 dBm
- n = 3, 4 or 5 (defined by manufacturer)
- Bluetooth interferer: GFSK with PRBS15 spaced ±2n MHz from wanted signal, level –39 dBm
- CW interferer: spaced ±n MHz from wanted signal, level –39 dBm
- 1,600,000 payload bits for analysis

Result:

- A BER of ≤ 0.1 % must be obtained for each of the three channels.

Setup and CMWrun

For this test the CMW creates the wanted signal and the Bluetooth interferer. An external generator provides the CW interferer. The signals are combined by hybrid combiners.

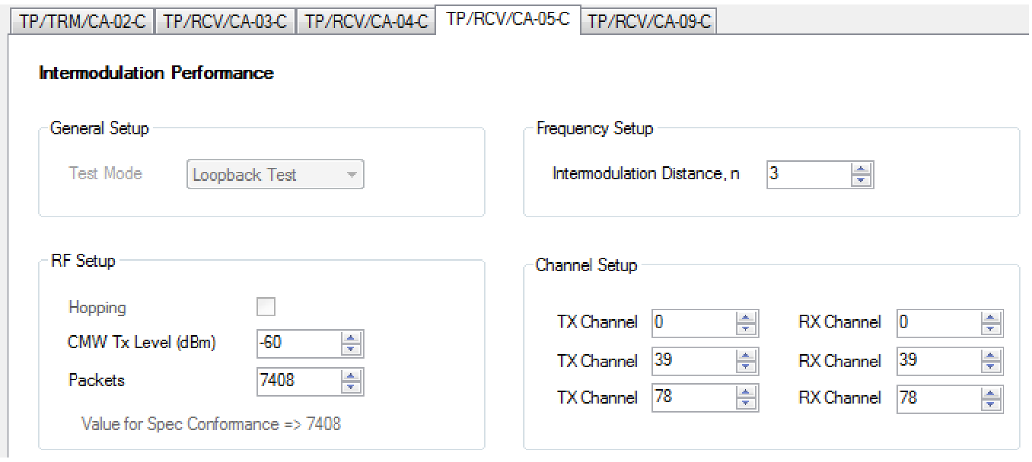


Fig. 3-13: Configuration: Intermodulation Performance (TP/RCV/CA-05-C)

TP/RCV/CA-05-C [Intermodulation Performance]	Lower Limit	Upper Limit	Measured	Unit	Status
Loopback Test, Hopping: OFF, DH1, n: 3					
Channel 0					
BER: BT Interferer @ 2396MHz & CW Interferer @ 2399MHz	---	0.1	0.00075	%	Passed
BER: BT Interferer @ 2408MHz & CW Interferer @ 2405MHz	---	0.1	0.00081	%	Passed
Channel 39					
BER: BT Interferer @ 2435MHz & CW Interferer @ 2438MHz	---	0.1	0.00131	%	Passed
BER: BT Interferer @ 2447MHz & CW Interferer @ 2444MHz	---	0.1	0.00125	%	Passed
Channel 78					
BER: BT Interferer @ 2474MHz & CW Interferer @ 2477MHz	---	0.1	0.00062	%	Passed
BER: BT Interferer @ 2486MHz & CW Interferer @ 2483MHz	---	0.1	0.00050	%	Passed

Fig. 3-14: Report: Intermodulation Performance

3.1.5 RCV/CA/09/C: EDR C/I Performance

The EDR C/I Performance test essentially corresponds to the test described under RCV/CA/03/C: C/I Performance. The test setup and sequence as well as the measuring equipment and accessories are identical. The two tests differ with respect to the packet type selectable for the wanted signal, the interfering signal, and the levels.

The Bluetooth test specification defines the following **settings**:

- Loopback mode
- Whitening on
- Hopping off (RX/TX on single channel)
- Three channels (3, 39, 75)
- DUT TX at maximum power
- Longest possible packet type for each modulation mode
- PRBS9
- Interferer: GFSK with PRBS15 on all BT channels in consecutive order
  - Co-channel interferer: same modulation as wanted signal
- 1,600,000 payload bits for analysis
- Reference level – 70 dBm
- For levels see Table 3-3 and Table 3-4.

EDR C/I level settings (π/4-DQPSK)				
Interference signal frequency		**Interferer level (abs)**	**C/I level**	**Wanted signal (abs)**
Co-channel ($f_{RX} = f_{Interference}$)		–73 dBm	13 dB	–60 dBm
Adjacent channel ($f_{Interference} = f_{RX} \pm 1$ MHz)		–60 dBm	0 dB	–60 dBm
Adjacent channel ($f_{Interference} = f_{RX} \pm 2$ MHz)		–30 dBm	–30 dB	–60 dBm
Adjacent channel ($f_{Interference} = f_{RX} \pm (3 + n)$ MHz)		–27 dBm	– 40 dB	–67 dBm
Image frequency ($f_{Interference} = f_{Image}$)	(Off. 2 MHz) (Off. 3 MHz)	–67 dBm –74 dBm	–7 dB	–60 dBm –67 dBm
Adjacent channel to image frequency ($f_{Interference} = f_{Image} \pm 1$ MHz)	(Off. 2 MHz) (Off. 3 MHz)	–80 dBm –87 dBm	–20 dB	–60 dBm –67 dBm

Table 3-3: EDR C/I parameter settings for π/4-DQPSK.

EDR C/I level settings (8DPSK)				
Interference signal frequency		**Interferer level (abs)**	**C/I level**	**Wanted signal (abs)**
Co-channel ($f_{RX} = f_{Interference}$)		–81 dBm	21 dB	–60 dBm
Adjacent channel ($f_{Interference} = f_{RX} \pm 1$ MHz)		–65 dBm	5 dB	–60 dBm
Adjacent channel ($f_{Interference} = f_{RX} \pm 2$ MHz)		–35 dBm	–25 dB	–60 dBm
Adjacent channel ($f_{Interference} = f_{RX} \pm (3 + n)$ MHz)		–34 dBm	– 33 dB	–67 dBm
Image frequency ($f_{Interference} = f_{Image}$)	(Off. 2 MHz) (Off. 3 MHz)	–60 dBm –67 dBm	0 dB	–60 dBm –67 dBm
Adjacent channel to image frequency ($f_{Interference} = f_{Image} \pm 1$ MHz)	(Off. 2 MHz) (Off. 3 MHz)	–73 dBm –80 dBm	–13 dB	–60 dBm –67 dBm

Table 3-4: EDR C/I Performance for 8DPSK

Results:

- For each modulation type, the BER may exceed 0.1 % for five interferer frequencies spaced ≥ 2 MHz from the carrier (test specification: "Spurious")
- For the interferer frequencies (max. five) at which the BER limit is exceeded, a BER of ≤ 0.1 % must be obtained for a C/I of –15 dB with π/4-DQPSK and a C/I of –10 dB with 8DPSK.

Setup and CMWrun

For this test the CMW creates the wanted signal and the interferer. CMW provides the interferer via an ARB file which is transferred to the CMW.

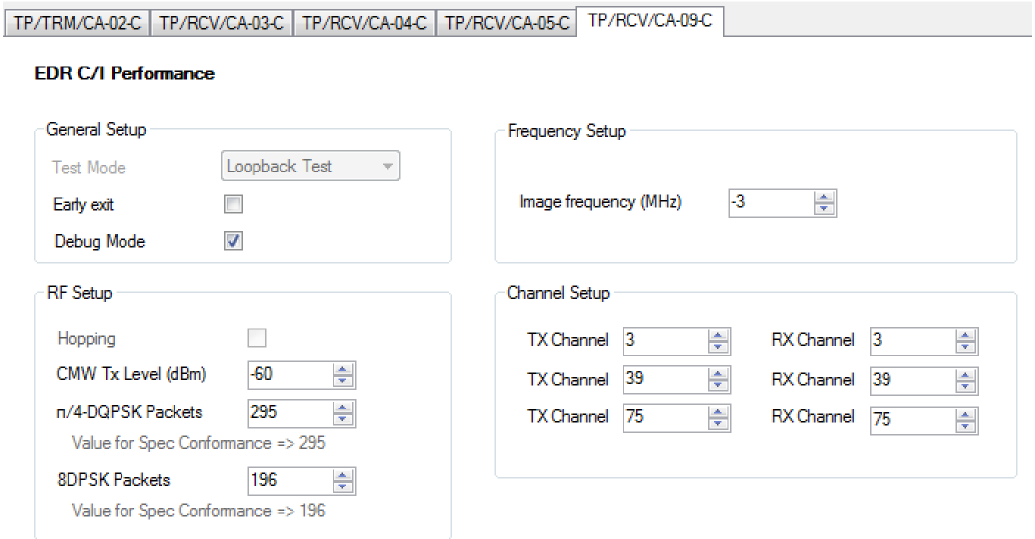


Fig. 3-15: Configuration: EDR C/I Performance (TP/RCV/CA-09-C)

If **Debug Mode** is ticked, the report shows every measurement. If **Early Exit** is enabled, the measurement is exited if more than five spurious frequencies are detected.

TP/RCV/CA-09-C [EDR C/I Performance]	Lower Limit	Upper Limit	Measured	Unit	Status
Loopback Test, Hopping: OFF, Debug Mode					
Packet Type: 2-DH5					
First run: Channel 3					
BER, Interferer TX Level: -60.0 dBm, Interferer Frequency: 2402 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -47.0 dBm, Interferer Frequency: 2403 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -60.0 dBm, Interferer Frequency: 2404 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -73.0 dBm, Interferer Frequency: 2405 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -60.0 dBm, Interferer Frequency: 2406 MHz	---	0.1	0.00000	%	Passed
BER, Interferer TX Level: -30.0 dBm, Interferer Frequency: 2407 MHz	---	0.1	0.00000	%	Passed

Fig. 3-16: Report: EDR C/I Performance

3.2 Tests for Bluetooth Low Energy

Fig. 3-17 shows a typical testplan for Bluetooth Low Energy.

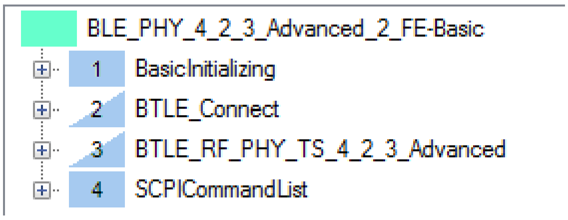


Fig. 3-17: testplan for Bluetooth Low Energy

It consists of the basic modules:

- BasicInitializing
- BTLE_Connect

and the advanced LE Tests in

- BLE_RF_PHY_TS_4_2_3_Advanced

For Bluetooth Low Energy, the signaling is not handled via the RF connection, instead, the CMW controls the DUT directly. This is handled in CMWrun via the module “BTLE_Connect”. Here you can configure the USB-to-RS232 connector. In addition you can configure the basic RF settings.

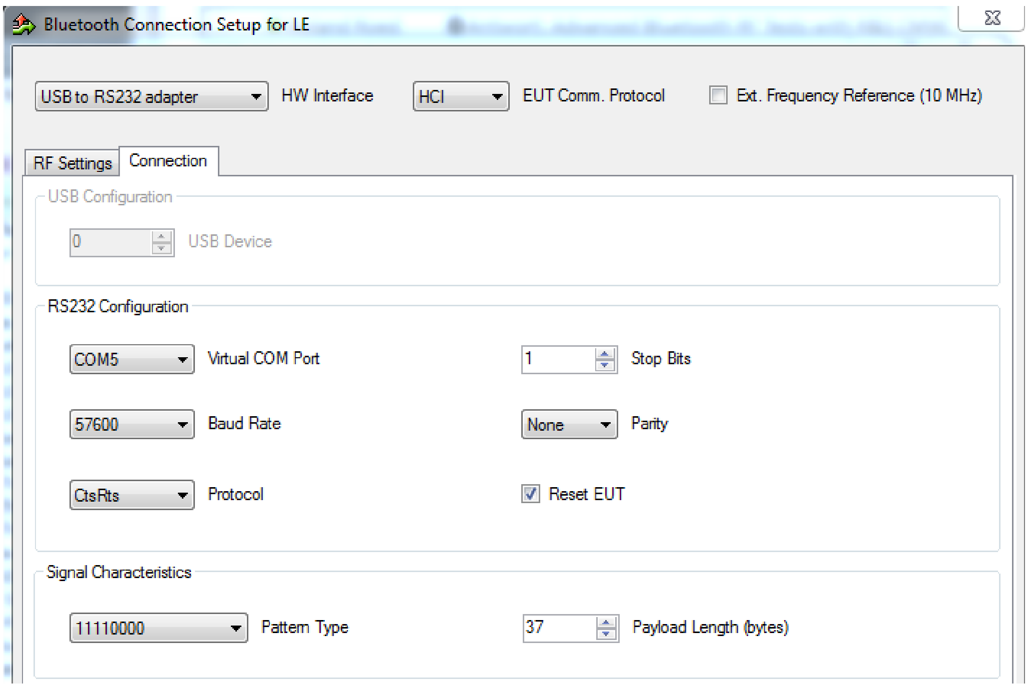


Fig. 3-18: RS232 settings in Bluetooth Connection LE

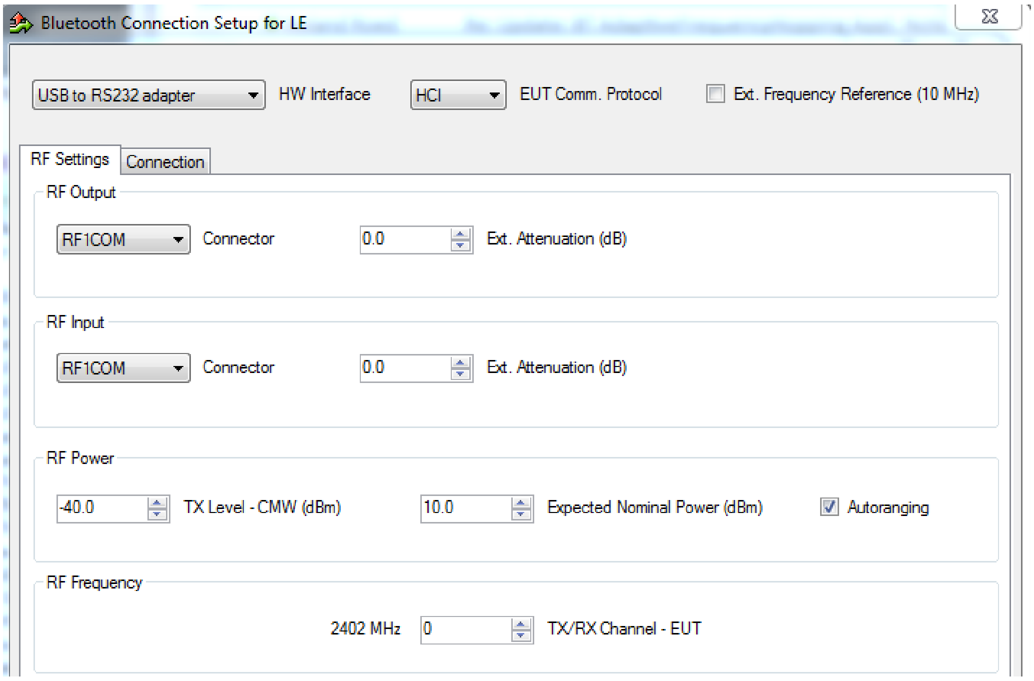


Fig. 3-19: RF settings in Bluetooth Connection LE

Payload length and packet error rate (PER)

If the DUT supports a data length extension, the Bluetooth test specification mandates a maximum supported payload length for Bluetooth receivers and transmitters, which shall be greater than 37 octets. A payload length up to 255 octets can be configured at the CMW. However, the maximum supported payload length of the DUT cannot be queried by the CMW.

The payload length affects the PER according to the formula:

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

Equation 3-1: PER upper limit calculation

- $X = 1 - BER$, e.g. X = 0.9990, if $MAX_{LENGTH} = 37$ octets
- MAX_{LENGTH} is the maximum supported payload length of the DUT:
  $37 \leq MAX_{LENGTH} \leq 255$ octets
- 72 in the formula is total length of synchronization word, PDU header, PDU length & CRC parts in LE test packet in bit unit.

An overview of some upper limits of the PER for maximum supported payload lengths of the DUT is given in Table 3-5. A complemented list of PER upper limits for payload lengths from 37 to 255 octets can be found in [1]. At CMWrun the configured payload length is automatically linked to the required PER upper limit as mandated by the Bluetooth test specification.

PER requirements at extended data lengths of the DUT		
Maximum supported payload length of the DUT	**BER**	**PER**
37 octets	≤ 0.1 %	≤ 30.8 %
38 octets	≤ 0.064 %	≤ 21.4 %
64 octets	≤ 0.034 %	≤ 18.0 %
128 octets	≤ 0.017 %	≤ 17.0 %
255 octets	≤ 0.017 %	≤ 30.2 %

Table 3-5: BER and PER requirements at maximum supported payload lengths of the DUT

3.2.1 RCV-LE/CA/03/C: C/I and Receiver Selectivity Performance

This test verifies the receiver performance of the DUT in presence of a Bluetooth co-/adjacent channel interferer within the Bluetooth band. The result is obtained by means of a packet error rate (PER) measurement.

The wanted signal is transmitted on a single channel in non-hopping mode. A Bluetooth interferer is likewise generated on a single channel, coupled in, and the PER is determined. In the next step, the Bluetooth interferer is generated on all channels one after the other, and the PER is measured for each interferer channel. The complete test sequence is repeated twice, i.e. the PER measurement is performed with the wanted signal on three channels in total (Fig. 3-20).

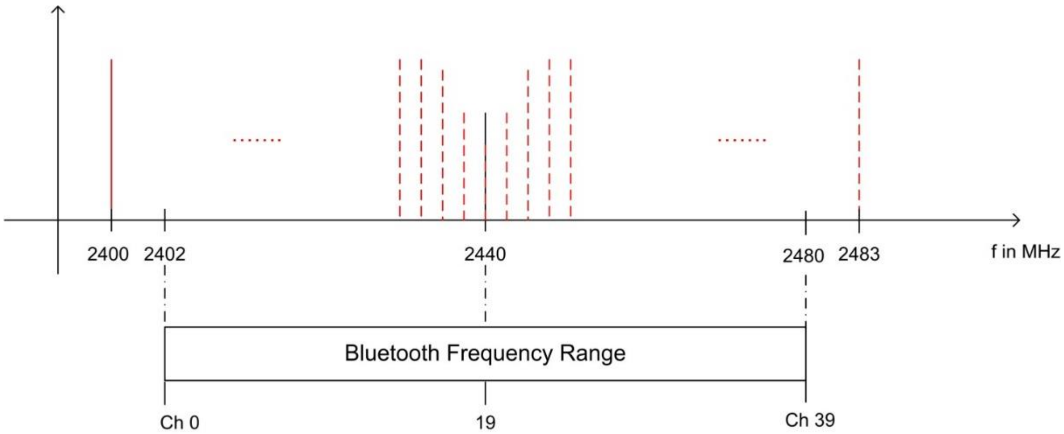


Fig. 3-20: C/I performance: For the three individual channels, the packet error rate in the presence of a Bluetooth interferer inside the Bluetooth band is measured. The measurement is repeated after shifting the interferer by 1 MHz.

The Bluetooth test specification defines the following **settings**:

- DUT in direct RX mode
- Hopping off (RX on single channel)
- Three channels (0, 19, 39)
- Test packets with 37 octet PRBS9 payload and up to 255 octet PRBS9 payload for DUTs with supported data length extension

- Interferer: GFSK (modulation index 0.5) with PRBS15 on all Bluetooth channels in consecutive order
- 1500 packets
- Wanted input level at EUT: –67 dBm
- For levels see Table 3-6.

C/I LE level settings			
Interference signal frequency	**Interferer level (abs)**	**C/I level**	**Wanted signal (abs)**
Co-channel ($f_{RX} = f_{Interference}$)	–88 dBm	21 dB	–67 dBm
Adjacent channel ($f_{Interference} = f_{RX} \pm 1$ MHz)	–82 dBm	15 dB	–67 dBm
Adjacent channel ($f_{Interference} = f_{RX} \pm 2$ MHz)	–50 dBm	–17 dB	–67 dBm
Adjacent channel ($f_{Interference} = f_{RX} \pm (3 + n)$ MHz)	–40 dBm	–27 dB	–67 dBm
Image frequency ($f_{Interference} = f_{Image}$)	–58 dBm	–9 dB	–67 dBm
Adjacent channel to image frequency ($f_{Interference} = f_{Image} \pm 1$ MHz)	–52 dBm	–15 dB	–67 dBm

Table 3-6: C/I and receiver selectivity test parameter settings.

Results:

- For all measurements, the PER shall be better than 30.8 % for a minimum of 1500 packets and a payload length of 37 octets. For greater payload lengths the PER shall be better than the value calculated in Equation 3-1.
- For each of the three wanted channels, the PER may exceed the required upper limit for five interferer frequencies spaced ≥ 2 MHz from the carrier and spaced ≥ 1 MHz from the image frequency.
- For the interferer frequencies (max. five) at which the PER limit is exceeded, the PER is measured in a second test run with a relaxed C/I of –17 dB. The PER upper limit is again the one calculated in Equation 3-1.

Setup and CMWrun

For this test the CMW creates the wanted signal and the interferer. CMW provides the interferer via an ARB file which is transferred to the CMW.

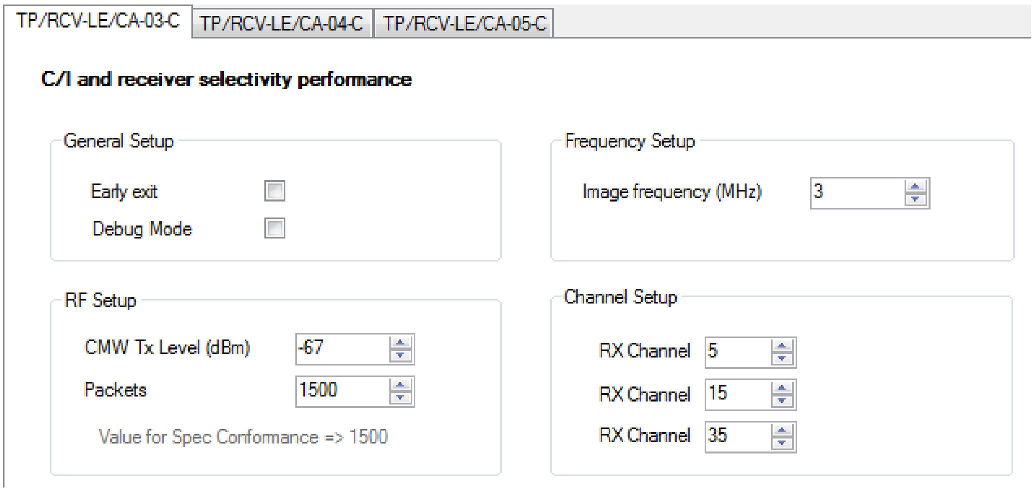


Fig. 3-21: Configuration: Low Energy C/I performance (TP/RCV-LE/CA-03-C)

If **Debug Mode** is ticked, the report shows every measurement. If **Early Exit** is enabled, the measurement is exited if more than five spurious frequencies are detected.

TP/RCV-LE/CA-03-C [C/I and Receiver Selectivity Performance]	Lower Limit	Upper Limit	Measured	Unit	Status
First run: Channel 5					
PER, Interferer TX Level: -40.0 dBm, Interferer Frequency: 2400 MHz	---	30.8	0.00000	%	Passed
PER, Interferer TX Level: -40.0 dBm, Interferer Frequency: 2401 MHz	---	30.8	0.00000	%	Passed
PER, Interferer TX Level: -40.0 dBm, Interferer Frequency: 2402 MHz	---	30.8	0.00000	%	Passed
PER, Interferer TX Level: -40.0 dBm, Interferer Frequency: 2403 MHz	---	30.8	0.00000	%	Passed
PER, Interferer TX Level: -52.0 dBm, Interferer Frequency: 2404 MHz	---	30.8	0.00000	%	Passed
PER, Interferer TX Level: -82.0 dBm, Interferer Frequency: 2405 MHz	---	30.8	0.00000	%	Passed

Fig. 3-22: Report: Low Energy C/I Performance

3.2.2 RCV-LE/CA/04/C: Blocking Performance

This measurement determines the receiver quality of the DUT if a continuous-wave (CW) interferer is present outside the Bluetooth band. The result is obtained by means of a packet error rate (PER) measurement.

The wanted signal is transmitted on a single channel in non-hopping mode. A CW interferer is likewise generated on a single channel, coupled in, and the BER is determined. In the next step, the CW interferer is generated at intervals in consecutive order over a specific frequency range, and the PER is determined for each interferer frequency (Fig. 3-23).

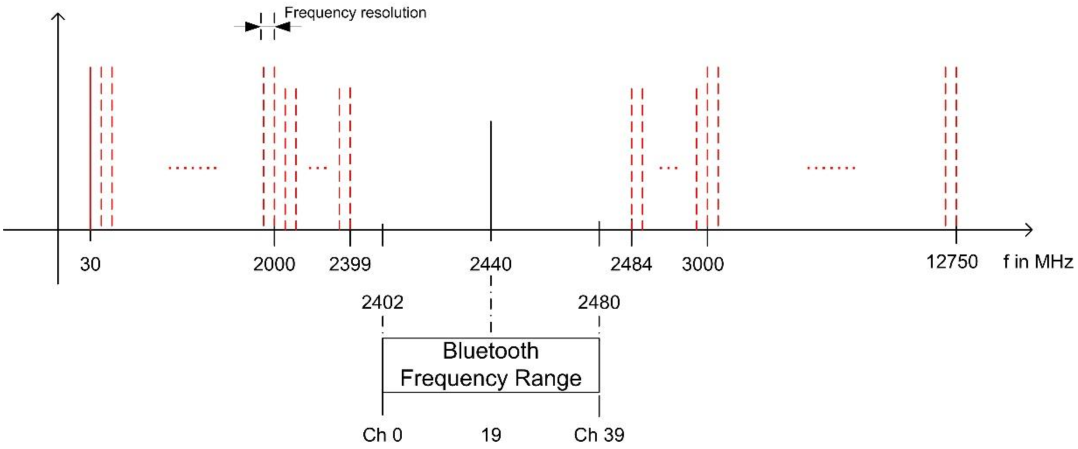


Fig. 3-23: Blocking performance: For one channel, the packet error rate in the presence of a CW interferer outside the Bluetooth band is measured. The measurement is repeated after shifting the interferer by the frequency resolution.

The Bluetooth test specification defines the following **settings**:

- DUT in direct RX mode
- Hopping off (RX on single channel)
- One channel (19)
- Test packets with 37 octet PRBS9 payload and up to 255 octet PRBS9 payload for DUTs with supported data length extension
- Interferer: CW signal; for levels and frequency ranges, see Table 3-7.

  Note: The additional option to alter the frequency resolution is provided when ticking the “Fine step mode” checkbox as illustrated in Fig. 3-24. Fine step mode will set the step to a fixed 1 MHz resolution.
- 1500 packets
- Wanted input level at EUT: –67 dBm

Blocking level settings

Interference signal frequency	Wanted signal level (abs)	Blocking signal level	Frequency resolution
30 MHz to 2000 MHz	–67 dBm	–30 dBm	10 MHz
2003 MHz to 2399 MHz	–67 dBm	–35 dBm	3 MHz
2484 MHz to 2997 MHz	–67 dBm	–35 dBm	3 MHz
3000 MHz to 12.75 GHz	–67 dBm	–30 dBm	25 MHz

Table 3-7: Blocking performance parameters, first test run.

Results:

- 1st test run: At each interferer frequency, 1500 packets are measured. The frequencies at which a PER is obtained, greater than the value related to Equation 3-1, are recorded. The number of frequencies recorded here must not exceed ten.
- 2nd test run: At each frequency recorded during the 1st test run, 1500 packets are measured at reduced interferer levels of –50 dBm. The frequencies at which a PER is obtained, greater than the value related to Equation 3-1, are again recorded. The PER limit may be exceeded for a maximum of three frequencies.

Setup and CMWrun

For this test the CMW creates the wanted signal. An external generator provides the CW interferer up to 12.75 GHz.

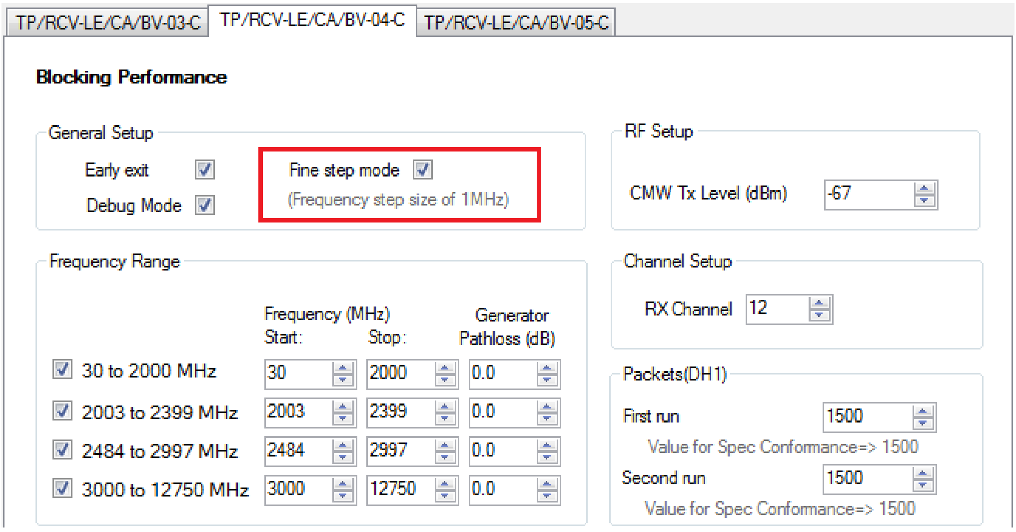


Fig. 3-24: Configuration: Low Energy Blocking Performance (TP/RCV-LE/CA-04-C)

If **Debug Mode** is ticked, the report shows every measurement. If **Early Exit** is enabled, the measurement is exited if more than ten spurious frequencies are detected.

TP/RCV-LE/CA-04-C [Blocking Performance]	Lower Limit	Upper Limit	Measured	Unit	Status
First run: Interferer Frequency from 30MHz to 2000MHz					
PER, Interferer TX Level: -30 dBm, Interferer Frequency: 30 MHz	---	30.8	0.00000	%	Passed
PER, Interferer TX Level: -30 dBm, Interferer Frequency: 40 MHz	---	30.8	0.00000	%	Passed
PER, Interferer TX Level: -30 dBm, Interferer Frequency: 50 MHz	---	30.8	0.00000	%	Passed
PER, Interferer TX Level: -30 dBm, Interferer Frequency: 60 MHz	---	30.8	0.00000	%	Passed

Fig. 3-25: Report: Low Energy Blocking

3.2.3 RCV-LE/CA/05/C: Intermodulation Performance

This measurement verifies the intermodulation performance of the DUT's receiver. A PER measurement is performed using two interferers that cause intermodulation at the DUT's receive frequency.

The wanted signal is transmitted on a single channel in non-hopping mode. A CW interferer spaced +n MHz and a Bluetooth interferer spaced +2n MHz from the wanted signal are generated, coupled in, and the PER is determined. The measurement is then performed with the interferers at –n MHz and –2n MHz. The two measurements are repeated on two more wanted channels (Fig. 3-26).

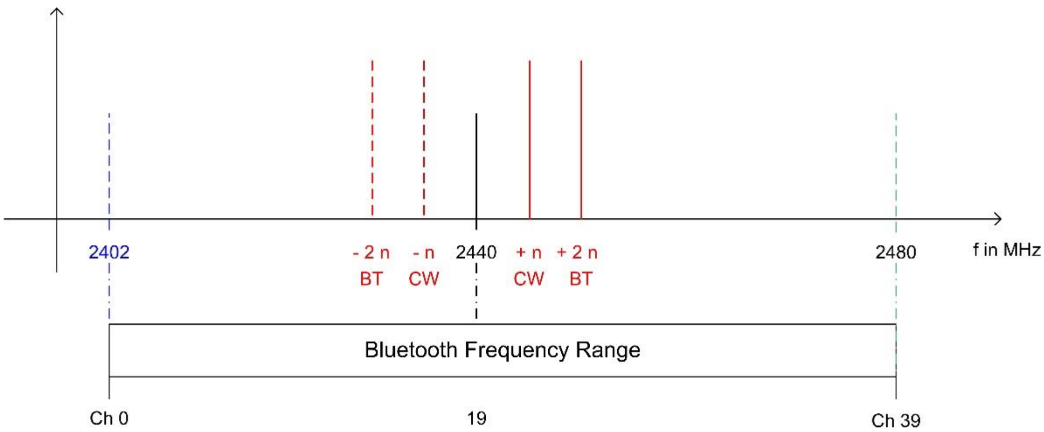


Fig. 3-26: Intermodulation performance: For each of three channels, the packet error rate in the presence of a CW interferer in a distance n and in the presence of a Bluetooth interferer in a distance 2n is measured.

The Bluetooth test specification defines the following **settings**:

- Hopping off (RX on single channel)
- Three channels (0, 19, 39)
- PRBS9
- Wanted signal level at –64 dBm
- n = 3, 4 or 5 (defined by manufacturer)
- Bluetooth interferer: low energy GFSK with PRBS15 spaced ±2n MHz from wanted signal, level –50 dBm
- CW interferer: spaced ±n MHz from wanted signal, level –50 dBm
- 1500 packets

Result:

- A PER better than the value related to Equation 3-1 must be obtained for each of the three channels.

Setup and CMWrun

For this test the CMW creates the wanted signal and the Bluetooth interferer. An external generator provides the CW interferer. The signals are combined by hybrid combiners.

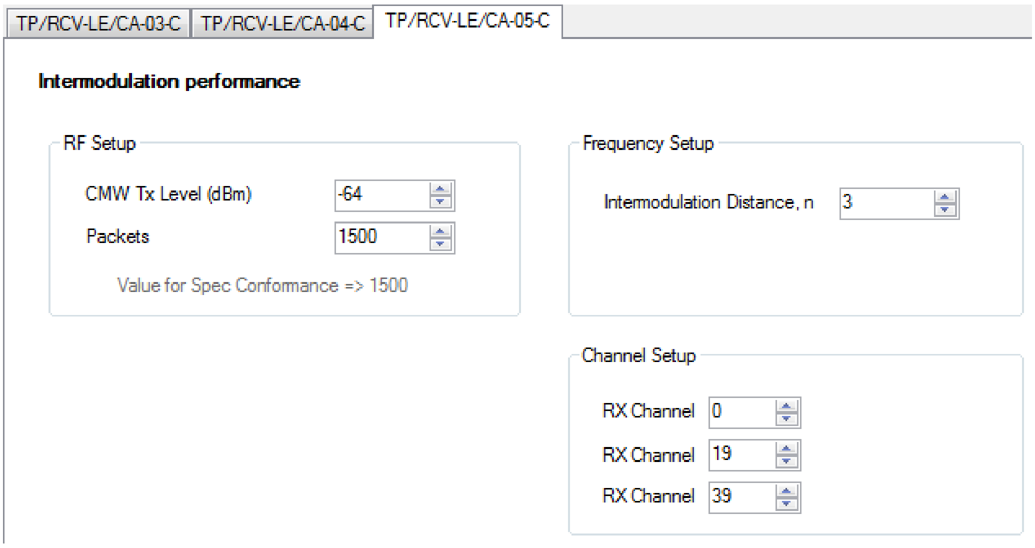


Fig. 3-27: Configuration: Low Energy Intermodulation Performance (TP/RCV-LE/CA-05-C)

TP/RCV-LE/CA-05-C [Intermodulation Performance]	Lower Limit	Upper Limit	Measured	Unit	Status
n: 3					
Channel 2402					
PER: BT Interferer @ 2396MHz & CW Interferer @ 2399MHz	---	30.8	0.00000	%	Passed
PER: BT Interferer @ 2408MHz & CW Interferer @ 2405MHz	---	30.8	0.00000	%	Passed
Channel 2421					
PER: BT Interferer @ 2415MHz & CW Interferer @ 2418MHz	---	30.8	0.00000	%	Passed
PER: BT Interferer @ 2427MHz & CW Interferer @ 2424MHz	---	30.8	0.00000	%	Passed
Channel 2441					
PER: BT Interferer @ 2435MHz & CW Interferer @ 2438MHz	---	30.8	0.00000	%	Passed
PER: BT Interferer @ 2447MHz & CW Interferer @ 2444MHz	---	30.8	0.00000	%	Passed

Fig. 3-28: Report: Low Energy Intermodulation Performance

4 Appendix

4.1 Literature

[1] **Bluetooth Test & Interoperability Working Group. 2014.** Radio Frequency (RF) PHY Bluetooth Test Specification; RF-PHY.TS.4.2.3. 07 2016.

[2] **—. 2014.** Radio Frequency (RF) Bluetooth Test Specification; RF.TS.4.2.3. 07 2016.

[3] **Rohde & Schwarz. 2012.** Bluetooth Low Energy Measurements Using CBTgo; Additional Tests. [Application Note]. 01 2012.

[4] **—. 2013.** Bluetooth Measurements Using CBTgo; Additional Tests. [Application Note]. 02 2013.

4.2 Additional Information

Please send your comments and suggestions regarding this application note to

TM-Applications@rohde-schwarz.com

4.3 Ordering Information

CMW Hardware		
Designation	**Type**	**Order No.**
Radio Communication Tester	**R&S®CMW500** **R&S®CMW290** **R&S®CMW270** **R&S®CMW100**	1201.0002K50 1201.0002K29 1201.0002K75 1201.0002K02
Basic Assembly	CMW-PS503 (CMW500) CMW-PS272 (CMW270)	1202.5408.02 1202.9303.02
Baseband Measurement Unit	CMW-B100A	1202.8607.02
Baseband Measurement Generator	CMW-B110A	1202.5508.02
Baseband Interconnection Board	CMW-S550B	1202.4801.03
Advanced RF Frontend Module **or** RF Frontend Module Extra RF Frontend Module	CMW-S590D CMW-S590A CMW-B590A	1202.8707.03 1202.5108.02
RF Converter Module Extra RF Converter Module	CMW-S570B CMW-B570B	1202.8659.03
Signaling Unit Universal (SUU)	CMW-B200A	1202.6104.02

CMW & CMWrun Software		
Designation	**Type**	**Order No.**
Bluetooth Basic Signaling	CMW-KS600	1208.1004.02
Bluetooth BR/EDR Signaling	CMW-KS610	1207.7650.02
Bluetooth, BR/EDR, TX Measurement	CMW-KM610	1203.6350.02
Bluetooth Low Energy Signaling	CMW-KS611	1207.8805.02
Bluetooth, Low Energy, TX Measurement	CMW-KM611	1203.9307.02
Bluetooth, BR/EDR & Low Energy, TX Measurements (CMW 100 only)	CMW-PKM611	1210.7264.02
Spectrum Analyzer	CMW-KM010	1203.5953.02
Wireless Connectivity Tests (BT, WiMAX™, WLAN) with CMWrun, Version 1.8.5 or later	CMW-KT057	1203.4205.02

CW Generator		
Designation	**Type**	**Order No.**
Signal Generator	**SMA100A**	**1400.0000.02**
Up to 6 GHz with electronic attenuator	SMA-B106	1405.0809.02
Vector Signal Generator	**SMBV100A**	**1406.6004.02**
Up to 6 GHz with electronic level attenuator	SMBV-B106	1407.9703.02
Signal Generator	**SMC100A**	**1411.4002.02**
Up to 3 GHz with electronic attenuator	SMC-B103	1411.6605.02
Microwave Signal Generator	**SMF100A**	**1167.0000.02**
Up to 22 GHz	SMF-B122	1167.7004.03
Step attenuator	SMF-B26	1167.5553.02
Vector Signal Generator	**SMW200A**	**1412.0000.02**
Up to 6 GHz	SMW-B106	1413.0104.03
Up to 12.75 GHz	SMW-B112	1413.0204.03
SGMA RF Source	**SGS100A**	**1416.0505.02**
CW up to 6 GHz	SGS-B106	1416.2308.02
Frequency extension to 12.75 GHz	SGS-B112	1416.1553.02
Step attenuator	SGS-B26	1416.1353.02
SGMA Vector RF Source	**SGT100A**	**1419.4501.02**
CW up to 6 GHz	SGT-KB106	1419.5708.02

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, radiomonitoring and radiolocation. Founded more than 80 years ago, this independent company has an extensive sales and service network and is present in more than 70 countries.

The electronics group is among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

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Sustainable product design

- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership

Certified Quality Management
ISO 9001

Certified Environmental Management
ISO 14001

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