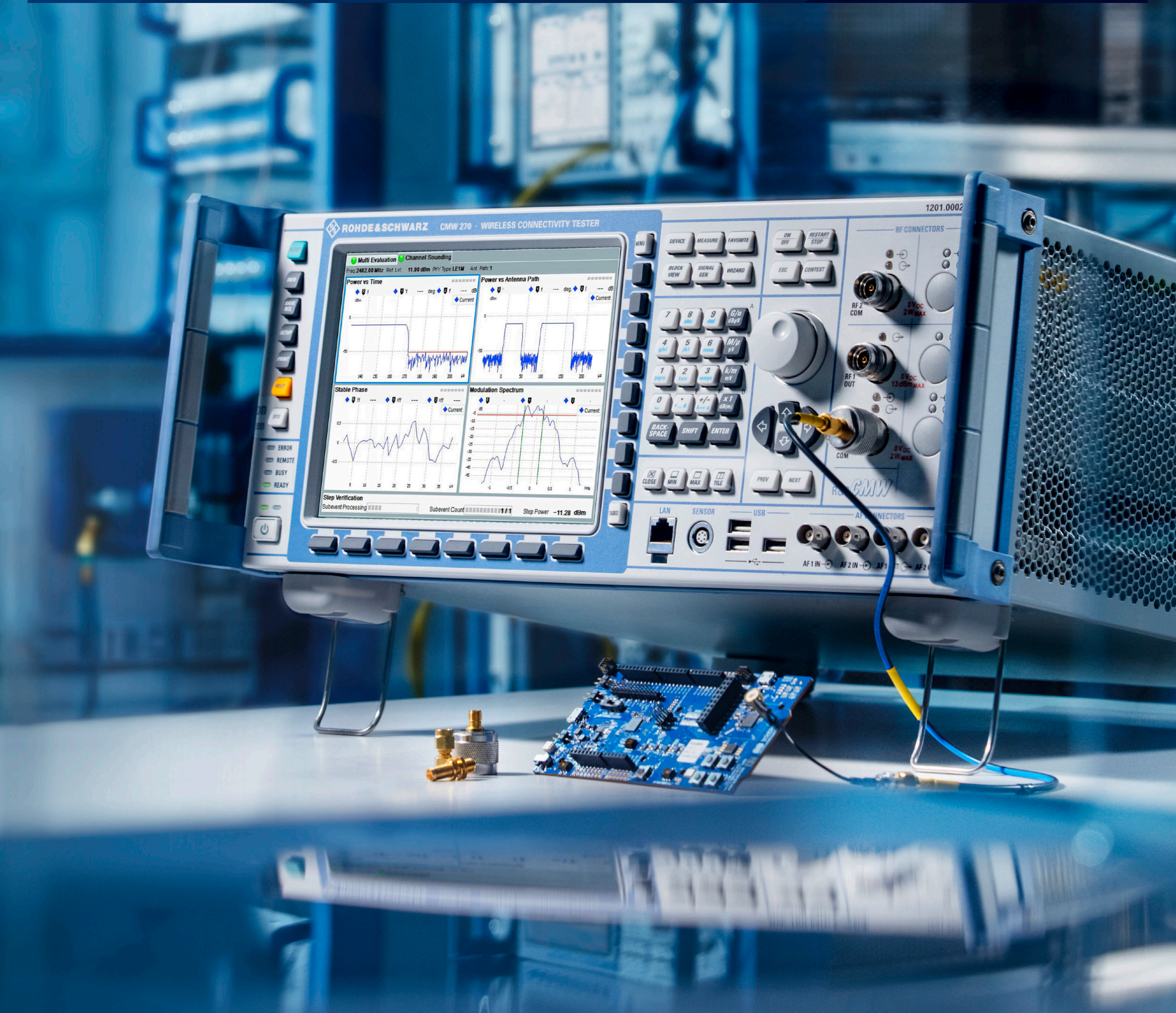
ROHDE&SCHWARZ

Make ideas real

BLUETOOTH® TESTING WITH THE CMW WIDEBAND RADIO COMMUNICATION TESTER

Application Brochure | Version 02.00



The development and proliferation of Bluetooth® is a success story. The number of devices that use Bluetooth® wireless technology is growing at a rate of 1 billion per year. As internet of things (IoT) technology advances, the number will grow significantly over the coming years. Bluetooth SIG anticipates nearly 7.7 billion new Bluetooth® enabled devices in 2028.

To ensure connectivity and trouble-free operation, each Bluetooth® enabled device has to be tested for conformance with Bluetooth SIG standards and regulatory requirements.

CONTENTS

Bluetooth SIG uses the terms "device under test" (DUT), "equipment under test" (EUT) and "implementation under test" (IUT). In this document, the term DUT is always used.

ROHDE & SCHWARZ BLUETOOTH® TESTING EXPERTISE

In 1998, Rohde & Schwarz was the first T&M specialist to join Bluetooth SIG. Rohde & Schwarz played a major role in developing Bluetooth® by providing innovative T&M solutions from the start.

Rohde & Schwarz competence in establishing Bluetooth® technology

In 1998, Rohde & Schwarz was the first T&M specialist to work with the Bluetooth Special Interest Group (SIG) and the company has worked closely with the SIG ever since. Back then, the technology was called MC-Link because it wirelessly linked a mobile phone (M) with a computer (C). At the time, Bluetooth® was just a project name. Only later did Bluetooth® become the official name of the technology.

Milestones in Bluetooth® testing

In 2000, Rohde & Schwarz introduced the R&S®PTW60 protocol tester, the first Bluetooth® test instrument. It was followed by the R&S®TS8960 Bluetooth® RF qualification test system in 2001. At that time, the Bluetooth SIG urgently needed solutions to verify the first Bluetooth® chips and components. The Rohde & Schwarz products met all the requirements, so Bluetooth SIG and almost all Bluetooth® test houses worldwide used the two Rohde & Schwarz solutions. At the same time, Rohde & Schwarz developed the first integrated tester for Bluetooth® RF based on the R&S®CMU200 universal radio communication tester. This tester was also launched in 2001. Another milestone was the R&S®CBT Bluetooth® tester in 2004, which offered flexibility, high measurement speed and versatile test options to become an R&D and production benchmark used by all major Bluetooth® players around the world.[1]

The next level

In 2010, Rohde & Schwarz started implementing Bluetooth® test functions in the CMW wideband radio communication tester in parallel with the R&S®CBT. In addition to current Bluetooth® RF and audio tests, the CMW platform also supports all mobile communications standards and WLAN. The CMW platform has been continuously enhanced with new functions. Even future Bluetooth® technology developments will be supported. The message to the user is clear: invest once and benefit for years.

[1] R&S®PTW60, R&S®TS8960, R&S®CMU200 and R&S®CBT have since been discontinued.

Development of the Bluetooth® technology

Technology overview
- Short-range wireless communications technology
- Works at 2.4 GHz in the ISM band
- High robustness by using frequency hopping spread spectrum (FHSS)

Bluetooth® Classic
- Application: mobile phones, headsets, stereo audio, automotive, PCs
- Application throughput: 0.7 Mbps to 2.1 Mbps, voice capable
- Up to seven active peripherals, high latency > 100 ms

Bluetooth® Low Energy (LE)
- Application: mobile phones, headsets, earbuds, automotive, medical, fitness, home sensors, advertisement, PCs
- Application throughput: up to 1.4 Mbps, voice capable
- Unlimited number of active peripherals, latency < 6 ms

Bluetooth SIG
- Curator, caretaker and innovator of Bluetooth® technology
- Develops the Bluetooth® specification to ensure interoperability
- Certification body and owner of the brand mark

SELECTION OF ROHDE & SCHWARZ BLUETOOTH® TESTING DEVICES

R&S®PTW60
Protocol tester for Bluetooth® solutions

First Bluetooth® protocol tester on the market

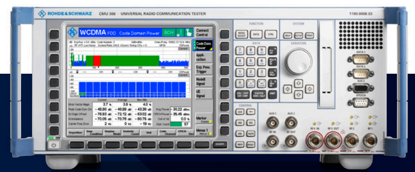
2000

R&S®TS8960
Bluetooth® qualification test system

First Bluetooth® qualification test system on the market

2001

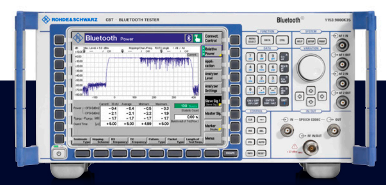
R&S®CMU200
Universal radio communication tester



First Bluetooth® signaling RF tester on the market

2001

R&S®CBT
Bluetooth® tester



Reference for Bluetooth® testing in R&D and production

2004

CMW
Wideband radio communication tester

Universal platform for testing Bluetooth® wireless technology and other wireless standards such as WLAN and LTE

since 2010

CMW PLATFORM OVERVIEW

The CMW wideband radio communication tester platform is future-proof and combines all major radio access technologies in a single compact tester. The platform is ideal for testing smartphones and tablets as well as wearables and wireless audio devices. The CMW covers all product creation phases from development to production.

Rohde & Schwarz – a reliable partner for Bluetooth® testing solutions

The CMW wideband radio communication tester platform supports Bluetooth® technology up to the latest release. It covers the Bluetooth® Classic signaling function and all Bluetooth® Low Energy (LE) transmitter and receiver tests including the signaling specified by Bluetooth SIG. The R&S®CMWrun sequencer software tool simplifies preconformance testing by automatically executing all Bluetooth SIG test cases. Options for fast and comprehensive production testing of Bluetooth® enabled devices speed up the production process. The CMW supports Bluetooth® technology, other non-cellular standards and all major cellular standards in one box.

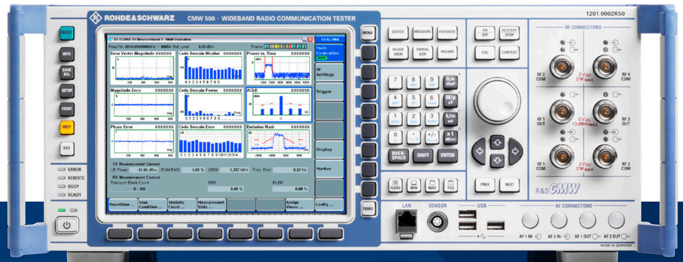
Numerous advantages of the future-ready CMW all-in-one platform

The user-friendly CMW platform has extremely stringent speed and reliability requirements to efficiently perform all measurement tasks – from complex lab tests to production line testing. While the high-end CMW500 covers the entire spectrum, the R&S®CMW270 specializes in non-cellular connectivity. The CMW100 and CMP180 testers are optimized for production. Since all CMW models are code compatible, code can easily be reused on other models, such as remote controls.

CMW BLUETOOTH® TESTING FOR ALL PRODUCT CREATION PHASES

CMW500

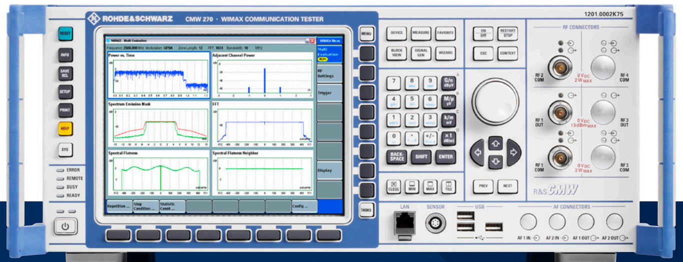
The all-in-one test platform



The CMW500 wideband radio communication tester available as Callbox for RF integration and as protocol tester. It is the solution with the widest range of supported technologies.

R&S®CMW270

The expert for all non-cellular technologies



The R&S®CMW270 wireless connectivity tester is a cost-effective alternative for development, prequalification, production and service. It supports Bluetooth®, WLAN and Zigbee technologies.

Wide variety of hardware and software options

The CMW platform has a scalable option concept and offers a variety of software and hardware options. As a result, the CMW can be individually configured to meet given T&M requirements. The CMW keeps pace with continuous technological developments by providing software updates and new software options. Hardware components can be upgraded as well. Unique software tools that extend the range of functions are also available. The CMW platform covers the entire T&M spectrum with a single instrument.

CMW Bluetooth® testing covers all technologies

Versatile hardware platform
- 6 GHz support (with extension up to 8 GHz)
- Up to 4 channels
- Internal audio analyzer and generator

Multi-RAT signaling
- Bluetooth®, WLAN
- LTE-A, WCDMA/HSPA+, GSM/GPRS/EGPRS
- CDMA2000® 1xRTT/EV-DO, TD-SCDMA

Bluetooth® LE and Bluetooth® Classic
- All Bluetooth SIG RF test cases in remote control mode with detailed test report
- Easy test setups based on OTA test solution
- Audio measurements

WLAN signaling support
- LTE-WLAN traffic offload
- WLAN E2E and access point testing
- In-device coexistence tests with other technologies

Outstanding features for production
- Multi-DUT testing for up to 16 devices
- Chipset support for all major suppliers
- Uniform GUI from development to production

CMW100

The compact RF tester for production

The CMW100 communications manufacturing test set is based on the CMW platform and can be used to calibrate and verify wireless devices in non-signaling mode (analyzer/generator).

CMP180

The non-signaling tester from R&D to mass production.

The CMP180 radio communication tester completes the vector signal analyzer/vector signal generator single-box tester portfolio for higher frequency ranges up to 8 GHz and provides a bandwidth of up to 500 MHz.

Development
- RF development
- Design optimization

Bluetooth® RF prequalification

Certification
- RF certification
- Bluetooth® qualification

Production
- Bluetooth® RF testing
- Bluetooth® audio testing

BLUETOOTH® APPLICATIONS

Today, Bluetooth® technology is everywhere: in cars, smartphones, computers, headsets, fitness trackers, toys, smart homes, medical technology, industrial applications and more. The range of applications is virtually limitless.

Automotive

All major car manufacturers offer Bluetooth® enabled hands-free calling systems. Bluetooth® technology offers more than hands-free calling. The systems also offer infotainment by connecting to the audio system so passengers and drivers can listen to whatever they want while driving or use apps to navigate, check traffic, view weather reports and restaurant information.

The over-the-air (OTA) car key system is a virtual smartphone key for company fleets, car-sharing companies and car rental agencies. The driver books the required car with a smartphone app and the OTA key system sends encrypted data to the cell phone to access the car.

New phone apps also use Bluetooth® technology to monitor and diagnose mechanical and electrical components. For example, the tire pressure monitoring and electronic tire information system permanently monitor inflation pressure and reliably alert drivers.

Health and medical

Bluetooth® technology is the ideal wireless standard for hospital and home applications, such as Bluetooth® LE enabled blood glucose monitors, pulse oximeters, heart rate monitors and asthma inhalers. Other products are becoming ever more common. Consumers like them because they can connect to Bluetooth® enabled PCs, tablets and smartphones. Patients and their care providers get critical information in real time, giving them a more accurate, full picture of the body's response to a prescribed treatment plan. This information can help them track health data over time, show trends and even sound alarms when necessary.

Wearables

The fast-growing wearables market includes activity monitors, smart glasses, headsets, child and pet monitoring, medical aids, head-mounted and hand-mounted terminals and cameras and even smart clothing. Most of these products use Bluetooth® technology for connectivity.

Wrist-worn fitness and wellness wearables are everywhere to monitor steps, activity, sleep and even emotional levels. Infotainment wearables range from audio headsets to smart watches and smart glasses that use Bluetooth® technology to connect to mobile apps. Industrial wearable applications include hands-free terminals and heads-up displays for more efficient logistics, inventory, production and worker safety.

Consumer electronics and home automation

These days, most consumer electronic devices are connected with smart, power-efficient, wireless Bluetooth® technology. Bluetooth® is basically a standard PC feature. Hundreds of millions of Bluetooth® devices have given music lovers wireless access to earbuds, headsets or speakers from their phone or PC. New products such as gaming VR headsets, toothbrushes, light bulbs, yoga mats, tools and lawn mowers now also have a wireless Bluetooth® connection.

Homeowners can control lights, temperature, household appliances, window and door locks and security systems in their homes from their phone, tablet or laptop. Since most homeowners have at least one Bluetooth® capable smartphone or tablet, they can use devices they are already familiar with.

Location services

The proliferation of Bluetooth® technology is opening up new markets. Beacons – small objects that transmit location information to smartphones with Bluetooth® LE – allow for mobile wallets and location based services. Beacons are already used for advertising in shopping malls, for indoor navigation in large stadiums and for contactless payment for parking. Other beacon uses include airports, transit stations and large event venues where they can easily send out notifications on departures, delays and other passenger information.

BLUETOOTH® LE TECHNOLOGY OVERVIEW

Bluetooth® LE is a radio standard developed as low-power wireless communication technology for mobile phone peripherals in 2010 in addition to Bluetooth® Classic.

Historical background

Bluetooth® (Classic) was originally developed in the late 1990's to replace cable connections with moderate data rates and low energy consumption that cover a limited area (approx. 10 m). In 2010, Bluetooth® LE was introduced for peripheral devices that were very energy sensitive such as wearables or location sensors powered from low capacity coin cells. Bluetooth® devices can either be single mode (either Bluetooth® Classic or Bluetooth® LE), or dual-mode types. Dual-mode devices are typically less power sensitive central devices such as laptops or smartphones.

Physical layers

Bluetooth® LE offers four different physical layers modes optimized for different use cases and RF channel conditions (see table on next page).

Channels

Bluetooth® LE uses two different channel maps within the 2.4 GHz ISM band. One for the LE 1M, LE 2M and LE coded PHYs, and one for channel sounding (CS). The standard (legacy) LE channel map uses 40 RF channels in total, with 2 MHz spacing. Three of these channels are exclusively used for primary advertising (0, 12, 39), and the remaining for 37 data/secondary advertising purposes.

The Bluetooth® specification uses 72 channels in total for with 1 MHz spacing for channel sounding. Along with the three primary advertiser channels, four guard channels protect the advertiser channels.

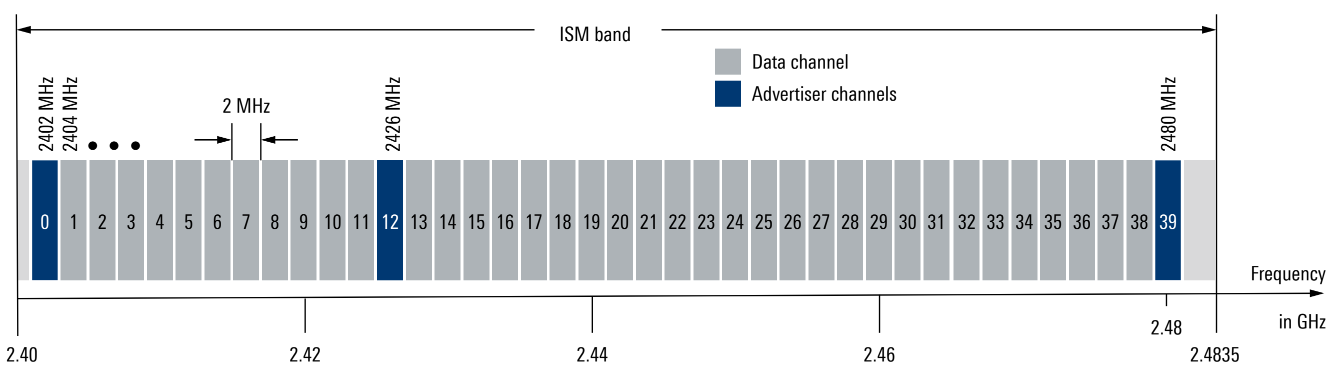
In advertising mode the primary advertiser channels are used to build up a connection. In connected mode data can be transmitted on the remaining channels.

Main differences between Bluetooth® LE and Bluetooth® Classic

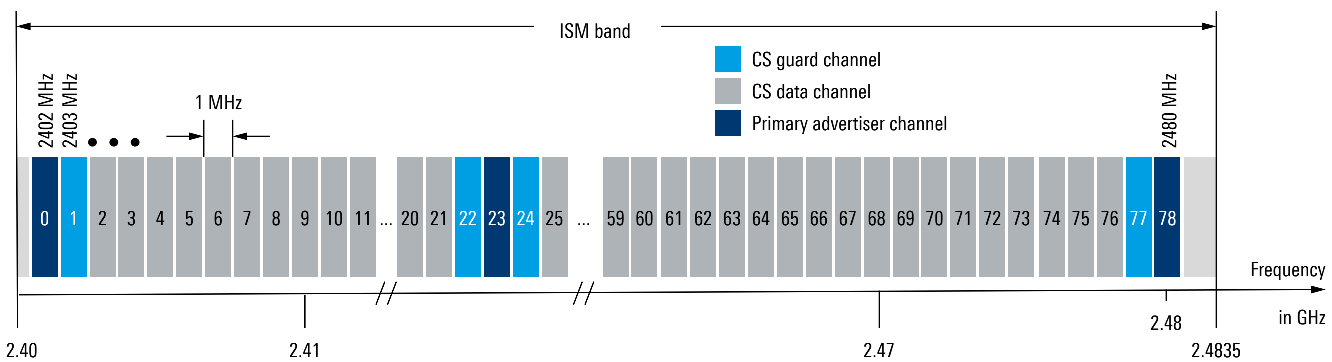
	Bluetooth® LE technology	Bluetooth® Classic technology
Channels	▶ 40 channels with 2 MHz spacing ▶ 79 channels with 1 MHz spacing for CS only	79 channels with 1 MHz spacing
Transmit power		
Class 1	20 dBm (max.), 100 mW	20 dBm (max.), 100 mW
Class 1.5	10 dBm (max.), 10 mW	–
Class 2	4 dBm (max.), 2,5 mW	4 dBm (max.), 2,5 mW
Class 3	0 dBm (max.), 1 mW	0 dBm (max.), 1 mW
Discovery/connect	advertising	inquiry, paging
Number of peripheral piconets	unlimited	7 active
Channel usage	frequency-hopping spread spectrum (FHSS)	frequency-hopping spread spectrum (FHSS)
Modulation	GFSK	GFSK, π/4 DQPSK, 8DPSK
Data rate	▶ LE 2M PHY: 2 Mbit/s ▶ LE 1M PHY: 1 Mbit/s ▶ LE Coded PHY (S = 2): 500 kbit/s ▶ LE Coded PHY (S = 8): 125 kbit/s	▶ EDR PHY (8DPSK): 3 Mbit/s ▶ EDR PHY (π/4 DQPSK): 2 Mbit/s ▶ BR PHY (GFSK): 1 Mbit/s
Modulation index	0.45 to 0.55 (SMI: 0.495 to 0.505)	0.28 to 0.35
Application data rate	0.2 Mbit/s to 1.4 Mbit/s	0.7 Mbit/s to 2.1 Mbit/s
Security	128 bit AES	64 bit/128 bit
Power consumption	"0.01" to "0.5", depending on use case	"1" as reference
Peak current consumption	< 15 mA	< 30 mA

Bluetooth® LE channel maps

Bluetooth® LE



Bluetooth® LE channel sounding (CS)



Four different physical layer types of Bluetooth® LE

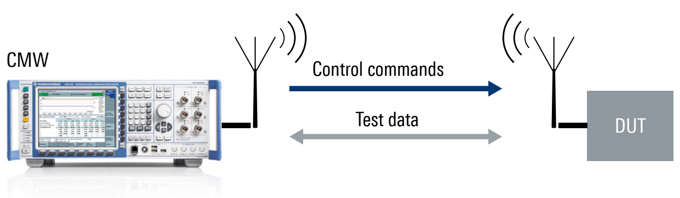
PHY	Symbol rate	Bandwidth-symbol time product (BT)	Coding scheme of access header	Coding scheme of payload	Data rate	Frequency deviation
LE 1M	1 Msymbol/s	0.5	uncoded	uncoded	1 Mbit/s	250 kHz
LE 2M	2 Msymbols/s	0.5	uncoded	uncoded	2 Mbit/s	500 kHz
LE 2M 2BT	2 Msymbols/s	2.0 [1)]	uncoded	uncoded	2 Mbit/s	500 kHz
LE Coded	1 Msymbol/s	0.5	S = 8	S = 8	125 kbit/s	250 kHz
				S = 2	500 kbit/s	

[1)] The BT of 2.0 is an optional security only available for the Channel Sounding feature.

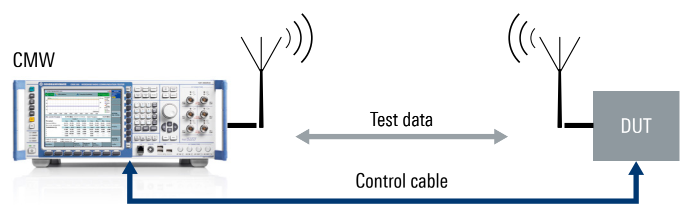
BLUETOOTH® LE TESTING SOLUTIONS FROM ROHDE & SCHWARZ

For every testing use case the right testing method.

Signaling, Bluetooth® LE test mode



Non-signaling, direct test mode



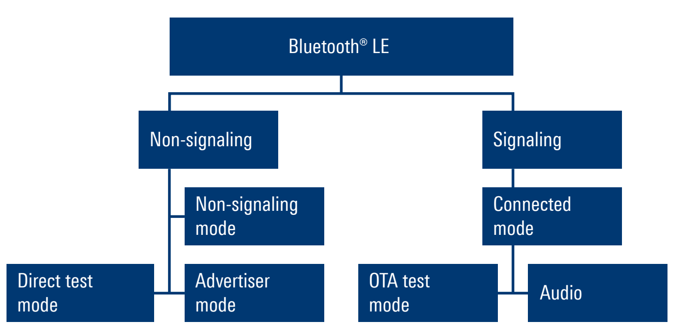
Signaling versus non-signaling test mode

The Bluetooth SIG defines a signaling test mode for Bluetooth® Classic qualification tests. By contrast, when Bluetooth® LE technology was introduced in 2010 the direct test mode (DTM), a non-signaling method, was defined. A signaling method with a unified test mode (UTP) was added in 2024 for Bluetooth® LE devices.

Both the DUT and the tester have a real connection when signaling. The test packages and control commands are sent over the same interface, either over the air (OTA) or via an RF cable.

In non-signaling, the DUT and the tester do not have a real connection. A controller (lower tester), possibly part of the tester, controls the DUT and tester during RF tests. The control commands are sent via an additional interface, as HCI or UART. The DTM is very fast but does not show real RF behavior in a real connection.

Bluetooth® LE testing on the CMW platform



Challenges for non-signaling

The additional control interface is a challenge for smaller IoT devices that use Bluetooth® LE. For example, where are such control interfaces located on hearing aids or as an additional USB-connection? Would it just be easier to test over the air?

Signaling connected

The connected mode uses the connected state of the DUT. The DUT is in a hopping connection with the signaling tester. In this mode, no control commands are exchanged between the DUT and tester. The RX and TX measurements use the exchange of arbitrary feature requests and feature response packages. But they are limited to data channels. The primary advertiser channels cannot be tested. The pre-qualification tests cannot use this mode.

Signaling UTP mode (OTA)

The LE UTP mode uses the connected state. The DUT has a hopping connection with the signaling tester. In contrast to the connected mode, the control commands for the RX and TX tests are exchanged over the air (or an RF interface). Using this mode all channels and all qualification tests could be tested as they would in the direct test mode. Along with known PER and PER search measurements, the UTP mode allows receiver testing at the BIT level with BER measurements. The chipset needs to support the UTP test mode.

Signaling audio

In a connected state, the CMW can provide RF and audio measurements on isochronous channels at the board level. The CMW platform has different profiles for device testing. The RF stability of audio connections can also be tested with profiles and sending different interferers.

Non-signaling direct test mode (DTM)

The DTM does not use a real Bluetooth® connection but a cable connection between the CMW tester and the DUT for control commands. The DUT typically has a UART interface with HCI or two-wire protocol.

The CMW sends the DUT a DTM command for TX testing. The DUT responds by sending Bluetooth® LE RF test packets to the CMW. The payload pattern, payload length and Bluetooth® channel settings are configured on the CMW and transmitted to the DUT via the control cable.

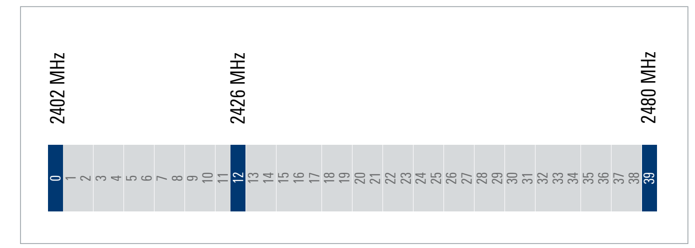
The CMW sends the DUT a DTM command that causes the DUT to switch to a specific Bluetooth® channel in receive mode for RX testing. Then the CMW sends a defined number of Bluetooth® RF test packets at a suitably low level. Depending on the level, the DUT receives some packets correctly while others have bit errors. The DUT counts the number of correctly received packets by calculating a CRC checksum for each received packet and compares the checksum to the one transmitted by the CMW. At the end of the test, the CMW transmits a test end command. The DUT transmits the number of packets correctly received via the control cable to the CMW. The CMW calculates and displays the packet error rate (PER).

Non-signaling advertiser mode

The advertiser mode uses the DUT advertiser state. The DUT advertises itself by sending advertising packets. In this state the CMW can run RX and TX measurements on the primary and secondary (general purpose) advertiser channels. This test method is used to test the transmitter functions in production. Data channel testing and qualification testing are not possible.

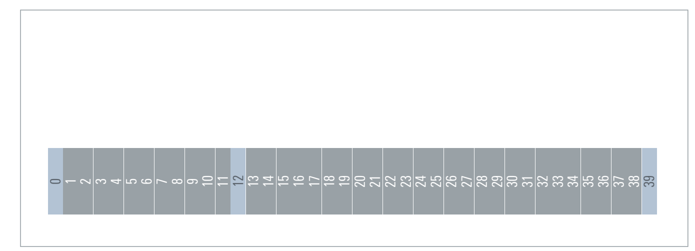
Bluetooth® LE band and test capabilities

Bluetooth® LE Advertiser test mode



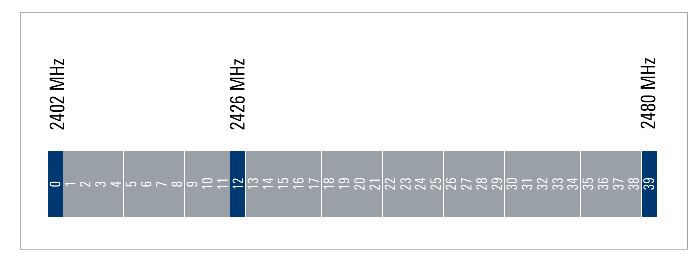
RF tests on **advertiser channels** only

Bluetooth® LE signaling connected mode



RF tests on **data channels** only

DTM and Bluetooth® LE test mode

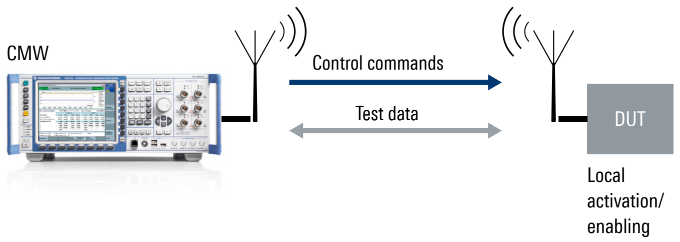


RF tests on **all channels**

BLUETOOTH® CLASSIC AND RF TESTING

The CMW covers all Bluetooth® RF transmitter and receiver tests. For Bluetooth® Classic, the RF tests are defined in a signaling test mode.

The CMW controls the DUT in the test mode via test control commands



Bluetooth® Classic

The term Bluetooth® Classic describes Bluetooth® devices with basic rates (BR) and enhanced data rates (EDR) as specified in the Bluetooth® core specification, version 1 and higher. The main characteristics of Bluetooth® Classic are:

- Conventional operation with low data rates (BR)
- Operation with improved transmission speeds (EDR)

Seventy-nine RF channels are available for data transfer, each with 1 MHz spacing in the 2.4 GHz ISM band. Frequency hopping between the channels prevents interference with ambient radio signals. Blocked channels are not used in adaptive hopping mode. While BR modulation uses Gaussian frequency shift keying (GFSK) with a gross data rate of 1 Mbit/s, EDR further enhances the data rate by using π/4-DQPSK (2 Mbit/s) and 8DPSK (3 Mbit/s) phase shift keying.

Signaling test mode for Bluetooth® Classic

The Bluetooth® core specification defines a mode for RF testing of Bluetooth® Classic DUTs based on a "real" Bluetooth® connections. The DUT must be enabled for the test mode via the internal host controller interface (HCI). Acting as the hub, the CMW sets up a Bluetooth® connection with the DUT (peripheral) by searching for Bluetooth® devices (inquiry) or directly addressing a specific DUT.

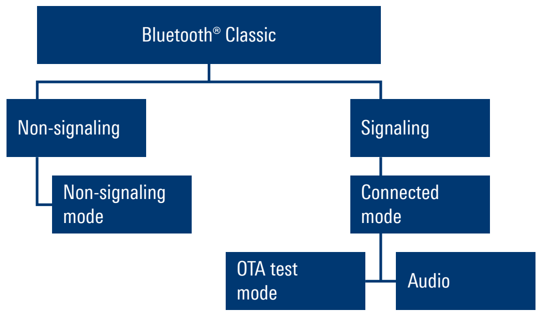
Once a Bluetooth® connection is established, the CMW uses test control commands for the DUT. The most important operating mode is the loopback test mode. The CMW sends Bluetooth® packets to the DUT and the DUT loops the packets back to the CMW. Both TX and RX tests are possible in this mode.

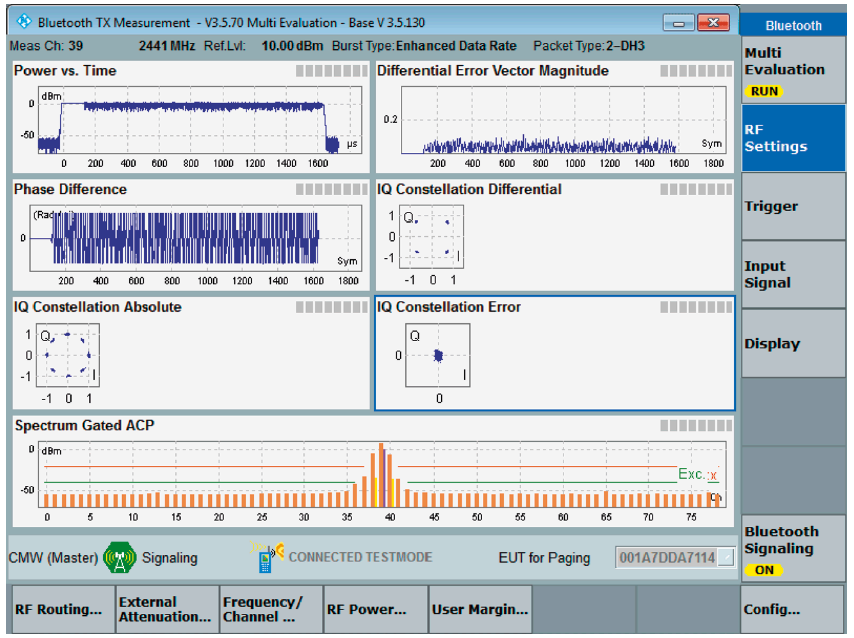
The CMW transmits at the "normal" level for TX tests, which usually generates no bit errors in the DUT. The DUT returns the packet to the CMW and the CMW measures the TX parameters for the DUT.

The CMW transmits at a very low level for RX tests. Bit errors occur in the DUT when the packet is received. The DUT sends the faulty packet back to the CMW and the CMW determines the bit error rate.

The Bluetooth® test mode permits a Bluetooth® connection both in hopping mode and at fixed frequencies.

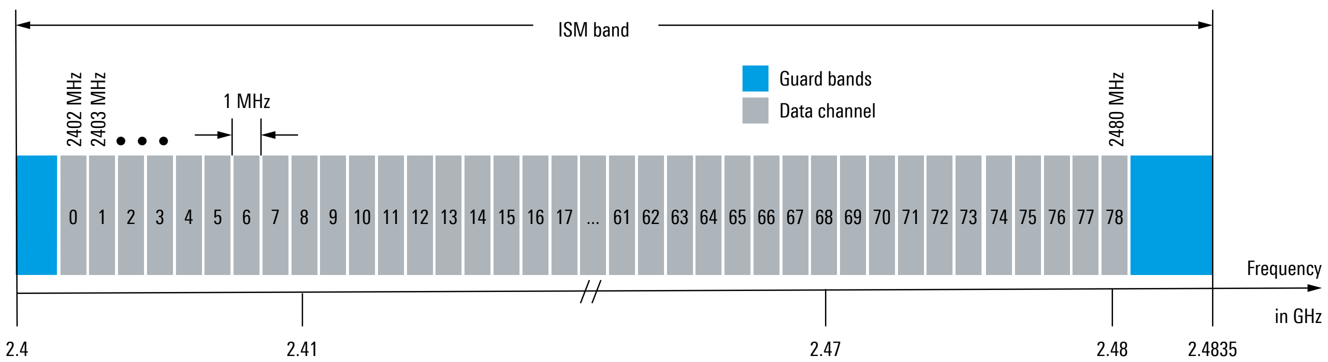
Bluetooth® Classic testing methods on the CMW platform





The Bluetooth® EDR multi-evaluation view provides an overview of the results for all simultaneous measurements. The overview and individual zoom views for the BR, EDR and LE modes are shown on the next few pages.

Bluetooth® Classic



HOW TO GET YOUR BLUETOOTH® PRODUCT TO MARKET

Two sets of approval requirements are needed before products with Bluetooth® technology can be legally placed on the market: Bluetooth SIG and national certification bodies require official certification.

Bluetooth® qualification

The Bluetooth® qualification program defined by the Bluetooth SIG aims to protect the value of Bluetooth® technology and its brand. The Bluetooth SIG compliance program ensures that a product complies with Bluetooth® specifications and can successfully operate with other products that support the same Bluetooth® profile.

First, any company using Bluetooth® wireless technology in products and services must be a Bluetooth SIG member. Depending on the product, the qualification process can require different test cases such as RF conformance testing, protocol and profile conformance testing and profile interoperability testing. After passing all the required tests and once a product is fully registered, suppliers can sell and brand the product or service with Bluetooth® trademarks.

National certification processes

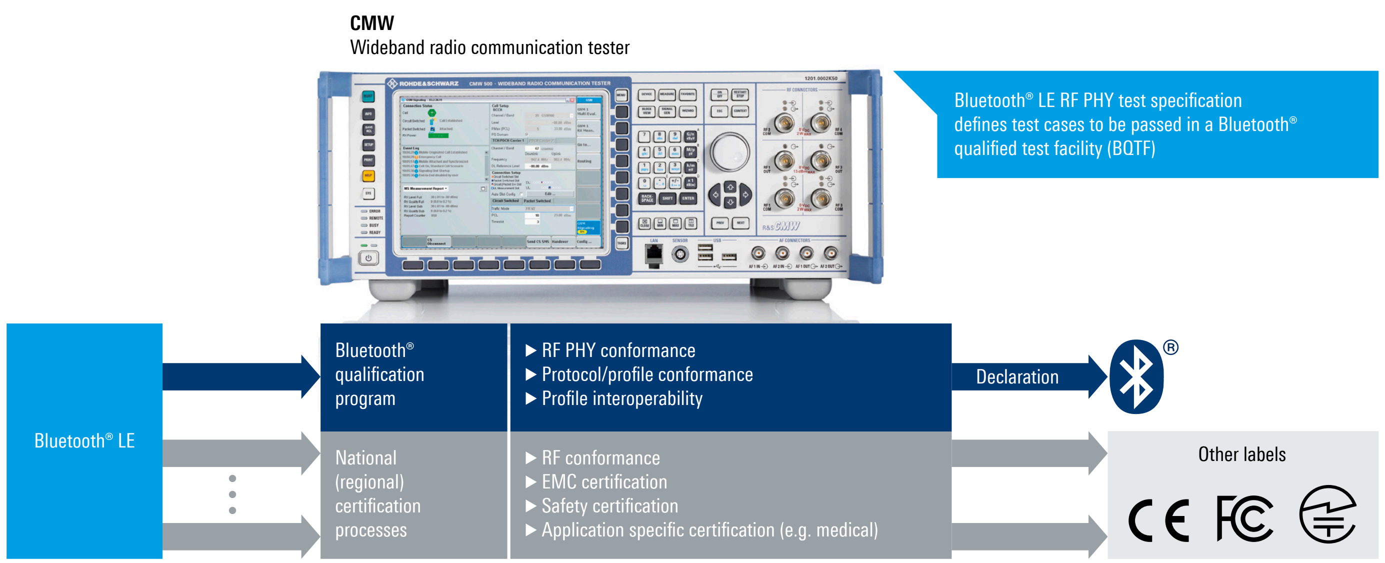
National approval requirements can also apply to Bluetooth® products and are required for market entry. Three product certification requirements generally apply to Bluetooth® products:

- Radio type approval for the RF transmitter/transceiver unit
- EMC certification of the RF section, usually when installed within the host unit and relative to normal configuration and conditions of use
- Safety certification, usually dependent on the product operating voltage and any associated power supplies

Accredited test houses: BQTFs and BRTFs

If RF conformance testing and national radio type approval are needed, testing is generally done at a test laboratory accredited by the Bluetooth SIG and the country of interest. The Bluetooth SIG accepts two different types of test houses for qualification conformance testing: a Bluetooth® Qualification Test Facility (BQTF) and a Bluetooth® Recognized Test Facility (BRTF). Only major test houses can become a BQTF and be recognized by the Bluetooth SIG capable of performing the qualification conformance testing in line with the test case reference list (TCRL). Very few companies receive BRTF status and are authorized to perform testing only on their own behalf and can help customers market their products faster.

Bluetooth® certification



BLUETOOTH® RF TEST CASES (TC)

The Bluetooth SIG defines the test cases (TC) for Bluetooth® Classic and Bluetooth® LE. The CMW platform and R&S®CMWrun support all Bluetooth® RF test cases.

Structure of the Bluetooth® test cases

Beside the qualification program the Bluetooth SIG is responsible for permanent development of new applications and features down to the RF layer, which is done in different releases. The definition, procedures and parameters of the applications are described in the Bluetooth® core specification in detail. The core specification is used to develop the RF test specification.

The RF test specification is based on the RF test specification for Bluetooth® Classic and the RFPHY test specification for Bluetooth® LE. The test specification describes the test cases for RF transmitter and receiver testing, including test purpose, initial conditions, test case configuration, test procedure and pass verdict. Below is a list of the test cases for Bluetooth® Classic and Bluetooth® LE.

BLUETOOTH® CLASSIC, RF UP TO REL. 5.0

Transmitter tests, TP/TRM/CA/BV-xx-C	
TC purpose	**TC**
Output power	01
Power density	02
Power control	03
TX output spectrum – frequency range	04
TX output spectrum – 20 dB bandwidth	05
TX output spectrum – adjacent channel power	06
Modulation characteristics	07
Initial carrier frequency tolerance	08
Carrier frequency drift	09
EDR relative transmit power	10
EDR carrier frequency stability and modulation accuracy	11
EDR differential phase encoding	12
EDR in-band spurious emissions	13
Enhanced power control	14
EDR guard time	15
EDR synchronization sequence and trailer	16

Receiver tests, TP/RCV/CA/BV-xx-C	
TC purpose	**TC**
Sensitivity – single-slot packets	01
Sensitivity – multi-slot packets	02
C/I performance	03
Blocking performance	04
Intermodulation performance	05
Maximum input level	06
EDR sensitivity	07
EDR BER floor performance	08
EDR C/I performance	09
EDR maximum input level	10

BLUETOOTH® LE IoT, RFPHY UP TO REL. 5.0

Transmitter tests	RFPHY/TRM/BV-xx-C							
Bluetooth® …	LE 1M, 1 Msymbol/s	LE 2M, 2 Msymbols/s	LE 1M, 1 Msymbol/s, SMI	LE 2M, 2 Msymbols/s, SMI	Coded, 1 Msymbol/s, S = 2	Coded, 1 Msymbol/s, S = 8	Coded, 1 Msymbol/s, SMI, S = 2	Coded, 1 Msymbol/s, SMI, S = 8
Output power	01/18	19/20						
In-band emission	03	08						
Modulation characteristics	05	10	09	11		13		
Carrier frequency offset and drift	06	12				14		

Receiver tests	RFPHY/RCV/BV-xx-C							
Bluetooth® …	LE 1M, 1 Msymbol/s	LE 2M, 2 Msymbols/s	LE 1M, 1 Msymbol/s SMI	LE 2M, 2 Msymbols/s SMI	Coded, 1 Msymbol/s, S = 2	Coded, 1 Msymbol/s, S = 8	Coded, 1 Msymbol/s, SMI, S = 2	Coded, 1 Msymbol/s, SMI, S = 8
Receiver sensitivity	01	08	14	20	26	27	32	33
C/I and receiver sensitivity [1)]	03	09	15	21	28	29	34	35
Blocking performance [1)]	04	10	16	22				
Intermodulation performance [1)]	05	11	17	23				
Maximum input signal level	06	12	18	24				
Packet error rate (PER) report integrity	07	13	19	25	30	31	36	37

BLUETOOTH® DIRECTION FINDING, RFPHY REL. 5.1

Transmitter tests					
TC purpose	TC	TC number			
		1 Msymbol/s PHY		2 Msymbols/s PHY	
Output power	TRM/BV-	15/21		22/23	
Carrier frequency offset and drift with CTE	TRM/BV-	16		17	
		2 µs slot	1 µs slot	2 µs slot	1 µs slot
TX power stability, AoD transmitter	TRM/PS/BV-	01	02	03	04
Antenna switching integrity, AoD transmitter	TRM/ASI/BV-	05	06	07	08

Receiver tests					
TC purpose	TC	TC number			
		1 Msymbol/s PHY		2 Msymbols/s PHY	
		2 µs slot	1 µs slot	2 µs slot	1 µs slot
I/Q samples coherency, AoD receiver	RCV/IQC/BV-	01	02	03	04
I/Q samples coherency, AoA receiver	RCV/IQC/BV-	05	–	06	–
I/Q samples dynamic range, AoD receiver	RCV/IQDR/BV-	07	08	09	10
I/Q samples dynamic range, AoA receiver	RCV/IQDR/BV-	11	–	12	–

1) Requires an additional signal generator.

BLUETOOTH® CHANNEL SOUNDING (CS), RFPHY REL. 6.0 [2)]

Transmitter tests (TRM), RFPHY/TRM/CS/BV-xx-C											
Test requirement	1 Msymbol/s				2 Msymbols/s				2 Msymbols/s, BT = 2.0		
	Mode-0	Mode-1	Mode-2	Mode-3	Mode-0	Mode-1	Mode-2	Mode-3	Mode-0	Mode-1	Mode-3
Stable phase			01				02				
Modulation characteristics										03	04
TX SNR output control		05		06		07		08		09	10

Transmitter tests (TRM-RCV), RFPHY/TRM-RCV/CS/BV-xx-C											
Test requirement	1 Msymbol/s				2 Msymbols/s				2 Msymbols/s, BT = 2.0		
	Mode-0	Mode-1	Mode-2	Mode-3	Mode-0	Mode-1	Mode-2	Mode-3	Mode-0	Mode-1	Mode-3
CS step mode-0, frequency verification	01				02				03		
CS step main mode, frequency verification		04	05	06		07		08		09	10
CS phase measurement accuracy reflector			11	12				13			14
CS phase measurement accuracy initiator			15	16				17			18

PURPOSE OF THE DIFFERENT CS MODES

CS mode	Purpose
Mode-0	Measuring frequency offset, timing estimation between inititator and reflector, used for calibration
Mode-1	Measuring round-trip time (RTT), measures time of arrival (ToA) and time of departure (ToD)
Mode-2	Measuring phase based ranging due to distance, unmodulated carrier, measures phase/amplitude of the channel
Mode-3	Combined mode-1 and mode-2, measuring both round-trip times and phase/amplitude in the form of I/Q

Explanations

- Test cases use the Bluetooth SIG RF-PHY test specification numbering system
- 2 µs slot size mandatory, 1 µs slot size optional
- C/I and receiver sensitivity tests, blocking performance tests and intermodulation performance tests require an additional signal generator
- Direction finding and channel sounding only supported for the unencoded PHYs
- AoA TX test cases only defined for 2 µs slot switching time

2) Currently any support for Bluetooth® Channel Sounding within the CMW is based on a working draft of a Bluetooth® specification that is subject to change.

RECEIVE/TRANSMIT RF VERIFICATION

The CMW platform makes testing Bluetooth® RF performance and quality easy. The CMW can perform all RF test cases specified by Bluetooth SIG up to Bluetooth® Rel. 5.1.

TX measurements

The CMW uses Bluetooth® RF test specifications to calculate measurement results. All measurements can be performed on any Bluetooth® channel and various parameters applied.

The CMW performs various TX measurements simultaneously. The multi-evaluation view gives an overview of all TX measurements. Users can switch from an overview to individual power, modulation and spectrum measurements for more detail. All signal parameters, including RF channel(s), packet type, pattern type, packet length and level can be directly and separately modified. The CMW gives users flexibility for troubleshooting in the lab. DUT RF design can be optimized quickly and easily.

The CMW supports power control for all TX measurements for Bluetooth® Classic. In addition to controlling individual power steps, users can examine the influence of DUT current power levels on modulation and frequency parameters.

The CMW is ready for RF test cases.

CMW TX measurements at a glance

TX measurements	Bluetooth® LE	Bluetooth® Classic (BR and EDR)
Power	average, peak and leakage power, constant tone extension (CTE) slot power, CTE slot power deviation	average, peak and leakage power (BR), GFSK and DPDK power (EDR)
Modulation	Δf_1 and Δf_2, avg., min. and max.	Δf_1 and Δf_2, avg., min. and max. (BR), Δf_2 99.9% (BR), DEVM: RMS, peak, 99% (EDR)
Frequency	frequency accuracy: with and without CTE: frequency offset, frequency drift, initial frequency drift, drift rate	frequency accuracy, frequency drift, drift rate (BR), ω_i, $\omega_{0\,max}$ (EDR)
Spectrum	in-band emissions (ACP)	20 dB bandwidth, frequency range, adjacent channel power (ACP) (BR), EDR in-band spurious emissions (gated ACP) (EDR)
Timing	–	packet timing (BR), guard period (EDR),
Others	–	constellation diagram, absolute and relative (EDR), phase difference graph (EDR), sync and trailer bit errors (EDR)

RX measurements

The CMW covers all Bluetooth® RX measurements in line with Bluetooth® RF test specifications.

Bit error rate (BER) and packet error rate (PER) testing
Possible RX measurements involve BER and PER testing at constant CMW output power. These tests can be performed as individual measurements using a configurable number of Bluetooth® packets (measurement in line with the specification) or as continuous measurements for error analysis.

Sensitivity measurements
The CMW has an automatic search function for determining the receiver sensitivity level. The CMW generator level is gradually reduced until the configured BER or PER limit is reached.

Dirty transmitter
Bluetooth® RX tests require a dirty transmitter. Depending on the operating mode (basic rate, EDR or LE), Bluetooth® RF test specifications define the dynamic behavior of the RF generator during RX measurements. The CMW dirty transmitter function can be switched on and off.

The table below shows the dirty transmitter behavior in "Bluetooth® LE unencoded, 1 Mbps" mode. After every 50 Bluetooth® packets, the generator parameters are changed in line with this table. Each packet is also superimposed with a defined frequency drift that switches its start phase between 0° and 180° from packet to packet.

In addition to the specification table mode, a single value mode is available for detailed analysis of Bluetooth® receivers. This mode makes it possible to individually change carrier frequency drift, modulation index and symbol timing error, and to activate the superimposed drift when required.

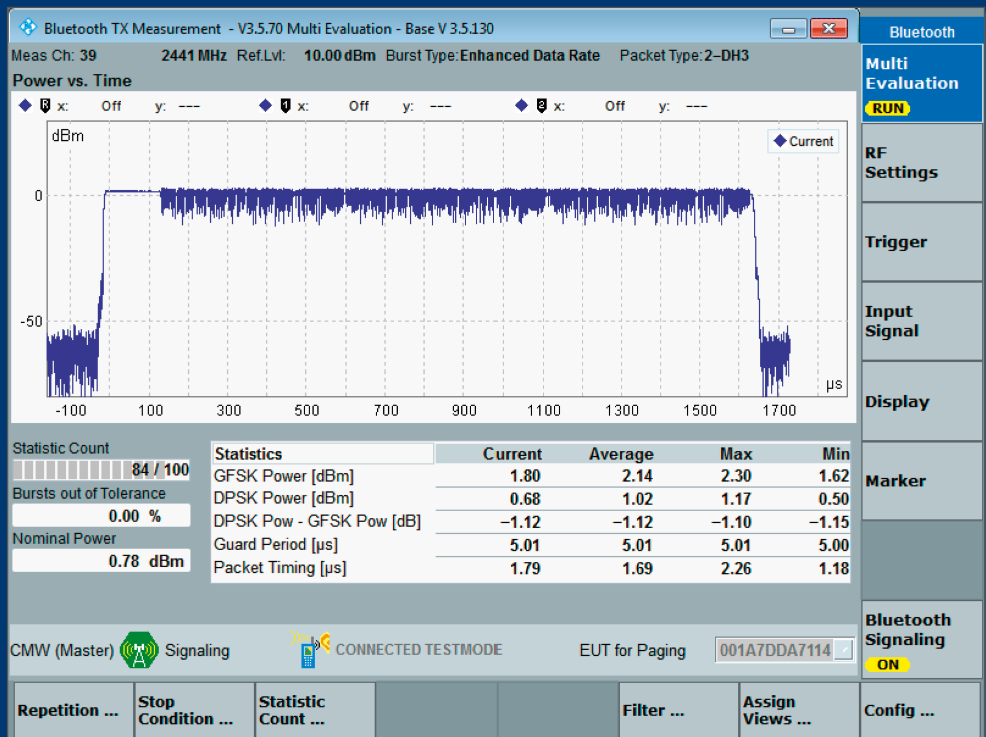
Adaptive frequency hopping (AFH) tests

The CMW provides an adaptive frequency hopping function for Bluetooth® Classic. This function permits users in remote control mode to examine the behavior of Bluetooth® connections that are impaired by external interferers.

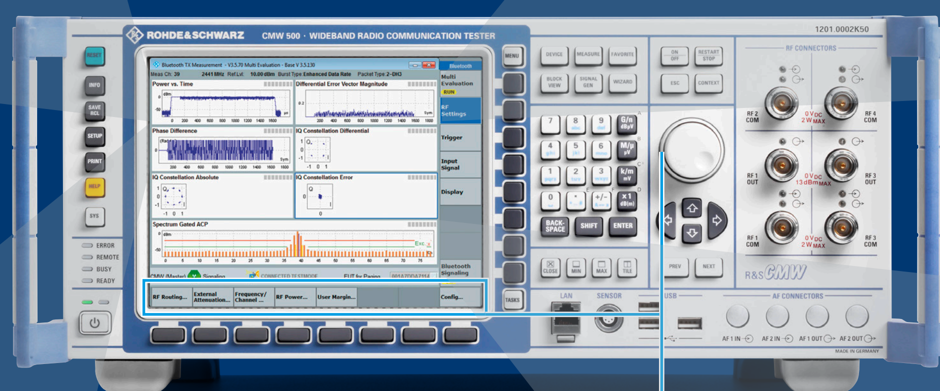
The following (remote) procedures are available on the CMW500:

- AFH channel map generation: all 79 Bluetooth® channels are queried and listed in a .csv file as blocked (0) or released (1) for AFH
- Bad channel detection based on
  - CMW and DUT combined detection
  - DUT-only detection
- User-defined AFH channel map: the user can apply individual settings; each of the 79 channels can be blocked or released provided that a minimum number of 20 channels is released

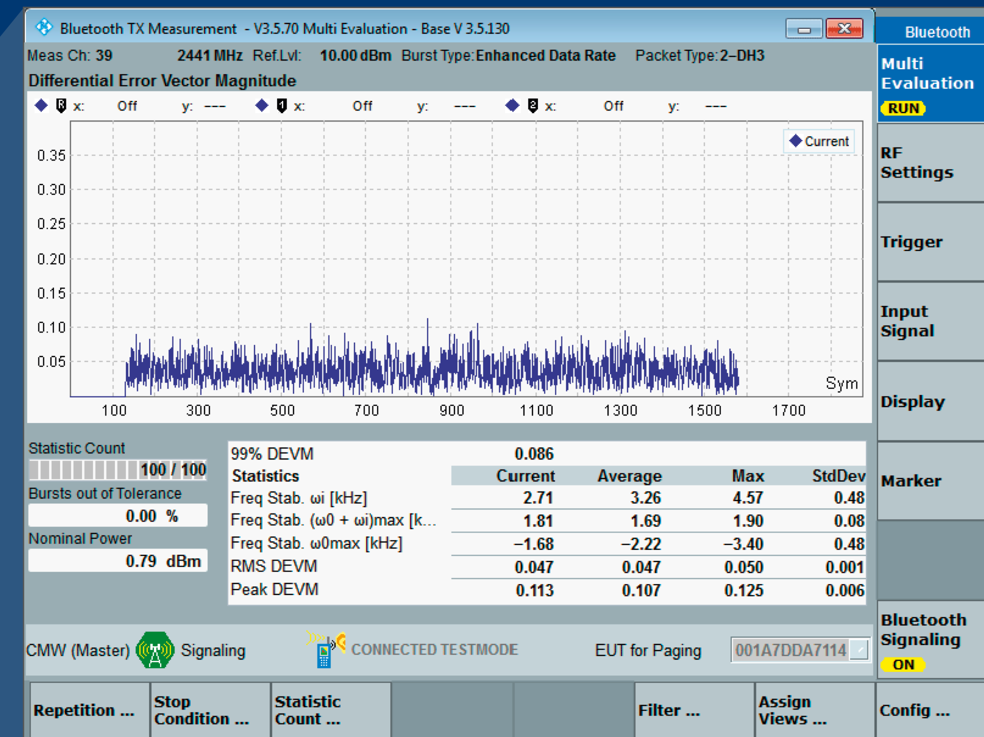
BLUETOOTH® CLASSIC EDR MULTI-EVALUATION MEASUREMENT



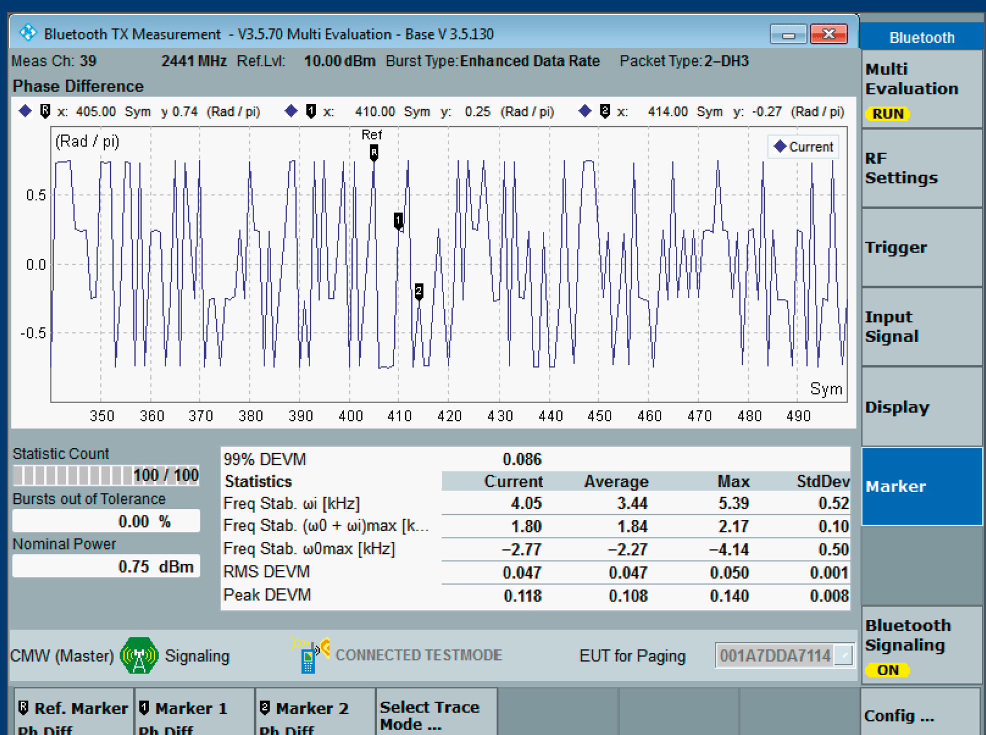
GFSK and DPSK power results: The CMW also measures the guard period and packet timing.



The overview shows all measurements in one window. Each measurement can also be displayed individually with additional details.

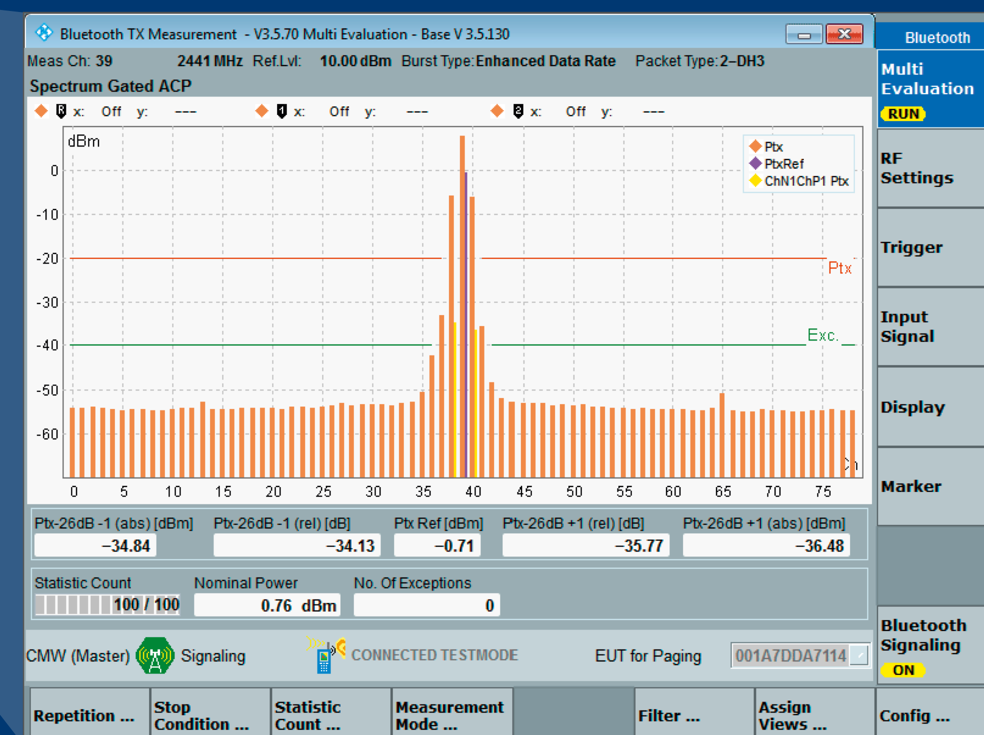


Differential error vector magnitude (DEVM) and frequency stability results: All measurements are performed according to the methods described in the Bluetooth® RF test specification.



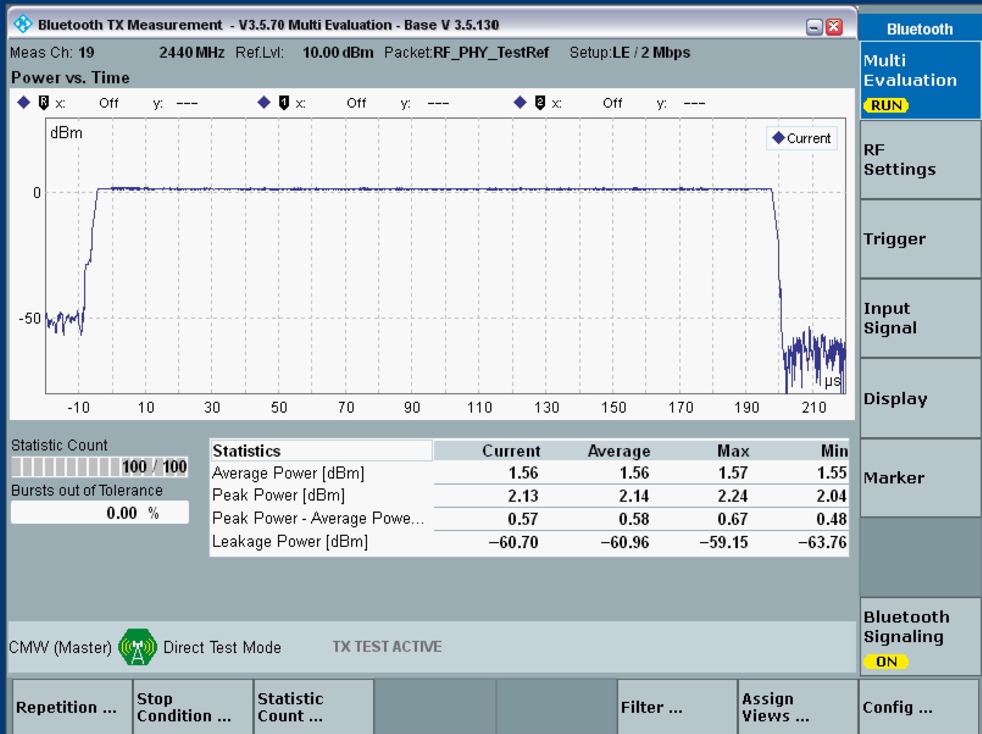
Phase difference graph: The phase difference between two consecutive symbols contains the encoded bit information of the DPSK payload. You can use the markers to verify the phase difference for each symbol.

The RF settings submenu lets you set up all RF related parameters, such as RF channels, frequency hopping, external attenuation values and CMW output power.

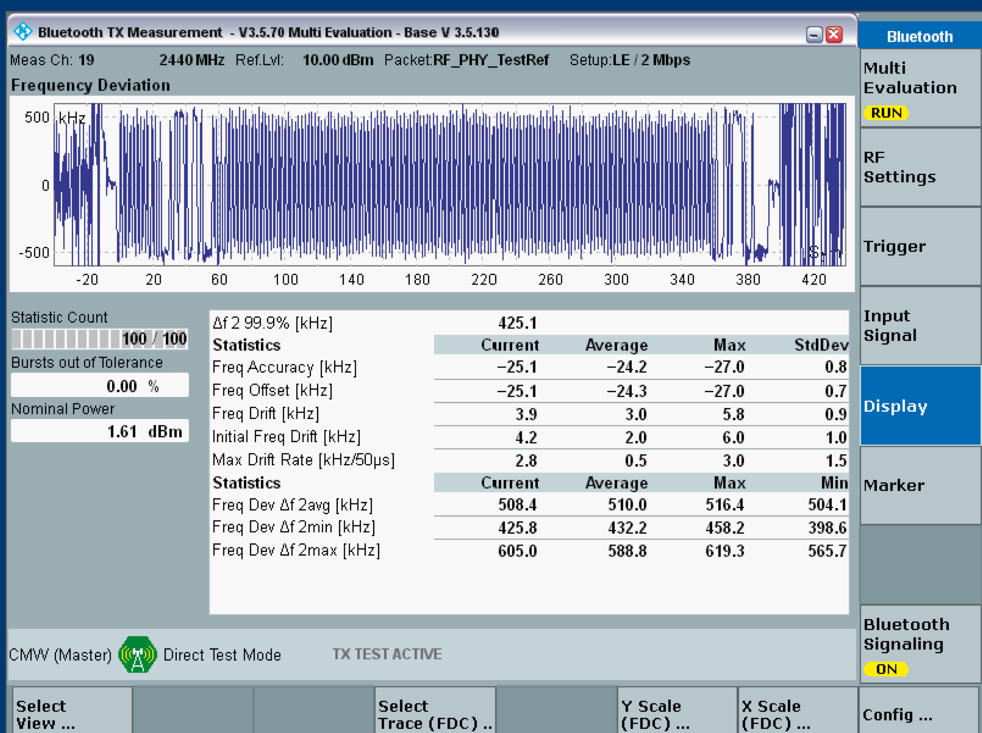


EDR in-band spurious emissions test case (gated ACP): The Bluetooth® RF test specification allows the level to exceed –40 dBm (see green limit line) on up to three channels. The CMW displays the number of these exceptions as one of the measurement results.

BLUETOOTH® LE MULTI-EVALUATION MEASUREMENT

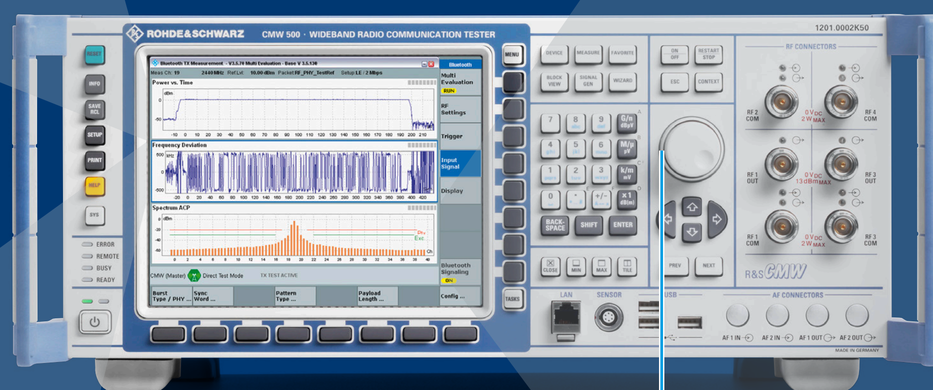


All power results: The CMW also displays the difference between peak and average power, which has to be checked according to the Bluetooth® RF test specification.

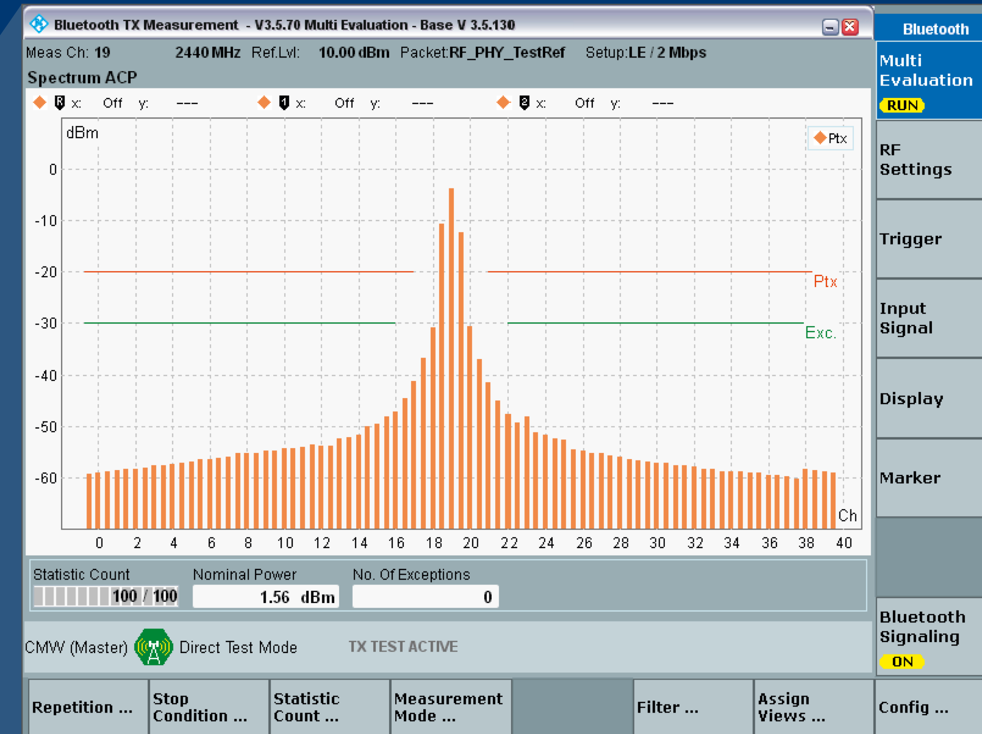


This screen shows all frequency-related results including Δf2 results if the 10101010 bit pattern is selected. The Δf1 results appear as soon as the bit pattern is changed to 11110000. The graph can be magnified to investigate the value of each single bit.

The overview shows all measurements in one window. Each measurement can also be displayed individually with additional details.



The input signal submenu lets you set up the direct test mode signal characteristics. This also includes a switch to select the PHY for testing devices that support Bluetooth® Rel. 5.



Bluetooth® LE ACP measurement (in-band emissions): This example shows the spectrum of a 2 Msps signal of a Bluetooth® 5 device. Markers allow you to read out the detailed results for all channels. Alternatively, you can select a table view of all results (see screen below).

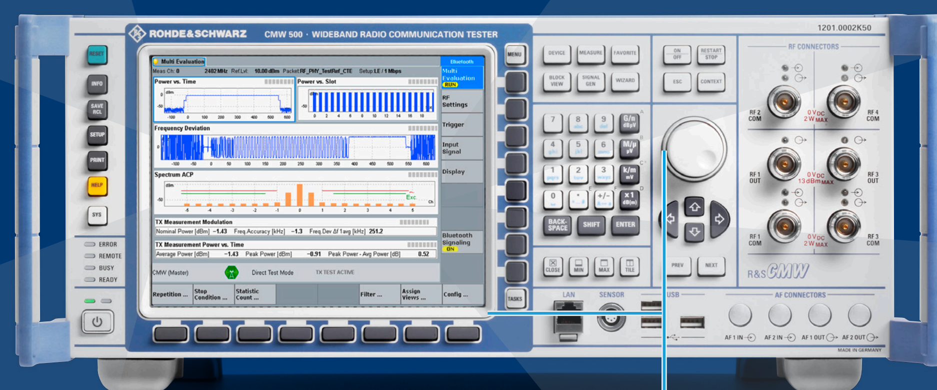
The table view shows the ACP results for all measured frequencies in form of a table. A key on the CMW front panel lets you toggle between the graphical view and the table view.

BLUETOOTH® LE DIRECTION FINDING MEASUREMENT

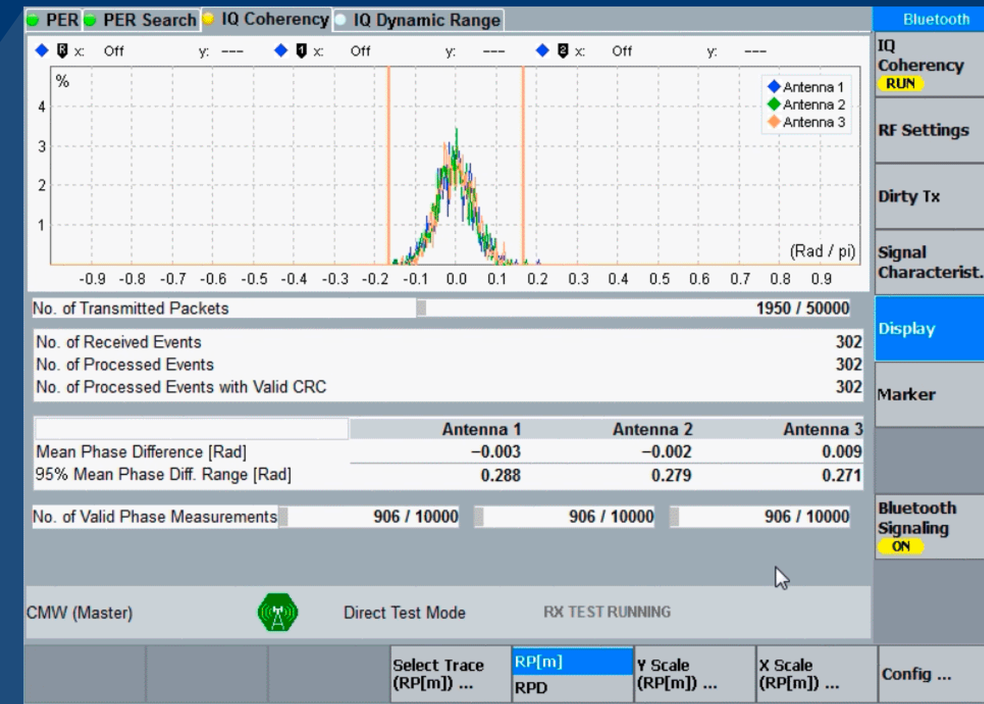
All power results: The CMW displays the average power of the reference antennae and the non-reference antennas per slot. The lower figure shows deviations from the average. According to the Bluetooth® RF test specification these cannot exceed a value of 0.25 or 6 dB.

Bluetooth® LE ACP measurement (in-band emissions): This example shows the spectrum of a 1 Mbps signal of a Bluetooth® 5.1 device. Markers allow you to read out the detailed results for all channels. A table view of all results is also available.

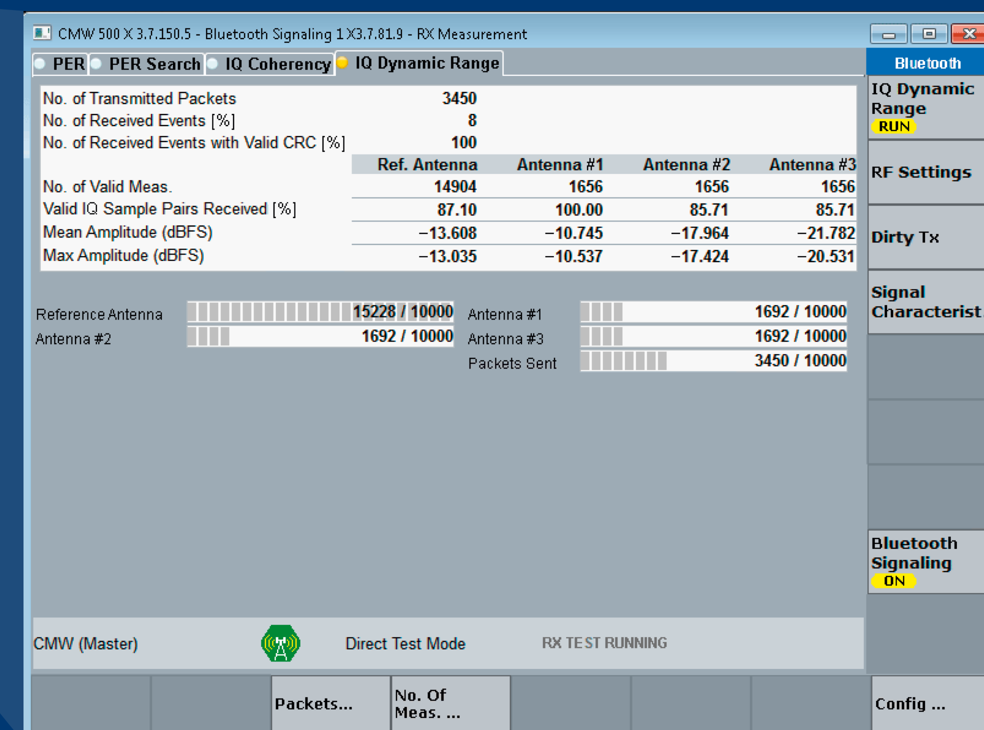
The overview shows all measurements in one window. Each measurement can also be displayed individually with additional details.



The input signal submenu lets you set up the direct test mode signal characteristics. This also includes a switch to select the PHY for testing devices that support Bluetooth® Rel. 5.1.

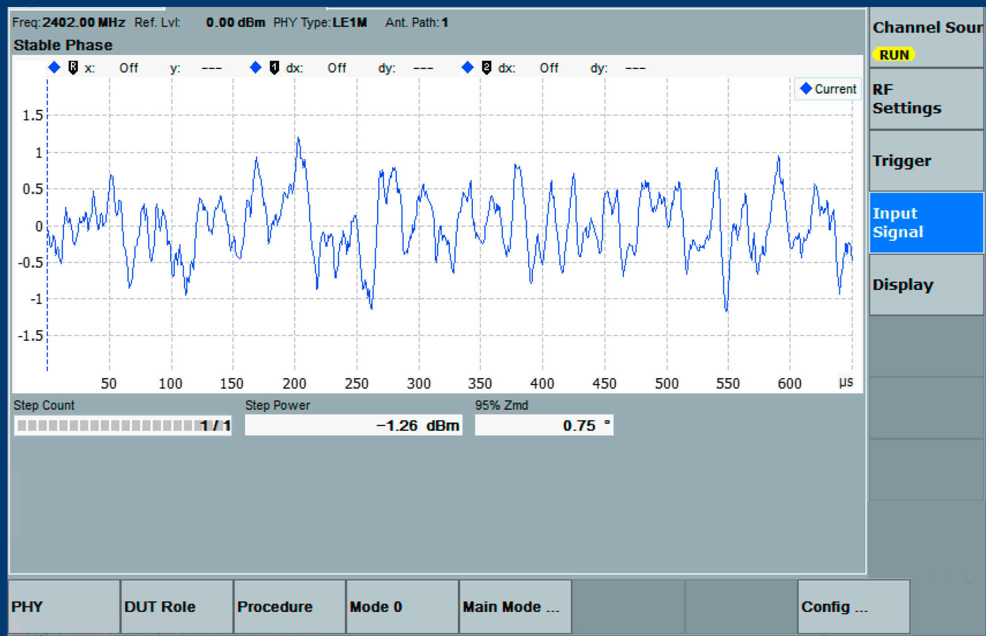


The I/Q coherency measurement presents the mean relative phase (RPm) results on non-reference antenna (antennas 1, 2 and 3) derived from the I and Q samples reported by the DUT's receiver. The non-reference antennas have the measurement values of 0.288, 0.279 and 0.271 radians respectively, which are within the limit of ±0.52 radians, therefore, the testcase is a PASS.



The I/Q dynamic range calculates the I/Q amplitude for all valid measurements. The testcase is PASS if the DUT reports 10 000 valid measurements per antenna and the mean amplitude values have the following order: Mean Antenna #3 < Mean Antenna #2 < Mean Antenna #0 (Ref. Antenna) < Mean Antenna #1, which is fulfilled.

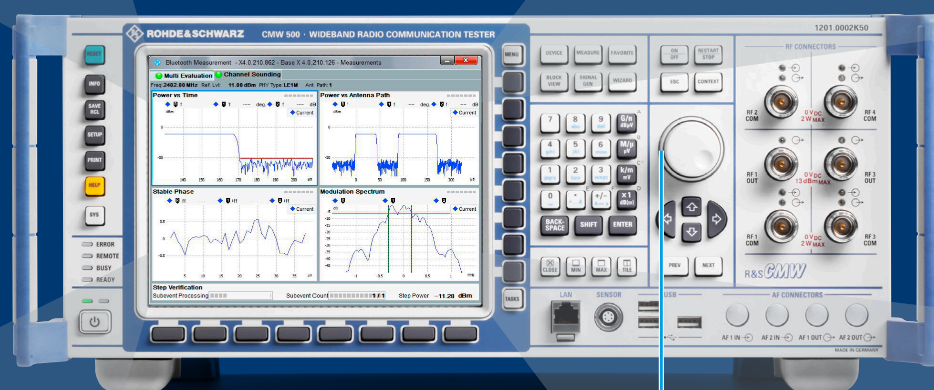
BLUETOOTH® CHANNEL SOUNDING MEASUREMENT



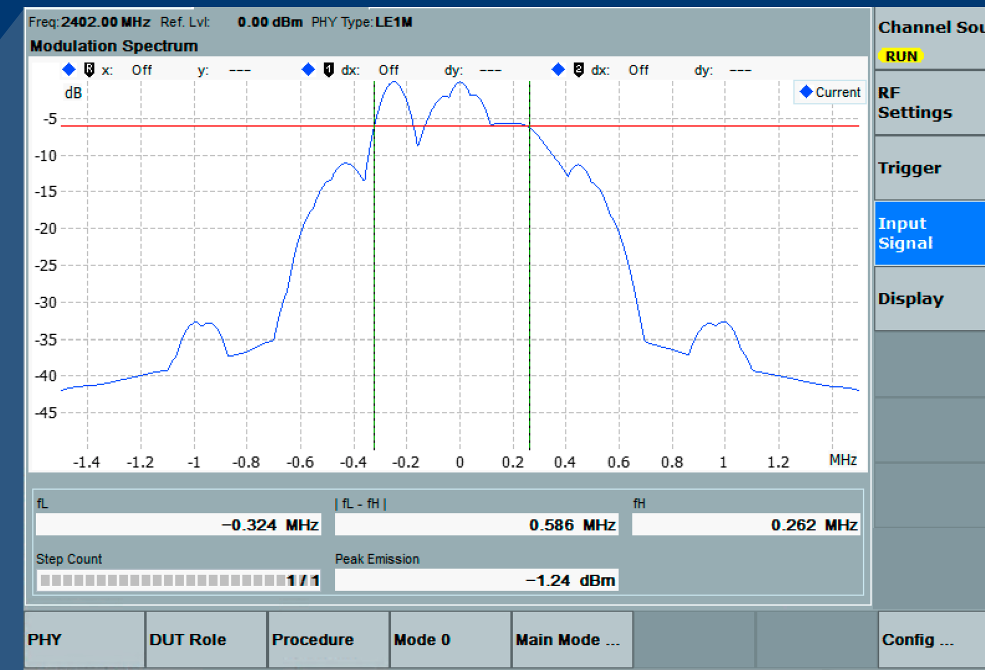
The stable phase test verifies that the DUT's carrier phase remains stable for the maximum duration of a CS tone used for a measurement. The test is passed when 95 % of 10 000 values of the zero mean detrended phase $\Phi zmd[n]$ are ≤ 20°. In the picture you can see a $\Phi zmd[n]$ of 0.75°.

The step mode frequency test verifies the frequency of each of the DUT's main mode transmissions are aligned with the frequency offset measurement. The limits for mode-1 and mode-3 (row 1 and 2) shall be < 20 kHz and for mode-2 and mode-3 (rows 3 to 6) shall be < 10 kHz for up to four antennas. In this example the test is passed.

The overview shows all measurements in one window. Each measurement can also be displayed individually with additional details.



The input signal submenu lets you set up the DTM signal characteristics. This also includes a switch to select the PHY for testing devices that support Bluetooth® Rel. 6.0.



The modulation spectrum test verifies that the DUT's transmitted emission of modulated packets are in a defined bandwidth. Bluetooth SIG defines that all Δf values shall have a 6 dB bandwidth of at least 500 kHz. In this case the bandwidth is 586 kHz, which will not pass the test.

Power vs. time shows the power portion of each antenna path in dBm. Here only one antenna was used. Additionally the ramp-up and ramp-down range duration to bring up or to remove the transmitted energy is measured which should be below 5 µs for each mode. In this example it is fullfilled.

BLUETOOTH® LOCATION SERVICES

Bluetooth® LE utilizing the channel sounding (CS) and direction finding (DF) features allow for precise, reliable and secure indoor and outdoor ranging capabilities. Location applications such as keyless entry, access control, indoor navigation, asset tracking and others are possible.

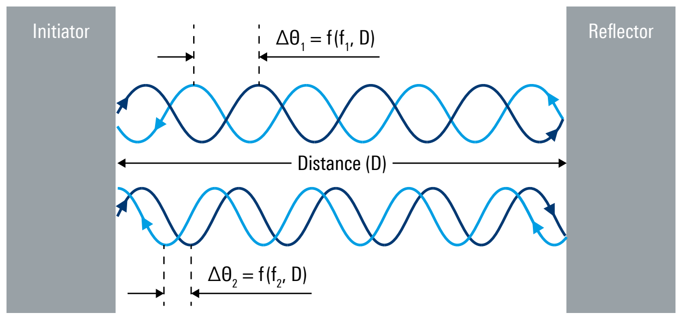
Principles of channel sounding (CS), previously known as high accuracy distance measurement (HADM)

The CS principle is based on two ranging methods; phased based ranging (PBR) tone exchange and/or round-trip-timing (RTT) packet exchange. PBR uses the phase shift (Θ) of a radio signal as it travels over distance D at frequency f. When two or more signals with different frequencies are used, the measured phase difference (ΔΘ) between the signals can be used to accurately estimate the distance.

RTT uses the packet transmission time (ToF) which is measured at both the initiator and reflector side using time-of-arrival (ToA) and time-of-departure (ToD).

Both methods can be used with minimum one antenna or more. The frequency spacing used for CS is 1 MHz rather than 2 MHz used for legacy LE. An additional PHY of 2M 2BT is specified for extra security to reduce symbol transition times.

Channel sounding PBR principle for high accuracy distance measurements

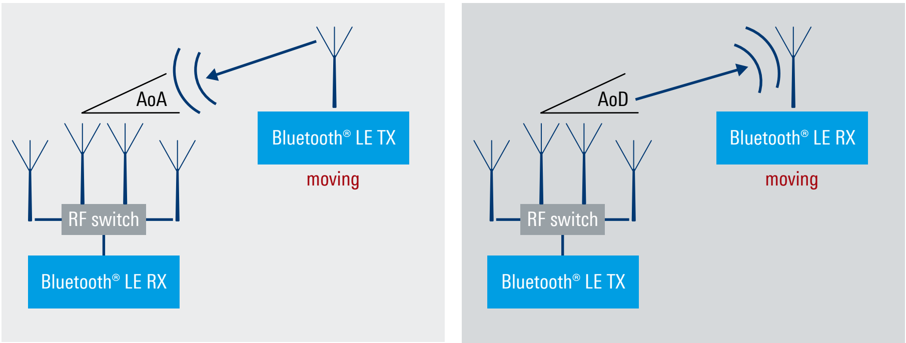


Principles of direction finding (DF)

Bluetooth® Rel. 5.1 defines two direction finding methods that use antenna arrays: angle of arrival (AoA) and angle of departure (AoD).

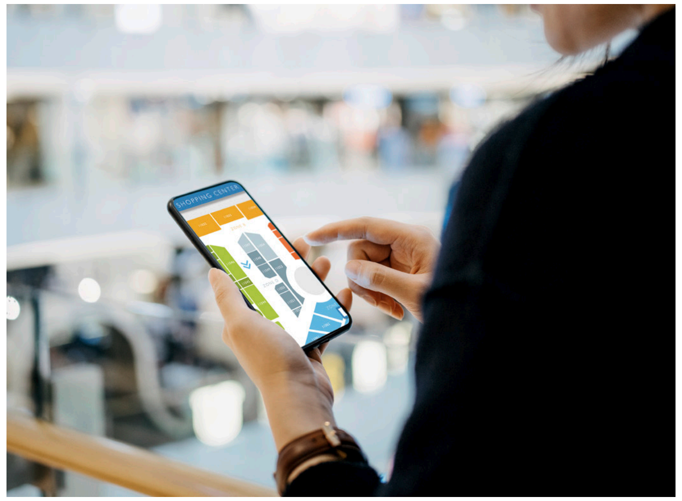
AoA, the incoming angle for a Bluetooth® direction finding signal with constant tone extension (CTE) can be determined by a locator with an antenna array. Whereas the AoD uses a Bluetooth® beacon signal transmitted over the antenna array. The receiver is typically a mobile device that receives the beacons and calculates the relative angle to the transmitter.

AoA (left) and AoD (right) techniques enable highly accurate location services



CS and DF measurement solutions with the CMW

The CMW platform can generate and analyze all required CS and DF signals in a one-box solution. This solution can be used to manually or automatically perform all RFPHY TCs, which are described in the section "Bluetooth® RF test cases (TC)" (pages 17ff). The DF feature in Bluetooth® Rel. 5.1 requires a total of 23 AoA and AoD transmitter and receiver test cases integrated in a mix of RF and I/Q tests. The CS feature in Bluetooth® Rel. 6.0 requires a total of 43 RFPHY test cases divided in transmit tests and transmitter-receiver tests.

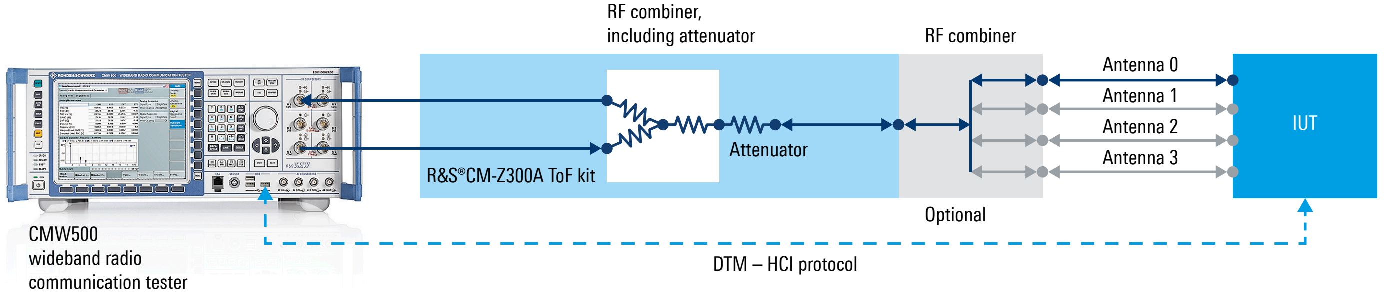


The CMW offers highly accurate CS phase and frequency measurements that go beyond what the RFPHY test specification requires.

The DUT is controlled via a UART/USB interface using the HCI protocol in direct test mode (DTM). All RFPHY measurements can be performed with the intuitive, user-friendly graphical user interface. All HCI reports can be logged for further analysis and debugging.

A fully automated Bluetooth® ranging test setup for user equipment with more than one antenna includes the CMW wideband radio communication tester and the R&S®OSP open switch and control platform. Both are controlled by the automated test solution R&S®CMWrun.

Channel sounding test setup



PRODUCTION SOLUTIONS

The CMP180 radio communication tester and the CMW100 communications manufacturing test set together with the R&S®WMT wireless automated testing framework are ideal for production testing. The solution has an optimal combination of flexibility, performance and capacity utilization.

Bluetooth® tests in signaling and non-signaling mode

The signaling mode is ideal for lab applications, such as system development and RF development/certification. During signaling, the DUT is controlled via messages on the protocol layer. Communications between DUT and tester take place via the RF signal.

The communications overhead caused by signaling can be eliminated in non-signaling mode. The DUT is not controlled with an RF signal but by a wired communications channel, such as a USB. Test software can send commands to control the DUT via the communications channel. Predefined waveform signals are sent from the ARB generator of the DUT tester.

Non-signaling mode allows only the PHY layer to be tested, which is typically enough for production verification. RF tests can be done faster in non-signaling mode than in signaling mode, but require software to directly control both the tester and the DUT.

The commands and events used to control DUTs in both Bluetooth® LE and Bluetooth® Classic modes of operation are specified within the Bluetooth® core specification. Vendor-specific commands for custom purposes (e.g. device calibration, crystal tuning) are also possible.

Key facts of the CMP180 and the CMW100

- Turnkey R&S®WMT wireless automated testing based production solution for different chipset suppliers
- Innovative smart channel solution for efficient multi-DUT testing
- Continuous frequency range up to 8 GHz
- Multitechnology solution
- Parallel testing on up to 16 RF ports
- High measurement performance and accuracy
- Support of a wide range of methods for reducing test time and maximizing capacity utilization
- Minimum space requirements and footprint

CMP180 and CMW100 for R&D and manufacturing testing

The CMP180 is designed for parallel tests with two independent RF channels, each with eight RF ports (16 RF ports total) and up to two analyzers and two generators. The CMW100 uses hardware resources most efficiently, each tester has one RF channel (one analyzer, one generator) and eight RF connectors. The CMP180 supports demanding technologies such as Wi-Fi 6E, Wi-Fi 7 and 5G NR FR1. The tester is designed for frequencies up to 8 GHz and bandwidths up 500 MHz. The CMW100 supports all technologies with frequencies up to 6 GHz and 160 MHz bandwidths.

The CMP180 radio communication tester is the ideal solution for R&D and production applications that require more ports, a higher frequency range and bandwidth.

Optimized production throughput with broadcast and smart channel modes

As the prices for Bluetooth® devices fall, costs for production testing needs to be reduced while maintaining the required testing depth. Fully utilizing tester hardware helps lower test costs.

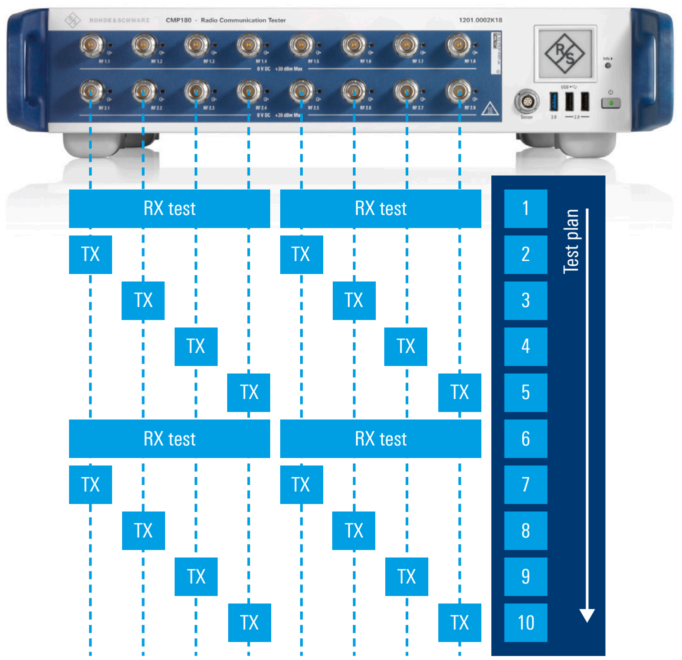
Test time optimization with R&S®SmartChannel, RX broadcast and interleaving significantly reduces calibration and verification times relative to single DUT testing. Multi-evaluation list mode provides the fastest measurements. Users can draw on existing implementation experience and considerably reduce development time.

The signal from one generator can be split and made available at all ports simultaneously for RX broadcasts. RX tests can be executed on up to eight DUTs in parallel, multiplying throughput eight-fold. Parallel testing requires all DUTs to be ready for testing at the same time. If this is not possible and the DUTs arrive sequentially, the test steps can be interleaved. While one DUT is measured, another DUT is configured for the next measurement and another DUT boots up. The R&S®SmartChannel solution splits the tester into virtual sub-instruments, where each DUT is connected to one independent smart channel to further speed up measurements since the required tester configuration and result handling for one DUT can be done while another is measured.

Turnkey R&S®WMT wireless automated testing based production solution for different chipset suppliers

As a turnkey solution, Rohde & Schwarz offers the R&S®WMT wireless automated testing framework for multi-DUT testing. It remotely controls the tester and the DUT with HCI standardized commands for Bluetooth® Classic. Since all Bluetooth® LE devices use the standardized direct test mode (DTM), all these devices are supported. Currently, R&S®WMT supports Bluetooth® non-signaling tests for a large number of chipsets and tools from many chipset vendors.

Execution of tests in parallel



The CMW100 communications manufacturing test set is ideal for use on fully automated robotic production lines.

R&S®CMWrun – SOFTWARE FOR AUTOMATED TESTING

The R&S®CMWrun sequencer software tool is a ready-to-use solution for configuring test sequences by remote control. R&S®CMWrun can be enhanced with options and used for all standards supported by the CMW family – for general RF testing, preconformance and superior user experience test scenarios.

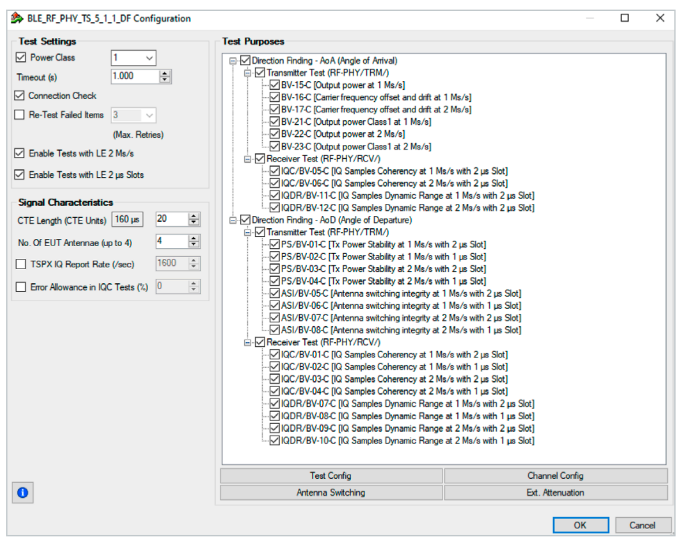
Applications and testing scope

R&S®CMWrun automation software meets all remote control test sequence requirements on the CMW platform for R&D, quality assurance, production and service, while also meeting the requirements for current and future wireless devices.

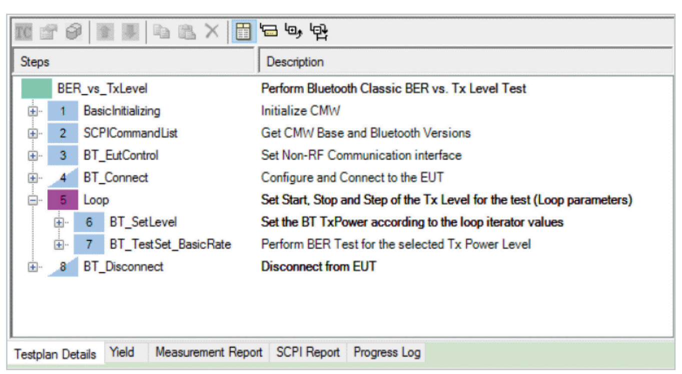
The R&S®CMWrun software engine is based on the execution of test dynamic link libraries (DLLs, plug-in assemblies). This architecture allows easy and straightforward test sequence configurations without specific programming knowledge for remote control of the instrument. Parameters and limits for the test items in the standard-specific R&S®CMWrun package options can be configured with full flexibility.

At the end of a test, an easy-to-read test report containing limits, test results and verdict is generated. The report is available in .csv, .txt, .xml and .pdf format.

The R&S®CMW-KT057 option for R&S®CMWrun offers a large number of Bluetooth® test DLLs for Bluetooth® Classic and Bluetooth® LE.



Test DLL



Test sequence

Bluetooth® prequalification testing

R&S®CMWrun supports all RF test cases defined in the Bluetooth® RF test specification. Two DLLs contain all "simple" test cases that can be performed with a single-channel CMW. Two additional DLLs include "advanced" test cases that require additional generators to act as interferers in the test setup. Either a second RF channel in the CMW or external generators can be used (see Bluetooth® RF test cases (TC) on pages 17ff).

Individual testing and example test plans

A wide variety of other DLLs are available for individual test sequences that use all the CMW capabilities. Some generic DLLs activate and configure the measurements; other DLLs can change parameters and the loop design within a test sequence. The R&S®CMWrun Bluetooth® software package contains a number of sample sequences that can be used as a basis when designing your own sequences.

RELATED PRODUCTS

R&S®CMW-Z10 RF SHIELD BOX

The standard in shielding and coupling

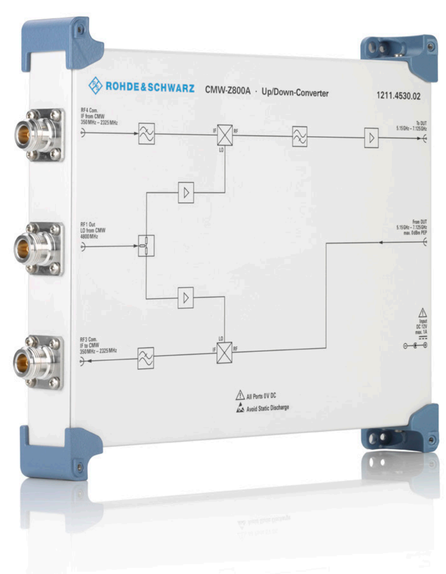
The R&S®CMW-Z10 RF shield box is designed for DUT OTA connection to a radio communication tester. Together with the high-quality R&S®CMW-Z11 antenna coupler, the setup has outstanding characteristics that protect against ambient emissions. The shield box can be used for frequencies up to 6 GHz. The numerous shielded connector feedthroughs make it ideal for all types of applications.

R&S®CM-Z300A ToF KIT

Channel sounding extension

The Rohde & Schwarz test solution for accurate time of flight measurements is easy to set up. The R&S®CM-Z300A UWB ToF measurement kit together with the CMW radio communication tester platform enables for Bluetooth® Channel Sounding typical time of flight measurements to be performed without the need for additional calibration and path delay measurements.

R&S®CMW-Z800A UP/DOWN-CONVERTER



6 GHz band extension for higher band use cases

The CMW itself can support frequencies up to 6 GHz. The external R&S®CMW-Z800A up/down-converter enables the CMW to perform IEEE 802.11ax WLAN in the 6 GHz band. The R&S®CMW-Z800A supports frequencies in the 5925 MHz to 7125 MHz range.

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