NEWS

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ROHDE&SCHWARZ

Security through technology

A new body scanner ensures greater airport security without compromising passenger convenience.

Wireless technologies

Test systems for V2X communications check transmitters and receivers

Broadcast and media

The best even better: TV transmitters now more compact and more efficient

Radiomonitoring / radiolocation

Drone monitoring system to counter the misuse of commercial drones

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NEWS

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Cover feature

When it comes to whether or not something that is technically feasible should be done, opinions vary. The debate becomes particularly emotional when individual liberties clash with public security interests. For instance, is it necessary to have full camera surveillance of certain areas, perhaps even with automatic face recognition, in the slight hope that it might record criminal activity or contain a picture of a person who is sought? Should we ease restrictions on the privacy of correspondence and telecommunications (protected in the EU by the European Convention on Human Rights) so that authorities could then track down criminal activities more easily? When it comes to aviation safety, this issue is less controversial, as the results of a representative survey recently conducted by the Federal Association for Information Technology, Telecommunications and New Media (Bitkom) show. The vast majority of those surveyed approved the use of state-of-the-art control technology at airports, which is understandable given the incidents that have occurred around the world in recent years. Of course we would like security controls to be as unobtrusive as possible, preferably not even noticeable. Body scanning technology has not come quite that far yet, but it's heading that way. The R&S®QPS from Rohde & Schwarz marks a milestone in this direction. Its technology, which is capable of detecting potentially dangerous objects, has broken new ground. The result is welcome news for passengers: a slight arm movement from a comfortable position in an open scanning area and you're done. People will come to appreciate this convenience at many airports in the future (page 40). In another area, the need for security is less obvious. Small drones are currently making headlines as delivery trucks of the future. However, since anyone can buy and fly one, they increasingly wind up in places where they are unwanted for reasons of confidentiality or safety – such as at airports, events and private areas. But there is a solution. Drone detection systems can alert you to these pests and even keep them at bay, if necessary. R&S®ARDRONIS from Rohde & Schwarz is such a system, and US President Obama is not the only one who has been protected by it (page 58).

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Dear NEWS Readers,

We want to ensure that the Rohde & Schwarz technology magazine addresses your needs and interests even better in the future and to do so, we need your help.

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The new R&S®THU9evo, R&S®TMU9compact and R&S®TLU9 TV transmitters are unique on the world market (page 53).

© Roger Eriksson / ESS

Particle accelerators such as the MAX IV in Lund, Sweden, use solid-state high-power amplifiers from Rohde & Schwarz (page 48).

R&S®ARDRONIS helps prevent the misuse of commercial drones (page 58).

R&S®Scope Rider decodes and triggers CAN/LIN signals

The new R&S®RTH-K3 software option converts the R&S®Scope Rider into the first handheld oscilloscope on the market that can decode CAN and LIN bus signals. Easy debugging of these buses is therefore possible directly in the field. The R&S®Scope Rider offers the comfort features of a laboratory oscilloscope, including convenient triggering on symbolic data in CAN DBC file format (airbag status, engine data, etc.). Decoding is possible through both digital and analog channels. Thanks to a separate memory for the bus data, the ongoing signal acquisition is not impaired by decoding. The sampling rate for triggering and decoding is a high 1.25 Gsample/s independently of the timebase setting and therefore ensures secure data acquisition under all operating conditions. In connection with the history function, up to 5000 waveforms can be saved and analyzed later. In addition to the CAN/LIN option, triggering and decoding options are already available for the I^2C, SPI and UART / RS-232 / RS-422 / RS-485 serial bus systems.

First mid-range four-port network analyzer up to 40 GHz

Many DUTs in RF engineering, such as mixers, have more than two ports, which means that a network analyzer with a corresponding number of ports is required for an efficient characterization of these DUTs. Until now, only high-end analyzers for the microwave range up to 40 GHz, such as the R&S®ZVA, have met this requirement. In many cases, however, their extensive functionality is not necessary at all. For this reason, many users will find the new R&S®ZNB40 four-port analyzer highly interesting. The instrument features excellent RF performance data at an attractive price and outperforms top-class instruments in terms of everyday practicality. It is quiet, easy to transport and has a small footprint. The large, high-resolution touchscreen ensures non-fatiguing work. Thanks to the bridges used for the directional element (directional couplers are usually deployed in the upper microwave range), the lower frequency limit is 100 kHz instead of the otherwise common 10 MHz, which means that low-frequency measurements are possible without additional T&M equipment. Last but not least, the R&S®ZNB40 has a modern, future-ready computer platform as a prerequisite for long-term product sustaining engineering.

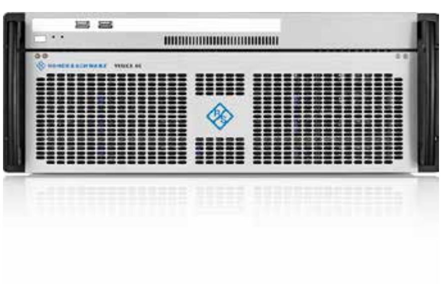
Compact DOCSIS® generator for tests on cable network components

The data over cable service interface specification (DOCSIS) has established itself worldwide as the leading broadcast standard for cable (TV) networks. DOCSIS allows the networks to be used for a large variety of applications, e.g. to create high-performance service packages consisting of TV, telephony and fast Internet in order to challenge the DSL networks of the telecommunications providers. With the latest evolutionary stage 3.1 published at the end of 2013, DOCSIS was catapulted into a completely new performance class, with downstream speeds of up to 10 Gbit/s, making it suitable for UHD TV and other data-hungry applications. Dedicated T&M equipment for DOCSIS 3.1 was long scarce, which meant that component manufacturers and network operators had to rely on broadcast equipment to generate signals. The R&S®CLGD cable load generator put things right in 2015. This multichannel device for simulating complex DOCSIS scenarios is now complemented by the single-channel R&S®SFD. The R&S®SFD generates a high-quality upstream or downstream signal in line with DOCSIS 3.1, 3.0 or J.83 / A / B / C in real time. It also handles analog TV signals (PAL, NTSC). Level, frequency, FEC and constellation can be set. The user data is received via the Ethernet interface or generated using an internal ARB. By adding noise, AC hum, tilt and bit errors, the signals can be modeled realistically. The device is operated using a web browser.

DOCSIS® is a trademark of CableLabs.

Compact IoT test system for carrier acceptance tests

Household appliances such as the often mentioned refrigerator that automatically ensures that it remains filled will forge ahead in the foreseeable future. They will be connected to the Internet through the home WLAN. This is not possible in the case of mobile devices, machines, sensors and equipment distributed over a wide area. Networking such devices requires the use of the cellular infrastructure. The applications involved are often low-end with low data rates, but special requirements in terms of power consumption and range. Cellular networks must be prepared for the sheer number of expected IoT radio modules. It is therefore necessary to test the terminal device radio properties. Some network operators, however, place special demands on user devices in their network. The new R&S®TS290 test system can be used to test compliance with these demands. It offers provider-dependent test cases for RF characteristics, protocol and performance. These test cases can be run automatically, controlled by the R&S®Contest test sequencer. As a result, terminal device manufacturers and system integrators can economically verify their IoT products.



Managing complex multicamera recordings

The R&S®VENICE ingest and playout platform acts as a data hub for broadcasters, TV studios and OB van providers. All recordings are collected and/or played out for transmission. The new R&S®VENICE Control ingest software considerably increases workflow efficiency. It enables the simultaneous recording of up to 16 independent channels in all common formats and resolutions. As a result, major events that involve the use of a large number of cameras can be broadcast with minimal resources. The channels can be bundled into groups and controlled jointly or separately. All settings used for a recording can be saved as scenarios – a time-saving feature for the recording of repetitive events, such as regularly produced shows. Automatic file and folder naming is another time saver. The user creates a single set of wildcard parameters such as the date or channel name, which is automatically filled with values during the recording. The client-server architecture also contributes to the high flexibility of an R&S®VENICE Control based workflow. The software can be installed on any number of clients and enables a redundant control of all ingest procedures. In case of a client breakdown, another software instance continues control without interruption. R&S®VENICE Control is available for Windows, Mac OS and Linux.

Automatic DUT monitoring during EMC measurements

The rules for electromagnetic compatibility (EMC) require that electrical products not emit any electromagnetic interference (EMI) and that they not react to external interference (electromagnetic susceptibility, EMS). These reactions can be completely different depending on the product under consideration. Insofar as such problems are indicated optically, e.g. by warning lamps or status display, a solution is now available for automatic detection: the R&S®AdVISE visual monitoring system. It consists of software, an R&S®AtomixLT video board and one to two video cameras and requires a workstation with NVIDIA GPU. R&S®AdVISE is typically run as an expansion of the R&S®EMC32 EMC software. It performs a real time analysis of the camera images of the DUT with up to 60 frames/s, for example, with views of the dashboard in the case of automotive measurements. For each camera image, the user can define up to 32 fields referred to as regions of interest (ROI), whose behavior is monitored and linked to event messages. Changes in the brightness, color and color intensity of an ROI are detected, as well as the length of bar diagrams. Each ROI is individually configurable. Even DUTS with complex reaction behavior can be measured automatically. R&S®AdVISE is available in three models from Lite to High Performance.

Test systems for V2X communications

Future automated vehicles will be wirelessly networked with their environment and will therefore be able to preventively respond to dangerous situations. To ensure that the safety-related information is received even under poor transmission conditions, the transmitter and receiver must comply with minimum standards. The R&S®TS-ITS100 and R&S®TS8980 RF test systems check whether this is the case.

Automated vehicles can safely navigate the road only if they have precise knowledge of their environment and the traffic situation. A wide variety of sensors and cameras already provide some of this information. New technologies are needed to further reduce the risk of accidents. Critical traffic situations can be detected before they occur thanks to the wireless exchange of information between vehicles (V2V communications), as well as between vehicles and the traffic infrastructure and all road users (V2X communications). If, for example, all vehicles approaching an intersection exchange information about speed and direction, potential collisions can be detected, warnings can be issued, and autonomous countermeasures can be initiated early on. For this reason, the exchange of information between the vehicles must be reliable even under poor transmission conditions and without line of sight.

Distortions compromise safety

Wireless links are prone to failure due to physical effects. Fading includes shadowing and interferences due to scattering, diffraction, refraction and reflection, which cause multipath propagation of the signal. This means that multiple versions of the same signal arrive at the receiving antenna at different times and with different signal levels and distortions. This superposition can distort, attenuate or even cancel the signal.

Another complication is that road users are also continuously moving, which results in time-variant fading scenarios. If a receiver cannot handle time-variant fading, then it might not be able to detect and process the signal. This loss cannot be compensated for by strong coding or a special protocol, creating a considerable risk, especially when drivers rely on the warnings by V2X systems.

Test of physical transmission

To minimize the safety risk arising from poor transmission conditions, the RF transmitters and receivers in the onboard units (OBU) and roadside units (RSU) of the communications system must exhibit certain characteristics. Developers and users integrating V2X components into their systems can use RF tests to verify these characteristics. The two lowest layers of the OSI model (Fig. 1) are relevant to these tests because they are responsible for the physical transmission of the message:

- The physical layer handles the physical transport of the data via a transmission medium. In the case of V2X communications, this transport is wireless. This layer uses specific modulation modes, carrier frequencies and bit rates. Often the quality of the transmission channel is also taken into consideration.
- The data link layer is divided into an RF section (MAC) and a protocol section (LLC). The medium access control (MAC) layer controls the access to the transmission medium for multiple users. This is relevant to RF measurements. The logical link control (LLC) layer handles tasks such as error detection and correction at the protocol level.

In contrast to RF tests, tests at the protocol level, i.e. from the LLC layer up to the application layer, are not suitable for verifying RF characteristics. These tests check that the bitstream, which is generated in the LLC layer from the received signal, is processed correctly. Therefore, the success of all tests at the protocol level depends essentially on whether the signal can be safely received and converted into a correct bitstream that will not contain more bit errors than the channel decoder can correct.

Layer	Name	
7	Application	
6	Presentation	
5	Session	
4	Transport	
3	Network	
2	Data link	Logical link control (LLC)
		Medium access control (MAC)
1	Physical	

Fig. 1: OSI layer model.

The RF module in the OBU (i.e. the MAC layer and the physical layer) must meet certain minimum requirements, e.g. with respect to power and frequency accuracy and packet error rate (PER). In addition, the transmitted signal may not interfere with any of the transmission technologies on adjacent frequencies.

How are the requirements for the RF module checked, and how can it be ensured that a transmitted message/action is actually received? A look at the wireless communications industry shows that three different types of RF tests are used to validate and certify smartphones:

- Regulatory tests check, for example, whether the transmit signal stays within power limits defined for other frequencies. The regulatory authority of a country usually specifies these values, and compliance with them is required by law. These types of specifications are now available for V2X units.
- Conformity tests ascertain whether a smartphone meets the RF specifications of the respective wireless standard. For example, smartphones must not exceed a specified maximum packet error rate or maximum transmit power. A separate test specification often describes how to perform and evaluate these tests.
- Stricter or additional tests as required by some wireless service providers help them to differentiate themselves from the competition by providing better transmission quality and higher network reliability. Only mobile devices that meet these specific requirements are approved for the network of this provider.

Fig. 2: The R&S®TS8980 (left, for LTE) and R&S®TS-ITS100 (for WLAN 802.11p) RF test systems perform all required conducted tests in the development stage.

Radio signals over cable

The automotive industry tests automotive components and electronic control units not only in the lab, but also on testing grounds or on roads. For wireless communications, this is the equivalent of field tests, offering a realistic environment for RF tests. However, external influences such as the weather may unpredictably change the RF characteristics of the radio link. The test setup and test sequence also depend on the vehicles involved and the antenna locations, and often they can only be changed with considerable effort.

Transmit characteristics

- Frequency accuracy
- Modulation accuracy
- Out-of-band emissions
- Transmission power level
- Spectrum emission mask
- Spurious emissions

Receive characteristics

- Adjacent channel rejection
- Nonadjacent channel rejection
- Decentralized congestion control
- Out-of-band emissions when transmitter is off
- Performance with fading (packet error rate)
- Sensitivity

Fig. 3: Examples of RF tests for checking OBU and RSU characteristics.

This is not practicable for testing in the development stage. That is why conducted tests are performed as an alternative to field tests, where RF test systems such as the R&S®TS-ITS100 or R&S®TS8980 (Fig. 2) simulate the signals in the radio channel and transmit them to the device under test (DUT) via cable. These RF tests can be performed for each prototype and each software or hardware modification. They provide a large number of advantages:

- The tests can be performed at any time and at relatively low cost.
- The test conditions are clearly defined and can be changed time and again irrespective of outside influences.
- Defined test sequences under identical conditions lead to comparable results, making troubleshooting easier.
- Unlike field tests, parameters such as the fading profile can be easily modified.
- Several tests can be combined into series and automated, e.g. as endurance tests to check the reliability of a prototype.
- RF tests such as error vector magnitude (EVM) or RX sensitivity tests only make sense as conducted tests, since uncontrollable noise and interference from external sources falsify the measurement results in field tests.

Depending on the selected scenario, channel simulation exactly simulates the physical characteristics of the radio link. The R&S®TS-ITS100 RF test system can also simulate the special V2X fading profiles in real time.

Field tests are useful nonetheless, especially for antenna measurements, e.g. for determining the antenna pattern or for beamforming tests. Conducted tests therefore cannot completely replace the field tests.

Detecting RF problems

To be able to compare the test results for the various hardware and software versions of a V2X unit, all test sequences must be clearly defined. Some countries have therefore laid down test specifications for V2X systems that include test cases in four categories (Fig. 3):

- TX in-band: The test cases in this group test the transmitter (TX) characteristics, such as maximum and minimum transmit power, frequency accuracy and modulation accuracy.
- TX out-of-band: The unwanted transmit power outside of the allowed frequency band must not disrupt other technologies. TX out-of-band test cases measure this transmit power and compare it against the permissible limit value.
- RX in-band: This category tests the receiver (RX), for example by measuring the lowest receive power at which the received signal can still be decoded or using performance measurements with fading. Fig. 4 shows a configured V2X fading profile on the R&S®SMW200A vector signal generator.
- RX out-of-band: Specialized test cases measure whether an OBU or RSU unintentionally emits power into other frequency bands when the transmitter is switched off.

Various V2X plugtests* have shown that especially the TX out-of-band and fading tests are problematic for many DUTs (Fig. 5). The R&S®TS-ITS100 can detect such RF problems as early as the development phase.

At present, various wireless technologies are under discussion for implementing V2X communications, in particular WLAN 802.11p, LTE and 5G, which will be available in a few years. Regardless of which technology is used, Rohde&Schwarz already offers the test solutions needed for V2X measurements. LTE-based solutions can be tested using the R&S®TS8980 RF test system family. The test scope is continually being adapted to the evolution of LTE, making it also suitable for V2X measurements.

* Events where products from different manufacturers are tested for compatibility based on a specific standard

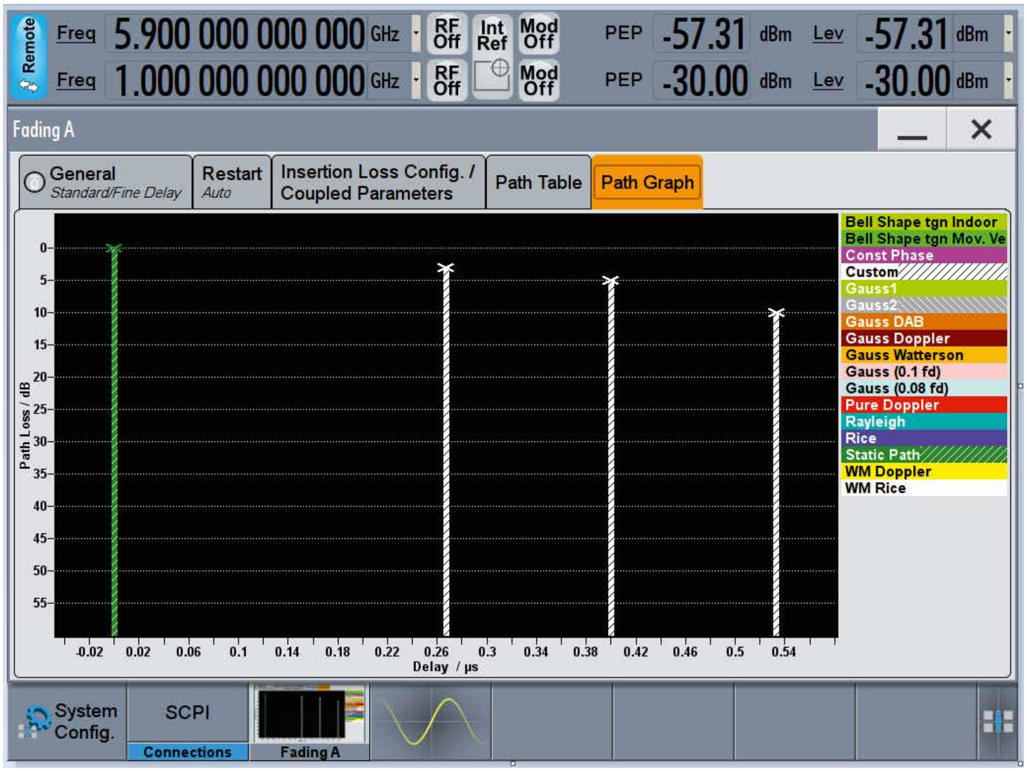


Fig. 4: Fading profile for V2X at 5.9 GHz on the R&S®SMW200A vector signal generator.

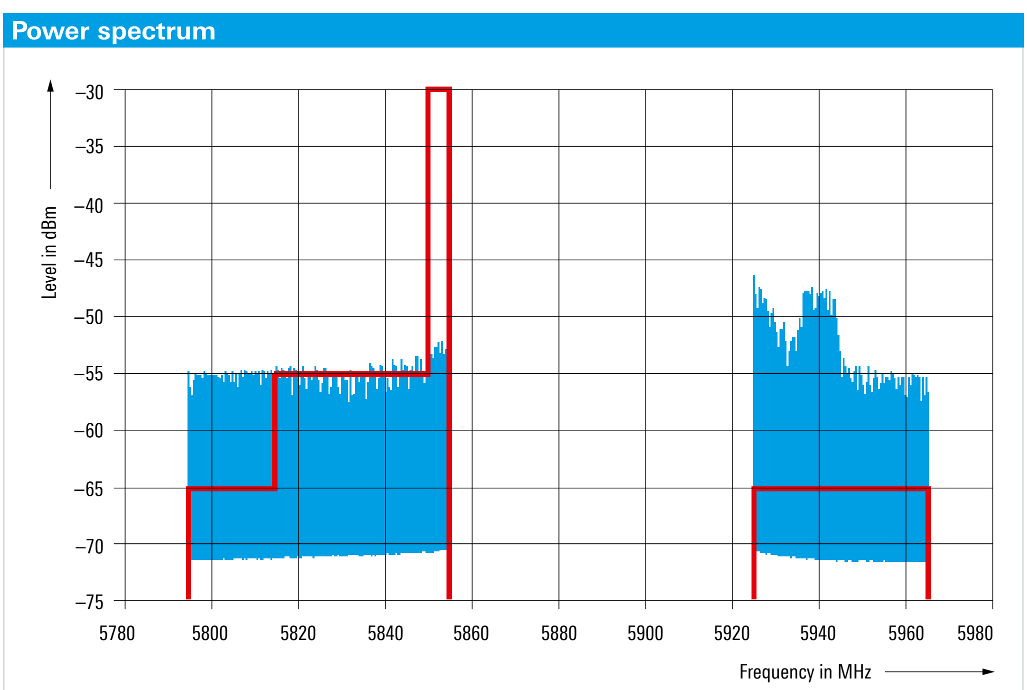
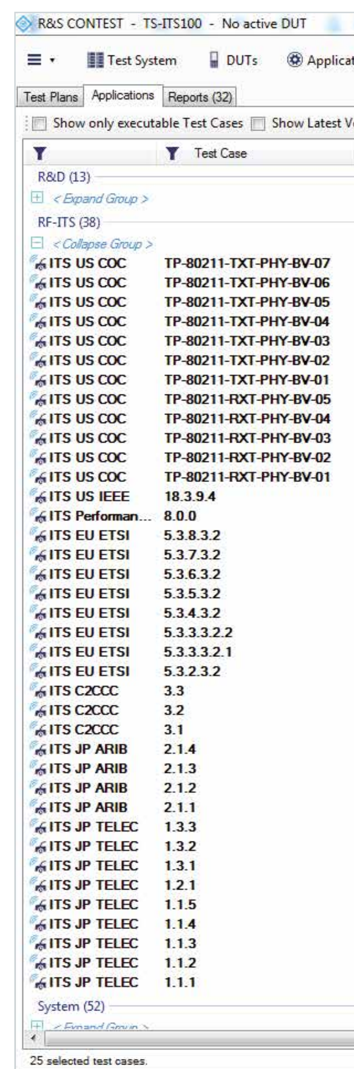


Fig. 5: TX out-of-band test: The transmit power (blue) of a WLAN 802.11p unit exceeds the permissible limit at multiple points (red line). The frequency range between 5855 MHz and 5925 MHz is reserved for V2X in Europe and in the US.

Fig. 6: R&S®Contest software for the R&S®TS-ITS100 and R&S®TS8980 RF test systems. The small window on the right shows some of the parameter settings that users can configure themselves.



For WLAN 802.11p, the R&S®TS-ITS100 RF test system contains the complete package of test cases for

- Europe at 5.9 GHz (ETSI EN 302 571),
- USA at 5.9 GHz (IEEE 802.11-2012) and
- Japan at 760 MHz (TELEC T257 and ARIB STD-T109).

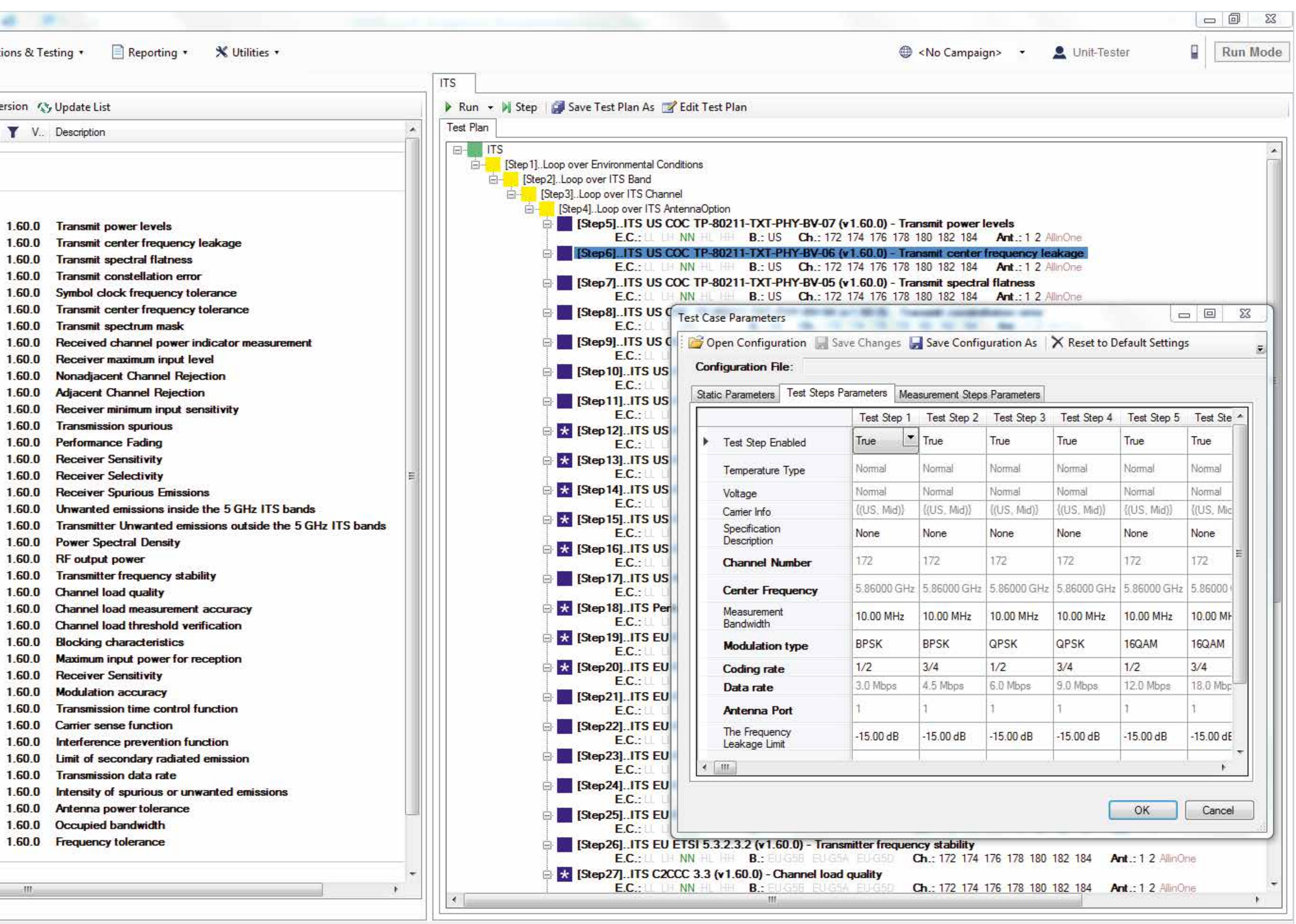
For out-of-band tests, the test system permits measurements up to 18 GHz and can use a variety of filters as needed for various regions. The system hardware is already set up to handle diversity and multiple input multiple output (MIMO). WLAN 802.11p tests pose a special challenge because there is no defined uniform interface to 802.11p units. In order to configure a unit for a test case, the test software must address the unit with individual commands. For this reason, the test system already contains ready-made plug-ins for many units to make fully automated testing possible.

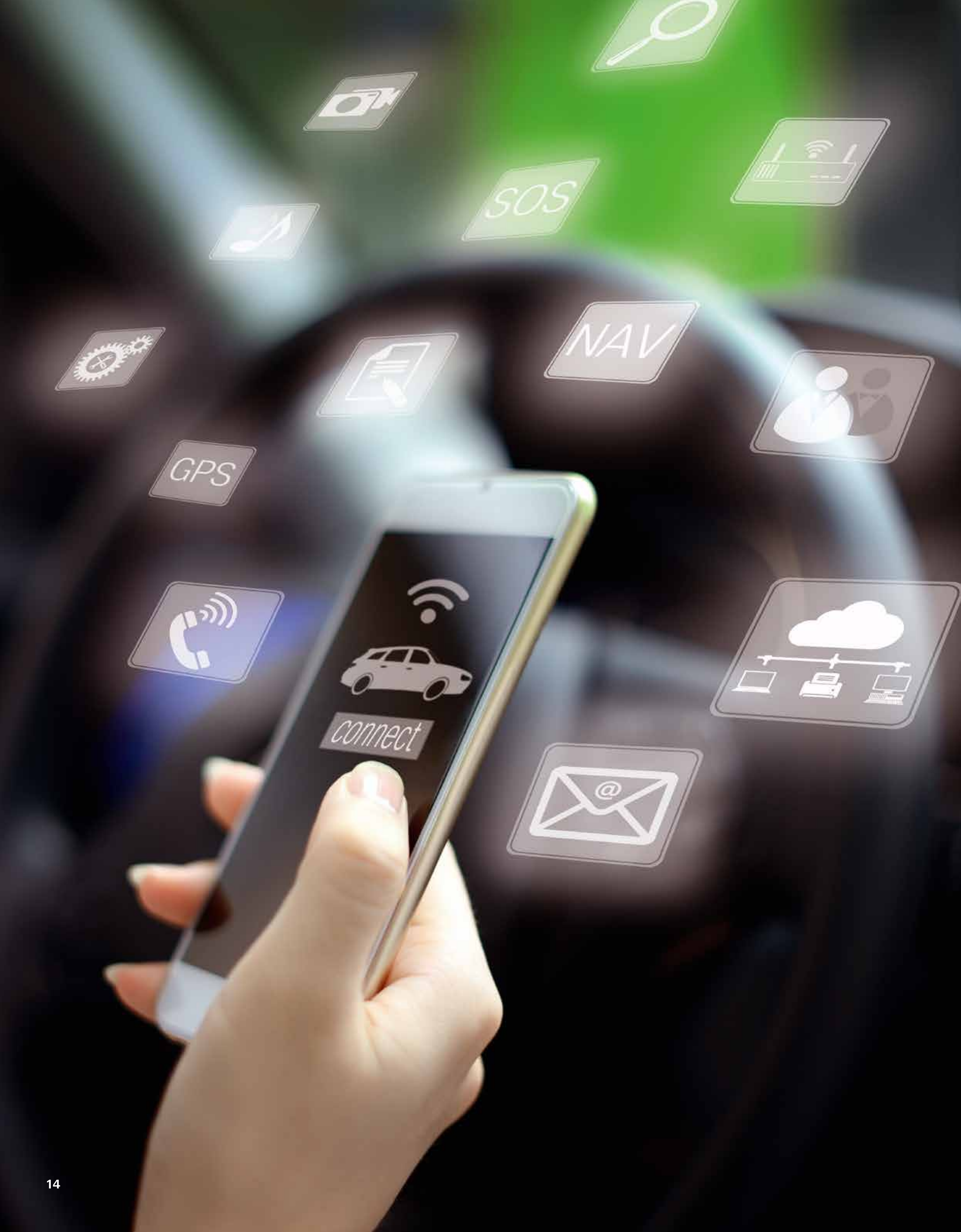
Both test systems are controlled fully automatically using the R&S®Contest software (Fig. 6). It provides a graphical interface for selecting the RF tests, as well as for compiling the test plans and evaluating the results. This software, which has been widely used in the wireless communications industry for many years, can also test WLAN 802.11p test cases. The R&S®Contest reports can be used for validation and certification.

Summary

In order to improve road safety, vehicles will be wirelessly connected to each other and to the traffic infrastructure in the future. The safety-related information exchanged must be reliably received under all external conditions. Only RF tests, such as those offered by the R&S®TS-ITS100 test system for 802.11p and the R&S®TS8980 test system for LTE, can ensure that the OBUs and RSUs meet minimum physical requirements, so that lives can be saved in case of emergency.

Dr. Thomas Brüggen




SOS
NAV
GPS
connect

RF and audio testing of Bluetooth® components with just one T&M instrument

Nearly all new vehicles today offer Bluetooth handsfree equipment. The Bluetooth connection between smartphone and infotainment system can also be used for numerous other applications. The individual components must undergo RF and audio tests to ensure that the headset, speakers, infotainment system and smartphone all function smoothly with each other.

During the development of new radio components, complex and often costly tests are required. These tests should be reproducible and fast. To be able to use and sell these components on the market, certification by officially approved test houses – an expensive undertaking by all accounts – is also necessary. It therefore makes sense to start performing these precertification tests in house early on. If any weak points are found in the DUT, development must continue until the tests show that the component has a high probability of passing the official tests.

The R&S®CMW wideband radio communication testers from Rohde & Schwarz were designed for such precertification testing and are approved by the Bluetooth Special Interest Group (SIG). The instruments can be used for RF and audio tests during development, production and service for Bluetooth® as well as for nearly every other commercially significant cellular and non-cellular wireless standard.

Initially, Bluetooth (BT) was used in the car primarily for connecting a wireless headset to a smartphone. Meanwhile, the radio standard is used to transmit all available information to the infotainment system. Users can make phone calls via the BT connection and upload their contact lists to the infotainment system. They can also play music or podcasts from a smartphone and listen to them over the vehicle's speakers. Some systems can read out text messages as audio. Some vehicles allow users to access their apps as soon as the smartphone connects with the car – for example, navigation, traffic reports, weather forecasts or points of interest in the vicinity.

Audio transmission via Bluetooth

The audio BT transmission is based on the Bluetooth Classic specification issued by the Bluetooth SIG. Due to the effective data throughput of 0.7 Mbit/s to approx. 2.1 Mbit/s and the adaptive frequency hopping (AFH) transmission method, Bluetooth Classic technology is a short-range radio technology for distances up to 10 m that is robust even in noisy environments. Today's widespread Bluetooth Low Energy technology, also called Bluetooth Smart, has been around since BT specification 4.0, which came out in 2010. However, it is currently not used for audio transmissions. The two BT technologies have been continually developed in parallel.

Bluetooth Classic operates with a synchronous link for voice transmission (synchronous connection-oriented, SCO) and an asynchronous link for data transmission (asynchronous connectionless link, ACL). Audio signals can be transmitted with different BT profiles for the synchronous link:

The **handsfree profile (HFP)** for handsfree units, for example, transmits audio signals from the microphone near the driver via the infotainment system to the smartphone and back. For voice transmissions in HFP, the continuously variable slope delta modulation (CVSD) voice codec with a maximum transmission rate of 64 kbit/s is used.

For the stereo playback of music via a BT interface, the **advanced audio distribution profile (A2DP)** is used. According to the BT standard, A2DP sources must support the low complexity subband coding (SBC) audio codec, which does not require a license. During SBC-based transmission of music from a smartphone, the device first decompresses the music, which is usually saved in compressed form, and then compresses it using the SBC algorithm for BT transmission. At up to 345 kbit/s, the available bit rate for the SBC coding is sufficient to ensure good audio quality. The SBC-encoded sound stream is transmitted from the smartphone to the infotainment system via ACL.

Criteria for audio measurements

For BT transmission of sound information, it is crucial that the tone is reproduced with as high a quality as possible, without noise or dropouts. This is ensured by separately testing all of the components in the transmission chain, i.e. both the radio link as a whole and the individual audio components.

The quality of the audio signal can be determined on the basis of criteria such as frequency response, total harmonic distortion and signal-to-noise ratio. Due to the low frequencies in the audio range, the settling times of filters play a role. Therefore, the T&M instrument should be able to adjust to the frequency of the test signal so that measurements can be performed as quickly as possible. This applies to level measurements as well as to complex analyses such as total harmonic distortion plus noise (THD+N).

A BT T&M instrument must be able to establish a complete BT connection to the DUT via the SCO link or ACL link. The tester should also support the relevant codecs and profiles for all audio transmissions. At present, these are the narrowband CVSD codec and the wideband mSBC codec with the handsfree profile and the wideband SBC codec with the A2DP profile. For precise audio analysis, the tester should also be able to send commands to set the level of the microphone and speakers. These level settings are specified in the Bluetooth SIG audio video remote control profile (AVRCP). All of these can be verified by using a T&M instrument that has been approved by the Bluetooth SIG.

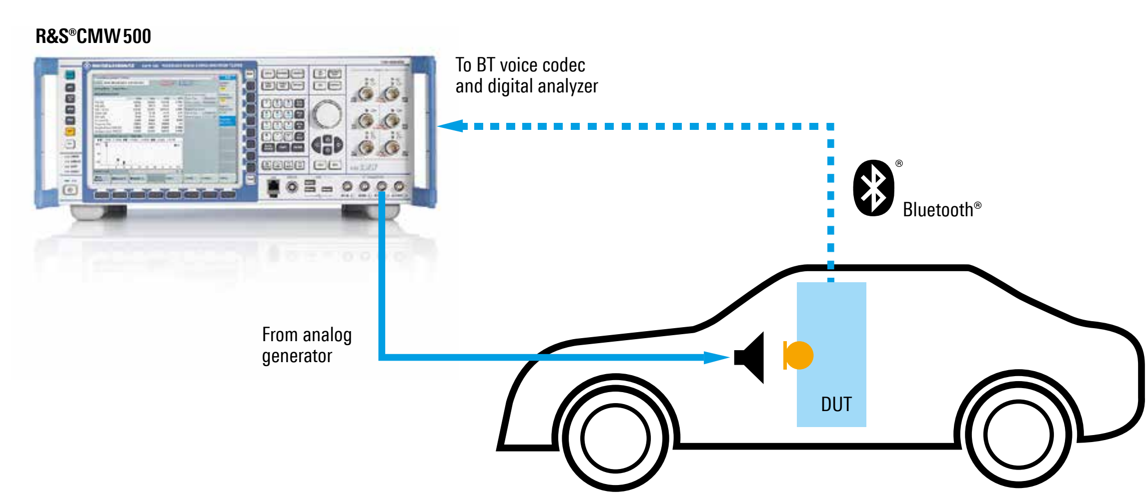
Relevant audio tests for developers

The R&S®CMW500 uses an integrated two-channel audio generator to check the BT audio quality. It offers various measurement procedures: in multitone mode, a developer can define up to 20 sounds for each audio channel (level and frequency) and measure the associated frequency responses.

In single-tone mode, the following parameters can be specified for a sine signal: audio level, frequency, signal-to-noise and distortion (SINAD) ratio, total harmonic distortion (THD) and THD plus noise (THD+N). There are also several filters that can be selected for the audio measurement.

Testing the microphone of a Bluetooth headset also involves testing the headset's audio input amplifier and A/D converter. The BT tester's audio generator produces the audio signal, which is transmitted to the microphone under test via a reference speaker. The microphone then transmits this audio signal via a Bluetooth link to the tester's audio analyzer, where the signal is measured and compared against the originally transmitted signal.

Microphone test



Stereo transmission of music

Stereo transmission of music is carried out via the A2DP profile with SBC coding and uses the wideband asynchronous link (ACL) for data transmission. BT devices that support A2DP must correctly process signals from SBC codecs. Tests with SBC-coded signals based on ACL also show whether the DUT correctly transmits lengthy packets. It is also practical if the BT tester can analyze and play all of the SBC codec modes such as dual, mono, stereo and joint stereo (dual mode for high-quality transmissions).

Relevant RF tests for developers

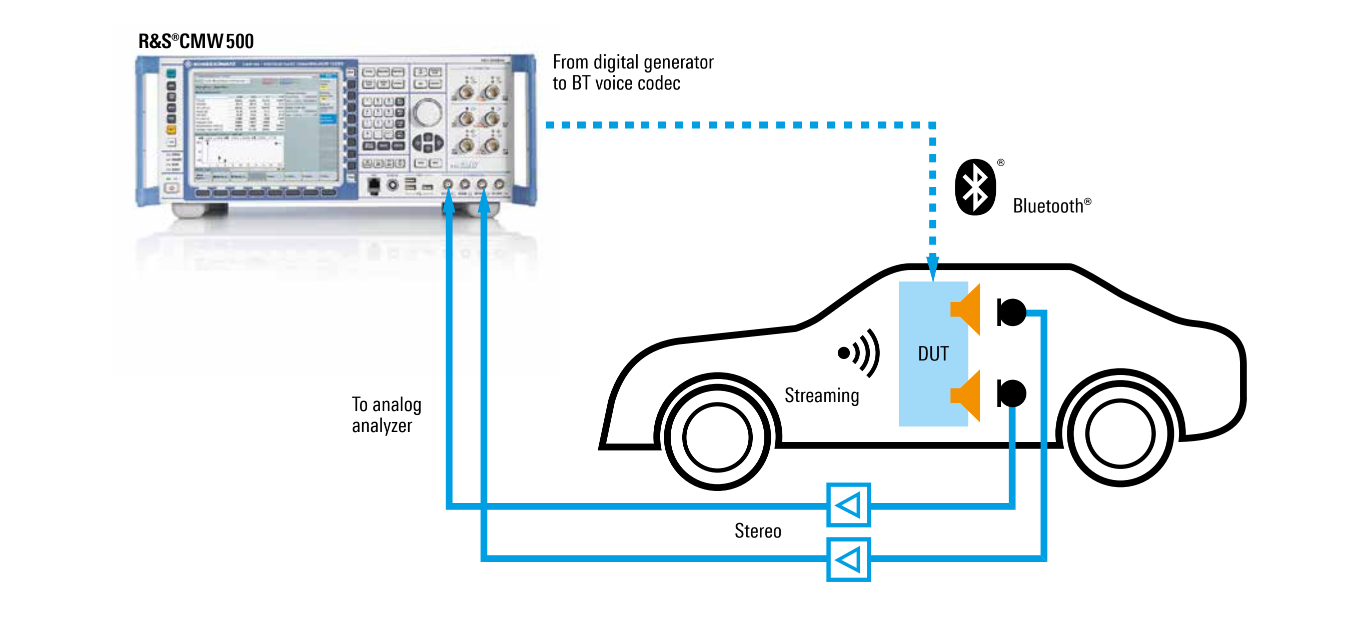
When developing a device with a BT interface, functional tests, interoperability tests and the range are relevant. The receiver sensitivity and transmit characteristics of the components are crucial for the range. In order to measure the transmit characteristics of a BT component, the developer must be able to reproducibly determine characteristic values such as power, spectrum, frequency accuracy, frequency drift, frequency deviation and the modulation index calculated from these values. This receiver sensitivity is measured using an artificially impaired signal generated by the BT tester (dirty transmitter).

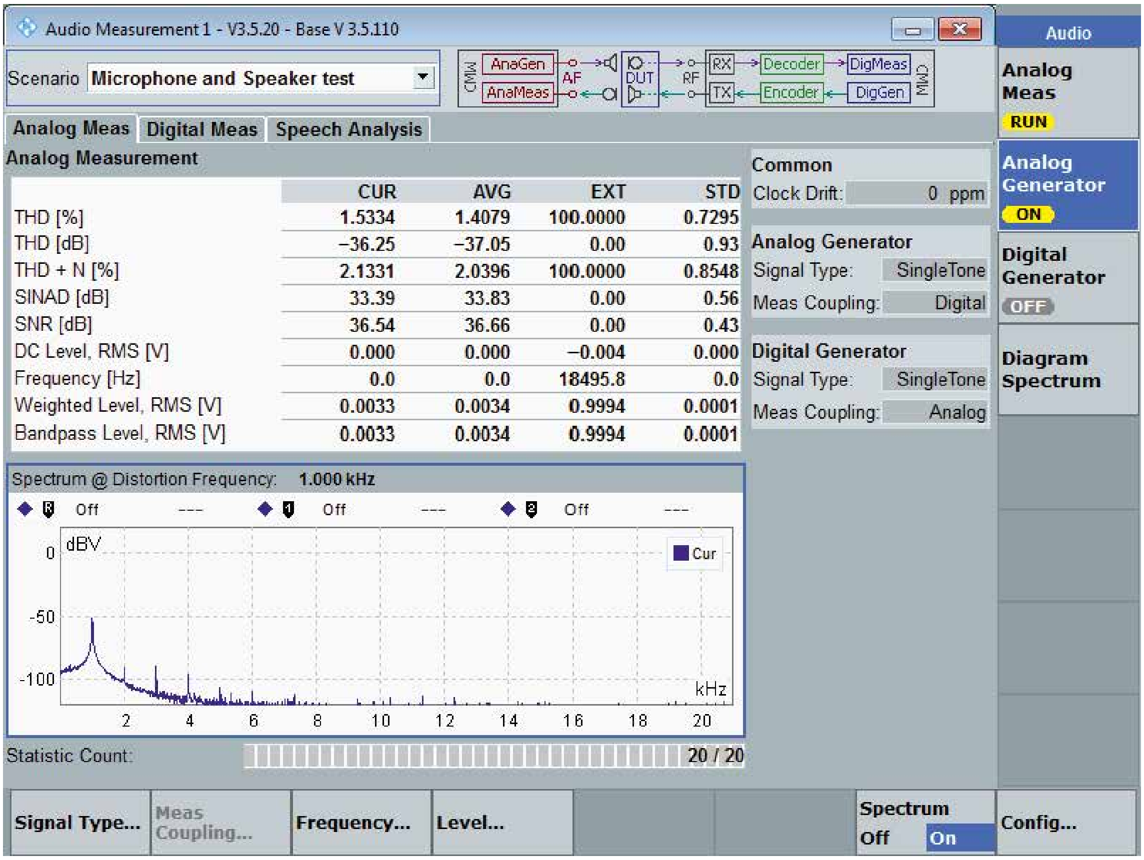
Bluetooth module receiver tests are performed by sending, with high accuracy, data from a precise generator to the receiver. The data is analyzed either by having the receiver return the bit sequence or by using an external control PC for analysis.

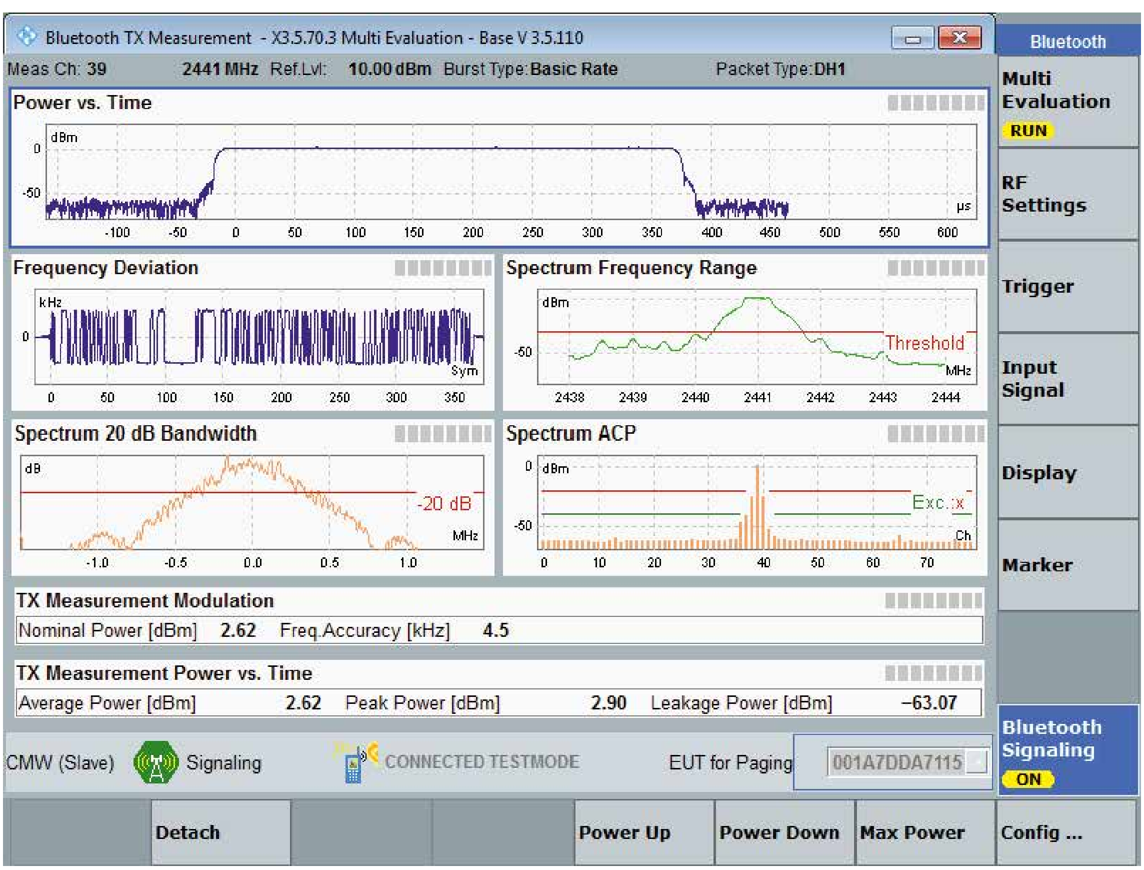
Numerous other RF signaling tests as well as spectrum measurements on newly developed BT components will be required until they receive certification from the Bluetooth SIG. The R&S®CMW testers support these audio tests, plus all 38 currently defined RF signaling tests, with all test cases. For the time-consuming spectrum measurements that are also part of Bluetooth qualification tests, the R&S®CMW provides first test results in less than one second, something no other BT tester on the market can do. The parametric test concept allows users to set all parameters themselves. They now have a compact solution for performing automated prequalification tests for Bluetooth Basic Rate, Enhanced Data Rate and Low Energy in line with Bluetooth core specifications 2.0, 2.1+EDR, 3.0+HS, 4.0, 4.1, 4.2 and 5. The easy-to-use R&S®CMWrun sequencer software also helps.

Testing of headset speakers also involves the D/A converter and the output amplifier in the headset. The BT tester's audio generator produces an audio signal and transmits it via a BT link to the headset. There it is amplified and converted to an acoustic signal via a sound converter. This signal is picked up by a reference microphone and sent via a reference amplifier to the tester's audio analyzer, where it is displayed and evaluated. Audio tests on the BT module of an infotainment system are performed in the same way.

Speaker and stereo test



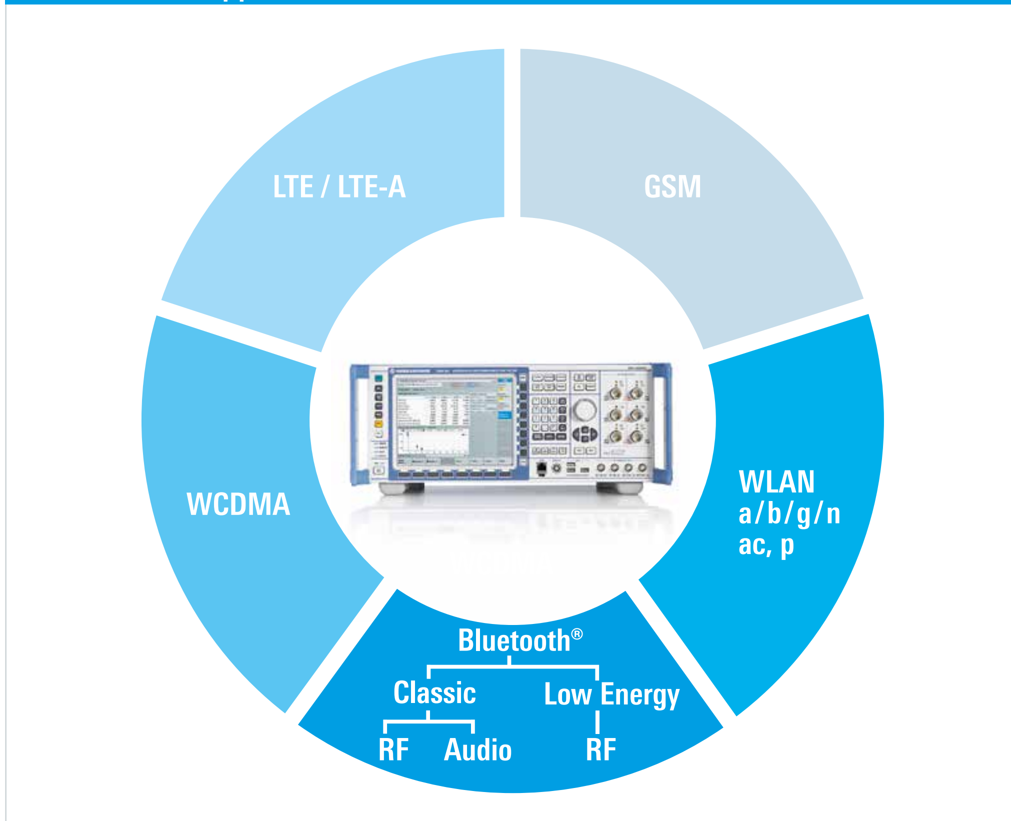




The R&S®CMW can output all test results on a single, clearly organized page, with the audio measurements (top) and the screen showing the Bluetooth RF test results (bottom).

The R&S®CMW test platform supports a number of different radio technologies. The modular approach enables individual configurations for the development, production and servicing of radio components.

R&S®CMW500 applications



Especially for production use, the R&S®CMW platform offers numerous hardware and software options so that the tester can be customized to the measurement requirements on site. The R&S®CMWrun sequencer software can be used to automate production tests. The software also makes it possible to integrate the tester into a comprehensive test system. The platform offers all essential measurements at an excellent price/performance ratio.

Bluetooth plus other radio technologies

The user can expand testing with the R&S®CMW to include other radio technologies. Many devices support more than just Bluetooth. They also support WLAN, GPS and various cellular technologies such as LTE, WCDMA and GSM. When WLAN and BT components use the same antenna, the developer can test both radio technologies with one test configuration. If the R&S®CMW is equipped with the appropriate hardware and software options, it is possible to test all of the integrated radio modules in a component up to precertification. This permits the developer to also check whether and to what extent the individual radio modules influence one another (coexistence testing).

Summary

Bluetooth has established itself as the short-range radio standard for communications between smartphones and infotainment systems in automobiles. Error-free functionality of BT components as well as their certification in line with the Bluetooth SIG specifications make standard-compliant RF tests necessary. Reliable audio frequency testing of BT products that use audio profiles is also a sensible idea. Both test tasks can be easily performed using the R&S®CMW family of testers. These are the only testers on the market with the capability of testing all cellular and non-cellular standards using just one instrument and one test setup.

Dieter Mahnken; Ute Philipp

R&S®SMW200A: first vector signal generator with 2 GHz bandwidth

With a new option, the R&S®SMW200A high-end vector signal generator implements the record modulation bandwidth of 2 GHz, at output frequencies up to 40 GHz. The only one-box solution on the market with these features, it is the perfect choice for all upcoming high-performance radio and radar applications.

100 MHz bandwidth with LTE-Advanced versus 20 MHz with LTE, 160 MHz with WLAN 802.11ac versus 40 MHz with 802.11n – in recent years, many new developments in wireless communications systems have had a considerably higher bandwidth than their predecessors. This trend is continuing: WLAN IEEE 802.11ad will require a bandwidth of 1.76 GHz, and 800 MHz is under discussion for the upcoming 5G wireless standard.

The signal sources used for developing these future systems must keep pace in terms of bandwidth and frequency range, and the R&S®SMW200A vector signal generator is leading the way. The newly developed R&S®SMW-B9 wideband baseband generator extends the instrument's internal modulation bandwidth to 2 GHz, making it the first fully calibrated wideband solution featuring up to 40 GHz in one box. Used together with the R&S®SZU100A I/Q upconverter, at this bandwidth the R&S®SMW200A even generates frequencies up to 65 GHz (see article on page 23). Not only is the generator an ideal tool for developing 5G and other future wideband communications systems, developers of advanced radar systems also benefit from its large bandwidth and excellent signal quality.

For current and future technologies

The R&S®SMW200A fulfills the bandwidth requirements for the currently favored 5G standard: up to 400 MHz below 6 GHz, and up to 800 MHz at 28 GHz and 39 GHz. Plus, its convenient software options are helpful when configuring the signals to be generated. For example, the R&S®SMW-K114 5G air interface candidates option supports developers working on potential technologies for accessing 5G mobile networks. The associated signal waveforms such as FBMC, UFMC, GFDM and f-OFDM are generated directly in the instrument (Fig. 1). And the R&S®SMW200A can already generate 5G signals based on the Verizon 5G open trial specification (V5G).

Established standards have not been neglected. The generator produces LTE signals up to and including release 12, providing 4G and 5G signals from a single box. Soon, other standards such as 3GPP FDD WCDMA and GSM will also be available for the wideband version of the generator. The signals of all important digital standards can be conveniently generated using the R&S®WinIQSIM2 PC software.

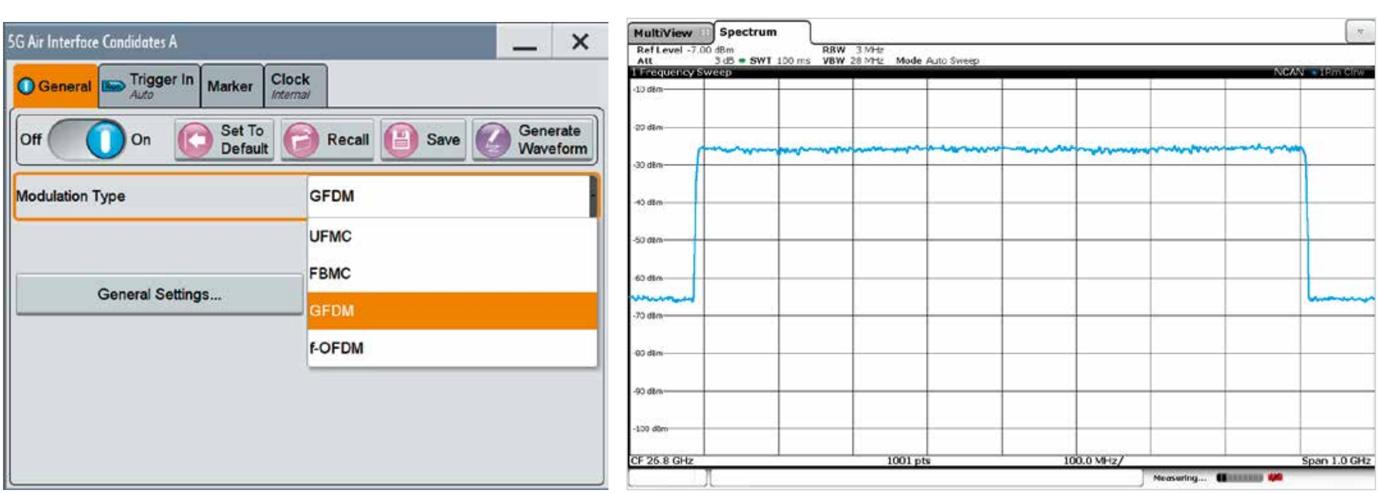


Fig. 1: The R&S®SWM200A is the ideal generator for developing new wideband communications systems. Left: the generator produces signals for 5G air interface candidates such as FBMC, UFMC, GFDM and f-OFDM. Right: example of an 816 MHz GFDM signal at 26.8 GHz.

Why a flat I/Q modulation frequency response is important

To generate signal scenarios of several 100 MHz up to 2 GHz, the I/Q modulation frequency response should be as flat as possible. Otherwise signal distortions will occur that could significantly impair the measurements. Some examples:

- A flat modulation frequency response leads to a low frequency response and better image suppression in the case of multicarrier CW signals, which are often used in component tests (Figs. 2 and 3). With measurements of this type, the signal distortions caused by the DUT are analyzed, which is why the signals provided by the generator should be as ideal as possible.
- With wideband, digitally modulated signals as occur in 5G or IEEE 802.11ad, the I/Q modulation frequency response directly influences EVM performance.
- Wideband chirp signals are often used in radar tests. A flat modulation frequency response results in better linearity.
- If modulated multicarrier scenarios with a large overall bandwidth are generated, a large modulation frequency response can considerably distort the relative level ratios of the carriers.

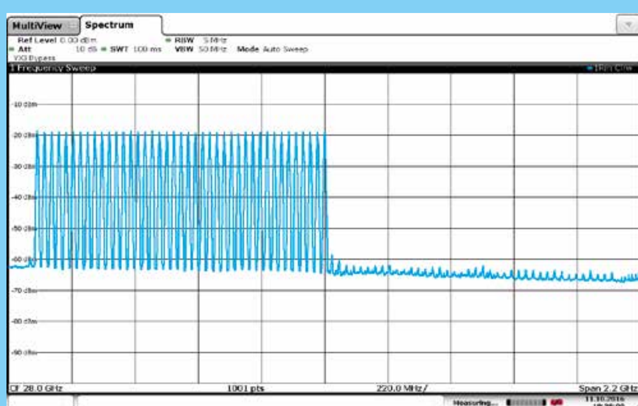


Fig. 2: The R&S®SMW200A generates high-quality wideband signals, even signals that are asymmetrical to the center frequency. The diagram shows an asymmetrical multicarrier CW scenario spanning 2 GHz (the right half of the carriers is switched off).

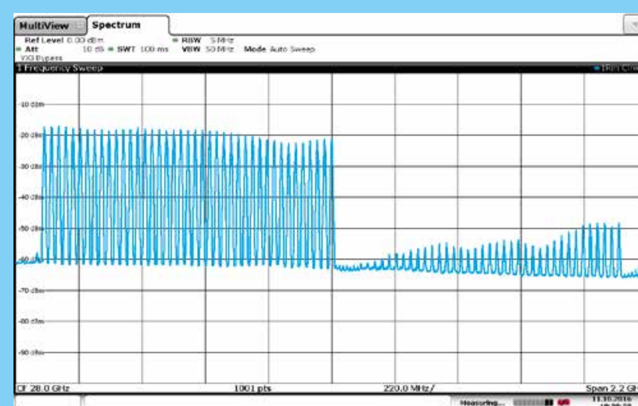


Fig. 3: This is what the scenario shown in Fig. 2 looks like when it is generated with a conventional generator that does not feature the excellent modulation frequency response of the R&S®SMW200A. The frequency response of the generated carriers and the unwanted images on the right side are clearly seen.

Outstanding modulation characteristics

A fully calibrated one-box solution, the R&S®SMW200A generates wideband signals with outstanding modulation characteristics, for example 1.76 GHz WLAN 802.11ad signals (MCS 12 at an IF of 15 GHz) with a measured EVM of –34 dB. Due to the very large bandwidths of the new communications standards, frequency response effects are considerably more noticeable than is the case with narrowband systems. In order to minimize unwanted signal distortions, a vector signal generator must exhibit a modulation frequency response that is as flat as possible (see box). The R&S®SMW200A attains values of < 0.4 dB over the entire bandwidth of 2 GHz (Fig. 4). To achieve anywhere near this kind of performance, existing multibox solutions require additional, time-consuming calibrations.

The core of the new baseband section is the R&S®SMW-B9 baseband generator. It includes an arbitrary waveform generator as well as a coder for real time signal generation and can be configured with different software options to match the specific requirements. The maximum signal bandwidth is 500 MHz in the base version, and 2 GHz in the fully configured instrument. There are also two configurations for the ARB memory depth: 256 Msample and 2 Gsample. Besides the aforementioned digital standards, the new baseband generator can generate user-defined digital modulation signals in real time with symbol rates up to 600 Msymbol/s. It supports many formats, including the higher-order quadrature amplitude modulation (QAM) formats that are often needed for simple receiver tests in satellite systems.

I/Q modulation frequency response

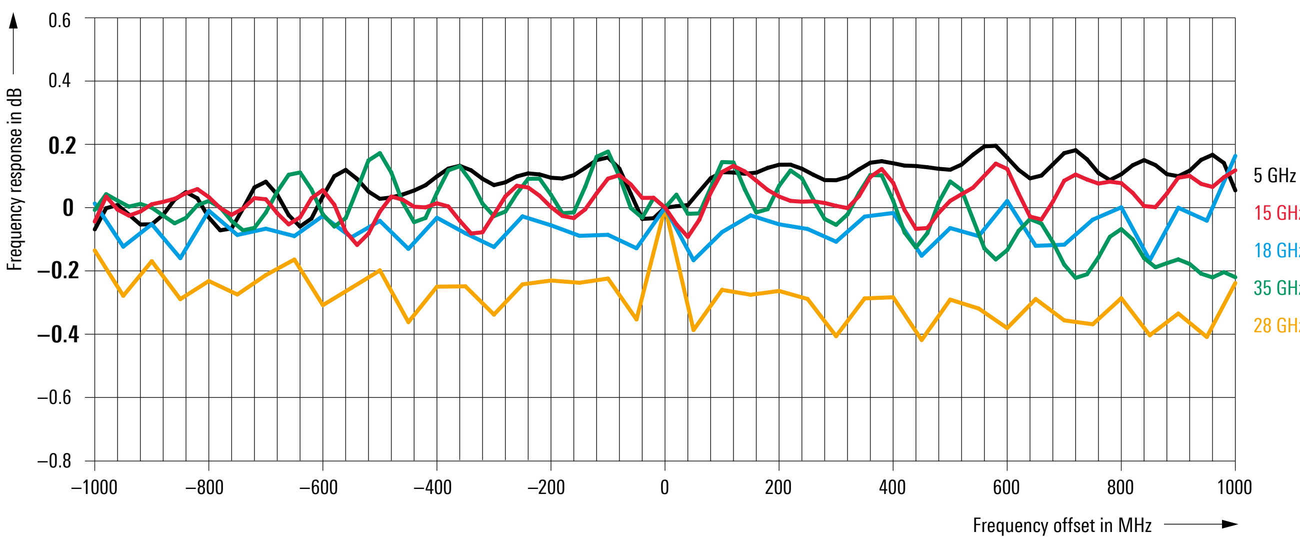


Fig. 4: Measured I/Q modulation frequency response with the R&S®SMW-B9 baseband generator option. The R&S®SMW200A attains values of < 0.4 dB over the entire bandwidth of 2 GHz.

There is room for up to two R&S®SMW-B9 baseband generators in a single instrument, allowing the R&S®SMW200A to generate two independent wideband signals up to 20 GHz with any desired modulation type. A setup of this kind previously required a vector signal generator and a separate wideband arbitrary waveform generator per signal source, i.e. an R&S®SMW200A replaces four instruments (Fig. 5). Now compact test setups are possible for sophisticated applications in A&D and wireless communications, for example to simulate complex radar scenarios or wanted/interfering signal configurations.

Summary

The new R&S®SMW-B9 wideband baseband generator upgrades the R&S®SMW200A, making it the first vector signal generator to feature an internal modulation bandwidth of 2 GHz in the frequency range up to 40 GHz. It is ideal for demanding applications that require top-quality, large-bandwidth signals, especially for developing advanced radar systems and new communications standards such as 5G and WLAN IEEE 802.11ad.

Dr. René Desquiotz

One R&S®SMW200A can replace four instruments

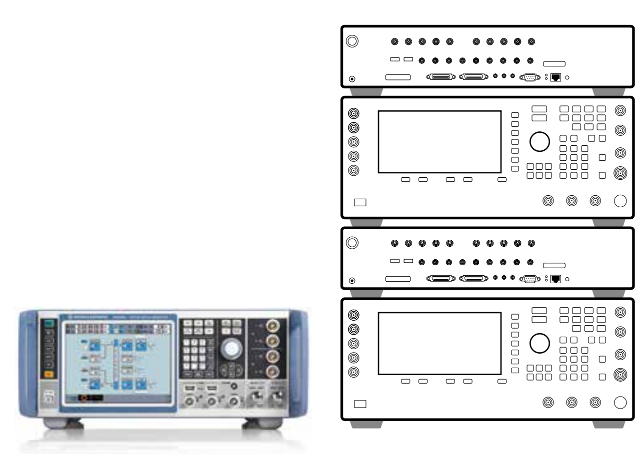


Fig. 5: Equipped with two built-in baseband generators, the R&S®SMW200A can generate two independent wideband signals up to 20 GHz with any desired modulation type. Previously, this required four instruments.

R&S®SMW200A vector signal generator: testing WLAN 802.11ad up to 65 GHz

Generating wideband signals up to 65 GHz for testing WLAN 802.11ad receivers is a major challenge. The R&S®SMW200A vector signal generator in combination with the new R&S®SZU100A IQ upconverter masters this task and allows objective evaluation of the receivers' performance.

Modern wireless communications scenarios require ever higher information data rates up to the Gbit range. Large amounts of data are managed in cloud storage and must be available quickly at any time. Wireless devices are the future: mobile phones that are quickly synchronized with multimedia libraries or laptops that exchange high video data volumes in 4K quality using wireless docks with external hard disks, servers, TV sets or projectors.

Signal generators for developing such applications must reach beyond conventional modulation bandwidths and frequency ranges. Requirement specifications include generating wideband signals up to the 60 GHz range as well as an RF bandwidth of 2 GHz – with high output power and excellent signal quality. This article describes how the new R&S®SZU100A IQ upconverter now expands the capabilities of the R&S®SMW200A vector signal generator up to 65 GHz, especially for WLAN 802.11ad applications.

65 GHz – a T&M challenge

Up to now, reproducible tests on millimeterwave receivers have been very complex. For some time, wideband test signals up to the 40 GHz range have been easily generated directly with vector signal generators such as the R&S®SMW200A. Signals up to the 60 GHz range (e.g. for receiver tests for WLAN 802.11ad) however, required an additional RF mixer in order to achieve the target frequencies from 57.32 GHz to 65.80 GHz. But these conventional mixer setups have some disadvantages. For example, for practical reasons, upconversion into the 60 GHz band often takes place in several stages. This typically results in local oscillator (LO) mixing products that lie in the operating band. Moreover, additional filters must be used to suppress unwanted sidebands that occur during mixing.

Conventional mixing concepts are also subject to fluctuating RF characteristics. Depending on frequency and level, the setup typically has a different frequency response. To cope with this, the actual frequency response must be recorded and tediously corrected using external measuring equipment. However, this compensation is only valid for one level and one frequency, which in practice requires a recalibration before each measurement, resulting in considerably longer measurement times.

The significantly stronger attenuation of the propagation of millimeterwaves compared to frequencies below 6 GHz complicates matters even more. In a conducted test setup, an attenuation of 7 dB to 10 dB per meter can be expected. However, due to the tight integration of the antenna array and RF frontend, WLAN 802.11ad receivers usually do not allow a wired connection. Consequently, tests for WLAN 802.11ad are generally only possible via the air interface.

In a typical over-the-air test setup, the generator signal is passed on to a transmitting horn antenna (e.g. with 23 dBi gain), and the receiver under test is placed at a distance of one meter, for example. At 60 GHz the free-field attenuation is 68 dB/m which means that these tests require a relatively high output power of the signal generator. To meet the WLAN 802.11ad receiver sensitivity limit of –53 dBm for an MCS 12 signal, the signal generator must produce a signal with at least –8 dBm transmit power. Losses in the test setup caused by switches, adapters or feed cables increase the required power to 0 dBm or more. If a WLAN receiver is to be tested up to its limits, very low levels with the same modulation quality and, in particular, good signal-to-noise ratio must also be generated – a major challenge for conventional test setups.

Vector signal generator for 65 GHz

A unique solution for these measurements is the new R&S®SZU100A IQ upconverter, which expands the R&S®SMW200A vector signal generator to the range of 57.32 GHz to 65.80 GHz (Figs. 1 and 2). The generator's wideband baseband option (R&S®SMW-B9) creates internal WLAN 802.11ad signals with the required symbol rates of 1.76 GHz. All WLAN-specific parameters such as modulation, coding, packet size and MAC header can be configured as required. This approx. 2 GHz baseband signal is fed to the R&S®SZU100A via the analog I/Q input, where it is upconverted to the 60 GHz band using an LO signal from the high-performance RF synthesis module of the R&S®SMW200A. The IQ upconverter is controlled via USB and integrates seamlessly into the R&S®SMW200A operating concept. Frequency and level are adjusted, as usual, via the signal generator's graphical user interface. Users can easily and conveniently operate the setup as with standalone vector signal generators from Rohde&Schwarz.

High output power

The R&S®SZU100A is designed as a remote millimeterwave head. It can be placed close to the DUT and flexibly positioned with its adjustable feet and variety of mounting points. A horn antenna can be directly mounted to its waveguide output (WR15) without requiring an additional adapter. The I/Q upconverter features its own output amplifier, an attenuator and, directly on the waveguide output, an integrated level detector. This makes it possible to precisely set levels from –80 dBm to +5 dBm with excellent linearity over the entire dynamic range as well as with virtually constant signal-to-noise ratio. Typically, an output level of even more than +10 dBm is available. The sophisticated synthesis concept ensures that spurs and mirror images are suppressed, eliminating the need for external filters with their undesired insertion losses. All of these measures minimize loss in the test setup and ensure high output power to test the DUT.

Test setup for WLAN 802.11ad measurements

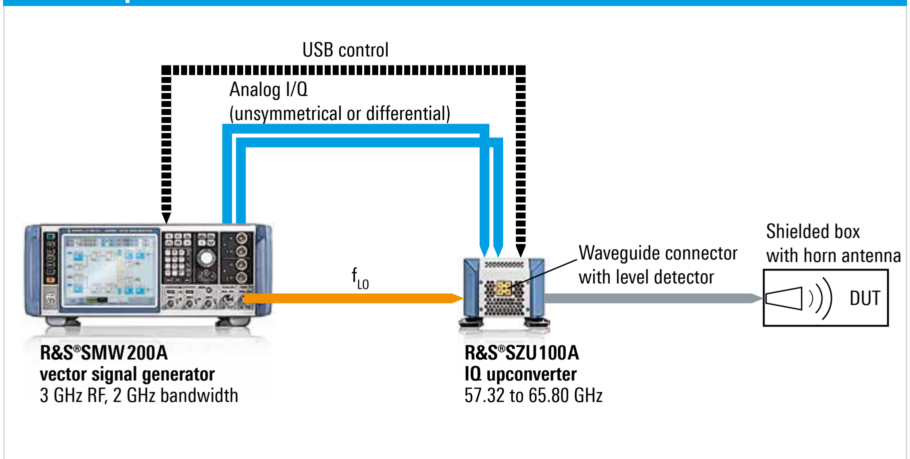


Fig. 1: The R&S®SZU100A IQ upconverter expands the R&S®SMW200A to the range of 57.32 GHz to 65.80 GHz for WLAN 802.11ad receiver measurements.

Frequency response correction in real time

Rohde&Schwarz fully characterizes the IQ upconverter in production and stores the frequency response correction data in its EEPROM. The R&S®SMW200A uses these values during operation to

correct the frequency response in real time (Fig. 3). This ensures a flat frequency response independent of the level, frequency and signal type, making it unnecessary to correct the setup before each measurement using expensive external calibration hardware. This not only reduces the cost of hardware, but also saves additional calibration cycles during operation and considerably shortens overall measurement time. Because the frequency response correction is independent of the transmit signal, maintaining a variety of predistorted waveforms for each individual test setup is unnecessary. It is possible to work with identical signals at different measurement stations. This reduces the effort required to manage waveform libraries and provides transparent results. Thanks to real time correction of the frequency response, the combination of R&S®SMW200A and R&S®SZU100A can achieve excellent EVM values of specified –31 dB; usually even –32 dB or better is reached (Fig. 4).

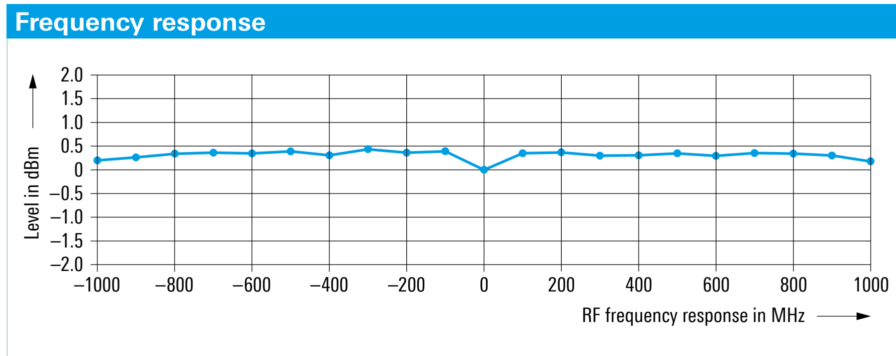


Fig. 3: Measured frequency response of the R&S®SMW200A in combination with the R&S®SZU100A at a carrier frequency of 64.80 GHz and output level of +0 dBm.

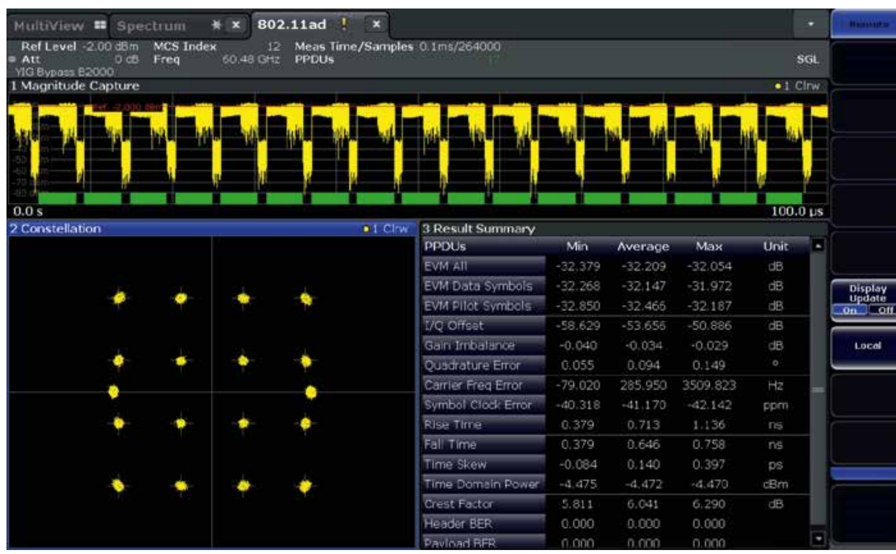


Fig. 4: Measured EVM of a WLAN 802.11ad signal (MCS 12) generated by the R&S®SZU100A and the R&S®SMW200A at 60.48 GHz.

Fig. 2: The R&S®SZU100A IQ upconverter fits seamlessly into the R&S®SMW200A operating concept.

Summary

The R&S®SZU100A IQ upconverter and the R&S®SMW200A vector signal generator are a powerful duo for WLAN 802.11ad measurements in the 60 GHz band. The setup generates standard-compliant PHY signals for testing components, modules and wireless devices with excellent signal quality and with impressive dynamic range. Thanks to the internal real-time frequency response correction, the signal is always correct. Special calibration with additional equipment before each measurement is not necessary. The setup is operated exclusively via the generator: make the necessary configuration and start measuring right away. This ensures a fast and uncomplicated workflow and enables users to successfully carry out their measurement tasks in the shortest possible time.

Simon Ache

Testing MIPI® interfaces with the R&S®RTO oscilloscope

Many components in modern smartphones communicate with each other via interfaces standardized by the MIPI® Alliance. R&S®RTO oscilloscopes can analyze these interfaces' signal integrity and data content with maximum efficiency to quickly locate errors.

The MIPI® standards' ecosystem

Each new generation of modern mobile phones enters the market with new features such as additional sensors, higher display resolutions and an extended range of equipment. The numerous components inside these devices communicate quickly and efficiently via common interfaces to offer smooth functionality. The most widely used standards for hardware and software interfaces in mobile phones are from the non-profit MIPI® Alliance, which consists of more than 280 member companies. According to the MIPI® Alliance, at least one of their standards is implemented in every modern smartphone and in about 90 % of all classic mobile phones. The MIPI® standards, which are constantly evolving, are also used in tablets and digital cameras as well as products for the automotive and health care sector. Fig. 2 shows the current status.

The standard framework defines three physical layers: D-PHY, C-PHY and M-PHY® (Fig. 3). These physical layers are optimized for high-speed (HS) data transmission while maintaining low power (LP) consumption. This optimization places special demands on test equipment during development. This article describes the interplay with oscilloscope parameters, as well as the variety of debugging capabilities offered by the R&S®RTO oscilloscopes (Fig. 1) for MIPI® protocol implementations.

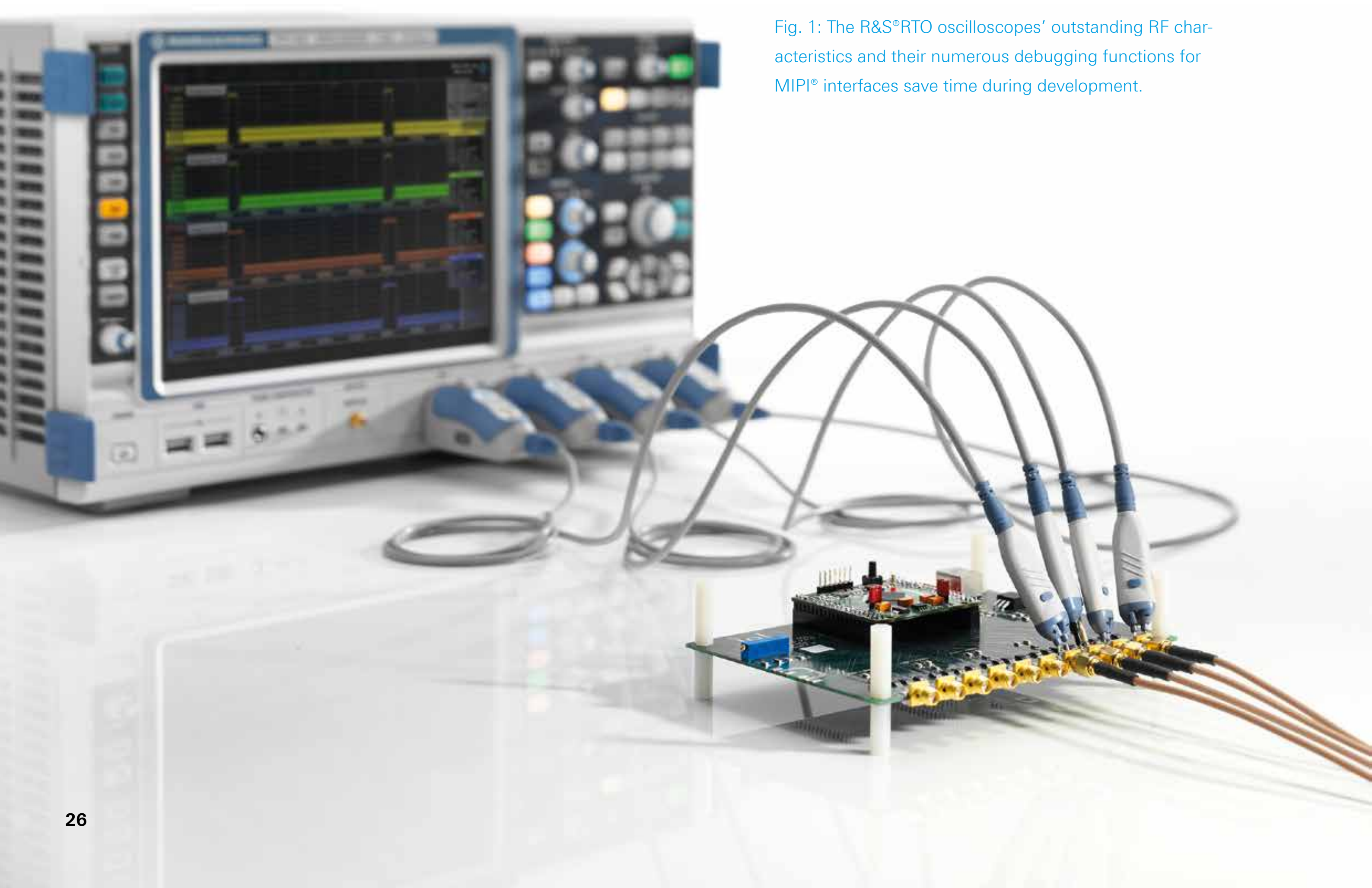
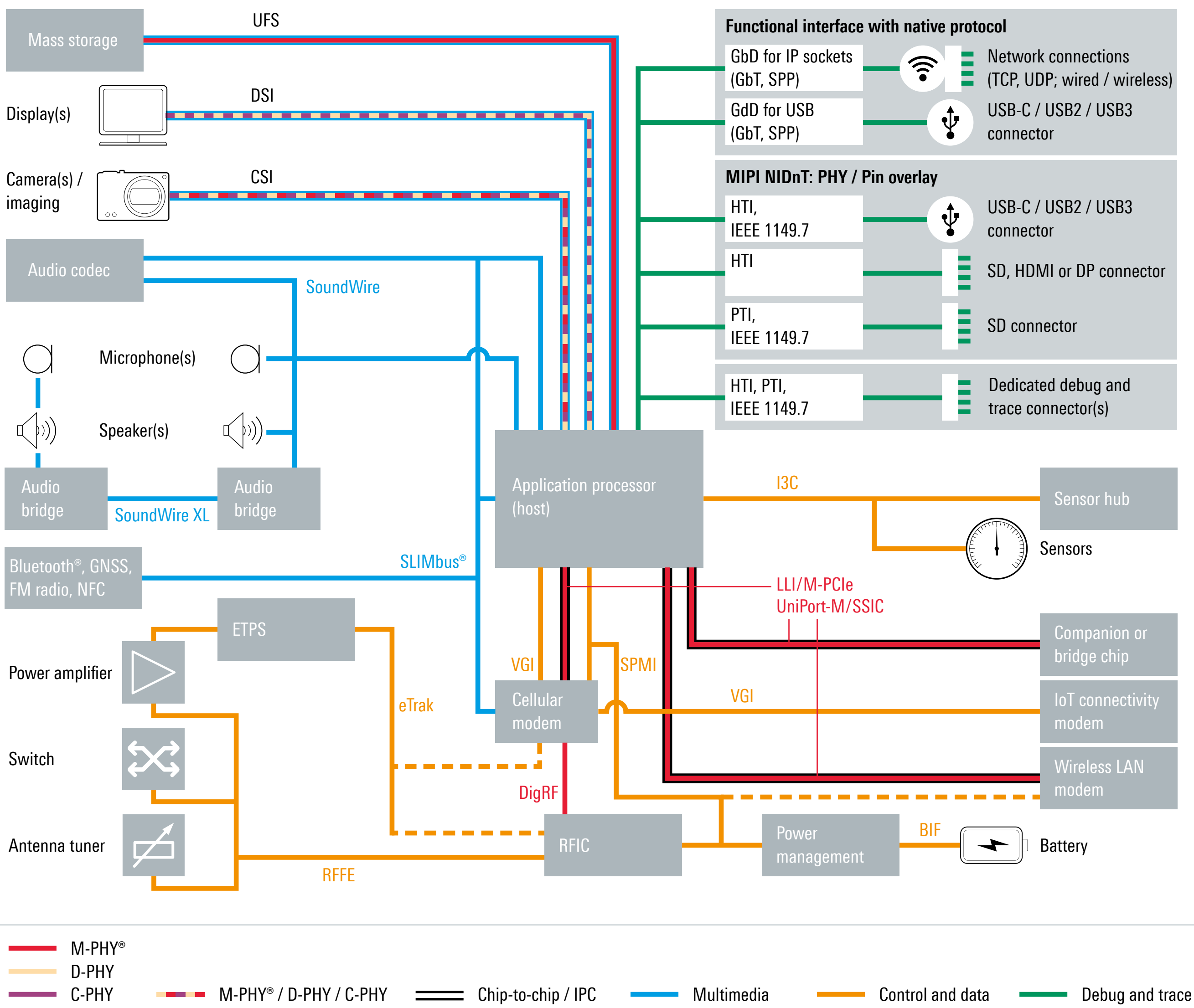


Fig. 1: The R&S®RTO oscilloscopes' outstanding RF characteristics and their numerous debugging functions for MIPI® interfaces save time during development.

MIPI® specifications for a mobile device



MIPI, DigRF, M-PHY, SLIMbus and SoundWire are registered service marks of MIPI® Alliance. Other designations for MIPI® specifications are service marks of MIPI® Alliance. All other trademarks are the property of their respective owners.

Fig. 2: Overview of the MIPI® specifications' ecosystem (source: MIPI® Alliance).

The physical layers – specifications and use

D-PHY, the most commonly used specification, supports camera and display applications. The recently published specification for C-PHY describes an efficient unidirectional streaming interface with low-speed, in-band reverse channel, which should replace D-PHY for higher speed requirements in the future. The third specification, M-PHY®, supports a broader range of applications, including interfaces for display, camera, audio, video, memory, power management and interchip communications, for example, between baseband chips and those for RF. In addition, it was adopted as a physical layer for protocols outside of the MIPI® ecosystem such as Mobile PCIe (M-PCIe) and SuperSpeed Inter-Chip (SSIC) USB.

Several higher-level protocols are specified for each physical layer (Fig. 3). Presently, the variants based on C-PHY are barely used. The Unified Protocol (UniPro) specification makes it possible to use the similarities for higher-layer

MIPI® Alliance specifications

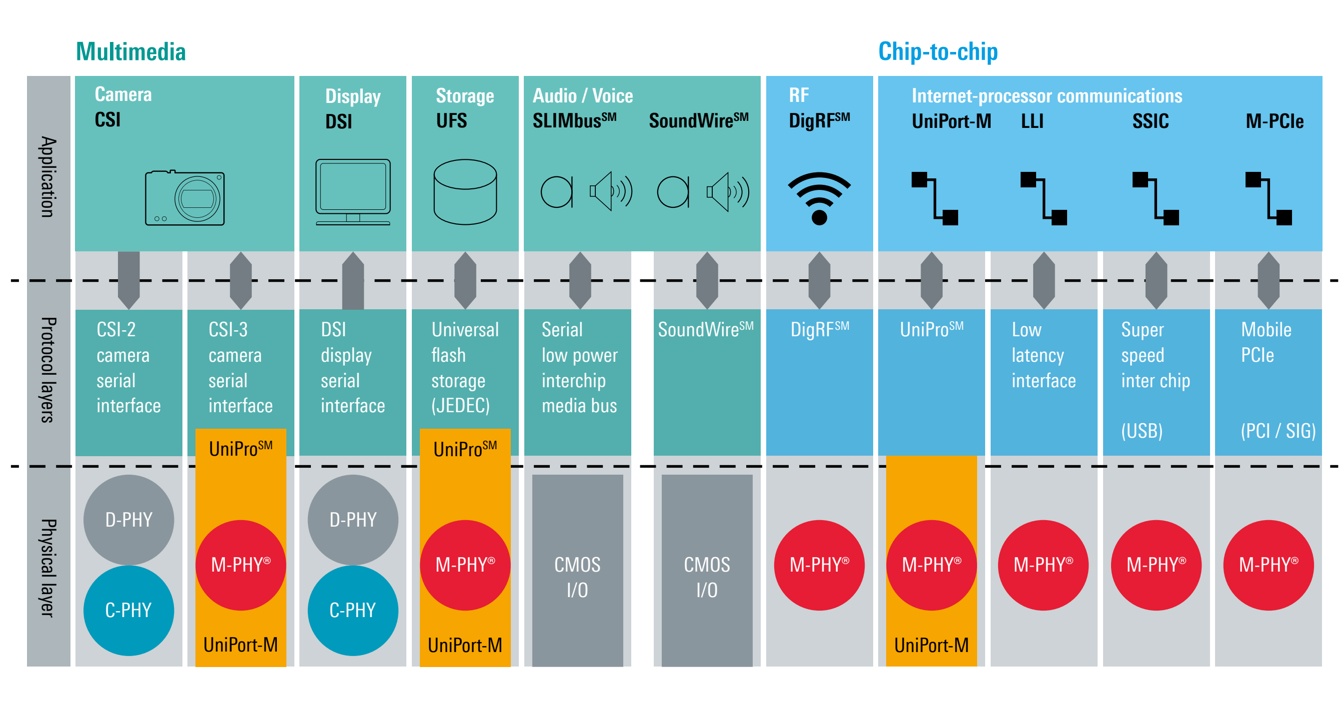


Fig. 3: Applications, protocols and physical layers of the MIPI® standards (source: MIPI® Alliance).

Physical layer	Triggering and decoding	Compliance tests
CMOS I/O	**R&S®RTO-K40** ▪ RFFE (V. 1.1)	
D-PHY	**R&S®RTO-K42** ▪ D-PHY (V. 1.2) ▪ CSI-2 (V. 1.2) ▪ DSI (V. 1.3)	**R&S®RTO-K26** (MIPI CTS for D-PHY V1.1)
M-PHY®	**R&S®RTO-K44** ▪ M-PHY 4.0 ▪ UniPro 1.6	

Fig. 4: Overview of MIPI® standards covered by the R&S®RTO oscilloscopes' analysis options.

protocols based on M-PHY® for interconnecting components within mobile devices. The specification is suitable for a wide range of components including application processors, co-processors and modems, as well as different types of data traffic including control signals, user data transfer and packetized streaming.

The R&S®RTO offers different software options for analyzing MIPI®-based protocols and their respective physical layers (Fig. 4). The following sections describe how the R&S®RTO effectively handles all T&M requirements of the MIPI® standards. Although both the D-PHY and M-PHY® MIPI® standards serve as examples, the arguments also apply to the other MIPI® options offered by the R&S®RTO.

Standard D-PHY

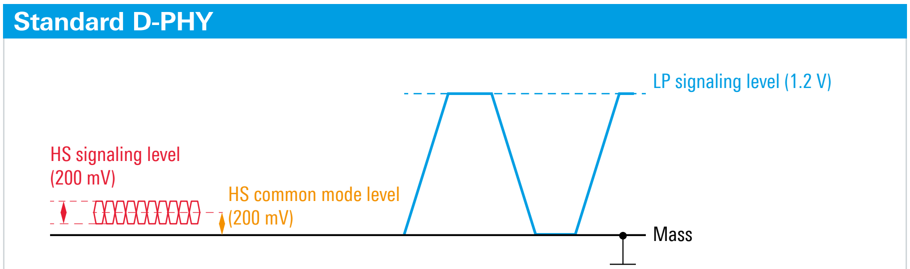


Fig. 5: Voltage levels of the MIPI® D-PHY signal.

Detailed analysis of the physical layer increases the tolerance range for the DUT

When analyzing the physical layer, it is essential to differentiate between the DUT's signal integrity and the signal fidelity of the test equipment. Critical oscilloscope parameters include noise, jitter, DC accuracy and bandwidth limitations at high amplification factors. The acquisition of consecutive LP and HS sequences, which have very different signaling levels, is particularly challenging. They require a high signal integrity in order to determine signal quality – especially for the HS components. Fig. 5 shows the respective voltage levels.

The better the characteristics of the T&M instrument at hand, the greater the tolerance range for the DUT, resulting in cost savings, lower scrap rates and more efficient measurements. Thanks to its excellent features, this is where the R&S®RTO excels – as shown in the following examples.

Simultaneous acquisition of 200 mV and 1.2 V voltages

When characterizing the physical layer, a full scale of 1.4 V is used to acquire the LP signal. 8-bit A/D converters as used in most oscilloscopes provide a full-scale resolution of 5.5 mV/bit. While this is theoretically sufficient for measurements on the 200 mV signal (assuming an ideal A/D converter), additional influences might render it insufficient. In practice, the A/D converter's effective number of bits (ENOB) is reduced by several influences such as offset error, gain error, nonlinearity error and static noise. The R&S®RTO oscilloscopes benefit from their low-noise frontend and precise A/D converters. The converters provide an unmatched dynamic range of > 7 bit (ENOB) that can be fully utilized over the full instrument bandwidth of 4 GHz.

In addition, the R&S®RTO oscilloscope's low noise reduces the influence of noise floor on the measurement. For example, actual RMS noise at the selected full scale of 1.4 V (i.e. 140 mV/div), is only about 5.0 mV. This value can be significantly higher on other oscilloscopes. The high dynamic range of the R&S®RTO and its low inherent noise increase measurement accuracy, thereby reducing the rate of rejected DUTs.

Overloading the frontend: a suitable workaround?

One workaround to reduce the oscilloscope's influence on HS signal measurements is to use higher amplification. Using a full scale of 300 mV, for example, increases the resolution to 1.2 mV/bit and reduces RMS noise to 1.1 mV. The disadvantage to this approach is that the amplifier in front of the A/D converter needs recovery time if operated outside its specified range. During this period, the energy stored in the amplifier causes signal distortions and makes results useless. Using this approach would only make sense if the signal of interest occurs much later than the transition from the LP to the HS state. The exact time needed for this is usually not specified by manufacturers but is typically in the range of several nanoseconds.

Even if an overloaded amplifier does not affect the area of interest, problems may still arise because many oscilloscopes limit the bandwidth for high amplifications in order to reduce noise. These limitations are often drastic and can go down to 500 MHz for the highest amplifications. Since the D-PHY standard requires rise and fall time measurements in the range of 100 ps, oscilloscopes with a bandwidth of at least 3.5 GHz are necessary. With an input sensitivity of 30 mV/div and a typical active probe with an attenuation factor of 10:1, the frontend must be set to 3 mV/div in order to capture the full range of the 200 mV differential signal. The bandwidth of most oscilloscopes is insufficient when set to this value. Thanks to its low-noise frontend and powerful A/D converters, the R&S®RTO oscilloscope's full instrument bandwidth down to 1 mV/div is available, offering the highest dynamic range for compliance measurements (Fig. 6).

Sensitivity versus bandwidth

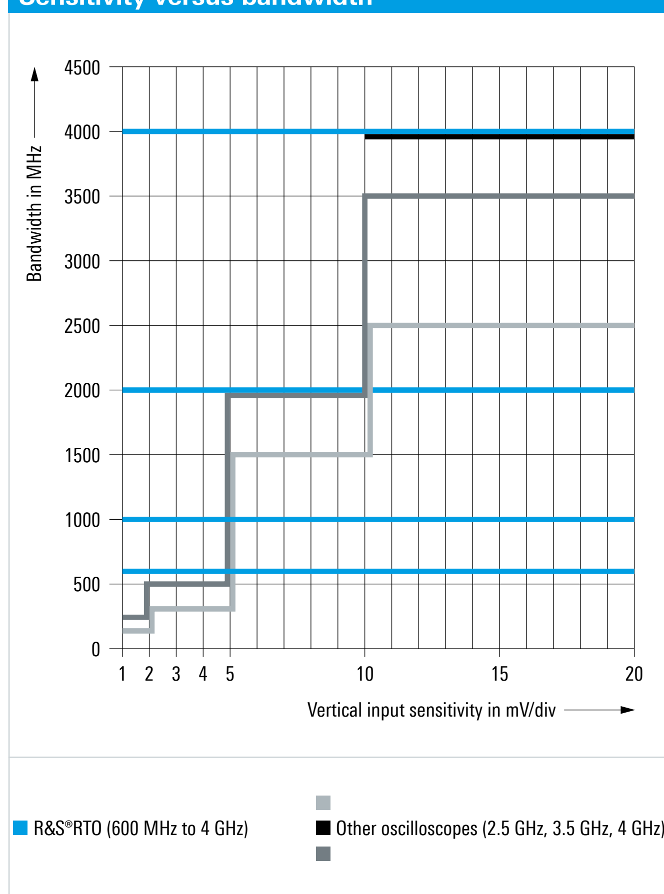


Fig. 6: The R&S®RTO oscilloscope offers full measurement bandwidth at every input sensitivity, even at 1 mV/div.

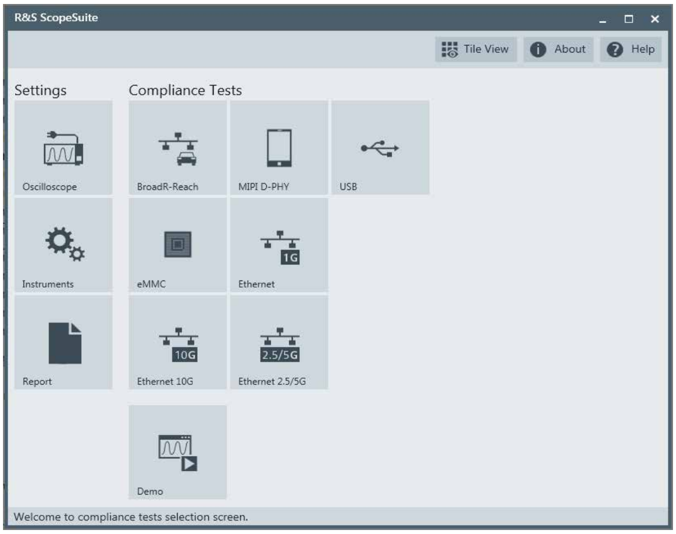


Fig. 7: The main screen of the R&S®ScopeSuite shows the available compliance tests.

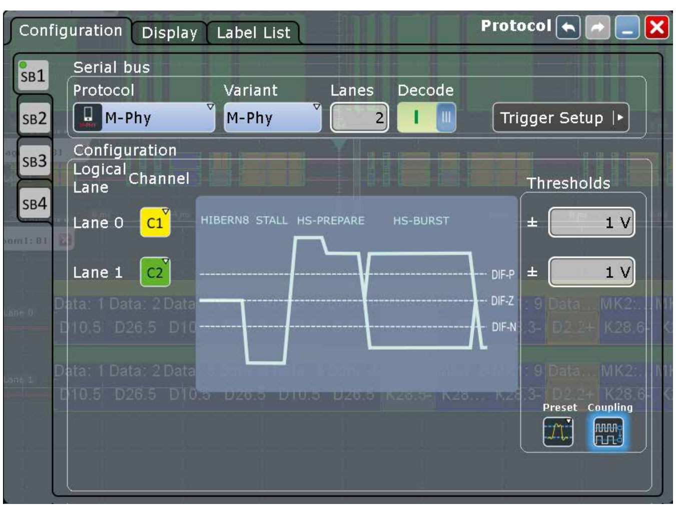
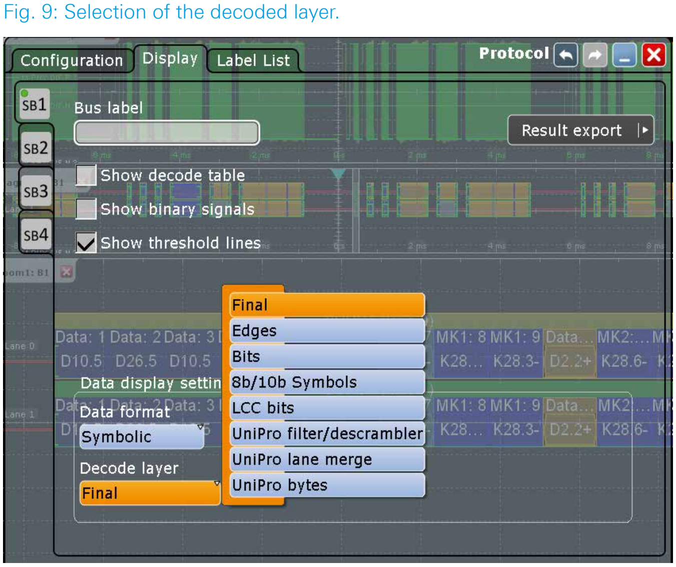


Fig. 8: Configuration of M-PHY® / UniPro protocol decoding.

Fig. 9: Selection of the decoded layer.



In addition to these technical details, an intuitive workflow quickly leading to results is crucial when performing compliance measurements. The R&S®ScopeSuite (Fig. 7) and the respective R&S®RTO-K26 compliance test option offer quick results. Step-by-step instructions and descriptive pictures ensure that measurements succeed on the first try. In addition, the R&S®RTO-K26 compliance test option uses the numerous possibilities of the oscilloscope's digital trigger system's numerous possibilities to quickly isolate the right signals and reduce measurement time.

Analyzing data communications between components

After verifying signal integrity, the next step in design development is to analyze and debug communications between different components. Oscilloscopes with MIPI® triggering and decoding options for serial communications protocols, such as those available for the R&S®RTO (Fig. 4), greatly simplify these measurements.

The R&S®RTO-K44 option, for example, supports debugging directly on the lowest physical M-PHY® layer as well as on the higher UniPro based protocol layers. The 4 GHz R&S®RTO2044 covers UniPro 1.6 up to HS transmission mode gear 2 (HS-G2, 2.9 Gbit/s), making it possible to debug protocols such as CSI-3, UFS and UniPort-M.

To setup the decoding of a two-lane M-PHY® signal, two differential probes (R&S®RT-ZD40) are connected to channel 1 and 2. A dialog box guides the user through the configuration (Fig. 8). Users simply need to select either M-PHY® or UniPro and set the number of lanes (up to four lanes are supported). Both coupled and individual threshold values can be used.

The data format and the layer to be decoded is set in a second step. Being able to choose layers is useful for debugging errors on different protocol levels, starting from the edge transitions, to the bits and symbols, up to the upper UniPro protocol layers (Fig. 9).

In Fig. 10, the setup and activated decoding illustrate the different bursts for data and markers (MK0, MK1, MK2). The decoding table provides an overview of the bursts. A second table provides details of the data (decode results details 1) for an in-depth analysis of individual bursts.

Protocol-dependent triggering of the R&S®RTO-K44 option separates the respective data telegrams from one another (Fig. 11). Use of the fast and precise digital triggers, in combination with additional software selection, results in an extremely high-performance workflow.

Summary

Thanks to the triggering and decoding as well as compliance test options, the R&S®RTO oscilloscopes cover all measurements in line with the MIPI® standards. Their outstanding RF characteristics and convenient operation enable development engineers to achieve better results in a shorter time.

Dr. Philipp Weigell

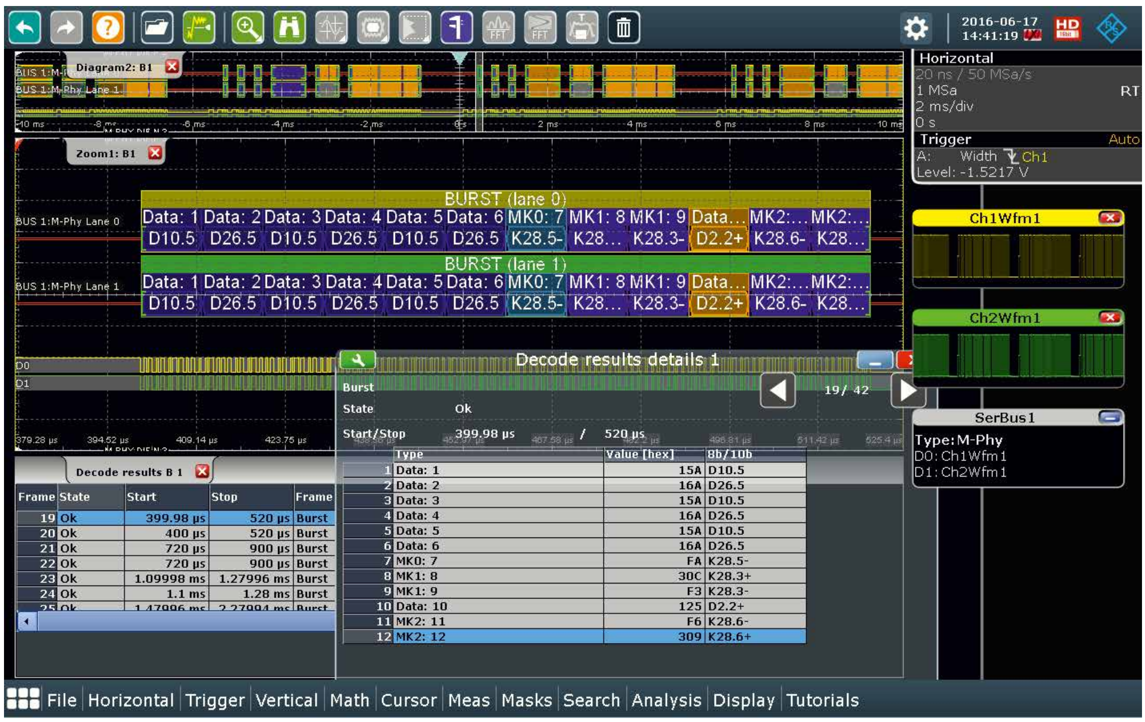


Fig. 10: M-PHY® layer decoding results with zoom and table display the details of the frames and bursts.

Fig. 11: M-PHY® / UniPro protocol decoding setup.

True multiport vector network analysis up to 20 GHz

The new R&S®ZNBT20 multiport network analyzer permits parallel measurements up to 20 GHz on up to 16 integrated test ports. It offers high speed and accuracy, which provides numerous advantages for measurements on complex multiport DUTs in development and production.

The multiport vector network analyzer portfolio has been expanded to meet the growing requirements for multiport measurements. In addition to the R&S®ZNBT8 (up to 24 ports / 8.5 GHz) and the R&S®ZN-Z84 and R&S®ZN-Z85 switch matrices, the R&S®ZNBT20 vector network analyzer is now available for the frequency range from 100 kHz to 20 GHz (Fig. 1). With eight test ports that can be expanded later to 12 or 16 ports, it can be used universally for applications in development and production. The many ports are also ideal for signal integrity measurements such as on data cables.

Best multiport performance on the market

In contrast to solutions based on switch matrix technology, the R&S®ZNBT20 features one measurement receiver and one reference receiver on every test port (Fig. 2). In the parallel mode, it can therefore measure on all ports at the same time, a decisive speed advantage compared with matrix-based multiport solutions (Fig. 3). Even when equipped with 16 ports, the network analyzer offers the excellent performance data of a comparable two-port device at every port because the switches to be provided in switch matrices between the test port and the receivers of the base unit are not required. With up to 130 dB dynamic range between all ports and the output level range from –60 dBm to +12 dBm, the R&S®ZNBT20 offers the best multiport performance on the market in the frequency range up to 20 GHz.

Fig. 1: With up to 16 test ports and an upper frequency limit of 20 GHz, the R&S®ZNBT20 supplements the vector network analyzer product range.

Automated measurements and high throughput

An external monitor and keyboard or an external touchscreen can be connected for operation. Using the intuitive user interface already known from the R&S®ZNB vector network analyzer, the R&S®ZNBT20 is easy to configure. Numerous wizards provide support for measuring tasks.

Remote controllability is a key factor for production applications. The R&S®ZNBT20 can be controlled via GPIB, USB or LAN. Using the handler I/O interface, it interacts directly with automated test systems. It controls an external part handler and the test sequence and automatically selects DUTs based on defined criteria.

Automatic calibration units help save time and achieve high measurement accuracy in a cost-efficient manner. They minimize the number of required screw connections and the systematic measurement errors since each test port has to be connected to the calibration unit only once. The R&S®ZNBT20 firmware supports all Rohde & Schwarz calibration units and guides the user step by step through the calibration.

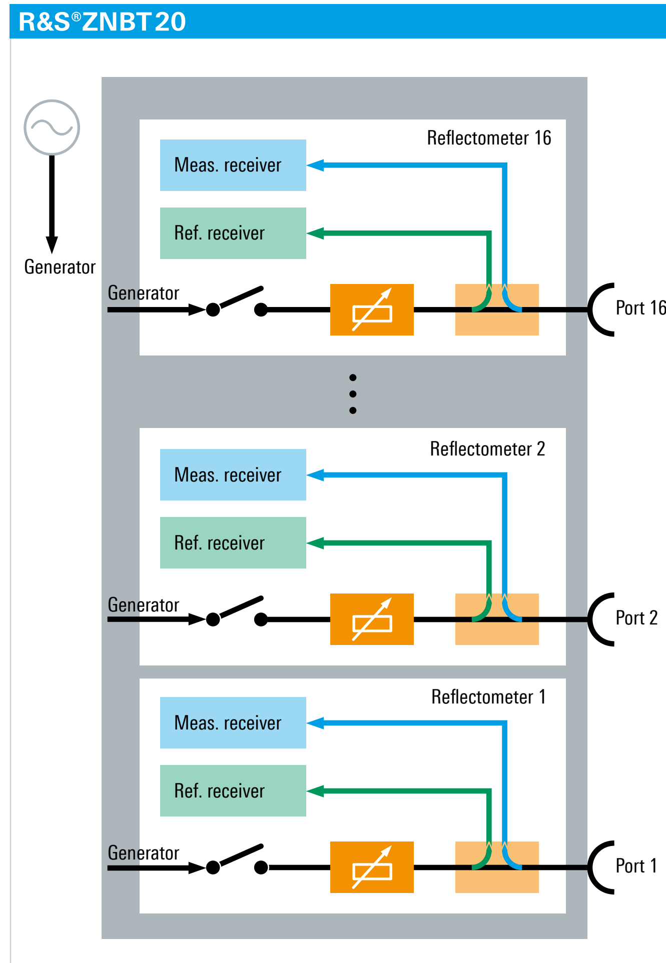


Fig. 2: The R&S®ZNBT20 network analyzer's multiport architecture ensures excellent RF characteristics.

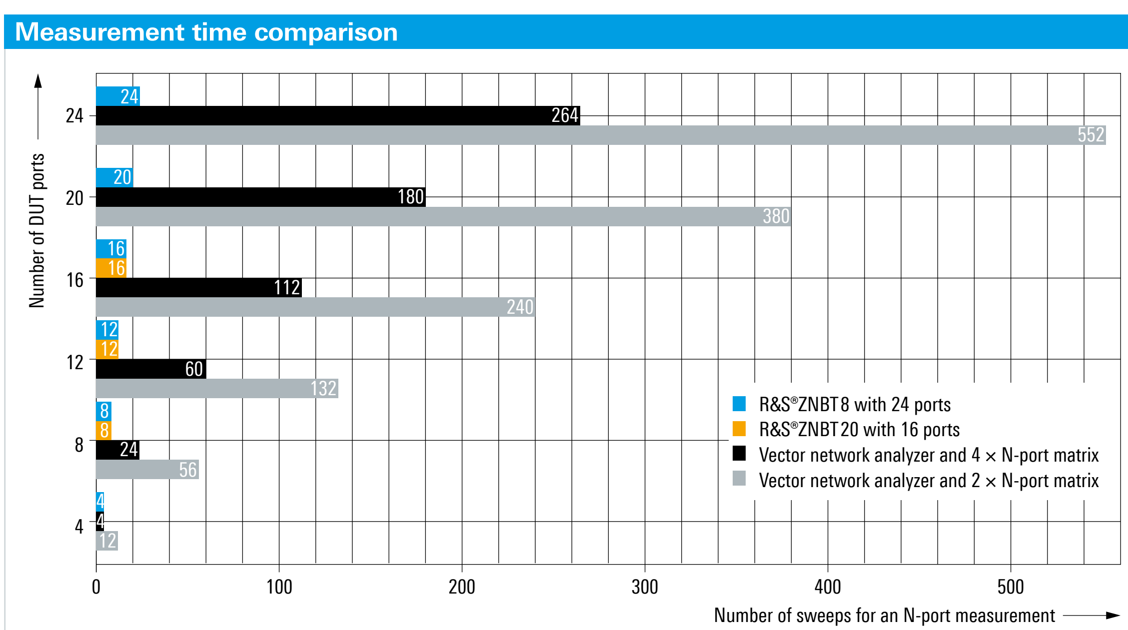


Fig. 3: Measurement time comparison between R&S®ZNBT8 / R&S®ZNBT20 and switch matrix based multiport solutions.

Example: time-optimized signal integrity measurements on data cables

Data cables generally consist of several twisted wire pairs that have to be tested simultaneously and whose parameters, such as crosstalk, skew or rise time, have to be determined. With its multiport architecture and possibility of measuring differential systems, the R&S®ZNBT20 is ideal for these tasks. Together with the R&S®ZNBT-K2 and R&S®ZNBT-K20 software options for time domain analysis, such DUTs can be characterized comprehensively. For this purpose, the data measured by the network analyzer in the frequency domain is transformed to the time domain and displayed as an eye diagram (Fig. 4). As a result, the transmission characteristics of the DUT can be conveniently analyzed, similar to the method known from time domain measurements. High-performance trace analysis functions complete the functional range. The simultaneous display of frequency and time domain measurements and eye diagram prevents complicated switching back and forth between different test setups and delivers all relevant analysis parameters at a glance – making configuration quick and easy.

The deembedding/embedding function of the R&S®ZNBT20 also makes it possible to remove the characteristics of test fixtures mathematically from the test setup so that only the characteristics of the DUT are obtained. Extensive network models and touchstone data are available for this purpose. This is vital for measurements of twisted wire pairs since the network analyzer only provides coaxial test ports. These measuring options have proven themselves, for example, in the measurement of cables for the USB, HDMI or DVI standards.

Summary

The R&S®ZNBT20 is a true multiport vector network analyzer up to 20 GHz with up to 16 integrated ports. Due to its sophisticated architecture, it simultaneously measures all test ports, which drastically reduces measurement time compared with switch matrix based solutions. Due to its excellent performance data, it can be used for applications in development and production. The large number of ports is advantageous for signal integrity measurements on cables since several wires can be measured at the same time. Eye diagrams are also available for the comprehensive analysis of DUTs in addition to time domain display.

Anja Paula

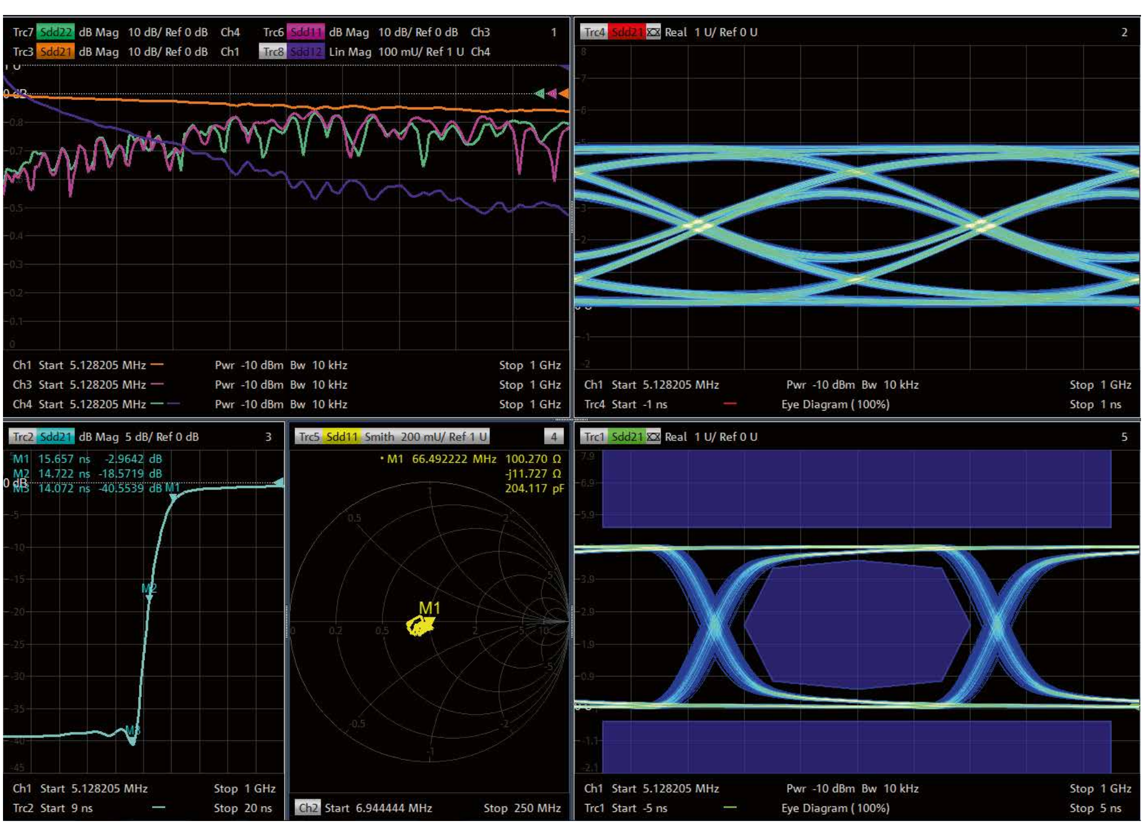


Fig. 4: Eye diagrams as well as frequency domain and time domain measurements are displayed simultaneously.

In brief

First over-the-air power measurement solution for 5G and wireless gigabit components

The R&S®NRPM is a new solution for direction-dependent measurements of the power of radio signals directly on the antenna. It enables users in development and production to calibrate the output power of a DUT in the high microwave range and to test the DUT's beamforming function.

Next generation mobile communications and WLAN base stations, access points, wireless devices and radio modules will use phased array antennas. Beamforming is used to control the direction of radiation of the transmit antenna in order to maximize the power level at the receiver. Due to their high integration, these antennas cannot be connected directly via cables. Therefore, measurements are performed using over-the-air (OTA) interfaces. The R&S®NRPM sensor system was developed for these measurements. It works in the frequency range from 27.5 GHz to 75 GHz, covering the 28 GHz band currently being discussed for 5G as well as the 55 GHz to 66 GHz band used by IEEE 802.11ad and IEEE 802.11ay gigabit WLAN systems.

The extremely low power levels to below –70 dBm that are to be measured do not allow the power sensor to be connected to the antenna via cable, since the line losses would be too high. The R&S®NRPM system is therefore distributed in two parts: the RF frontend, or diode detector, is integrated directly into the antenna module, while the signal processing electronics is accommodated in a separate module that has the form of a conventional power sensor. The sensor module has three channels for connecting up to three single-polarized Vivaldi antennas (dual-polarized antennas are in preparation). In addition to avoiding power loss, the integration of the diode detector in the antenna also has the advantage that the frequency response of the antenna module with the diode detector can be calibrated in the plant. This increases precision and simplifies the measurement procedure so that the user does not need to worry about this aspect.

With a single antenna module, the user can calibrate a DUT's output power, for example. Multiple, spatially distributed antenna modules make it possible to test a DUT's beamforming function. If more than three antennas are needed for a test setup, users can operate any number of sensor modules in parallel. The additional measurement points thus obtained increase the resolution during beamforming tests and allow the setup of 2D matrices for swiveling the antenna beam about two axes.

The free R&S®Power Viewer Plus PC software is available for evaluating and processing measured data. At present, the software can be used to monitor and display measured data from up to twelve channels and to determine the average power, for example.

Users who wish to acquire signals in a shielded test environment in order to obtain reproducible results can use the R&S®TS7124 19" shielded RF test box. For this solution, a shielded and filtered cable feedthrough is available as well as a dielectrically neutral plastic structure for flexible mounting of the antennas.

The R&S®NRPM consists of at least one antenna with an integrated diode detector, plus a spatially offset electronics module (sensor module). Measurement accessories for operation in a shielded chamber are also available.

VCO measurement at the push of a button

Voltage-controlled oscillators (VCO) can be found in almost all RF applications, and their technical parameters significantly influence the quality of the components in which they are used. The R&S®FSWP phase noise analyzer and VCO tester can comprehensively test VCOs at the push of a button.

The core components in almost all RF applications are voltage-controlled oscillators (VCO), as in mobile communications, for example. These oscillators change their oscillating frequency as the applied voltage changes. The available voltage range must be sufficient for a VCO to cover the target frequency band. The important quality characteristics of a VCO that need to be measured are its spectral quality, the frequency range that it covers, the output power and the current consumption (particularly for mobile applications) and also the tuning slope, which is responsible for smooth settling.

All of these VCO measurements can now be performed by a single measuring instrument at the push of a button: the R&S®FSWP phase noise analyzer and VCO tester (Fig. 1). With firmware release 1.30, the R&S®FSWP can measure VCOs without the need for an additional option. The user simply adjusts the supply voltage, the tuning voltage range and the number of measuring points. The R&S®FSWP then quickly determines all of the required characteristics. It only needs a few milliseconds for each measuring point. Consequently, the total measuring time primarily depends on the settling time of the VCO. Settling times can also be specified, so that the R&S®FSWP waits accordingly before it starts to measure.

A typical measurement can be seen in Fig. 2, in which all characteristics are shown in parallel. The markers can be coupled via different windows in order to collect all of the important parameters for a certain tuning voltage in a table.

Fig. 1: The R&S®FSWP delivers VCO and phase noise measurements at a glance: the top pane displays the VCO characteristics, the bottom pane shows the phase noise measurement at 2 GHz.

Fig. 2: A typical VCO measurement. Key parameters such as frequency, power, sensitivity (tuning slope) and current consumption are measured relative to the tuning voltage.

External voltage sources are not required. The R&S®FSWP has low-noise sources on board (Fig. 3). The tuning voltage can vary from –10 V to 28 V, with a maximum noise voltage of 1 nV/√Hz (at 10 kHz). An operating voltage source of 16 V – more than sufficient for any oscillator on the market – with a maximum current consumption of 2000 mA is also available. It can also be operated as a current source. The third voltage source in the R&S®FSWP is useful for measurements on VCOs that require an additional (even negative) voltage. The R&S®FSWP can also tune the operating voltage. This is useful for checking the behavior of a transmitter with a weakening battery.

Phase noise is also important for a transmitter's transmission quality and adjacent channel power, and must be measured. Here the R&S®FSWP excels as the fastest and most sensitive phase noise tester on the market today (see NEWS 214, page 37). For such measurements, the multichannel concept of the R&S®FSWP makes it possible to simultaneously display the phase noise at a certain operating voltage together with the VCO's characteristics (Fig. 1). A screenshot therefore fully documents all of the main parameters.

Summary

With the new capability to comprehensively characterize VCOs at the push of a button, the R&S®FSWP phase noise analyzer and VCO tester more than lives up to its name. External voltage sources are not needed for the measurements since the tester comes with internal low-noise sources.

Dr. Wolfgang Wendler

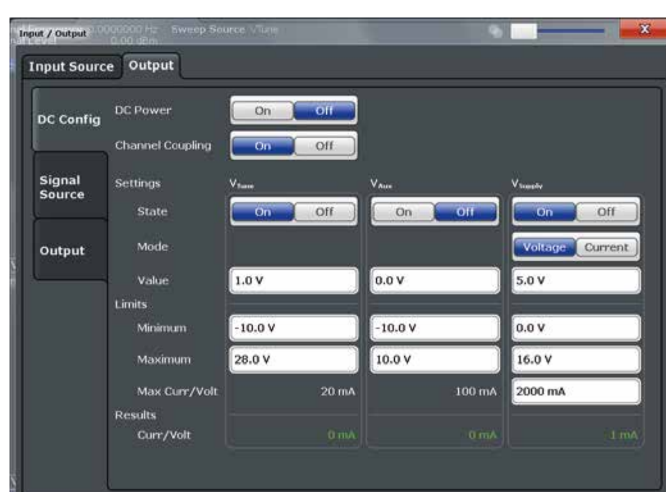


Fig. 3: Setting menu for the internal R&S®FSWP voltage sources.

Real-time spectrum analysis of frequency hoppers and ultrashort interference signals

With a new option, the R&S®FSW signal and spectrum analyzer characterizes frequency agile systems at a real-time bandwidth of 512 MHz and reliably detects even extremely short interference signals.

Cordless communications systems such as headsets or handsfree equipment in vehicles often use frequency hopping in order to be less susceptible to interference signals or other applications in the same frequency range. In tactical communications systems and in radar applications, frequency hopping is used to increase protection against eavesdropping and to minimize the influence of wanted interferences. To analyze frequency agile systems of this type, the signals must be displayed accurately, quickly and seamlessly in real time. This is the only way to analyze short unwanted signals in detail.

Up to now, the R&S®FSW signal and spectrum analyzer was equipped with the R&S®FSW-B160R option for these tasks. The new R&S®FSW-B512R option makes it possible to measure at a real-time bandwidth of 512 MHz and to calculate up to 1.1 million spectra per second. It covers the real-time bandwidth more than three times and doubles measurement speed (Fig. 1). With a probability of intercept (POI) of 100 %, the analyzer accurately detects signals with a duration of only 0.91 µs and even captures those with a duration of only a few nanoseconds – although with reduced level accuracy. Because the human eye can only process approx. 30 images per second, the options offer different display modes and features to investigate the events in the frequency and time domain in detail and provide access to the information contained in the many spectra. With a conventional real-time display, a detector analyzes many thousands of traces to form a spectrum of maximum values. The display shows if a signal or interferer is present, even if the event lasted only a few nanoseconds. Thanks to the spectrogram display that presents all spectra with color-coded signal levels in horizontal lines, users are able to resolve the behavior in the frequency domain over time. Frequency hoppers are shown without any interruptions. Fig. 2 shows hop sequences of a Bluetooth® transmitter as well as a WLAN signal that is also found in the ISM band (bottom right). The minimum time resolution is 55 µs. If the user stops continuous recording, a time resolution of 20 ns can be achieved via the zoom function during postprocessing of the spectral display. This makes it possible to easily resolve the preamble as well as modulation details of WLAN signals (Fig. 3).

Key parameters in real-time analysis

	R&S®FSW-B512R	R&S®FSW-B160R
FFT length	1024 to 32k	1024 to 16k
Maximum real-time analysis bandwidth	512 MHz	160 MHz
Maximum FFT rate	1,171,875	585,938
POI	0.91 µs	1.87 µs
User-configurable resolution bandwidth (RBW) for span/RBW ratio	6.25 to 6400	6.35 to 3200

Fig. 1: Comparison of the real-time analysis options for the R&S®FSW signal and spectrum analyzer.

In the persistence spectrum, the analyzer writes all available traces on top of each other and color-codes them according to their probability of occurrence: frequently occurring signals in red, and sporadic ones in blue, for example. If a signal no longer occurs, it disappears from the persistence spectrum after a certain time (Fig. 2, top). The persistence spectrum provides an overview of the dynamic range of frequency agile systems. Frequency hops, such as those occurring in the ISM band where Bluetooth® and WLAN signals collide, reducing data rates, can be accurately analyzed and better frequency hopping algorithms can be found. The analyzer also helps detect extremely short interferers or hidden signals that are hardly detected by conventional spectrum analyzers.

Frequency mask trigger (FMT)

The frequency mask trigger should be used if only one specific signal, perhaps one that has been discovered in the spectrogram or the persistence display, or whose frequency is known, is of interest. The user defines a mask in the frequency domain and the analyzer compares this mask with up to 1.1 million spectra per second. If a signal violates the mask, the analyzer stops real-time analysis and records it. The time before (pre-trigger) and after (post-trigger) the signal to be recorded can be set. The user can also select whether the analysis should automatically continue after recording. Continuing the analysis provides an overview of how often certain signals occur and whether they behave similarly each time.

Thanks to multistandard real-time (MSRT) analysis, the recorded data can also be used for other applications such as analog modulation analysis or vector signal analysis (R&S®FSW-K7 / R&S®FSW-K70 options), in order to find out for example, how interference affects the modulation characteristics of a wanted signal. The R&S®FSW-K6 option is used for extensive analysis of pulsed signals and the R&S®FSW-K60 / -K60H options are used for automatic analysis of hop sequences.

Summary

With the new option, the R&S®FSW high-end signal and spectrum analyzer characterizes frequency agile systems at a large real-time bandwidth. This makes it possible to detect extremely short interferers – a valuable additional feature for developers of radar or communications applications, who can also use the instrument to accurately measure all RF parameters of an application.

Dr. Wolfgang Wendler

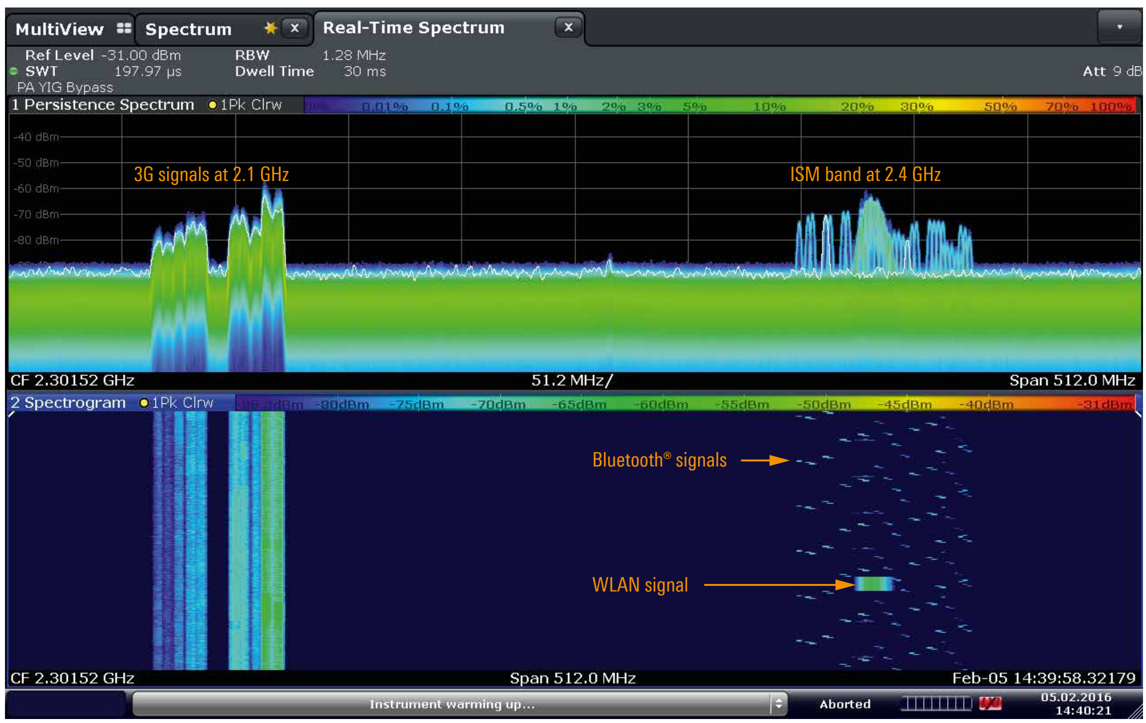


Fig. 2: 3G signals at 2.1 GHz and Bluetooth® / WLAN signals in the ISM band can be simultaneously analyzed with the R&S®FSW-B512R option (top: persistence spectrum, bottom: spectrogram).

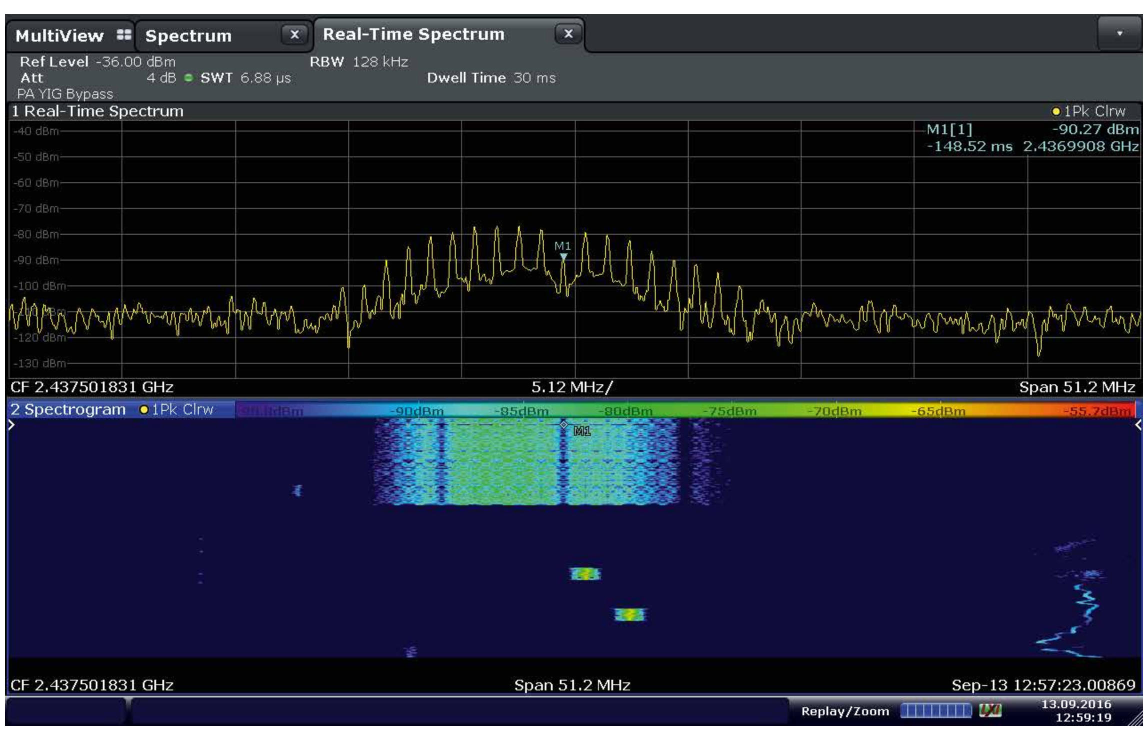


Fig. 3: The time resolution in postprocessing can be significantly increased via the zoom function. This makes it possible to quickly analyze frequency hopping systems or detect modulation details.


ROHDE&SCHWARZ

Security through technology

How can air traffic security be improved without bothering passengers with yet more checks? An innovative body scanner shows the way.

The typical air traveler has conflicting feelings about security. According to a representative survey by the German Federal Association for Information Technology, Telecommunications and New Media (Bitkom), most passengers favor the extensive use of security technology, including body scanners, at airports. At the same time, they are annoyed about a variety of inconveniences, ranging from the restrictions on carry-on luggage and having to take off various items of clothing at the security checks, to the unnatural posture required by conventional body scanners and the pat-downs by security officers. And these are only compounded by the long waits at security checkpoints. Because it is unlikely that security standards will be relaxed any time soon, it is up to technology to find answers to this dilemma in the face of even tighter security.

The goal is to maintain the highest level of security while preserving the greatest degree of convenience possible for passengers. The new R&S®QPS body scanner (Fig. 1) is a significant step in this direction.

A product category takes shape

The first body scanners were developed in the early 1990s, even before an appreciable market for them existed. These backscatter devices operating in the X-ray range were seldom used at airports. These were followed several years later by devices operating in the microwave range, even though demand remained limited. After the dramatic events of 9/11, it became clear that the market for security equipment would

Fig. 1: The R&S®QPS200 scanner with two panels is primarily intended for use at airports. It can be integrated without barriers into virtually any gate architecture. The R&S®QPS100 model (not shown) has only one panel; the test person turns 180° for a complete scan.

develop dynamically. As a result, Rohde&Schwarz very quickly decided in 2007 to become a partner in a consortium working on a project to offer a European alternative to the products from the United States, the pioneers in this category. A three-year research and development phase culminated into a proof of concept that confirmed the consortium's path. However, divergent conceptions of a series production model caused the participating industry partners to forge their own, separate paths. As part of QPASS, the follow-on project initiated by Rohde&Schwarz and funded by the German Federal Ministry of Education and Research, Rohde&Schwarz worked with the Institute of Microwaves and Photonics at the University of Erlangen-Nuremberg, Germany, to develop a preproduction prototype that showed the potential for meeting all expectations, even though new EU requirements would bring additional challenges.

Previously, devices were designed to generate images that could then be evaluated by human screeners. The fact that intimate details were also visible led to an emotionally charged public debate that forced authorities in the US and Europe to change their acceptance regulations. It is now forbidden to display photo-like images at checkpoints. A seemingly simple regulation, but with extremely grave technical consequences. The challenge now was to develop a method of detecting suspicious objects fully automatically. This required that the millimeterwave technology be expanded with a rapid image processing system that could reliably filter out anomalies from the measured data for display on an avatar (Fig. 2). The development team assembled for this task made such rapid progress that a series production model, the R&S®QPS100, was ready for introduction by 2014. Tested under real-life conditions, continually improved, furnished with all applicable certifications and extended to include the

A brief history of airport security checks

The history of airport security, at least as pertains to protection against attacks, is tied to a series of key events and the responses to those events. During the first decades of commercial aviation, airport security was essentially nonexistent since flying was an exclusive adventure limited to wealthy customers and still far from becoming a stage for violent crimes requiring protective measures. Even as hijacking, primarily for political motives, became prevalent – with an all-time high of 82 hijackings in 1969 – authorities still did not see any need for significant countermeasures. Metal detectors were used on passengers only when there was cause for suspicion. It was not until the 1980s, when the US in particular intensified its war on drugs that passenger checks on the ground were stepped up and sniffer dogs were introduced. The 1988 Lockerbie bombing brought about random luggage scans in Europe; however, it was not until 2003 that a check of every piece of luggage was made mandatory by EU regulation.

In many ways, the 9/11 attacks of 2001 represented the "zero hour" in terms of security policies. At all conceivable levels, authorities did everything possible to prevent repeat attacks, ranging from extensive, cross-border reconciliation of passenger data to the deployment of sky marshals, from prohibiting pointed or sharp objects such as nail files in carry-on luggage to installing armored cockpit doors (installing these doors cost Lufthansa alone more than EUR 30 million, according to the company's statements). Preboarding security checks also saw rapid change from that point on. The attempt by Richard Reid in December 2001 to detonate explosives hidden in the heel of his shoe was thwarted, but the US and a few other countries responded by requiring passengers to take off their shoes for examination. The prohibition against large volumes of liquids came about in 2006 after a plan was uncovered in Great Britain to use liquid chemicals in an attack. During Christmas in 2009, the creativity of attackers extended even to undergarments, when a Nigerian national tried to detonate explosives hidden in his underwear shortly before landing in Detroit ("underwear bomber"). The Transportation Security Administration (TSA), established in the US in response to 9/11, reacted to this attempt by introducing full-body scanners at airports nationwide. Installation of these instruments – which were developed in the 1990s – had already begun in 2007 at airports in the US and else-

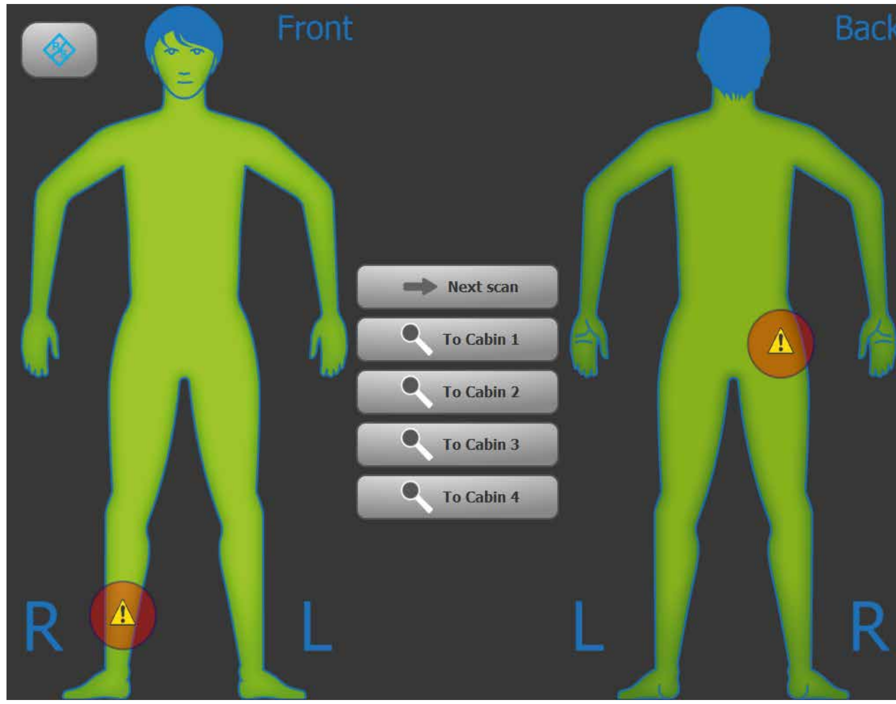


Fig. 2: The scan result is displayed on a neutral graphic (avatar). No personal details are displayed and no personal data is stored.

where, such as Amsterdam, but their widespread use did not start until 2010. This first generation of scanners was based on X-ray technology that made not only potentially dangerous objects visible, but also intimate body details, leading to heavy public criticism. X-rays additionally have an ionizing effect and are therefore damaging to cells, even though authorities ruled out any jeopardy to health due to the low level of radiation from the devices (measurements show that the level is approximately equivalent to what passengers are exposed to during just a few minutes of cosmic radiation). Nevertheless, these backscatter devices have largely disappeared from the market and are now banned in many countries. Even the TSA made an about-face when it removed all first generation devices between the fall of 2012 and May 2013, replacing them with the alternative technology of millimeterwave devices. However, that move was not made out of concerns for public health, but rather because the device manufacturer had not been able to implement a software update on schedule that would depersonalize scan results. In response to the public outcry, US authorities had included a clause in the FAA Modernization and Reform Act of 2012 to the effect that the naked images generated by body scanners should be replaced with a symbolic body graphic identical for all test persons.

Out of health concerns, the European Union banned X-ray scanners (and all technologies using ionizing radiation) in a regulation issued in November 2011. The preservation of personal and data protection rights is also mandatory. Germany conducted its first field trial of a first generation millimeterwave scanner in 2010 at the Hamburg airport. The field tests were carried out and scientifically assisted by the research center of the German Federal Police. 800,000 volunteers, including German Federal Minister of the Interior de Maizière, allowed themselves to be scanned. The objectives of the large-scale trial were to determine how the devices would hold up under real-life conditions, to uncover any trouble spots, and to find out how to optimally implement common test methods. National authorities work directly with the European Civil Aviation Conference (ECAC), which is responsible for certifications related to air transportation, and the Hamburg trial played a pioneering role here. The test results (which included a high percentage of false alarms) led the German Federal Government to conclude that the devices currently available on the market were not yet suited for general use. Manufacturers have since stepped up efforts to improve reliability.

Latest generation scanners, such as the R&S®QPS from Rohde & Schwarz, are considerably more mature than their predecessors and are suitable for unrestricted, widespread use. Regulatory agencies are also demanding that the scanners speed up security checks rather than slowing them down. The fast devices now available make this possible. The increased use of automated security equipment brings justifiable hope that the perceived burden on passengers will be reduced to a bearable extent in the foreseeable future. A first step in this direction was the EU-wide elimination of the ban on large volumes of liquids in carry-on luggage in 2014 (although limited to medications, special foods, and products obtained from the airport duty-free zone). This was made possible by new technology capable of detecting liquid explosives. Advances in scan technology will soon make it possible to screen through thick layers of clothing, so that passengers will no longer be required to take off their coats and jackets. Solutions are already visible on the horizon that will work behind the scenes, i. e. passengers will be subjected to security checks without even noticing it. The hope is that air travelers will be able to board without challenge, unlike the woman who had her Christmas cake confiscated in Las Vegas because the security guard thought the icing looked a little too much like explosives.

R&S®QPS 200 model, the R&S®QPS platform today serves as an innovative security solution not only for airports, but for all environments requiring high-security, restricted access. The demand is high. Countries like Germany are following the example of the US, which began in 2010 to successively outfit all airports with scanners. With the July 2016 signing of a framework agreement between the German Federal Ministry of the Interior and Rohde & Schwarz for the delivery of 300 units, the R&S®QPS 200 is on its way to becoming a familiar sight at German airports.

New paths

The R&S®QPS differs from competitive products in how it looks, how it operates and how scans are performed. The tight spaces common with booth solutions are a thing of the past. The visually appealing, space-saving flat panels can be integrated without barriers into the checkpoint area (Fig. 1). The open design gives security personnel an unobstructed view of the entire checkpoint. The scan procedure – considered to be unpleasant with traditional equipment because passengers are required to hold their hands up in the air as if being stopped by police – is now significantly more comfortable for passengers. Arms are slightly spread in a natural pose that is possible even for physically impaired individuals and is considered to be ethically correct across cultures.

The R&S®QPS is a fully electronic, low-noise solution with no moving parts. It is the only device on the market that relies on the multistatic principle familiar from radar technology, where the reflected transmit signal is applied to a large number of receive antennas simultaneously (Fig. 3). This provides better illumination of the scanned individual, leading to an improved quality of detection.

Aside from a six-monthly calibration check, the system is virtually maintenance-free. These checks are provided on site, of course. Setup and commissioning take under an hour because all time-intensive preliminary work is performed at the plant.

Fig. 3: Multistatic principle of operation: While only one of the 3008 transmitters is active at a time in a panel, all 3008 receiving antennas receive the reflected signal. Since every transmitter also rapidly steps through 128 frequencies before the next one starts transmitting, each scan cycle delivers more than a billion (!) complex values per panel (magnitude and phase), all within only 32 ms.

The technology behind the R&S®QPS

Traditional microwave scanners illuminate objects at frequencies below 30 GHz. In contrast, the R&S®QPS achieves higher spatial resolution as it operates in the millimeterwave frequency band between 70 GHz and 80 GHz, the band also used by vehicle parking sensors. At about 1 mW, the peak transmit power is approximately three orders of magnitude lower than that of cellphone emissions and is almost undetectable in the spot where the scanned person stands.

The scan volume is resolved in finely granulated, 1.9 mm × 1.9 mm × 5.7 mm voxels, which is achieved not only due to the high frequency band, but also through the multistatic operating principle. Implementing this in a high-resolution, close-range scanner was anything but a trivial task. To make a multistatic millimeterwave scanner workable, its surface would have to be fully covered with antennas – which translates into a quarter million antennas per panel for a scanner the size of the R&S®QPS. The effort to reduce the number of antennas to a reasonable level took years of fundamental research and was the basis for more than one doctoral thesis. The result was a structure consisting of 3008 transmitters and 3008 receivers distributed in 32 clusters over each panel in a checkerboard pattern (Fig. 4). In addition to transmitters and receivers, the clusters contain the electronics required for frequency processing and conversion. The receive signals are downconverted to a 25 MHz IF, and the signals from four clusters each are taken to one of a total of eight IF modules located behind them. In the IF modules, they undergo analog-to-digital conversion and are processed into raw "image" data. In a final step, the data is routed via two centralized boards and a PC adapter to an integrated interprocess communications (IPC) module, where final data analysis takes place. Potentially dangerous objects are automatically detected, and their precise location is calculated and displayed. Each panel also houses a synthesis generator for signal generation as well as auxiliary components such as the power supply, signal distribution, interface ports and display elements.

The R&S®QPS200 is designed to perform a full scan in just 32 ms per panel. Computer analysis at present takes several seconds, a time that will be significantly reduced in the future through more powerful data processing technologies. High-performance graphics processing units (GPU) optimized by the graphics cards industry for massively parallel processing introduce new options on the way toward implementing real-time analysis, an essential prerequisite also for future walk-through solutions.

Structure of an R&S®QPS panel

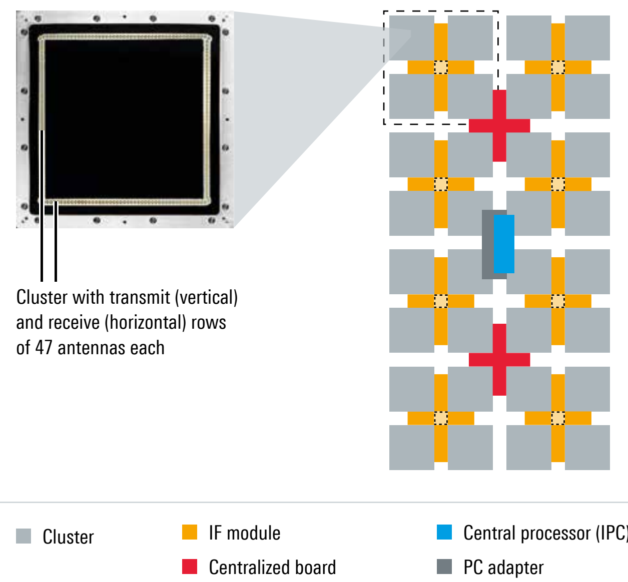


Fig. 4: The R&S®QPS has a modular design. The RF frontend is distributed into 32 clusters in a checkerboard pattern.

The challenge of automated detection

On the surface, a body scanner works much the same as a classic passport photo booth. The person is illuminated, the reflected light is replicated onto a medium (in the case of the scanner to data instead of paper), and the image is developed – by means of scanner software. However, a fully automatic scanner is not intended to generate photographs for human viewing. Instead, its purpose is to deliver an image interpretation, an assessment – which is a significantly more demanding task.

The task is as simple and challenging as this: detect all potentially dangerous objects that are carried on the body or in clothing, regardless of type, size, location and material composition.[1)] The all-encompassing scope of this task quickly leads to the conclusion that obtaining a positive validation, i.e. detecting concrete objects by way of comparison against patterns, is predestined to failure. There are simply too many materials and shapes that can be used for firearms or knives, for example. A scanner would have to be capable of recognizing a "thing in itself", based on its characteristics and purpose, irrespective of shape, material or form – a hopeless endeavor. The goal of the scan, therefore, is not to identify objects but to identify areas on the body that, in the estimation of the analysis software, significantly deviate from the unsuspicious canonical form. The developers' task thus was to teach the software what is considered unsuspicious. However, any attempt to do this based on a "white list" of harmless combinations is likewise a futile task, and for the same reason as stated above. There are too many possible variations, even with a seemingly easy example such as men's clothing. Is the test person wearing a pullover or a shirt, is it made from wool or synthetics and does it close with zipper or buttons, which in turn might be large or small, made of plastic, metal or mother-of-pearl and placed in a placket down the middle or the side, is there a lanky youth standing in front of the scanner or a burly man of six and a half feet – the scanner must assess all of these and more without error and allow them to pass as normal. It was clear that solving this awkward problem would require a completely new approach, one that brought together methodologies from image processing, machine learning and, most especially, deep learning, a state-of-the-art method for creating artificial intelligence.

Each scan cycle produces a huge data set of amplitude and phase values from the 3D scan volume that can be used as the basis for analysis. The scanner operates in a similar way as a vector network analyzer. Received signals are compared against transmitted signals in amplitude and phase, and the differential value contains all necessary information about the test subject. The challenge lies in interpreting this information through appropriate modeling, i.e. by mapping the physical data into concrete object characteristics and attributes. Examples of these attributes include signal intensity, surface roughness, and the strength of multiple reflections. In fact, more than a thousand different attributes can be defined and combined into a high-dimensional attribute space. Suspicious objects or materials leave behind characteristic "fingerprints" in this space in that they manifest in specific subsets of attributes (= attribute combinations) in specific ways. Classifiers are used to model these subsets (Fig. 5).

Fig. 6 demonstrates this principle based on a classifier that uses the attributes signal intensity and surface roughness. In this two-dimensional attribute space, an unsuspicious body region can well be distinguished from a region in which, for example, a black powder substitute was concealed under the clothing. Clear decision boundaries are an essential criterion for the usability of a classifier.

At the time that development of the R&S®QPS was started, suitable attributes and classifiers still had to be defined and parameterized manually (feature engineering). During the past few years, however, enormous advances have been made in the area of machine learning, in particular deep learning. The latest version of the R&S®QPS detection software has also been trained using deep learning algorithms.

Mapping of measured data to object characteristics by means of classifiers

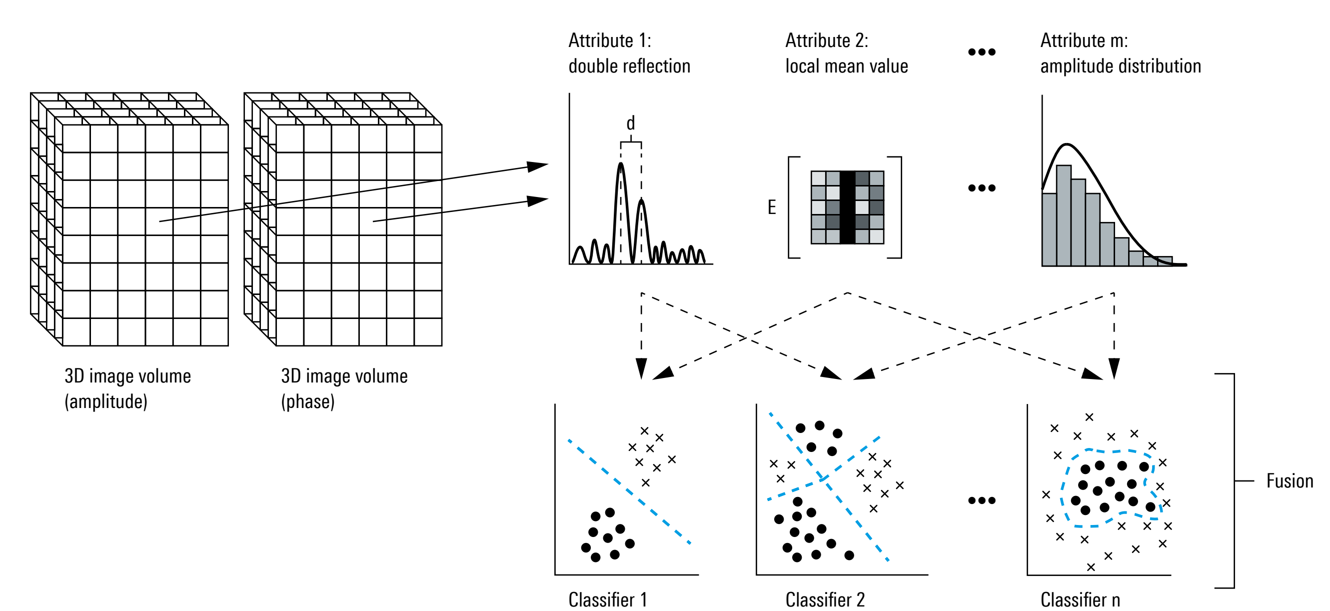


Fig. 5: From the basic physical information (amplitude and phase), attributes are extracted and combined into n-dimensional classifiers, each of which responds to a specific object characteristic or object class. In this example, there are three classifiers, each with two attributes. The superposition (fusion) of all classifiers yields the final detection result.

Deep learning methods have replaced conventional machine learning algorithms in many fields of application. Google's Android voice recognition, Facebook's face recognition and Skype's voice translation are based on deep learning. In early 2016, Google's AlphaGo computer program attracted global attention by defeating multiple worldclass Go players, a feat previously considered impossible. The software's playing strength lay in algorithms and analysis rules generated from neural networks using deep learning.

Neural networks are capable of delivering astonishing results when it comes to pattern recognition. For example, networks especially appropriate for image processing – referred to as convolutional neural networks – now surpass even humans in tasks such as traffic sign recognition. For a neural network to complete a task, its topology and neuron switching functions must be perfectly attuned. The networks behind the R&S®QPS software were therefore developed in-house at great effort and expense. To find out whether a network will function as intended, it must first be sufficiently trained with high-quality data[2)]. In this case, the software was fed a large set of labeled training data obtained by scanning many thousand test subjects[3)]. Labels are used to mark any problem zones if existing on a test subject. The type of problem (knife, explosives, etc.) is irrelevant. From the huge number of samples it processes, the software learns on its own what patterns calling for an alarm look like. In an extremely processor-intensive optimization process in which millions of parameters are varied, the deep learning algorithm works its way through the database, finding those attributes and classifiers that are best suited for identifying critical cases. The solution thus obtained is implemented in the R&S®QPS firmware. The overall cycle of learning and application is extremely unbalanced in terms of the time required. An extended learning phase (long computational runs on a GPU cluster) produces a program that in actual use can make decisions in seconds.

Deep learning offers crucial advantages in the development of scanner software. This method not only makes it possible to achieve high detection quality, but is also especially attractive because solutions are automatically generated. The software becomes a partner in development, relieving engineers from monotonous routine tasks. Engineers can instead invest their time into perfecting neural networks and deep learning algorithms, leading to even better detection results.

1) Millimeterwave scanners cannot see under the skin, i.e. inside the body, since their waves reflect off the surface – or, more accurately, off the water stored in the skin – one of the reasons for their negligible effect on health.

2) The networks are trained with prequalified data, so this type of machine learning is also called supervised learning.

3) These scans are performed under Rohde & Schwarz control at the plant. Data obtained during normal operation at an installation site must never be used.

Principle of a classifier

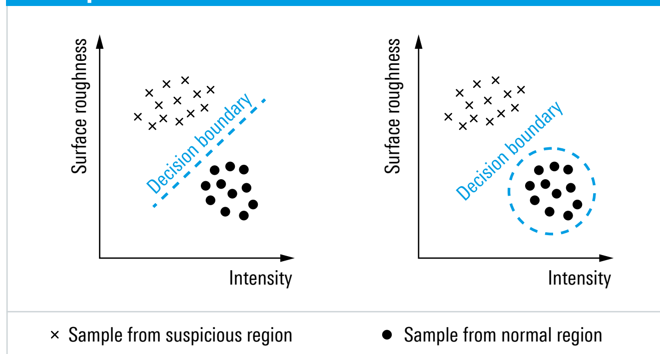


Fig. 6: Example classifier with two attributes for detecting a specific object characteristic. The attributes must be selected so that a clear decision boundary can be defined; two possible boundaries are shown here.

Summary and future developments

With the R&S®QPS family of body scanners, Rohde & Schwarz opens a new chapter both for this device category and for flight security. Innovative hardware and software solutions satisfy the requirements of operators responsible for airport security while meeting passenger expectations to the greatest extent possible. Operators can integrate the space-saving devices into the checkpoint area without barriers to ensure high passenger throughput. Passengers experience a comfortable and completely non-discriminatory scan procedure. The technical design of the R&S®QPS leaves leeway for developing new models to meet future requirements. In the medium term, rapid progress in the field of massively parallel computing in particular will bring walk-through scanners to the market that will not even be perceived as security equipment and will not impede passenger handling.

Volker Bach

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- A detailed description of the principles and technology behind the R&S®QPS is available at: http://ieeexplore.ieee.org/document/6305002/ and in:
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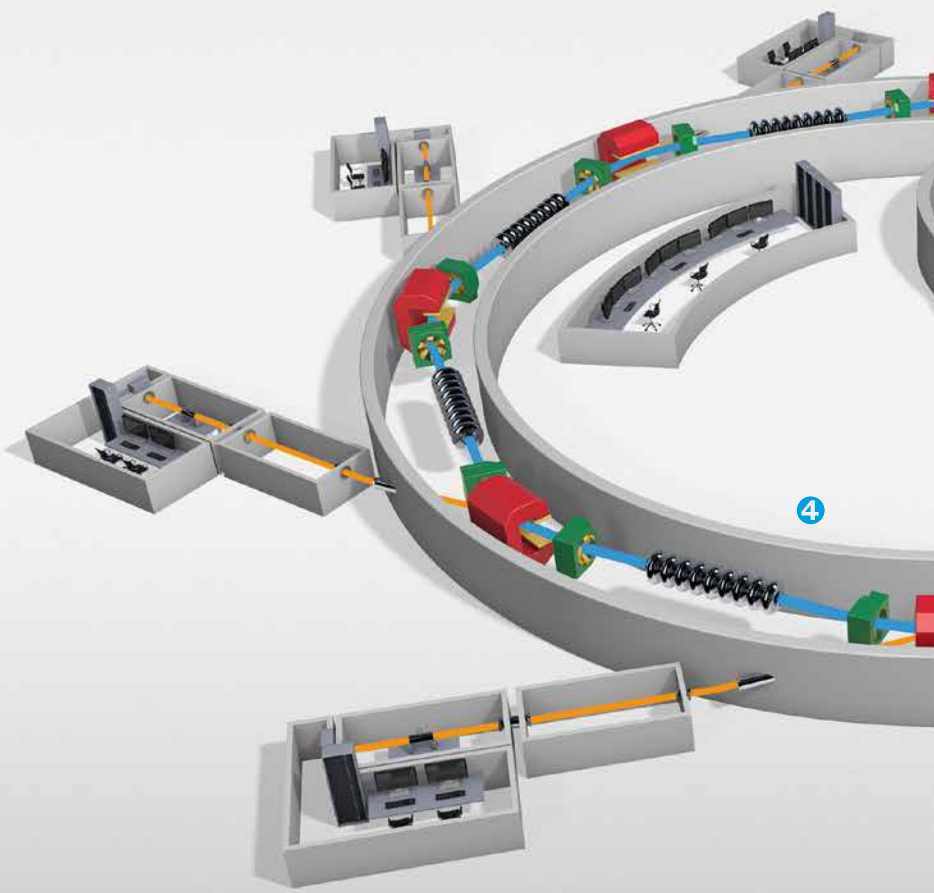
RF amplifiers for particle accelerators

RF high-power amplifiers are required in order for particles in particle accelerators to reach their final velocity. In the past, tube amplifiers were used. These can now be replaced by solid-state amplifiers, which has many advantages.

How do particle accelerators work?

Particle accelerators are used worldwide in R&D and in medical and industrial applications. The accelerators typically accelerate electrons to generate photons, i.e. light (UV light or X-rays), or protons and other ions. Neutrons can be generated by colliding protons against a suitable target. For detailed information on particle accelerators, see [1].

All accelerators produce the particles in a particle source (❶). The particles are propelled up to speed in a linear accelerator (LINAC) (❷). Depending on the facility, an experiment or application is carried out at the output of the LINAC, or the particles are injected into a booster ring (❸) to be accelerated further. The particle beams then enter the storage ring (❹), which maintains their speed. Depending on requirements, the accelerated particles are then diverted into the beamline (❺) in order to perform the experiment or application in the end station (❻).



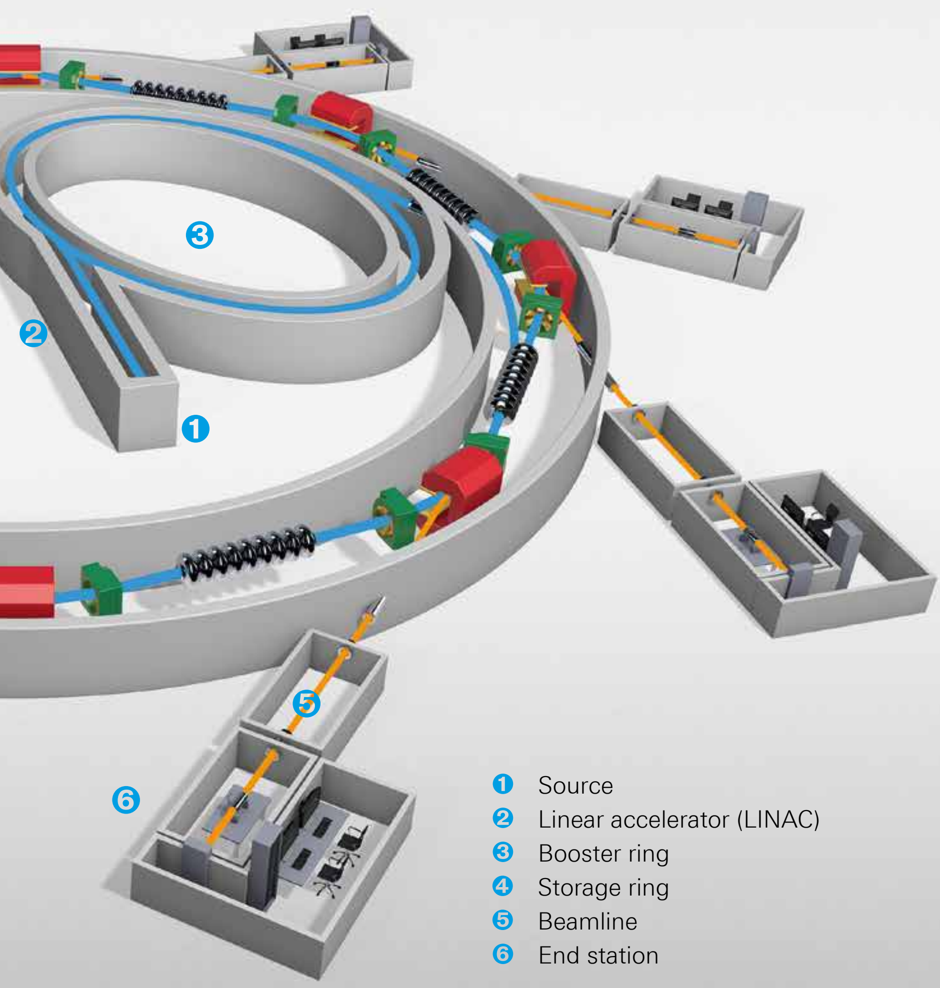
Narrowband high-power amplifiers in particle accelerators

Narrowband high-power amplifiers accelerate the particles in the LINAC or in the booster or storage rings (Fig. 1). This requires RF powers ranging from several 10 kW to the megawatt range. This RF energy is fed into cavities where it accelerates the particle beams passing through by giving them an energy kick with the appropriate phase.

Traditionally, these high-power amplifiers used tubes, e.g. tetrodes, klystrons or traveling wave tubes. Advances in semiconductor technology led to successful construction of solid-state high-power amplifiers that supply 100 kW and more output power and can therefore replace tube-based solutions. Solid-state amplifiers have an efficiency comparable to that of tube amplifiers, but without their disadvantages. If a tube is defective, the entire amplifier fails, making an expensive repair necessary. Power transistors in solid-state amplifiers are simple and inexpensive to replace. When operating these amplifiers at reduced power, high efficiency can be achieved by adjusting the voltages on the semiconductor, which is not possible with tube-based solutions. As a result, solid-state amplifiers operating at low power consume significantly less energy than tube amplifiers in the same mode. Solid-state amplifiers are safer to service and maintain since their operation does not require high voltage.

Rohde & Schwarz broadcast transmitters use solid-state amplifiers with different output powers and frequency ranges. These standard broadcast products are based on the R&S®THx9 transmitter family (Figs. 2 and 7) and only need to be slightly modified for optimal use in particle accelerators.

Fig. 1: Basic structure of a particle accelerator.



1 Source
2 Linear accelerator (LINAC)
3 Booster ring
4 Storage ring
5 Beamline
6 End station

Rohde & Schwarz has been developing and producing RF amplifiers for more than 60 years.

Rohde & Schwarz has a long-standing tradition in the development and manufacture of high-power RF amplifiers. Rohde & Schwarz built Europe's first FM transmitter, which went into operation in 1949. In 1956, TV transmitters were added to the product portfolio. Rohde & Schwarz products always were and still are at the technological forefront and in tune with the times. The first broadcast amplifiers were based on tubes, and transistor amplifiers followed in the 1980s – initially air-cooled. In 1999, Rohde & Schwarz was the first manufacturer to introduce liquid cooling for its high-power broadcast amplifiers. As a result, the company could offer transmitters that were more efficient and more compact.

The operators of the MAX IV particle accelerator (Fig. 3) were impressed by the advantages offered by this generation of transmitters. They ordered eight liquid-cooled high-power solid-state amplifiers, each with 60 kW output power at 100 MHz. They enjoy the benefits of the robust and rigorously tested design of the broadcast amplifiers and the automated series production in one of Europe's most cutting-edge production facilities [2]. These high-power amplifiers are designed to keep delivering output power even if transistors and power supplies fail, and the amplifier units can be hot swapped. This feature, which has been adopted from the broadcasting world, facilitates uninterrupted operation of the particle accelerator in case a transistor or power supply fails.

Fig. 2: The robust R&S®THx9 broadcast transmitters only need to be slightly modified for use in particle accelerators.

Fig. 3: MAX IV, currently the most powerful synchrotron radiation facility worldwide, uses Rohde & Schwarz RF high-power amplifiers.

Defective component	Output power with a failed component	Number of failed components for a power loss of 1 dB	Total number of these components in the system
Amplifier unit	97.2 kW / –0.120 dB	8	72
Power supply	99.1 kW / –0.039 dB	24	216
Transistor	99.8 kW / –0.015 dB	63	576

Fig. 4: Solid-state RF high-power amplifiers ensure uninterrupted operation even if multiple components fail.

Fig. 4 shows how little a component failure in a 100 kW R&S®THx9 solid-state amplifier impacts the output power. If the maximum amplifier power is set somewhat higher than is required for the application, it is even possible to compensate for the power loss due to a component failure by utilizing the power reserves of the amplifier. Work can continue as usual and the defective component does not have to be replaced until the scheduled maintenance date.

Also in demand: broadband RF power amplifiers

Broadband power amplifiers are also employed in particle accelerators – in the feedback loops of the storage rings (Fig. 5). A signal picked up on a ring can be amplified using a broadband amplifier and fed back in on the opposite side of the ring at a dedicated phase angle. The feedback loop helps to reduce the size and energy distribution

Amplifier for the MAX IV particle accelerator

On June 21, 2016, the Prime Minister of Sweden, Stefan Löfven, inaugurated the MAX IV particle accelerator in the presence of Carl XVI Gustav, the King of Sweden. MAX IV, currently the most powerful synchrotron radiation facility* worldwide [3] [4], consists of a linear accelerator with two storage rings. The smaller storage ring, which has a circumference of 96 m, is optimized for generating UV light and operates at 1.5 GeV. The larger ring, which has a circumference of 528 m, produces high-quality X-rays and operates at 3 GeV. For these two storage rings, Rohde & Schwarz has supplied a total of eight liquid-cooled high-power solid-state amplifiers, each with 60 kW output power at 100 MHz.

* If electrons are diverted at speeds close to the speed of light, they “counteract” the change of direction by emitting part of the energy as synchrotron radiation in the form of electromagnetic waves.

of a particle beam within the storage ring (Fig. 6). Rohde & Schwarz offers a wide range of proprietary broadband amplifiers that cover several frequency ranges from 9 kHz to 6 GHz and produce powers up to 10 kW (Fig. 7).

Summary

Both narrow and wideband power amplifiers are required for particle accelerator applications. Thanks to advances in semiconductor technology, transistors replace expensive tubes in RF power amplifiers. A component failure in a solid-state amplifier will result in only a minor power loss, increasing the availability of the particle beam in accelerator systems.

Based on its range of broadcast amplifiers, Rohde & Schwarz offers efficient and robust solid-state high-power amplifiers. The portfolio of broadband amplifiers is also ideal for accelerator applications.

Dr. Wolfram Titze

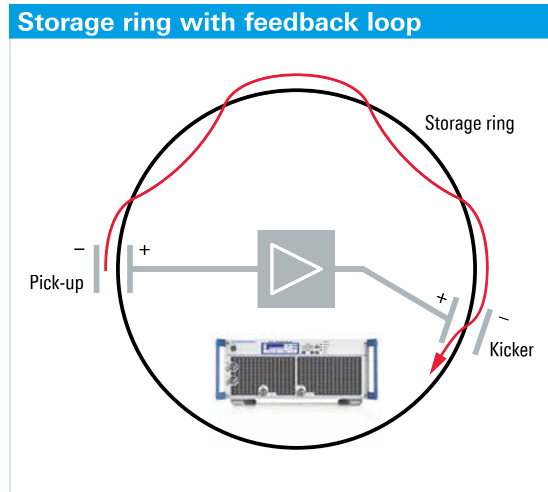


Fig. 5: Example of using a broadband RF power amplifier in the feedback loop.

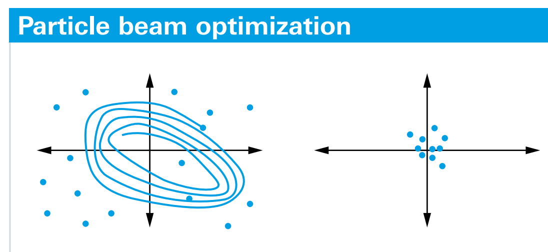


Fig. 6: Distribution of the particle packets before (left) and after the feedback loop.

Amplifier family	Frequency range	Max. CW output power
R&S®BBA150	9 kHz to 1 GHz	2.5 kW / 3 kW
R&S®BBA150	0.8 GHz to 6 GHz	800 W / 400 W
R&S®BBL200	9 kHz to 225 MHz	10 kW
R&S®THR9	87.5 MHz to 108 MHz	80 kW
R&S®THV9	170 MHz to 254 MHz	60 kW
R&S®THU9	470 MHz to 862 MHz	100 kW

Fig. 7: All Rohde & Schwarz RF power amplifiers at a glance.

Other Rohde & Schwarz solutions for particle accelerator applications

Other Rohde & Schwarz products, such as oscilloscopes with special features for accelerator applications and the R&S®FSWP phase noise analyzer and VCO tester, also offer advantages for operators of particle accelerators. Two flyers, which are available for download, provide an overview of suitable products (search term "particle accelerator"):

"Excellence in precision solutions for particle accelerators"

"RF amplifiers from Rohde & Schwarz in accelerator physics"

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[2] Awards received by the Rohde & Schwarz Teisnach plant include:
– 2010, 2014 "Factory of the Year", Germany
– 2013 "Best Factory", award winner of European industrial excellence competition
– 2014 "Bavarian Quality Award"
[3] Website: https://www.maxiv.lu.se/
[4] Eriksson, Mikael and Einfeld, Dieter: "MAX IV paves the way for ultimate X-ray microscope". CERN Courier, Volume 56 Issue. 7, September 2016.

TV transmitters: the best even better

Thanks to their combined features, TV transmitters from Rohde & Schwarz already had a leading position worldwide, but now they have been improved even more.

Radical change in the broadcast industry

Terrestrial broadcast network operators are undergoing major changes since their main task of providing quality broadcast signals to as many households as possible is becoming increasingly demanding. Rising cost pressure, not least caused by competing transmission paths such as satellite, cable and IPTV, is forcing them to reduce costs and operate with minimal staff. In addition, conventional television is now competing with customized video offers from providers such as YouTube, Netflix and Amazon Prime for viewers and advertising revenue. These costs must be saved in other areas. For network operators this means finding the right balance between network reliability and signal quality expenses on the one hand, and reduced personnel and minimum operating costs on the other.

Successful in competition

To succeed in this difficult market, network operators must use TV transmitters capable of exploiting the full cost savings potential. Rohde & Schwarz now offers such cost-effective transmitters since it was able to further improve on its already leading terrestrial TV transmitters. Thanks to numerous innovations, the new R&S®THU9evo, R&S®TMU9compact and R&S®TLU9 transmitters (Figs. 1 and 5) combine outstanding signal quality with maximum availability and are easy to operate and maintain. Their high efficiency minimizes operating costs and their easy upgradeability, to accommodate new TV transmission standards for example, makes them future-ready. In addition, remote frequency changes at the push of a button are possible – without needing to make hardware modifications. This is what makes them the only terrestrial TV transmitters on the market to combine major operating efficiency and maximum flexibility.

Reduction of operating costs

Low energy costs

Energy costs are one of the biggest expenses for network operators. Therefore, savings in this area have the biggest impact. For this reason, Rohde & Schwarz introduced R&S®Multiband Doherty technology in the R&S®Tx9 transmitter generation in 2012. This highly efficient amplifier technology has become synonymous with energy cost savings for network operators worldwide. Today, thousands of amplifier modules employing R&S®Multiband Doherty technology are in use worldwide. Compared with conventional amplifier technology, they save more than 400,000 kWh of power every day – the daily consumption of a medium-sized European town.

The R&S®THU9evo, R&S®TMU9compact and R&S®TLU9 terrestrial TV transmitters are unrivaled in terms of energy efficiency and power density. They achieve energy efficiency of up to 40 % (COFDM) and 43 % (ATSC) in the UHF bands IV/V at the transmitter end, including the cooling system*. In addition, the transmitters also provide excellent efficiency values with outstanding performance and signal quality even with significantly reduced output power.

* Before the introduction of Doherty technology by Rohde&Schwarz in 2012, a maximum COFDM efficiency level of 25 % was the norm.

Low infrastructure costs

Apart from energy costs, infrastructure accounts for the majority of costs incurred during the lifecycle of a transmitter system. These costs are reduced thanks to the small footprint of Rohde&Schwarz transmitters which have the highest power density on the market for solid-state transmitters. The R&S®THU9evo, for example, generates output power of up to 17.4 kW (COFDM) and up to 19 kW (ATSC) from a single 19" rack. In comparison to the high power density of its predecessor, the R&S®THU9, this corresponds to a further 30 % improvement. The R&S®TMU9compact and R&S®TLU9 transmitters also reduce space requirements by at least 30 % in comparison to their predecessors.

Highly integrated components for signal generation and system control push the new transmitter's compactness to extremes. The new shared R&S®TCE901 exciter platform provides signal processing as well as transmitter and system control functionality at the same time. In addition, the exciter offers numerous functions and options such as a built-in satellite receiver or integrated system components for N+1 configurations, which make additional equipment unnecessary. This reduces space requirements for R&S®Tx9 systems by more than 50 % compared with conventional transmitters in this power class.

Fig. 1: Top – the R&S®TLU9 UHF low-power TV transmitter with output power levels from 5 W to 200 W. Bottom – the air-cooled R&S®TMU9compact UHF medium-power TV transmitter with output power levels from 400 W to 600 W in 3 HU or 6 HU, consisting of an R&S®TCE901 exciter and an R&S®PMU905 amplifier (400 W in this case).

Efficient service concept

Service intervals and maintenance significantly influence a transmitter network's operation. This is why the new transmitters were developed with long service intervals and easy maintenance in mind. Thanks to their modular design, most modules can be replaced directly on site which minimizes technical and logistical complexity during servicing (Fig. 2). Individual components can also be used across models in the entire R&S®Tx9 transmitter family, simplifying spare parts handling and cutting spare parts stocking expenses.

An absolute innovation is the ePaper display of the R&S®PMU905 amplifier, which displays the selected Doherty range even if the amplifier is without power – simplifying spare part inventory management because there is no need to switch on the amplifier or open its housing.

Maximum on-air time

The widely used R&S®Tx9 transmitter generation from 2011 featured extremely low failure rates. The new TV transmitters follow the same design principles, are partially based on their tried and tested components, and ensure reliability and high signal quality. The R&S®TCE901 exciter, for example, directly generates the digital TV signal using FPGA and TX-DAC, which dispenses with the need for the analog I/Q modulator and avoids its potential amount of errors.

Thanks to a new integrated monitoring feature for temperature and humidity, network operators are able to control their transmitters' operating conditions and maximize their lifetime – keeping downtime to a minimum.

In addition to maximum robustness, the new transmitters offer a unique feature that minimizes the negative effects of mains voltage interruptions. An integrated exciter backup battery powers the CPU and the signal processing

Fig. 2: Modules that are easy to replace on site speed up and simplify service and repair.

Redundancy configurations for maximum availability

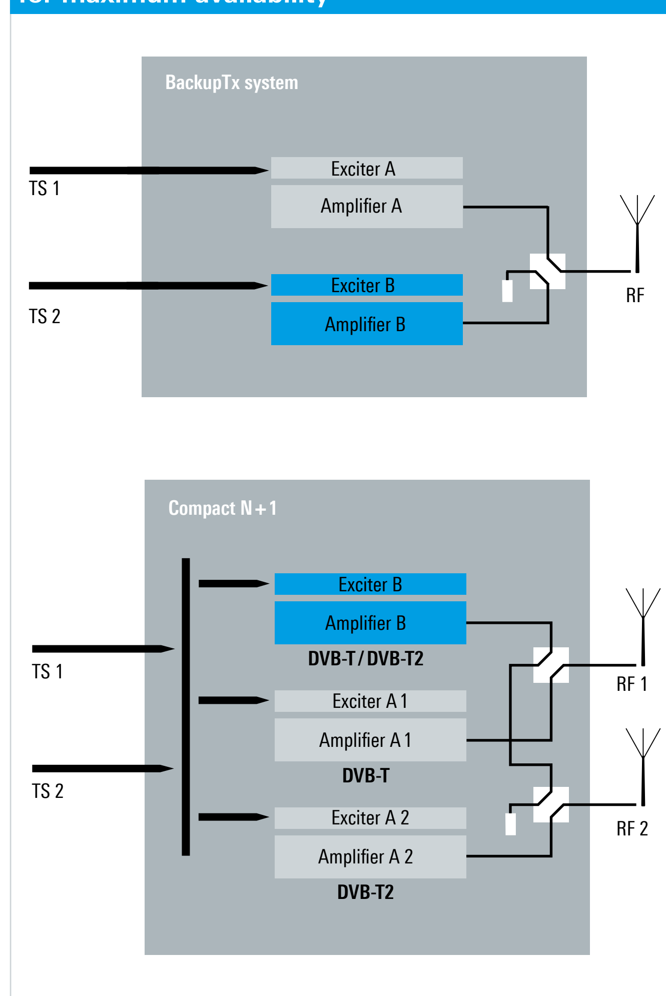


Fig. 3: Sophisticated redundancy concepts – the blue standby components simultaneously take over function of the system control.

components during voltage interruptions, ensuring that interruptions of up to 10 seconds do not result in a complete reboot of the transmitter. This reduces off-the-air time, without requiring a full-featured uninterruptible power supply (UPS).

With the Compact N+1 and BackupTx systems (Fig. 3), the transmitters offer sophisticated redundancy concepts at system level. Compact N+1 is the enhanced version of the well-known N+1 configuration. In a BackupTx system, two R&S®TLU9 transmitters operate in a fully symmetrical 1+1 configuration. The two transmitters monitor each other, making extra hardware for system monitoring and control unnecessary. Doing away with a separate, governing control unit eliminates the risk of a single point of failure.

Transmitter network operation – as simple as possible

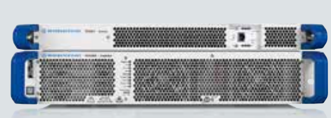
The new terrestrial TV transmitters offer the same ease and convenience as the R&S®Tx9 transmitter family via a 7" touchscreen (Fig. 4) or web interface which reduces training effort for operating personnel if multiple transmitter families are used in the same network. The straightforward GUI displays the structure and system status at a glance

Fig. 4: The R&S®TLU9 low-power TV transmitter is easy to operate and configure via the touchscreen of the optional R&S®TDU901 transmitter display unit.

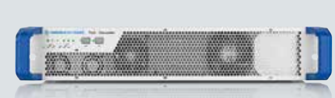
The new transmitters at a glance

R&S®THU9evo
Liquid-cooled UHF high-power TV transmitter with output power levels from 1 kW to 106 kW in one to six racks:
- Minimized operating costs for every application
- Low space requirements
- Highest output power in this class

R&S®TMU9compact
Air-cooled UHF medium-power TV transmitter with output power levels from 400 W to 600 W in 3 HU or 6 HU:
- 50 % lower operating costs than the predecessor model
- Smooth integration
- Minimum service costs
- Very high availability



R&S®TLU9
UHF low-power TV transmitter with output power levels from 5 W to 200 W in 1 HU or 2 HU:
- 25 % lower operating costs than the predecessor model
- Very high availability
- Future-ready design
- Minimum service costs



and offers network operators the convenience they want and need when installing, commissioning and operating transmitters. Touching the transmitter components on the touchscreen provides direct access to the related parameters.

Moreover, the R&S®THU9evo, R&S®TMU9compact and R&S®TLU9 transmitters offer intelligent technologies to optimize transmission. They feature power agile efficiency, i.e. transmitter efficiency remains optimal even at reduced power. Previously, this optimization required specialist know-how and could only be performed by Rohde&Schwarz transmitter production at the Teisnach plant.

The newly developed intelligent R&S®Efficiency Optimization feature ensures the potential to maximize energy economy under all transmitter operating conditions. It optimizes the parameters of the amplifier for maximum efficiency at the push of a button, whether changing channels, signal quality or the transmitter output power.

Challenge: digital dividend II

The release of the 700 MHz band for mobile radio (digital dividend II) requires TV transmitter network operators to switch parts of their networks to new frequencies. Usually, this should be achieved without procurement of new transmitters. Often, conversion must take place by a certain deadline, when all transmitters of a single-frequency network (SFN) along with subsequent RF components such as filters, combiners and antennas have to be switched over to a different frequency or replaced – a lot of work within a relatively short period of time. In such situations, strategies to minimize the effort to switchover are appreciated.

The R&S®Tx9 transmitters can be very easily adapted by a single switchover command in the GUI. The implementation of the intelligent R&S®Multiband Doherty technology allows Doherty configurations to be operated over the entire frequency range without modifications. Adjusting the Doherty frequency range at the amplifier is only required to achieve maximum efficiency. Thus, it can be planned as a subsequent measure with lower resource costs over a longer period of time. In addition, Doherty transmitters from Rohde&Schwarz are the only transmitters on the market to offer the highest efficiency over the entire frequency range. Even with a switch to the lower channels in the UHF band at system level, efficiency levels of 38 % or more can be achieved. No other competitor products on the market can offer this combination of maximum efficiency in all channels and simultaneous flexibility.

Summary

The new R&S®THU9evo, R&S®TMU9compact and R&S®TLU9 TV transmitters are uniquely compact and energy-efficient, which ensures minimized operating costs. Outstanding product quality and innovative redundancy concepts allow network operators to benefit from a high degree of availability. In addition, the transmitters can be easily integrated into existing infrastructures and are identical to operate thanks to their systemwide concept. Thus, the new transmitters are unique on the world market.

Maurice Uhlmann; Johannes Sinnhuber

Fig. 5: Liquid-cooled R&S®THU9evo UHF high-power TV transmitter with output power levels from 1 kW to 106 kW in one to six racks.

Drone alert!

The market for small commercial drones is booming. However, these inexpensive and easy-to-fly devices also pose security problems. The R&S®ARDRONIS drone monitoring system helps businesses, government authorities and critical infrastructures to protect personnel and goods.

Commercial drones: the next big thing

Incidents with commercially available drones appear almost daily in the media: drones in the vicinity of airports or even in the flight paths of aircraft (e.g. Heathrow, Munich, Warsaw, Taipei), drones above power plants and governmental buildings (the Japanese Prime Minister's office, the White House South Lawn), drones at political events (German Chancellor Dr. Angela Merkel's election rally in Dresden), drones above automotive test tracks or in the skies over Paris.

Currently, more than 300,000 drones are sold per month through online shops or brick-and-mortar stores around the world. In the USA alone, about one million devices were sold in the weeks leading up to Christmas 2015. It is estimated that by 2025 the commercial drone market will reach a volume of more than 8.5 billion euros. The explosion of relatively inexpensive and easily operated flying drones represents a new type of challenge for the protection of public and private spaces. The devices – which are both readily available and easy to fly – provide ample opportunity for misuse. Difficult to detect and capable of carrying payloads up to a few kilograms, drones increasingly represent a threat to critical infrastructures and public figures and at public events. Security agencies, government authorities as well as private organizations and facilities that require protection must have the technological approach to counter this threat.

The first challenge is to detect these small flying objects, and a number of methods are available to accomplish this. Once detected, the intruder must be classified in order to determine whether countermeasures are necessary. Instead of visual detection or radar monitoring, the Rohde & Schwarz solution identifies, finds the direction of and disrupts radio control links to and from the drone. The R&S®ARDRONIS automatic radio-controlled drone identification solution from Rohde & Schwarz has already proven itself in operations requiring the highest level of security, such as the June 2015 G7 summit held at Elmau Castle in Bavaria, Germany, and US President Barack Obama's trip to Germany for the Hanover Trade Fair in 2016 (Fig. 2).

A few facts about commercial drones

Unmanned aerial vehicles (UAV) – alternately known as small drones, minidrones or micro UAVs – are remotely controlled from the ground, although higher-end models often additionally provide navigation technology so that they can independently fly predefined routes. UAVs are typically grouped into the following categories: drones for private use (toy and hobby), drones for commercial applications (aerial views, logistics, etc.) and drones for military applications (artificial targets, reconnaissance, combat). R&S®ARDRONIS is intended exclusively for commercial use. The rapid increase in the intelligence of commercial drones, (e.g. automated target recognition by logistic drones), the cost savings achieved through the use of drones in general and the intense interest from the private sector have all combined to cause the number of commercial drones to skyrocket exponentially. There are two basic types of drones: multicopters and fixed-wing drones. Fixed-wing drones are used in only limited numbers. Their greater range and altitude make them primarily suited to special tasks such as cartography and ground mapping. Reports in the media about drones almost always refer to multicopters. Additional criteria for the classification of drones include size, payload, speed, endurance, range, altitude – and the type of control. The last criterion is of particular interest for R&S®ARDRONIS, which is designed to detect the control signals.

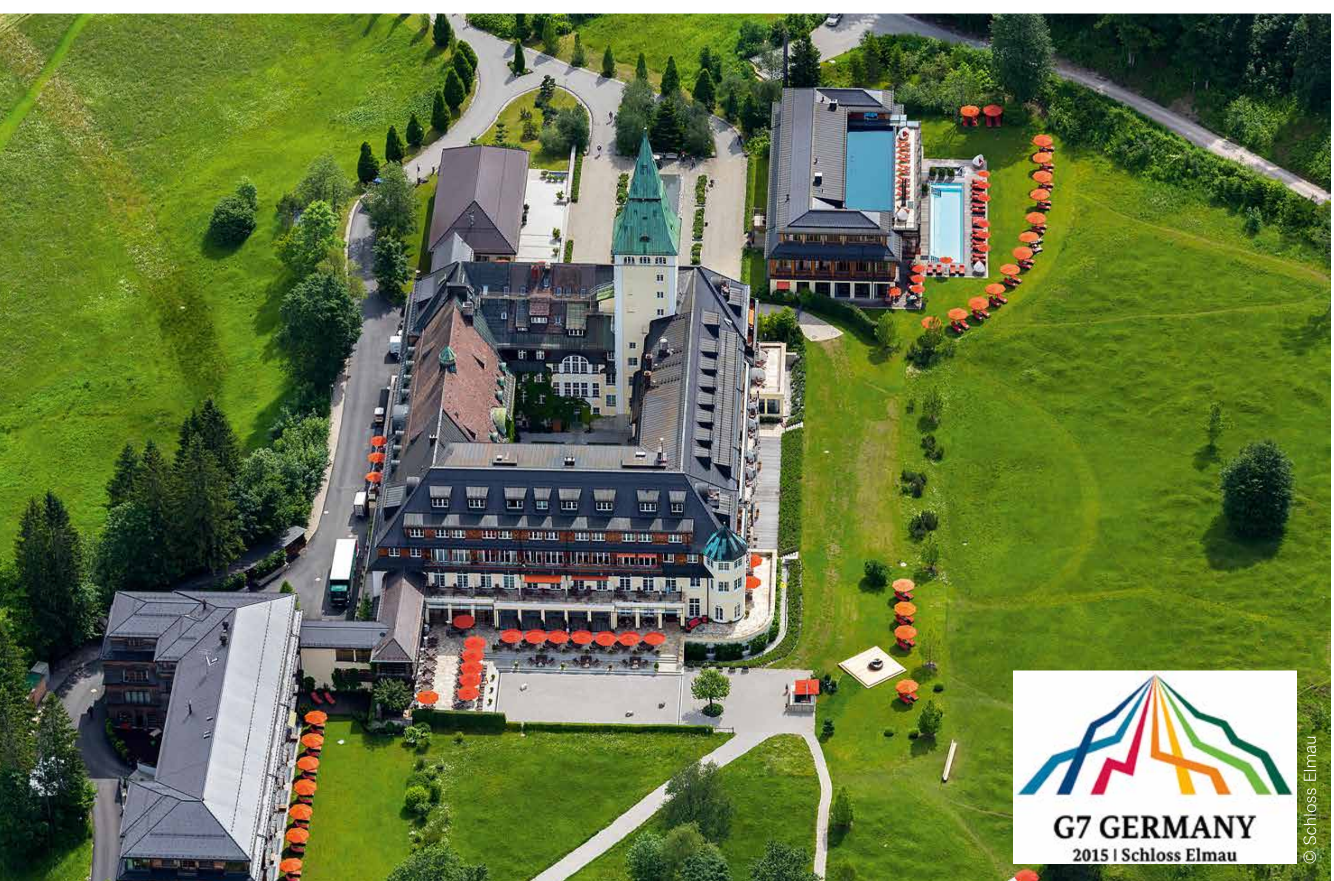
Proprietary FHSS/DHSS control systems	WLAN	Bluetooth®
▪ Most common (> 80 %) ▪ Range: < 1 km at up to 100 mW transmit power 3 km with power amplifier ▪ Some standards include telemetry data in the downlink (e.g. Jeti, Graupner)	▪ Range: up to 100 m (standard) up to 2 km with power amplifier ▪ Some models can be controlled via first person view (FPV) and / or GPS navigation	▪ Low-cost models ▪ Range up to 60 m

Fig. 1: Typical drone remote control systems.

Fig. 1 provides an overview of the various types of controls available on the market. More than 90 % of all drones communicate over the commercially available industrial, science and medical (ISM) bands, which are also used for telecommunications, e. g. for WLAN and Bluetooth® radio systems. The 2.4 GHz and 5.8 GHz bands see the most use, while use of the 433 MHz band is rare.

By far the most commonly used (> 80 %) radio technologies for remote drone control are proprietary implementations of frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS). In order to increase immunity to interference, both methods use a broader spectrum than is actually required to transmit the wanted signal. FHSS alternates the carrier frequency in a pseudorandom hopping sequence. The transmitter and receiver must be synchronized and use the same hopping algorithm in order to maintain the connection. In contrast, DSSS occupies a fixed, very large bandwidth, although it decreases the spectral power density to such an extent that the wanted signal is barely above the noise floor and can only be retrieved by using a precisely matching demodulator. The two methods, which are sometimes also used in combination, are perfect for the heavily used ISM bands, where many users and radio technologies must coexist. FHSS / DSSS is therefore considered to be a quasi-standard for drone control and is used by most manufacturers. However, the game of hide and seek being played with FHSS / DSSS radio links within the spectrum make them difficult to detect and disrupt. R&S®ARDRONIS is up to the challenge with its powerful online hopper analysis. It analyzes the technical radio parameters such as hop lengths, symbol rate and modulation type and is able to unerringly classify the transmission system, e. g. HOTT (Graupner), FASST (Futaba), M-Link (Multiplex) or DSMX (Spektrum) (Fig. 4).

Fig. 2: Typical applications for drone monitoring and countermeasure systems: high-ranking events (for example, R&S®ARDRONIS guarded the G7 governmental heads in 2015 at Elmau Castle), test tracks for secret prototypes, critical infrastructures, sporting events, public rallies.



R&S®ARDRONIS key features and capabilities

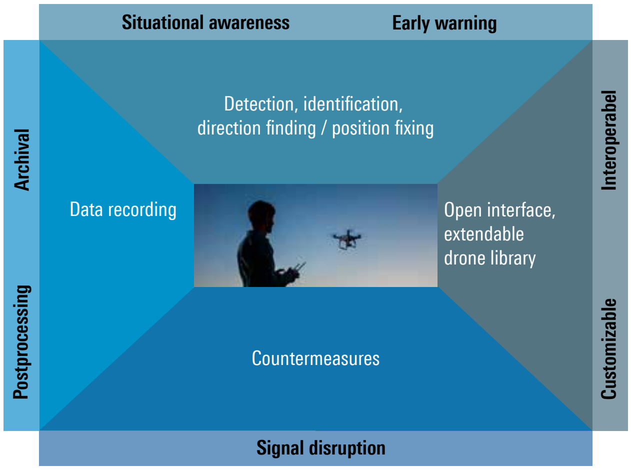


Fig. 3: R&S®ARDRONIS is a reliable, comprehensive system.

Advantages of a radiomonitoring solution

The interception of drone control signals provides certain advantages over alternative methods such as radar, optical or acoustical detection.

❙ Reliable detection without false alarms

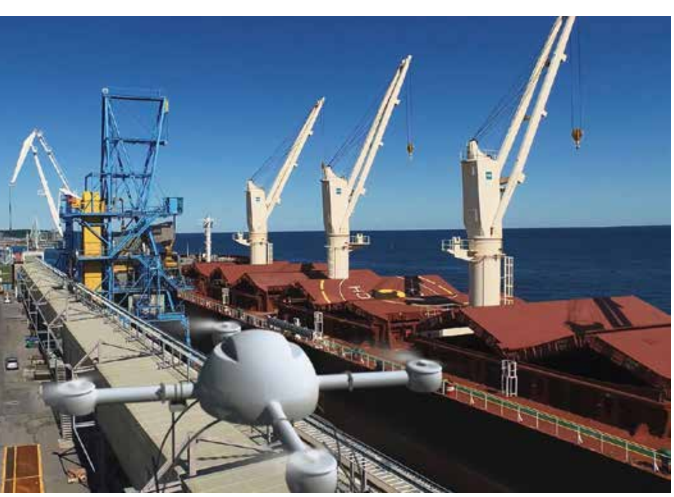
The system is not confused by other flying objects, such as birds, balloons or kites.

❙ Earliest possible detection

R&S®ARDRONIS issues an alert as soon as a remote control unit begins transmitting, i.e. even before the drone takes off. This allows countermeasures to be deployed without delay.

❙ Direction finding / position fixing of drone operators

Because R&S®ARDRONIS detects both the drone via its downlink signals and the remote control unit via its uplink signals, it can immediately determine the bearing of the drone



operator. By using multiple direction finders, it is even possible to fix the operator's precise position (in preparation).

Situational awareness

R&S®ARDRONIS not only detects all drones over a large monitored area, but in many cases can also indicate the type of drone by analyzing its radio signature, thus allowing an assessment of its threat potential. The downlink activities of the drones are additionally registered, for example whether video transmissions are taking place.

Signal disruption

The R&S®ARDRONIS system can be upgraded with a jammer that can effectively disrupt the radio link to a drone. This forces the drone into failsafe mode so that it will either land immediately or return to its point of origin. The jamming is so selective that it does not affect other radio activities. R&S®ARDRONIS creates radio parameter sets for all detected drones, making it possible to intercede at any time, e.g. to respond automatically when a protected area is breached. The setting speed of the R&S®WSE follower jammer is so fast that even rapid FHSS frequency hoppers do not pose any problem.

Reliable protection, easy operation

R&S®ARDRONIS uses antennas, direction finders and signal analysis solutions from Rohde & Schwarz. These tried and tested high-tech components, combined with a powerful detection algorithm, permit reliable interception of short-duration signals with a signal duration as low as 350 microseconds, even – and most especially – in the densely occupied ISM frequency bands. Under optimal conditions, the range is from one to three kilometers, depending on the drone and remote control transmit power and on the environment. To prevent unnecessary alarms, the alerts can be linked to an intrusion into a protected area (Fig. 5). The technical parameters for each transmission are compared against defined profiles and the matching drones are sorted into three categories: black list (e.g. potential threats), white list (e.g. own drones) and unnamed (e.g. unknown drones). A user-friendly operator interface lists the detected drones and their critical parameters (Fig. 4). If direction finding or position fixing functionality is implemented (R&S®ARDRONIS-D/P), DF beams or location markers are used to display the detection results on a map. An expert view with detailed information about detected signals is available for radio analysts (Fig. 6).

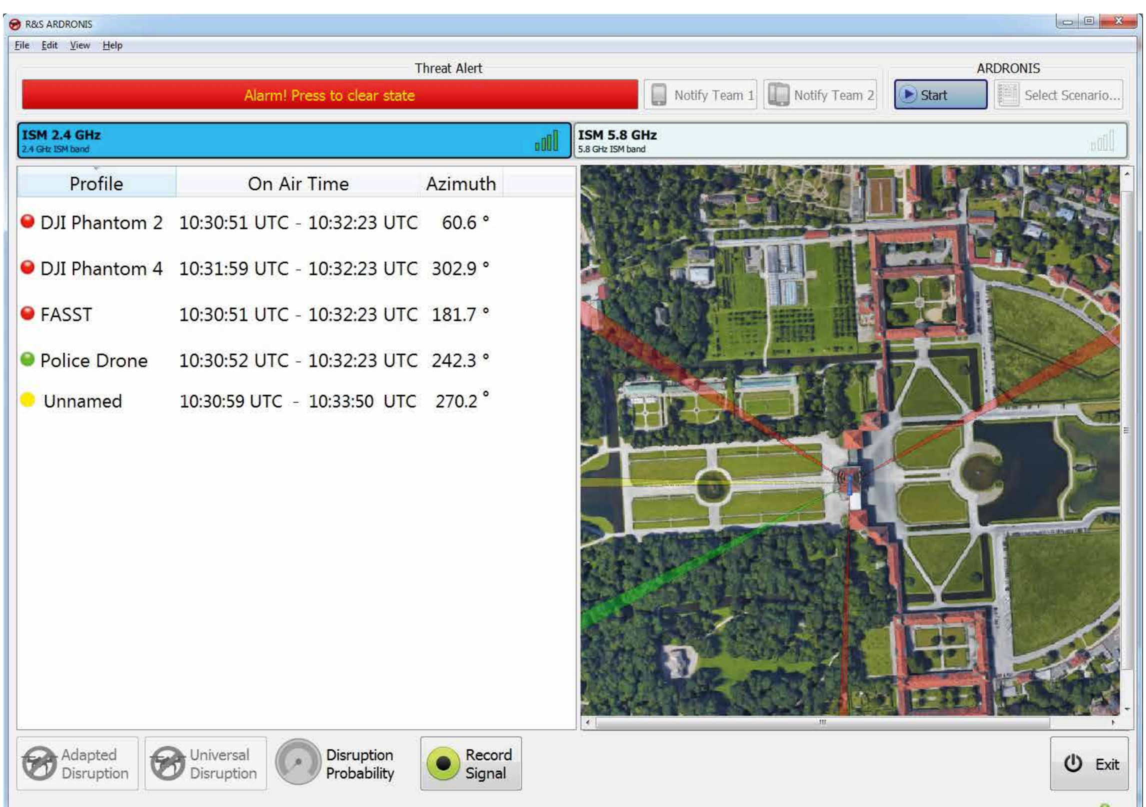


Fig. 4: Speed is of the essence in critical situations. The standard user interface therefore offers only the most important information and control buttons.

Protected area and detection range of R&S®ARDRONIS

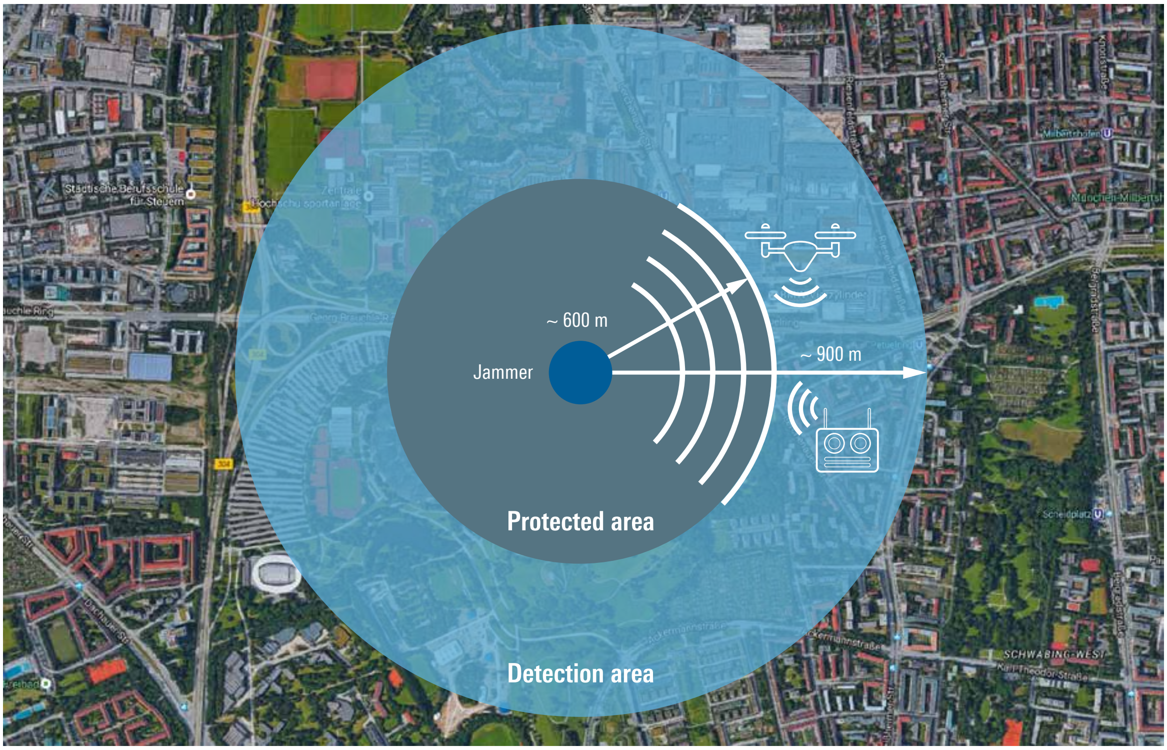
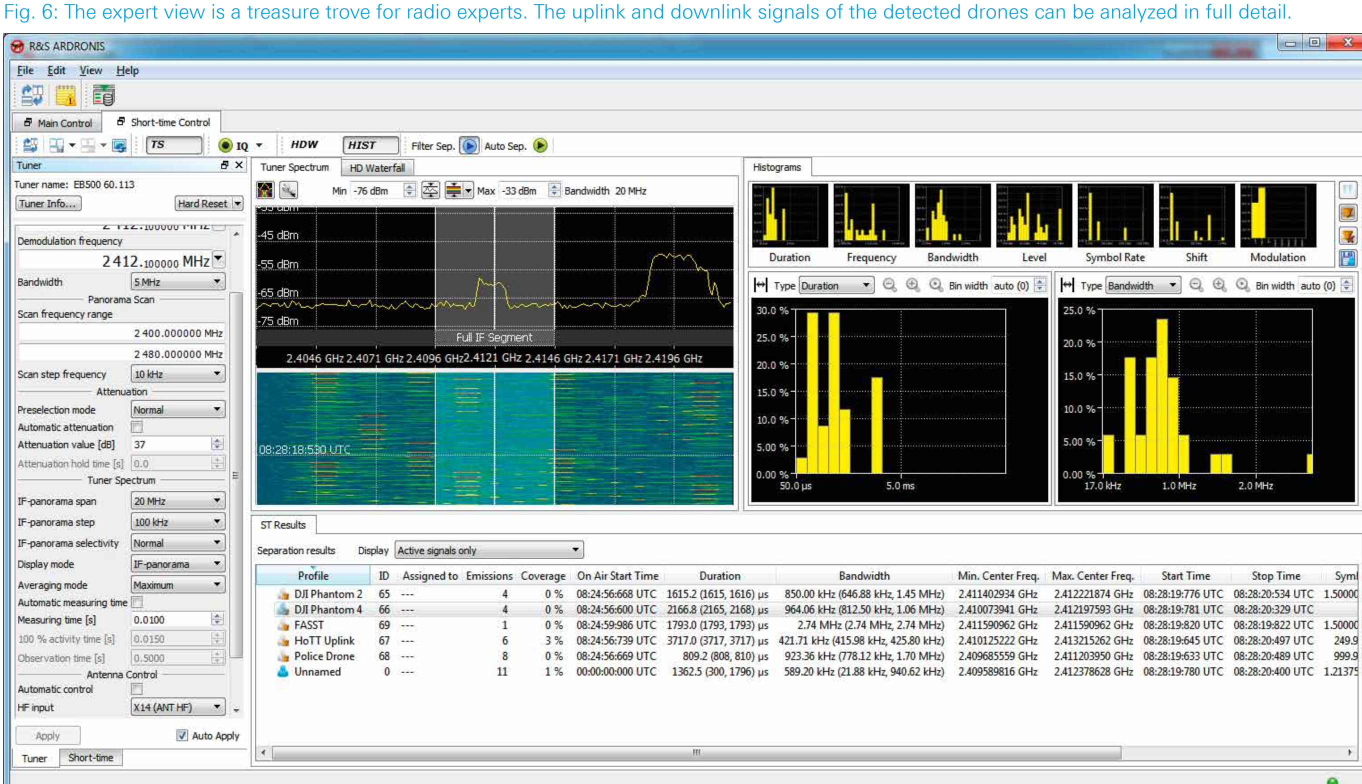


Fig. 5: R&S®ARDRONIS permits the definition of protected areas. If a drone flies into the defined area, the remote control radio link is automatically disrupted.

Fig. 6: The expert view is a treasure trove for radio experts. The uplink and downlink signals of the detected drones can be analyzed in full detail.



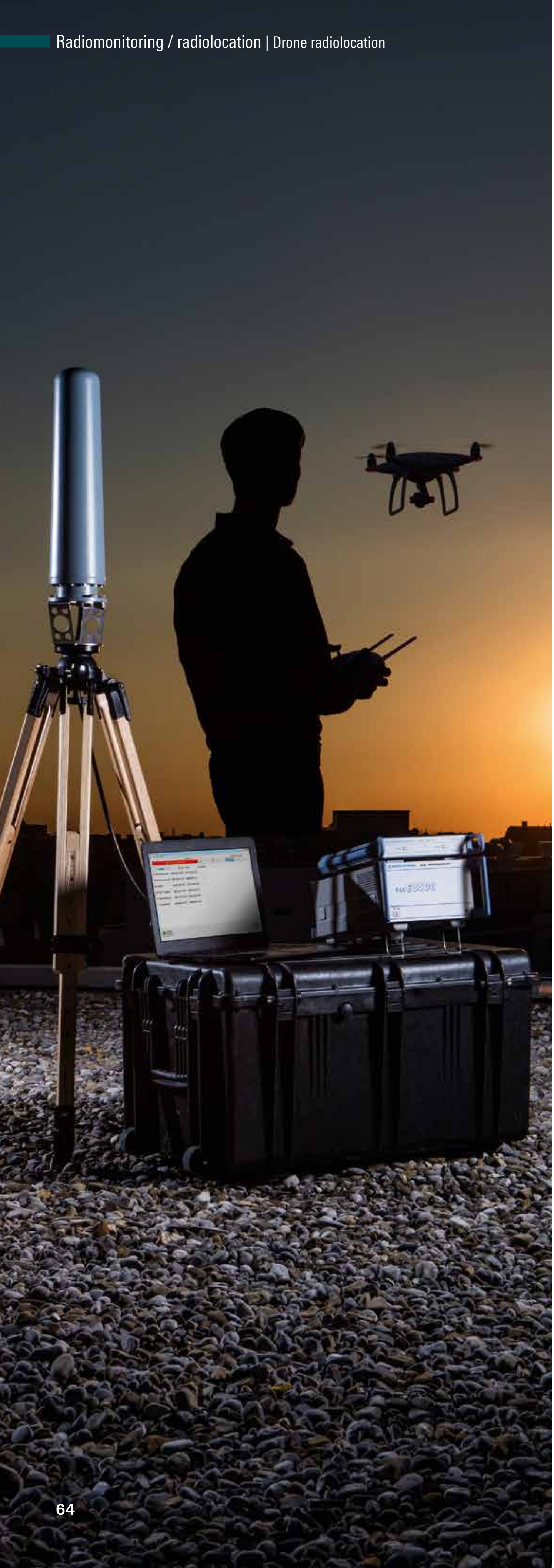


Fig. 7: R&S®ARDRONIS is made up of only a few components and can be easily transported to different sites. The photo at the bottom shows R&S®ARDRONIS-D; all others show R&S®ARDRONIS-I.

Package	Designation	Functionality		
		Identification	Direction finding / position fixing	Countermeasures
R&S®ARDRONIS Detection	R&S®ARDRONIS-I	•	–	–
R&S®ARDRONIS Direction	R&S®ARDRONIS-D	•	•	–
R&S®ARDRONIS Disruption	R&S®ARDRONIS-R	•	–	•
R&S®ARDRONIS Protection	R&S®ARDRONIS-P	•	•	•

Fig. 8: R&S®ARDRONIS – the right configuration for every application (contact us for availability).

As a reliable, comprehensive automated monitoring system, R&S®ARDRONIS also permits data recording. Everything that the system "sees" can be archived, both individual detection results and entire RF scenarios.

R&S®ARDRONIS is suited to stationary or mobile applications. Security agencies in particular must provide protection for events at a variety of venues. The turnkey system is therefore preconfigured as an easily transported plug&play solution (Fig. 7).

The right configuration for every application

Four different R&S®ARDRONIS packages with differing functionality are available for ordering (Fig. 8). R&S®ARDRONIS-I is the right solution for customers wanting to detect drone activity within a defined area, for example over a sports stadium or a commercial facility. R&S®ARDRONIS-R is suited for permanent monitoring and protection of an entire zone, such as a government district. Countermeasures are deployed automatically when an intrusion is detected within the protected area. If there is a valid need to track down or even apprehend the drone operator, the R&S®ARDRONIS-D or R&S®ARDRONIS-P packages should be used.

Inclusion in integrated drone monitoring and countermeasure systems

As described above, a drone identification system based on radio signal interception has several advantages and even unique selling points over other methods, most particularly the ability to provide very early alerts, to prevent false alarms and to identify the perpetrator. However, there are situations in which R&S®ARDRONIS will not show the way to the target in the truest sense of the word. If a drone remains "mute" and does not emit any radio signals, it will not be detectable. Nor will disruption of radiocommunications force the drone to turn back or land if it has been programmed with a fixed flight path. Customers requiring comprehensive protection, including these types of situations, can integrate R&S®ARDRONIS into a system that includes other position fixing and protection components, such as radar. R&S®ARDRONIS includes an open interface for this purpose. The product is continually updated with new functions. Regular maintenance includes a refresh of the profile database to add new drone models. One planned new capability is position fixing by means of a cross-bearing fix.

Summary

The rapid proliferation of commercial drones is equally problematic for both security agencies and private organizations. The possibilities for misuse of drones range from invasion of privacy to white-collar crimes such as corporate espionage all the way to the endangerment of public personalities and capital offenses such as terrorist attacks. With R&S®ARDRONIS, Rohde&Schwarz is introducing a system that provides early detection of threats. R&S®ARDRONIS intercepts radio links between a remote control unit and a drone and uses it to find both the drone and its pilot, something no other method can do. Detection occurs immediately after the remote control is turned on, before the drone is in the air, making early countermeasures possible. An open interface allows integration of R&S®ARDRONIS into complex drone defense systems that can include other position fixing methods such as radar as well as effective countermeasures.

YingSin Phuan

Rohde & Schwarz Cybersecurity is founding member of ECSO

The European Cyber Security Organisation (ECSO) was founded in June 2016 to protect the European domestic market against IT security incidents. As a founding member, Rohde & Schwarz Cybersecurity supports ECSO in developing innovative European security technology. EU institutions, research centers and universities, associate countries and IT security companies cooperate with each other through ECSO. The organization advises the EU with regard to the allocation of EUR 450 million in research funds. EU Commissioner Günther Oettinger and EU Commission Vice President Andrus Ansip hosted the signing ceremony, which took place in Strasbourg on July 5, 2016. Oettinger emphasized the importance of ECSO for creating a worldwide major digital EU domestic market.

At the signing ceremony, from left: Harald Reisinger (RadarServices), Günther Oettinger (EU Commissioner) and Peter Rost (Rohde & Schwarz Cybersecurity).

DVB-T2 network for Oman

The transmitter site in Ruwi, a district of Oman's capital Muscat, is the main station of the Public Authority for Radio and Television.

Oman TV, the country's national broadcaster, is converting its transmitter network, which currently has four programs, to digital TV. For this purpose, Rohde & Schwarz is supplying a turnkey countrywide DVB-T2 network. With 69 transmitter sites, it is one of the biggest in the Middle East. Key components such as high-power transmitters, gap fillers, headends, monitoring equipment, satellite receivers, multiviewers and network management systems, as well as various T&M instruments are from Rohde & Schwarz. In addition, the Rohde & Schwarz project team integrated numerous components and devices from other manufacturers. The new network will be put into operation step by step between January 2017 and September 2018.

Peruvian regulatory authority relies on Rohde & Schwarz

On behalf of the Peruvian Ministry of Transportation and Communications (MTC), Rohde & Schwarz has installed a countrywide system for monitoring the frequency spectrum. One stationary and one mobile measurement and direction finding system from Rohde & Schwarz were put into operation in 15 different cities. The MTC uses the equipment to monitor the frequency spectrum, specifically to ensure interference-free reception of radiocommunications services. The system is suitable for use in Peru's different climate zones, from the desert regions on the Pacific to the Andean highlands.

The core of the system installed in Peru is the compact R&S®UMS300 monitoring and radiolocation system.

First ATSC 3.0 SFN transmitter network worldwide in South Korea

In September 2016, the Seoul Broadcasting System (SBS) transmitter network operator commissioned Rohde & Schwarz to build a next generation transmitter network for Seoul. It will be based on a single-frequency network (SFN) and comply with the new ATSC 3.0 TV broadcast standard. SBS wants to broadcast the 2018 Winter Olympics in Pyongyang in ultra high definition (UHD) with the first worldwide terrestrial TV network of this kind. The Rohde & Schwarz solution includes R&S®THU9 liquid-cooled transmitters with output power of 5 kW and 2 kW. Today, Rohde & Schwarz already offers ATSC 3.0 upgrades for these and other existing TV transmitters.

1000 broadband amplifiers sold in seven years

In September 2016, the 1000th broadband amplifier of the R&S®BBA family left the Teisnach plant. Rohde&Schwarz has been producing the successful family of amplifiers for seven years and is continually enhancing them. They remain among the most advanced on the market. In the near future, a high output power model will be added to the family. Broadband amplifiers are needed to test the electromagnetic compatibility (EMC) of electronic components, devices or systems. The R&S®BBA amplifies signals that act as simulated spurious emissions on the DUT. Instruments for the frequency range from 9 kHz to 6 GHz and for output power of 15 W to 3 kW have been produced so far.

Signals from the R&S®BBA test whether and to what extent DUTs withstand the spurious signals or whether they need to be better shielded.

300 security scanners for Germany

In July 2016, the Procurement Office of the German Federal Ministry of the Interior signed a three-year framework agreement with Rohde&Schwarz. The agreement includes delivery and maintenance of 300 R&S®QPS200 security scanners. The German Federal Police will use the security scanners for passenger screening at airports throughout Germany. The scanners can also be used for security access control in other places, such as ministries. This framework agreement represents the largest order for security scanners to date for Rohde&Schwarz. Additional orders from other countries have already been received. The scanner is presented in an article on page 40.

Award for Professor Rohde

The IEEE Microwave Theory and Techniques Society (MTT-S) has awarded Prof. Dr.-Ing. habil. Dr. h.c. mult. Ulrich L. Rohde the 2016 Microwave Application Award for his significant contributions to the development of low-noise oscillator performance. The award recognizes an individual, or a team, for an outstanding application of microwave theory and techniques, which has been reduced to practice nominally 10 years before the award. The award ceremony took place in May 2016 during the annual IEEE International Microwave Symposium in San Francisco.

R&S®Scope Rider is 2016 ICT Product of the Year

The readers of the German trade magazine "funkschau" have voted the R&S®Scope Rider digital handheld oscilloscope the top 2016 ICT Product of the Year in the T&M instruments category. The rugged, battery-operated instrument with the performance and capabilities of a lab oscilloscope received nearly 1000 reader votes. The "funkschau" readers' choice award is one of the largest B2B surveys in the ICT sector – a total of more than 113,000 votes were cast in 20 categories.

Award for Memmingen plant

In the summer of 2016, Rohde&Schwarz won the Lean&Green Management Award in the "General Manufacturing Industry OEM/Group" category. The Memmingen plant scored points above all with its integrated approaches to lean and resource management. The Growtth Consulting Europe and Quadriga Consult consulting companies conduct the annual benchmark in Germany. The evaluation was based on various factors such as workplace quality, infrastructure, planning and control as well as supply chain management. The jury was impressed by how Memmingen connects lean and green elements and continuously develops them as part of the production model.

Award for Teisnach plant

The Rohde&Schwarz production plant in Teisnach has been crowned the overall winner of the "Global Excellence in Operations" (GEO) prize in 2016. The German business magazine "Produktion", together with the consulting firm A.T. Kearney, have been presenting the award since 1992 to recognize top performance by innovative companies. The jury was particularly impressed by the optimization of value streams across all processes and the shorter turnaround times at the plant that were achieved as a result. It also paid tribute to the gradual introduction of new production technologies and the extremely high level of in-house manufacturing. Teisnach also scored extra points thanks to its extremely flexible employees, low absence rates and a staff turnover rate that is close to zero.

Standard-compliant usage of quantities, units and equations

ROHDE&SCHWARZ

Foreword

During their studies or vocational training, natural scientists, engineers and technicians usually learn how to correctly use physical quantities, units and equations. In their professional lives, however, this often fades into the background. This brochure, which will refresh this knowledge and serve as a reference, provides an overview of the relevant international standards. It exclusively deals with the units of the International System of Units (abbreviated as SI from the French “Système international d'unités“) and the quantities of the International System of Quantities (ISQ). In addition, it describes the units and quantities that can be used in accordance with the SI or ISQ as well as the logarithmic quantities with decibel as the unit. For other units and quantities, see references [3] and [4].

Legal units and the International System of Quantities

The International System of Units (SI) was adopted in 1960 by the General Conference on Weights and Measures (Conférence Générale des Poids et Mesures, CGPM). The current status is specified in the French version of the SI Brochure published by the International Bureau of Weights and Measures (Bureau International des Poids et Mesures, BIPM) [1].

The SI units have been adopted as the legal units in almost all countries worldwide.

The national standards have been agreed upon with the competent international organizations (ISO and IEC) and describe the internationally recognized state of the art. For the current international standards, see references [3] and [6] to [8]. References [3], [4] and [5] define the SI units on the basis of the International System of Quantities (ISQ).

While the laws only apply to business and official use, the relevant standards are valid without this restriction.

The ISQ base quantities and the SI base units are listed in Table 1, and the derived quantities with special unit symbols in Table 2. Table 3 provides examples of derived quantities without special unit symbols. Table 4 contains the prefixes and prefix symbols for decimal submultiples and multiples of units. Prefixes and prefix symbols are exclusively used together with unit names and unit symbols. Prefix symbols and unit symbols are not separated by a space; together, they form the symbol for a new unit. Table 5 contains examples of the use of prefixes and prefix symbols.

The derived SI units are defined as products, quotients and powers of the base units, the numerical factor always being 1. This system of units is coherent. Table 6 contains units outside the SI that can be used in connection with the SI.

Table 1: ISQ base quantities and SI base units

ISQ base quantity		SI base unit	
Name	**Letter symbol**	**Name**	**Unit symbol**
Length	l	meter	m
Mass	m	kilogram	kg
Time, duration	t	second	s
Electric current	I	ampere	A
Thermodynamic temperature	T, Q	kelvin	K
Amount of substance	n, v	mole	mol
Luminous intensity	I_v	candela	cd

The letter symbols for the SI units are standardized internationally and are identical in all languages. They must be written as stipulated by law and standard and may not be modified by appending additional information such as indices or attachments.

Table 2: Derived quantities and derived units with special unit symbols

Derived ISQ quantity		Derived SI unit			
Name [1]	**Letter symbol**	**Name**	**Unit symbol**	**Expressed in terms of**	
				other SI units	**SI base units**
Plane angle	$\alpha, \beta, \gamma, \varphi$	radian	rad		1
Solid angle	Ω	steradian	sr		1
Frequency	f, ν	hertz	Hz		s^{-1}
Force	F	newton	N		$m\ kg\ s^{-2}$
Pressure, stress	P	pascal	Pa	N/m^2	$m^{-1}\ kg\ s^{-2}$
Energy, work, amount of heat	W	joule	J	N · m	$m^2\ kg\ s^{-2}$
Power, radiant flux	P	watt	W	J/s	$m^2\ kg\ s^{-3}$
Voltage, electric tension	U, V	volt	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
Electric charge	Q	coulomb	C		A s
Electric capacitance	C	farad	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
Electric resistance	R	ohm	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
Electric conductance	G	siemens	S	A/V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
Magnetic flux	Φ	weber	Wb	V · s	$m^2\ kg\ s^{-2}\ A^{-1}$
Magnetic flux density	B	tesla	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
Inductance	L	henry	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
Luminous flux	Φ_v	lumen	lm	cd · sr	cd
Illuminance	E_v	lux	lx	lm/m^2	m^{-2} cd
Activity referred to a radionuclide	A	becquerel	Bq		s^{-1}
Absorbed dose	D	gray	Gy	J/kg	$m^2\ s^{-2}$
Dose equivalent	H	sievert	Sv	J/kg	$m^2\ s^{-2}$
Catalytic activity		katal	kat		$mol\ s^{-1}$

[1] If it is absolutely clear from the context that quantities of electricity are being referred to, the adjective "electric" can be omitted.

Table 3: Examples of derived quantities without special unit symbols

Derived ISQ quantity		Derived SI unit		
Name	**Letter symbol**	**Name**	**Expressed in terms of**	
			other SI units	**SI base units**
Area	A	square meter		m^2
Volume	V	cubic meter		m^3
Speed, velocity	v	meter per second		$m\ s^{-1}$
Acceleration	a	meter per second squared		$m\ s^{-2}$
Angular velocity	ω	radian per second	rad/s	s^{-1}
Angular acceleration	α	radian per second squared	rad/s^2	s^{-2}
Moment of force	M	newton meter	N · m	$m^2\ kg\ s^{-2}$
Heat flux density	q	watt per square meter	W/m^2	$kg\ s^{-3}$
Heat capacity	C	joule per kelvin	J/K	$m^2\ kg\ s^{-2}\ K^{-1}$
Thermal conductivity	λ	watt per meter kelvin	W/(m · K)	$m\ kg\ s^{-3}\ K^{-1}$
Energy density	e	joule per cubic meter	J/m^3	$m^{-1}\ kg\ s^{-2}$
Electric field strength	E	volt per meter	V/m	$m\ kg\ s^{-3}\ A^{-1}$
Magnetic field strength	H	ampere per meter		$A\ m^{-1}$

Table 4: Prefixes and prefix symbols for decimal submultiples and multiples of units

Prefix	Symbol	Factor
yocto	y	10^{-24}
zepto	z	10^{-21}
atto	a	10^{-18}
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	µ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deca	da	10^{1}
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}
peta	P	10^{15}
exa	E	10^{18}
zetta	Z	10^{21}
yotta	Y	10^{24}

Table 5: Examples of the use of prefixes and prefix symbols

Unit	Unit name	Relation
km	kilometer	1 km = 10^{3} m
mm	millimeter	1 mm = 10^{-3} m
µm	micrometer	1 µm = 10^{-6} m
nm	nanometer	1 nm = 10^{-9} m
TW	terawatt	1 TW = 10^{12} W
GW	gigawatt	1 GW = 10^{9} W
MW	megawatt	1 MW = 10^{6} W
kW	kilowatt	1 kW = 10^{3} W
mW	milliwatt	1 mW = 10^{-3} W
µW	microwatt	1 µW = 10^{-6} W
nW	nanowatt	1 nW = 10^{-9} W
pW	picowatt	1 pW = 10^{-12} W

When referring to mass, the prefixes must be added to the gram.

Table 6: Non-SI units accepted for use with the SI

Quantity	Unit name	Unit symbol	Relation	Value in SI units
Time	minute	min		1 min = 60 s
	hour	h	1 h = 60 min	1 h = 3600 s
	day	d	1 d = 24 h	1 d = 86 400 s
Plane angle	degree	°		1° = (π/180) rad
	minute of an arc	´	1´ = (1/60)°	1´ = (π/10 800) rad
	second of an arc	ʺ	1ʺ = (1/60)´	1ʺ = (π/648 000) rad
Area	hectare	ha		1 ha = 10^{4} m^{2}
Volume	liter	L, l		1 L = 10^{-3} m^{3}
Mass	ton	t		1 t = 10^{3} kg
Pressure	bar	bar	10^{5} Pa	1 bar = 10^{5} m^{-1} kg s^{-2}

Quantities

Physical phenomena are described qualitatively and quantitatively by physical quantities. Every value of a quantity can be expressed as the product of numerical value and unit. If the unit changes (for example, by adding a prefix symbol), the numerical value changes as well. The product of numerical value and unit remains constant; it is invariant with respect to a change of unit.

Example: U = 0.1 V and U = 100 mV describe the same quantity value.

Letter symbols for physical quantities are specified in the international IEC 60027 standards ([6], [7] and [8]) and in IEV 112 [5].

Multiple-letter abbreviations of names should not be used as quantity symbols. When it is necessary to indicate a special meaning of a quantity symbol, letters or numerals can be added to the general quantity symbol as indices.

> Letter symbols for quantities should not contain any reference to specific units.

Quantities of the same kind are specified in the same unit and are distinguished either by different letter symbols or by letter symbols with index. Tables 7, 8 and 9 contain some examples of quantities of the same kind. Only quantities of the same kind can be added to or subtracted from each other.

Quantities can be multiplied or divided in order to define additional quantities (see Table 10 for examples).

Quantities can be multiplied or divided using numerical factors.

Table 7: Examples of quantities of the kind of quantity referred to as length

Quantity		Unit	
Name	**Letter symbol**	**Name**	**Letter symbol**
Length	l	meter	m
Width	b	meter	m
Height	h	meter	m
Thickness	D, d	meter	m
Radius	r, R	meter	m
Diameter	d, D	meter	m
Circumference	u, U	meter	m
Wavelength	λ	meter	m

Table 8: Examples of quantities of the kind of quantity referred to as power

Quantity		Unit	
Name	**Letter symbol**	**Name**	**Letter symbol**
Power	P	watt	W
Signal power	P_s	watt	W
Noise power	P_n	watt	W
Active power	P, P_p	watt	W
Reactive power	Q, P_q	watt	W (also var)
Apparent power	S, P_a	watt	W (also VA)

Table 9: Examples of quantities of the kind of quantity referred to as voltage or electric tension

Quantity		Unit	
Name	**Letter symbol**	**Name**	**Letter symbol**
Voltage, electric tension	U, u	volt	V
RMS value of an alternating voltage	U_{RMS}	volt	V
Peak value of an alternating voltage	U_p	volt	V
Rectified value of an alternating voltage	U_m	volt	V
Complex amplitude of a sine voltage	$\underline{U}$	volt	V

Table 10: Examples of derived ISQ quantities

Name [2]	Letter symbol	Expressed in terms of	
		other ISQ quantities	**ISQ base quantities**
Area	A		l^2
Volume	V		l^3
Speed, velocity	v		$l\, t^{-1}$
Acceleration	a		$l\, t^{-2}$
Force	F		$l\, m\, t^{-2}$
Pressure, stress	P	F/l^2	$l^{-1}\, m\, t^{-2}$
Energy, work, amount of heat	W	$F \cdot l$	$l^2\, m\, t^{-2}$
Power, radiant flux	P	W/t	$l^2\, m\, t^{-3}$
Voltage, electric tension	U, V	W/I	$l^2\, m\, t^{-3}\, I^{-1}$
Electric charge	Q		$I\, t$
Electric capacitance	C	Q/U	$l^{-2}\, m^{-1}\, t^4\, I^2$
Electric resistance	R	U/I	$l^2\, m\, t^{-3}\, I^{-2}$
Magnetic flux	Φ	$U \cdot t$	$l^2\, m\, t^{-2}\, I^{-1}$
Magnetic flux density	B	$\Phi\, /l^2$	$m\, t^{-2}\, I^{-1}$
Inductance	L	Φ/I	$l^2\, m\, t^{-2}\, I^{-2}$
Moment of force	M	$F \cdot l$	$l^2\, m\, t^{-2}$
Heat flux density	q	W/l^2	$m\, t^{-3}$
Heat capacity	C	J/T	$l^2\, m\, t^{-2}\, T^{-1}$
Thermal conductivity	Φ	$W/(l \cdot T)$	$l\, m\, t^{-3}\, T^{-1}$
Energy density	e	J/l^3	$l^{-1}\, m\, t^{-2}$
Electric field strength	E	U/l	$l\, m\, t^{-3}\, I^{-1}$
Magnetic field strength	H	I/l	$I\, l^{-1}$

[2] If it is absolutely clear from the context that quantities of electricity are being referred to, the adjective "electric" can be omitted.

Quantities with reference values, level quantities

Level quantities indicate the difference to a defined reference value that is other than zero. Every value of a level quantity can be expressed as the product of numerical value and unit. The letter symbol for the level quantity must additionally include a note relating to the reference quantity, or a special letter symbol must be used.

For two values each of a level quantity, it is possible to form a difference that is a quantity. The difference quantity is independent of the reference value.

The temperature difference can be indicated in kelvin or degree Celsius; the values are identical.

Adding the values of a level quantity only makes sense if the sum is divided by the number of addends. This yields the mean value, which is also a level quantity.

A quantity of the same kind can be added to or subtracted from a level quantity. The result is also a level quantity.

Table 11: Examples of level quantities

Level quantity	Letter symbol	Reference value	Unit	Unit symbol
Height coordinate of a terrain point	h_{NHN}	national benchmark, standard zero level	meter	m
Water level coordinate of a water body	h_{P}	staff gage zero	meter	m
Electric potential	φ	zero potential, e.g. ground potential	volt	V
Time of day	t_{d}	midnight, 0:00 h	second, minute, hour	s, min, h
Celsius temperature	T_{C}	$T_0 = 273.15$ K	degree Celsius	°C

Table 12: Examples of level quantity differences

Level quantity	Difference	Difference quantity	Unit	Unit symbol
Height coordinate of a terrain point	$\Delta h = h_{\mathrm{NHN},2} - h_{\mathrm{NHN},1}$	height difference	meter	m
Water level coordinate of a water body	$\Delta h = h_{\mathrm{P},2} - h_{\mathrm{P},1}$	level difference	meter	m
Electric potential	$U = \Delta\varphi = \varphi_2 - \varphi_1$	voltage, electric tension	volt	V
Time of day	$\Delta t_{\mathrm{d}} = t_{\mathrm{d},2} - t_{\mathrm{d},1}$	duration	second, minute, hour	s, min, h
Celsius temperature	$\Delta T_{\mathrm{C}} = T_{\mathrm{C},2} - T_{\mathrm{C},1}$	temperature difference	degree Celsius, kelvin	°C, K

Table 13: Examples of mean values of level quantities

Level quantity	Mean value	Mean level	Unit	Unit symbol
Height coordinate of a terrain point	$h_{\mathrm{m}} = (h_{\mathrm{NHN},2} + h_{\mathrm{NHN},1})/2$	mean height coordinate	meter	m
Water level coordinate of a water body	$h_{\mathrm{m}} = (h_{\mathrm{P},2} + h_{\mathrm{P},1})/2$	mean water level coordinate	meter	m
Electric potential	$\varphi_{\mathrm{m}} = (\varphi_2 + \varphi_1)/2$	mean potential	volt	V
Time of day	$t_{\mathrm{d,m}} = (t_{\mathrm{d},2} + t_{\mathrm{d},1})/2$	mean time	second, minute, hour	s, min, h
Celsius temperature	$T_{\mathrm{C,m}} = (T_{\mathrm{C},2} + T_{\mathrm{C},1})/2$	mean temperature	degree Celsius	°C

Physical constants

Every value of a physical constant can be expressed as the product of numerical value and unit. In equations, it can be treated like a quantity.

Table 14: Examples of fundamental physical constants

Name	Letter symbol	Relation	Expressed in SI units	
Speed of light in vacuum	c, c_0			$299792458\ \frac{m}{s}$
Magnetic field constant	μ_0		$\frac{4\pi}{10}\,\frac{\mu H}{m}$	$4\pi \cdot 10^{-7}\,\frac{V\ s}{A\ m}$
Electric field constant	ε_0	$\varepsilon_0 = \frac{1}{\mu_0\ c^2}$	$8.854\ \frac{pF}{m}$	$8.854 \cdot 10^{-12}\,\frac{A\ s}{V\ m}$
Field characteristic impedance	Z_0	$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \mu_0\ c$		$376.730\ \Omega$
Elementary charge	e		$1.602 \cdot 10^{-19}\,C$	$1.602 \cdot 10^{-19}\,A\ s$
Electron mass	m_e			$9.109 \cdot 10^{-31}\ kg$
Gravitational constant	G			$6.674 \cdot 10^{-11}\ \frac{m^3}{kg\ s^2}$
Boltzmann constant	k_B			$1.381 \cdot 10^{-23}\ \frac{J}{K}$
Loschmidt constant	N_L			$2.687 \cdot 10^{25}\ m^{-3}$

Note: The value for the speed of light is precise, whereas all other numerical values are rounded.
The values of numerous fundamental physical constants can be found in [11] and [12].

Equations

The terms quantity equation, scaled quantity equation and numerical value equation as well as the relation “value of quantity equals numerical value times unit“ are based on the work of Julius Wallot and others between 1922 and 1933. In 1931, discussions about this topic led to the first edition of the German DIN 1313 standard on the notation of physical equations. For the current edition of this standard, see [9].

In equations, the letter symbols for quantities, constants and units must be treated like algebraic variables.

Quantity equations

Quantity equations are equations where the letter symbols represent physical quantities or mathematical symbols ([2], [3], [5]). These equations are independent of the selected units. When evaluating quantity equations, the products of numerical value and unit must be substituted for the letter symbols. Numerical values and units in quantity equations are treated as independent factors.

Example: The equation

$$U = R \cdot I$$

always yields the same result for voltage U, irrespective of the units in which resistance R and current I are expressed, provided that the associated products of numerical value and unit are substituted for R and I.

Scaled quantity equations

Scaled quantity equations are quantity equations where every quantity appears with its unit in the denominator [9].

Examples:

$$U/\mathrm{V} = (R/\Omega) \cdot (I/\mathrm{A})$$

$$U/\mathrm{V} = (R/\mathrm{k}\Omega) \cdot (I/\mathrm{mA})$$

$$U/\mathrm{kV} = 10^{-3} \cdot (R/\Omega) \cdot (I/\mathrm{A})$$

The parentheses can be omitted if the assignment of quantities and units is clear without parentheses, for example on the left side of the above equations or when horizontal fraction lines are used:

$$\frac{U}{\mathrm{kV}} = 10^{-3} \cdot \frac{R}{\Omega} \cdot \frac{I}{\mathrm{A}}$$

The advantage of a scaled quantity equation is that the quotients of quantity and unit directly represent the numerical values. However, the equations remain correct even if the products of numerical value and unit in other units are substituted for the quantities. In this case, however, the units must be converted. The use of the scaled quantity equation is recommended for representing results.

Numerical value equations

Numerical value equations are equations where the letter symbols represent the numerical values of physical quantities or mathematical symbols. These equations are dependent on the selected units.

Numerical value equations should no longer be used because they are considered outdated. According to ISO 80000-1 [3] they must be indicated as numerical value equations; units must be specified for all quantities.

When coherent units are used, the numerical value equations coincide with the corresponding quantity equations. When identical letter symbols are used for quantities and numerical values, it is not possible to distinguish between a quantity equation and a numerical value equation.

To indicate the numerical value and the unit of a quantity, the standards use braces or brackets with the following meaning:

$\{U\}$	numerical value of quantity U
$[U]$	unit of quantity U
$U = \{U\} \cdot [U]$	quantity = numerical value · unit

This notation is only required when units outside the SI are used. According to the relevant standards, it is not allowed to add units in brackets to quantity symbols in equations or to write the units in brackets in front of, beside or under the equations.

Examples of incorrect usage:

U [kV] = $10^{-3} \cdot R$ [Ω] $\cdot I$ [A]	incorrect
$U = 10^{-3} \cdot R \cdot I$ U [kV], R [Ω], I [A]	incorrect

Such notations must never be used. To show the relation between numerical values, the scaled quantity equation is the preferred form. The following notations are correct: U in kV, R in Ω, I in A. These notations have the advantage that they are identical in English and German.

Example:

$U = 10^{-3} \cdot R \cdot I$ U in kV, R in Ω, I in A (correct but not recommended)

Equations with level quantities

For level quantities, scaled quantity equations or numerical value equations should be used.

Example: conversion of a thermodynamic temperature into the corresponding Celsius temperature:

As a scaled quantity equation:

T_C/°C = T/K – 273.15

As a numerical value equation:

$T_C = T - 273.15$ T_C in °C , T in K

Logarithmic ratios of quantities, attenuation and gain figures

In telecommunications and acoustics, an attenuation or gain figure describes the logarithmic ratio of two electrical quantities of the same kind that identifies the characteristics of a two-port or of a transmission path. The unit used is the decibel (dB). The arguments of the logarithm are numerical values. The unit dB is not an SI unit but – like SI units – should not be modified by appending additional information. The function "lg" describes the logarithm to base 10; "log" is the general logarithm function.

In the following equations, the index 1 designates the input quantity, whereas the index 2 designates the output quantity of a two-port.

Definition for power quantities

Example: active power

Power attenuation figure of a two-port:

$$A_P = \left(10 \text{ lg } \frac{P_1}{P_2}\right) \text{dB}$$

Power gain figure of a two-port:

$$G_P = \left(10 \text{ lg } \frac{P_2}{P_1}\right) \text{dB} = -A_P$$

Definition for quantities whose square is proportional to a power quantity

Example: complex amplitudes or RMS values of alternating voltages

Voltage attenuation figure of a two-port:

$$A_U = \left(20 \text{ lg } \left|\frac{\underline{U}_1}{\underline{U}_2}\right|\right) \text{dB} = \left(20 \text{ lg } \frac{U_{1\,\text{RMS}}}{U_{2\,\text{RMS}}}\right) \text{dB}$$

Voltage gain figure of a two-port:

$$G_U = \left(20 \text{ lg } \left|\frac{\underline{U}_2}{\underline{U}_1}\right|\right) \text{dB} = \left(20 \text{ lg } \frac{U_{2\,\text{RMS}}}{U_{1\,\text{RMS}}}\right) \text{dB}$$

These quantities used to be called field quantities, but this designation was misleading. Power and energy densities are both field and power quantities. Electric voltage and electric current are not field quantities but integrals over field quantities. Therefore, ISO 80000-1 [3] introduced the designation "root power quantity". This designation was adopted in the draft for the next version of the IEC 60027 standard.

Logarithmic ratios of quantities, level

In telecommunications and acoustics, the logarithmic ratio of two quantities is defined as a level when the denominator is a fixed value of a reference quantity of the same kind as the numerator [8]. The unit used is the decibel (dB). The value of the reference quantity should always be specified for numerical values of levels. To abbreviate this specification, the reference quantity in parentheses can follow the dB symbol. If the numerical value of the reference quantity equals 1, it can be omitted in the parentheses. To make clear that this is not a special unit but only a designation for the reference value, a space should separate the dB symbol and the expression in parentheses (see [8]). Reference [8] also mentions some abbreviations introduced by the International Telecommunication Union (ITU) [10]. In these abbreviations, dB is directly followed by a letter or a sequence of characters to identify the reference value. IEC 60027-3 ([8]) recommends not to use these abbreviations.

Definition for power quantities

Example: power P, reference value P_0

$$L_P(\text{re } P_0) = L_{P/P_0} = 10 \text{ lg } \frac{P}{P_0} \text{ dB}$$

Definition for quantities whose square is proportional to a power quantity

Example: voltage U, reference value U_0

$$L_U(\text{re } U_0) = L_{U/U_0} = 20 \text{ lg } \frac{U}{U_0} \text{ dB}$$

Table 15 contains some level definitions and their short forms. Other level definitions that are common in telecommunications are listed in IEC 60027-2 [7].

The short forms in columns 5 and 6 of Table 15 are only suitable for indicating measured values and results. In general, signs denoting reference values and measurement methods should be appended to the quantity symbol and not to the unit symbol. This applies not only to the SI units but also to the decibel. In acoustics, the previously common units including additional information (e.g. dB(A)) are no longer used.

Relation between electric and magnetic field strength levels

The field strengths are linked by the equation $E_{\text{RMS}} = Z_{\text{C}} \cdot H_{\text{RMS}}$, where Z_{C} is the characteristic impedance.

Table 15: Examples of level definitions with different reference quantities

Quantity, reference value	Letter symbol		Level, definition	Unit, short form	
	Long form	Short form		IEC [3]	ITU [4]
Electric power, reference value: 1 mW	L_P (re 1 mW)	$L_{P/\text{mW}}$	$10 \text{ lg} \left(\frac{P}{1 \text{ mW}}\right) \text{ dB}$	dB (mW)	dBm
Voltage, electric tension, reference value: 1 V	L_U (re 1 V)	$L_{U/\text{V}}$	$20 \text{ lg} \left(\frac{U_{\text{RMS}}}{1 \text{ V}}\right) \text{ dB}$	dB (V)	dBV
Voltage, electric tension, reference value: 1 µV	L_U (re 1 µV)	$L_{U/\mu\text{V}}$	$20 \text{ lg} \left(\frac{U_{\text{RMS}}}{1 \ \mu\text{V}}\right) \text{ dB}$	dB (µV)	dBµV
Electric current, reference value: 1 µA	L_I (re 1 µA)	$L_{I/\mu\text{A}}$	$20 \text{ lg} \left(\frac{I_{\text{RMS}}}{1 \ \mu\text{A}}\right) \text{ dB}$	dB (µA)	dBµA
Electric field strength, reference value: 1 µV/m	L_E (re 1 µV/m)	$L_{E/(\mu\text{V/m})}$	$20 \text{ lg} \left(\frac{E_{\text{RMS}}}{1 \ \mu\text{V/m}}\right) \text{ dB}$	dB (µV/m)	not: dBµV/m [5]
Magnetic field strength, reference value: 1 µA/m	L_H (re 1 µA/m)	$L_{H/(\mu\text{A/m})}$	$20 \text{ lg} \left(\frac{H_{\text{RMS}}}{1 \ \mu\text{A/m}}\right) \text{ dB}$	dB (µA/m)	not: dBµA/m [5]
Relative noise level Carrier power: P_{c} Spurious signal power: P_{n}	L_{n} (re P_{c})	$L_{\text{n},P_{\text{c}}}$	$10 \text{ lg} \left(\frac{P_{\text{n}}}{P_{\text{c}}}\right) \text{ dB}$	dB (P_{c})	dBc

[3] To be replaced by dB (without additional information) in quantity equations.
[4] These short forms should be avoided.
[5] These short forms are incorrect.

Conversion into level:

$$20\ \lg\left(\frac{E_{\mathrm{RMS}}}{1\ \mu\mathrm{V/m}}\right)\ \mathrm{dB} = 20\ \lg\left(\frac{H_{\mathrm{RMS}}}{1\ \mu\mathrm{A/m}}\cdot\frac{Z_{\mathrm{C}}}{1\ \Omega}\right)\ \mathrm{dB}$$

$$= 20\ \lg\left(\frac{H_{\mathrm{RMS}}}{1\ \mu\mathrm{A/m}}\right)\ \mathrm{dB} + 20\ \lg\left(\frac{Z_{\mathrm{C}}}{1\ \Omega}\right)\ \mathrm{dB}$$

The expression

$$A_{Z/\Omega} = 20\ \lg\left(\frac{Z_{\mathrm{C}}}{1\ \Omega}\right)\ \mathrm{dB}$$

and the letter symbols in Table 15 can be used to describe the relation between the field strength levels as follows:

$$L_{E/(\mu\mathrm{V/m})} = L_{H/(\mu\mathrm{A/m})} + A_{Z/\Omega}$$

where $A_{Z/\Omega}$ is the impedance conversion figure (suggested designation). This is not a level because the reference value is neither a power quantity nor a root power quantity. dB (Ω) can be used as the short form; dBΩ should be avoided. The characteristic impedance Z_{C} can be a line characteristic impedance or the field characteristic impedance Z_0 (Table 14).

Mathematical operations for logarithmic ratios of quantities

In equations, a logarithmic attenuation or gain figure should be treated like a quantity and a logarithmic level like a level quantity.

The mean value of two levels with identical reference values is also a level:

$$L_\mathrm{m} = (L_1 + L_2)/2$$

The difference between two levels with identical reference value is an attenuation or gain figure:

$$\Delta L = A = L_1 - L_2$$

Attenuation or gain figures can be added to and subtracted from each other or multiplied by and divided by real factors:

$$A_\mathrm{s} = A_1 + A_2, \quad A_\mathrm{d} = A_1 - A_2, \quad A_\mathrm{p} = \mathrm{k} \cdot A_1, \quad A_\mathrm{q} = A_1/\mathrm{k}$$

Attenuation or gain figures can be added to or subtracted from levels:

$$L_1 = L_2 + A, \quad L_1 = L_2 - A$$

This mathematical operation only complies with the rules of algebra if both the level and the attenuation or gain figure are specified in dB without any additional information.

These relations should be regarded as quantity equations. The values for level and attenuation or gain figures must be entered as products of numerical value and the unit dB without any additional information.

If ITU-compliant units are used for the level (e.g. dBm), the equation for the level difference can either be written as a scaled quantity equation

$$\Delta L/\mathrm{dB} = A/\mathrm{dB} = L_1/\mathrm{dBm} - L_2/\mathrm{dBm}$$

or as a numerical value equation:

$$\Delta L = A = L_1 - L_2$$

ΔL, A in dB, L_1, L_2 in dBm
(correct but not recommended)

The mean value is obtained from the scaled quantity equation:

$$L_\mathrm{m}/\mathrm{dBm} = (L_1/\mathrm{dBm} + L_2/\mathrm{dBm})/2$$

Notation

The notation for quantities and units is standardized internationally in [3]; see also [1] and [2].

Italics

The following are written in italic (sloping) type:

- Letter symbols for physical quantities, e.g. *m* (mass); *U* (electric voltage)
- Letter symbols for variables, e.g. *x; n*
- Symbols for functions and operators with user-definable meaning, e.g. *f(x)*

The standards recommend that a serif font (e.g. Times) be used for these letter symbols.

Roman type

The following are written in roman (upright) type:

- Units and their prefixes, e.g. m; mm; kg; s; MW; µV; dB
- Letter symbols for constants, e.g. c (speed of light)
- Numerals, e.g. 4.5; 67; 8-fold; 1/2
- Symbols for functions and operators with fixed meaning, e.g. sin; lg; π
- Chemical elements and compounds, e.g. Cu; $\mathrm{H_2O}$

The standards do not recommend a special font for these letter symbols.

For numerals, a font such as Arial should be used to clearly distinguish the numerals "one" (1) and "zero" (0) from a lowercase L ("l") or an uppercase i ("I") and an uppercase o ("O").

Letter symbols for units are written in lowercase (e.g. m, s), unless they are derived from a name (e.g. A, W). If unit prefixes indicate decimal submultiples, they are written in lowercase. If unit prefixes indicate decimal multiples, they are written in uppercase – except for k.

Quantity values in tables and diagrams

Tables 16 and 17 show examples of standard-compliant and incorrect labeling of table headers and coordinate systems.

The labeling used for the displays of electronic equipment, in particular of test and measurement instruments, should also follow these recommendations. The extensive functionality of state-of-the-art electronic equipment often causes problems because space and character set are limited. Therefore, it is sometimes necessary to make compromises.

Table 16: Labeling of table headers and coordinate systems

Correct				Incorrect [6]
U	*U*/V, *U* in V	*E*	*E*/(µV/m), *E* in µV/m	*U* [V], *U* in [V]
1 V	1	1 µV/m	1	1
2 V	2	2 µV/m	2	2
3 V	3	3 µV/m	3	3
…	…	…	…	…

[6] Do not put units in brackets.

Table 17: Labeling of table headers and coordinate systems for large value ranges

Correct			Incorrect [7]
P	*P*/W	*P*/W	*P*/W
1 TW	$1 \cdot 10^{12}$	10^{12}	1 T
1 GW	$1 \cdot 10^{9}$	10^{9}	1 G
1 MW	$1 \cdot 10^{6}$	10^{6}	1 M
1 kW	$1 \cdot 10^{3}$	10^{3}	1 k
1 W	1	1	1
1 mW	$1 \cdot 10^{-3}$	10^{-3}	1 m
1 µW	$1 \cdot 10^{-6}$	10^{-6}	1 µ
1 nW	$1 \cdot 10^{-9}$	10^{-9}	1 n
1 pW	$1 \cdot 10^{-12}$	10^{-12}	1 p

[7] Do not use prefixes alone.

Frequent mistakes

Many articles in technical journals, documentation and papers do not comply with the correct usage of quantities, units and equations as specified by the relevant national and international standards.

It is common bad practice to add indices to units. This practice violates the relevant standards. An index must always be appended to the quantity symbol, not to the unit symbol. As a result of this incorrect usage, units are converted when conversions of quantities are referred to. In this context, the decibel (dB) causes particular problems. All these problems can be avoided if quantities are defined instead of special units and the reference value is appended to the quantity symbol as an index.

Another case of noncompliance with standards is placing the unit in brackets next to the quantity symbol. This bad practice is unfortunately very common. A scaled quantity equation should be used when both the unit and the quantity are to be indicated.

Dr. Klaus H. Blankenburg, November 2016

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[5]	IEC 60050-112:2010, IEV PART 112: QUANTITIES AND UNITS (E/F) (www.electropedia.org)
[6]	IEC 60027-1:1992, Letter symbols to be used in electrical technology – Part 1: General
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[11]	Fundamental Physical Constants – Extensive Listing (http://physics.nist.gov/constant)
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Designations of the cited institutions

CGPM	Conférence générale des poids et mesures (General Conference on Weights and Measures)
JCGM	Joint Committee for Guides in Metrology
BIPM	Bureau International des Poids et Mesures (International Bureau of Weights and Measures)
ISO	International Organization for Standardization
IEC	International Electrotechnical Commission
CENELEC	Comité Européen de Normalisation Electrotechnique (European Committee for Electrotechnical Standardization)
DIN	Deutsches Institut für Normung (German Institute for Standardization)
ITU	International Telecommunication Union
NIST	National Institute of Standards and Technology

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