224/2021

NEWS

ROHDE&SCHWARZ

Make ideas real

DO NOT DISTURB

An increasing number of products have wireless modules. Coexistence and conventional EMC tests ensure interference-free operation.

Universal tester for 5G NR

Easy deembedding in network analysis

Networking test labs securely

NEWS

Published by
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Chief editor: Volker Bach, Rohde & Schwarz
Editor and layout: Redaktion Drexl & Knobloch GmbH (German)
English translation: Dept. GF-BS2
Photos: Rohde & Schwarz

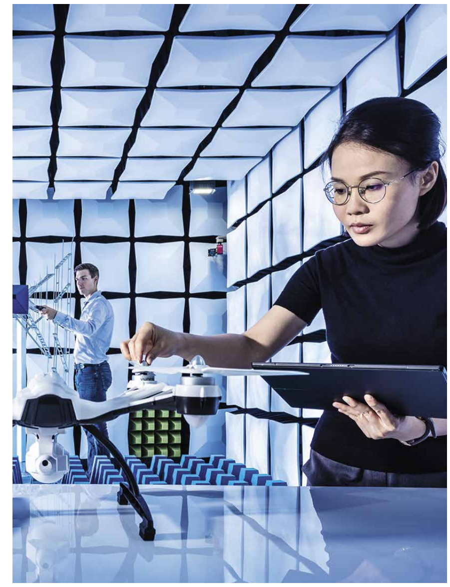
Printed in Germany
Circulation (German, English and Japanese)
approx. 35 000 two times a year

Volume 61
Issue 1/2021, no. 224

ISSN 0028-9108
Supply free of charge through your nearest
Rohde & Schwarz representative

PD 3609.2981.72

COVER FEATURE



When the radio era started in the 1920s, it was soon discovered that the general electrification that began at the same time was not conducive to the new medium. Intense noise caused by interference impaired users' already modest listening pleasure, making it clear that there was only one electromagnetic spectrum and everyone had to share it. As a result, regulatory requirements were soon put in place, and radio interference suppression became obligatory. At the start, however, there was no test and measurement equipment available for the systematic implementation of interference suppression. Rohde & Schwarz was one of the first companies to tackle the challenge, and produced its first measuring receivers soon after it was established (page 48).

Today, a century after the birth of radio broadcasting, the number of radio products has long since surpassed the number of people on the planet. An extensive regulatory framework ensures that electrical devices of all kinds are compatible with their surrounding environment, and transmitters and receivers are subject to supplementary regulations. However, (mobile) radio technology is progressing so rapidly that legislation often lags behind. As a consequence, the industry is called upon to develop its own solutions and coordinate them with authorities (page 40). Interference and wanted signals have to be considered together during product development. This applies more than ever when high RF power levels are involved. In line with the motto that "those who dish it out must also be able to take it," base stations are exposed to interference signals during conformance testing and must be able to function in line with specifications under these conditions (page 30). Microwave ovens generate even stronger RF signals, which naturally cannot be allowed to escape. Their EMC properties can now be determined more quickly than ever; the method is explained in the article on page 45.

OVERVIEW
NEWS 224/2021

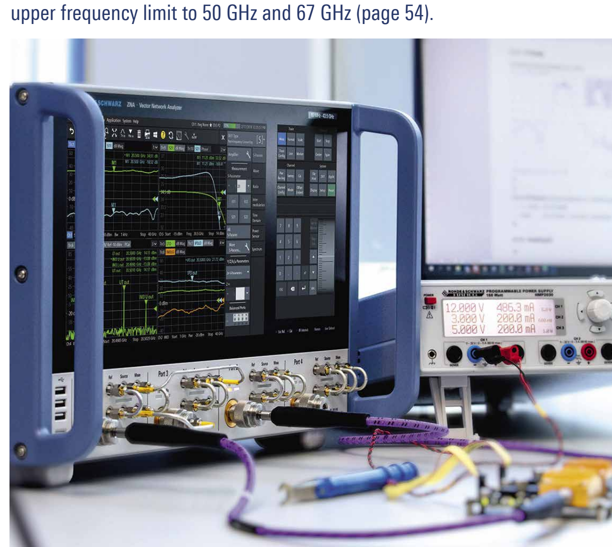
COVER FEATURE

EMC/field strength

WIRELESS

Increased use of augmented reality is just one aspect of future factories. People and machines will be wirelessly connected in many different ways (page 25).

The new R&S®ZNA50 and R&S®ZNA67 vector network analyzers push the upper frequency limit to 50 GHz and 67 GHz (page 54).



The broadband R&S®SAM100 system amplifier for the microwave domain is a perfect combination of high power large bandwidth and low noise (page 62).

AEROSPACE AND DEFENSE

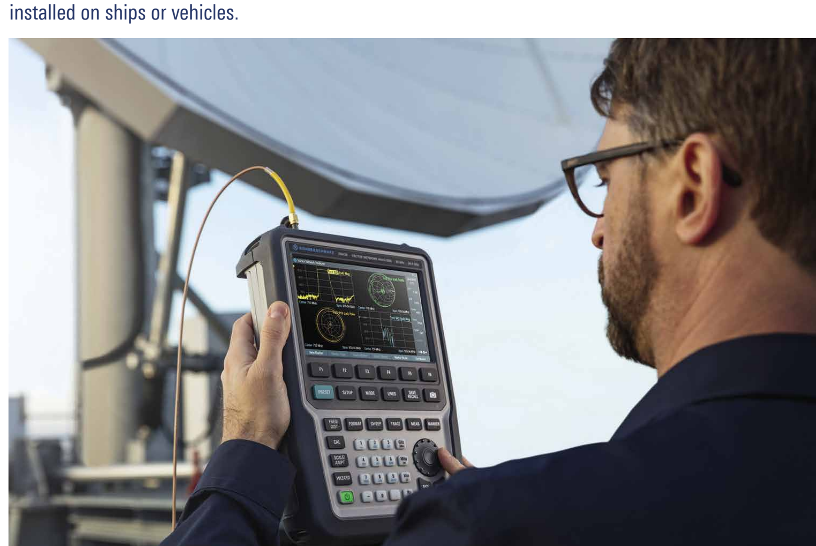
T&M equipment for multichannel radar and GNSS receivers

GENERAL PURPOSE

MISCELLANEOUS

Six-channel radar/GNSS test system (page 33).

As part of its standard repertoire, the new R&S®ZNH handheld analyzer with a frequency range up to 26.5 GHz allows measurements on radar, microwave and satellite systems, whether stationary or installed on ships or vehicles.



NEWS COMPACT

AUSTRALIAN PATROL BOATS COMMUNICATE WITH NAVICS®

Rohde & Schwarz (Australia) has signed a contract with the Austal Limited shipyard for the supply of integrated communications systems for six Cape class patrol boats (CCPB). These are currently being built for the Royal Australian Navy at the Henderson shipyard in western Australia and are scheduled for delivery starting in September 2021.

The core of the contract is equipping the boats with the NAVICS® communications system. NAVICS® covers all shipboard communications as well as interfaces to long-distance communications systems. The NAVICS® system is based on widely used industry standards (VoIP, Ethernet) and commercial off-the-shelf hardware, making it future-proof, scalable and easy to maintain. It has already been deployed on numerous naval vessels, including the Type 26 frigates of the British Royal Navy, and was on display at the INDO PACIFIC 2019 maritime exhibition in Sydney. Along with the technical aspects, a decisive factor for awarding the contract was the willingness of Rohde & Schwarz to keep added value in Australia and involve local resources.

The Australian Cape class patrol boats (CCPB) have been in service since 2013. The fleet will be enlarged by six new ships.

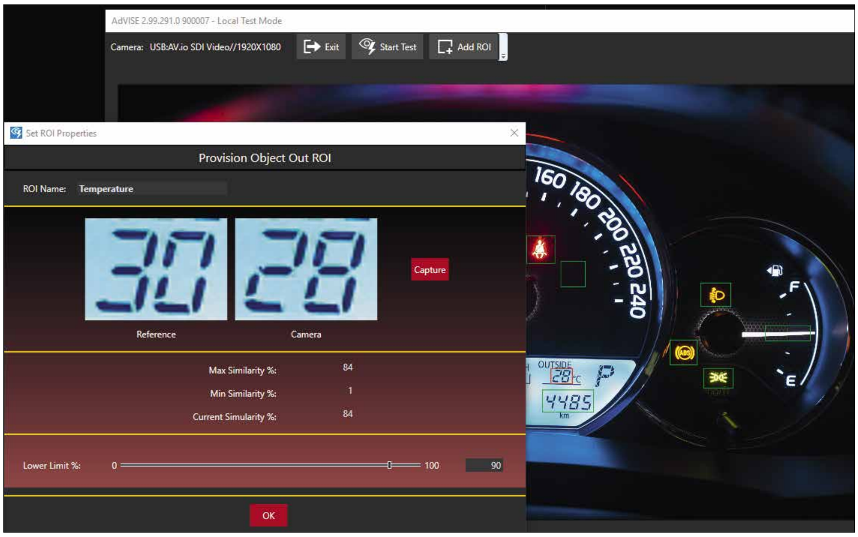
POWER SENSORS WITH NEW E BAND CONNECTOR

Up to now, millimeterwave components have been connected through type V coaxial connectors (for the V band from 50 GHz to 70 GHz) or type W coaxial connectors (for the W band from 75 GHz to 110 GHz), which have inner conductor diameters of 1.85 mm and 1 mm, respectively. The V band connector, which was introduced over 30 years ago, is sturdy and suitable for industrial applications, but it is limited to a maximum frequency of 70 GHz. It is therefore not a candidate for new applications such as automotive radar or 802.11ay WLAN. The frequency range of the W band connector starts too high for some important applications, and installing the connector requires fine mechanical precision. It also tends to come loose unexpectedly, so it needs constant attention during use and is not suitable for large-scale deployment.

In light of this, a group of experts from Germany's national metrology institute, Rosenberger Hochfrequenztechnik, Spinner and Rohde & Schwarz developed a connector that fills the gap between the V and W types. The key features of this type, specified for the E band between 60 GHz and 90 GHz, are an inner conductor diameter of 1.35 mm, a metric fine thread, a reliable pin gap when connected, and an integrated latching profile for optional push-pull coupling to protect the connection. The design was accepted in 2019 for the next release of the IEEE 287-2007 standard for precision coaxial connectors, and it has also been accepted by the IEC, which will publish it as IEC 61169-65.

The first instruments to be equipped with the new connector type are the R&S®NRP90T (USB) and R&S®NRP90TN (USB and

VISUAL MEASUREMENT MONITORING SOFTWARE



R&S®AdVISE 5.0 is used for electromagnetic susceptibility (EMS) measurements in the automotive industry and is also suitable for any other measurement where the DUT generates visible or audible responses.

Tedious measurements that require constant visual monitoring of the DUT or the instruments can now be conveniently automated using the new version 5.0 of the R&S®AdVISE inspection software. One of the main applications of R&S®AdVISE is electromagnetic susceptibility (EMS) measurements in the automotive industry, but it can also be used for any other type of measurement where the DUT produces a visible or audible response. A PC with adequate processing power and a high-resolution video camera with a DVI, HDMI™ or HD SDI interface are needed for operation. R&S®AdVISE supports up to four cameras simultaneously if their signals are combined in a multiviewer.

A typical task for R&S®AdVISE is monitoring vehicle dashboards and indicators during EMS measurements. The user can define up to 32 independent regions of interest (ROI) in the video image whose contents must be monitored and linked to messages. A wide variety of changes are possible. R&S®AdVISE detects switch-on and switch-off processes, variations in brightness and color, the presence or absence of objects, motion of analog pointers, and with integrated OCR, specific phrases and numbers including Chinese and Korean fonts. In addition, change rates and times can be compared with target values and motion-freeze situations can be detected. A new version 5.0 feature is the ability to include audio signals in the monitoring. Users can define spectral masks corresponding to the desired signal characteristic, which is much more effective than working with simple level monitoring. Together with other new features such as vibration compensation and automatic recalibration of the ROI set after changing camera settings, this makes R&S®AdVISE 5.0 the most versatile tool available in its class.

LAN) thermic power sensors for frequencies up to 90 GHz. Like previous models, they boast the highest accuracy and measuring speed of all commercially available sensors based on the same operating principle. They can be operated with an R&S®NRX display and control unit, a PC, or selected Rohde & Schwarz instruments.

The R&S®NRP90TN power sensor is the first instrument on the market with the new 1.35 mm coaxial connector.

ROHDE & SCHWARZ TRANSMITTERS ALSO DEPLOYED FOR THE SECOND DAB+ BUNDESMUX

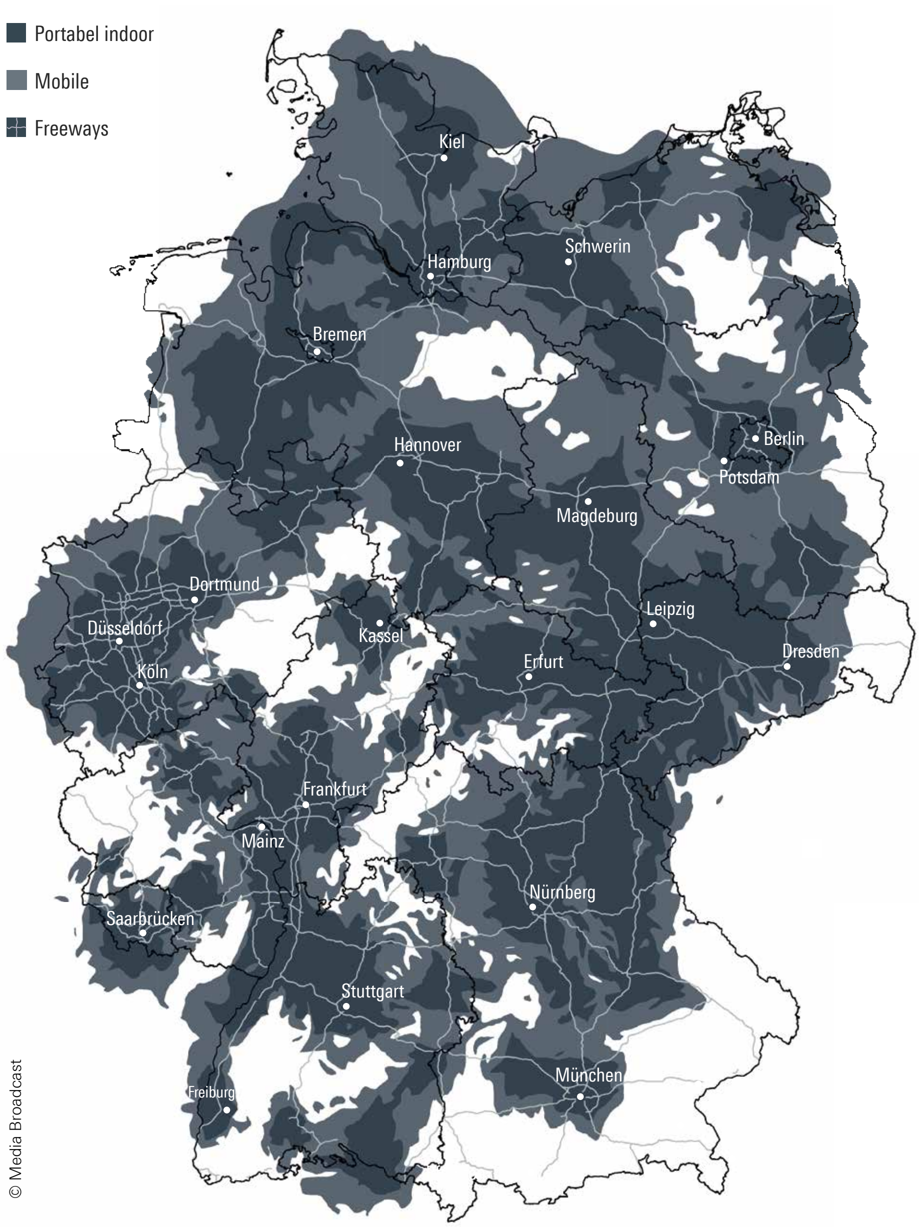
The popularity of digital radio in Germany has been growing for years, especially now that it can be received nearly everywhere, both outdoors and indoors. In 2020, the number of DAB+ receivers grew by more than 33 % compared with the previous year, and the use of DAB+ as the primary audio broadcasting distribution channel increased by 26 %. The restriction of new radio sales to DAB+ capable radio devices, effective from the end of 2020 in Germany, will further accelerate migration away from the FM band. In line with this deadline, the choice of channels is again boosted by the go-live of the second national DAB+ multiplex, commonly known as Bundesmux 2. Existing offerings have now been augmented by 16 private broadcasters, making at least 35 DAB+ channels available nationwide. Both Bundesmux systems are broadcast with Rohde & Schwarz transmitters.

The launch of the second Bundesmux was originally scheduled for early 2019, but a disappointed bidder contested the decision of the awarding body, the State Media Authority of Saxony. After settlement of the legal dispute in the beginning of 2020, the operation contract was awarded to Antenne Deutschland*, a consortium of Media Broadcast and Absolut Radio Digital. The network, initially consisting of 70 transmitters, started operation in early October. The transmitters are located in metropolitan areas and along the freeway network.

The coverage simulation (see figure) shows that these 70 transmitters already serve about 83 % of the population. In the dark gray areas the signal is strong enough for indoor reception. However, the network is probably still not complete with these 70 transmitters. Additional transmitters can be expected if the platform is commercially successful.

Antenne Deutschland subcontracted transmitter procurement in equal parts to Media Broadcast and Divicon Media. Each company was allocated 35 transmitter sites. They chose the same technology, even though this was not a requirement – both companies ordered 35 transmitters from Rohde & Schwarz, which were delivered on time despite the corona crisis.

The deployed R&S®THV9 and R&S®TMV9 models are tried and tested products with very low failure rates, and have been transmitting the broadcasts of the first DAB+ multiplex for years in trouble-free operation. This was also a strong reason to choose these transmitters for the second multiplex.



Initial coverage of the DAB+ Bundesmux 2. Indoor reception is possible in the dark gray areas.

* Antenne Deutschland is a consortium of Absolut Digital – a company of the Neue Welle radio corporation – and Media Broadcast – a subsidiary of freenet.

5G BROADCAST READY TO GO

5G Broadcast/Multicast – the technology for sending broadcast/multicast content to mobile devices via TV transmitters – is ready to go at the transmit end. With the launch of the R&S®BSCC2.0 broadcast service and control center, along with Rohde & Schwarz TV transmitters (which with suitable options have had this capability for some time), TV broadcasters and mobile network operators now have all the components they need to set up this service. This puts Rohde & Schwarz a step ahead of the game, since mobile devices with this capability are not yet on the market. However, commercially mature signal generation and transmitting equipment is essential for the development of device chipsets and wide area tests with high transmit power.

The R&S®BSCC2.0 upgrades a mobile core network by adding the ability to send broadcast and multicast data streams to mobile devices via TV transmitters. Video content already makes up the lion's share of data volume on mobile networks and will continue to grow. Live events can be transmitted much more efficiently with dedicated broadcasting technologies because only one channel is needed, regardless of the size of the audience, and an excellent quality of experience is ensured. 5G Broadcast/Multicast enables media rights owners to transmit live events in top quality to mobile devices, independent of the mobile network supply situation, as well as the option of time-shifted viewing (VoD, preloaded content) with suitable app support.

Live video streaming, however, is only one of many potential uses of 5G Broadcast/Multicast. This IP based service can distribute any type of data over a wide area, making it suitable for any application that addresses a large target group or a large number of similar devices, such as an IoT sensor network or a vehicle fleet, for software updates. In compliance with 3GPP Release 16, the R&S®BSCC2.0 supports the HLS and MPEG/3GP-DASH streaming standards as well as the FLUTE data transfer protocol.

As you would expect from the market leader in TV transmitters, particular attention has been given to the development of the transmitter interface. An R&S®BSCC2.0 can supply multiple transmitters with different streams at the same time, regardless of whether they operate in a single-frequency network or a multiple-frequency network. All current Rohde & Schwarz TV transmitters can be easily set up for 5G Broadcast/Multicast.

The R&S®BSCC2.0 broadcast service and control center upgrades a mobile core network by adding the ability to use TV transmitters to provide broadcast and multicast content. Current Rohde & Schwarz transmitters, such as the R&S®THU9evo (right), are ready for 5G Broadcast.

SAARLAND PUBLIC SERVICES PIONEER IT SECURITY

The State Chancellery of Saarland.

IT infrastructures in the public sector are subject to strict requirements for data protection and data security. This means that not only data at rest and local IT installations of public services must be protected, but also intersite data traffic. The state government of Saarland, under the leadership of its IT Service Center (ITSC), therefore launched a project with the aim of equipping its public services with the latest cryptotechnology for secure site networking. The implementation was entrusted to the project partners T-Systems and Rohde & Schwarz Cybersecurity. With the multipoint-to-multipoint encryption system, consisting of a central management component and distributed high speed encryption devices, Saarland is now one of the first German federal states with an advanced layer 2 encryption solution that fulfills the strict requirements of the Federal Office for Information Security for the transfer of material classified as restricted. In the future, every site of a state public service will be equipped with a device for real-time end-to-end encryption of data traffic with other sites. Several other federal states are now also preparing security systems based on the same technology for deployment in their state administration networks.

ROHDE & SCHWARZ CYBERSECURITY RESEARCHES NEXT GENERATION ENCRYPTION

Quantum computers will be able to solve problems that current systems cannot handle, and they will make the asymmetrical encryption algorithms underlying current public key methods insecure. At the same time, however, quantum technology, using post-quantum cryptography and quantum key exchange, offers ways and means to continue communicating securely. Quantum computers are still several years away from being able to process meaningful tasks, but quantum cryptography systems are already in operation. What is needed now is detailing of the various approaches and development of products suitable for everyday use.

Rohde & Schwarz Cybersecurity is contributing its crypto expertise to several quantum technology research projects.

The **HQS** (hardware based quantum security) project funded by the Federal Ministry of Education and Research, which ended in October 2020, focused on the development of hardware for quantum based key exchange in combination with conventional encryption systems and the implementation of high-security communications on this basis. Optical communications both through fiber-optic cables and through the air were researched.

The goal of the European **OpenQKD** project (QKD = quantum key distribution) is to strengthen Europe’s position in the field of quantum communications. This includes setting up test beds to evaluate QKD usability for various use cases, better meshing of the industrial and scientific sectors, creation of an innovation ecosystem, fostering of quantum technology commercialization, and provision of small demonstrators to introduce network functionality and use cases to potential end users and relevant interest groups.

The **QuNET** project, initiated in November 2019, is building a pilot network for quantum communications in Germany, intended to provide secure and tamper-proof data transmission. R&S®SITLine encryption devices will also be used with a QKD interface developed in the HQS project. As a member of the advisory board, Rohde & Schwarz Cybersecurity is active in the project funded by the Federal Ministry of Education and Research, along with the Fraunhofer Society, the Max Planck Society and the German Aerospace Center.

IN A CLASS OF ITS OWN

The first midrange vector signal generator up to 44 GHz

In response to rising user numbers and data volumes, boosted by IoT products in the future, the mobile communications industry is penetrating into ever higher frequency ranges because only they offer frequency bands with the required bandwidth. Test and measurement equipment, including vector signal generators, supports this trend over the entire value chain. While top-class features are essential in R&D, the maxed-out specs and extensive configuration options of development instruments are not necessary for end-of-line test stations in production. The new R&S®SMM100A is tailored to this need. Technologically related to the R&S®SMW200A, it shares some of the latter's high-end features but dispenses with aspects such as extremely broad bandwidth, a second channel and fading capability.

Standard	Frequency	Maximum channel bandwidth
5G New Radio FR1	< 7.125 GHz	100 MHz
5G New Radio FR2	> 24.25 GHz	400 MHz
Wi-Fi 6E (IEEE 802.11ax)	< 7.125 GHz	160 MHz
Wi-Fi 7 (IEEE 802.11be)	< 7.125 GHz	320 MHz
HRP UWB (IEEE 802.15.4z)	< 10.6 GHz	500 MHz

High-performance wireless standards are increasingly operating at frequencies above 6 GHz.

For current and upcoming standards

Both 5G and upcoming WLAN standards operate in part above 6 GHz. With a choice of upper frequency limits (6 GHz, 7.5 GHz, 12.75 GHz, 20 GHz, 31 GHz and 44 GHz), the R&S®SMM100A is ready for this, making it unique among currently available midrange signal generators. The modulation bandwidth is also variable and can be extended by keycode from 120 MHz to 240 MHz, 500 MHz or 1 GHz. Real-time generation of standard-compliant signals (internal baseband) for 5G, LTE, WLAN and many other standards can also be activated by keycode. An arbitrary waveform generator with up to 2 Gsample memory depth enables playback of user-defined signals, the typical operating mode in production.

Performance to spare

With a carrier frequency of 1 GHz and 20 kHz offset, the SSB phase noise of the R&S®SMM100A is less than –129 dBc, and typically even 5 dB lower. The measured amplitude frequency response deviates by less than 0.4 dB over the maximum modulation bandwidth of 1 GHz. These values directly impact the modulation and adjacent channel characteristics, as reflected in the EVM and ACLR performance. For example, the error vector magnitude with a 100 MHz wide 5G NR signal at 28 GHz (conforming to 3GPP test model 3.1) is less than –42 dB (0.8 %), significantly better than the requirement of the standard. This is also true of the ACLR performance: –69 dBc with a 10 MHz wide LTE test signal conforming to 3GPP test model 1.1.

Excellent performance is an essential requirement for a microwave signal generator, and delivering high output power is an important part of this. With up to +18 dBm output power at 29 GHz, the R&S®SMM100A fully meets this requirement, and a respectable +15 dBm is available at 40 GHz.

All in all, the features of the R&S®SMM100A put it in a class of its own in the midrange signal generator segment. It is a very versatile instrument for the mobile communications industry, both in production and on the lab bench – and at a very attractive price.

Michael Kaltenbach

5G DEVICE TEST SYSTEM

On the long road from a prototype in a development lab to a production-ready version, mobile network devices undergo countless tests of many different types. This is especially true for 5G with its many new features. The mobile communications industry is therefore looking for user-friendly T&M equipment to make their testing as straightforward as possible. The R&S®CMX500 tester fills the bill.

Radio communication testers are king of the hill in the mobile communications T&M world. Although other types of test equipment are also used along the value chain, such as signal generators and signal analyzers, radio communication testers have almost the same set of functions on board, albeit not with the same depth and precision. They must be able to simulate a mobile network for the DUT, with all of its functional diversity, and to initiate, measure and evaluate every possible interaction between a smartphone or another mobile device and the network. The tests encompass three entirely different radiocommunications layers: physical, which must remain within tight tolerances, logical (signaling), which structures data exchange, and application, which is becoming increasingly important in the internet era. The R&S®CMX500 5G tester does all of these and features a unique operating concept for easy management of complex test tasks. A uniform user interface allows users to configure exactly the functions and displays they need for the task at hand, such as RF parameter measurements, protocol tests, performance analyses, application tests and extensive validation test runs. The look and feel is always the same, making it much easier to create a homogeneous test landscape along the value chain.

Seamless integration into existing test ecosystems

The R&S®CMX500 adds 5G NR capabilities to existing test systems for LTE and legacy standards. Users already operating an R&S®CMW500 or R&S®CMWflexx test system can continue using it and simply add an R&S®CMX500 tester and

Fig. 1: The R&S®CMX500 tester and the R&S®CMQ500 test chamber allow detailed analysis of 5G devices and modules.

R&S®CMQ500 test chamber (Fig. 1). This setup is suitable for testing all 5G NR use cases in the framework of 3GPP Option 3x and Option 2 in both non-standalone (NSA) mode, which requires an LTE substructure, and pure 5G standalone (SA) mode in all 5G frequency bands (FR1 and FR2).

One for all: the R&S®CMsquares test environment

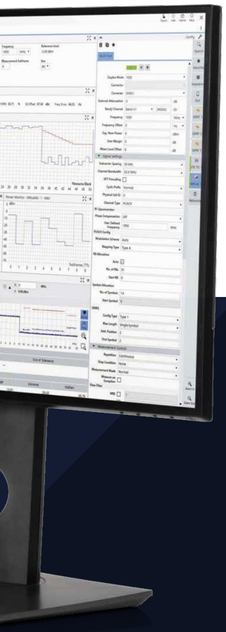
The R&S®CMX500 does not have any controls. Its functions are accessed with the R&S®CMsquares software, a browser based test environment that uses advanced web technologies. R&S®CMsquares supports manual testing in an interactive callbox mode as well as automatic sequencer-driven tests. It includes tools to support all the practical tasks of these automatic test programs, such as configuring the emulated 5G network, measuring RF parameters, measuring IP data throughput and analyzing protocol stack messages over all layers.

The home screen of the graphical user interface is a dashboard with direct access to the key tools and work environments, whose squares give the software its name (Fig. 2). From the home screen, the user can build a complete test environment in just a few steps. The first step is creating the 5G network, such as an NSA network with LTE anchor cells or a pure 5G NR network, as a virtual network layout in the network square by using drag and drop. Next, the user quickly switches to the settings menu of the newly created LTE or 5G cells, where they can access all key parameters such as frequency bands, bandwidths, antenna interconnections and cell transmit power (Fig. 3). Typical network data services can then be added and configured in the services square to perform data tests, simulate IMS VoLTE and VoNR calls, and enable data links to the internet via the integrated DNS server.

Once the virtual network has been set up, the focus shifts to the DUT, which is displayed at the center of the test environment square (Fig. 3). Device-specific data such as SIM card profiles and the antenna configuration can be entered here. During tests, the square also displays the real-time status of the connection between the device and the network as well as other information about the 5G device that is important for the user, such as its IP address assigned by the network.

The user can then access the various measurement applications in the workspace window. Advanced web technologies enable a very free, targeted combination of RF, protocol and application measurements. The presentation can also vary, with a choice of a graphical or tabular display depending on the required level of detail.

A popular test scenario is checking all the LTE and 5G bands supported by the device as well as mixed 5G/LTE operation (dual connectivity, EN-DC). This can be done with the sequencer – a campaign manager included in



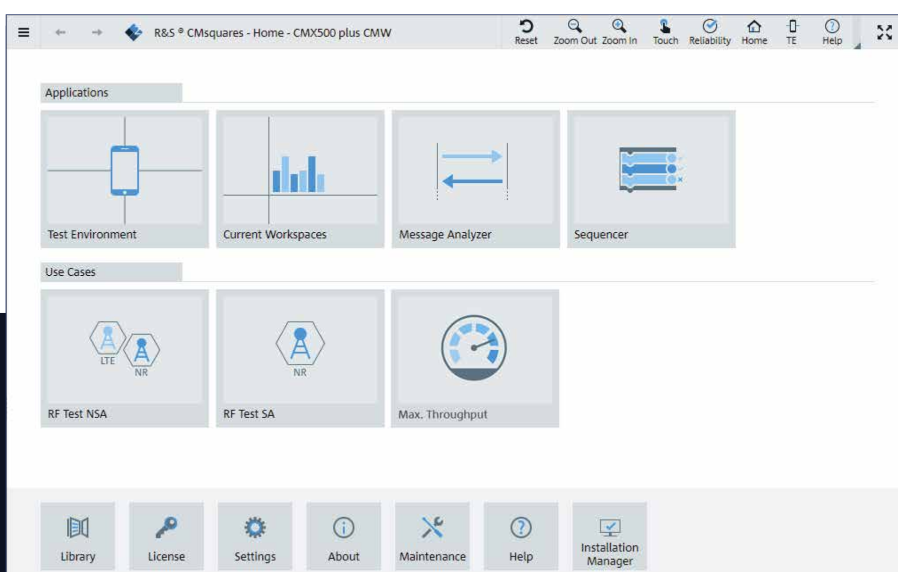


Fig. 2: All function groups can be accessed from the R&S®CMsquares home screen.

R&S®CMsquares that runs predefined test scenarios and enables users to create their own scenarios (Fig. 4). Graphically displayed test sequences can be created from the included function blocks and can even contain user-defined scripts developed in the Python API environment of R&S®CMsquares (Fig. 5). User

Fig. 3: The DUT and its parameters are at the center of the test environment square. Also available are the configured network (top left and right side) as well as information on the services active in the network (bottom right) and the selected measurement functions (bottom left). The user can configure the size of all the windows. A nice feature is that the stylized smartphone also acts as an adjustment handle for changing the window layout with a single mouse motion.

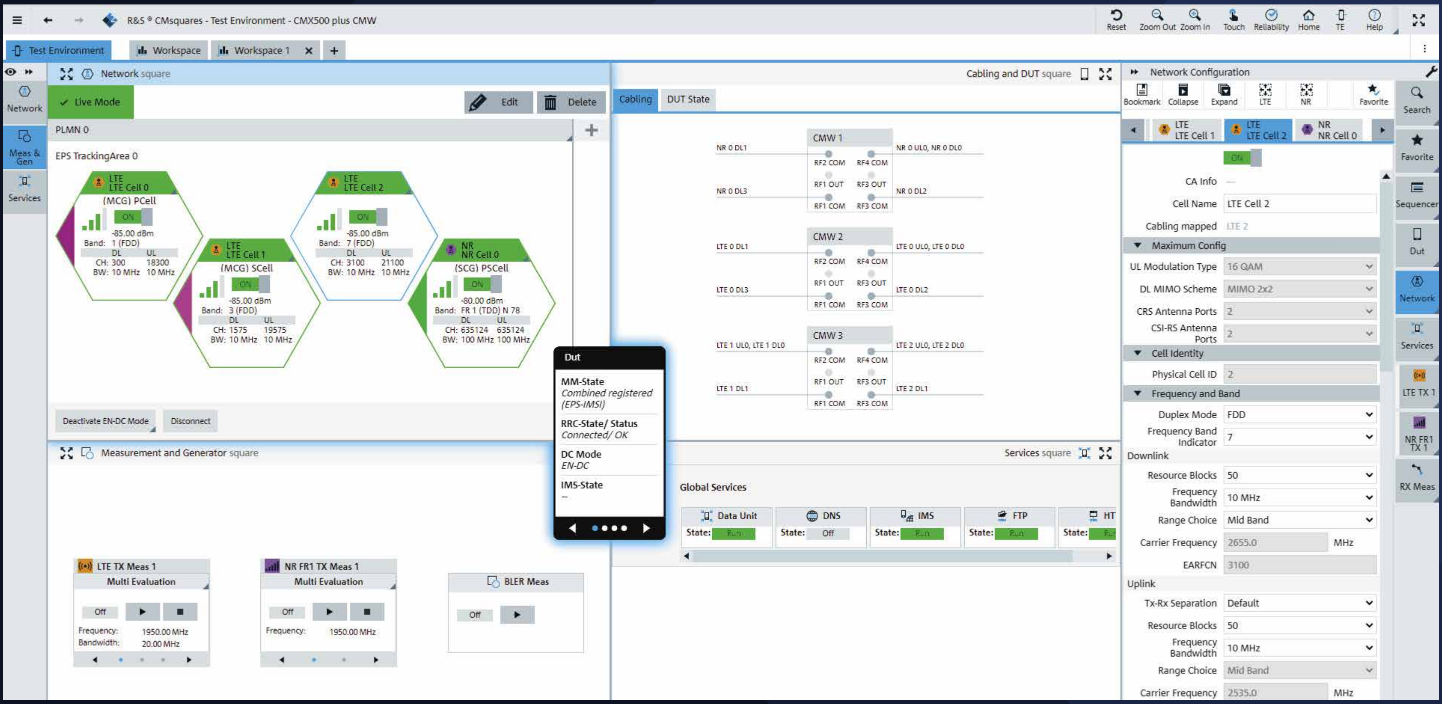
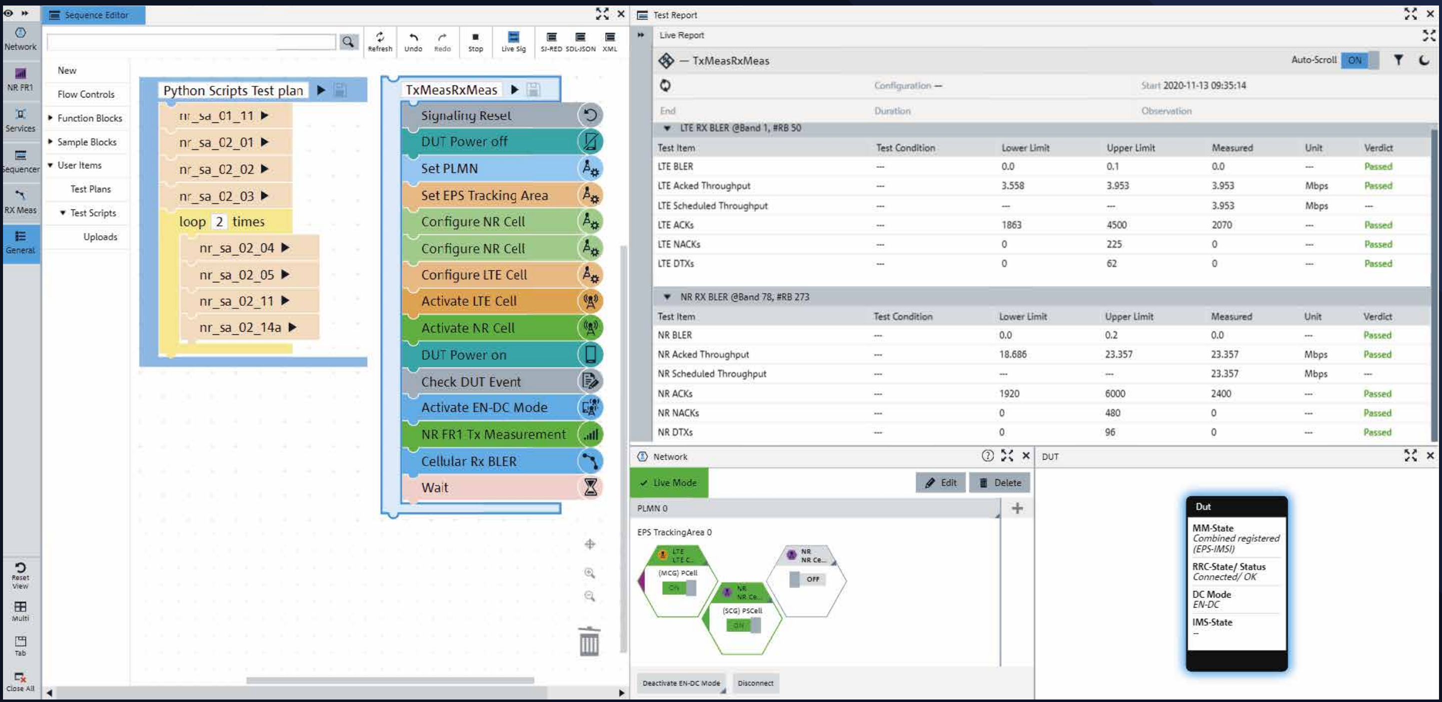


Fig. 4: The sequencer is for running user-created test programs and 3GPP test cases.



scripts can be named and saved in the sequencer library, and they can be assigned to softkeys for quick access. The automatic and interactive modes are fully synchronized, making it easy to quickly switch back and forth between script-driven tests and manually triggered actions during development – a very useful feature.

Fig. 5: Scripts written in the integrated Python development environment can address all device functions.

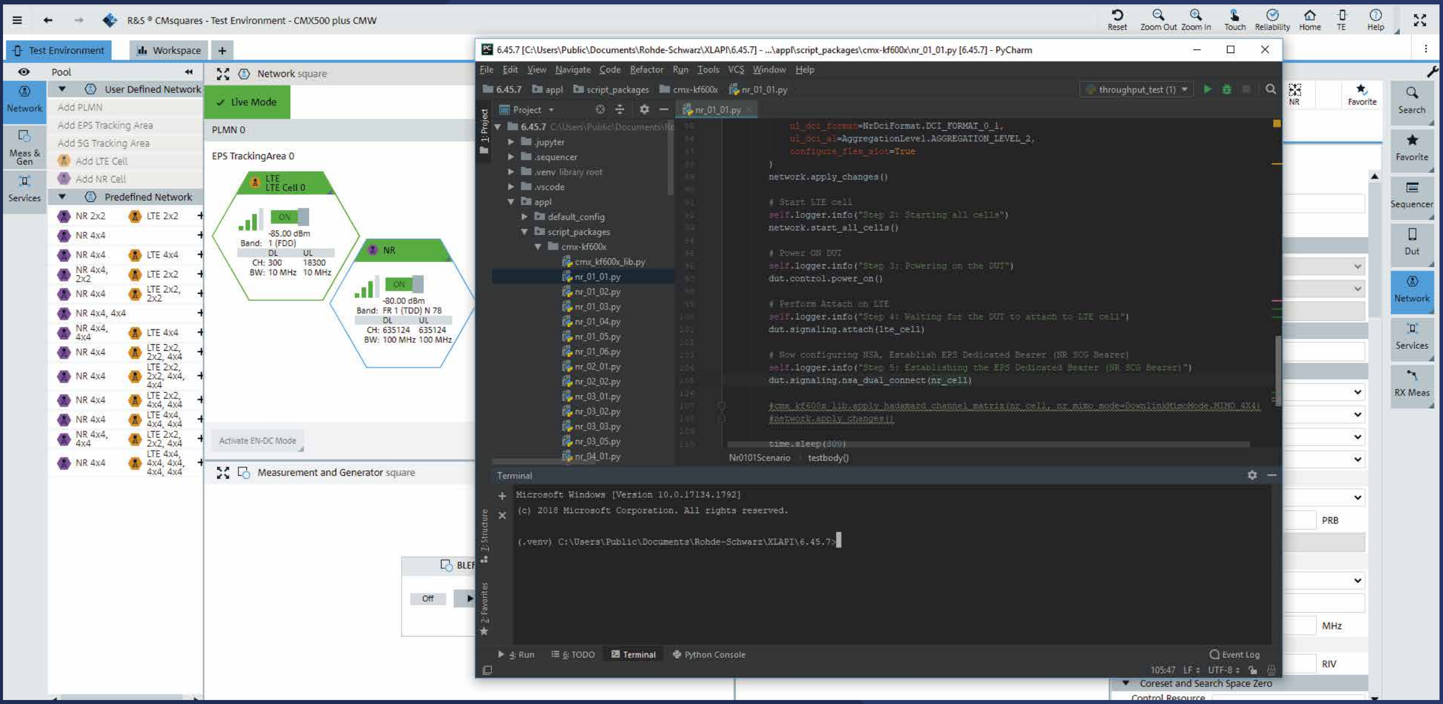
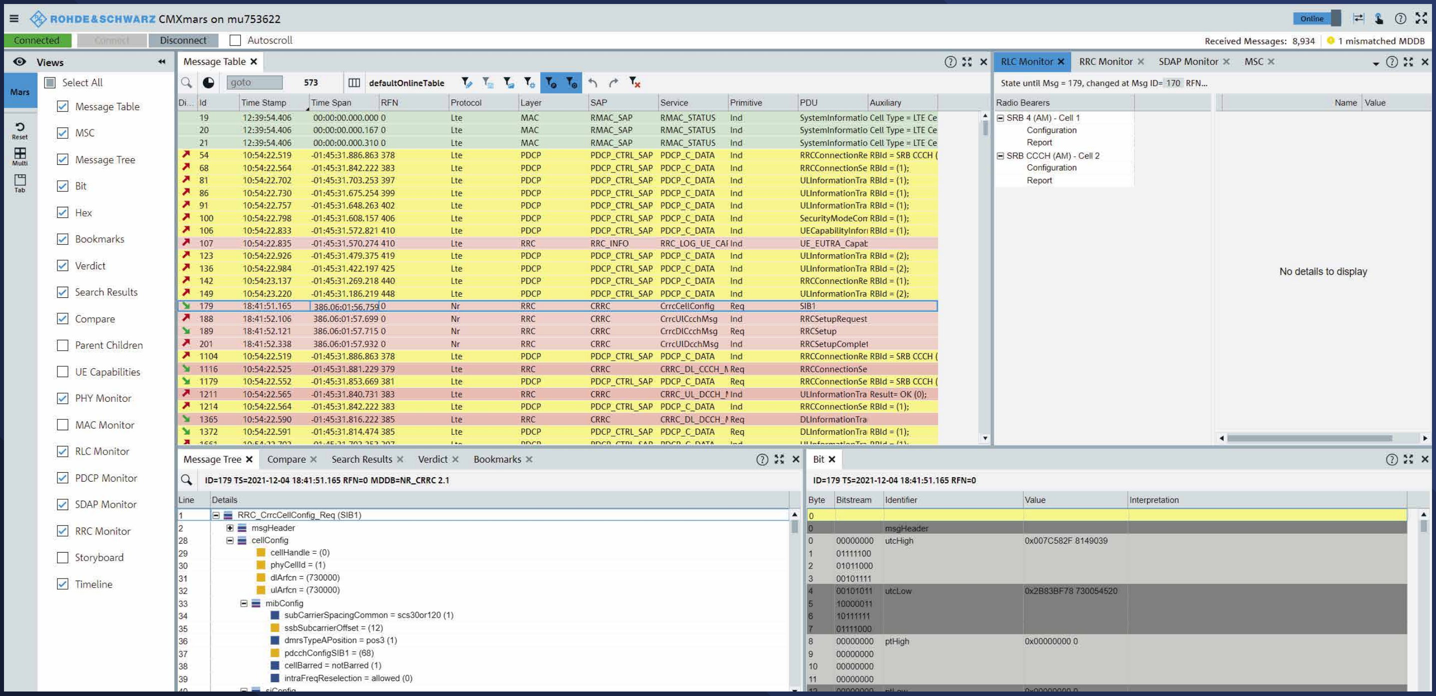


Fig. 6: The message analyzer square allows all messages exchanged between the device and the network to be viewed in real time and analyzed in detail.



Every test, whether initiated interactively, controlled by the sequencer or remotely controlled via SCPI, can be analyzed for errors using the real-time display of protocol messages exchanged via the air interface. The message analyzer square presents these messages in various levels of detail down to the bit level (Fig. 6), so errors in the LTE or 5G protocol stack in any layer can be tracked down quickly. All messages exchanged between the DUT and the emulated network are saved in logs for offline analysis.

The basics: RF measurements

High-performance data transmission via the air interface is only possible with devices that have perfect transmit and receive characteristics. The transmit power must remain within defined limits and the signal quality must meet minimum requirements, not only to ensure the quality of the device connection but also to avoid interference with other users.

The key RF transmitter measurements of the 5G standard, such as modulation quality, transmit power and spectral parameters, can be performed in all test modes (Fig. 7), as well as receiver measurements such as BLER.

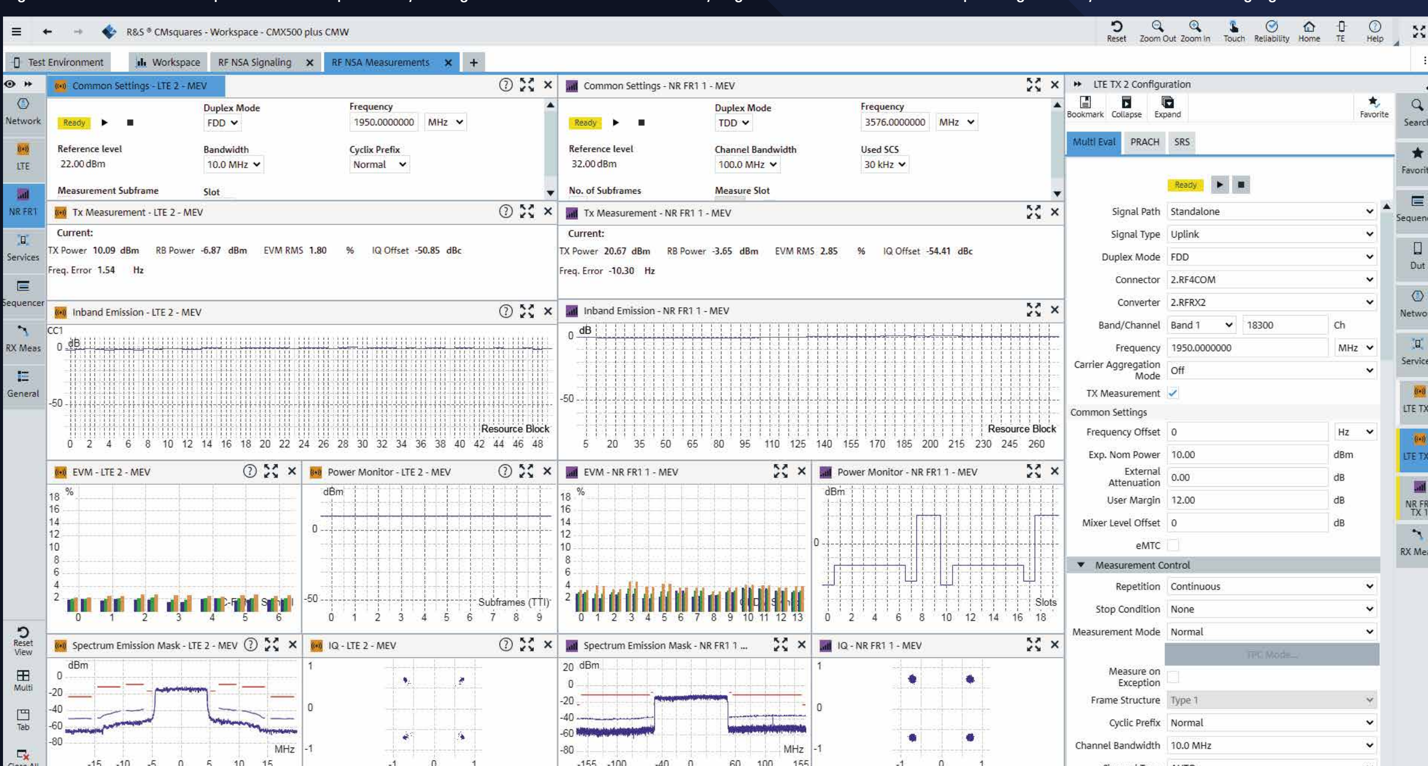
3GPP specifies extensive test cases for transmitter and receiver measurements in TS 38.521 sections 6 and 7. These are included ready-made in the sequencer and can be run there.

Putting it all together: application tests

Mobile devices are integrating an increasing number of internet based services and applications. With its all-IP architecture, 5G is perfectly equipped for this. IP services in mobile communications, which includes voice transmission with 5G NR, are increasingly being reflected in device test programs. R&S®CMsquares supports this with a complete end-to-end test environment.

IPv4/6 configuration, throughput measurements with iPerf and directly deployable web, FTP, DNS and IMS services enable extensive device tests at the IP level. The user-friendly data test solutions bundled in the services square dramatically reduce test times thanks to reproducible test conditions, and effectively support achievement of the required quality of service. The latter is important to device manufacturers and in particular network operators, who market the devices and need to be confident of their functionality based on their own lab tests.

Fig. 7: The measurement square visualizes previously configured measurements in a clearly organized view and allows setup changes at any time without changing screens.



Meeting the test needs of network operators

Successfully passing a series of 3GPP test cases is a necessary requirement for trouble-free device operation in a real network, but is not necessarily sufficient. The many options for fashioning a 5G network (FR1, FR2, NSA, SA, etc.) and providing network services create countless functional crosslinks and dependencies that can differ from network to network or country to country and cannot be dealt with using standardization. New, attractive features and functions can be launched on the market before suitable mandatory 3GPP tests are available, and the rapidly growing field of IP applications is simply not addressed by 5G standardization.

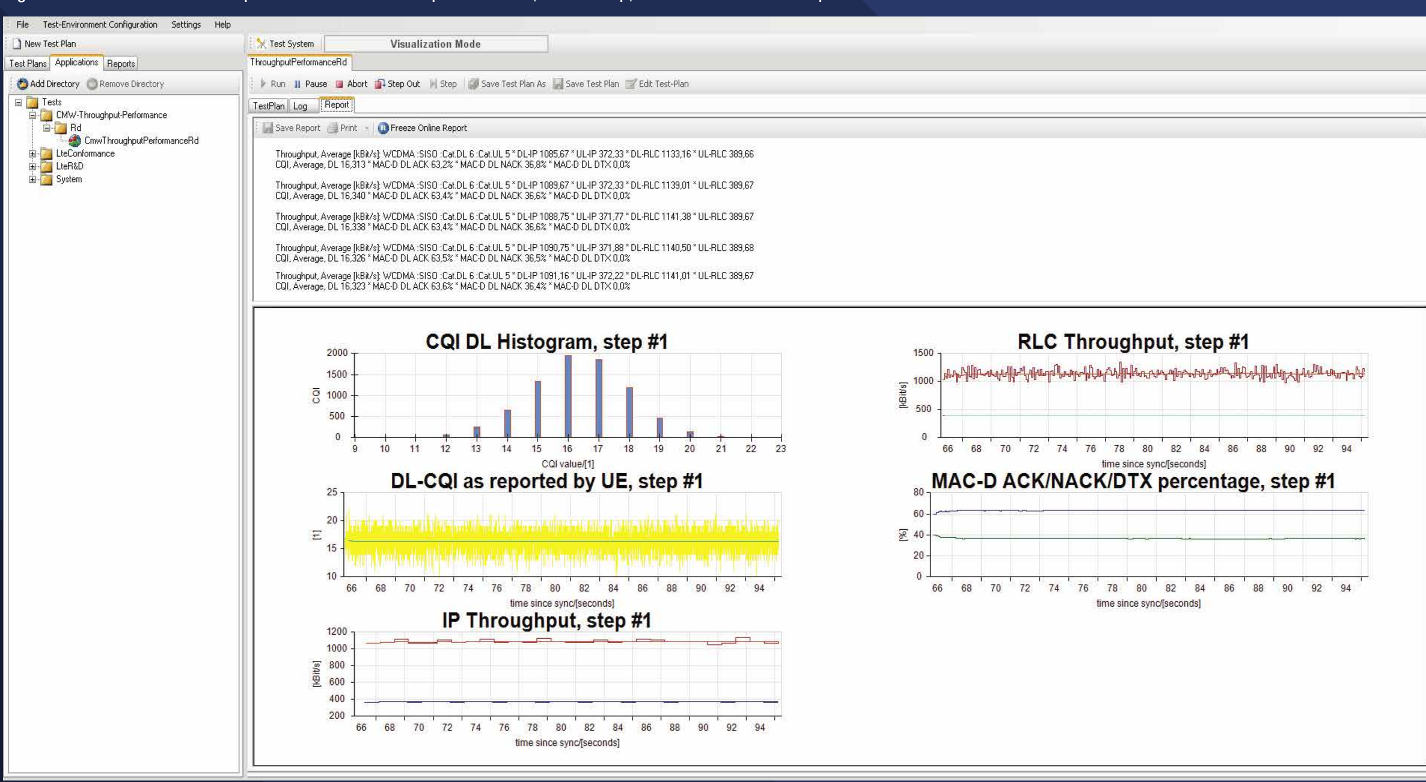
Network operators therefore devise their own extensive test plans to cover their specific needs, known as carrier acceptance tests. Device manufacturers, who naturally want to sell their products in the large networks, subject their devices to these tests, as do network operators. A radio communication tester that does not support these tests would be functionally incomplete, so Rohde & Schwarz works closely with various tier 1 network operators to make their requirements testable. This is also supported by the R&S®CONTEST test platform (Fig. 8), which is deployed in large type approval test systems. Typical tests include VoNR, the US emergency call service E911, location based services (LBS), Rich Communication Services (RCS, e.g. group chat, enriched calling, file sharing) and data throughput measurements with various MIMO configurations.

Summary

The R&S®CMX500 radio communication tester is a comprehensive 5G test solution. All commercially relevant versions of the 5G NR standard (NSA, SA, FR1, FR2) and all test dimensions (physical, protocol, application) and carrier-specific special features can be easily tested. The R&S®CMsquares test environment has been designed with special care and attention. It combines a uniform look and feel over a wide variety of test functions with a high degree of customization and a short learning curve, enabling users to work efficiently.

Aytac Kurt

Fig. 8: The R&S®CONTEST test platform for carrier acceptance tests (R&S®NetOp) extends the R&S®CMsquares test environment.



EVEN FASTER

An outline of the upcoming 802.11be WLAN standard

Standardization of the current WLAN generation 802.11ax, also known as Wi-Fi 6 or High Efficiency (HE), is nearly finished. The main goal of 802.11ax is (more) efficient utilization of the spectrum, especially in scenarios with high user density. The market penetration of 11ax devices is still relatively low, but work is already underway on the next generation 802.11be, also known as Wi-Fi 7 or Extremely High Throughput (EHT). While the main aim of 802.11ax is better servicing of users in multi-user operation, 802.11be again focuses on increasing data throughput.

Despite the different focuses of 802.11ax and 802.11be, the physical layer (PHY) will inherit many aspects of 802.11ax, such as OFDMA and MU-MIMO. However, a boost is in the works for the key parameters that determine throughput. For instance, higher order modulation schemes will be supported (up to 4096QAM), the number of spatial streams will be increased (up to 16) and the channel bandwidth will be enlarged (up to 320 MHz). Additional improvements will also be introduced in 802.11be. The OFDMA tone plan will be modified to improve frequency availability, and grouping of multiple subcarrier packets (resource units) will be possible for devices that need high throughput. The data preamble will have a new field to improve compatibility between different WLAN versions and simplify data handling in future versions.

The key 802.11be PHY innovations are outlined below.

Status and documents

The 802.11 task group publishes updates on the status of their activities at [1]. On January 19, 2021, draft version 0.3 of the 802.11be standard amendment was released for voting members of the task group. This is a preliminary draft with a number of open questions. Version 1.0 with answers to these questions is expected to be ready in May 2021. The stable draft version 2.0 is planned for March 2022. This article refers to the draft version 0.1.

Although 802.11 draft versions are only available to voting members of the task group, the 802.11be specification framework document (SFD) is freely available [2]. It contains the features and requirements that have been agreed by the members of the task group. Most of the information in this article is based on version 15 of the SFD.

Goals and features of 802.11be

The main goal of 802.11be is to increase throughput in the unlicensed bands from 1 GHz to 7.125 GHz. Specific goals are stated in the project approval request [3]:

- Provision of at least one operating mode that enables throughput greater than 30 Gbit/s measured at the MAC access point (SAP)
- Backward compatibility and coexistence with older 802.11 devices operating in the 2.4 GHz, 5 GHz and 6 GHz bands
- Definition of at least one operating mode with better worst-case latency and jitter than 802.11ax
- Attaining higher throughput with lower latency for use cases such as video, virtual and augmented reality, gaming, remote work and cloud computing

Key parameters of the physical layer (PHY)

802.11be devices will be able to operate in the 2.4 GHz, 5 GHz and 6 GHz bands. A device must be able to interoperate in these bands with other devices that conform to the physical layer specifications of previous standards. Accordingly, the tables in Fig. 1 show many similarities between 802.11ax and 802.11be.

Preamble with version ID

802.11be defines two PPDU formats for transmitting data: a trigger based (TB) PPDU and a MU PPDU. The TB PPDU serves the same purpose as in 802.11ax, i.e. for a transmission that is a response to a triggering frame from an AP. The MU PPDU is used for transmissions to a single user or to multiple users. This is different from 11ax, which has a separate PPDU format for transmissions to a single user. The MU PPDU has two modes: OFDMA and non-OFDMA.

The preamble of 802.11be PPDUs is very similar to the preambles of previous PHYs. It contains legacy fields (L-STF, L-LTF, L-SIG and RL-SIG) to ensure coexistence and backward compatibility, as well as fields specific to 802.11be such as U-SIG, EHT-SIG, EHT-STF and EHT-LTF (Fig. 2).

	802.11n	802.11ac	802.11ax	802.11be
Channel bandwidth (MHz)	20, 40	20, 40, 80, 80 + 80, 160	20, 40, 80, 80 + 80, 160	20, 40, 80, 80 + 80, 240, 160 + 160, 320
Subcarrier spacing (kHz)	312.5	312.5	78.125	78.125
Symbol duration (µs)	3.2	3.2	12.8	12.8
Cyclic prefix (µs)	0.8	0.8, 0.4	0.8, 1.6, 3.2	0.8, 1.6, 3.2
MU-MIMO	no	in downlink	in uplink and downlink	in uplink and downlink
Modulation	OFDM	OFDM	OFDM, OFDMA	OFDM, OFDMA
Data subcarrier modulation	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM, 256QAM	BPSK, QPSK, 16QAM, 64QAM, 256QAM, 1024QAM	BPSK, QPSK, 16QAM, 64QAM, 256QAM, 1024QAM, 4096QAM
Coding	BCC (mandatory) LDPC (optional)	BCC (mandatory) LDPC (optional)	BCC (mandatory) LDPC (mandatory)	BCC (mandatory) LDPC (mandatory)

Fig. 1: Comparison of 802.11be and previous WLAN standards.

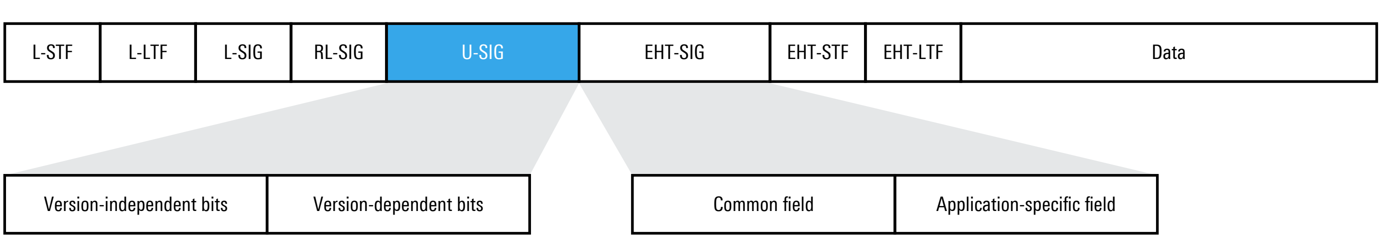


Fig. 2: 802.11be preamble with the new U-SIG field.

The new U-SIG field will also be present in all future 802.11 versions. It contains version-dependent and version-independent bits such as the PHY version. Including the PHY version in the version-independent bits enables 802.11be devices and future devices to easily determine the packet type. In earlier generations, increasingly complicated automatic recognition markers were developed to distinguish between packet versions, such as 802.11ac versus 802.11ax.

In addition to the PHY version, other version-independent information includes:

- ► Downlink/uplink flag
- ► BSS color
- ► Bandwidth
- ► TXOP (duration of channel use by the device)

BW	RU combinations	Mandatory in non-OFDMA for:	Mandatory in OFDMA for:
80 MHz	484 + 242	AP, STA	uplink: only non-AP STA
160 MHz	996 + 484	AP, STA	uplink: only non-AP STA
	996 + (484 + 242)	AP, STA	not supported
320 MHz	4 × 996, 3 × 996 + 484, 3 × 996	AP, STA	uplink: only non-AP STA

Fig. 4: Multiple resource unit (MRU) combinations required to be supported by access points (AP) and stations (STA).

Multiple resource units

In 802.11ax, only one frequency packet (resource unit, RU) in the service bandwidth can be assigned to each device. 802.11be will enable multiple resource units (MRU) to be assigned. An advantage of MRUs is more flexibility for efficient spectrum use. However, MRU assignment must be signaled to the station, which increases the overhead, and a large number of possible RU combinations leads to higher complexity in the access points and stations. 802.11be therefore limits this number. Large RUs with 242 or more carriers (RU 242, RU 484, RU 996) can only be combined with other large RUs, and small RUs with fewer than 242 carriers (RU 26, RU 52 and RU 106) can only be combined with other small RUs. In addition to this restriction of RU combinations, 802.11be only supports a subset of the possible combinations of small RU sets. The row labeled RU 78 in Fig. 3 shows the allowable combinations of RU 26 + RU 52 in an 80 MHz channel.

The 802.11be standard prescribes support for broad MRU combinations, depending on the transmission bandwidth capability of the device (see Fig. 4), because they are important for coexistence with other technologies and flexible and efficient use of frequency resources.

Tone plan (subcarrier plan)

The 802.11be tone plan is based on the tone plan of 802.11ax, but with some differences. The subcarrier spacing, 78.125 kHz, is the same in both standards, as are the 20 MHz and 40 MHz tone plans. The 80 MHz tone plan, however, differs from the tone plan for 802.11ax (see Fig. 5). If the 80 MHz segment is punctured or is used with an OFDMA transmission, the tones are shifted.

This small change eliminates potential problems with the 802.11ax tone plan:

- ► ETSI regulatory changes to frequency mask requirements: For 802.11, ETSI recently introduced stricter mask requirements for uplink and downlink that allow a maximum level of only –20 dBr at a distance of 1 MHz

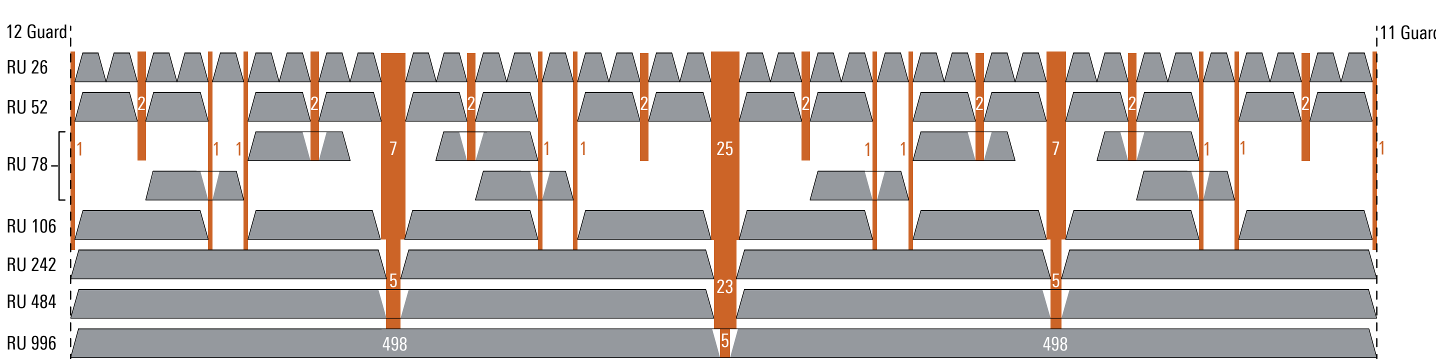


Fig. 3: Resource units in an 80 MHz channel. Stations (STA) must also support the combination RU 26 + RU 52 (RU 78).

from the edge of a 20 MHz channel. Simulations have shown that it may be necessary to leave an RU 242 unused to meet the new mask requirements.

- Some of the RU 26 blocks in the 802.11ax tone plan are close to DC carriers or a band edge. In practice, however, these RU 26 blocks often remain unused because it is easier for an OFDMA scheduler to ignore them [4].
- For the 80 MHz and 160 MHz EHT non-OFDMA transmissions, the tone plan is the same as the HE tone plan. However, the pilot locations are changed to match the pilot locations of the EHT OFDMA 80 MHz transmission.

Summary

Although WLAN devices conforming to the 802.11ax standard are only now becoming available, the draft v1.0 of the next generation standard 802.11be is expected to be ready in May 2021. In contrast to 802.11ax, which targeted improving efficiency, 802.11be again aims for higher data rates. For this, it uses larger bandwidths, higher order modulation schemes, future-oriented signaling and more flexible handling of frequency packets. As with previous standards in the 802.11 family, Rohde & Schwarz will provide suitable T&M equipment for all product groups where needed

Werner Dürport, Lisa Ward

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[2] mentor.ieee.org/802.11/documents?is_dcn=1262&is_group=00be
[3] development.standards.ieee.org/myproject-web/public/view.html#pardetail/6886
[4] mentor.ieee.org/802.11/dcn/20/11-20-0666-02-00be-80mhz-ofdma-tone-plan.pptx

– Rohde & Schwarz white paper: IEEE 802.11ax technology introduction (search for "1MA192")

Abbreviations

AP	Access point
BSS	Basic service set
BW	Bandwidth
DC	DC carrier (unused subcarrier)
DL MU	Downlink multi user
LTF	Long training field
MAC	Medium access control
MRU	Multiple resource unit
MU-MIMO	Multi-user MIMO
OFDMA	Orthogonal frequency-division multiple access
PPDU	Protocol packet data unit
PHY	Physical layer
RU	Resource unit
SAP	Service access point
SIG	Signal field
STA	Station
STF	Short training field
SU	Single user
TB	Trigger based
Tone	Subcarrier
TXOP	Transmission opportunity
U-SIG	Universal signal field

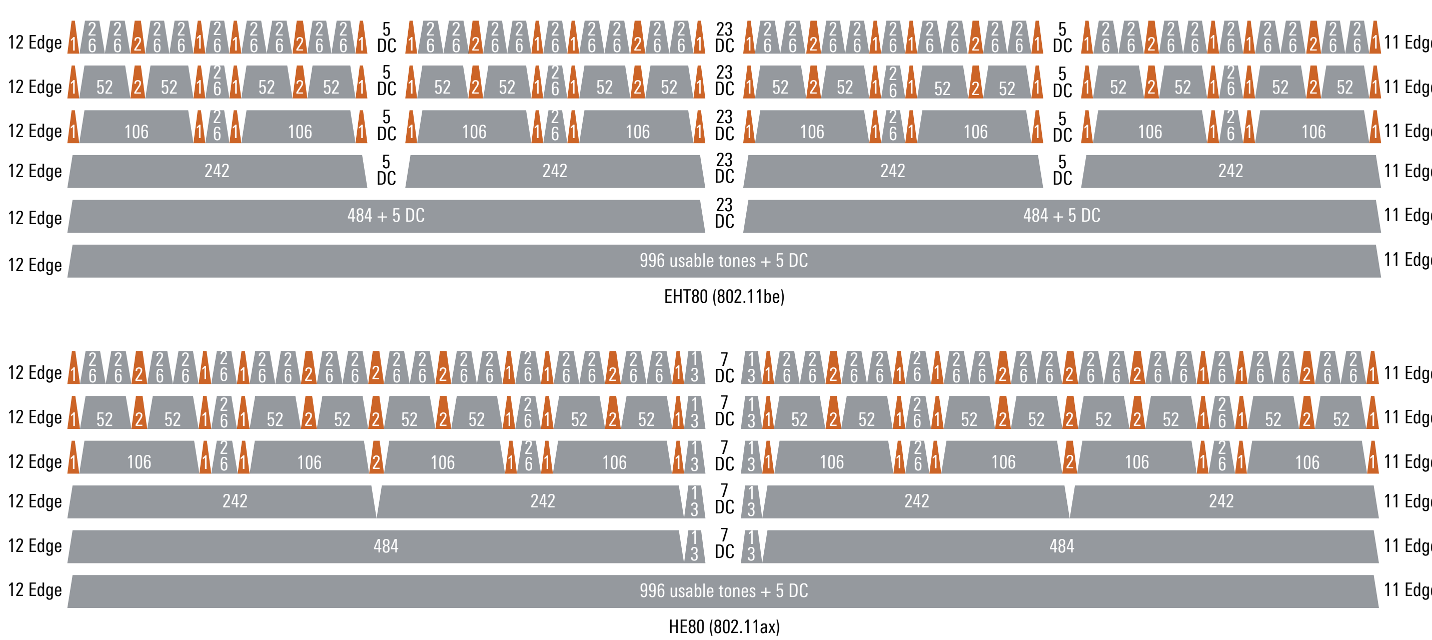
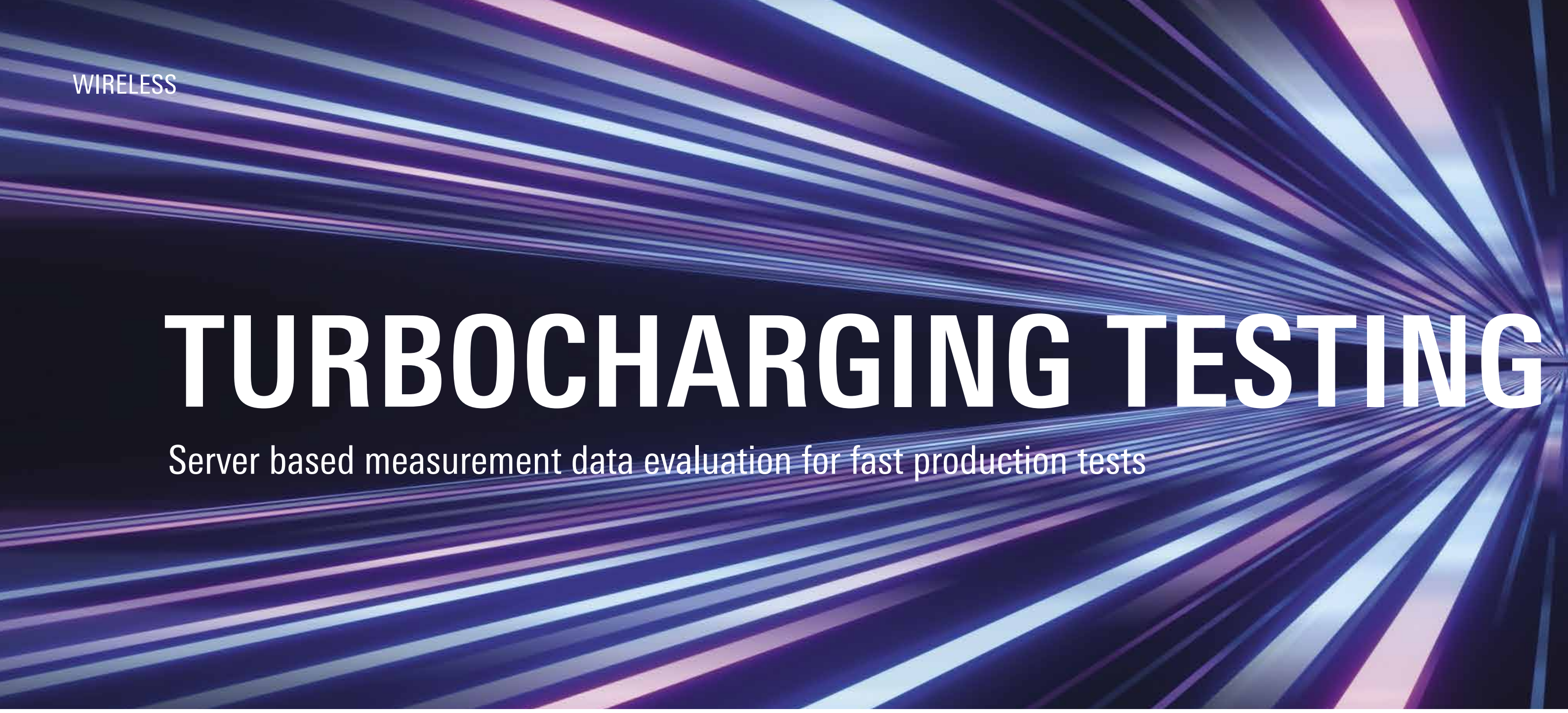


Fig. 5: Comparison of tone plans for 80 MHz channels in 802.11ax (HE80) and 802.11be (EHT80). The orange tones are unused.



TURBOCHARGING TESTING

Server based measurement data evaluation for fast production tests

Compliance with the tightly toleranced specifications of advanced RF products, such as mobile network base stations, is only possible with random-sample measurement and calibration of devices in production. Experience shows that the level of complexity in testing rises with each new generation. With 5G, the test effort is driven not only by the additional frequency ranges, broader frequency bands and number of antenna paths to be calibrated due to massive MIMO, but also by the higher installation density of the base stations. To meet ambitious coverage specifications, more locations than ever must be equipped and a corresponding number of base stations must be produced. Manufacturers therefore welcome every possible way to shorten cycle times on the production line.

RF parameters are generally measured by signal and spectrum analyzers. The working speed of these instruments has increased over the years, in line with progress in information technology. Rising test effort, particularly in production, has negated this performance gain, resulting in new demand for shorter test times. Restructuring the test process offers an opportunity to meet this need without having to use ever faster instruments.

Divide and conquer

Signal analysis can be roughly divided into two phases: acquisition and evaluation. In signal acquisition, the baseband information is obtained from the RF frequency range of interest and passed on to the analysis section in the form of I/Q data written to memory. Evaluation of signal metrics by analysis of the I/Q data is a computation process and therefore does not require an instrument. Signal and spectrum analyzers perform both tasks because they usually serve as universal T&M instruments in the lab, with measurement results shown directly on the screen. Here "directly" can be taken literally because the measurement speed of advanced instruments is so high that even demanding analyses can run in nearly real time and parameter changes take at most a few seconds to result in a new display.

In mass production, however, every second counts – especially when the overall measurement process consists of a sequence of many individual measurements whose times add up, as with base station tests. The decisive consideration for boosting efficiency is that calculating measurement results always takes significantly longer than capturing measurement data. Data capture pauses during analysis, so the costly instrument is not used to full capacity. To eliminate the evaluation bottleneck, it makes sense to assign data capture and data processing to two separate entities (Fig. 1).

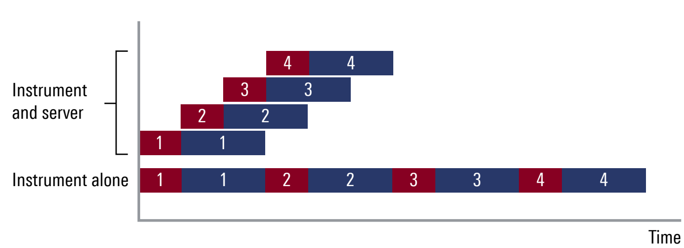


Fig. 1: The two measurement steps – data capture (red) and data analysis (blue) – usually run sequentially in the signal analyzer. New data capture is paused during the analysis phase, as otherwise the buffer would quickly overflow. If the measurement data is sent in real time to a server with sufficient processing power for evaluation, the instrument can constantly capture data and utilize its full acquisition speed. The 2:1 ratio between processing and capture times assumed in this example can be significantly larger in practice, which makes splitting the tasks even more worthwhile.

OF BASE STATIONS

Server based testing

This is exactly what R&S®Server Based Testing (SBT) from Rohde & Schwarz does. It is specifically aimed at manufacturers of 5G base stations and RF components that need higher test throughput, and it considerably improves the speed of repetitive automated tests.

Fig. 2 shows the timeline of a test sequence composed of 59 test steps, as it typically occurs in the characterization of 5G NR power amplifiers. Each step consists of multiple subtasks: preparation, data capture, data transmission and error vector magnitude calculation. To allow the instrument – for example an R&S®FSVA3000 signal and spectrum analyzer (Fig. 3) – to be operated at maximum acquisition speed without creating a data backlog, the server should process 16 analysis tasks in parallel. This reduces the test execution time by a factor of 5.5 compared with sequential operation. Depending on the concrete testing scenario, a further increase in overall speed performance is possible.

Implementation

SBT is a Linux based modular software platform that can be scaled according to the required degree of parallelization and the processing power of the computer hardware. The degree of parallelization can be defined at runtime. Computation is performed by SBT microservices, which effectively represent the granular processing units of the platform. Server hardware architectures that can process hundreds of measurement tasks simultaneously are available at reasonable prices. This allows the data streams of multiple I/Q sources or test stations to be handled in parallel.

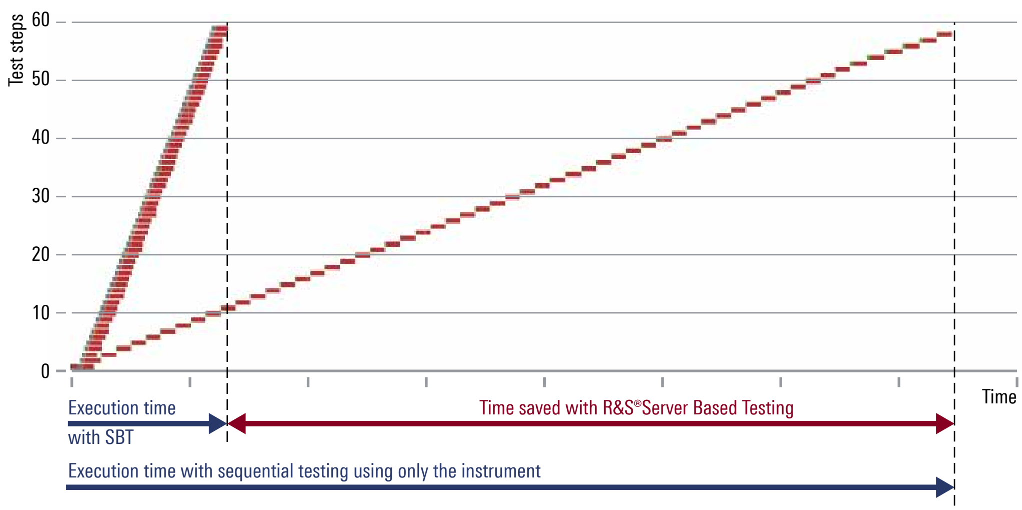


Fig. 2: This EVM measurement of a base station power amplifier, consisting of 59 test steps, can be accelerated by a factor of 5.5 by relocating the calculations to a server.

Fast data transmission between the instrument and the server takes place via Ethernet. The R&S®FSVA3000 can be equipped with a 10 Gbit/s LAN interface for this task. Other instruments can also be used as data sources. The choice depends on the required RF performance and test throughput.

R&S®Server Based Testing currently consists of components required for typical scenarios in the production of 5G and LTE/4G base stations in line with 3GPP standards. Along with standard-compliant analysis of modulation quality (error vector magnitude, EVM) in uplink and downlink channels, SBT can also efficiently calculate spectral parameters such as ACLR and SEM. Other metrics can be implemented quickly and cost-effectively as needed.

Integration of R&S®Server Based Testing into existing test ecosystems is remarkably easy: job tickets containing specific measurement instructions can be passed through a REST-compliant interface. Asynchronous parallel processing enables optimal utilization of the available hardware platform. Measurement results are sent back to the test executioner over the same interface.

Summary

Instrument performance is increasing perceptibly with every generation. Unfortunately, this is also true for the requirements of new technologies, which often negate these gains. Advanced digitalization of T&M equipment makes it possible to accelerate performance-hungry testing by parallelization. This consists of fragmenting the analysis of measurement data in I/Q format and handing it over to a server that can be scaled in line with requirements. This allows the high signal acquisition rate of advanced RF instruments to be fully utilized. For manufacturers of demanding products such as mobile network base stations, this is especially beneficial. With relatively modest investments in their server landscape, they can dramatically increase test throughput on the production line without having to procure more instruments.

Dividing data capture and data analysis between different technical entities is clearly the way ahead for production test equipment, but it also offers benefits for development engineers. For example, the R&S®Cloud4Testing SaaS enables time-offset measurement data evaluation over the internet (see NEWS 223).

Sascha Laumann

More information is available at
www.rohde-schwarz.com/serverbasedtesting

Fig. 3: The basis for high-performance characterization of base station amplifiers consists of an R&S®SMBV100B vector signal generator as the stimulus source, an R&S®FSVA3000 signal and spectrum analyzer as the supplier of I/Q data, and a standard PC for communicating with the server that calculates measurement results.

Increased use of augmented reality is just one aspect of future factories. People and machines will be wirelessly connected in many different ways.

NETWORK TESTS PAVE WAY FOR SMART FACTORIES

5G has everything future smart factories need for wireless connectivity, but network tests are essential.

3GPP Release 15 standardized 5G technology and is the basis for current 5G networks. Significant improvements in latency, network synchronization and industrial Ethernet network integration are expected from Release 16, which the 5G Automotive Association (5GAA) and the 5G Alliance for Connected Industries and Automation (5G-ACIA) have played a strong role in shaping. The release helps 5G evolve into a technology suitable to meet smart factory requirements (Industry 4.0). These requirements are characterized by data driven real-time control of all processes and the quick and flexible reconfiguration of production lines. Full connectivity of machines, people, plants, logistics and products is only feasible with wireless technology. Fast wireless 5G based links will be the nervous system coordinating the complex factory structure. Even a brief data flow interruption can have serious consequences and high costs, meaning the wireless network must be designed, set up and monitored with great care. The process requires several phases (including testing), as described below.

Vital KPIs for mobile networks in wireless connected factories

A smart factory is a critical environment that must fulfill strict requirements for machine connectivity and reliability as well as data security and human safety, especially if connectivity is provided by wireless technologies.

Redundancy is a proven way to increase reliability. Every location in a smart factory must be served by at least four wireless access points.

On-site tests are the only way to verify this access, not only upon installation but after every machinery reconfiguration or change to the building layout, since structural changes can impact the propagation conditions of radio waves.

Reliable ubiquitous wireless accessibility is necessary but not sufficient for trouble-free operation. Another requirement is the proper performance measured not only in achievable data throughput but also – and often more importantly – latency or the time needed for a signal to pass through the system. The latencies of previous mobile communications technologies, up to and including 4G, were not short enough to meet real-time control requirements. This is no longer true for 5G, which has latencies of a few milliseconds.

Latency comes in two forms: round-trip and one-way (Fig. 1). Augmented or virtual reality use cases need short round-trip latency for very quick image content updates when people wearing AR/VR glasses move their

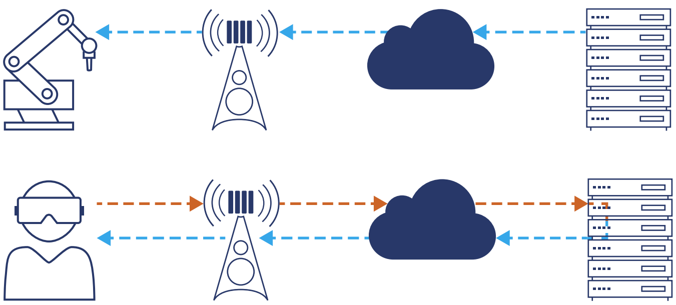
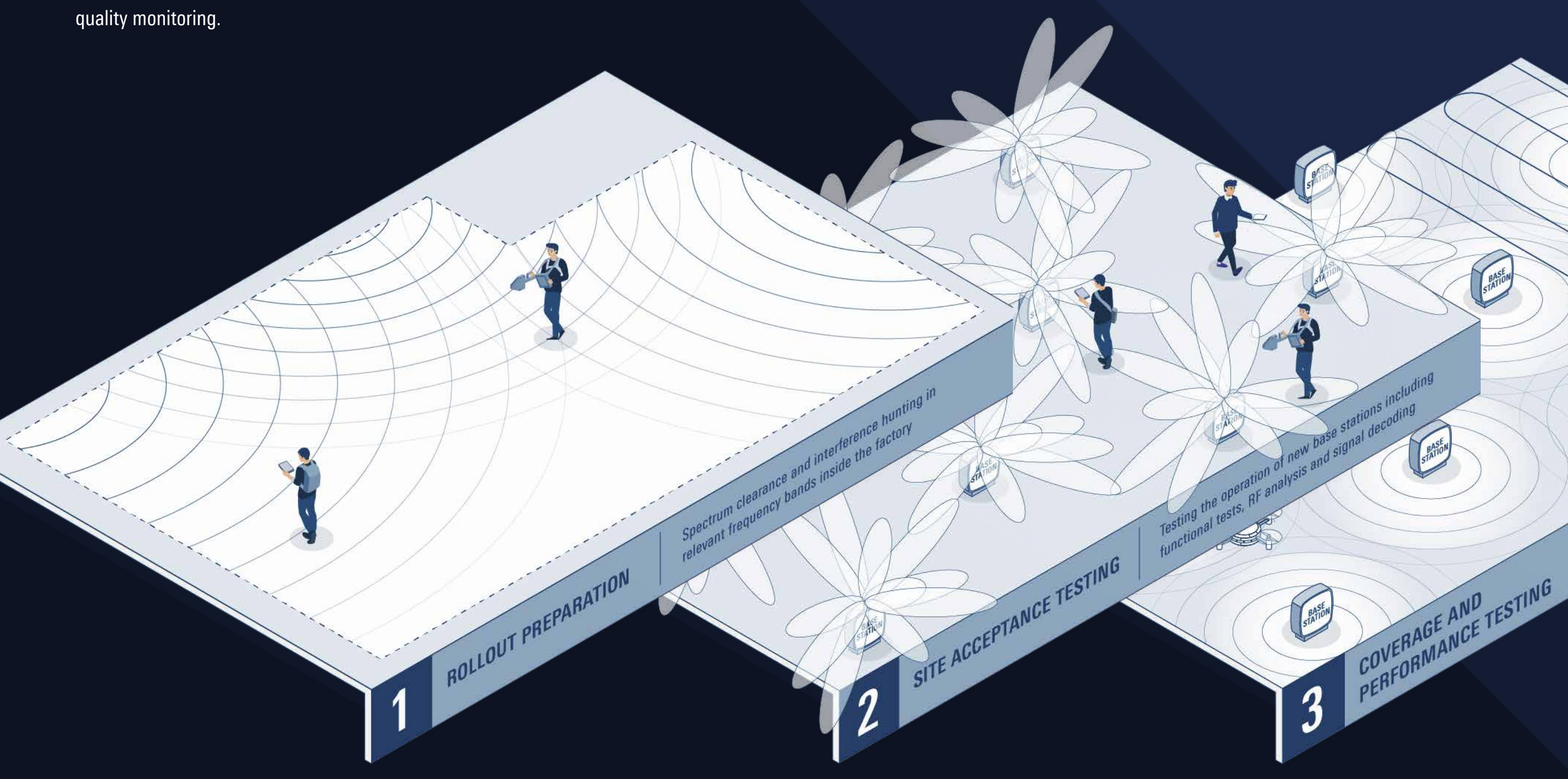


Fig. 1: The one-way latency is the signal delay from the transmitter to the receiver (top image), while the round-trip latency includes the response time of the receiver and the return delay.

Fig. 2: Network test phases 1 to 4 – from rollout preparation to 24/7 service quality monitoring.



head, to keep the merged data consistent with the live image. By contrast, real-time control of a connected machine requires low one-way latency. Control commands, for example a stop command for a robot, must lead to immediate action.

The five phases of network testing

When planning a factory as a whole, wireless networks are implemented in phases based on a five-phase test plan. Fig. 2 shows the first four phases for verifying that the network fulfills strict reliability and performance requirements.

Phase 1: Rollout preparation

In Germany and some other countries, 5G frequencies are reserved for campus networks or private networks and factory operators can apply to use these frequencies. Setup and operation of the network can be organized inhouse, but is usually done by service providers. In countries without dedicated campus frequencies, factory connectivity involves booking resources from a major network operator, who in turn consolidates their network around the factory or installs additional base stations in the factory to meet requirements.

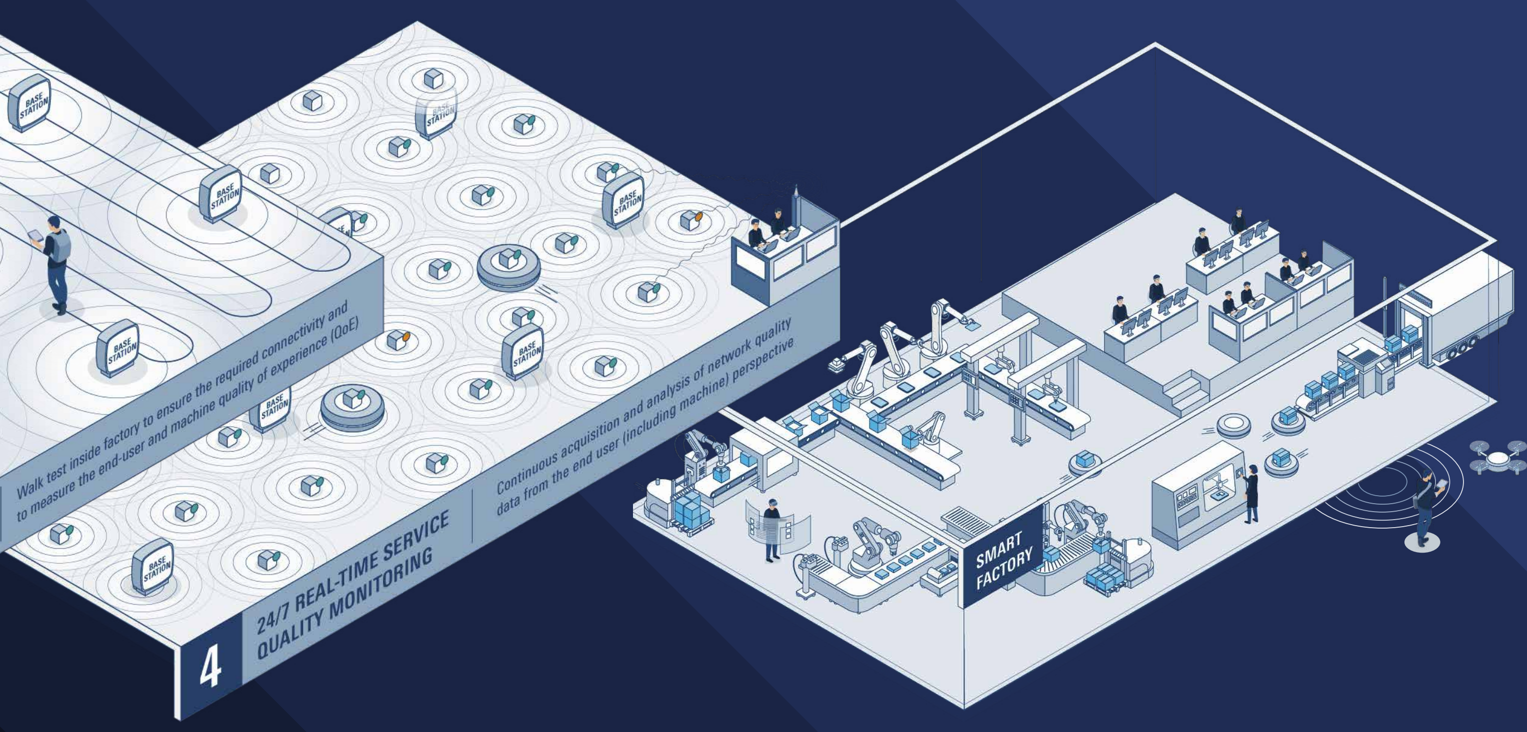
If the network uses campus frequency bands, the spectrum needs an initial check for interference. Experience shows that this cannot be taken for granted with a newly assigned and previously unused spectrum. R&S®TSMx6 network scanners, R&S®FPH / R&S®FSH handheld spectrum analyzers and R&S®MNT100 / R&S®PR200 portable test receivers perform the necessary measurements.

Phase 2: Site acceptance testing

The second phase involves testing and validating newly deployed base stations. This includes simple functional tests such as download/upload tests, round-trip latency measurements, over-the-air (OTA) RF spectrum analyses and signal decoding to verify PCI, SSB and SIB data for 5G and LTE anchor signals.

Signal decoding also helps troubleshooting specific parameters in case of problems or unexpected results.

Fig. 3: The environment of smart factories should be periodically checked for interference, which may originate from the campus network.



The Rohde & Schwarz product portfolio has the right instruments for these tasks. QualiPoc Android, a smartphone based measurement software, evaluates the mobile network service from the user perspective with functional tests (DL, UL, ping/TWAMP). The R&S®Spectrum Rider FPH handheld spectrum analyzer is ideal for OTA spectrum measurements, while the R&S®5G site testing solution provides a comprehensive mobile network situational overview that allows quick identification of any weaknesses or problem areas.

Phase 3: Coverage and performance testing

Now comes the real test. The aim is to make sure the network delivers the required performance throughout the entire factory. R&S®TSMx6 network scanners measure over the entire factory site to see how many different network access points have good reference signal received power (RSRP) and good quality as signal to interference plus noise ratio (SINR) at every location. As previously mentioned, at least fourfold redundancy is desirable.

QualiPoc Android can test the real-time capability of the connection by combining the emulated traffic profile, latency measurement and transmission quality in a single interactivity test (see box below).

The R&S®SmartONE real-time optimization software enables immediate visualization of measurement results and targeted improvement of problem areas.

Phase 4: Service quality monitoring

Phase 4 measurements are necessary in factories where the wireless network is critical infrastructure where malfunction would result in large profitability and productivity losses. This means the factory owner needs a clearly defined service level agreement (SLA) with their network operator and the ability to continuously check compliance with the SLA. Custom RF sensors are distributed throughout the factory and in automated guided vehicles (AGV) and autonomous mobile robots (AMR). They periodically measure connection quality – including latency – at every location and report the results to the monitoring center (SmartMonitor), where they are visualized on a real-time dashboard. Tools like

Digression: A new method for measuring network performance

Ensuring superior network performance with full coverage is essential in factories. The latency and data throughput must meet the minimum requirements everywhere in the coverage area. A new method implemented in the smartphone based QualiPoc Android software solution makes such measurements easy and reliable.

Latencies are conventionally measured with ping echoes. Ping is part of the internet control message protocol (ICMP) used to exchange diagnostic and error messages in computer networks. However, the ping method has inherent accuracy shortcomings, which impact low latencies such as those needed in 5G factory networks. It is not suited for precise measurements of very low latencies and cannot emulate traffic patterns. A better method is based on the two way active measurement protocol (TWAMP), which the Internet Engineering Task Force has specified for measuring end-to-end performance between two nodes of an IP network. What TWAMP can do in a measurement application strongly depends on its implementation. The Rohde & Schwarz solution is part of the QualiPoc Android measurement software and computes a meaningful overall score from several metrics. This innovative method has been proposed for standardization.

Fig. 4: The interactivity test based on the two way active measurement protocol (TWAMP) can measure the delay (latency) between two IP nodes and other KPIs such as packet losses.

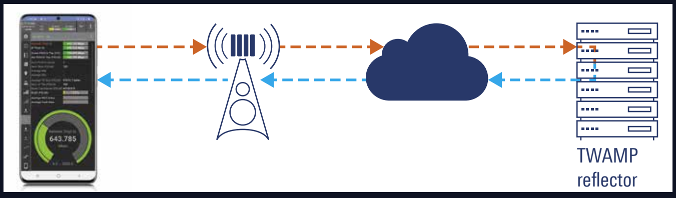
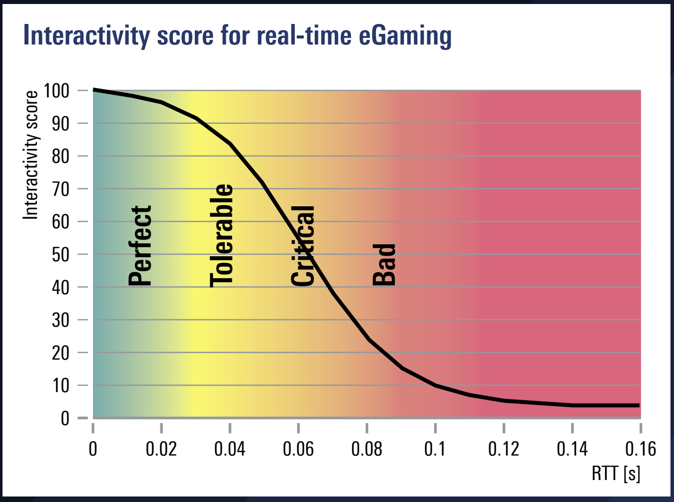


Fig. 5: Interactivity scores for various application classes. The S-shaped latency curve passes through a range of quality zones whose positions and widths vary from one application to the next.



SmartAnalytics offer more detailed offline data analysis. The software uses machine learning to identify trends and anomalies and promptly indicates aberrations so that preventive measures can be taken before the fault case actually occurs.

Phase 5: Verifying prescribed compatibility with the outside world

Completion of phase 4 marks the end of the setup process and the network is operational. The final task is to ensure compliance with the license conditions for private networks that specify leakage signals outside the intended coverage area must remain below defined limits. This helps prevent interference with any neighbors using the same frequency band or an adjacent frequency band. Factory owners are recommended to check compliance and can do this with a walk test solution such as the R&S®Freerider 4 or a network scanner mounted on a drone (Fig. 3).

Summary

Several industries will need to convert their current factories into smart factories. Conventionally organized operations will have difficulty competing with the flexibility and cost advantages of the new generation of factories. One feature is complete connectivity of equipment with low latency (5G) wireless communications. The right T&M support makes setting up and operating these networks easy. The Rohde & Schwarz product portfolio offers network operators and factory owners everything they need.

Arnd Sibila

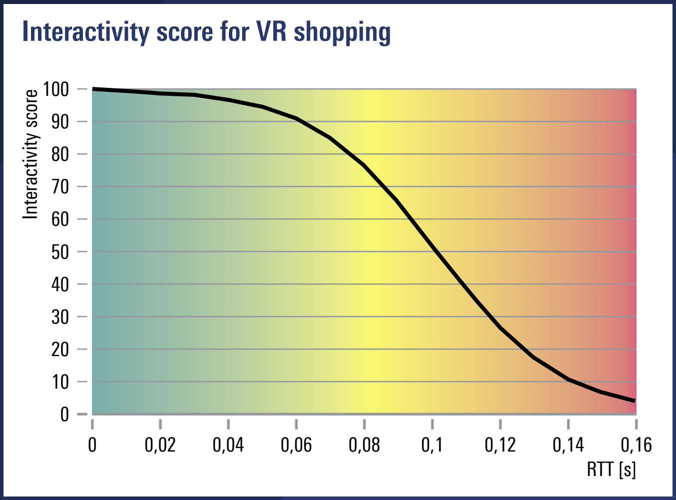
Tutorial videos and more information are available on a dedicated smart factory webpage: www.rohde-schwarz.com/mnt/smart-factory

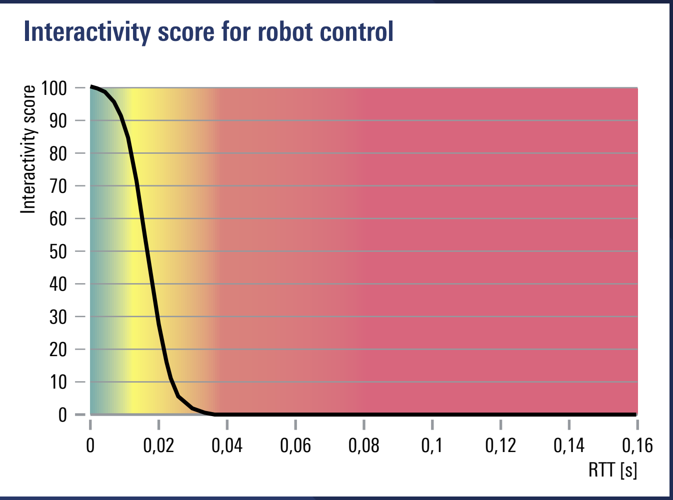
The QualiPoc smartphone sends a stream of application-specific data packets via the UDP transport protocol emulating a realistic traffic profile of a specific use case class to a TWAMP capable server (TWAMP reflector), which immediately sends them back (Fig. 4).

The QualiPoc software determines the round-trip latency from reflected data, its range of variation (minimum and maximum measured values) and the packet error rate, and combines these three KPIs to form an interactivity score for this specific use case class.

This is a scalable QoE model that can be tailored to different application classes. Fig. 5 shows example score curves for example use cases.

The software is attractive not only for service measurements, but also for every real-time wireless application. Suitable profiles are being developed in cooperation with the respective industries.





A WIZARD FOR CONFORMANCE TESTING OF 5G NR BASE STATIONS

With the new version of the 5G NR software for the R&S®SMW200A vector signal generator, all required parameters for conformance testing of 5G NR base stations can be set up in no time with just a few clicks.

The conformance tests specified by 3GPP for 5G NR are documented in TS 38.141-1 for conducted and TS 38.141-2 for OTA tests. This includes measurements for evaluating transmitter characteristics and receiver performance under noise and fading conditions. Base stations need to pass conformance tests in the region where they will be installed before they can start operation in the field.

The R&S®FSW signal and spectrum analyzer and the R&S®SMW200A vector signal generator are leading hardware solutions for applications such as base station tests (Fig. 1). The signal generator usually has to provide several defined signals, in most cases with additional noise or fading (Fig. 2). Furthermore, base stations are typically tested with many different settings (e.g. bandwidths), leading to several hundred individual tests that need to be performed. Correct configuration of the individual test signals can be very time-consuming.

Faster with the wizard

With the R&S®SMW-K144 option, the R&S®SMW200A offers a complete solution for 5G NR signal generation. A convenient part of this option is the test case wizard (Fig. 3), which supports the user with specification-compliant signal configuration. All conformance test cases for conducted and OTA measurements are supported.

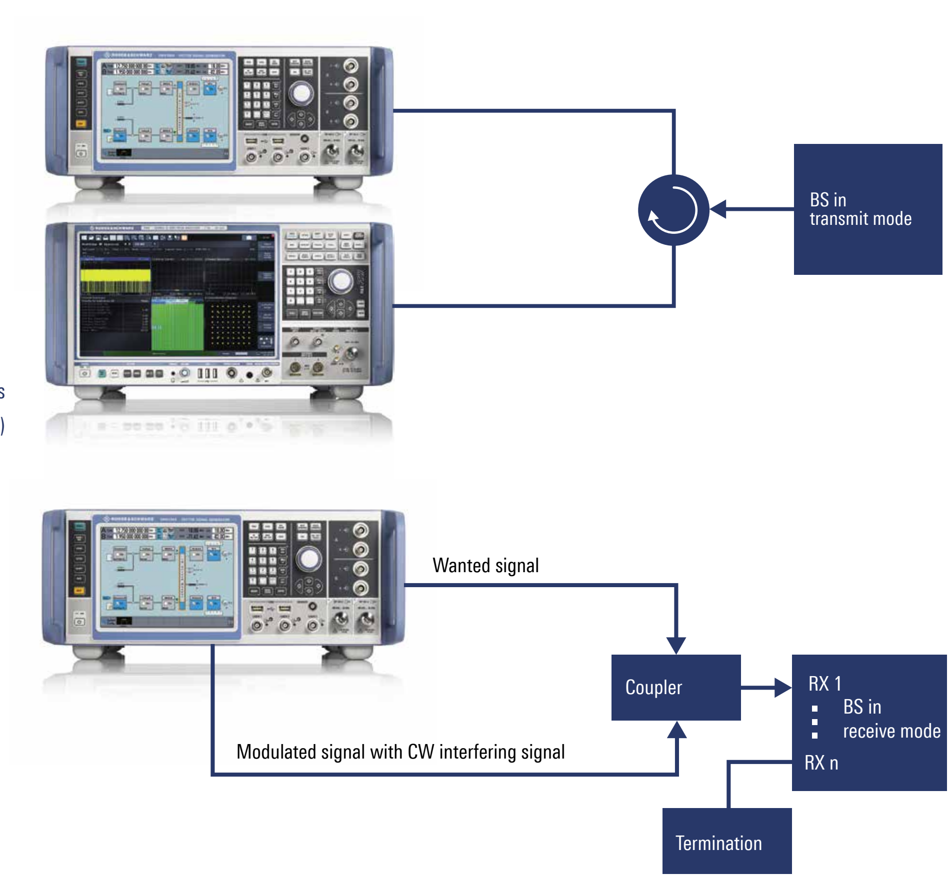


Fig. 1: Typical test setups for transmitter tests (top) and receiver tests (bottom) on base stations.

Test case according to 3GPP TS 38.141	Wanted signal	AWGN	Modulated interfering signal	CW interfering signal	Fading	Real-time HARQ and timing adjustment
6.7 (6.8 OTA) Transmitter intermodulation	–	–	■	–	–	–
7.7 Receiver intermodulation	■	■	■	■	–	–
8.2.1 Performance requirements for PUSCH	■	■	–	–	■	■

Fig. 2: Required signals for selected TS 38.141 test cases.

After selection of the relevant test case, complex test scenarios can be configured in just a few steps. The user only has to enter specific signal parameters, such as bandwidth or cell ID, in a clearly structured user interface. The graphic representation of the resulting test signals provides a good overview of the signal configuration.

Accurate signals with minimum calibration effort

Precise output levels of the wanted and interfering signals are crucial for accurate receiver measurements. The R&S®SMW200A uniquely allows all signals to be generated internally and output on eight RF ports when connected to up to six R&S®SGT100A generators. This also applies to signals with additional channel emulation since the generator can be equipped with internal fading simulators. Compared to a conventional setup with individual signal generators and external fading simulators, this fully integrated solution offers the advantage of high precision output signals with minimum calibration effort.

Matthias Weilhammer

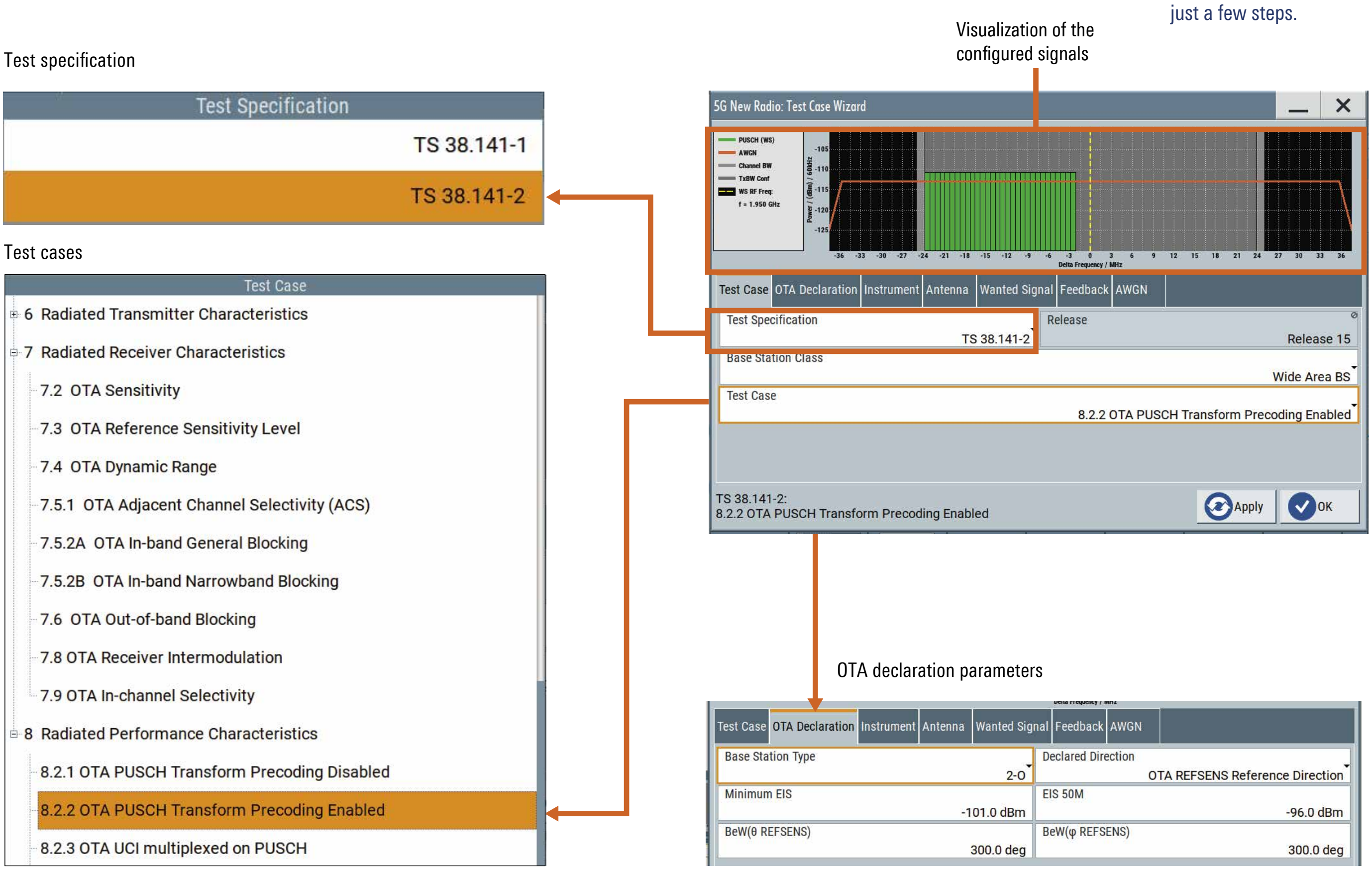


Fig. 3: Test case wizard details. Complex test signals can be composed in just a few steps.

T&M EQUIPMENT FOR MULTICHANNEL RADAR AND GNSS RECEIVERS

Multichannel receivers are used in military radar warning systems and for security-critical GNSS reception. Testing these receivers requires special solutions for signal generation and analysis.

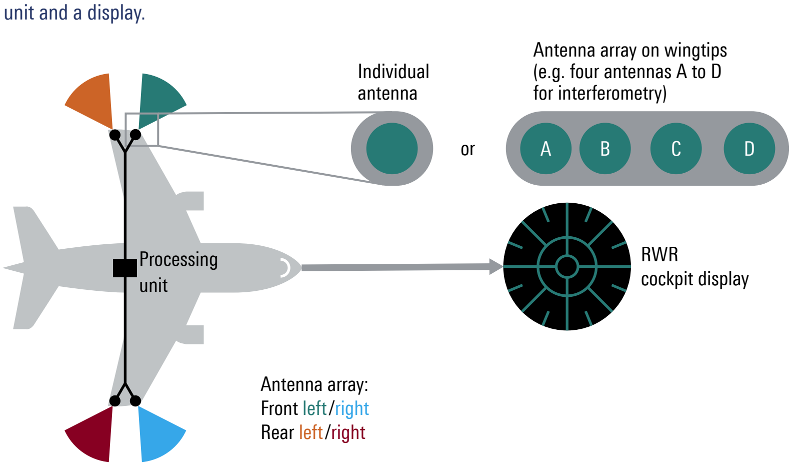
SIMPLIFICATION

Radar warning receivers and GNSS anti-jam systems often use multiple phase coherent antennas to determine the signal angle of arrival. A new test system uniquely supports both applications.

Multichannel receivers can process signals from multiple distributed antennas or an antenna array at the same time. This is useful for determining the direction of incoming signals by means of signal analysis. This knowledge is helpful in many situations. For example, it allows jamming or spoofing signals originating from the ground or the air to be distinguished from satellite signals and suppressed when receiving signals from global navigation satellite systems (GNSS). Radar warning systems usually have multiple receive channels to allow determination of the signal fingerprint as well as the directions of the signal sources. The receive channels are often phase coherently linked to increase angular resolution.

The connected antennas are generally arranged in a strict geometric pattern, either flat in a plane or distributed over a platform (e.g. an aircraft) to achieve 360° coverage of receive directions.

Fig. 1: Aircraft with a multichannel radar warning system consisting of multiple receive channels, a central processing unit and a display.



Multichannel radar warning receivers

Radar warning receivers (RWR) are used on aircraft or other platforms for detection, identification, classification and localization of incoming radar signals and their sources. The antenna configuration required for direction determination (Fig. 1) depends on the signal properties to be evaluated:

- ▶ Time difference of arrival (TDOA)
- ▶ Amplitude differences
- ▶ Phase differences (interferometry)

The analysis results are acoustically and visually signaled to the pilot and form the basis for automatic self-protection measures. Radars operate at frequencies from several 100 MHz to 40 GHz, so radar warning systems and the corresponding test systems must cover this bandwidth.

Multichannel GNSS receivers

GNSS receivers operate similarly to radar warning receivers. They use controlled radiation pattern antenna (CRPA) architectures to suppress unwanted signals. The overall receive characteristic of the antenna array can be altered by suitable weighting of the signals from the individual antennas (Fig. 2). In this way, interference signals can be specifically blanked out (nulling) or the required GNSS signals can be amplified at their angle of arrival (beamforming). A combination of these two methods is also possible. The antenna arrays typically consist of four to seven elements. The number of interference signals that can simultaneously be suppressed increases with the number of elements.

Up to now this technology has primarily been used in military applications, but it can be expected to make a significant contribution to robust navigation in autonomous driving and flying.

Shared requirements for test systems

Although multichannel radar and GNSS systems are entirely different applications, they share some requirements for test systems:

- The RF outputs of the test system must be connected to the antenna inputs of the receiver. A separate signal must be provided for each input, so the test system must have an independent signal source for each simulated antenna.
- The test system must be calibrated at the RF interface to enable exact adherence to the relative amplitudes and phases between the channels.
- The phase relationships between the simulated signals must remain stable during the simulation timeframe (phase coherence).
- Test systems for multichannel applications are often operated in a hardware-in-the-loop (HIL) environment. High update rates and low latencies are essential for this, because a computer feeds signal data into the test system at high speed.

Application-specific requirements

There are also application-specific test requirements:

A complex RF environment must be simulated on all receive channels in order to supply the radar warning receiver with realistic signals. This environment must contain many different radar and disturbance signals. It is also important to support long simulation times, moving transmitters and receivers, and electronically steered antenna patterns and antenna scans. For testing of multichannel interferometric receivers, it must be possible to calculate and configure the channel phase angles for each pulse as a function of signal frequency, antenna arrangement, and the positions of transmitters and receivers in three-dimensional space.

For tests on GNSS CRPA receivers, the test system must act as a multichannel GNSS simulator and take into account all aspects of a satellite navigation system. For example, the signals of all standard satellite navigation systems must be generated in all GNSS frequency bands, with attention to correct satellite orbits, signal propagation characteristics and realistic modeling of the dynamically changing receive environment. Configuration of the antenna array in terms of geometry and the receive characteristics of the individual antennas must also be included. Along with the GNSS signals, disturbance signals must be generated at the same time to enable testing of the DUT's interference suppression functions.

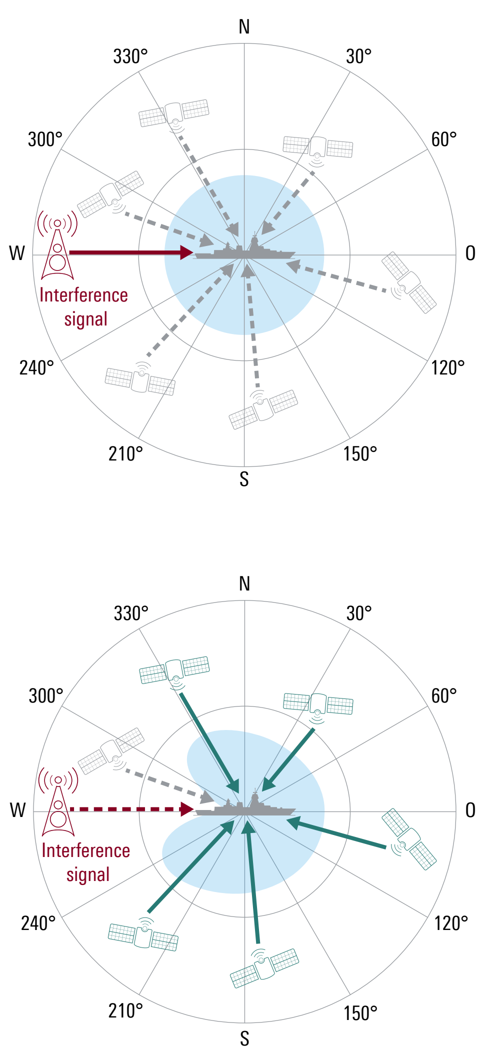


Fig. 2: The GNSS antenna in the upper image has only one element, so its characteristic cannot be modified. A sufficiently strong interference signal can prevent the receiver from processing the GNSS signals, making satellite based navigation impossible. In contrast to the individual antenna, the characteristic of the antenna array in the lower image can be modified by combining and weighting the signals of the antenna elements. The interference signal is suppressed at its angle of arrival, and the GNSS signals can be received. A disadvantage is that GNSS signals from the same direction as the interference signal are also suppressed.

Two applications, one system

Radar warning receivers and CRPA systems are often used side by side in the A&D environment on naval or airborne platforms. Previously two separate test systems were required to test these two systems. The solution described here covers the test requirements of both applications.

All necessary signals, including those for GNSS, are generated internally by the modular software defined R&S®SMW200A vector signal generator. Multiple signal generators are operated in parallel to test multichannel receivers.

Fig. 3: A six-channel radar/GNSS test system consisting of three R&S®SMW200A vector signal generators and an R&S®SMA100B analog signal generator for the LO signal.

With each generator equipped with two channels, three devices are sufficient to set up a six-channel test system (Fig. 3). RF port alignment software allows the entire system to be calibrated at the RF interface, so the properties of the test system do not corrupt the simulated signal differences between the RF ports.

The shared LO signal for the vector signal generators is provided by the high-end R&S®SMA100B analog signal generator, with adequate signal level and extremely low phase noise.

The system can even be embedded in an HIL environment with real-time streaming signal data input, such as the motion profile (position, speed, acceleration, vehicle attitude) of the simulated GNSS receiver or a radar scenario in the form of pulse descriptor words (PDW).

Summary

Compared with two separate test systems – often from two different manufacturers – the package solution is more compact, more economical and advantageous in many respects, such as shorter test preparation times, less effort and expense for familiarization and startup, and easier operation. Support, maintenance and service come from a single source, and additional RF channels or simulation features can easily be retrofitted later on by purchasing hardware components or software licenses.

Dr. Markus Irsigler, Robert Vielhuber

PHASE COHERENT MULTICHANNEL PULSE ANALYSIS ON RADAR SYSTEMS

The R&S®RTO and R&S®RTP oscilloscopes combine phase coherent multichannel RF signal analysis with extensive functions for signal integrity and digital interface testing. This makes them an excellent choice for radar module analysis.

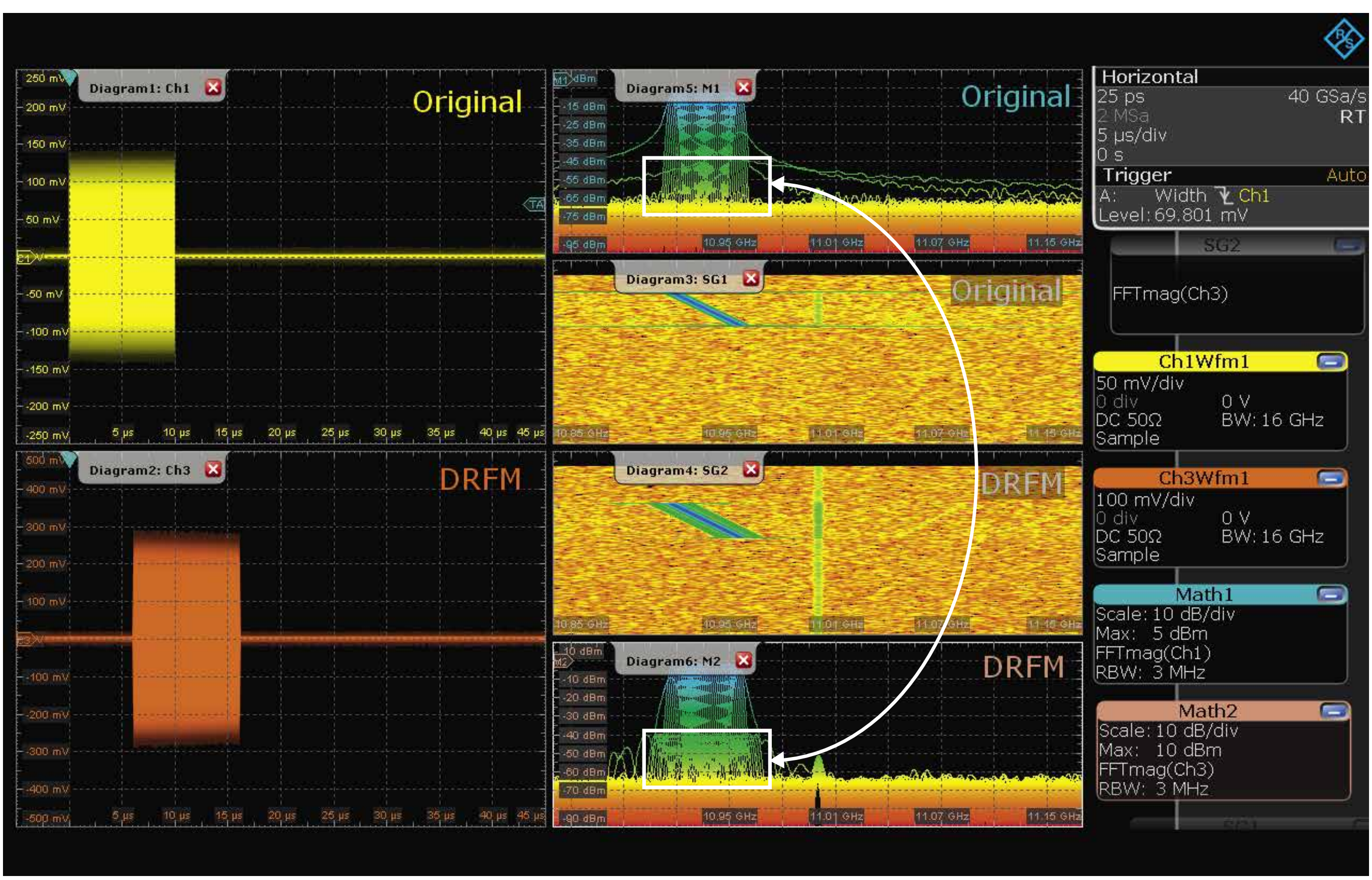
Multichannel analysis of a digital radio frequency memory

Oscilloscopes have multiple measurement channels and can correlate their signals. This makes them suitable for multichannel analysis on digital radio frequency memories (DRFM) deployed in jammers on defense platforms. Modern jammers not only attempt to disturb and overload enemy radar systems but they also create false targets. The jammer core is a DRFM, which stores a digital image of the enemy radar signal and retransmits it using modified parameter values.

For DRFM characterization, the receiver input signal and the transmitter output signal of the DRFM module are analyzed simultaneously. An important parameter is the time delay between the incoming radar signal and when a copy of this signal is available at the transmitter output.

Oscilloscopes can directly acquire even higher frequency radar signals. For example, the R&S®RTP with 16 GHz bandwidth covers nearly the entire Ku band and fully covers the X band, which is important for defense applications. As a result, the R&S®RTP can be directly connected to

Fig. 1: Simulated DRFM scenario. The replicated pulse (DRFM pulse, orange) is delayed by 6 µs relative to the original pulse (yellow), and its amplitude is nearly twice as high. The spectrogram shows that the frequency and chirp match well, while the replicated (DRFM) signal exhibits distortions (white arrows).



the DRFM frontend, with no need for signal downconversion.

Even the standard functions of the R&S®RTP provide extensive analyses in the time and frequency domain. Fig. 1 illustrates the simultaneous acquisition of the input and output signal of a simulated DRFM including frequency hopping analysis. The spectrogram shows that while the original and the replicated signal in the DRFM match well, there are slight distortions in the manipulated chirp. The 6 µs time difference (clearly visible in the left part of the screenshot) is intentional, since a range gate pull-off scenario is being simulated, with the jammer retransmitting the replicated signal with a delay to create a false range target.

In cases where the pulse repetition interval (PRI) is only slightly extended after each pulse, it is worthwhile to check whether all transmitted pulses comply with the required parameters. The R&S®RTP has an acquisition mode suitable for this purpose. In normal mode, the instrument cannot detect any pulses while the acquired data is being analyzed by the processor. By contrast, in fast segmentation (or segmented capture) mode, the oscilloscope memory is first filled with the acquired data, then analysis starts. This reduces oscilloscope blind time to below 350 ns compared to normal acquisition mode.

Once all the acquired data is saved to the oscilloscope memory, the time domain trace of the data can be displayed. Fig. 2 shows the envelopes of the original and the replicated pulse, which are calculated using math functions, and the time delay between the two pulses, which is determined using the delay measurement function.

Analysis of a radar warning receiver

The oscilloscope trigger unit allows triggering on a signal different from the signal to be examined. For example, a serial bus used to control a T/R module can be decoded and used as a trigger source. Another useful trigger application is to isolate a specific radar signal in a scenario with multiple radar transmitters. Figs. 3 and 4 show a scenario of this type generated with the R&S®Pulse Sequencer software. An airborne radar is tracking a target

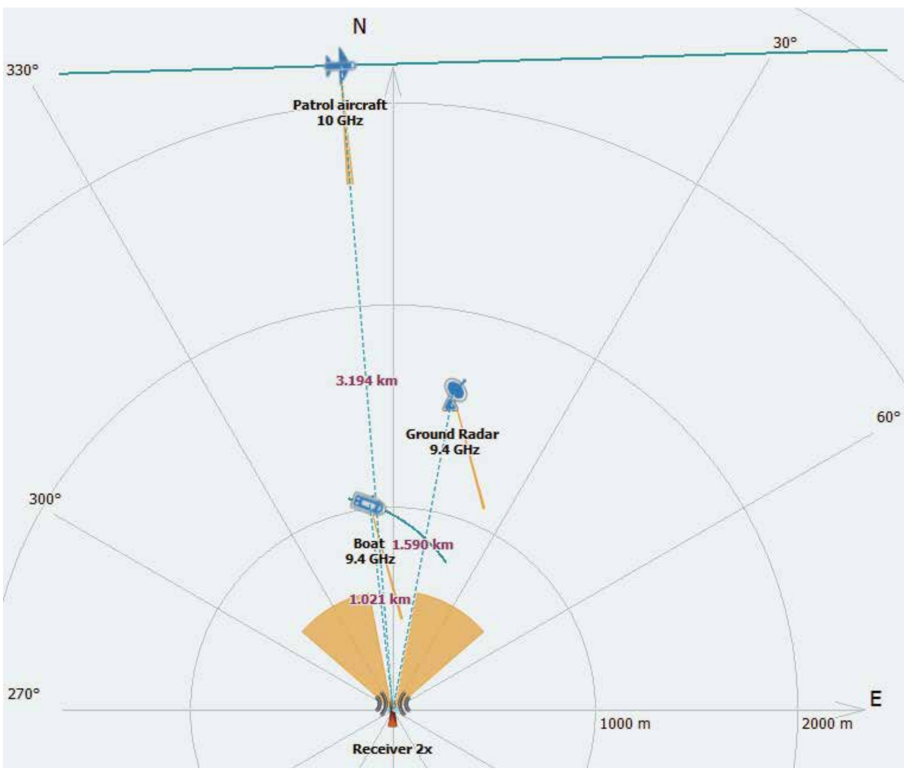
Fig. 2: Simulated DRFM scenario. The envelopes of the original and the replicated pulse are calculated using math functions. The time delay between the two pulses is determined over all acquisitions (here: 1000) and displayed over the entire measurement time using the oscilloscope´s delay measurement function. The sawtooth curve indicates that an object is moving away.

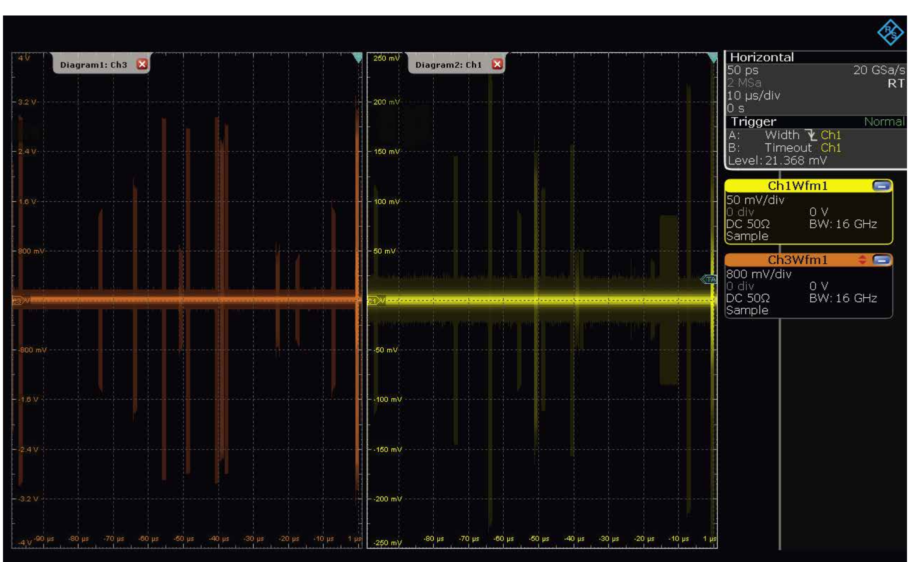
and moving laterally past the target. Additional radar signals come from an imaginary patrol boat and a stationary air surveillance radar. This signal mix is output by a dual-channel R&S®SMW200A signal generator, simulating the outputs of two receive channels of a multichannel radar warning receiver (RWR). The objective in this example is to isolate and analyze the airborne radar signal.

Fig. 3: Example measurements on a radar warning receiver. The radar scenario was generated with the R&S®Pulse Sequencer software.

Type	Pulse width (µs)	PRI (µs)	Modulation
Patrol aircraft	1	100	None
Stationary radar	5	20	Barker 13
Patrol boat	5	16	Up-chirp

Fig. 4: Radar scenario simulated with the R&S®Pulse Sequencer software in the program-specific representation. In this scenario, the radar warning receiver, or the oscilloscope, sees multiple different pulse shapes (screenshot below).





The oscilloscope trigger unit allows the pulse characteristics of the signals to be examined separately. The required trigger settings are described in detail in an application card*. Pulses are selected according to time criteria in A-B-R trigger mode. In this example, the A-B-R trigger will only cause pulses with a width of 1 µs to be acquired (Fig. 5).

Another analysis option is fast segmentation mode. If an airborne radar transmits pulses with a PRI of 100 µs, a 1 s simulation period would require 40 Gbyte of memory capacity (40 Gsample/s × 1 s × 1 byte/sample). Using the A-B-R trigger, the recording period per acquisition is reduced to 1.2 µs (48 ksample), and a period of 4.16 s is continuously recorded in the oscilloscope 2 Gsample segmented memory.

Dedicated solution for advanced multichannel pulse analysis

Radar developers often need to measure specific pulse parameters such as pulse width, droop and PRI. Here it is advisable to use specialized software that can determine these parameters automatically. The R&S®VSE K6A extended pulse analysis option available for the R&S®VSE vector signal explorer software now supports phase coherent multichannel analysis. All functions of the oscilloscope trigger unit are available with this option, ensuring stable and precise detection of the pulses to be analyzed.

Beside comparing the input and output signals of a DRFM module, the R&S®VSE software can be used to analyze radar warning receiver performance. In A-B-R trigger mode, the software measures in detail the airborne radar signals in the RWR (Fig. 6). Using the R&S®VSE analysis routines, the phase difference between the two receive channels can be determined, either via markers or from tabular values. The results can be used, for example, to determine RWR long-term stability by observing the trend or the phase distribution.

Ezer Bennour, Dr. Andreas Ritter

* Trigger on radar RF pulses with an oscilloscope (Application card, search term: PD 3609.2000.92, Rohde & Schwarz GmbH & Co. KG)

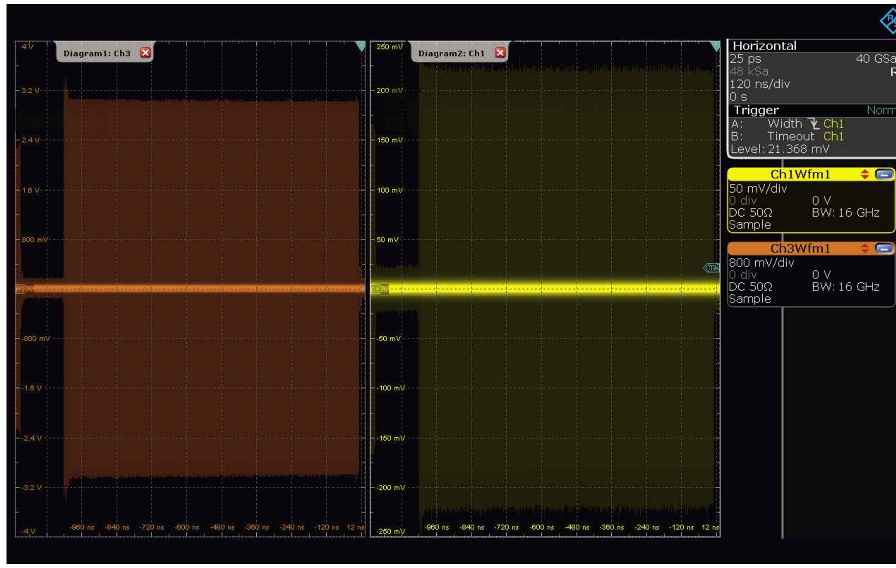
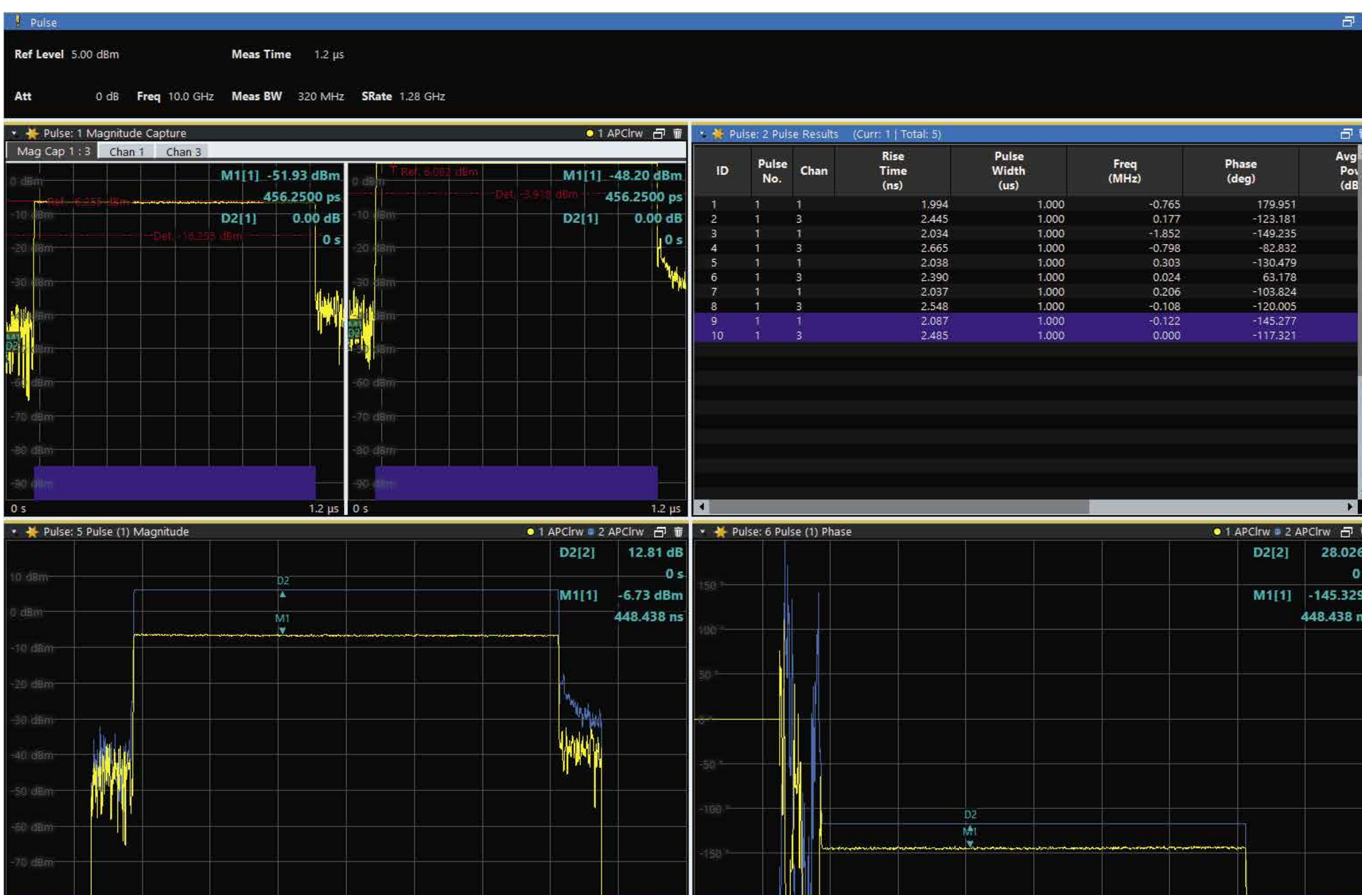


Fig. 5: The radar of the patrol aircraft is isolated in the multiradar scenario using A-B-R triggering on one of the two RWR receive channels (yellow channel in this case).

Fig. 6: Using the R&S®VSE software to analyze the example airborne radar signal on the simulated outputs of a dual-channel radar warning receiver. R&S®VSE automatically measures the radar parameters and displays them in tabular form. Phase and amplitude differences can be determined in detail using markers (lower screenshots).



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LIVE AND LET LIVE

The number of radio products has long since surpassed the number of people living on Earth by many times and continues to grow. The interference-free coexistence of these products is a problem, but state-of-the-art test and measurement equipment can help manufacturers master this challenge.

Connected products must not emit electromagnetic interference into their surroundings and they must be able to operate smoothly when subjected to external electromagnetic interference. International electromagnetic compatibility (EMC) standards make it possible to comply with these requirements.

The test specifications for any particular product depend on its product group, frequency of operation and industry. Different test standards apply to medical devices, consumer goods, military equipment, automotive, aerospace and defense, and many other industries. The CE mark in Europe indicates that a product complies with relevant standards. A corresponding FCC label is optional in the USA, but every product must be accompanied by a supplier's declaration of conformity (SDoC).

In Europe, products with integrated radio components must also comply with the radio equipment directive (RED). The RED expands the EMC rules to include requirements for transmitting and receiving equipment. It is specifically intended to prevent radio products from interfering with each other and to enable coexistence. The incorporation of the RED regulations into specific test rules is the responsibility of standardization bodies such as ETSI, which integrates these requirements in harmonized standards and is valid among the EU member states and EFTA countries.

A question of coexistence

EMC tests have been around for decades. They are based on standards and norms that have only gradually evolved.

The measurement parameters use base electrical quantities such as (interference) field strength, current and voltage. The signal forms of these quantities are not important. Susceptibility measurements can therefore be performed using very simple signal forms such as CW, AM and pulse.

However, the product landscape has changed dramatically in recent years. More and more products have wireless modules with internet connectivity. Over 20 billion wireless internet-capable units are currently in use around the world and the numbers are growing. All are subject to the EMC standards specified for their product group. Conventional EMC measures and tests are not enough to ensure interference-free operation in harsh electromagnetic environments. The additional coexistence tests initiated by RED and similar regulations increasingly have become more and more important.

These tests require proof of a radio product's compatibility with other wireless services in the intended field of application. The latter can be a significant specification with a large impact on test design. Formal compliance with a standard may not be enough if the standard fails to consider the specific product's operating conditions. Manufacturers must work with authorities to avoid product liability risks or simply to obtain market access, especially when products are used in the healthcare sector.

The problem with the blocking test

Blocking tests were identified as suitable for coexistence capability testing and have been included in European standards associated with the RED. Performing the test involves establishing a connection between the DUT and a radiocommunications tester with specified parameters such as frequency and signal level. A defined interference signal generated by a signal generator is superimposed on the connection. A robust receiver can still operate as intended even in the presence of strong interference signals. Otherwise, follow-up work will be needed.

However, tests that simply comply with standards cannot ensure that a device will be as immune to interference in regular use as suggested by the test results. The reason is that standards cannot keep up with the market as it evolves and as rapid advances are made in radio technology, meaning tests only cover the bare minimum. A completed and properly documented test may create legal certainty for major product faults, but the market will remain unimpressed and gives users false confidence in a faulty product. Actual product performance in real-world EM environments is what ultimately matters.

ETSI EN 300328 V2.2.2 for devices operating in the 2.4 GHz band is one example of a European standard with room for improvement. Coexistence is especially critical in this densely occupied band in which WLAN, Bluetooth, household microwaves and other devices jostle for space. The standard blocking test is fairly easy to pass, but hardly depicts the situation in the real world. This idealized interference scenario uses a CW interference signal with a constant signal level and a noise floor limited to twice the signal bandwidth. However, these CW interference signals are not realistic and actual broadband modulated signals can degrade reception quality even at lower levels. Complete blocking of communications by interferers is unlikely. Instead, data throughput drops because individual data packets get lost and must be requested again. This means a device can have insufficient interference immunity despite passing a coexistence test (Fig. 2).

Realistic approaches

Not all standards lag behind current requirements. One example is EN 303340 version 1.1.2. for DVB-T and DVB-T2 broadcast receivers. The standard demands the use of various types of interference signals, including simulation of a fully occupied LTE base station signal. The standard uses state-of-the-art interference signals but has other weaknesses.

	LTE800	LTE2600	WLAN	Bluetooth
LTE800				
LTE2600				
WLAN				
Bluetooth				

Fig. 1: Coexistence scenario with typical radiocommunications services. Radiocommunications service pairs in the same frequency band or adjacent bands (red, orange) are critical. This is where coexistence testing comes into play.

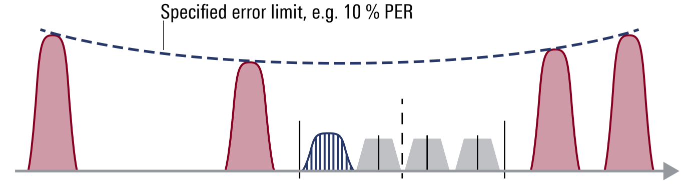


Fig. 2: The greater the frequency offset of the interference signal from the wanted signal, the larger the permissible interference level, as illustrated here with a noisy interference signal (AWGN).

It is virtually impossible to judge how well a receiver works in practice simply based on whether it passes a test in line with this standard, since the primary value for measuring degradation is the frequency with which picture failure points occur. If the picture failure points occur no more than every 15 seconds when interference signals are applied, the device is standard-compliant and can be sold. Whether the customer is happy with this level of quality is another question.

Ensuring coexistence in the IoT era

The growing omnipresence of wireless products mean coexistence will be a key issue for the industry (Fig. 3). However, all devices cannot be lumped together and differences need to be made. A wireless pacemaker or an automotive emergency call system need much more accurate testing and greater quality certainty than a WLAN controlled toy.

Another area where current standards also come up short is user experience. Many wireless connected devices have integrated screens and speakers. If interference can be heard on the speakers and seen on the screens due to poor coexistence behavior of the devices, certification should take this into account.

Standardization is a lengthy process because so many different parties are involved, where interests must be weighed and a wide variety of aspects taken into consideration. The urgent need for practical solutions has caused manufacturers to take the initiative and develop testing procedures that ensure the reliable operation of their products under operating conditions. Manufacturers have greater legal certainty for product liability and a competitive advantage thanks to the valuable user experience they have gathered.

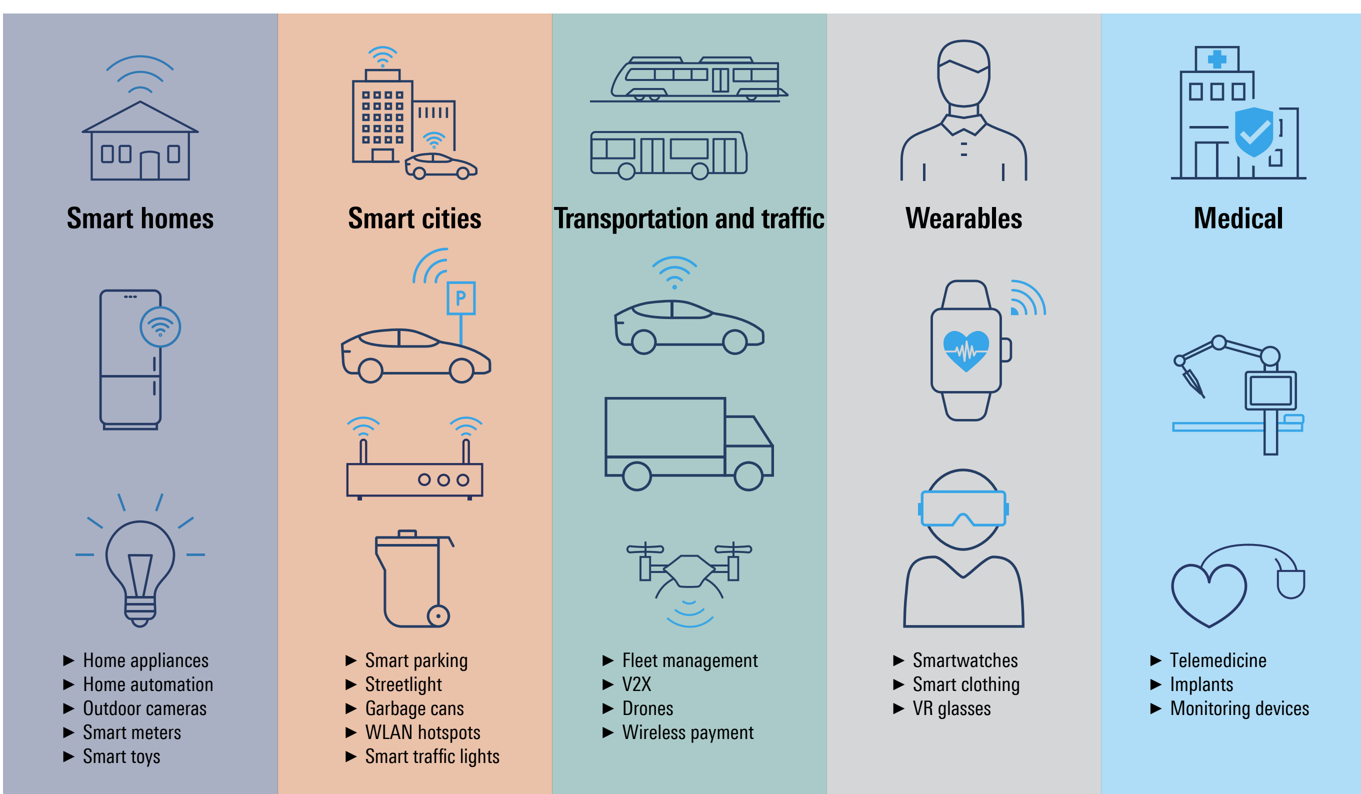
Modern coexistence test methods should include the following four aspects:

1. Estimate risk

Test requirements strongly depend on product group and operating conditions (Fig. 4). The greater the potential harm from product failure, especially harm to life and health of the users, the stricter the test conditions.

The requirements placed on medical technology are particularly high. In the USA, the Food and Drug Administration (FDA) defines medical device approval rules instead of the Federal Communications Commission (FCC). The FDA demands a declaration of conformity with ANSI C63.27 for the coexistence of wireless devices. This standard refers to

Fig. 3: Radiocommunications is penetrating nearly all aspects of our lives, making coexistence increasingly important.



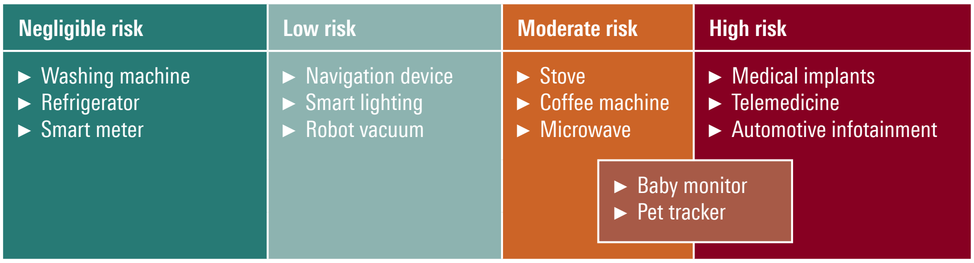


Fig. 4: Example four-level risk classification of wireless connected devices, based on ISO 14971 (which has five levels). Device classification by the authors.

ISO 14971 for medical device risk management, which has an evaluation chart to help manufacturers estimate their product's risk. The FDA and ANSI do not provide specific testing procedures for proof of conformity, but instead leave test criteria (KPI) formulation and the development of a suitable test procedure to manufacturers, placing a large responsibility on them. However, all manufacturer assessments and measures must be submitted plausibly to authorities together with a risk assessment, detailed test records and uncertainty analyses.

To avoid having to start from scratch with each new product, the industry is interested in developing test methods that cover entire product classes. Rohde & Schwarz is now working with a test house to develop tests for a medical device manufacturer.

2. Take user experience into consideration

Coexistence quality should cover more than just physical layer performance criteria, it should also examine the application layer and consider user experience. Coexistence problems can be clearly noticed in devices with visual and/or audio interfaces. Since users do not judge products by data sheet performance but everyday usefulness, a general analysis of product quality as part of coexistence testing makes sense, such as with the R&S®AdVISE inspection software (presented on page 7) that captures every visual or audio signal irregularity. Audio and video quality testing also has become a routine task.

3. Take radio module installation location into consideration

Products with integrated radio modules behave differently than modules alone since radio characteristics are influenced by the housing and installation location. Some countries still do not require coexistence testing for fully assembled products. The incoming direction of wanted signals and interference signals affecting the DUT also play a role. This makes varying the angle of incidence with DUT and antenna positioners important for reliable testing.

4. Choose the right interference signals

As mentioned above, the signals specified in some standards do not put the DUT under enough stress to exclude coexistence issues in real-world situations, making it necessary to apply worst-case interference signals. This includes the interference signal power level, bandwidth and spectral position compared to the intended signal and the quality of unintended signals.

If all these factors are taken into account in the blocking test, there should be nothing to prevent trouble-free product operation.

A typical coexistence test setup

Fig. 5 shows a test setup for low-risk devices that satisfies all the criteria. The setup includes a radiocommunications tester, a vector signal generator, a spectrum analyzer, real-time inspection software and an optional power amplifier. Measurements are performed in a completely reflection-free, electromagnetically shielded anechoic chamber. The number of interference signals can be significantly expanded for high-risk products by adding further signal generators and antennas to model complex signal scenarios.

First, the radiocommunications tester establishes an end-to-end connection with a normal signal level to the DUT by emulating its radio interface, either as a local area standard such as WLAN or a cellular 2G, 3G, 4G or 5G network (5G is not possible with the R&S®CMW500 alone). The power amplifier is needed to boost the signal level. For 5G, a combination of the R&S®CMW500 and R&S®CMX500 is required.

A functional test is performed without any interference signals and the results are recorded for all relevant physical and application layer KPIs (data throughput, PER, BLER, video and audio performance) to create a baseline performance threshold. The power level of the wanted signal is reduced to the point where communications is just barely possible (10 % PER on the wanted system), to reproduce the worst-case scenario or cell edge conditions. After the interference signal is activated, the measurements are repeated.

If the DUT generates visual and/or audio output, the inspection software monitors the DUT using a HD webcam and microphone to check whether the outputs have the desired quality. Deviations are documented with a timestamp and evidence data.

A spectrum analyzer monitors the RF spectrum during the measurement process. The spectrum analyzer can be used to check whether the wanted and interference signals have the right frequencies and levels and whether any external signals are present that could invalidate the test result.

Summary

Ensuring interference-free coexistence of radio products will grow ever more important in the IoT era. Rapid technological developments and changes in the market have left current coexistence test standards often unable to adequately represent actual operating conditions. This is why manufacturers of particularly high-risk products work with test houses to go beyond the required tests and develop more realistic tests. These tests reduce liability risk while boosting user satisfaction and the quality brand image of their products. With a few principles taken into account, appropriate tests can be easily carried out with state-of-the-art T&M equipment from Rohde & Schwarz.

Mahmud Naseef, Christian Reimer

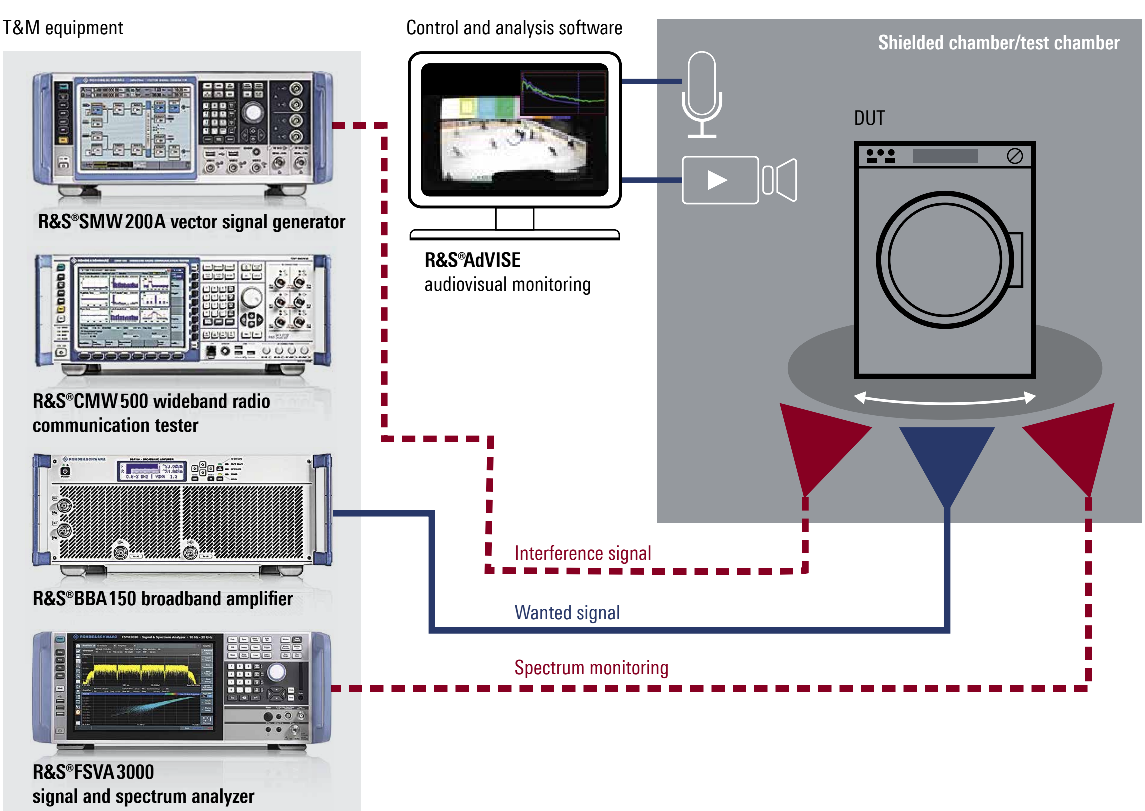


Fig. 5: The coexistence behavior of many product classes can be analyzed with this test setup.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A FASTER ROUTE TO DISTURBANCE-FREE MICROWAVE BANDS

Many devices generate frequencies in the gigahertz range, even though they are not radios. They must comply with internationally standardized limits to avoid disturbing established radiocommunications services. A new measurement function allows this to be verified faster than before.

Wireless and near field communications nowadays are increasingly carried out at frequencies above 1 GHz, so it is especially important to keep this frequency range free of disturbances. While ensuring that radios comply with strict requirements for the spectral purity of their emissions, other high frequency devices need to be handled carefully to prevent the spectrum from being overburdened with disturbance signals. For a long time, EMC test standards focused on the range below 1 GHz, but the rapid development of microwave radiocommunications has made repeated revisions necessary to tighten requirements. The CISPR 11 standard, for example, defines radio disturbance limits and measurement procedures for devices that generate high frequency energy for industrial, scientific, medical and domestic purposes, such as household microwave ovens. These ovens operate in the license-free ISM band at 2.4 GHz but generate high frequency disturbance signals up to 18 GHz.

To better evaluate the effect of interference from ISM devices on licensed radiocommunications services outside the 2.4 GHz band, the CISPR standardization group added a new measurement procedure to their CISPR 11 standard a few years ago. The procedure measures the amplitude probability distribution (APD) in the observed spectrum. The APD is the cumulative distribution of the amplitudes of a disturbance within a defined time interval and bandwidth [1] and indicates how strongly the EUT disturbs digital communications systems.

[1] CISPR 16-1-1:2019 (Ed. 5) Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus.

An APD measurement function has been available for some time for the R&S®ESW EMI test receiver, a world-renowned golden device for standard-compliant EMI measurements (Fig. 1). The new R&S®ESW-K58 software option enables multichannel measurements, making the process significantly faster. This is especially beneficial for time-consuming test sequences with many repetitions in type testing and quality testing.

The multichannel APD measurement function can be illustrated using the example of disturbance field strength measurements on microwave ovens between 1 GHz and 18 GHz in line with CISPR 11 [2]. Microwave ovens operate in pulse mode with frequency drifts due to their design. The oven's disturbance signals are first measured in a preview measurement using a peak detector (Fig. 2). This only measures the maximum value, not the signal's behavior during the measurement period, so it does not reflect the true disturbance effect and is not suitable for evaluation. Studies have shown that the effect of disturbance on the bit error rate can be evaluated significantly more precisely using the probability distribution of the disturbance amplitude.

[2] CISPR 11:2019 (Ed. 6.2) Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement.

CISPR 11 therefore requires an evaluation measurement of pulses exceeding the peak limit. The APD measurement function can be used for this. Due to the drifting operating frequency of microwave ovens and the resulting drift of the harmonics, the current edition of CISPR 11 [2] specifies an acquisition range of 20 MHz. This is covered by five measurement channels symmetrically positioned around the critical frequency with offsets of 0 MHz, ±5 MHz and ±10 MHz. The APD limit defines a maximum probability of 10^{-1} for amplitudes greater than 70 dB (µV/m). This means the probability that the measured disturbance amplitude exceeds the limit during the defined measurement period of 30 s is at most 10 percent. If the EUT fulfills this requirement, the final test case verdict is PASS.

The R&S®ESW-K58 acquires the five required channels in parallel and presents them in a 2D diagram with a color-coded probability distribution, along with the test case verdict PASS, MARGIN or FAIL (Fig. 3).

The software can do even more than the standard requires. For measurements during development, the number of channels, acquisition bandwidth, minimum amplitude probability and acquisition time can be freely chosen within limits. For example, up to 21 channels with an analysis bandwidth of 1 MHz per channel can be measured in parallel to provide seamless coverage of the 20 MHz range. This ensures that even a narrowband fluctuating disturbance source will be acquired in at least one of the channels. Up to 67 channels are possible with an acquisition bandwidth of 300 kHz or less.

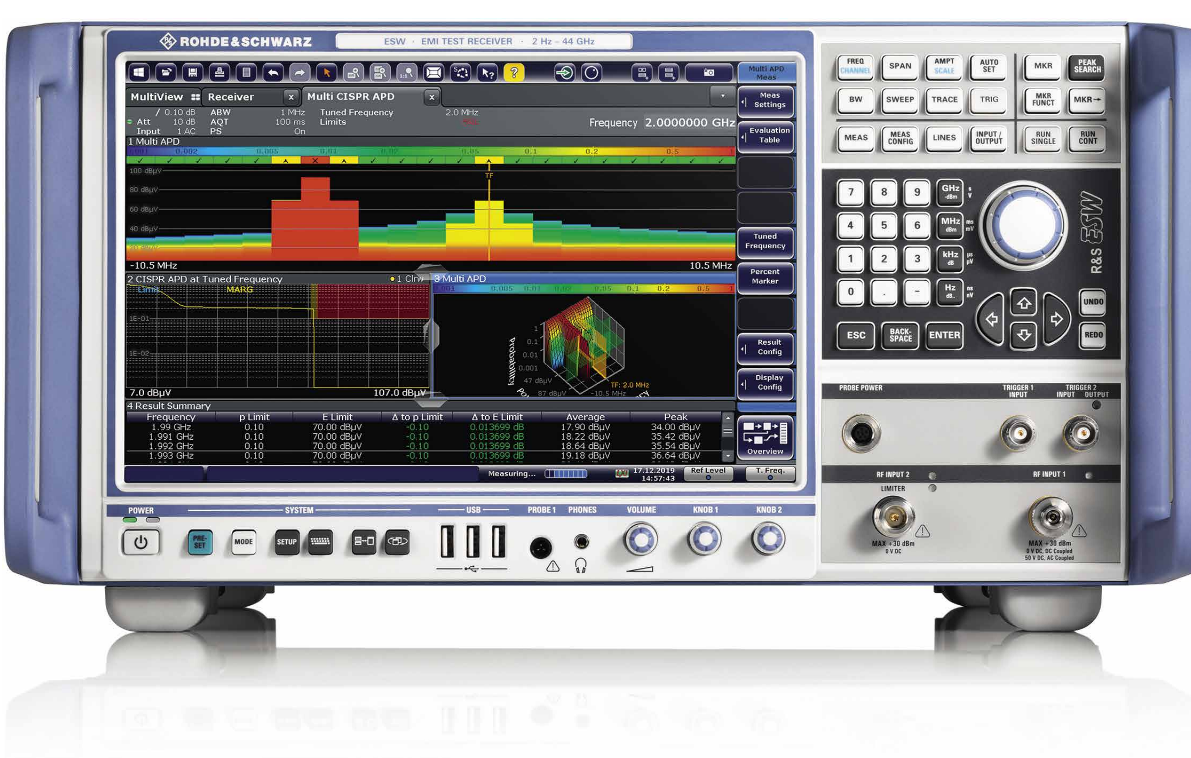


Fig. 1: R&S®ESW EMI test receiver with multichannel APD measurement function.

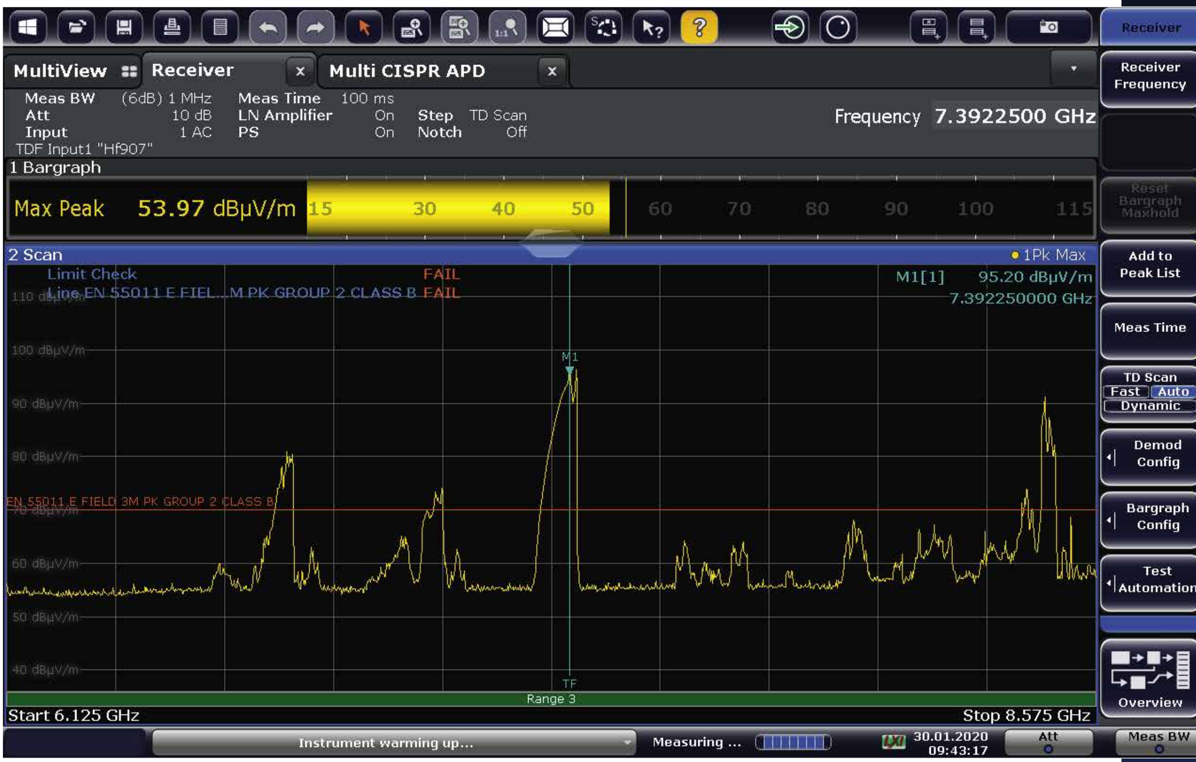


Fig. 2: Preview measurement on a microwave oven with the peak detector in subband 3 (6.125 GHz to 8.575 GHz). "FAIL" means that the measurement result exceeds the limit, so further APD measurement around the noncompliant frequency (here 7.39 GHz) is necessary.

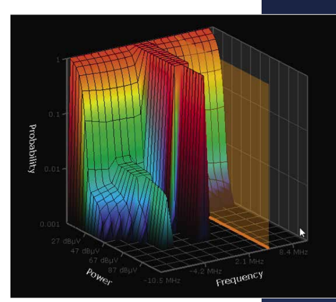


Fig. 4: 3D view of a 20 MHz wide seamless APD measurement over 21 channels.

Fig. 3: Further measurement on the critical frequency using the multichannel APD measurement function. The 2D diagram provides a qualitative and quantitative result at a glance.

For detailed disturbance signal analysis, a 3D view is also available, which can be rotated and zoomed with touch gestures (Fig. 4).

The R&S®ESW-K58 measurement function offers clear advantages over conventional measurement methods and the single-channel method:

- ▶ An alternative to the log-AV method for disturbance field strength measurements on microwave ovens in line with CISPR 11, with the advantage that the true (linear) average value can be determined
- ▶ At least five times faster than single-channel APD measurement
- ▶ Higher accuracy and reproducibility than methods with logarithmic average values on a spectrum analyzer (log-AV method with 10 Hz video bandwidth)
- ▶ Fast PASS/FAIL visualization of all channels simultaneously in the 2D diagram
- ▶ Detailed disturbance signal analysis using touch-controlled rotation and zoom functions in the 3D diagram

Jens Medler

Specifications of the R&S®ESW-K58 multichannel APD measurement function

- ▶ Maximum number of channels: 67 (ABW ≤ 300 kHz), 21 (ABW = 1 MHz)
- ▶ Acquisition bandwidth (–6 dB): 1 Hz ≤ ABW ≤ 1 MHz
- ▶ Minimum amplitude probability: 10^{-7}
- ▶ Maximum acquisition time: 120 s
- ▶ Compliant with the CISPR 16-1-1 standard

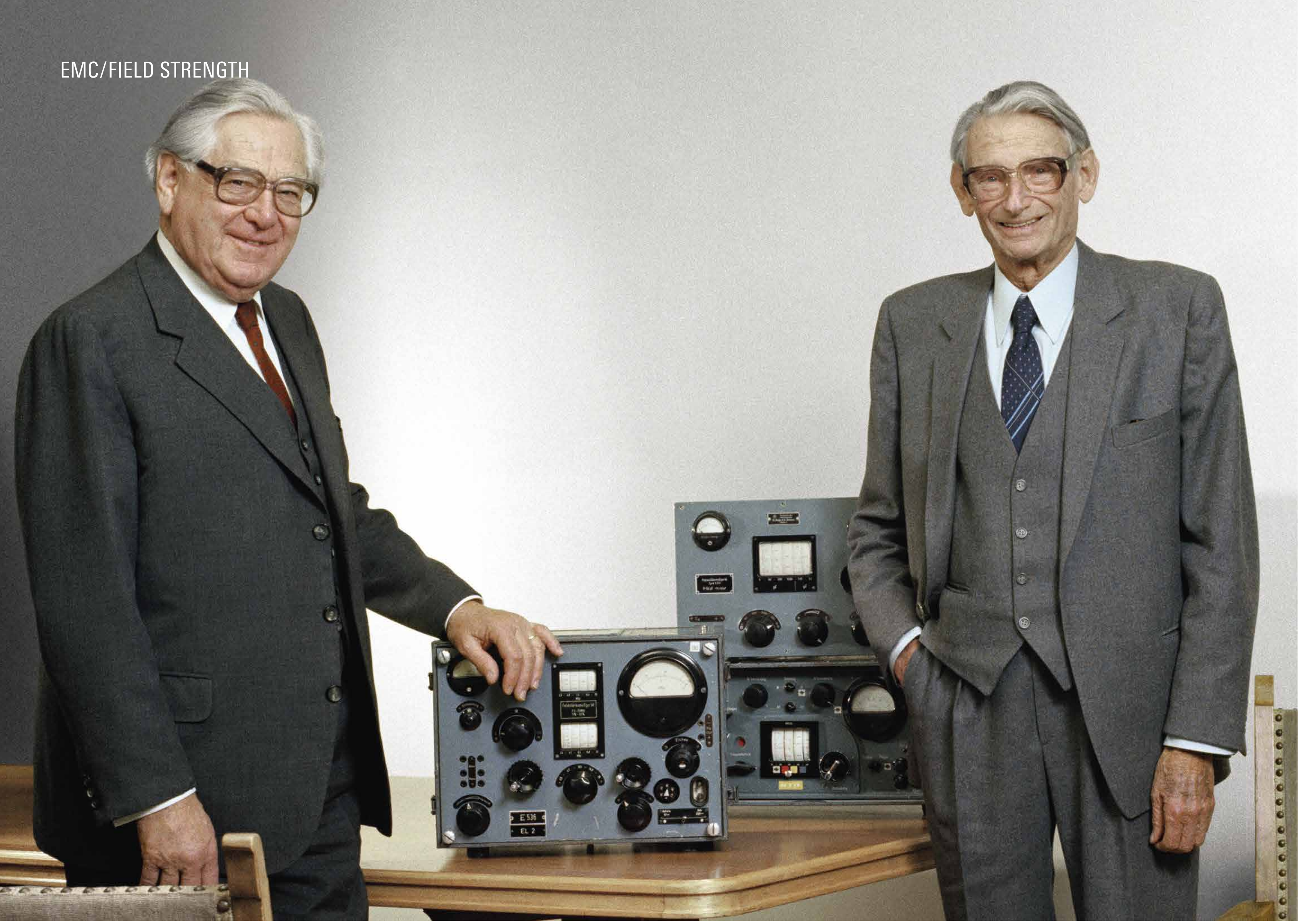


Fig. 1: Dr. Lothar Rohde (right) and Dr. Hermann Schwarz in front of products from the first decade of the company, with the HHF far field meter in the foreground. It was developed in 1937, roughly the birth year of measuring receivers at Rohde & Schwarz.

THE HISTORY OF MEASURING RECEIVERS AT ROHDE & SCHWARZ

Rohde & Schwarz has been building EMI test receivers for a long time. The first field strength meter for measuring electromagnetic interference was built in the 1930s. Today Rohde & Schwarz is the world market leader for standard-compliant instruments of this type.

The need for EMI test receivers arose with the introduction of AM broadcasting in the 1920s. Numerous interference complaints from radio listeners made RFI suppression necessary for existing electrical devices and equipment, but suitable measurement procedures and instruments were not yet available. Systematic research for defining uniform measurement procedures to protect broadcasting started only after the establishment of the International Special Committee on Radio Interference (CISPR) in 1933.

It was soon recognized that the effect on radio reception depended on the type of interference (broadband or narrowband) and the radio service concerned. In particular, the dependence on the pulse repetition frequency led to the definition and introduction of the well-known quasi-peak detector. The aim was to keep RFI suppression costs low, which meant RFI suppression should only be performed to the extend absolutely necessary. Test and measurement should only indicate the need for action with a frequency when subjectively justified. Low pulse frequencies are perceived much less disturbing than higher ones (for example, a 100 Hz impulsive disturbance has the same effect on a mediumwave receiver as a 10 dB stronger 10 Hz disturbance), so they could be weighted less in the measurement, which is exactly what the quasi-peak detector does. Quasi-peak evaluation therefore amounts to a simulation of the AM radio receiver together with the subjective noise sensitivity.

In 1941, the Association of Electrical, Electronic and Information Technologies (VDE) published the draft standards VDE 0876 “Specification for radio disturbance and immunity measuring apparatus and methods” and VDE 0877 “specifications for the measurement of radio frequency conducted disturbances (disturbance voltages and currents)”. This nomenclature is still valid today. VDE 0876 mirrors the CISPR 16-1-x series of basic standards (apparatus for measuring radio disturbance emissions), while VDE 0877 mirrors the CISPR 16-2-x series of basic standards (methods for measuring radio disturbance emissions).

The first epoch: early beginnings

Rohde & Schwarz started developing and building field strength meters in the 1930s. The first instruments were the HHK field strength meter and the HHF far field meter in 1937 (Fig. 1). The HHK was available in two versions, for the frequency ranges 2.3 MHz to 23 MHz and 23 MHz to 107 MHz. With three versions, the HHF covered a total frequency range from 100 kHz to 100 MHz and enabled field strength measurements from 1 μV/m to 0.1 V/m. It was followed by the HHN near field meter in 1938, also available in three models covering the frequency range from 100 kHz to 100 MHz.

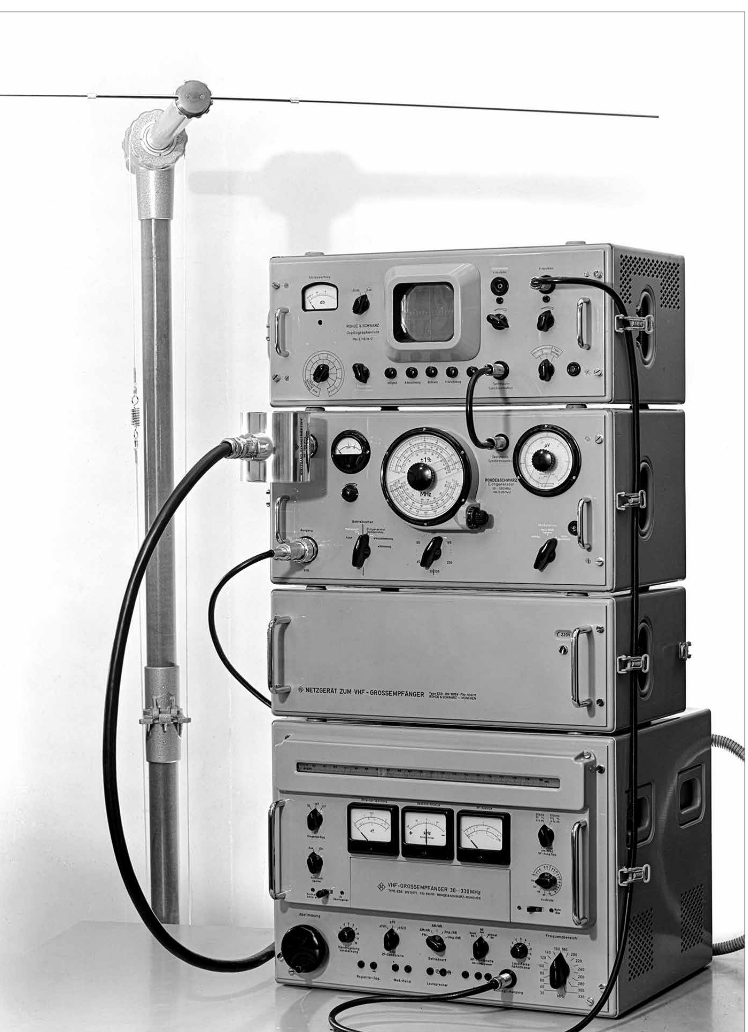
In the postwar period, Germany was confronted with a new situation for broadcasting. The Copenhagen plan for radio frequencies in Europe, which took force in 1948, was

This article is an excerpt from a complete history of measuring receivers at Rohde & Schwarz up to the present day. It can be downloaded from www.rohde-schwarz.com (search term measuring receiver story).

Fig. 2: The advent of radio broadcasting made RFI suppression necessary. This bronze American figure is listening to a radio speech by President Franklin D. Roosevelt in his memorial in Washington, DC.

not kind to the losing countries of World War II and allocated them only very few and unfavorable frequencies in the mediumwave band. As a result, Germany pushed the exploitation of the VHF and UHF bands for broadcasting. A milestone of this development was the first European VHF transmitter, built by Rohde & Schwarz and operating at 90.1 MHz, which was put into service by the Bavarian public broadcaster Bayerischer Rundfunk on February 28, 1949, in Munich-Freimann. Field strength meters were needed for planning the transmitter site and monitoring transmitter operation. In 1949, Rohde & Schwarz launched the HFD field strength meter for frequencies from 87 MHz to 470 MHz as a companion to the HHF. The HFD core was the ESD measuring receiver, a heterodyne receiver with a built-in 100 MHz calibration generator. The good reproducibility of voltage calibration enabled very accurate comparison measurements in the linear measuring range even with small changes in field strength, while the logarithmic measuring range allowed the measurement and recording of strongly varying field strengths. Reception of FM or AM transmitters was also possible.

Fig. 3: VHF interference measuring system (new version starting 1957) with ESG VHF measuring receiver (bottom) and EZS interference measurement supplement (top).



Opening of the VHF band from 30 MHz to 300 MHz for radio and TV broadcasting brought new requirements for EMI measuring equipment. The standards also had to be updated, from disturbance voltage measurements up to 20 MHz to disturbance field strength measurements up to 300 MHz. CISPR additionally demanded measurement of the disturbance voltage from the DUT at the AC line connection below 30 MHz and the radiated disturbance field strength above 30 MHz. Rohde & Schwarz supported this process with the development of a UHF interference measuring system that was used by the Fernmeldetechnische Zentralamt (FTZ, German Telecommunication Engineering Center) in Darmstadt and the interference measuring stations of Deutsche Bundespost to investigate the effect of interference on UHF broadcasting.

The noise effect of electrical interference on AM radio broadcasting was known from earlier investigations, but the effect of interference on TV and FM radio broadcasting was largely unexplored. At first it was thought that the effect of interference could be determined by measuring the peak value of the interference pulses. Accordingly, a series of unweighted peak value displays independent of the pulse repetition frequency was selected. An oscillograph (as the instrument was known at the time) was used for qualitative assessment of the interference pulses in terms of shape and width and for comparison of interference and test pulses. It turned out that clearly defined individual pulses were fairly uncommon. The usual pattern was pulse trains with more or less distance between the pulses, e.g. from bouncing contacts, ignitions of internal combustion engines, sparking commutators of electric motors, or corona discharges on high voltage transmission lines. Experience showed that the oscillographic measurement method for acquisition and evaluation of pulse trains was not satisfactory. For instance, the readout varied considerably depending on whether the rare very high pulses of the disturbance signal were used for comparison with the test pulse from the calibration generator or a more frequent average value was assumed. Furthermore, a measurement procedure was needed that directly mapped the effect of interference on TV reception.

It was found that the subjective perception of picture distortion was also dependent on the pulse repetition frequency of the interference pulses, but with a steeper drop compared to aural interference perception with radio reception. Mapping the weighting all the way down to individual pulses would have required measuring receivers able to process amplitude differences greater than 50 dB without overloading. This was not possible at the time, and even now it would be a major challenge for a measuring instrument. The CISPR therefore proposed and implemented a flattened weighting curve for quasi-peak indication in CISPR Band C (30 MHz to 300 MHz), which is still part of the CISPR 16-1-1 standard. It specifies a 43.5 dB devaluation for single pulses relative to the peak value. For the rectifier, CISPR defined a charge time constant of 1 ms and a discharge time constant of 550 ms to ensure reproducible results. Finally, the measurement bandwidth had to be adapted to the new broadcasting services. It was initially set to 200 kHz for interference measuring systems, but later the CISPR recommended a value of 120 kHz. All this was integrated in the EZS interference measurement supplement, replacing the oscillographic measurement method by an instrument display. The system was deployed from 1957 by Deutsche Bundespost and the supervisory authorities of other European countries as the standard measuring system. Initially (from 1953) the VHF instruments ESM 180 (30 MHz to 180 MHz) and ESM 300 (85 MHz to 300 MHz) were used as the measuring receiver. From 1955 these were replaced by the ESG measuring receiver (Fig. 3) (30 MHz to 330 MHz).

The HUZ VHF field strength meter for the frequency range from 47 MHz to 225 MHz was also launched at this time. It had a peak voltage display with CISPR weighting. Although this instrument did not meet the high requirements of CISPR Recommendation 305 or the revised VDE Regulation 0876 with regard to absolute accuracy and overload resistance, the portable HUZ instrument could be used for exploratory field measurements, for example to investigate ignition noise in connection with motor vehicle interference suppression.

In 1959, the tried and tested HHF field strength meter was replaced by the HFH (Fig. 4). Unlike the separate instrument variants of the previous generation HHF, the HFH covered the entire frequency range from 100 kHz to 30 MHz in a single instrument. It could be used for direct field strength measurements with a choice of three

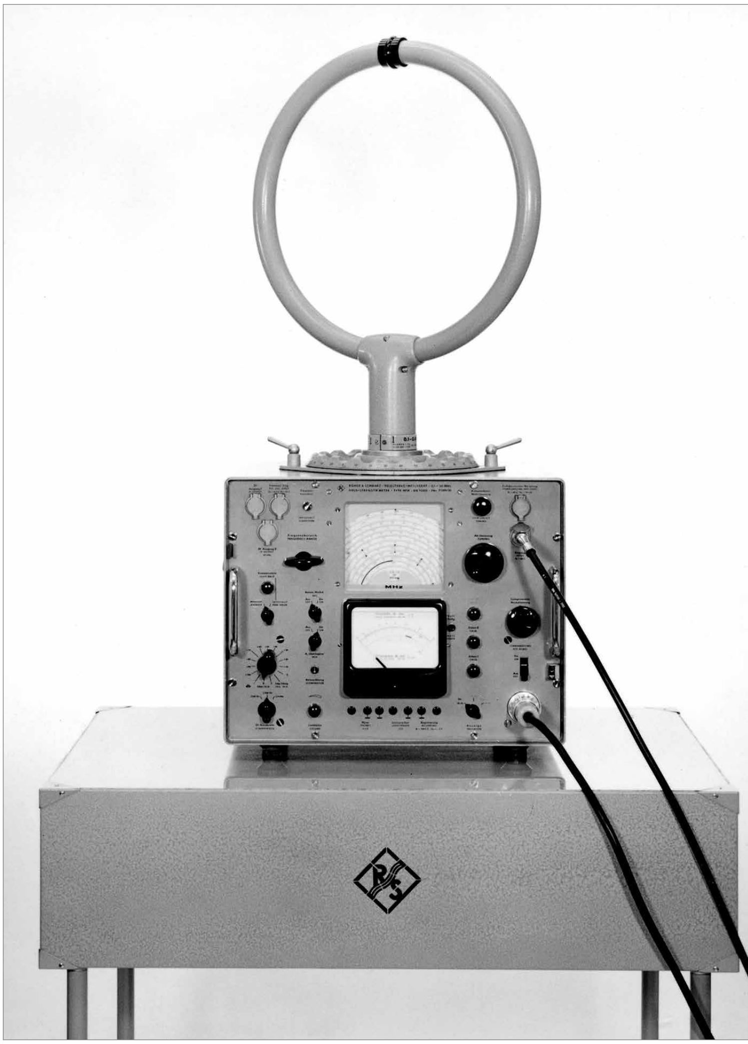


Fig. 4: HFH field strength meter with attached loop antenna for direct field strength readout in the 100 kHz to 30 MHz frequency range. The transport case has been converted into an equipment table.

loop antennas for the ranges 0.1 MHz to 0.4 MHz, 0.4 MHz to 1.6 MHz and 1.6 MHz to 30 MHz, or with a remote rod antenna and later with a remote loop antenna. The tracking calibration generator was an innovation. It enabled calibration at every frequency, including the loop antenna, allowing direct readout of field strength values without the use of calibration curves. The display could be switched between average and peak voltage measurement for disturbance voltage measurements. The instrument came with inductive and capacitive probe antennas for purposes such as testing shielding effectiveness. As a special feature, the transport case could be converted into a table for the test equipment. In addition, the frequency range could be extended down to 10 kHz with the HFHL longwave accessory.

The second epoch: the age of analog heterodyne receivers with CISPR weighting detectors

The ESU VHF/UHF measuring receiver (Fig. 5) was launched in 1961. It covered the frequency range from 25 MHz to 900 MHz with three interchangeable plug-ins: RF Part I (25 MHz to 225 MHz), RF Part II (160 MHz to 475 MHz) and RF Part III (460 MHz to 900 MHz). RF Part IV (900 MHz to 1300 MHz) was added in 1969. The ESU was a superheterodyne tube receiver with a spiral analog scale for frequency display. With its sturdy metal enclosure, it weighed in at 30 kg, and it had a measuring signal input conforming to the Dezifix-B standard – a connector type developed by Rohde & Schwarz that was commonly used in the 1960s.

Fig. 5: The ESU VHF/UHF measuring receiver had interchangeable RF plug-ins and a measuring signal input conforming to the Dezifix-B standard – a connector type developed by Rohde & Schwarz that was commonly used in the 1960s.

The tracking calibration generator, which could be used to calibrate the instrument at every measuring frequency, was a major advancement. Operation was also simplified by selectable display ranges (linear 20 dB, logarithmic 40 dB or 60 dB), switchable average or peak value display, selectable pass bandwidth (25 kHz or 120 kHz) and optional automatic frequency control.

The ESU was the core element of the HFU VHF/UHF field strength meter, which also included a broadband dipole antenna for 25 MHz to 80 MHz, a broadband log periodic antenna for 80 MHz to 1000 MHz, a stand and a tower, cables with Dezifix connectors and a transport case. The HFU was intended as a frequency extension accessory for the HFH and replaced the previous HHF and HFD field strength meters.

The ESU did not have a built-in weighting function for disturbance field strength measurement according to VDE 0876. The separate EZS interference measurement supplement had to be connected to the IF output (2 MHz) for this purpose. After frequency tuning and calibration, the EZS display had to be set to approximately 0 dB using the ESU level switch and the EZS attenuator. The measurement result in dB above 1 µV was calculated as the sum of the dB value of the EZS attenuator, the ESU level switch setting and the deviation from 0 dB on the EZS display. Then the disturbance field strength in dB above 1 µV/m could be obtained by adding the antenna factor. Although this manual process was complicated, it produced valid results. Automatic evaluation in later instruments made things significantly easier for users.

Portable instruments were also necessary to cover the UHF band. This led to the launch of the HUZE UHF field strength display in 1964 for the frequency range 470 MHz to 850 MHz, as a sort of extension to the tried and tested HUZ. With peak value rectification and an IF bandwidth of 500 kHz, the HUZE was highly suitable for determining the propagation conditions of television signals in the UHF band.

The portable HFV VHF field strength meter (Fig. 6) followed in 1970. It could measure the field strengths of wanted and disturbance signals from 25 MHz to 300 MHz. The entire band could be tuned without switching ranges. The switchable average and peak value display, the large measuring range of 130 dB, AM and FM demodulation, and disturbance weighting according to VDE and CISPR with the standardized measurement bandwidth of 120 kHz made this instrument ideal for a wide variety of radio monitoring and interference measurements. The HFV was the first Rohde & Schwarz interference measuring receiver with standard-compliant weighting. It was followed by many generations up to the present.

Matthias Keller, Jens Medler

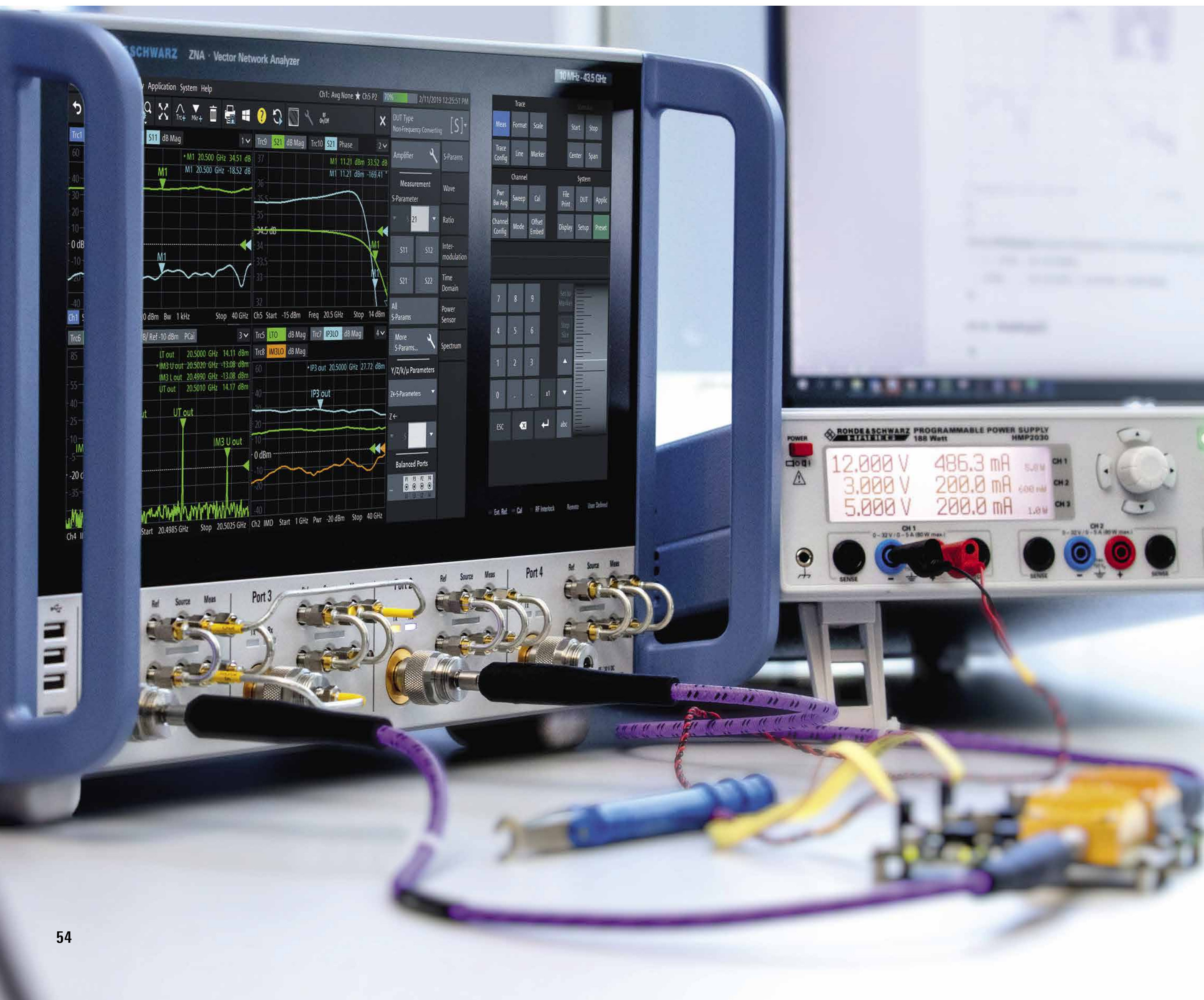
Fig. 6: HFV mobile VHF field strength meter with dipole antenna. This was not only the first fully solid-state Rohde & Schwarz measuring receiver, but also the first one able to perform automatic disturbance weighting according to VDE 0876.

HIGH-END NETWORK ANALYSIS NEWS

VNA models up to 67 GHz, convenient noise figure measurements up to 40 GHz

The R&S®ZNA VNA series launched about two years ago has set new standards in vector network analysis. Since then the instruments have continuously been enhanced with new functions. A major enhancement is under way with two new models soon to be launched – the R&S®ZNA50 and R&S®ZNA67 extend the frequency range up to 50 GHz and 67 GHz. Together with series R&S®ZCxxx mmWave converters, the R&S®ZNA even operates in the THz range, which has also been possible with the previous models (see NEWS 223).

The unique R&S®ZNA hardware platform offers up to four internal, phase coherent sources plus a fifth source, which can be used as a second internal LO source for measurements on frequency converters and mixers. Together with up to eight truly parallel measurement receivers, this



hardware architecture is ideal for demanding measurements on components and modules for the aerospace and defense sector and the mobile and wireless communications industries (5G, 6G). The new models also provide signal integrity measurements on differential lines up to 67 GHz, and even beyond with four R&S®ZCxxx converters connected to the R&S®ZNA.

Noise figure measurements made easy

Characterizing low-noise amplifiers (LNA) requires not only the S-parameters to be measured but also the noise figure. Especially with on-wafer device characterization, it makes sense to measure all parameters with just a single contact between the integrated circuits under test and the probe tips. The VNA determines the noise figure in the calibration plane. A new firmware option for the R&S®ZNA26 and R&S®ZNA43 models supports noise figure measurements (Figs. 1 and 2). It guides users through calibration and test configuration and performs all the required settings automatically. The analyzer's receiver noise figure, which must be known for the measurement, is stored in the instrument firmware. After the user enters an estimated gain value for the LNA, the R&S®ZNA has all the information it needs for the measurement.

Measurements can be adapted to match the DUT by making appropriate test configurations based on hardware options. In many cases a preamplifier is required, especially with low LNA gain and noise figure. If the R&S®ZNA is equipped with a preamplifier and the necessary filters, the firmware can activate and deactivate the preamplifier.

The source monitor option provides direct access to the reference signal, i.e. it allows the reference signal to be picked up before the source step attenuator. This provides a better signal-to-noise ratio, resulting in shorter measurement time. The directional coupler at the receive port can be reversed by reconnecting the jumpers on the instrument front panel, which improves the analyzer's receiver noise figure by 10 dB. This also avoids the higher coupler attenuation (roll-off) at low frequencies.

It is crucial that all components in the signal chain are in the linear range and no compression occurs during calibration and measurement. To ensure this, the new firmware option calculates a link budget as well as the correct power at the source port. In addition, it displays recommendations for an optimal test setup to boost measurement speed. Users can influence measurement time by specifying an allowable trace noise level, for which the network analyzer calculates matching detector times.

All this makes noise figure measurements easy.

Andreas Henkel

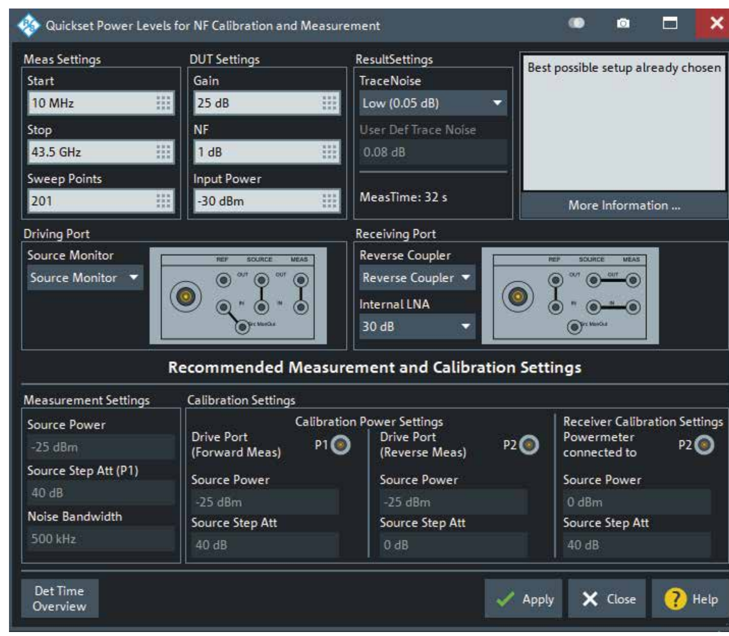


Fig. 1: Noise figure measurement configuration menu. If options such as preamplifier and source monitor are installed (as in this case), they are included in the configuration menu.

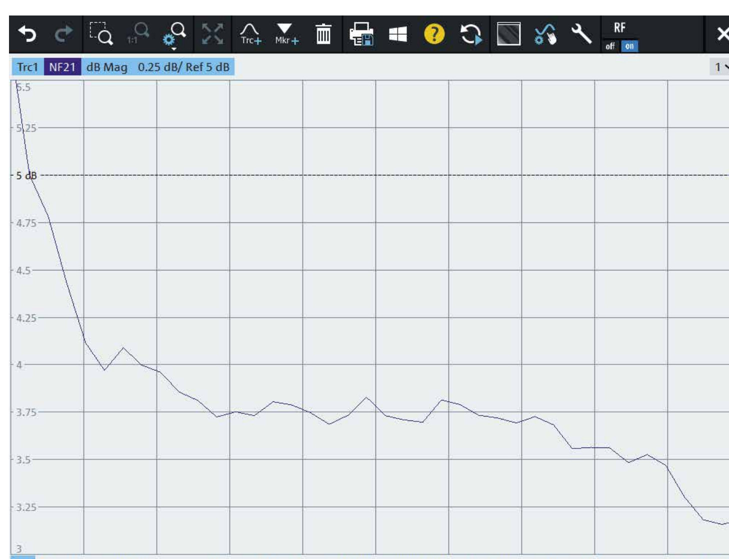


Fig. 2: Noise figure measurement result with the R&S®ZNA26 or R&S®ZNA43.

DEEMBEDDING MADE EASY

Working effectively with a vector network analyzer

Deembedding, which means eliminating the effects of connectors, cables and adapters in a test setup, is a well-established procedure. It is becoming increasingly important in the microwave domain, where components that are not part of the DUT have an especially negative impact. Four new algorithms for Rohde & Schwarz network analyzers make life much easier for circuit designers.

Fig. 1: Calculating the effects of PCB traces based on reference measurements is one of the functions of the new deembedding options.

Next generation RF communications systems will process data rates in the multiple Gbit/s range and frequencies far above 20 GHz. These signals require tightly toleranced module specifications. In addition, microwave frequencies with wavelengths approaching component dimensions cause significant distortions on test adapters, cables, connectors and PCB traces. How can this be countered with T&M equipment?

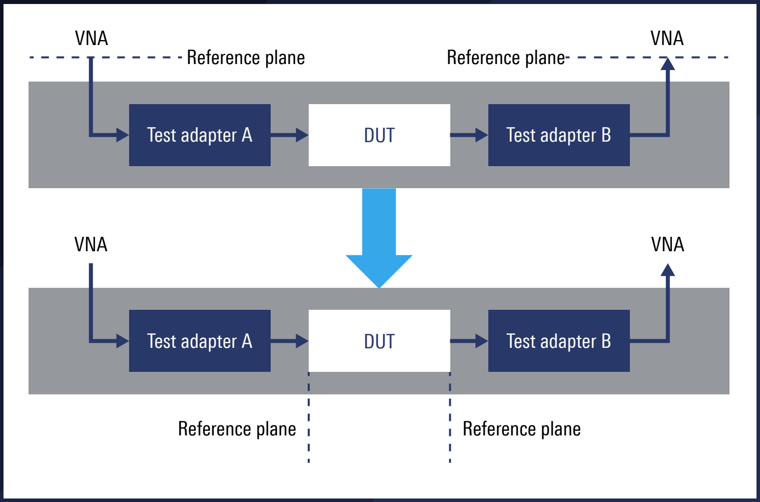
Deembedding with software algorithms

Vector network analyzers (VNA) are the preferred tool for precisely measuring the transmission characteristics of RF components and describing them in the form of S-parameters. A prerequisite for precise measurement, however, is characterization of the transmission characteristics of the entire test setup down to the DUT, as otherwise the specific characteristics of the DUT cannot be measured correctly. This is not easy, especially with integrated circuits such as analog components that cannot be probed directly because they are soldered on a PCB. In this case the connection to the VNA is made using a test fixture, unless the PCB has coaxial connectors. The RF transmission characteristics of the test fixture, as well as the characteristics of the signal traces to the DUT on the PCB, must be mathematically eliminated from the measurement. This is the job of the new software options.

What is deembedding?

When characterizing the RF transmission characteristics of a DUT, it must be ensured that all components of the test setup between the network analyzer (VNA) and the DUT can be neutralized by measurement to avoid corruption of measurement results. This is done by mathematically shifting the reference plane of the VNA to the DUT. The reference plane of the VNA is the point up to which the VNA is fully calibrated, physically located at the outer end of its coaxial connectors. In order to include the elements of the test setup external to the VNA in the calibration, their S-parameters must be known. If all elements of the test setup are connected by coaxial lines and coaxial connectors, measuring them is not difficult, but things are different if the line type changes or the last part of the path to the DUT is not accessible. In this case good estimations based on reference measurements are necessary, and they can be provided by the described deembedding algorithms.

Shifting the calibrated reference plane in the deembedding process.



The procedure is as follows:

First the test engineer measures the S-parameters of the reference path on a test coupon (Fig. 2, bottom) containing the components to be deembedded, such as a coaxial-to-coplanar transition and a length of line. Usually a 2× thru reference is constructed for this, consisting of symmetrical input (fixture A) and output (fixture B) lines to and from the DUT, because this results in more accurate measurements. Then the engineer measures the S-parameters of the path including the DUT (Fig. 2, top). The two measurement results are input to a software algorithm that calculates the transmission characteristics of the bare DUT from the measured data.

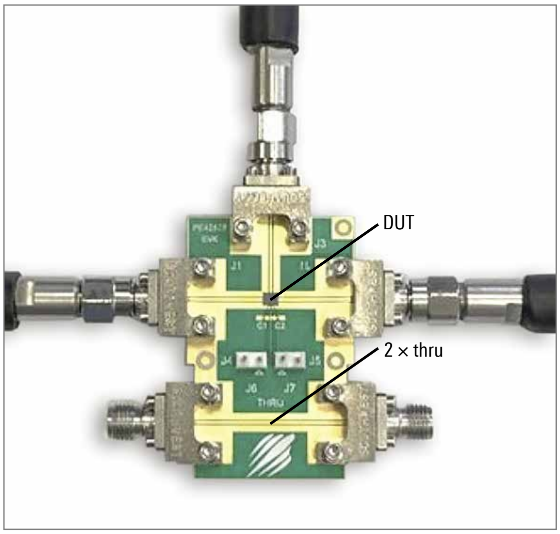


Fig. 2: Example test coupon with a 2× thru configuration. The input and output lines of the DUT to be deembedded are duplicated as reference paths on the same PCB as the DUT so they have the same transmission characteristics as the actual input and output lines, which is a prerequisite for accurate deembedding.

The quality of the deembedding process is only as good as the quality of the test fixture and the test coupon. The algorithm also assumes that the electrical characteristics of the reference path and the path including DUT are the same. This easy to set up on a PCB (Fig. 2).

Simple workflow fully integrated in the VNA user interface

The algorithms used in the software options are widely accepted in the industry (Fig. 3). The first three options have essentially the same functionality and can be used interchangeably, but the Delta-L method characterizes the frequency-dependent attenuation of RF PCBs in dB per inch and, unlike the other options, does not calculate all the S-parameters of the embedding network. Intel recommends this method for measurements on PCBs for its high speed components (Figs. 1 and 5).

Fig. 3: Available options.

	Easy deembedding (EZD) R&S®ZNx-K210 option	In-situ deembedding (ISD) R&S®ZNx-K220 option	Smart fixture deembedding (SFD) R&S®ZNx-K230 option	Delta-L PCB characterizing (Delta-L) R&S®ZNx-K231 option
Supported DUTs				
All DUTs with non-standardized connectors (without Cal Kit) and connectorless DUTs	●	●	●	–
Workflow without/with impedance correction	● / –	Planned / ●	Planned / ●	– / –
Two-port and four-port topologies	●	●	●	–
PCB traces (semi-ideal, no vias)	●	●	●	●
Supported test coupon structures (single-ended and differential)				
2 × thru	●	●	●	–
1 × open + 1 × short	–	●	●	–
1 × open	–	●	●	–
Delta-L coupons with 1 L, 2 L oder 3 L	–	–	–	●
Methods and results				
Measurements	All	All	All	Loss/inch
Full deembedding	●	●	●	–

All options use a convenient workflow (Fig. 4) integrated in the VNA user interface. It guides the user quickly and effectively through the required measurement steps. A big advantage of the integrated solution is that the measured deembedding S-parameters do not have to be imported or exported.

The deembedding options can run on all top-end and midrange VNAs from Rohde & Schwarz: R&S®ZNA, R&S®ZNB, R&S®ZNBT and R&S®ZND. Using these options, it is now possible to eliminate the effects of test fixtures that do not probe the DUT through coaxial connectors. They are suitable for both single-ended and differential DUTs.

Mathias Leutiger

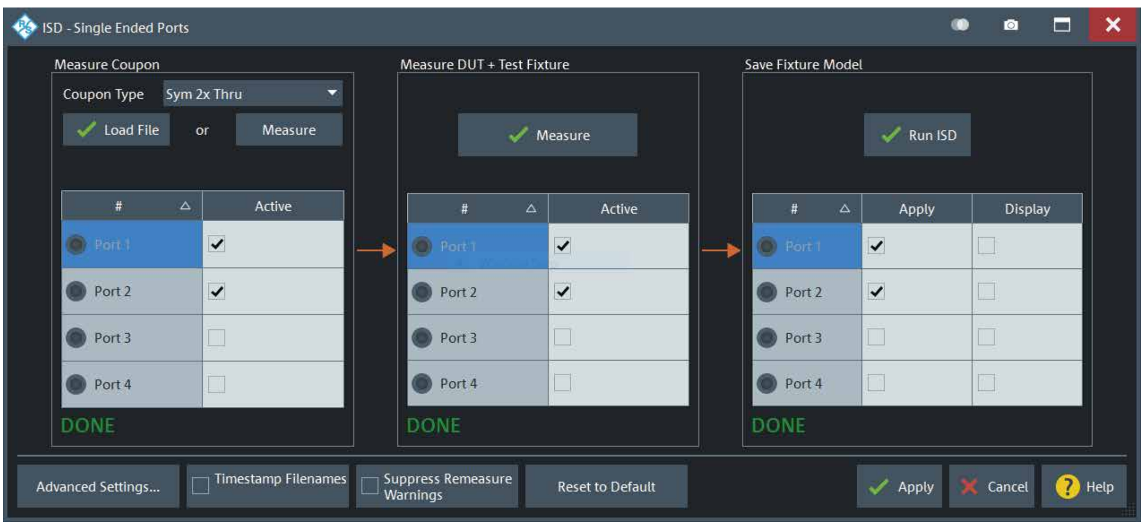


Fig. 4: Example screen of the R&S®ZNx-K220 deembedding option. The task is performed after a simple three-step process.

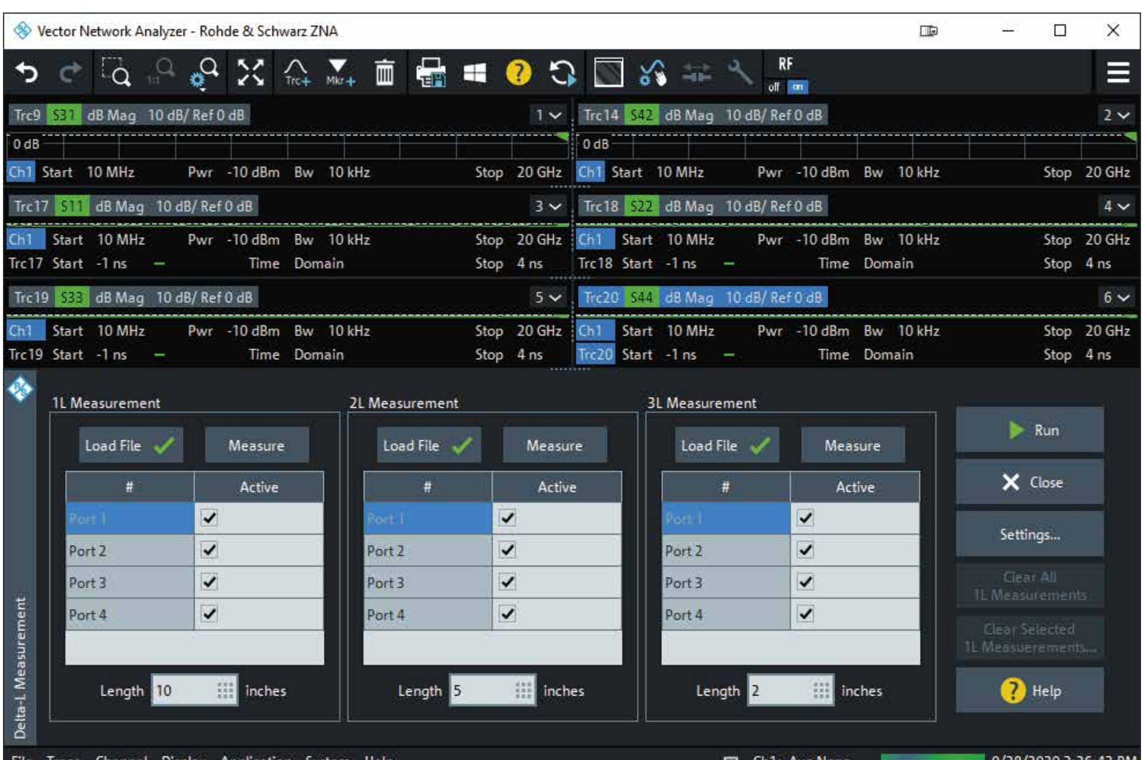


Fig. 5: The Delta-L PCB characterization method recommended by Intel (R&S®ZNx-K231 option) measures and deembeds traces on printed circuit boards.

FLYING HIGH

Two-port handheld vector network analyzer up to 26.5 GHz featuring S-parameter measurements

The Rohde & Schwarz product portfolio previously included the R&S®ZPH (up to 4 GHz) and the R&S®ZVH (up to 8 GHz) for field work at RF transmitter and receiver sites*. Now a third model has been added. The R&S®ZNH extends the measurable frequency range up to 26.5 GHz. Measurements on radar, microwave and satellite systems, whether stationary or installed on ships or vehicles, are part of the standard repertoire of the new handheld. Thanks to its outstanding RF performance, including a dynamic range of typically 100 dB, output power up to 0 dBm and a spurious level as low as 0.0025 dB RMS, the analyzer is also a good choice for various tasks in development, production and service.

The R&S®ZNH is the first two-port vector network analyzer in the Rohde & Schwarz handheld VNA series. Featuring a four-receiver architecture, it measures all four S-parameters, plus it supports advanced calibration methods such as UOSM (unknown through, open, short, match), a useful feature when measuring DUTs with a mix of connector types at the input and output. All classic one-port measurements on antennas and cables, such as distance-to-fault (DTF) measurements, are also supported.

Lightweight design, heavyweight performance

For efficient mobile use, instruments must be easy to handle and quick to configure. The R&S®ZNH is housed in the same compact case as the other members of its family and shares their proven user interface, with a combination of hardkeys and a gesture enabled 7" capacitive touchscreen. A measurement wizard helps even inexperienced users make the right settings, which can be combined to create automated, standardized test sequences.

Remote control capability is a key aspect for field use. Not every qualified engineer is a qualified climber. Sometimes an engineer on the ground must guide an assistant on the tower through the measurements. The R&S®ZNH does away with such workarounds. When connected to a (mobile) WLAN router, the instrument can be operated on a tablet just like on the instrument itself.

* The product line is complemented by the R&S®FPH and R&S®FSH handheld spectrum analyzers. The R&S®FSH also provides measurements on modulated signals.

Custom configuration

On-site testing usually involves not only antennas and cables, but also filters, splitters and amplifiers. The R&S®ZNH has all it takes to perform these measurements. Capabilities beyond the standard two-port VNA configuration can be ordered separately and enabled via keycode:

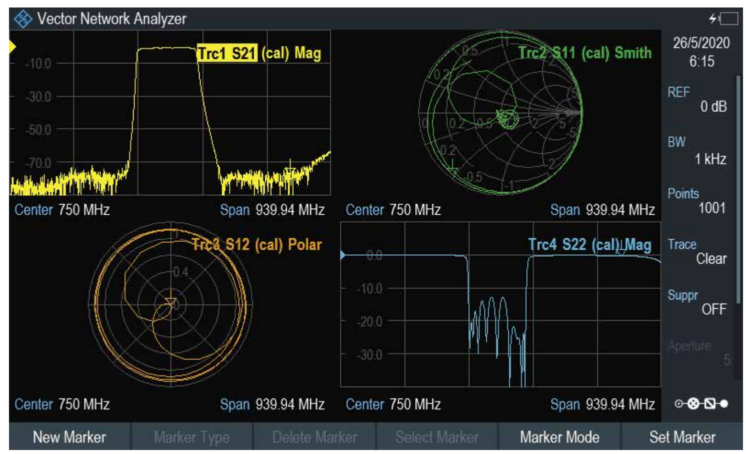
- Support of terminating, directional and optical power sensors, which can be used to test transmit power and matching as well as the optical signal feed to a base station's common public radio interface (CPRI).
- Pulse measurement option for detailed analyses on radar and microwave systems.
- Tower mounted amplifiers (TMA) are usually powered through the RF cable – a task that can be handled by the R&S®ZNH.
- A vector voltmeter displays the amplitude and phase for a fixed frequency – a measurement function that is useful, for example, when working on phased array antennas. The required signal source and VSWR bridge are available in the R&S®ZNH.
- The four phase coherent receivers of the R&S®ZNH cannot only perform S-parameter measurements. In addition, the wave quantities and arbitrary ratios of wave quantities can be measured and saved in two parameter sets. Based on this functionality, the R&S®ZNH can be used, for example, as a frequency selective power meter or to align two RF channels of a phased array antenna in amplitude and phase.

The R&S®ZNH greatly simplifies installation and maintenance of antenna systems up into the microwave range. As an allrounder in the lab, the handheld instrument can in many cases replace a stationary network analyzer.

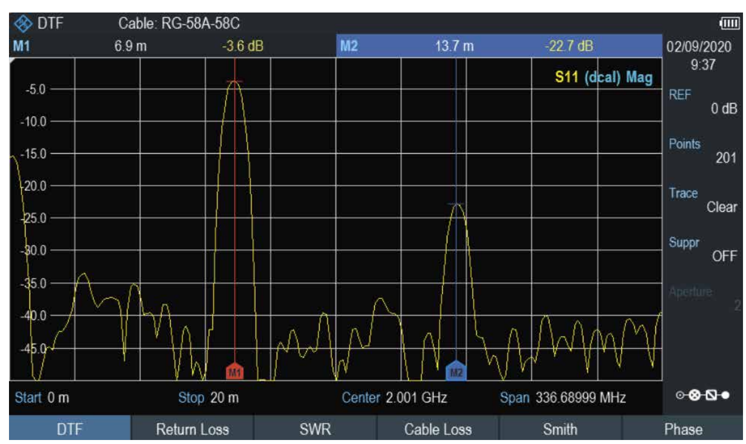
Stefan Stahuber

Convenient configuration and visualization of S-parameters.

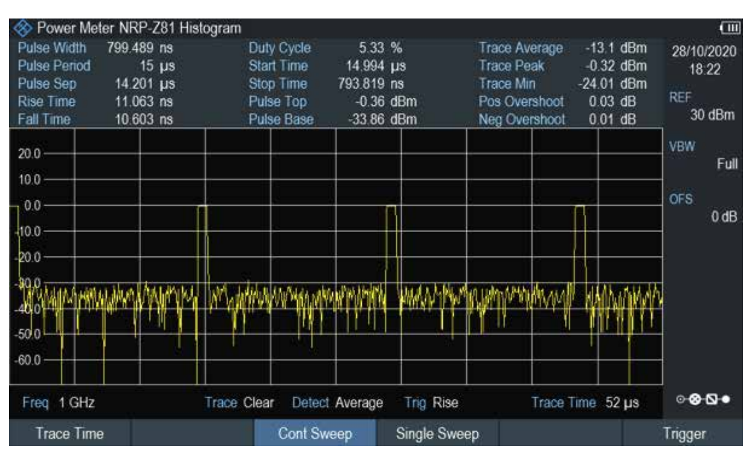
The quad display shows all S-parameters simultaneously.



The cable measurement functions include distance-to-fault (DTF) measurements.



The pulse measurement option checks the pulse characteristics and output power of radar transmitters.



POWER PACKAGE

Power is a persistent issue in the microwave domain. Often, more power is needed, so a convenient universal booster like the R&S®SAM100 is good news.

Test setups for microwave devices and components, especially those involving long cables and many coaxial adapters in the signal path, often suffer from power losses between the source and the sink higher than what is acceptable to test engineers. Then workarounds need to be found so that the setup can be operated with a sufficient power margin. The compact, broadband R&S®SAM100 system amplifier does away with such makeshift solutions. With up to 20 W output power, it boosts signal levels between 2 GHz and 20 GHz so that sufficient RF power is available even for complex setups. Its outstanding linearity and very good noise characteristics make the compact system amplifier suitable for use in a wide variety of test setups and system configurations. It is a high-quality alternative to tube amplifiers and multiband systems composed of single amplifiers connected in parallel.

Countless applications

Development engineers can use the R&S®SAM100 in product and design validation tests (PVT/DVT) in the lab, for example when developing, testing and creating the specifications for microwave mixers, filters, receivers and antennas. In test configurations including generators and spectrum or network analyzers, the small box acts as a booster for test signals. System integrators and test engineers can integrate the plug-in version into automatic

The broadband R&S®SAM100 system amplifier is a perfect combination of high power, large bandwidth and low noise.

production test systems, where up to three units can be accommodated side by side in a 19" rack. Installation in PXI frames is also possible. Thanks to its compact design, the R&S®SAM100 is not restricted to stationary applications. The desktop version with a detached power supply opens up a wealth of further applications, with the advantage that RF power can be applied directly to the DUT thanks to short cable connections.

State-of-the-art technology

The circuit design based on advanced gallium nitride high electron mobility transistor (GaN HEMT) technology and high-performance heat sinks with heat pipe technology make it possible to deliver up to 20 W output power with a very low noise power density of < –100 dBm (1 Hz) over a one-decade bandwidth. Semiconductor dies directly bonded onto printed circuit boards result in high power yield and prevent parasitic effects. An optimal class A bias point provides excellent linearity across the entire frequency range. With its low noise factor versus bandwidth and high gain, the R&S®SAM100 considerably improves the system noise factor and dynamic range.

Designed for reliability

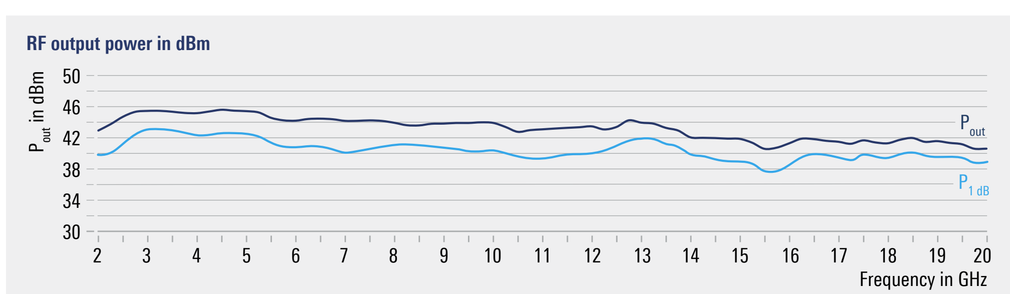
Integrated protective circuits safeguard the amplifier against overtemperature and mismatch at the RF output. Full output power is available up to a VSWR of 2 and the amplifier will reduce output power stepwise to avoid damage if the ratio is higher. To ensure stable connections, easy-to-replace sacrificial connectors are used on the actual RF input and output connectors. The female sacrificial connectors accept 2.92 mm and 3.5 mm connectors.

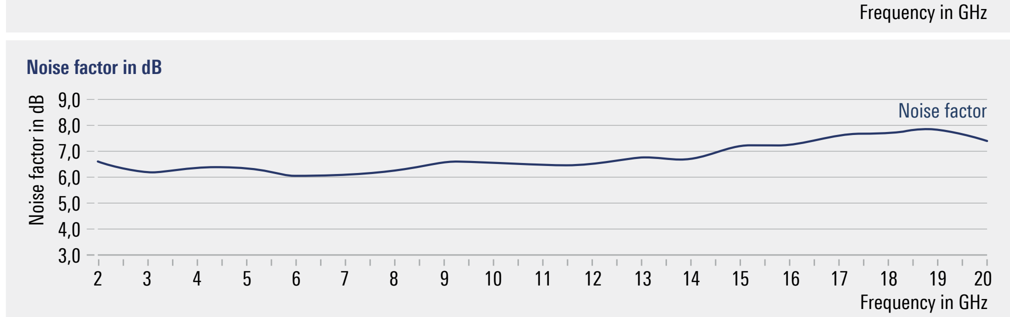
Low latency switching

The power switch on the device is sufficient for lab use. The operating state is indicated by status LEDs. A digital interface with a 9-pin D-Sub connector enables remote control in system operation. It transfers all relevant control and status signals and includes lines for the interlock and mute functions. If the R&S®SAM100 is integrated in an interlock protection loop, the RF signal is deactivated within microseconds in the event the loop is opened. In contrast, the mute function supports intentional fast switch-on and switch-off. A rising edge on the signal line switches on the RF power at the output after 120 µs, a falling edge switches it off after 12 µs.

The R&S®SAM100 is the first model of the new R&S®SAM system amplifier family, with additional models in preparation.

Michael Hempel, Harald Specker





MAKING NETWORKED TEST LABS SECURE

Networked labs and remote access to measurement applications are features of a modern development environment – and not just since the corona pandemic. Any security reservations previously standing in the way of wider proliferation are being eliminated by a new unified approach.

OT vs. IT

For many decades, instruments and test systems have been equipped with interfaces for remote control and transfer of measurement data. In recent years, IP based Ethernet networking has become established as the industry standard, enabling existing corporate IT infrastructures to be used for these purposes. It forms the basis for advanced T&M protocols such as VXI-11 and HiSLIP.

This creates advantages from the operation technology (OT) perspective due to ease of use, but it causes headaches for corporate IT security. T&M equipment and systems are usually connected to the normal local area network, giving them IP addresses and network access over the existing IT infrastructure without any special security precautions. Of course, the corporate networks of large enterprises are usually professionally set up and protected by virus scanners and firewalls. However, these protective measures have their limits, as can be seen from successful attacks with malware such as WannaCry, Conficker and NotPetya. A single infected memory stick or compromised computer connected to the system is enough to trigger a disaster. The consequences can be devastating if a compliance measuring system or a production environment is affected, preventing normal output. Walling off everything is not the answer, especially since the need for intersite networking is constantly rising for T&M facilities and applications. A better solution is strict data flow control with real-time monitoring of the communications of all networked components and individual data packets for compliance with rule sets. This is only possible with a unified approach over all networks and protocol layers and leads to the latest generation of unified firewalls, serving as secure application gateways specifically designed for deployment in the T&M environment.

A unified firewall as a central data flow controller in networked test labs

The stability and availability of operational measurement and control equipment are top priorities in the industrial sector. In the past, IT security often took second place or was not able to pass a critical review. Cultural friction was inevitable when OT personnel accustomed to standalone, proprietary measurement and control systems had to deal with IP based network equipment as a result of technological progress. Either network experts had to learn how to work with unfamiliar equipment and applications, or test specialists had to wrap their minds around alien network architectures and IT security concepts. Since equipment usually lacked the features of a strong security architecture, IT security had to be retrofitted with external measures, including an outdated or complicated firewall in case of doubt.

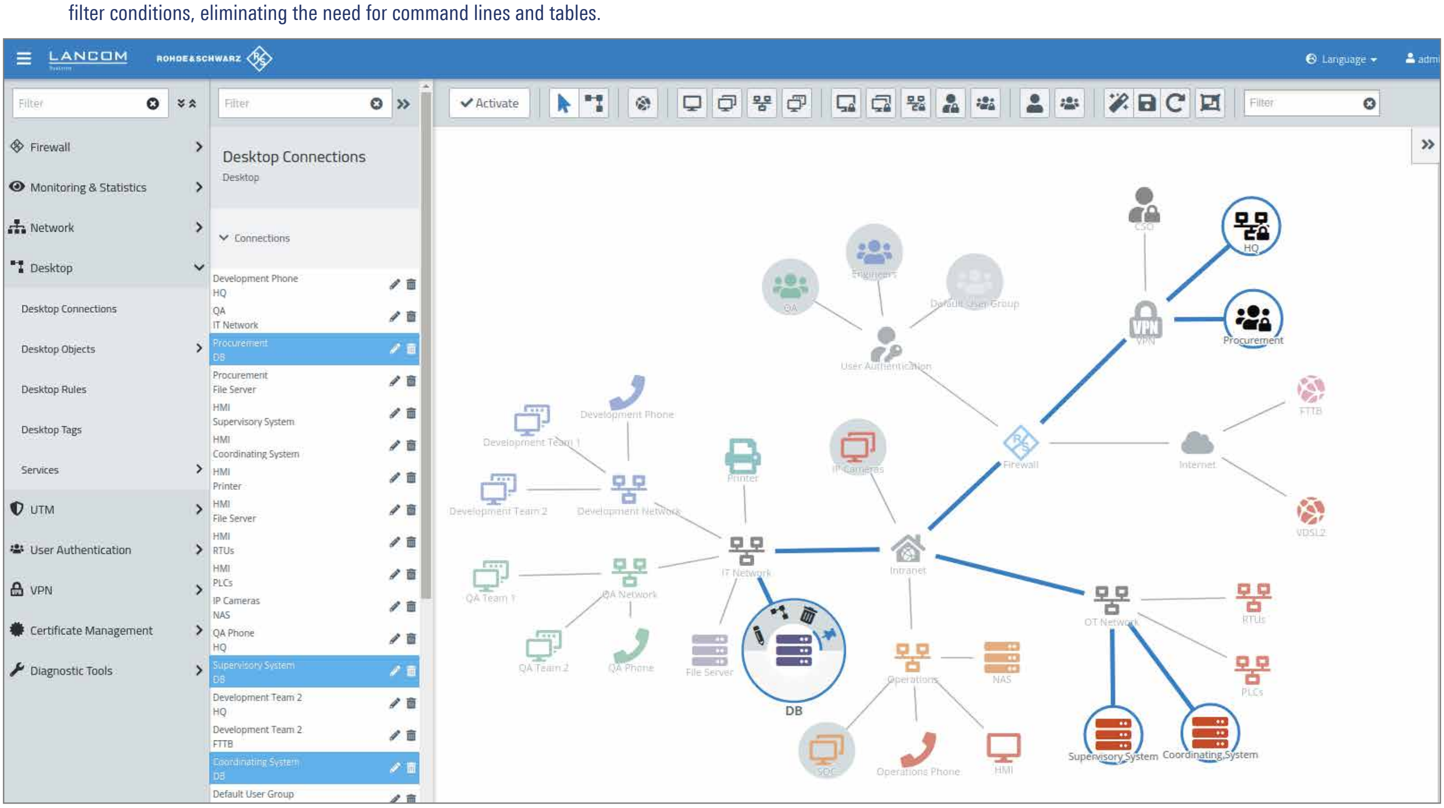
Legacy packet filter firewalls only examined data packet headers to enable or block port access based on target addresses, so applications were identified by the target ports of the packets instead of their content. Distinguishing between software applications and Trojan horses was therefore not straightforward. Administration of these legacy firewalls via complex rule tables was time-consuming and error-prone, and it required a skilled hand.

By contrast, next generation firewalls (Fig. 5) are equipped to deal with sneaky forms of attack. In line with the motto "trust is good, but control is better", they not only check the headers but also perform deep packet inspection to filter information from the transported data and the communications pattern of the connection. This means they use the entire data stream to reliably identify the target application.

Each data packet is associated with an active session (stateful firewall) and is rejected if there are signs of inconsistent communications behavior. In addition, files in standard formats (pdf, docx, etc.) as well as macros and executables that could take advantage of a zero-day exploit are first run and analyzed in an isolated test environment (sandboxing) to prevent malware from ending up in the operational network.

Application based filtering and routing of data streams by an advanced firewall makes it possible to design highly secure networks for dedicated applications, because the better the transmitted data structures and contents can be classified, the easier it is to block and forbid all others. In a network consistently laid out for T&M equipment, only data traffic based on T&M protocols and typical data, such as SCPI remote control commands, is possible.

Fig. 1: The user interface of the unified firewall visualizes all functions for network configuration and definition of filter conditions, eliminating the need for command lines and tables.



This sort of T&M network or subnet cannot be compromised by unauthorized persons, even with known IP addresses and open internet access. Operational and administrative access to the network components is governed by secure authentication mechanisms. Available AD LDAP servers can easily be linked and used for local role based user authentication and for remote access through a VPN on demand tunnel.

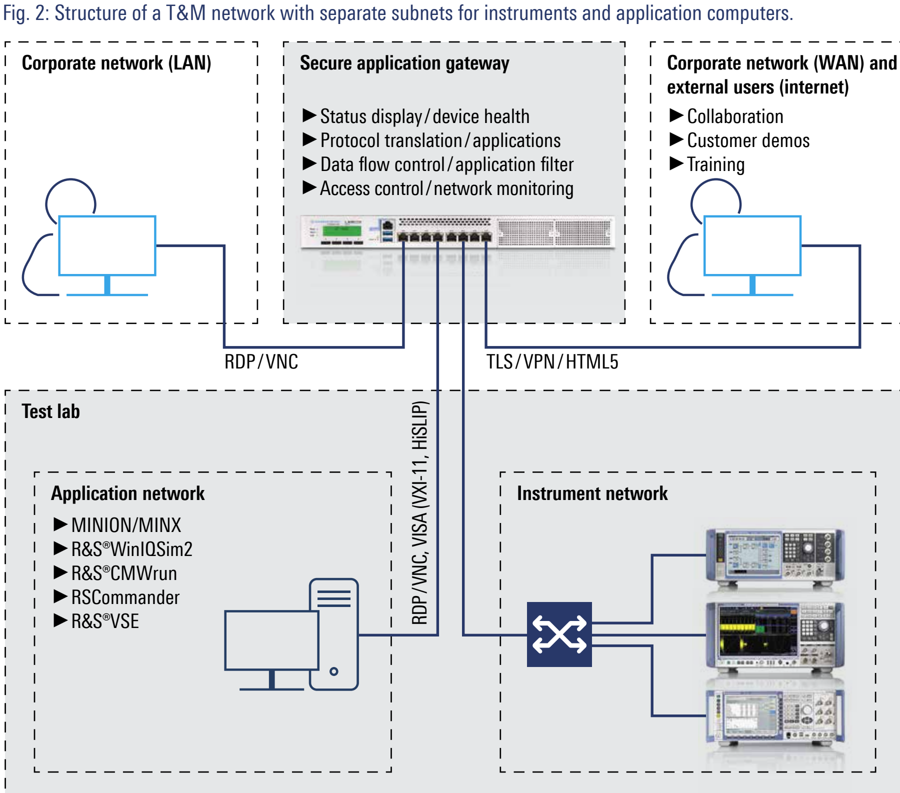
The central role of the firewall as a gatekeeper makes it easy to isolate the T&M subnet from the corporate network. Depending on the configuration, the firewall can perform further segmentation in smaller units, such as a device subnet containing only instruments and an application subnet with computers running measurement software. This segmentation capability also allows a device to be moved into a quarantine network for the duration of remote maintenance, with the move taking only a few seconds.

Setting up a secure network

The unified firewall can be set up offline using an advanced web interface and a current web browser (Fig. 1). Graphical abstraction of the network and the rules set on a dashboard makes configuration quick and reliable.

Fig. 2 shows the basic architecture of a test lab networked in this way. The instrument network, the network for the lab PCs and application services, and the higher level corporate network are strictly separated from each other in this reference configuration. All data connections, both within the T&M equipment subnet and to the outside, pass through the firewall and its rules set. The network is laid out with a star topology to ensure this. All components are connected directly or indirectly (e.g. via a switch) to the firewall as a central hub.

Fig. 2: Structure of a T&M network with separate subnets for instruments and application computers.



The rules set includes static and dynamic connection rules. An example of a static rule is that the lab computer is allowed to send a ping into the instrument network and receive a response, but ping requests from other sources, in particular outside the instrument network, are rejected.

Managing and real-time filtering of remote control connections, which comes into play when a user outside the lab wants to use its resources either from the same location or over the internet, is more complicated than a simple static rule. That's where data control by the firewall's dynamic application filter plays an active role. The rules set must address and monitor remote desktop protocols, such as VNC and RDP, as well as T&M LAN protocols such as VXI-11 and HiSLIP, used to transport SCPI remote control commands.

Due to its unique dynamic port assignment function, the VXI-11 protocol is especially difficult to secure with static rules. For each session, the port of the addressed instrument for the remote control connection is assigned anew by the port mapper service of the instrument's operating system in response to a remote procedure call. The firewall's application filter extracts this information from the data stream and enables the port only for the session concerned. This eliminates the security and handling issues that would arise from permanently opening all ports potentially needed for VXI-11, which differ from one manufacturer to the next and might have to be updated when the device pool is changed.

The final component of a secure application gateway

How does the user of a test lab know which resources are available there? This information is provided by a T&M specific device discovery and management system, consisting of the MINX[1] and MINION[2] software tools from Rohde & Schwarz. MINION is a network scanner that finds and lists all instruments present in a network. For security reasons, these scans are not allowed from outside the test lab, so the service runs inside the protected area on the lab's application computer. MINX, installed on the user's workstation computer, fetches this information and displays it on a dashboard where further actions can be carried out and, in particular, remote access to the instruments is possible through the MINION service (Figs. 3 and 4).

Authorized users can also access the lab computer through MINX (via RDP, VNC or HTML5) and use the measurement software suites installed there, such as R&S®CMWrun, R&S®WinIQSim2 or R&S®VSE, in the usual way. Whether data is allowed to be transferred out of the lab, and if so which data, can be precisely defined in rule sets, along with much more.

This makes a secure remotely controlled test lab a reality, eliminating barriers to spatially distributed project activities. Additional natural applications include customer demos and training courses, which can now be conducted in full scope without personal contact – a boon in times of a pandemic.

Summary

Digitalization of equipment is advancing rapidly and now gives electronics engineers tools for efficient project work in distributed locations. Previously anyone who wanted to allow external access to a networked test lab had to accept high IT security risks or incur considerable effort and expense for protection. The secure application gateway from Rohde & Schwarz puts an end to this dilemma. Behind the protective shield of an advanced unified firewall that blocks all data traffic not needed for T&M purposes, instrument pools and measurement applications can be made accessible to authorized users at any desired location. The firewall's wizard based graphical user interface puts an end to error-prone text entry and enables bombproof configuration, even for lab engineers. Another feature of this solution is simple and easily modifiable segmentation of the test lab into subnets, each governed by different rule sets. This allows the lab layout to follow the changing requirements of the operator without hardware alteration.

Katja Hohrath, Christian Wicke

1) MINX: measurement instrument network eXplorer.
2) MINION: measurement instrument network interactive organizational node.

Fig. 5: The LANCOM R&S®Unified Firewalls family currently consists of six models to meet every throughput requirement, all with the same look and feel.

Fig. 3: The MINX dashboard is the data and control center for remote control of the equipment pool, here consisting of four units.

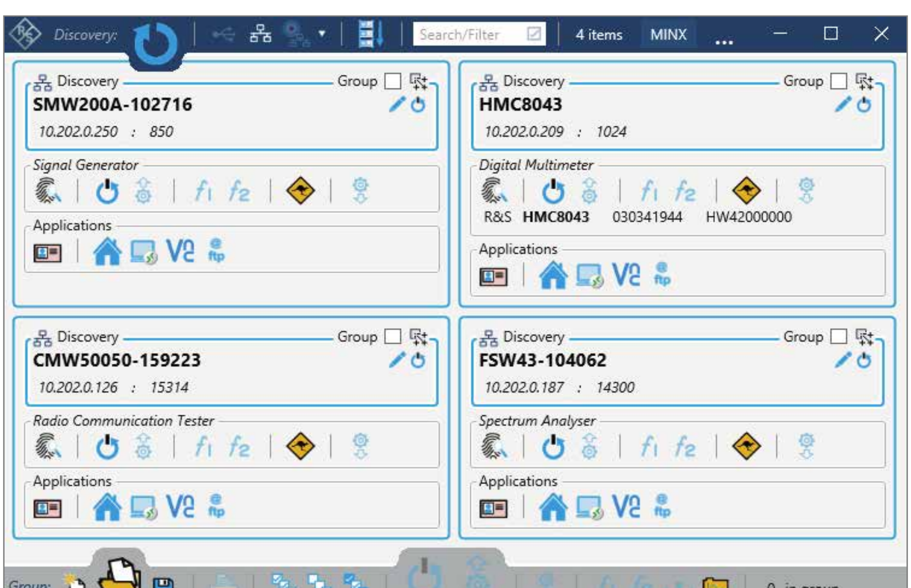


Fig. 4: The fingerprint function in a MINX tile generates a list of all installed options of the instrument concerned. The "Skippy" (SCPI) kangaroo and user definable function keys can be used to save and run remote control command sets, allowing instruments to be configured according to the user's needs at the touch of a button.