228/2024

NEWS

ROHDE&SCHWARZ
Make ideas real

AI – BUILDING BLOCK FOR INNOVATION AND LEADING-EDGE TECHNOLOGY

Artificial intelligence: a neural receiver for mobile communications

5G NTN: non-terrestrial networks

R&S®FExx frontends: multichannel signal analysis up to 170 GHz

Rohde&Schwarz represents leading-edge technology at the limits of the technically possible. Industry and government customers use our products and solutions to shape their digital and technological sovereignty –

TO ENSURE A SAFER AND CONNECTED WORLD.

MASTHEAD

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COVER FEATURE

Dear Readers,

Artificial intelligence is the cover story for this issue of NEWS. We find ourselves in good company since one in three top corporations mention artificial intelligence in their quarterly reports. AI is clearly not just a practical everyday helper such as ChatGPT but is shaping entire businesses and industries.

Our colleagues will take a brief look at the potential future of technology in the B2B sector. Starting on page 12, you can find out what a neural receiver is and how it benefits mobile communications. The AI application is not the only fascinating aspect in this project. NVIDIA and Rohde&Schwarz, two companies with rather different core competencies, are working together. This collaboration generated a lot of interest at Mobile World Congress, as our Technology Manager Andreas Rößler reports in an interview starting on page 16.

Classifying network traffic is another AI application. For optimal resource allocation, network operators need to know whether a data connection is being used for live streaming or to download data packets for later consumption – all without reading out the data. The necessary analysis software has been available for some time but faces ever increasing challenges when it comes to generating good results since network traffic is protected with up-to-date encryption standards. Read more on page 20 about what a modern solution trained with high-quality data looks like.

This issue also discusses other very exciting and state-of-the-art topics. 5G is significantly advancing with non-terrestrial networks (NTN), 6G research is in full swing, broadcasters in North America now have an entirely new service package on offer, and you'll find many new T&M products and expansions.

Enjoy this issue of our NEWS magazine.

Sincerely

Christian Reiter,
Vice President Corporate Marketing and Communications

COVER FEATURE

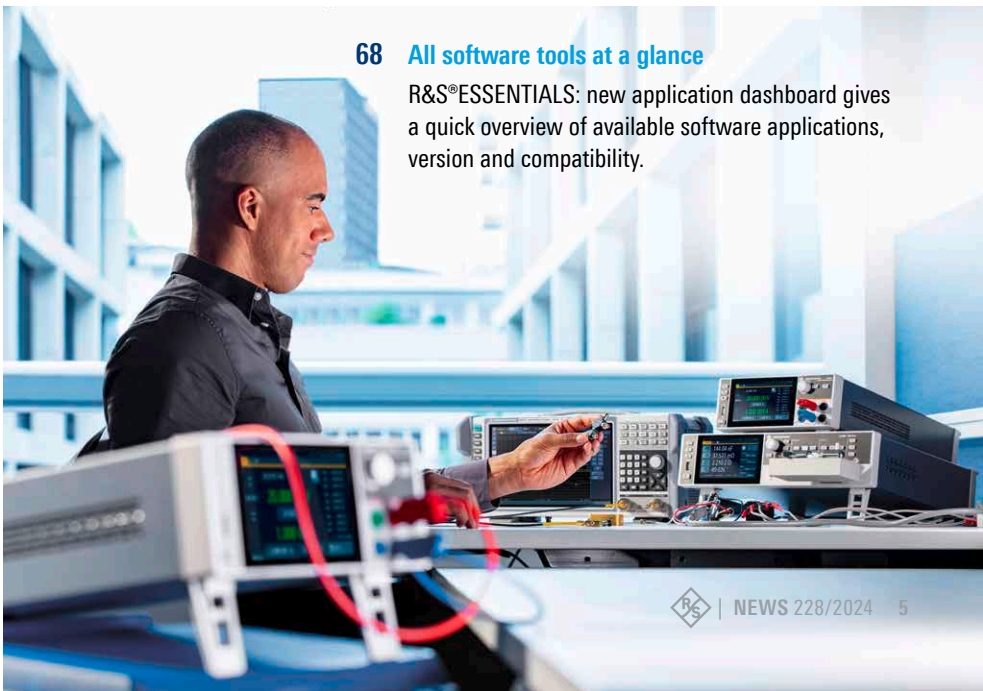
ARTIFICIAL INTELLIGENCE

MOBILE COMMUNICATIONS

NETWORKS

BROADCAST & MEDIA

GENERAL PURPOSE



NEWS COMPACT

20 YEARS OF THE ENGINEERING COMPETITION

Rohde&Schwarz hosted the 20th installment of its international student competition. This year's challenge focused on 6G mobile communications. First place and a EUR 10,000 prize went to the TU Munich team.

What started as a case study competition in 2004 has since become a red-letter day for countless universities and colleges around the world. The Engineering Competition sets out a practical task for students of electronics and communications engineering based on a current technology topic.

This year called for innovative ideas relating to four key areas of interest in 6G: extended reality (XR), artificial intelligence (AI), integrated sensing and communication (ISAC) and reconfigurable intelligent surfaces (RIS). A fifth category called Wild Track invited solutions to the following question: How can we use 6G technologies to ensure a safer and connected world? Following a virtual preliminary round, twelve teams with the most impressive submissions went on to take part in the three-day final competition at the Rohde&Schwarz headquarters in Munich. In addition to working on their projects, students also gained exclusive insights into the Rohde&Schwarz work environment and exchanged ideas with other students from around the world.

At the awards ceremony on June 21, 2024, at the Wirtshaus in der Au restaurant in Munich, Team Ollsoft from the Technical University of Munich (TUM) claimed first place overall and walked away with a cash prize of EUR 10,000.

At the opening ceremony with Yatish Mohan, Managing Director of Rohde&Schwarz India (left), Andreas Pauly, Managing Director and Chief Technology Officer of Rohde&Schwarz (right), explains, "India isn't just a growth market for us – it's an essential part of our global strategy."

PRESENCE EXPANDED IN INDIA

In April 2024, Rohde&Schwarz celebrated the opening of a new location in Manyata Tech Park in Bengaluru, which now houses research and development, system integration and calibration and repair services. Rohde&Schwarz is building out its presence in India's third-largest city while also strengthening its commitment to the Indian government's Make in India initiative by promoting innovation in the automotive, telecommunications, semiconductor, electronics, aerospace and defense sectors.

ATC RADIO COMMUNICATIONS FOR POLISH ARMED FORCES

At the beginning of June 2024, the Polish Armaments Agency awarded Rohde&Schwarz the contract to supply multiple VHF/UHF R&S®M3SR Series4400 software defined radio stations from the SOVERON air traffic control (ATC) family. The radio stations will help the Polish armed forces improve safety and operational efficiency in military ATC. The contract covers modernization of existing infrastructure in compliance with the strict directive in the contract with the Polish Armaments Agency. The VHF/UHF radio stations have software update that incorporate the HAVE QUICK II and SATURN secure communication functions.

Software defined R&S®M3SR Series4400 VHF/UHF radios of the SOVERON family.

THE WORLD'S MOST COMPACT OSCILLOSCOPES WITH UP TO 2 GHz BANDWIDTH

The new oscilloscopes in the MXO 5C series are designed for 19-inch rack installation.

MXO 5C oscilloscopes are the first from Rohde&Schwarz without an integrated display. The 2U version can be installed in 19-inch racks and is perfect for automated test systems. The scopes can be operated with an integrated web interface or automatically as high speed digitizers.

The oscilloscopes have either four or eight channels, bandwidths up to 100 MHz, 200 MHz, 350 MHz, 500 MHz, 1 GHz and 2 GHz and a compact design, making them ideal for measurements with high channel density. They have the same technical specifications as the MXO 5 oscilloscopes and can be connected to an external display to create a standalone universal oscilloscope.

You can find more information about the instrument at: https://www.rohde-schwarz.com/product/mxo5C

COLLABORATIONS THROUGHOUT THE GLOBAL QUANTUM VALUE CHAIN

Within a short period of time the Rohde&Schwarz subsidiary Zurich Instruments has finalized several collaborations with quantum computing companies and research facilities.

KRISS, Norma and KAIST – Korea

South Korea plays an important global role in quantum research. Zurich Instruments delivered a Quantum Computing Control System (QCCS) to the Korea Research Institute of Standards and Science (KRISS) in 2022. The institute is currently using the QCCS in a government project to develop a quantum computer with 50 qubits.

In the past few months Zurich Instruments has extended its collaboration with KRISS and established new partnerships in South Korea. A Memorandum of Understanding (MoU) with Norma, a software provider for quantum computer end users, has been in place since summer 2024. A key element of the partnership is to develop an interface between Norma's Q Platform and the QCCS from Zurich Instruments. The second partnership with the renowned Graduate School of Quantum Science & Technology of the Korea Advanced Institute of Science & Technology (KAIST) aims to educate highly qualified quantum computing experts, by utilizing advanced hardware and software from Zurich Instruments. A corresponding MoU to set up joint teaching and training programs has already been signed.

Fig. 1: Director Yong-Ho Lee (left), Center for Superconducting Quantum Computing System, Korea Research Institute of Standards and Science (KRISS) with Moritz Kirste (right), Head of Business Development Quantum Technologies at Zurich Instruments.

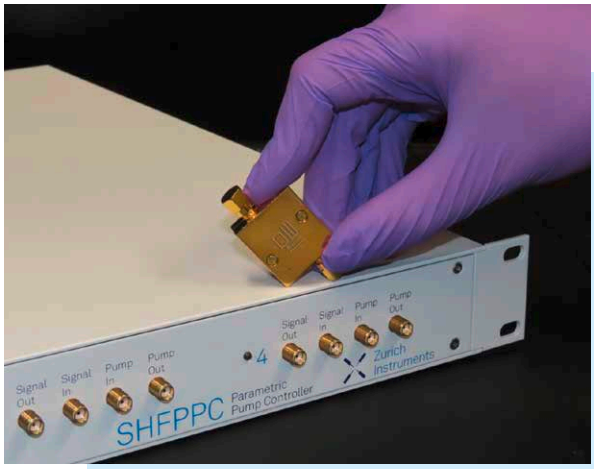


Fig. 2: Zurich Instruments and QuantWare are developing an integrated offering that allows for a quantum-limited readout performance in the fastest possible way. Fig. 2 shows the two primary components: a SHFPPC periodic pump controller und a Crescendo-S parametric amplifier.

QuantWare – Netherlands

In spring 2024, Zurich Instruments entered a partnership with QuantWare, a Dutch manufacturer of superconducting quantum processors. Together they are developing an out-of-the-box solution for the fast control and readout of qubits with extremely pure signals. The solution combines QuantWare's low-noise parametric amplifier Crescendo-S with the SHFPPC periodic pump controller from Zurich Instruments. Crescendo-S is based on traveling wave parametric amplifier (TWPA) technology, which is proven excellent for readout of superconducting qubits. The SHFPPC handles the entire signal generation and processing for parametric amplification. It can be used to operate up to four channels for reading out superconducting qubits.

Photonic – USA/Canada

Another partnership has been established with the US subsidiary of Canadian manufacturer Photonic. The company develops distributed quantum computers based on spin qubits. Their approach stands out thanks to its scalability, fault tolerance and good manufacturability. Photonic handles qubits with the Quantum Computing Control System (QCCS) from Zurich Instruments. The QCCS generates extremely pure, phase-coherent signals and can easily be expanded if the number of qubits increases.

Fig. 3: The SHFQC from Zurich Instruments is part of the Quantum Computing Control Systems (QCCS) that Photonic uses to control its distributed quantum computer system.

LEADING REPRESENTATIVES OF THE QUANTUM COMMUNITY COME TO VISIT

Zurich Instruments is collaborating with Munich Quantum Valley in the field of quantum computing. Munich Quantum Valley is a scientific association working to develop a competitive quantum computer in Bavaria.

Industrial and research leaders have agreed to build a quantum computer demonstrator with 100 qubits in Munich and make it available to a wide range of users in the cloud. This ambitious goal secured 44.2 million euros of funding, as part of the MUNIQC-SC collaborative project. The project is funded by the Federal Ministry of Education and Research (BMBF), and it will run from January 2022 to December 2026 under the name Munich Quantum Valley Quantum Computer Demonstrators – Superconducting Qubits.

The Rohde&Schwarz subsidiary, Zurich Instruments, is part of the project. The fourth regular meeting (progress meeting) was hosted at Rohde&Schwarz facilities in Munich in early 2024. A total of 70 participants from 15 project partners discussed progress, challenges and the next steps of the collaboration. They also enjoyed a guided tour of the company. “These were very interesting insights for our partners in the scientific community, who were shown the security scanners and the environmental laboratory”, says Dr. Lukas Sigl when summing up the visit. Sigl is Lead Application Scientist for Quantum Technologies at Zurich Instruments and was responsible for the event organization. Participation in MUNIQC-SC is an added value for Rohde&Schwarz. “This puts us in contact with leading researchers”, says Dr. Claudius Riek, Managing Director of Zurich Instruments Germany. “Having a good understanding of the challenges that research laboratories face helps us further develop our products and solutions and position them for the future.”

PROFESSOR ROHDE RECEIVES MULTIPLE HONORS

Prof. Dr.-Ing. habil. Dr. h.c. mult. Ulrich L. Rohde was honored as a Fellow of Industry Academy of the International Artificial Intelligence Industry Alliance (AIIA) in January 2024. A few weeks later, in recognition of his outstanding achievements in the field of microwave technology, he was named a Fellow of the Asia-Pacific Artificial Intelligence Association (AAIA). The two associations, which are independent of one another, promote the development of artificial intelligence (AI) applications. The AAIA, founded in Hong Kong in 2021, is an academic, non-profit and non-governmental organization that brings together 1600 academicians worldwide. The AIIA was founded in 2023, also in Hong Kong. Its more than 3000 members come from the world of academic research as well as companies, institutions and organizations working in the field of AI.

Professor Rohde was honored with two fellowships at the beginning of 2024. Back in December 2023, he received the Entrepreneur Achievement Award for Leadership in Entrepreneurial Spirit for his entrepreneurship in signal generation, signal processing electronics and CAD tools. The IEEE USA Board of Directors gives this award to members who have made a major contribution to promoting entrepreneurial growth and spirit in the USA.

CRITICAL INFRASTRUCTURE: JOINT TRAINING WITH THE ITU

Rohde&Schwarz and the International Telecommunication Union (ITU) have a longstanding, close working relationship. One result of this is a joint training program with the ITU Academy. In June 2024, the five-day course entitled Introduction to Frequency Monitoring Systems in Accordance with ITU-R Recommendations was held at the Rohde&Schwarz training center. A total of 15 specialists from 14 countries who work in critical infrastructure security were given the necessary expertise to independently implement frequency monitoring systems in accordance with ITU-R recommendations. The course was led by six industry and regulatory experts who presented the latest ITU recommendations and reports as a basis, discussed various aspects of frequency monitoring in several practical modules, and taught the technical principles of wave propagation and antenna technology, as well as how receivers, direction finders and software work.

The excellent working relationship between Rohde&Schwarz and the ITU Academy is being expanded. In the future, there will be more joint training programs, and there is no shortage of common topics.

Participants and trainers in the exclusive ITU Academy course.

PROFESSOR ROHDE AS GUEST SPEAKER IN MTL SEMINAR SERIES AT MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Professor Rohde gave a lecture at the Microsystems Technology Laboratories (MTL) on the MIT campus.

In its MTL Seminar Series, the prestigious Massachusetts Institute of Technology (MIT) regularly invites guest speakers to Cambridge, Massachussetts in the USA. The series, which is held at the Microsystems Technology Laboratories (MTL) on the MIT campus and made publicly accessible via online video streaming, covers a wide range of technology topics: from cloud based artificial intelligence to wireless communications. Prof. Dr.-Ing. habil. Dr. h.c. mult. Ulrich L. Rohde was invited to speak on Problems and Solutions of HF/UHF Systems. In his talk, which Rohde&Schwarz expert Thomas Bögl also contributed to, he discussed the challenges of operating military radio transmission stations in a small area. Using the example of software defined radio transceiver architecture, he explained which mechanisms cause interference and how they can be minimized.

The talk can be found online under:
https://www.mtl.mit.edu/events-seminars/seminars/problems-and-solutions-hfuhf-systems

TESTING 5G eCALL INTEROPERABILITY WITH A QUECTEL 5G MODULE

The IoT specialist Quectel Wireless Solutions and Rohde&Schwarz successfully validated a 5G eCall module from Quectel in February 2024. It is one of the first of its kind and standardization for eCall 4G/5G is still in progress.

The European Union's eCall automatic emergency call system for vehicles is based on 2G/3G circuit-switched cellular networks. But because these networks will soon be decommissioned, the emergency call systems for onboard vehicle electronics and the infrastructure associated with those systems must be adapted to 4G/5G mobile networks. The European Commission initiative to update the eCall standards, and legislation to transition eCall to 4G and 5G networks is ongoing. The automotive industry is also working on products that conform to the new standards. Quectel has already validated the eCall function of a module for 5G transmissions.

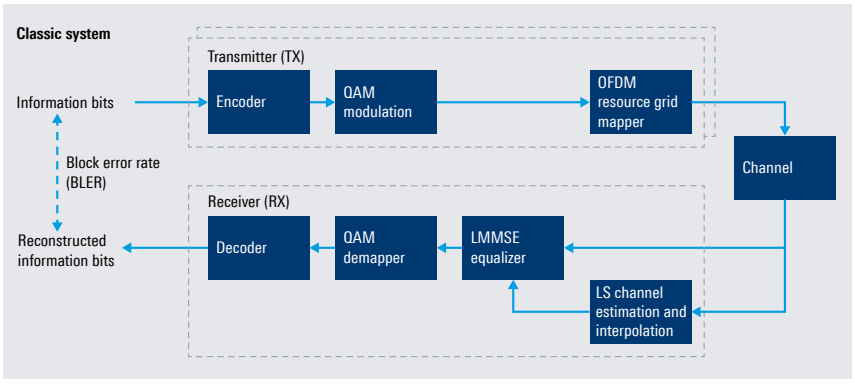
The test setup used to validate the 5G eCall functionality of the Quectel module includes the CMX500 radio communications tester with the R&S®CMX-KA098 5G eCall test option, which simulates an NG eCall public safety answering point (PSAP), and an R&S®SMBV100B vector signal generator for GNSS simulation. It provides reliably reproducible and configurable 5G network conditions. The test confirmed successful establishment of an 5G emergency call between the Quectel module and the PSAP.

To accelerate the deployment of this technology, collaboration between companies in the industry is crucial. The cooperation between Rohde&Schwarz and Quectel has enabled and accelerated mutual validation of both companies' solutions.

Rohde&Schwarz and Quectel presented the test setup at Mobile World Congress 2024.

ARTIFICIAL INTELLIGENCE: A NEURAL RECEIVER FOR MOBILE COMMUNICATIONS

The potential of artificial intelligence is being explored worldwide. Receivers can use neural networks to help process signals. The concept is known as a neural receiver, and is designed to provide more stable data transmission that optimizes itself during operation. Rohde&Schwarz is working with NVIDIA to develop a test setup.



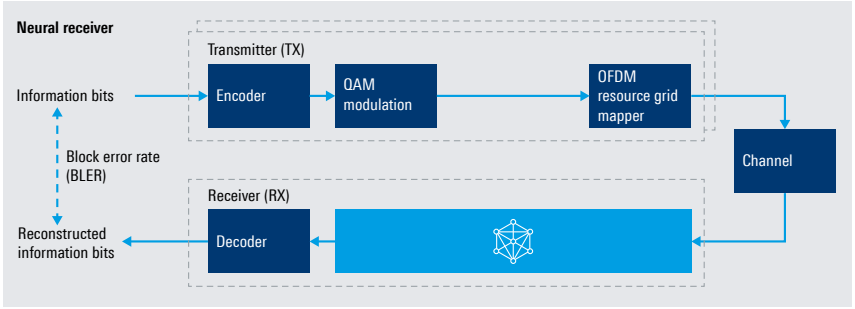


Fig. 1: In a neural receiver (below), a trained machine learning model handles channel estimation, equalization and demapping. In the classic linear minimum mean squared error (LMMSE) receiver architecture shown above, deterministic software algorithms perform these tasks.

Wireless transmissions are always subject to interference. To compensate, today's mobile communications rely on channel estimation and equalization. The transmitter sends additional pilot signals known by the receiver along with the actual data stream. If any distortions are detected in the pilots when they arrive at the receiver, a digital signal filter equalizes them. Powerful signal processing algorithms calculate the right filter parameters based on the degree of distortion in the pilot signals.

These interference suppression methods account for different conditions that commonly occur in mobile communications. Interference in a wireless transmission sent by someone riding a bike in the countryside will be different than one from a crowded pedestrian area or on a moving train.

Where artificial intelligence comes in

Every successful data connection to a mobile device is proof positive of how sophisticated current signal processing already is, but there are still limits. Optimization methods are never perfect because signal processing algorithms are developed on the basis of standardized channel profiles – assumed models that only give an approximation of actual operating conditions. Training AI models with data sets that better reflect real-world conditions would enable more effective methods for channel equalization, and thus more stable wireless connections with higher data throughput.

A permanent fixture in mobile communications

Figure 1 shows the specific approach NVIDIA is taking with neural receivers: in the receiver (RX), the signal processing block for channel estimation, channel equalization and demapping is replaced by a trained machine model that handles all three tasks. The neural receiver was developed using NVIDIA's SionnaTM open source software library, which is specifically designed for 5G and 6G research.

The computing power needed to effectively train a neural receiver is still very high and requires graphical processing units (GPU). However, initial findings indicate that the results justify the expense. Researchers are also optimistic that the AI models can be trained with less computing power. Many experts now assume that AI models will become a permanent fixture in 6G mobile communications signal processing.

Whether there is enough high-quality, real-world training data is still an open question. The need for actual data from the field will increase as the market matures. Up to now, synthetic training data from simulations or generated data sets have been perfectly adequate in the current phase of research.

T&M equipment to evaluate performance

Rohde&Schwarz already provides the right signal sources and signal analysis tools needed to set up a test environment for the neural receiver. The R&S®SMW200A vector signal generator emulates transmitting signals from individual users in MIMO signal configuration and adds noise and fading as needed to simulate realistic radio channel conditions. The receiver in the current test setup is the R&S®MSR4 universal satellite receiver with four parallel receive channels. It forwards the signals through a real-time streaming interface to a server, where the R&S®VSE vector signal explorer software synchronizes the signals and performs a fast Fourier transform (FFT). This FFT data set is then used as input for the neural receiver.

To assess quality, the reconstructed data blocks are compared with the original data. Calculating the ratio of data blocks with errors to the total number of transmitted data blocks yields the transport block error rate (TBLER).

EDITORS

"THE REAL BREAKTHROUGH WAS INCORPORATING THE TRANSMITTER INTO THE TRAINING PROCESS."

Andreas Rößler has intimate knowledge of the neural receiver mobile communications research project with NVIDIA. In this interview, he reveals how the industry reacted to the first demonstration, what to keep in mind when training neural networks, and how to measure neural receiver performance.

Read more about the neural receiver project in the previous article starting on page 13.

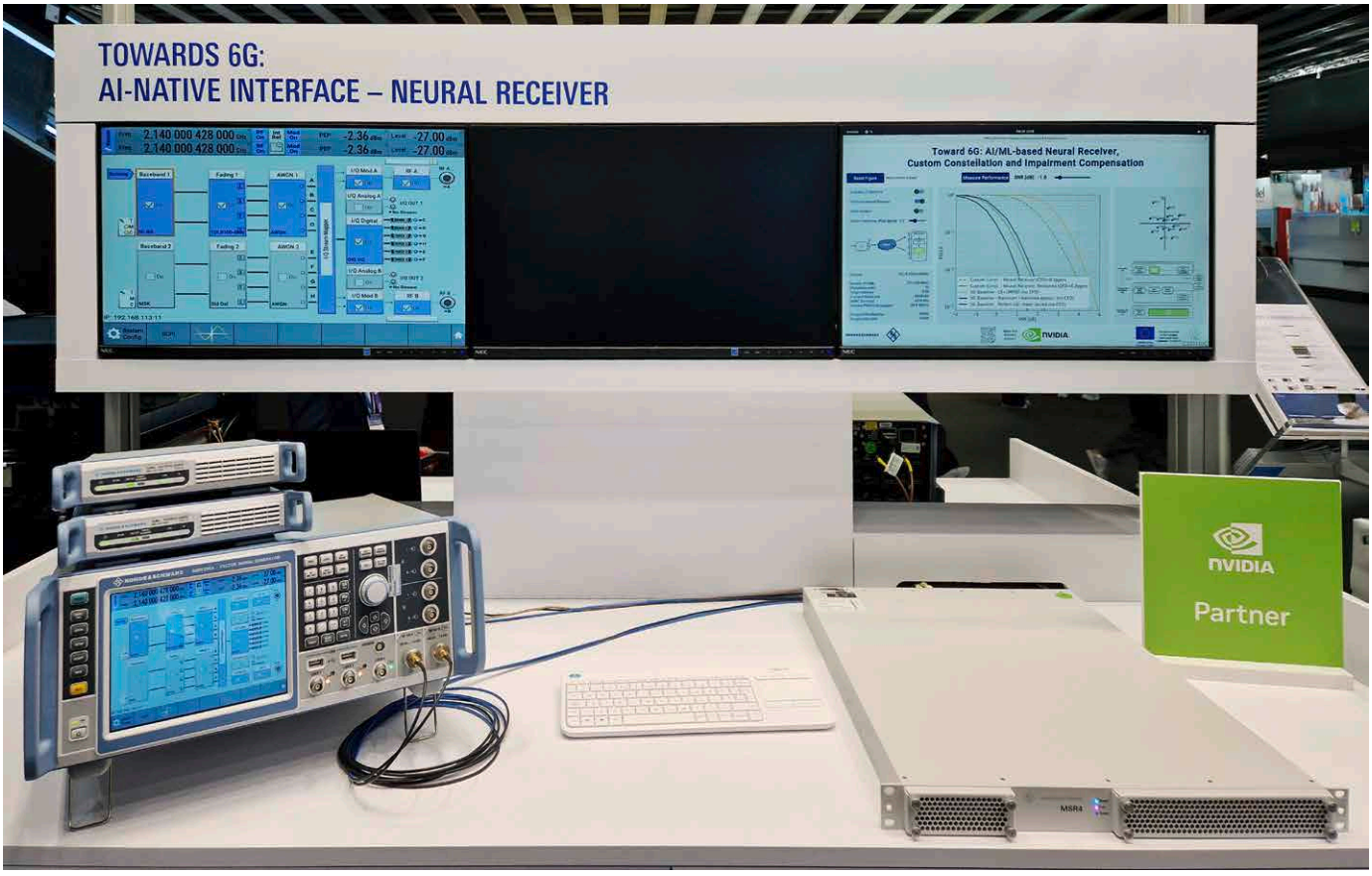


Fig. 1: The Rohde&Schwarz booth at Mobile World Congress 2024 showcased a test setup for the neural receiver with the signal generator and receiver (left).

NEWS: Mr. Rößler, the neural receiver was first demonstrated at Mobile World Congress 2023. How was the response from the industry?
Rößler: From the perspective of wireless communications and next generation mobile communications, AI and ML were not as prominent at MWC 2023 as they were this year (2024). Rohde&Schwarz and NVIDIA have really broken new ground in this area. What was unique about our demonstration is that it came from two independent partners. We integrated solutions from both companies and tested them together. That had never been done before, so it's no surprise it garnered a lot of attention – both out of pure curiosity and professional interest.

Discussions with our customers involved in chipset and modem development, infrastructure manufacturing and cell phone production were also important. We covered topics like scenario selection, resulting challenges, the technical background and details, and insights gained.

NEWS: How has the project evolved since then?
Rößler: The project has continued to develop since MWC 2023. The real breakthrough was incorporating the transmitter (TX) into the training process. We're working on the assumption that the first version of the 6G standard will initially use AI based signal processing in network infrastructure, i.e. base stations. Greater complexity and computing power also mean higher energy consumption. This challenge is still the subject of intense research to improve efficiency.

NEWS: How does the transmitter come into play?
Rößler: The transmitter also has something valuable to offer when it comes to customized or non-uniform constellations. This involves training an AI model to learn the best possible constellation for a chosen modulation method, taking the channel into account. We've expanded the neural receiver model and added the current 5G option to our test and measurement equipment,

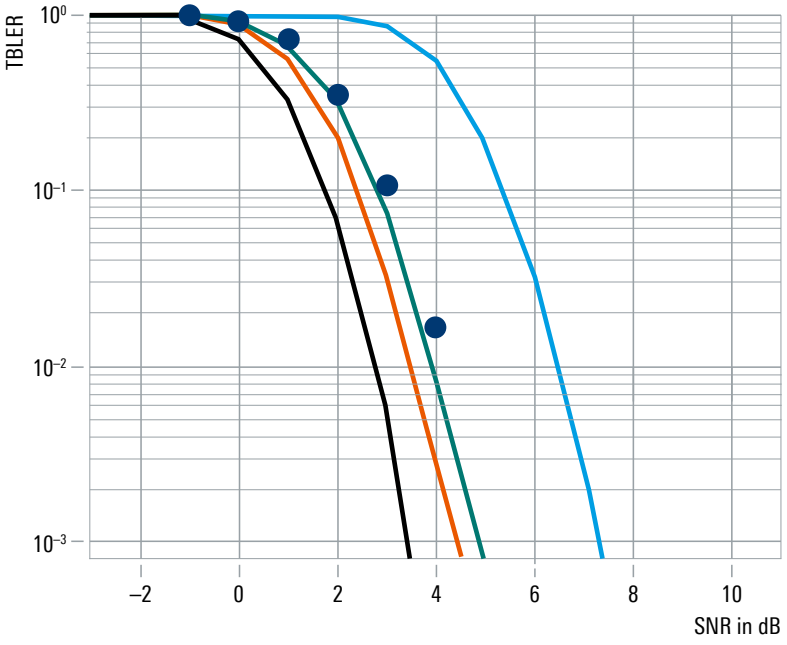


Fig. 2: Simulation of transport block error rate (TBLER) against the signal-to-noise ratio (SNR) of four different receiver implementations. The blue points correspond to real measurements for the neural receiver and confirm the simulation (green curve).

the R&S®SMW200A vector signal generator and the FSW signal and spectrum analyzer. Based on the trained AI model, every constellation point can now be redefined at the I/Q level in terms of amplitude and phase.

The advantage of this approach is that pilot signals are no longer needed in the transmitter signal, which frees up resources for data transmission. This makes the entire transmission more efficient. Our analyses show efficiency gains of up to 7 % while other studies suggest increased spectral efficiency of up to 14 %. However, this depends heavily on the chosen configuration and the frequency of the pilot signals.

NEWS: How do you train the AI?
Rößler: We train it offline using NVIDIA's Sionna software. Neural receivers tend to overfit if they're trained for a specific channel model. That's generally not wanted, which is why our receiver has been trained on the 3GPP UMi channel model for different Doppler shifts and spreads. This ensures that it generalizes well and covers as many scenarios as possible.

The neural receiver is based on the current 5G New Radio standard to make the results comparable. The receiver was trained on 16QAM modulation. Since the QAM constellation is embedded in the trained weights of the neural network architecture, retraining is required if the modulation needs to be changed to QPSK, 64QAM or even 256QAM. In other words, different modulations require different AI models.

5G is based on OFDM, which is a multicarrier modulation scheme. The model is trained on a subcarrier spacing of 30 kHz, which is used by all commercial 5G networks in TDD mode. Just as retraining is required when the modulation is changed, switching to a 60 kHz subcarrier also requires retraining.

NEWS: A video (see QR code on the right) shows the measurement curve of Fig. 2. What does it show, and what does it tell us about the performance of the neural receiver?
Rößler: To evaluate performance, the block error rate was plotted against the signal-to-noise ratio (SNR) and compared across four different receiver implementations.

The black curve represents performance in an ideal scenario, where all channel characteristics are known. This represents the theoretical limit that can be achieved. Nothing beyond this is possible. The green curve is the neural receiver, while the orange and cyan show two conventional implementations. The first of these, the cyan curve, uses the least squares method for channel estimation and a linear MMSE multi-user MIMO detector to cancel out interference. Compared to the other scenarios, the

“Although the neural receiver doesn’t outperform this approach, it gets very close but with considerably less computational power.”

computational complexity of this implementation is relatively low and it is a good illustration of what a practical yet basic implementation looks like.

The second conventional implementation, shown by the orange curve, is based on the maximum likelihood estimation. It is more complex and therefore requires more computation. Although the neural receiver doesn’t outperform this approach, it gets very close but with considerably less computational power. All four curves are based on simulations with the same input data.

NEWS: The graph also has actual measurements in addition to the simulated lines.
Rößler: This is where Rohde&Schwarz measuring equipment comes into play. We use the signal generator and analyzer setup mentioned above to generate 3GPP 5G NR-compliant signals. This data is then fed into the architecture of the neural receiver. In this example, we’re working in the SNR area, starting at –1 dB. We increase the SNR by 1 dB for each step. This is stored in the software that controls the test setup. In the demo, two users receive different channels. In this example, user one encounters the TDL-B model with a delay spread of 100 ns and a Doppler frequency of 400 Hz. For user two, it’s TDL-C with a delay spread of 300 ns and a Doppler frequency of 100 Hz. The curves shown are the cross-sectional throughput achieved for the set signal-to-noise ratio (SNR). In the test setup measurement, only the (simulated) green curve is remeasured.

EDITORS

The video is available here.
Skip to 4 minutes for the measurement curves.

AI PROVIDES TRANSPARENCY FOR HIGH-VOLUME DATA TRAFFIC

Analysis software that can classify network data is important for security and efficient data management in large telecommunications networks. Smart software modules using artificial intelligence (AI) and machine learning (ML) are setting new benchmarks while helping to keep up with the dynamic development of 5G and 6G.

AI clearly has enormous potential when it comes to analyzing huge volumes of data. It can not only predict precise patterns and trends using machine learning but it can also be used to optimize automatic networks and derive targeted preventive measures. With the ever-increasing sophistication of cyberattacks, AI is clearly a game changer for early detection of critical security anomalies.

So far, only a handful of suppliers have managed to successfully deploy ML in real-time network applications such as gateways or cybersecurity solutions. Many current methods are geared towards postprocessing, meaning they can detect anomalies or forecast network traffic. Very few solutions are capable of monitoring all the applications running in a network in real time (application visibility). But now, an innovative, ML based software module from ipoque, a Rohde&Schwarz subsidiary and the market leader in application awareness, offers help. The new ipoque product supports real-time network analysis that surpasses existing solutions in this area.

Fig. 1: Analysis software can provide an overview of network data traffic without reading any of the actual data packets. It is like looking at a container port where hundreds of containers of different colors and sizes are stacked, where characteristics like labels and tags help to give an overview of what is inside.

Protection of corporate data

For companies that want to use AI software modules, data protection is a key criterion, especially where sensitive data is involved. The problem is that AI providers generally do not have their own generic training data sets. Most providers of solutions that classify protocols and applications require customer-specific training data sets, which are pre-processed for each use case. In this process known as baselining, the ML model needs access to the customer's infrastructure and data. But, for data protection reasons, such access is unacceptable for both network

service providers and equipment suppliers. Furthermore, the product is typically not usable in practice until a certain period of time has elapsed after the set-up date (usually, two weeks).

To get around these problems, ipoque uses a pool of existing data sets collected by its products over a period of almost 20 years. This allows the company to avoid complicated baselining during ML model training.

Worldwide AI data generation

To complement its existing pool of data, ipoque has also developed a global framework for generating high-quality training and test data. The data is collected continuously and automatically under controlled lab conditions at various Rohde&Schwarz locations. It is based on real, regionally-specific network traffic. This global, cross-site collaboration will play an important role in the development of future network analysis solutions using AI.

Next generation application awareness

So far, network service providers have been reluctant to introduce AI-supported tools. Typically, this is due to data protection and compliance. However, even conventional network analysis techniques sometimes evaluate IP header data and payloads for pattern recognition. In this sense, they are not in compliance with certain data protection regulations, especially in the EU. In addition, the latest advances in 5G and next generation 6G mobile communications require the use of AI technologies like ML and deep learning (DL) that are integrated into solutions deployed by network service providers and OEMs.

To meet this requirement, ipoque is developing the next generation of application awareness. Network traffic that is encrypted using the current TLS 1.3, ESNI, ECH and DNS-o-X standards is pushing conventional methods to their limits. A new classification approach is required that works in real time in order to handle customer use cases.

The ML and DL based software solution for classification of applications, protocols and services was developed so that network or security teams could carry out greatly improved real-time classification of a broad range of applications while avoiding any impact on quality due to encryption. This is especially attractive for telecommunications equipment suppliers and network service providers as well as cybersecurity and cyber defense companies.

For a safer and connected world

As a leading partner for network analysis, ipoque is helping companies and government agencies create a safer and connected world using highly advanced network analysis solutions. Classification of applications and services in real time without any baselining during the commissioning phase is a unique capability that greatly speeds up the implementation of solutions.

Moreover, ipoque focuses on quality over quantity when defining classifications. The system performs classification based on the type of communications – OTT video content, for instance – and not based on the applications used for communications. This approach dovetails with the requirements of telecommunications providers while simultaneously fulfilling the rules and regulations that apply to the anonymity of existing data. Currently, there is no other comparable solution on the market.

APPLICATION AREA: TELECOMMUNICATIONS EQUIPMENT

- Distinguishing between over-the-top download (OTT) and on-demand traffic, since OTT involves services that are provided via the internet in a non-carrier-dependent manner, e.g. video streaming platforms or messaging apps
- Categorization of data traffic with unknown protocols and applications
- Coverage of the top 150 applications (based on percentage of global traffic)

APPLICATION AREA: CYBERSECURITY

- Detection of advanced anonymization tools
- Categorization of VPN data traffic for unknown VPN apps

Fig. 2: The ipoque software solution for classification of applications, protocols and services allows network and security personnel to perform real-time classification for a wide range of applications.

Real-time awareness despite encryption

The software uses ML to classify network protocols, applications and services. For providers of telecommunications infrastructure and cybersecurity solutions as well as for network service providers, the software is designed to offer effective network transparency despite any encryption or obfuscation that may be implemented.

Benefits include:

- Real-time awareness of protocols, applications and services
- Extremely high performance up to 14 Gbps per core
- Low memory usage (only 410 bytes per network flow)
- Compatible with various CPU architectures, including x86 and ARMv8
- Most accurate and reliable solution on the market
- Global generation of training data and internal, ML-supported value creation to build trust
- Encrypted traffic analytics uses ML technology for network transparency in accordance with the rules and/or regulations relating to anonymity of existing data
- Weekly updates ensure that ML modules are up to date
- Modular software can be customized to individual requirements
- Seamless integration within clearly defined APIs for ease of handling

Overall, ipoque offers an advanced, reliable network transparency solution that is easy to integrate.

DR. MARTIN MIETH, ROHDE&SCHWARZ


5G

UNIVERSITY PARTNERSHIPS FOR SECURE MOBILE NETWORKS

Researchers are currently exploring how machine learning (ML) and deep learning (DL) can improve the resilience of 5G and 6G mobile networks. The Rohde&Schwarz subsidiary ipoque collaborates with several universities in this area. This article cites two examples of how to secure 5G campus networks and protect against certain types of cyberattacks.

Hardening mobile communications against DDoS and jamming attacks

Mobile Network Protector is a joint project between ipoque and Chemnitz University of Technology focused on developing technical innovations in the domain of cybersecurity. This collaborative effort focuses on securing 5G and 6G mobile networks, especially in the context of distributed denial of service (DDoS) and jamming attacks. Very few practical solutions have been available in this segment of the cybersecurity market so far.

Mobile Network Protector is a system that will help network operators to securely deploy their 5G and 6G mobile networks. The first step is researching and analyzing DDoS

RESEARCH PARTNERSHIPS WITH UNIVERSITIES

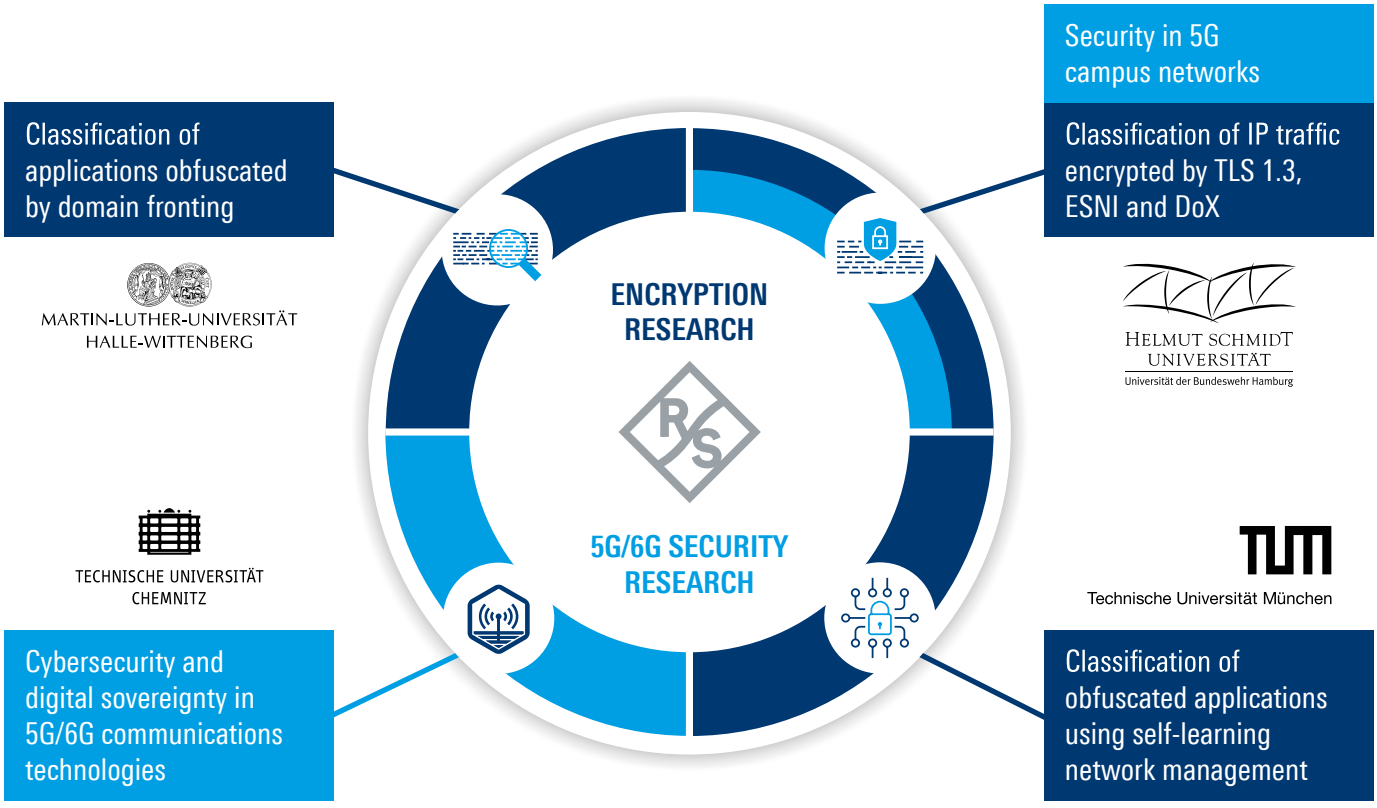


Fig. 1: As part of its efforts to improve cybersecurity and digital sovereignty in mobile communications, Rohde&Schwarz is involved in several joint research projects with universities.

and jamming attacks on networks to find vulnerabilities in the affected systems and understand how to protect network operators.

For use in Mobile Network Protector, ipoque's ML based software module for network transparency (see article on page 21) is being extended to include systems that detect attacks to recognize and respond to threats in real time. To cover as many applications as possible, ongoing cooperation with leading mobile equipment suppliers is planned.

Mobile Network Protector was created in response to the cybersecurity and digital sovereignty in 5G/6G communications technologies funding program of Germany's Federal Office for Information Security (BSI). In response to the call for funding proposals, ipoque joined forces with the Chair of Communications Networks and the Professorship of Communications Engineering at Chemnitz University of Technology.

Better security for 5G campus networks

As local networks, 5G campus networks enable faster and more dependable communications between machines and devices. This has generated significant interest across a number of sectors in operating their own secure campus networks on company premises. "Security in 5G campus networks" is the internal designation for a research project between ipoque and Helmut Schmidt University, University of the Federal Armed Forces Hamburg, aimed at meeting this need. The strategy driving the project is based on promoting information flow and transparency in security architecture and raising overall security in 5G campus networks. The project covers a variety of aspects, starting with the transparency of the architecture and extending all the way through to actual defense against attacks. Scientists at ipoque are collaborating on the project with the Professorship of Electrical Measurement Engineering at Helmut Schmidt University.

Compatibility with two networks on site

Special emphasis is placed on compatibility with a private standalone 5G campus network deployed by Deutsche Telekom at Helmut Schmidt

University implemented using equipment from Ericsson and with a 5G solution from Campus Genius. The project team is also taking into account potential overlap between private and public networks to prevent security holes.

To ensure comprehensive network coverage, ipoque is integrating device simulation. Some potential physical 5G devices are also included. Inclusion of further stakeholders such as professorships is helping to promote collaboration and shared learning. At the same time, it generates enough network traffic to enable prompt detection of overloading and potential security risks to subsequent operation.

Modern techniques for fast startup

Another focal point involves digital twins and virtualization for fast startup and a flexible test environment. Use of network traffic for drone detection helps boost security in physical environments. Support for 20 GHz applications as well as functional security applications ensure the network can manage high bandwidths and critical processes.

Cooperation with potential partners offers medium-term to long-term benefits. The Active Research Environment for the Next generation of Automobiles (ARENA2036) in Stuttgart, Germany is a good example. It serves as a test environment for real-world applications.

Simulated attacks and defense

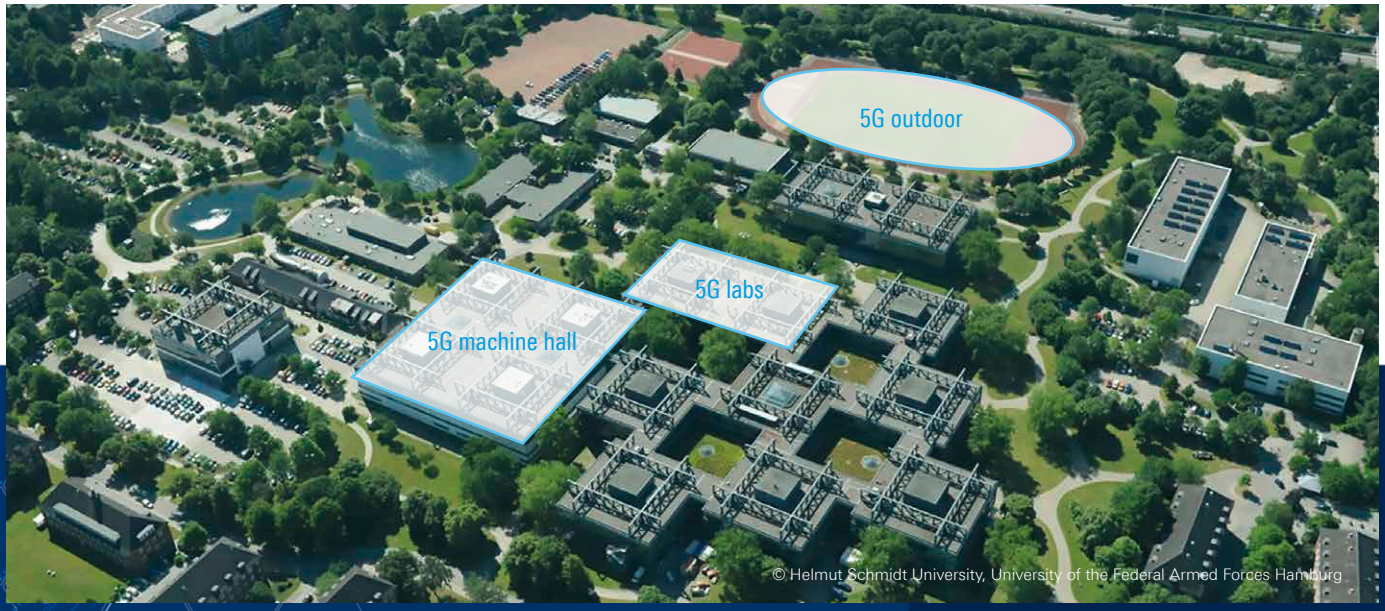
The project has a variety of different objectives. Network analysis solutions from ipoque offer transparency and insights into network traffic that can identify potential vulnerabilities. Verification of protocols such as OPC-UA ensures compliance with security standards. To enable a proactive response to potential threats, the project team is working to identify attack scenarios and carry out attack simulations. The systems for attack detection can assess threats in real time and take countermeasures.

Project objectives also include development of strategies for mitigating attacks to minimize the consequences of security breaches. All of these efforts aim to improve the security of 5G campus networks while creating a secure and reliable communications infrastructure.

By collaborating with various universities, ipoque is helping to provide highly effective and advanced tools network operators can use to keep their 5G and 6G mobile networks secure.

DR. MARTIN MIETH, ROHDE&SCHWARZ

Fig. 2: Deutsche Telekom installed six indoor and two outdoor 5G antennas on the campus of the Helmut Schmidt University, University of the Federal Armed Forces Hamburg.



5G NTN:
NON-TERRESTRIAL NETWORKS FOR 5G MOBILE COMMUNICATIONS

As 6G research advances, the 5G mobile communications standard continues to develop toward ambitious targets. The transition to non-terrestrial networks is a paradigm shift that both opens up exiting new use cases and presents new challenges. In this article, we look at what this means from a test and measurement perspective.

USE CASES FOR 5G NTN

Freight monitoring and earth observation

Logistics companies are deploying wireless sensors that can securely transmit data around the world. This lets them track and trace shipments to prove that goods are transported undamaged or ensure an uninterrupted cold chain all the way to the customer. Wireless sensors communicating via 5G NTN over terrestrial and non-terrestrial infrastructure also allow for geographic and animal observations on a much larger scale than ever before. Large-scale monitoring would enable rapid detection and geolocation of wildfires, weather information and insights into climate change, to name just three examples.

Reliable communications for disaster response

In Europe, there is a lot of interest in resilient and sovereign mobile networks as well as new methods for establishing failsafe communications channels for disaster response. 5G NTN satellite connections and other flying network nodes can quickly compensate for mobile communications base stations rendered inoperable by floods or power outages.

What does the popular Foo Fighters song "Learn to Fly" have in common with 5G? In the future, cell phones will not only be able to connect to mobile networks via the closest base station but also via planes, satellites and drones acting as flying network nodes – cellular infrastructure is learning to fly. The 3GPP standards development organization is promoting this development under the name 5G non-terrestrial networks (5G NTN), signaling a merging of mobile and satellite communications – two worlds that have always been separate.

Why all the effort?

The motivation behind such a large project is probably best illustrated by a statistic: in 2022, even though cellular coverage reached an impressive 80 % of the world's population, it covered less than 40 % of global land mass. Closing these huge coverage gaps around the world would involve significant costs with purely terrestrial infrastructure, which is why 5G NTN is expanding mobile communications with NTN platforms like satellites. The main goals are to make mobile communications services globally available, increase resilience, and improve how existing wireless technologies interact with each other.

Table 1: Five frequency bands have already been provided for 5G NTN. More are bound to follow.

FREQUENCIES FOR 5G NTN

Frequency band	Status	Uplink	Downlink
n255	Approved (Release 17)	1626.5 MHz to 1660.5 MHz	1525.0 MHz to 1559.0 MHz
n256	Approved (Release 17)	1980.0 MHz to 2010.0 MHz	2170.0 MHz bis 2200.0 MHz
n510	Approved (Release 18)	27.5 GHz to 28.35 GHz	17.30 GHz to 20.20 GHz
n511	Approved (Release 18)	28.35 GHz to 30.0 GHz	17.30 GHz to 20.20 GHz
n512	Approved (Release 18)	27.50 GHz to 30.0 GHz	17.30 GHz to 20.20 GHz
Ku, Q, V bands	Under discussion		

Two use case categories

In general, the 5G NTN standard envisages two use case categories. Simple data services with low data rates and no special requirements in terms of latency or service quality are called internet of things NTN, or simply IoT NTN. As the name suggests, this category focuses on IoT applications – but on a global scale. The second category is direct satellite communications (data and voice link), referred to as NR NTN. Initially, NR NTN will only allow for basic functions via satellite link, such as emergency calls on a smartphone or emails without large attachments. Technical advancements will then dramatically expand these capabilities. However, the data rates of non-terrestrial connections will likely never compete with those of their terrestrial counterparts, which is why 5G NTN will augment rather than replace ground mobile communications infrastructure.

Mobile communications development: from coexistence to integration

Technologically, 5G NTN has grown out of a long-term evolution. Its origins stretch back to the time when terrestrial and non-terrestrial wireless networks – satellite television and mobile communications, for instance – were supposed to work side by side without interfering with each other. Today, we are starting to integrate non-terrestrial networks into existing 5G networks. The 3GPP standardization committee has specified the relevant technical requirements in Release 17. However, this integrated approach will only be an interim step. In the long term, terrestrial and non-terrestrial networks are expected to merge into unified networks. Based on current plans, these unified networks will start springing up when the next generation of mobile communications (6G) arrives around 2030.

Challenges for the air interface

The introduction of 5G NTN presents certain challenges for both the air interface and the 5G protocol stack. The effects of atmospheric conditions such as rain, cloud cover and the electromagnetic field of the ionosphere on the diffusion of wireless signals have to be taken into consideration because the signals are no longer being transmitted exclusively close to the ground. Development teams often use wireless channel models (fading profiles) provided by official standardization bodies as a guide.

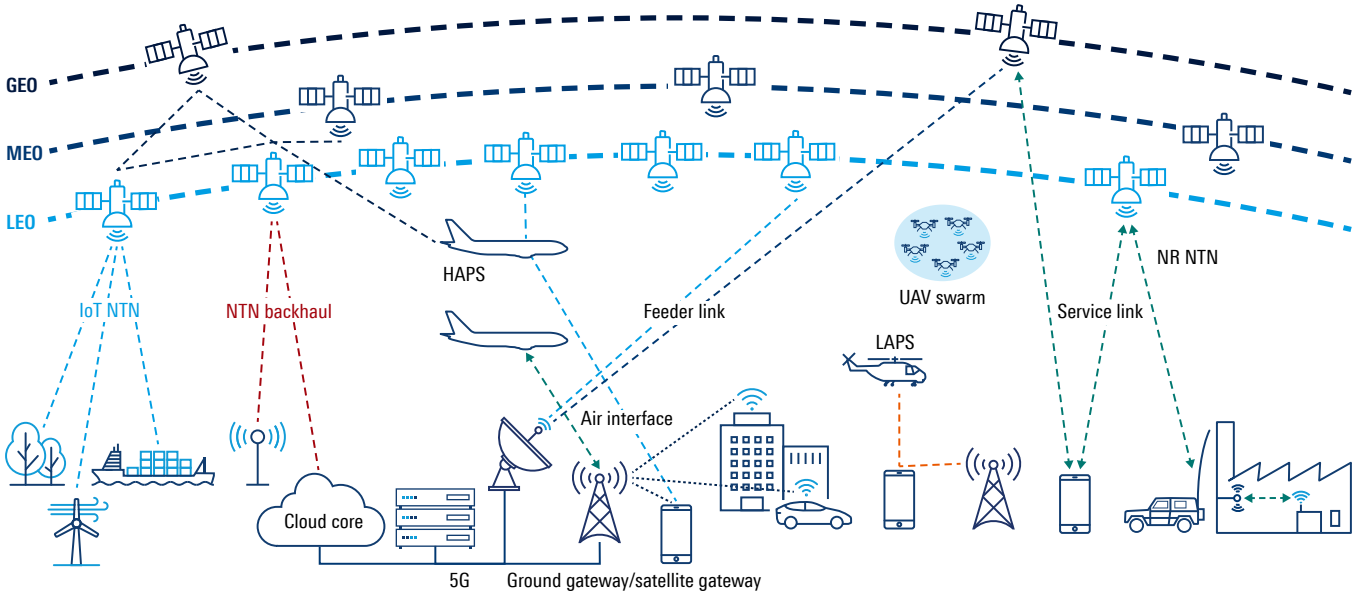


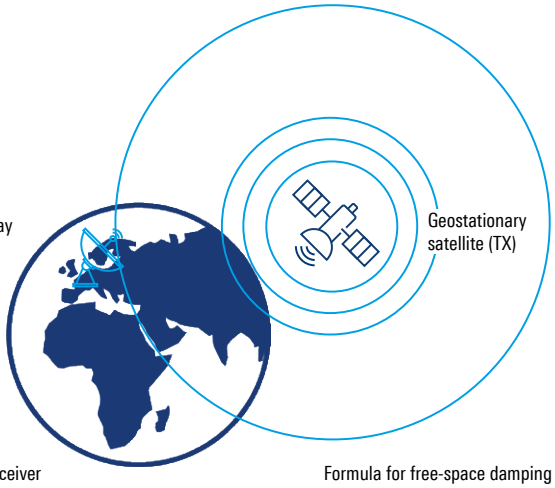
Fig. 1: A simplified representation of three-dimensional unified networks in 6G mobile communications. Satellites in different orbits will connect end-user devices to both mobile networks and base stations (backhaul). A satellite gateway on the ground will connect to the 5G core network.

GEO	Geostationary satellite (about 36 000 km)	LEO	Low earth orbit (200 km to 2000 km)	LAPS	Low altitude platform system
MEO	Medium earth orbit (2000 km to 36 000 km)	HAPS	High altitude platform system	UAV	Unmanned aerial vehicle

NTN frequencies and wave propagation

The fundamental question for every wireless technology is what frequencies are available. The n255 and n256 bands (see Table 1) were the first frequencies approved by 3GPP for 5G NTN. They are in the conventional region below 6 GHz. Further bands have since been added, some in frequency region 2 (FR2 includes frequency bands from around 24 GHz to 71 GHz). Although these frequency ranges are familiar territory for 5G technology, a new duplexing method was introduced in FR2. Up to now, 5G has only operated in this region with time division duplexing (TDD). 5G NTN however, will use frequency division duplexing (FDD), which is more spectrum efficient because it avoids the long guard intervals necessary to switch between transmission and reception due to a long delay. As a result, some extra work is required using optimization methods such as channel estimation, equalization and beamforming. With TDD, these methods are implemented directly at the transmitter (channel reciprocity) while FDD requires a bilateral communication loop. Known reference signals from the transmitter enable the receiver to estimate channel characteristics and feed them back to the transmitter (channel status reporting).

Fig. 2: Illustration of free-space loss: if waves are propagated spherically, the transmission power of the geostationary satellite is distributed evenly over a spherical surface. Only a tiny fraction (on the order of $1/1^{20}$) of the output power reaches the receiver on earth, corresponding to a whopping 200 dB of attenuation.



P_{RX} = Power receiver
P_{TX} = Power transmitter
c = Speed of light
d = Distance
f = Frequency
G = Gain
γ = Medium dependent, in air $\gamma = 2$

Formula for free-space damping (according to Harald Friis, Danish physicist, also Friis transmission equation)

$$\frac{P_{RX}}{P_{TX}} = G_{antenna} \left(\frac{c}{4\pi f d} \right)^{\gamma}$$

Free-space path loss

One of the biggest challenges for 5G NTN is free-space path loss (FSPL). This occurs primarily due to the long distance between the transmitter and receiver. In the most extreme case, an end-user device on the ground is connected to a geostationary satellite 35 786 kilometers (22 236 miles) above the earth (see Fig. 3).

Aside from transmission power, gain in both the receiving and transmitting antennas is vital for stable communications. The good news is that free-space loss can be managed with improved antenna gain – with beamforming, for example – making it possible for mobile devices on the ground to communicate with satellites.

Propagation delay

Compared to communications via ground infrastructure, propagation delay – often referred to as round trip time (RTT) – is much longer with a satellite connection. Suppose an end-user device on the ground requests a data packet from another mobile device on the ground via satellite in geostationary orbit. The propagation delay from earth to the satellite and back (two round trips) will be around 544 milliseconds. Compare that to the 20 to 30 milliseconds delay measured for terrestrial 5G networks. Existing 5G software protocols therefore need to be adapted to these longer delays.

System architecture for 5G NTN

The point of integrating NTN into 5G is to facilitate direct communications between satellites and end-user devices on the ground. Additions and improvements are expected in future 3GPP releases. In the initial implementation of 5G NTN, most of the mobile network will be terrestrial, consisting of base stations (gNB) and the core network. Satellites will act as simple "bent pipe" or "transparent payload" repeaters. The disadvantage of this approach is that propagation delay (measured from client to server with acknowledgment) includes the distance between the satellite and the earth four times. However, the advantage of this approach is that most modifications required for 5G NTN can be carried out in the more easily accessible terrestrial network. Future architectures will shift more of the signal processing load to the satellites. Some server functions can be integrated into the non-terrestrial components of the

network, so that the satellite will handle channel assignment (scheduling) and packet retries. This will reduce latency and increase the level of autonomy.

Influence on propagation delay

From the point of view of earth based transmitters and receivers, a sunup-sundown effect occurs with satellite communications, causing propagation delays to vary depending on the position of the satellite. The satellite only becomes visible on the horizon when it reaches the minimum elevation angle (sunup) and disappears again when it falls below this angle (sundown). The propagation delay is longest at both of these times and shortest when the satellite is positioned directly above the transmitter or receiver (Fig. 3).

This has consequences for the higher protocol layers. On the one hand, they have to tolerate a longer propagation delay, while on the other, they have to synchronize the signal received by the satellite. The timing advance (TA) method can be used to overcome these challenges, but it is important to bear in mind that synchronization with 5G NTN is much more difficult than it is in a purely terrestrial network. You can find more detailed information about this in the 5G NTN takes flight white paper (QR code provided at the end of the article).

Doppler effect

Compared to a network of fixed base stations, a constellation of satellites that can quickly change their relative position to end-user devices represent a paradigm shift. The high relative speed of satellites to ground stations causes the frequency to shift, a phenomenon known as the Doppler effect. How much the frequency shifts depends on the frequency used, the height of the satellite's orbit and its relative speed. In Fig. 3, the Doppler shift is plotted against the elevation angle and follows an S-curve.

To compensate for this, the satellite sends trajectory data (ephemeris) to the device with system information. The mobile device uses navigation services (GNSS) to determine its own terrestrial position and pre-compensate for the Doppler shift.

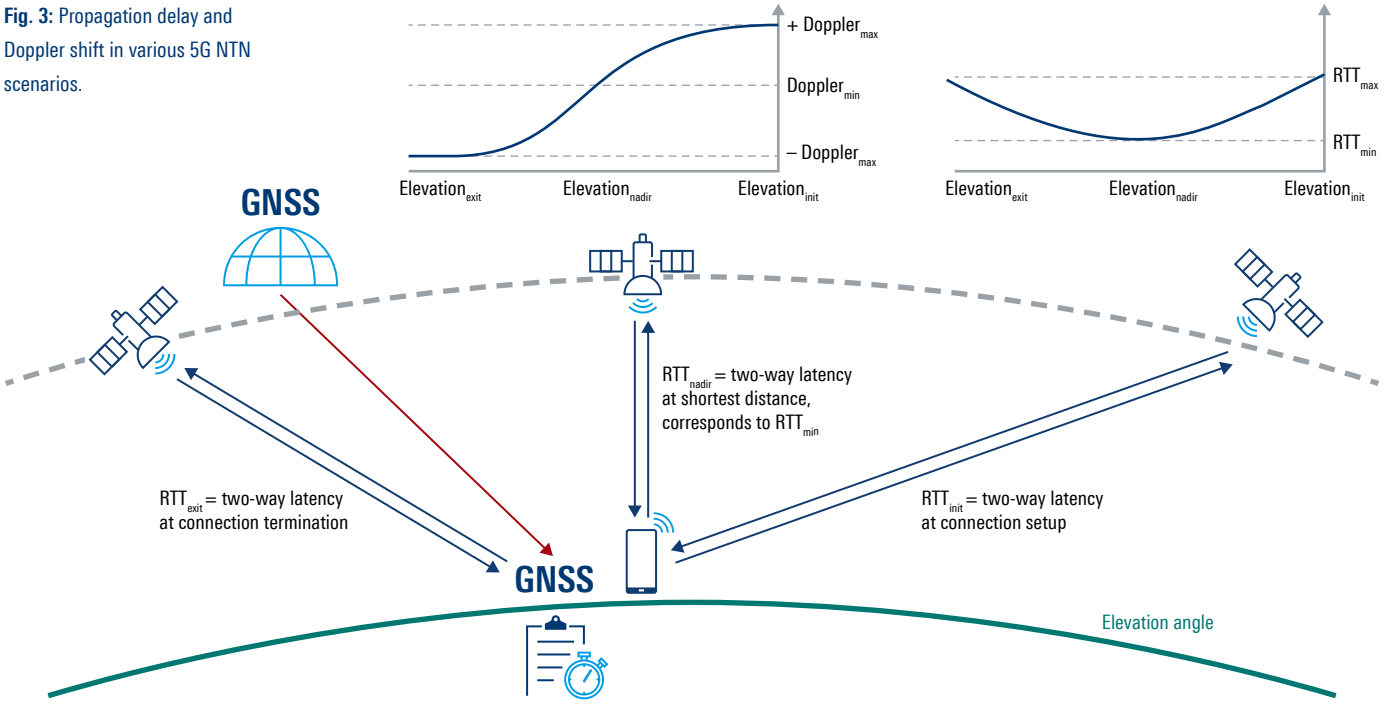


Fig. 3: Propagation delay and Doppler shift in various 5G NTN scenarios.

The role of test and measurement equipment in 5G NTN and IoT NTN

The measurement methods used in non-terrestrial networks need to be adjusted, both in terms of infrastructure and end-user devices. To verify device reliability, a system simulator must simulate not only high latency and the Doppler effect but also signaling parameters and handover scenarios. In some scenarios, positioning also requires a GNSS signal.

Test solution for end-user devices

Combining the CMW500 wideband radio communication tester with the R&S®SMBV100B vector signal generator creates the perfect test solution for IoT NTN applications. This setup emulates a GNSS navigation signal that allows the end-user device to determine its position. The CMW500 lets users test physical parameters, signaling processes and end-to-end connections (E2E). They can also expand this setup by adding the CMX500 radio communication tester to test NR NTN-capable devices.

Test solution for infrastructure

Signal generators and signal analyzers can be used to test the functions of infrastructure components like satellites. Rohde&Schwarz has expanded the capabilities of the R&S®SMW200A signal generator to emulate radio channels, which allows receivers to measure infrastructure components. The FSW signal and spectrum analyzer can be used to test the transmission properties of infrastructure components, including spectral measurements for interference emissions and coexistence testing.

Re-looking test metrics

5G NTN also affects test metrics such as over the air (OTA). For example, if a moving satellite and end-user device are 1000 kilometers (621 miles) apart and both are using beamforming antennas, then a beam-peak deviation of 1° in the direction of the transmitting antenna will cause it to shift by 30 kilometers (19 miles) on the receiving side. This yields useful new test metrics such as directional beam accuracy, long-term stability of antenna characteristics, and the speed and accuracy of readjustment.

Fig. 4: Various test solutions for 5G NTN devices: combining the R&S®SMBV100B signal generator and the CMW500 radio communication tester (above) emulates IoT NTN use cases. Users can test NR NTN applications by combining the signal generator with the CMX500 radio communication tester (below).

Fig. 5:
Satellite manufacturer Thales Alenia Space uses the R&S®SMW200A signal generator and the FSW signal and spectrum analyzer to test 5G NTN infrastructure components in Madrid.

Further reading:
[1] 5G NTN takes flight: technical overview of 5G non-terrestrial networks. Stuhlfauth Reiner, white paper, July 2022.

Rohde&Schwarz offers customers additional test and measurement equipment to monitor satellites, design satellite links and even aid the production of highly integrated parts and components for satellite technology.

Future prospects

Three-dimensional, uniform and organic network structures are the long-term goal of 5G NTN. Although 5G NR Release 17 laid the foundations for 5G NTN, it should only be viewed as a springboard. Two ecosystems that were previously separate – satellite and mobile communications – are now growing together.

Rohde&Schwarz is one of only a handful of companies that can be called a global technology leader in both mobile communications test and measurement technology and satellite communications. The company helps further develop this technology with proven expertise and extensive experience.

REINER STUHLFAUTH, ROHDE&SCHWARZ

LICRIS RESEARCH PROJECT:

BUILDING THE 6G RADIO CHANNEL

Reconfigurable intelligent surfaces (RIS) will be an important technology pillar of the next mobile communications standard 6G. The objective is to use RIS to actively control radio channels, which until now have always been passive. Active control will improve cellular coverage and data throughput while reducing power consumption. Rohde&Schwarz is coordinating the 6G LICRIS research project to create liquid crystal RIS.

Even though the next mobile communications standard is still a few years away from introduction, we already know two things: 6G will enable new use cases and will increase wireless communications between devices.

On the way to 6G

To open up more bandwidth, 6G uses parts of the higher and largely unused frequency spectrum but higher attenuation and increased shadowing from buildings will also be factors during signal transmission. Both reduce network coverage. More transmitting antennas can compensate for the attenuation and shadowing, but only with greater power consumption.

Another option is modifying how radio waves are propagated. Reconfigurable intelligent surfaces (RIS) hold a lot of promise. Suspending them from building facades, they can control the reflection of 6G radio waves to provide sufficient network coverage with far fewer transmitting antennas and far greater energy efficiency.

Beyond Shannon

The Shannon model is the classic transmitter-receiver model used in communications engineering and assumes that a radio channel is a fixed quantity. This model focuses on encoding and decoding processes to maximize data throughput. RIS can be used to actively adapt the radio channel during operation for the first time so that the channel is no longer passive. This opens the door to completely new optimization methods for radio communications far beyond the familiar territory of the Shannon model.

Radio channels and wave propagation were generally regarded as constant. Radio channels were fixed for example when passing through the walls of a building indoors. RIS now makes it possible to actively reflect and target radio channels and wave propagation for better coverage in the future.

Reconfigurable intelligent surfaces

RIS are antennas and integrated circuits that use special diodes or liquid crystals. They form a flat structure and can be configured to reflect incoming radio waves and forward them to receivers. Compared to classic RF amplifiers (repeaters) which contain a transmitter and receiver, RIS are cheaper to purchase and more efficient to operate. Current development projects use RIS as passive components that simply reflect signals, with no amplification. We observe the frequency range below 6 GHz (FR1) or the millimeterwave range (FR2). Using the surfaces as active signal amplifiers might be interesting but higher energy demands and construction costs mean that this use is not a top priority.

PROFILE: 6G LICRIS

For about three years, Rohde&Schwarz has been working with industry and research to develop innovative surfaces (RIS) that actively and accurately modify the radio channel for cellular signals in the FR1 and FR2 bands. RIS are one of a total of ten major research fields identified for 6G mobile communications. The German Federal Ministry of Education and Research (BMBF) is funding the project.

PARTNERS

- Rohde&Schwarz GmbH & Co. KG (project coordinator)
- Ericsson Antenna Technology Germany GmbH, Rosenheim
- Merck KGaA, Darmstadt
- University of Stuttgart, Institute for Large Area Microelectronics
- IMST GmbH, Kamp-Lintfort
- Brown-iposs GmbH, Bonn
- Fraunhofer HHI, Berlin
- Berlin Technical University

Budget: EUR 6.59 million
Project duration: October 2022 to September 2025
Associated partners:

- Ericsson Germany (EDD)
- Airbus Defence and Space
- Robert Bosch
- NXP Semiconductors
- m4 wireless

RIS use cases

In general, RIS are best in densely populated areas and in industrial environments. They improve spectral efficiency and make it easier to generate and manage directional radio beams. When radio transmission requirements change, the RIS adjusts radio channels during operation. When installed on a building facade, an RIS will direct mobile communications into streets and interior spaces – areas where cellular coverage has been difficult.

Fig. 1 shows how RIS can increase network coverage when the line of sight between the transmitter and receiver is blocked. This will apply to both indoor scenarios and outdoor scenarios in the future. In Fig. 2, an RIS transmits the signal from a roof-mounted base station to two people in the radio shadow. Also important to the mobile communications industry: RIS can improve indoor base station signal transmissions by integrating them into window glass as metalenses [1]. RIS are best installed close to the transmitter or close to the receiver to effectively minimize the loss of very high frequency signals (FR2) over the transmission path.

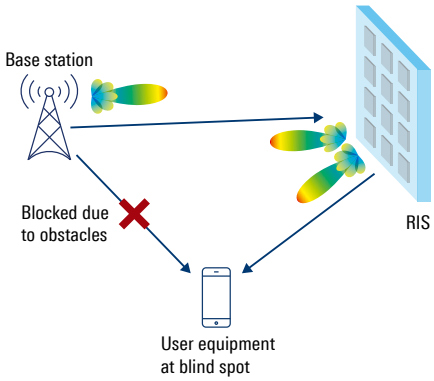


Fig. 1: Mobile communications in the FR2 band is sensitive to obstacles in the transmission path. RIS can eliminate such gaps in network coverage.

The LICRIS project

The 6G liquid crystal reconfigurable intelligent surfaces (LICRIS) project is developing RIS using liquid crystals [2]. These are better in the high frequency ranges than semiconductors (also an option).

The project is funded by the German Federal Ministry of Education and Research (BMBF) and covers phases for developing new liquid crystal materials, constructing RIS and testing them in a mobile radio test network. The final step will place 6G LICRIS technology in a real network environment to demonstrate data transmission from one device to another (end-to-end data transmission).

The project also bolsters German and European digital and technological sovereignty by building up basic knowledge and production expertise for new types of liquid crystals.

Metamaterials

To keep power consumption low, RIS use metamaterials to reflect electromagnetic waves. The Greek word μετα means beyond and metamaterials have properties that go beyond those of natural materials. In optics, metamaterials can have a negative refractive index (natural materials always have a positive refractive index). They are used in lenses with very high imaging quality or, more experimentally, to guide light around objects to act as a cloaking device. RIS metamaterials have excellent electromagnetic properties in the RF range.

Metamaterials have certain basic structures called meta-atoms. The geometry and arrangement of meta-atoms determine the properties of a

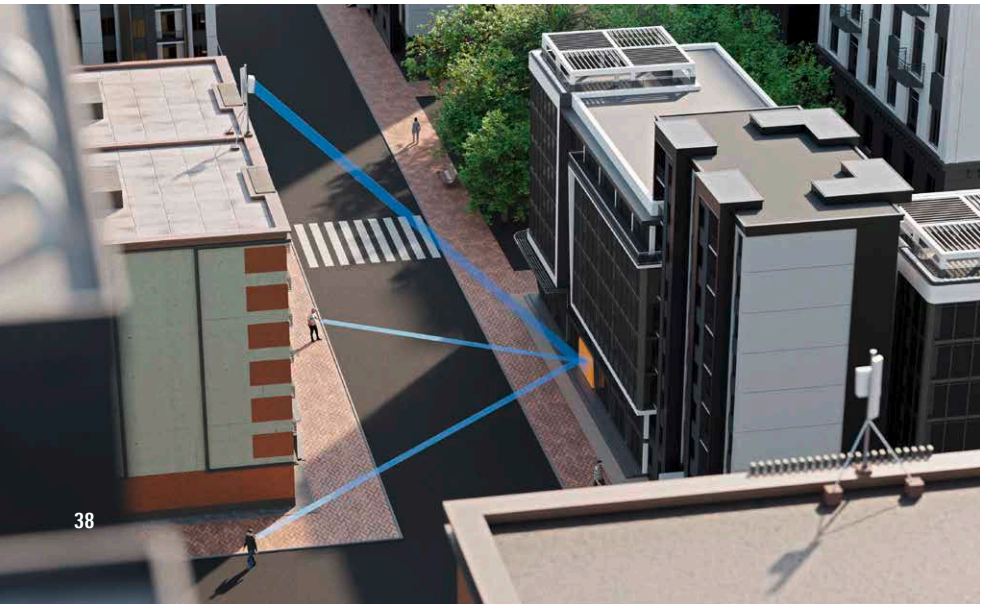


Fig. 2: RIS installed outside directs the signal from a base station on the roof to two pedestrians on the sidewalk.

LIQUID CRYSTALS – BETWEEN CRYSTAL AND LIQUID

Liquid crystals were discovered in 1888 by Friedrich Reinitzer, who recognized them as a previously unknown phase of liquids. He was surprised to discover that their physical properties are also anisotropic (direction-dependent) in the liquid state, which until then had been considered a classic characteristic of solid crystal structures. Today, many different classes of liquid crystals are now known and the underlying mechanisms are well understood [6]. This research was so fruitful and fundamental that Pierre-Gilles de Gennes was awarded the Nobel Prize in Physics in 1991.

Their anisotropy is due to rod-shaped molecules (Fig. 3), which are uniformly oriented in the liquid crystalline phase and form an axis. Fig. 4 illustrates the nematic phase that occurs in the class of thermotropic liquid crystals. Liquid crystal displays (LCD) use this type of liquid crystal. In this case, anisotropy refers to the fact that the extent to which the nematic liquid crystals change the polarization of an electromagnetic wave (in this case, light from the LCD backlight) depends on the angle at which the wave strikes the axis.

In an LCD, an electric field changes the orientation of this axis in order to change the polarization direction of the light in a controlled manner. The liquid crystals are located between two polarization filters arranged perpendicular to one another and act like a light valve that controls the brightness of the individual display pixels.

Due to their widespread use in LCDs, liquid crystals are a billion-dollar market today. The Merck Group in Darmstadt, Germany is the global market leader in the production of liquid crystals. Merck is one of the partners in the 6G LICRIS project.

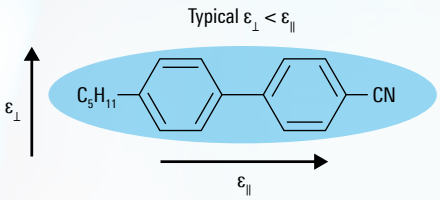


Fig. 3: Example of a rod-shaped molecule in a liquid crystal. The anisotropic molecular shape leads to anisotropic physical properties such as the different electrical permittivity ε in parallel and perpendicular directions of incidence.

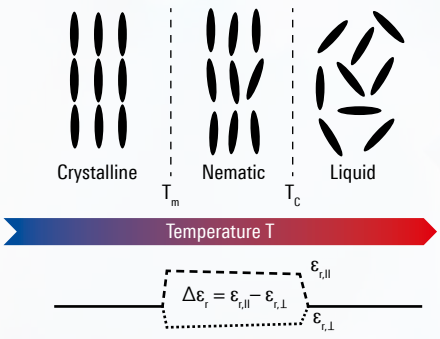


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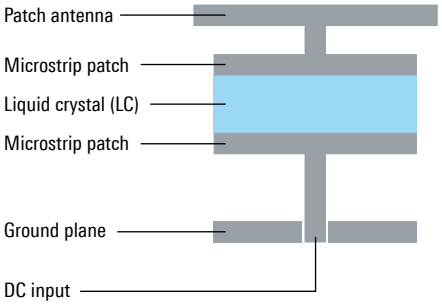
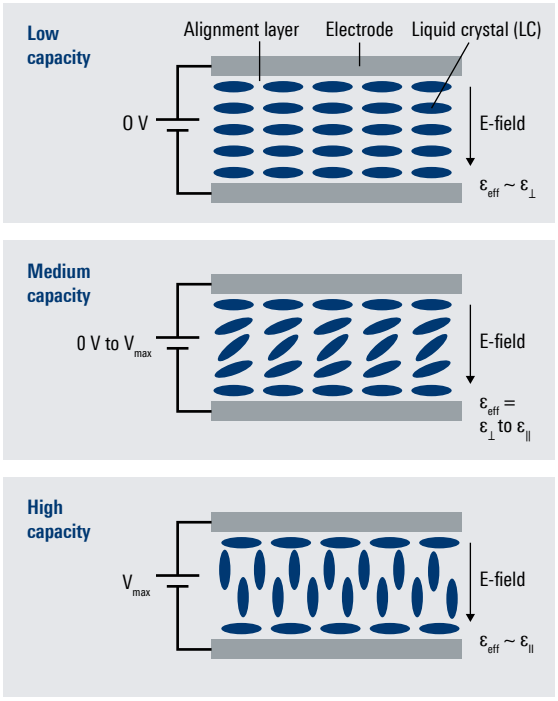
Fig. 4: Thermotropic liquid crystals change their phase depending on the temperature. At the melting point T_m, the crystalline material passes into the nematic phase and turbidity sets in. At the transparency point T_c, the uniform orientation of the molecules is lost and the liquid becomes transparent. One current research objective is to create liquid crystal mixtures with the greatest possible Δε, which expresses their "tunability".

Fig. 5: Variable plate capacitor with liquid crystals as a dielectric between two glass substrates for RF applications. When no voltage is applied, the top layer (called the orientation layer or alignment layer) stimulates the liquid crystals to align the molecules parallel to the substrate. As the voltage increases, the molecules gradually align themselves vertically and the capacitance C of the capacitor increases (right). How this component can be integrated into a (simplified) antenna structure is shown on the left.





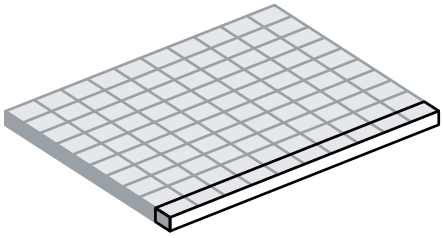
metamaterial. A real advantage since both can be controlled in the manufacturing process. The metamaterial properties can be tailored to a specific application.

Meta-atoms are dimensioned to the application and always have wavelengths shorter than those of the signals that the metamaterial reflects. Light has a short wavelength and requires much smaller meta-atoms than radio signals which have longer wavelengths. Metamaterials can influence the propagation of electromagnetic waves in a way that is not possible with any other material. As a result, metamaterials give researchers an enormous amount of freedom when designing RIS and can improve properties such as the reflection, absorption and transmission of electromagnetic waves [3].

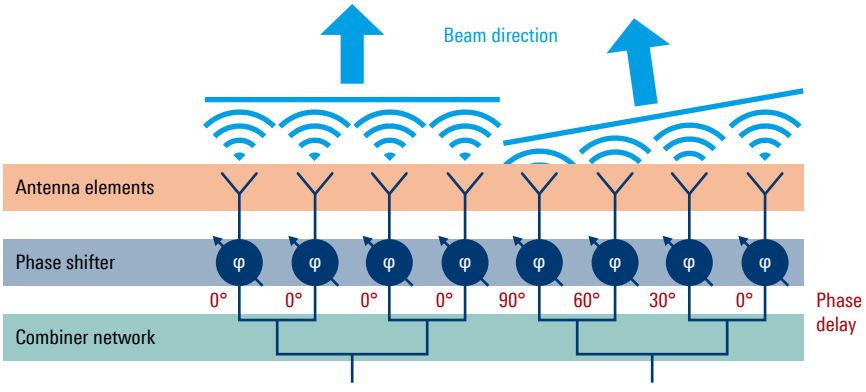
Liquid crystals for RF applications

Liquid crystals are a mature technology, which is a major advantage. Liquid crystals have been used in PC monitors and smartphone screens for decades, their electrical control methods are well known and the industry has mastered production of

Fig. 6: Flat phased array directional antenna (left) consisting of many identical antenna elements in a square arrangement. Phase shifters are the central components, controlling the phase of each antenna element and generating the directional effect (right).



Phased array patch antenna



large-area liquid crystal layers. The technology is now being transferred to the RF sector. Liquid crystals are used in smart antennas [4]. Not only can they change the polarization of light (see text box: liquid crystals – between crystal and liquid), they can also change effective capacitor permittivity or capacitance (Fig. 5). They are perfect for setting up phase shifters for directional RF antennas. Similar to screen pixels, phase shifter pixels can be constructed and combined to form large-area directional antenna arrays or large RIS. Fig. 6 shows one such setup.

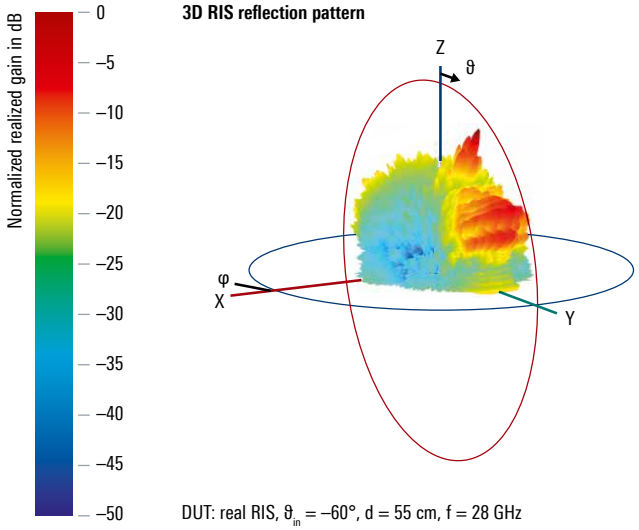


Fig. 7 above: Test setup for characterizing phased array antennas in an anechoic chamber, which can also be used in a similar form for RIS. You can see both the device under test (marked with a crosshair) and the feed antenna.

The figure left shows the 3D reflection pattern of a real RIS provided by Greenerwave (www.greenerwave.com).

Two RIS variants

The 6G LICRIS project is developing two RIS versions that work on the principle of phased array directional antennas. The first type is for high frequencies from 26 GHz to 27 GHz (FR2) and uses liquid crystals. The second type is for signals between 6 GHz and 7 GHz and has conventional, reconfigurable RF components that can be manufactured using PCB technology. In principle, liquid crystal based RIS also work with significantly higher frequency signals. So far, usability up to 100 GHz has been demonstrated. The limiting factor in such a metamaterial concept is the switching time when the electric field is turned off. Liquid crystals have a certain rotational viscosity depending on liquid crystal layer thickness, with a relaxation period before all the liquid crystals can be arranged parallel to the alignment layer again. Layer thickness of 5 µm can take tens of milliseconds but this switching time is good enough for many practical applications.

Before the project officially ends in 2025, it will also look at specific use cases for RIS, create concepts for network integration and develop measurement concepts to characterize them. One possibility for the latter is based on a conventional setup with a feed antenna in an anechoic chamber, as shown in Fig. 7.

Future prospects

RIS technology is a promising approach to mobile network coverage in the FR2 range and beyond. Further technological development will focus on reducing costs to compete with existing alternatives such as access points and repeaters.

After all, use cases for network operators also depend on economic factors. RIS technology will be used where the benefits of installing an RIS exceed the costs (development and acquisition costs, possibly also rental payments for installation on building facades). The potential is certainly there.

Another interesting use case for Rohde & Schwarz is reconfigurable intelligent surfaces that can change electromagnetic conditions in measuring chambers. This would allow testing teams to create quiet zones in any required shape and size or change channel conditions to suit specific applications.

Together with project partners, Rohde & Schwarz continues to explore the potential of liquid crystals in RF applications and drives their commercial use in 6G mobile communications, which will be introduced around 2030.

DR. TARO EICHLER, ROHDE & SCHWARZ

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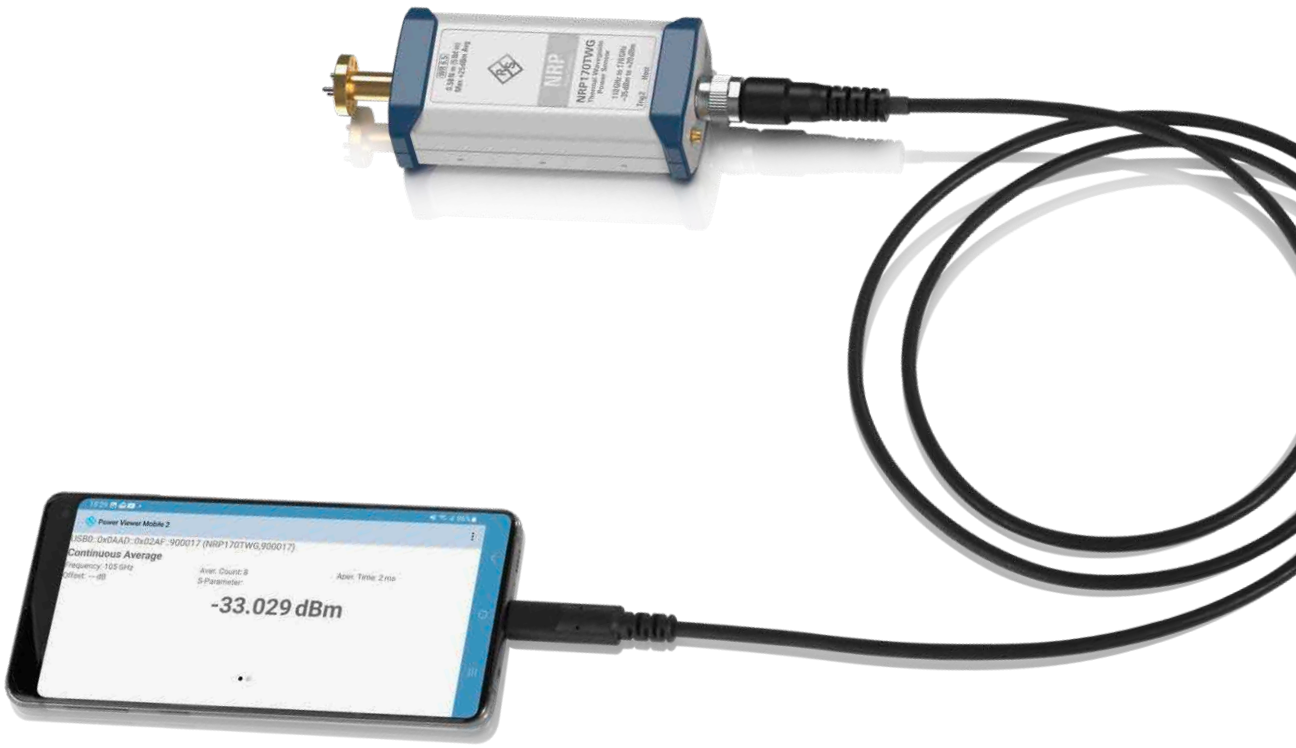


THE FOUNDATION HAS BEEN LAID:
TRACEABLE FOR THE FIRST TIME

If new frequency bands are to be used commercially, they will need calibrated RF power meters. The R&S®NRP170TWG was introduced in 2023 and is the only instrument on the market that can be used to calibrate the D band. Rohde&Schwarz now also offers transfer standards for the D band so that national metrology institutes can trace and transfer RF power measurements.

The D band covers the 110 GHz to 170 GHz frequency range. The R&D departments at mobile device manufacturers and in the automotive industry are currently very interested in this range. Radar sensors that use the D band can generate greater spatial resolution than previously possible. In the mobile communications sector, the D band is a promising candidate for 6G.

Why is traceability important?

While market-ready products for the D band will not be available for a while, the foundation for market approval needs to be laid much earlier. Calibrated RF power meters are needed to ensure that transmit power remains within legal limits. A standard needs to be created and made available to test equipment manufacturers that lets them

R&S®NRP170TWG

The R&S®NRP170TWG are thermal RF power meters for research, development and production. The TWG refers to the measurement principle (T = Thermal) and type of RF connector (WG = Waveguide). One unique feature is the fully traceable measurement range up to 170 GHz. The range transforms the power meters into accredited test equipment for legally binding compliance verifications with set mobile equipment transmit power limits.

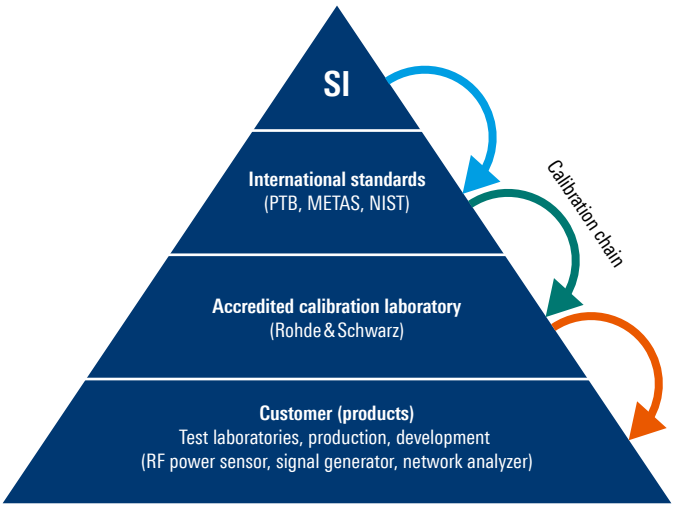
The temperature compensation within the specified operating range from 0 °C to +50 °C makes the sensors very precise, accurate and stable in challenging broadband applications. A dynamic range from –35 dBm to +20 dBm and support for up to 500 measurements per second give the meters a wide measurement range and very high test speeds. The R&S®NRP170TWG can be quickly integrated into any test setup with the plug-and-play design.

The USB interface enables uncomplicated sensor controls and the easy exchange of data. The R&S®NRP170TWGN version has a LAN interface for larger systems with multiple power meters positioned at different points where readouts are required.

Fig. 1: The R&S®NRP170TWG is palm-sized and weighs only a few hundred grams.

calibrate measurement scales for power meters and make them traceable to national reference standards. This very challenging and expensive standard creation was completed for the D band in 2023. Rohde&Schwarz was a partner in the joint European project. The company worked with Germany's national metrology institute (PTB) and other national metrology institutes. R&S®NRP170TWG power meters were also calibrated for the D band. The meters are the only available RF power meters with a calibrated measurement range for frequencies above 110 GHz.

Fig. 2: Basic calibration hierarchy and calibration chain. At great expense, government agencies work to produce extremely precise national standards for the key measurands derived from defined base quantities (SI units). The measurement accuracy is then transferred to manufacturing companies via accredited calibration labs.



The role of Rohde&Schwarz in the calibration hierarchy

Fig. 2 illustrates the international principle underlying the calibration hierarchy and calibration chain.

As Germany's national metrology institute, the PTB ensures that key measurands can be verified with extremely high accuracy. The PTB maintains high-precision test instruments and equipment for monitoring the measurement environment. Both together form the national standard. In the case of RF power, the national standard consists of an RF power meter and a microcalorimeter. For more information and to find out how Rohde&Schwarz traces RF power measurements, see [1] and [2].

The accredited calibration laboratories represent the next level. In Germany, the Deutsche Akkreditierungsstelle GmbH (DAkkS) is responsible for these accreditations. The company has a network of over 600 calibration labs. The labs maintain reference standards (RF power meters with measurement accuracy precisely derived from measurements based on the national standard and documented measurement uncertainty).

In this principle, measurement accuracy is transferred from the top to the bottom of the calibration hierarchy or calibration chain. Measurement uncertainty increases slightly with each additional link in the chain.

Rohde&Schwarz is situated directly below the PTB in the calibration hierarchy. The company operates accredited calibration labs in Memmingen, Munich and Cologne that are tasked with ensuring traceability to the national primary standard. These laboratories are a key element in our calibration infrastructure and industrial quality assurance.

Special reference standard features

The reference standards at the accredited calibration laboratories must be compatible with the calibration systems used by national metrology institutes. Only passive power meters based on thermistors or comparable technology can be used as a reference standard. In the industry, this sensor type has not been used for RF power measurements for a while. The excellent long-term stability of thermistors mean they are still used by national metrology institutes.

Rohde&Schwarz is one of only a few manufacturers worldwide that produces thermoelectric RF power meters that are suitable for tracing the RF power measurand. Such transfer standards can be used as reference standards by accredited calibration laboratories. Rohde&Schwarz now offers these transfer standards for the D band. The company is making a solid contribution to quality assurance and commercialization of new frequency bands for applications such as mobile radio.

Further reading on traceability of RF measurands:

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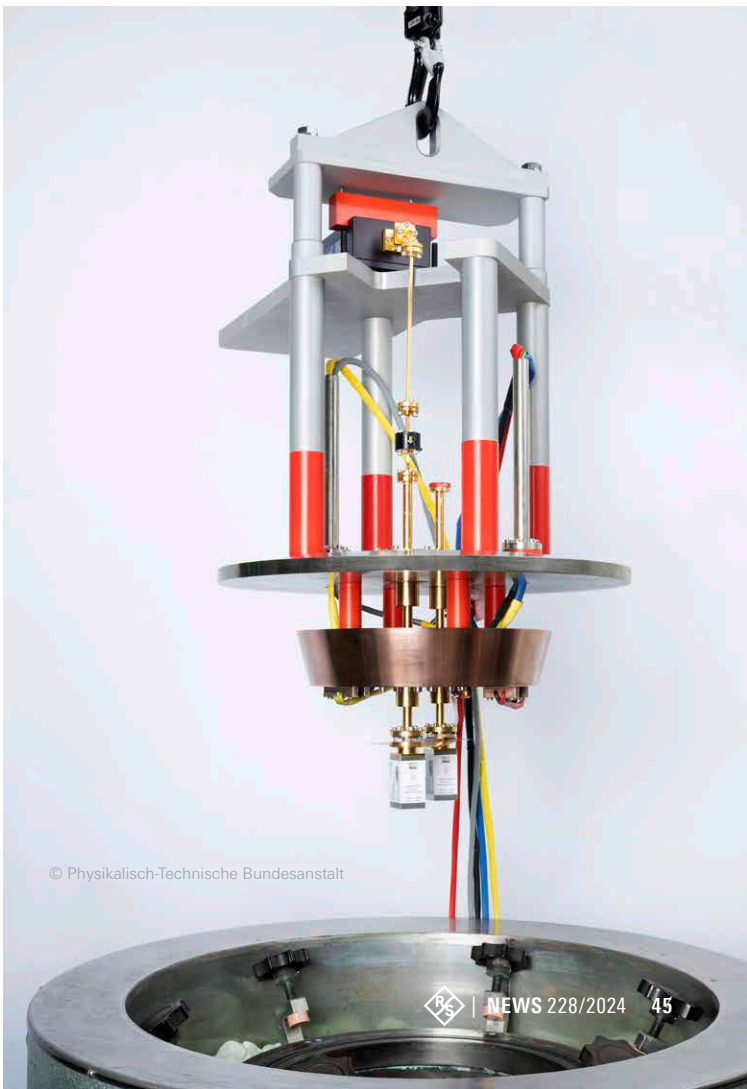


Fig. 3: Two R&S®NTS170TWG transfer standards are used for measurements in the microcalorimeter at the National Metrology Institute in Braunschweig in line with the DC substitution principle. Only the active sensor is supplied with a high frequency signal, the passive sensor serves as a reference. A differential temperature measurement in the millikelvin range uses a thermal column (series switching of thermal contacts) to determine power sensor efficiency. Transfer standards are suitable for primary regression in the microcalorimeter thanks to their structure.

WLAN OPTIMIZED AT THE TOUCH OF A BUTTON FOR M-NET

M-net moved to its new headquarters on Frankfurter Ring in Munich and brought the campus and business network infrastructure into one place for full-coverage WLAN across all company divisions. M-net picked German infrastructure provider LANCOM Systems to provide network components. The LANCOM Active Radio Control™ 2.0 (ARC 2.0) is a self-learning automation tool that optimized M-net's WLAN based on actual usage data.

Up until 2021, M-net used network components and Wi-Fi access points from several different manufacturers and some had become very outdated. The move to a new head office in Munich was the perfect opportunity to harmonize M-net's network infrastructure. German infrastructure manufacturer LANCOM Systems was on the final shortlist of three providers. The straightforward component management was particularly important to the selection process. As project manager Peter Voit explains: "Ultimately, the decision was easy, since LANCOM is a German manufacturer of quality products. We were persuaded by the consistent management, cloud options, superior and straightforward patch management, stability, durability, and the technical reliability of the components."

Including Wi-Fi router test lab

Once LANCOM was named preferred partner for network equipment, the first step was getting the campus and business networks in place. First the setup and the Wi-Fi access points were commissioned for the head office, followed by subsidiaries, data centers and shops. The M-net Munich head office also had "RF labs" for testing Wi-Fi routers and Wi-Fi components from other manufacturers. The labs were a particular challenge, since testing and the many components in the lab could significantly disrupt productive WLAN connections.

For over 25 years, leading Bavarian fiberoptic provider M-net has been supplying large parts of Bavaria, the Ulm metropolitan area in Baden-Württemberg, and the Main-Kinzig district in Hesse with fiberoptic telecommunications services. The company has strong vertical integration – offering fast internet, phone, TV and cellphone services, networking and data center solutions, and high speed internet connectivity for business clients. These activities are handled by 850 employees, based at the Munich head office, three sales subsidiaries, two data centers and eleven shops for customers. As a pioneer in the migration to fiberoptic infrastructure, M-net has worked with shareholders, municipal utilities in major Bavarian urban areas and a wide range of infrastructure partners to invest in the expansion of its fiberoptic broadband network.
www.m-net.de

© M-net

Fig. 1: M-net has equipped its Munich head office, subsidiaries in Augsburg, Nuremberg and Kempten, and eleven shops with a centrally managed WLAN solution from LANCOM Systems.

Fig. 2: In shops with many WLAN devices and challenging RF environments, the LANCOM LN-1700UE access points ensure stable Wi-Fi.

Phase 1

Together with a partner, Ekahau equipment was used to survey and measure the available space. Readings were used to manually optimize channels and transmission performance as well as settings for access points and Wi-Fi clients.

Phase 2

The "Wi-Fi Adaptive RF Optimization" tool integrated into the LANCOM access points brought significant improvement with a very positive effect on local access points.

Phase 3

In difficult areas, three extra LANCOM access points were used as frequency analyzers and Wi-Fi networks were optimized based on analysis results.

Phase 4

The internal SSIDs were switched off in the 2.4 GHz band to determine the smallest-scale wireless cells with high throughput. The SSIDs for the production networks are used only in the 5 GHz band. The results were impressive, with significant interference reductions.

Phase 5

In the final phase, ARC 2.0 enabled a breakthrough in stability, availability and throughput. ARC considerably simplifies wireless network optimization: the cloud based tool leverages computer based learning and real-world usage data to calculate the best Wi-Fi network configuration. Since the wireless network was optimized with ARC 2.0 settings, it has operated smoothly almost everywhere. Peter Voit: "Our step-by-step approach has steadily improved the performance and stability of the wireless network and ARC 2.0 added the finishing touches."

An obvious improvement

You can see the benefits of ARC 2.0 during a typical day at the M-net office. During the pandemic, few employees came into the office, so Wi-Fi coverage was virtually perfect. In recent months, more employees have come back to work in the office and wireless resources have been pushed occasionally to their limits. Performance tends to suffer when entire teams log into an access point at the same time. ARC 2.0 helps determine a configuration at the touch of a button to keep the WLAN up and running without disruption, even when user numbers grow. If employees keep coming in to work, Peter Voit is ready to meet the challenge with LANCOM wireless components and ARC 2.0 wireless network optimization.

Summary

"We can now offer employees uniform infrastructure plus a wireless local area network that runs smoothly and problem free at any of our locations," says Peter Voit. He also sees a real benefit in the central cloud management interface with integrated patch management that minimizes administrative workload for day-to-day operations. "Our wireless LAN is now so well-tuned, we're even considering a Wi-Fi first strategy for user devices and working out how LANCOM can help make this a reality."

ECKHART TRABER, LANCOM SYSTEMS

NEW TRANSMITTER
NEW SERVICE

The latest broadcast transmitter from Rohde & Schwarz is the R&S®TE1 for North America. With up to 96 kW transmit power, outstanding 50 percent efficiency and a completely new service concept, broadcasters can improve their sustainability and adopt new business models.


24.50 kW
Refl Power 0.0 W
PA Efficiency 50.5 %
26 °C
26 °C
0 %
2.8 Bar
°C
26 l/min
0 %
0 %
0 %

Fig. 1: As part of the new RMTX service concept, Rohde & Schwarz experts provide continuous support, maintenance and monitoring of broadcast transmitters.

Rohde & Schwarz is known worldwide as a global technology group. The company's TV and radio broadcast transmitters are particularly important to their brand recognition. The company's latest model is the R&S®TE1 – a liquid-cooled UHF transmitter for the North American market. It has normal transmit power (NTP) of up to 96 kW and supports the ATSC 3.0 TV standard. Moreover, remote transmitter monitoring (RMTX) brings a whole new level of service to the broadcasting sector.

Up to 50 percent efficiency

Today's legally binding climate targets mean that every modern information company needs data infrastructure that produces the least possible amount of CO_2. Efficiency is key in broadcast transmitters. Over 99 percent of CO_2 emissions from the R&S®TE1 are from energy consumed during operation. Up to 50 percent efficiency means the R&S®TE1 sets new standards and helps make transmitter installations much more sustainable while also cutting operating costs. A typical field setup (two 34 kW transmitters) upgraded to R&S®TE1 transmitters will produce around 3000 fewer tons of CO_2 emissions over a ten-year operating period and reduce energy costs by 40 %.

If a typical setup consisting of two 34 kW transmitters is upgraded to R&S®TE1, transmitters will produce around 3000 fewer tons of CO_2 emissions over a ten-year operating period.

Easy to use and failsafe

Many parameters must be correctly set to efficiently operate a broadcast transmitter within prescribed limits. Until now, this was done manually during commissioning. The new transmitter from Rohde&Schwarz comes with intelligent software to automatically detect optimal working parameters at the touch of a button. This saves time and means no expertise is required.

Certain tried-and-tested design features from the R&S®TH1 transmitter help ensure failsafe performance, including liquid cooling, self-diagnostic features and a decentralized electronic control unit (ECU) distributed evenly across redundant exciters.

Remote monitoring counters skills shortage

Broadcasters also suffer from a shortage of skilled workers, but Rohde&Schwarz has the answer: the RMTX service product – a first in the broadcasting industry. As part of a service contract, Rohde&Schwarz provides continuous support, maintenance and monitoring for any companies lacking the necessary staff (Fig. 4). The concept is based on remote monitoring and was developed and tested in cooperation with one of the top four US broadcasters.

How does RMTX work?

The two most serious issues for broadcasters occur when transmitters operate outside of their defined specifications, for example when the transmit power is too high or low or when they stop working completely. The R&S®TE1 records every relevant parameter that needs to be monitored and helps prevent any of these issues. A secure gateway (SAG360-FW) from the Rohde&Schwarz subsidiary, LANCOM Systems, sends data to a central collection point – the monitoring platform from Rohde&Schwarz, which is subject to the strict European Union data protection regulations. Automated software and HF experts from the Rohde&Schwarz service team assess the data and prioritize error patterns by urgency. If on-site intervention is needed, Rohde&Schwarz will contact the broadcaster's team and immediately guide them through any action that is required. Broadcasters no longer need to keep HF experts on staff. The RMTX has other customer benefits that make troubleshooting quicker and easier. Rohde&Schwarz can proactively provide spare parts with express delivery and plan on-site specialist visits without any delay.

Backward compatible with the R&S®Tx9

RMTX is available for everything from small installations with just one transmitter to large broadcasting networks with several transmitters. The service is now available in North America for R&S®TE1 transmitters and the R&S®Tx9 transmitter series. Rohde&Schwarz plans to offer RMTX in other countries in the near future.

R&S®TE1 OVERVIEW

Transmit power	Up to 96 kW
Frequency	470 MHz to 700 MHz (UHF band). Up to 862 MHz on request.
Standards	ATSC, ATSC 3.0
Primary market	North America
Dimensions per cabinet [1] (B × H × T)	600 mm × 2000 mm × 1100 mm (23.62 in × 78.74 in × 43.31 in)

[1] Maximum configuration has four transmitter cabinets.

Fig. 2: The R&S®TE1 is designed for modular expansion of transmit power using a rack system. Each cabinet has space for up to 14 racks for 24.5 kW of total transmit power.

Preventive maintenance and development optimization on the horizon

In the long term, RMTX will also allow broadcasters and transmitter manufacturers to work together in new ways. With the right user agreements in place, anonymized transmitter data can be used to determine the perfect operating conditions or fine tune the development of future transmitter generations. Customer-specific updates based on real operating data are also possible – not to mention developing concepts for preventive maintenance. The latter is especially interesting for the broadcasting industry since high availability is the top priority. Until now, the only way to ensure failsafe performance has been highly redundant transmitters and/or very tight maintenance cycles.

Fig. 3: The maximum configuration of four cabinets and 56 amplifiers generates 96 kW of transmit power.

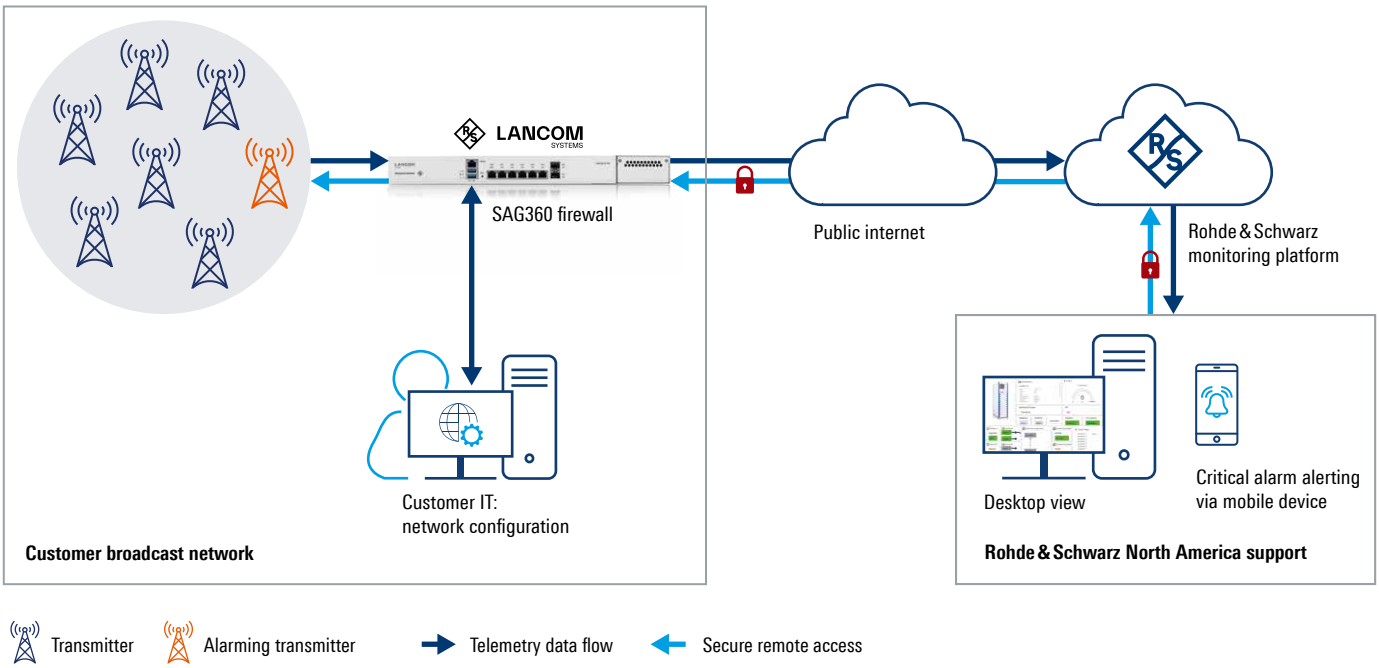


Fig. 4: Broadcasters can configure the firewall for remote transmitter monitoring themselves and adjust it as needed.

New business models

To date, broadcasting networks have always aired linear TV and radio programs. Now, the industry has started to discuss the possibility of using existing broadcast infrastructure to transmit general traffic and navigation data to vehicles. This navigation aspect is commonly referred to as a broadcast positioning system (BPS) and is a valuable addition to GPS.

Broadcasting infrastructure is a logical candidate for sending out hazard warnings or missing person notifications due to its excellent coverage. Broadcasting can be used to reach areas with poor cellular or satellite reception without building completely new infrastructure. Streaming services sent to smartphones and tablets as broadcasts or multicasts have been discussed for a while. Unlike the current process, this would not require an individual connection for each device. Instead, a single signal could be sent out to all devices. This approach means that transmission quality will not decrease as the number of devices increases.

When and whether any of these scenarios play out is impossible to say right now. However, two standards are available: 5G Broadcast and ATSC 3.0. It remains unclear which standard will be used for which application. Fortunately, the R&S®TE1 lets broadcasters use both, since the transmitter contains the hardware for both 5G Broadcast and ATSC 3.0 and software makes them easy to adjust.

EDITORS

Fig. 1: The R&S®RTP high-performance oscilloscope with two R&S®FE110 frontend modules.

MULTICHANNEL SIGNAL ANALYSIS UP TO 170 GHz

R&S®FExx external frontends extend the measuring frequency of R&S®RTP oscilloscopes to 170 GHz. When used with the 16 GHz R&S®RTP164B oscilloscope, this enables multichannel analysis with up to 10 GHz bandwidth.

The R&S®FExx external frontends let users extend the usable frequency of Rohde&Schwarz signal and spectrum analyzers, oscilloscopes and signal generators. They are available in various models and cover the range from 24 GHz to 170 GHz. The frontends allow the measurement unit to be placed closer to the device under test (DUT), reducing cable losses while increasing receiver sensitivity and generator output power. The compact, fully calibrated, comprehensive solution ensures the highest signal quality thanks to built-in high-performance local oscillators (LO). Various bandpass filters are also available as smart accessories that can be connected directly to the remote frontends. The base unit controls and corrects the entire system via Ethernet.

Frontend control integrated into the user interface

Traditional setups with mixers, LO sources and base units are often complicated to use and require a lot of calibration. In contrast, R&S®FExx frontends are a compact solution with an integrated LO that is fully calibrated during production, with the data stored on an internal EPROM.

To ensure simple error-free operation, control of the frontends is fully integrated into the firmware of the R&S®RTP oscilloscope. The external frontend setup dialog guides users through configuration, including connecting the IF output, reference signal and LAN communications to the oscilloscope for the first time. Once the LAN connection is established, the R&S®RTP reads the correction data and uses it to calculate the correction filters. Users only need to define the frequency and the level of the test signal to start the measurement.

Multichannel analysis with up to 10 GHz measurement bandwidth

Up to four frontend modules can be connected to an R&S®RTP for

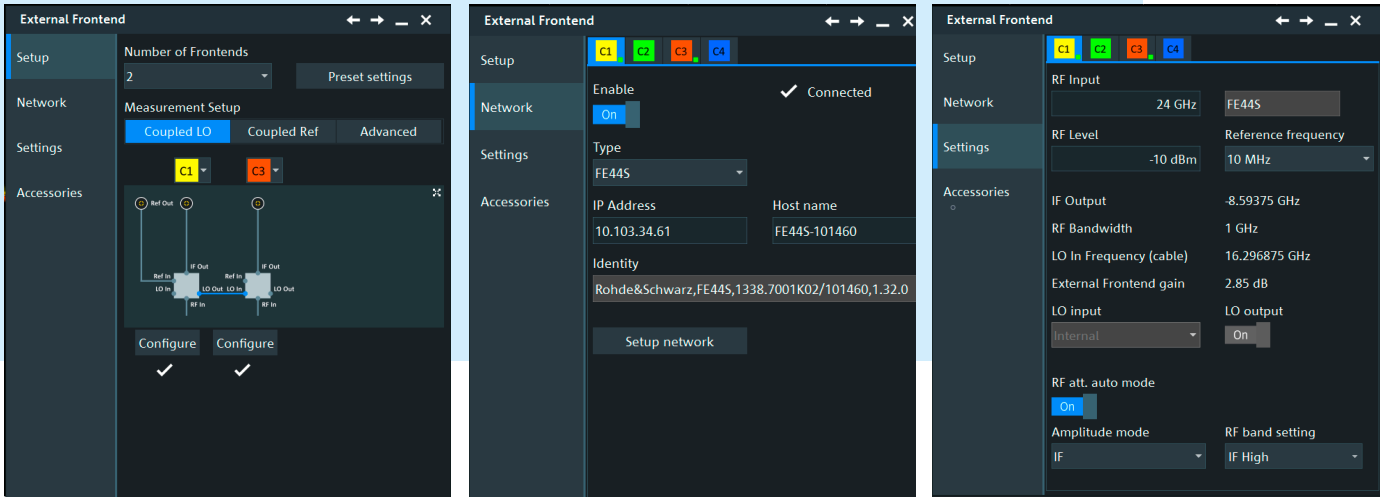


Fig. 2: The external frontend setup dialog in the R&S®RTP oscilloscope user interface: setup with two R&S®FE44S, network connection configuration and configuration of RF frequency and level.

multichannel signal analysis – to analyze multiple MIMO cellular signals in the FR2 range (approx. 26 GHz to 52 GHz), for instance. The R&S®FE44S and R&S®FE50DTR modules are perfect for this use case. The R&S®FE110SR and R&S®FE170SR allow for very wide bandwidth measurements (up to 10 GHz) with up to two modules. The R&S®FE110SR frontend (70 GHz to 110 GHz) is designed for the latest automotive radar systems and mobile communications as well as military applications. The R&S®FE170SR frontend (110 GHz to 170 GHz) is suited to 6G development projects for future broadband wireless communications and sensing.

The R&S®RTP oscilloscope also supports mixing different frontend modules in multichannel configurations, for example for interference measurements. When configuring reference signals, you can choose between Coupled LO (the LO signal runs from one frontend module to the next) and Coupled Ref (the reference signal is distributed using a splitter and each frontend uses its own LO).

Deembedding frontend modules and accessories

In I/Q mode, where the modulated IF signal is converted to I/Q data in the R&S®RTP oscilloscope for further signal analysis, frontend modules are automatically corrected based on the amplitude and phase responses measured during production (Fig. 3). It is also possible to integrate the cable connecting the IF output and the oscilloscope input into the correction. Users load an appropriate S-parameter file in the frontend setup dialog by selecting Accessories.

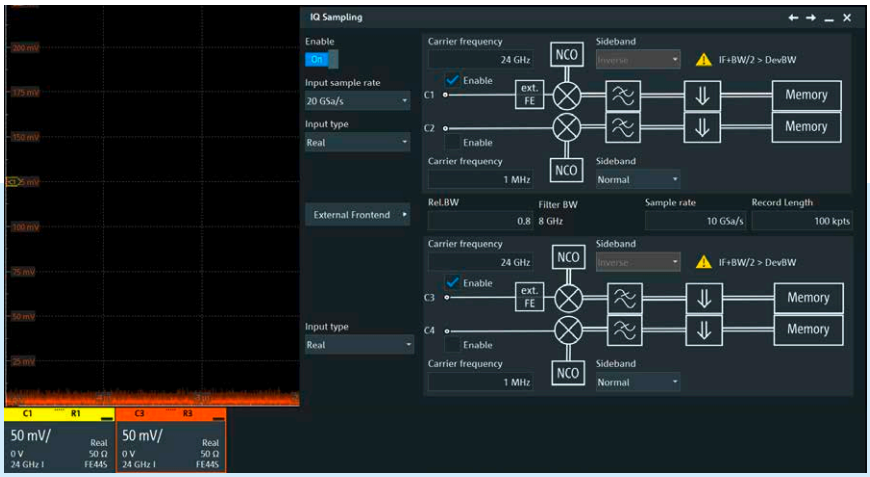


Fig. 3: I/Q mode setup dialog – example of the configuration of two frontend modules at channels 1 and 3.

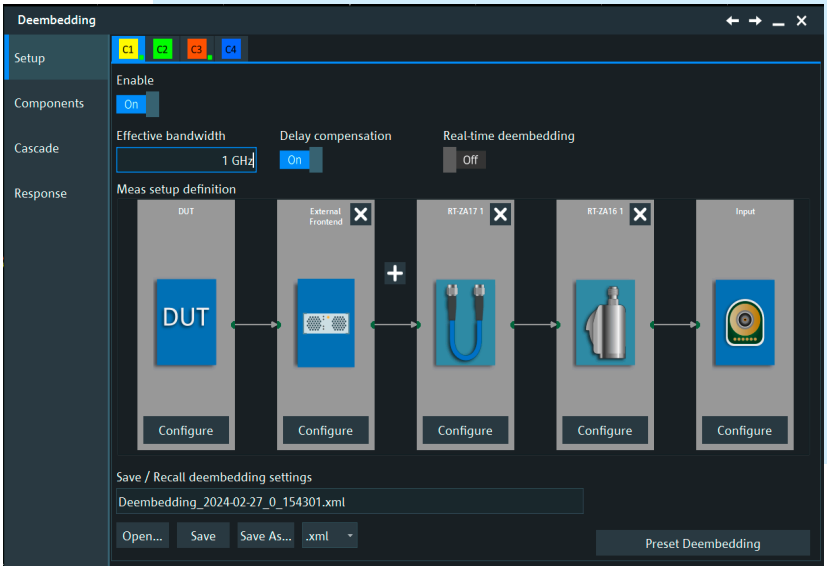


Fig. 4: Configuration of the signal path from the external frontend module to oscilloscope input (with corresponding S-parameters) for calculating a correction filter.

As an alternative to I/Q mode, you can also start signal analysis based on the normal waveform. In this case, correction of the frontend module and other components such as cables and adapters in front of the oscilloscope input is performed via the R&S®RTP-K121 deembedding option. Fig. 4 shows an example of this configuration.

Signal analysis

The spectrum function of the R&S®RTP oscilloscope provides a quick overview of the signals downconverted by the external frontend (Fig. 5). It is important to note that the frequency of the IF signal from the external frontend depends on its configuration and the RF input frequency. You can look up the IF output frequency in the External Frontend setup dialog under Settings to help you select the correct center frequency for spectrum analysis.

The signal analysis itself is handled by R&S®VSE vector signal explorer software (Fig. 6), which can be used either directly on the R&S®RTP oscilloscope or as software running on a separate PC. The R&S®VSE software uses the initial configuration of the frontend modules and the recorded waveforms or I/Q data for the selected signal analysis. Various R&S®VSE options are available, including pulse, transient, OFDM and 5G MIMO analysis.

Summary

With external frontends, the R&S®RTP high-performance oscilloscope offers new possibilities for wideband signal analysis up to 170 GHz. Coherent measurements with up to four channels are possible. Control of the external frontends is fully integrated into the oscilloscope user interface for a fast and smooth workflow.

GUIDO SCHULZE, MATTHIAS WEILHAMMER AND ANDREAS RITTER, ALL ROHDE&SCHWARZ

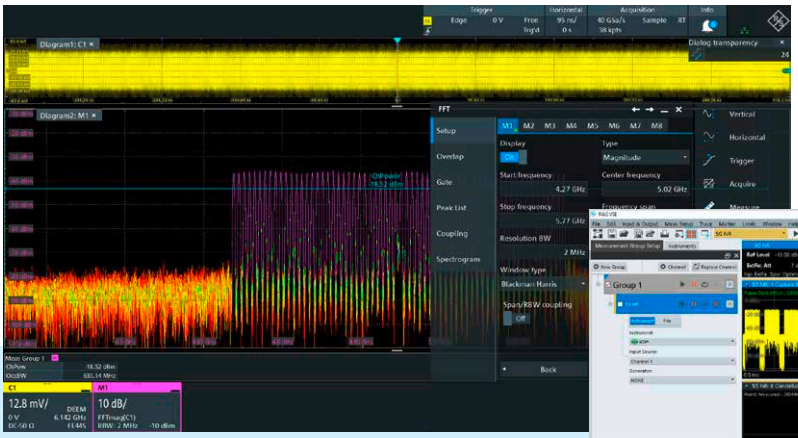


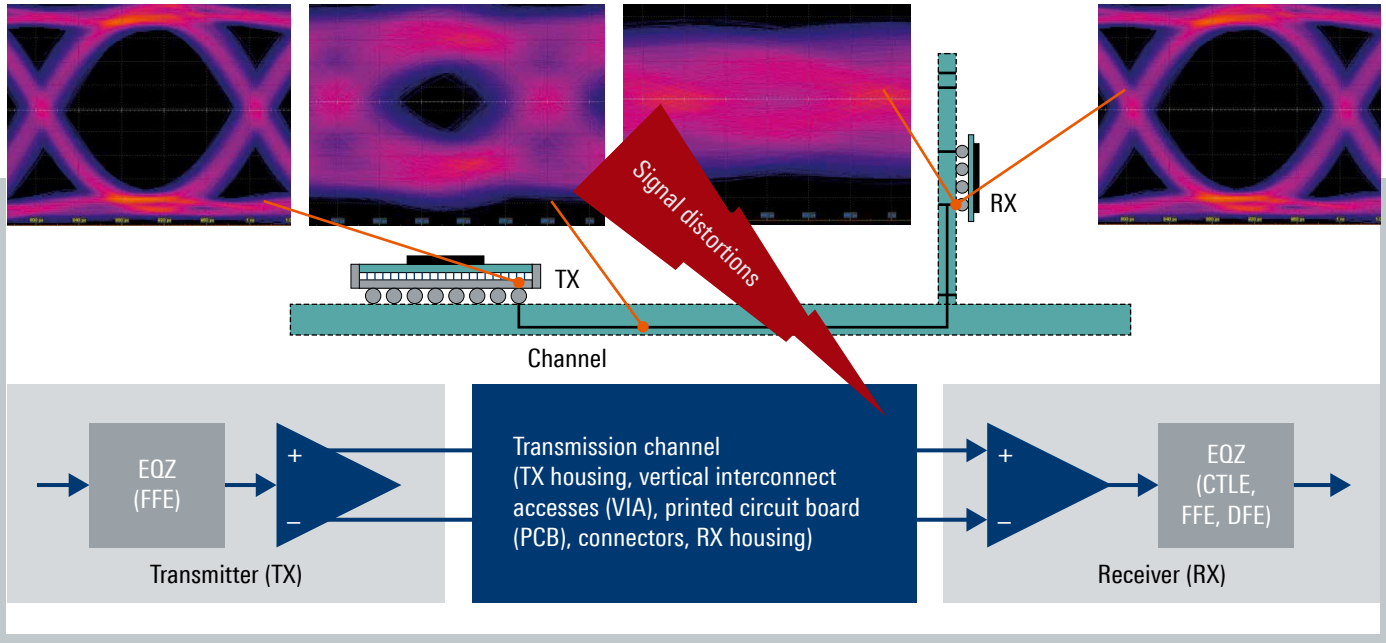
Fig. 5: FFT measurement of a 28.1 GHz RF signal being converted to an intermediate frequency (IF) of 5.02 GHz with the R&S®FE44S external frontend module.

Fig. 6: 5G analysis at 80.0 GHz using R&S®VSE vector signal explorer software.

EMULATING SIGNAL LOSS AND EQUALIZATION

When developing designs with data interfaces such as USB 3.2, PCI Express or HDMI, signal integrity must be verified on both the transmitter and receiver sides. The R&S®RTP164B 16 GHz oscilloscope provides a range of new possibilities – for example, adding signal loss caused by signal channels and using filtering to equalize losses to the signal at the receiver.

Fig. 1: Example of signal transmission loss: the eye pattern at the receiver is closed but equalization filters can recover signal information.



The design of the transmission channel is a major challenge when developing applications with fast data interfaces. In addition to the correct dimensioning of the transmission bandwidth, impedance control, especially at the transitions, is also crucial as is protection against crosstalk from other signals.

Signal loss from transmission lines

The problems and limitations of the transmission channel appear as signal distortion, known as intersymbol interference. Parts of neighboring signal symbols overlap due to the attenuation of high frequency signal components and the "blurring" of the symbol energy. Reflections caused by impedance mismatches can also cause signal symbols to overlap. In the worst case, signal distortion leads to errors in the receiver, which can no longer distinguish data symbols correctly. Fig. 1 shows an example of this signal distortion. The eye pattern at the transmitter output is wide open but completely closed at the receiver.

Equalization filters for improved signals

Equalization filters on both the transmitter and receiver sides can reduce signal loss with fast data interfaces and even recover signal symbol information because they compensate for frequency dependent losses in the transmission channel.

The USB 3.2 Gen 2 standard defines a 3-tap FIR filter for predistortion at the transmitter and a 1st-order CTLE filter with a 1-tap DFE filter at the receiver. Depending on channel quality, the filter parameters and interaction of the filters can be optimized even further. The table below outlines the design and function of common equalization filters.

Test requirements

To measure the compliance of fast data interfaces, an adapter (test fixture) is necessary for the contact between instrument and transmitter. However, signal loss caused by the test fixture should not affect test results. Deembedding makes it possible to compensate for losses on the signal path from the transmitter to the outputs of the test fixture using a filter. However, interface standards also define other test points within a transmitter-receiver transmission link. As such, specified transmission paths can be added using filters to emulate signal losses for the measured transmitter signal. This method is called embedding. Last but not least, the test specification also defines how to emulate the equalization filters. For the actual signal analysis, automatic amplitude and time measurements as well as data eye pattern and jitter/noise analyses are available.

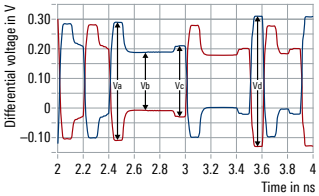
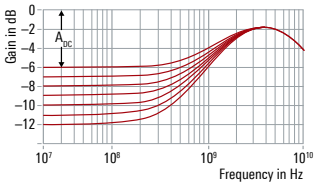
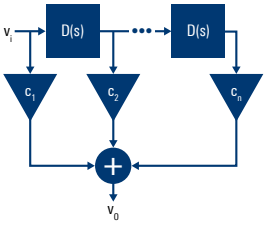
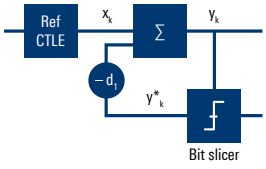
TRANSMITTER	RECEIVER		
TX-FFE (feed-forward equalizer)	**CTLE (continuous time linear equalizer)**	**FFE (feed-forward equalizer)**	**DFE (decision feedback equalizer)**
			
► Amplifies high frequency energy at symbol boundaries	► Inverts the lowpass characteristic of the transmission channel	► Overlays various delayed and weighted signal copies ► Operates at the symbol rate ► More taps possible than TX-FFE	► Nonlinear, with feedback loop ► Operates at the symbol rate and requires clock data recovery ► Often combined with CTLE/FFE
+ Compensates for simple lowpass behavior	+ Compensates for simple lowpass behavior – Amplifies noise	+ Reduces impedance discontinuities – Can amplify noise	+ Best compensation for discontinuities in the frequency response – Can suppress noise

Fig. 2: Definition of a cascade of transmitter predistortion (TX-FFE), embedding of additional transmission paths and RX equalization filter.

Test solution with the R&S®RTP oscilloscope

The R&S®RTP-K121 deembedding and R&S®RTP-K126 embedding and equalization options for the R&S®RTP oscilloscope allow users to define relevant signal paths. Test fixtures and additional transmission paths can be added or removed based on S-parameters that define relevant transmission losses. Common equalization filters such as CTLE, FFE and DFE can be configured according to interface standards and individual requirements.

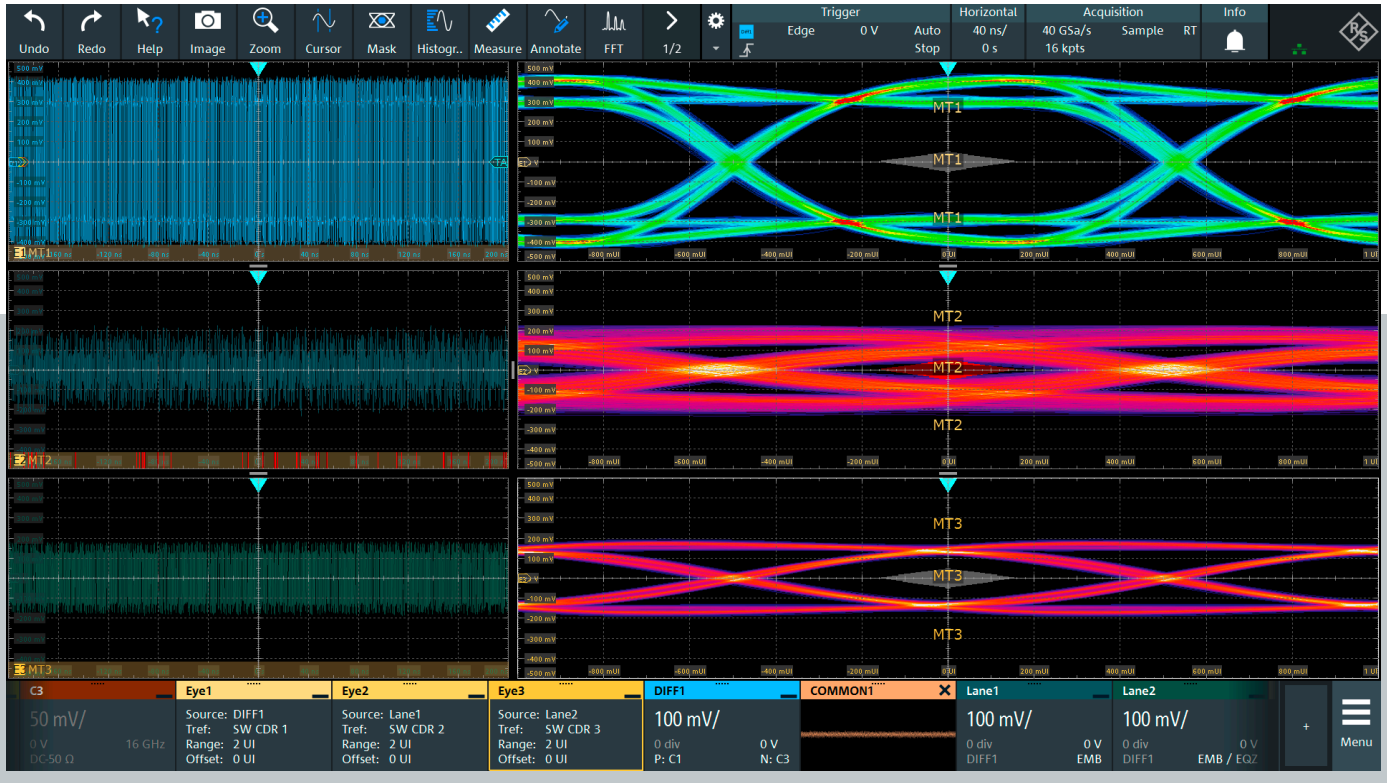
Fig. 3 shows an analysis example with a USB 3.2 Gen 1 data signal (5 Gbit/s). In this example, signal integrity is measured at three different points and compared using an eye pattern: directly at the transmitter, after embedding a channel designed in accordance with the specifications of the USB Implementers Forum (3-meter cable and 5-inch PCB) and after emulation with CTLE filter.

Summary

The R&S®RTP high-performance oscilloscope offers a range of tools for analyzing signal integrity. By emulating additional transmission paths and equalization filters, users can easily include other system conditions in their analyses.

GUIDO SCHULZE, JOHANNES GANZERT AND
FRANCISCO JAVIER GARCIA GOMEZ, ALL ROHDE&SCHWARZ

Fig. 3: Comparison of waveforms and eye patterns at different test points for a USB 3.2 Gen 1 signal (5 Gbit/s):
Diff1/Eye1: original measurements at transmitter output; Lane1/Eye2: additional transmission channel embedded; Lane2/Eye3: additional CTLE equalization filter applied.



R&S®ESSENTIALS
HIGH-PRECISION POWER SUPPLIES FOR PEAK POWER

The R&S®NGL, R&S®NGM and R&S®NGU have easy-to-use interfaces, fast load regulation and high speed logging of measured values. Different application tools help optimize and test IoT and mobile devices as well as characterizing semiconductors.

Demand for mobile IoT devices continues to grow. Energy efficiency is a key requirement along with connectivity. The devices must deliver optimal performance, consume minimal amounts of energy and be as durable as possible.

High-precision power supplies for IoT applications

Along with rapid voltage and current fluctuations during operation, minimal power consumption in standby mode also makes testing a challenge for many energy-efficient devices. R&S®ESSENTIALS high-precision power supplies address these challenges with exceptional accuracy and rapid load recovery times, making them ideal for complex IoT applications.

The integrated Rohde&Schwarz ammeter can measure current drain from nanoamps to amperes in a single pass – with no additional measurement sweeps needed. The R&S®NGU series has current resolution up to 100 picoamps and is ideal for applications with quiescent current levels over 100 nanoamps, including NB-IoT, LTE-M, 2G, Bluetooth® Low Energy, ZigBee and Wi-Fi.

Identify battery-intensive processes faster

Battery cycle and battery modeling tools let users create battery models with defined charging and discharging for pulsed and constant current sources. The tools are ideal for battery characterization and qualification testing. The battery simulation function can realistically simulate the power supply in battery-operated devices.

The integrated ammeter records the power consumption of IoT devices in real time while the logging and charting tool saves and displays the information in a live chart to help identify battery-intensive processes and minimize power consumption.

Record precise I/V curves

Combining current (I) and voltage (V) in an I/V curve is essential when assessing the key properties of semiconductor technology components such as diodes, LEDs and solar cells. Users can create precise I/V sweeps for semiconductor characterization with Rohde&Schwarz high-precision power supplies. A range of sweep tools, quick arbitrary functions and logging functions make such sweeps easy. The four-quadrant

architecture of R&S®NGU400 source measure units also supports both positive and negative voltage polarity, which is crucial for power-added efficiency (PAE) and qualification testing, including reverse polarity testing (ISO 16750-2) for electronic control units (ECU).

Linear design

Linear-regulated power supplies have stable output voltage, minimal ripple, low noise and rapid regulation. The supplies are essential when powering complex electronic circuitry sensitive to voltage fluctuations because they mitigate interference when powering devices under test (DUT) and generate less electromagnetic interference than switched-mode power supplies. The linear design and low interference with voltage and current ripple below 500 µV and 1 mA of R&S®ESSENTIALS high-precision power supplies make them ideal for developing power amplifiers and MMIC.

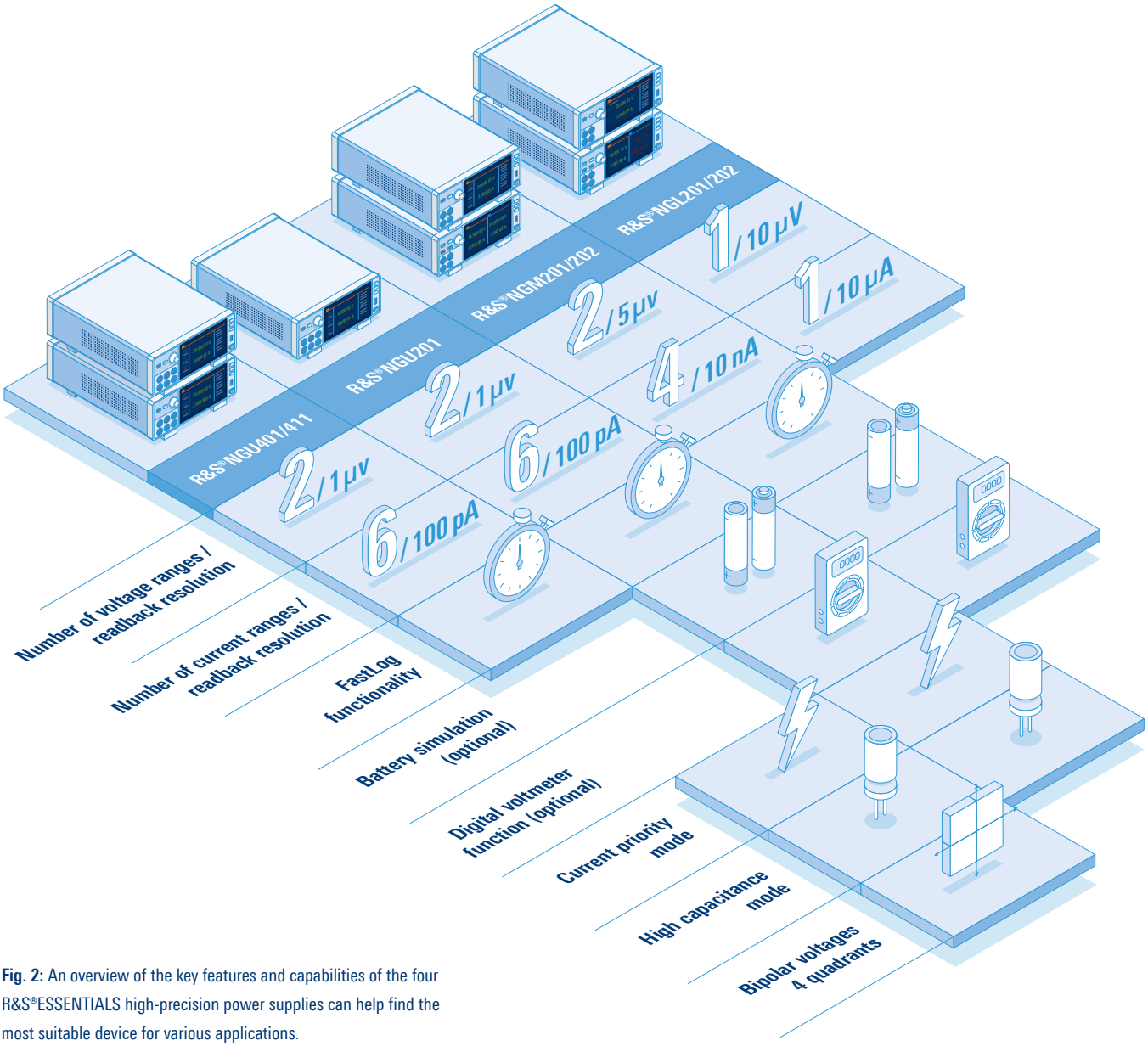


Fig. 2: An overview of the key features and capabilities of the four R&S®ESSENTIALS high-precision power supplies can help find the most suitable device for various applications.

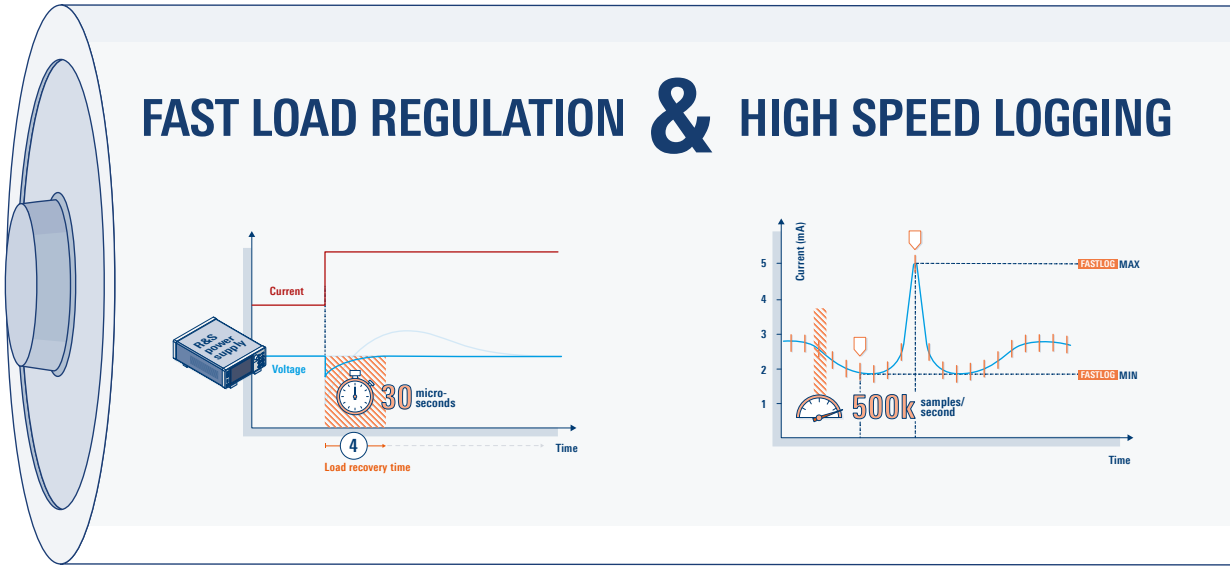


Fig. 1: Rohde&Schwarz high-precision power supplies have exceptionally short load recovery times and unparalleled precision. They reliably record dynamic load changes to help improve testing capabilities for battery-operated devices.

Fast load regulation

Consumer electronics such as cell phones and IoT devices have fluctuating power requirements and rapidly transition from low-power sleep mode to high-power transmit mode. Our power supply series has optimized control circuits for a fast load recovery time of less than 30 microseconds to manage load changes effectively with minimal overshoot.

High speed logging

The R&S®NGM and R&S®NGU power supplies also have fast logging with a sampling rate of 500,000 samples per second, allowing them to record detailed voltage and current data down to 2 microseconds or with the precision of an oscilloscope. Fast logging makes it easier to analyze energy consumption, identify circuit faults and accurately measure current through sensors such as photocells and thermistors. FastLog data can be stored externally and accessed remotely with USB and Ethernet connections.

Intuitive user interface

Users can quickly navigate through menus with an intuitive user interface for easy access to functions and settings, configuration of voltage and current ranges and the active operation mode display. The power supplies can be controlled from anywhere via a VNC remote connection. A large touchscreen with 6½-digit resolution makes it easy to read data, even from a distance.

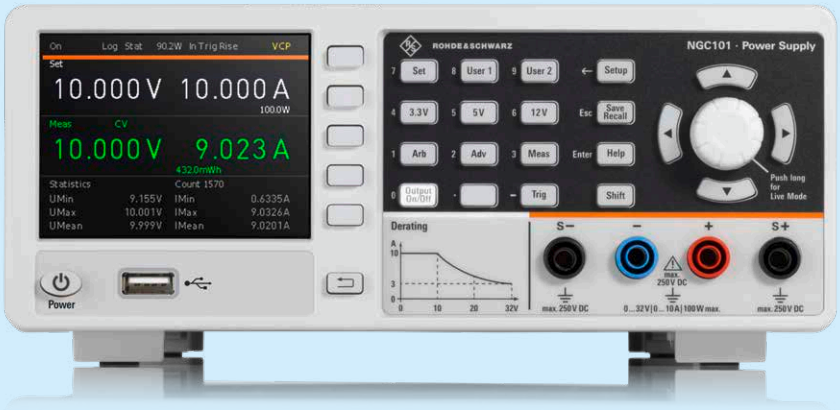
Summary

Rohde&Schwarz high-precision, application-specific power supplies serve as an electronic load but also simulate battery characteristics. Versatile application tools provide IoT device engineers with insights into battery capacity and discharge processes, allowing them to optimize battery design, extend battery life and ultimately develop reliable and sustainable battery-powered devices.

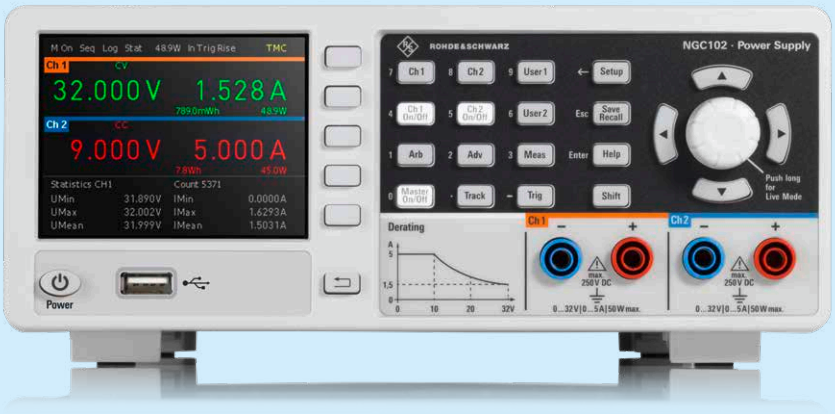
SHIVAM ARORA, ROHDE&SCHWARZ

VERSATILE, EFFICIENT AND COMPACT: THE NEW R&S®NGC100 POWER SUPPLY SERIES

The new R&S®NGC100 power supplies are ideal general purpose benchtop power supplies for fully automated testing environments and labs. The series has one-channel, two-channel and three-channel models that can deliver up to 32 V, 10 A and 100 W of DC power and an exceptional range of functions.



R&S®NGC101(-G): single-channel power supply, 100 W, 1 × 32 V/10 A.



R&S®NGC102(-G): two-channel power supply, 100 W, 2 × 32 V/5 A.

Integrated remote sensing measures voltage at circuit inputs instead of power supply outputs to make sure the new DC power supplies precisely deliver power. Users can program voltage and current changes for a test sequence, avoid steep ramp-ups to protect devices under test (DUT) and simulate different operating conditions.

Independent channels

R&S®NGC102 and R&S®NGC103 channels can be used independently based on the application. The channels can be connected in series for 96 V of maximum voltage or in parallel for up to 10 A of current. Full galvanic isolation keeps channels connected to supply balanced circuits without grounding problems.

Output delay helps switch on channels in a specified sequence. Voltage and current can be logged on all channels simultaneously with a sampling rate of 1000 measurements per second.

Dual data interface

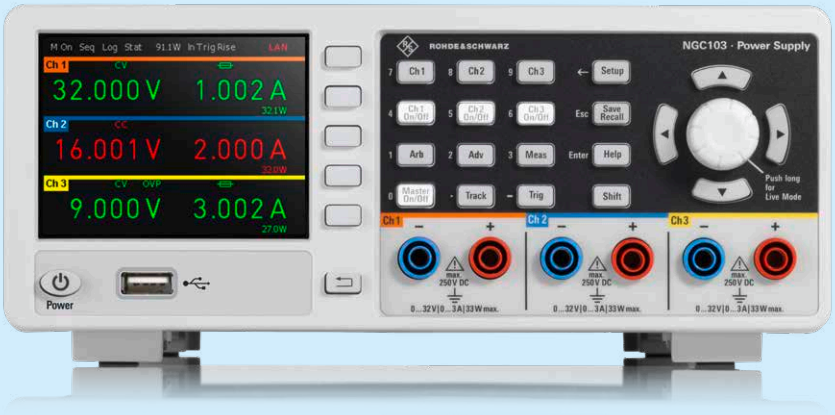
All models in the R&S®NGC100 series have a standard dual interface with USB and LAN ports. R&S®NGC100-G models also come with a GPIB interface. A digital trigger supports TTL inputs for initiating functions such as logging via external signals. Two analog inputs (0 V to 10 V and 4 mA to 20 mA) enable direct control of the output voltages across the full range. Comprehensive safety features protect people and devices under test (DUT) from surges and high current levels.

Neatly housed

The R&S®HZC95 rack adapter lets the power supplies be installed in 19-inch racks (industry standard) and can even hold two devices next to each other. Additional connections are available for all channels and remote sensing on the rear panel for easy use in system cabinets.

The switching technology of the new power supplies is highly efficient with minimal heat dissipation. A temperature-controlled fan cools the power supplies and is quiet even under peak loads. The new R&S®NGC100 power supply series is ideal for applications with up to 100 W output power.

ANJA FENSKE, ROHDE&SCHWARZ



R&S®NGC103(-G): three-channel power supply, 100 W, 3 × 32 V/3 A.

ALL SOFTWARE TOOLS AT A GLANCE

An extensive range of application software programs are available for R&S®ESSENTIALS lab power supply and measuring instruments. A new application dashboard gives a quick overview of available software, installed versions and instrument compatibility.

The R&S®ESSENTIALS portfolio of lab power supplies and measuring instruments includes different series and models for diverse requirements in development labs, test systems and production. While an R&S®NGP800 power supply can feed up to four power-hungry DUTs at the same time, the R&S®NGU201 can measure sleep and standby current with resolution of 100 pA.

A variety of application software

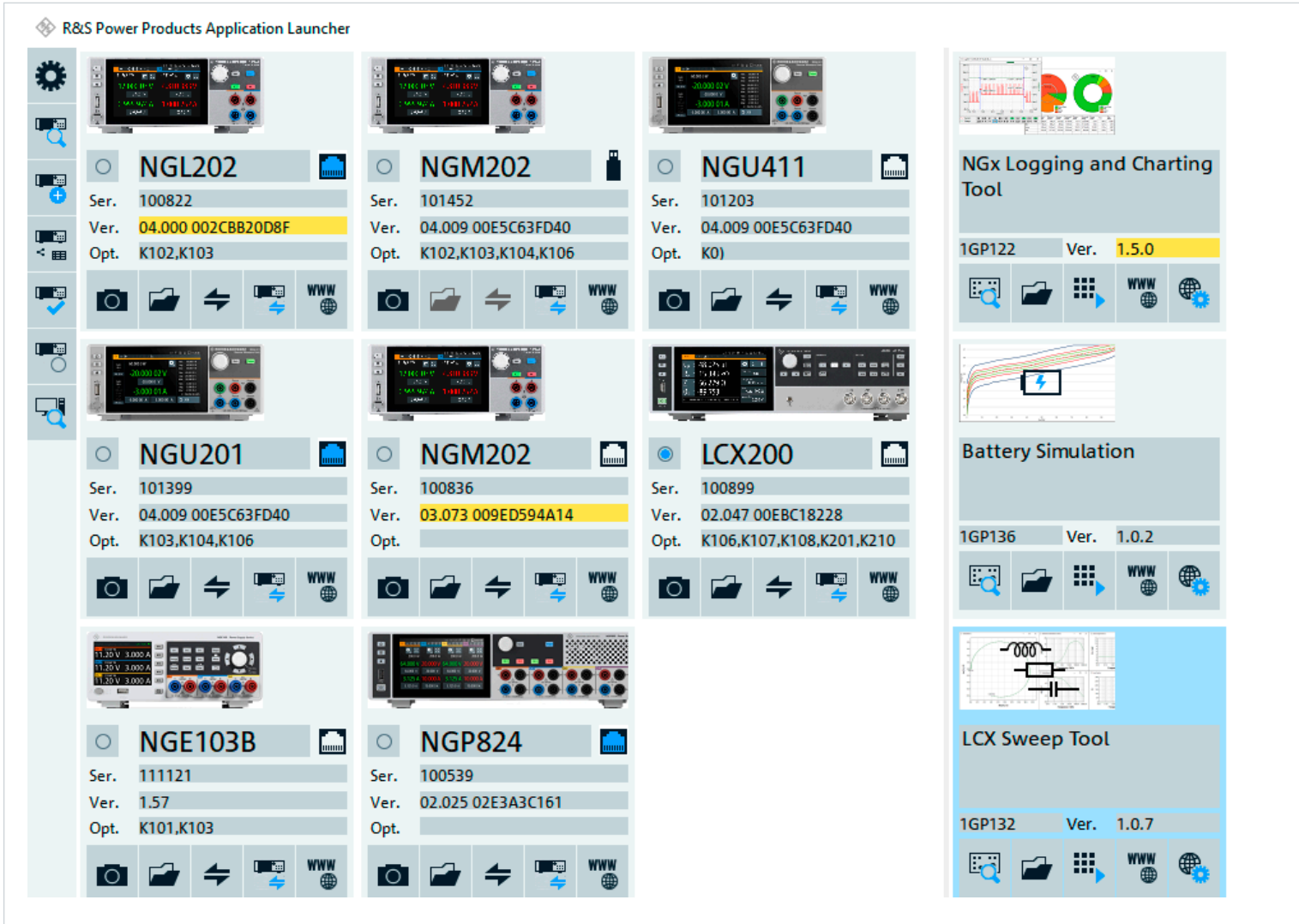
Measurement functions have been expanded thanks to extensive documentation and application software. Instrument software support depends on the measurement at hand. The new application dashboard for power supplies and meters makes it quick and easy to find out if an instrument supports an application. The dashboard is a central source of information and lists versions of installed firmware and application programs, available updates, and links to relevant documentation and application notes.

Application dashboard for power supplies and meters

The dashboard is divided into two display fields with a tile view for instruments and one for application software.

All instruments at a glance

The first field shows all instruments in the supported product range with remote control connections. Each instrument has a tile with information about the type, serial number, firmware version, installed options and remote connection type. Front views make instruments easier to identify and current screenshots are available at the touch of a button. In some instruments you can also open an FTP connection in Windows File Explorer or a VNC connection in a web browser once they are connected via Ethernet. A link to the product page is also available, where you can find all available information and material about a given instrument.



PRODUCT DESCRIPTION	FUNCTIONAL DESCRIPTION	R&S®NGE100B	R&S®NGC100	R&S®NGA100	R&S®NGP800	R&S®NGL200	R&S®NGM200	R&S®NGU	R&S®LCX
Logging and charting tool	Standard logging, fast logging and data collection with chart display and data analysis.	•	•	•	•	•	•	•	•
Remote control of multiple DC power supplies	Common control of a stack of power supply channels.					•	•		
Sweep tool	I/V sweep with chart display.						•	•	
Battery cycle tool	Battery cycling with logging and chart display. Generation of battery model from logged data.					•	•	•	
Battery simulation	Relaxation measurement, charging and discharging of batteries with logging and chart display. Generation of battery models from logged data.						•	•	
LCX sweep tool	Fast logging with chart display and analysis functions.								•
LCX accuracy calculation	Calculation of measurement accuracy depending on measured value and measurement parameters.								•

Fig. 2: Overview of currently available application software for R&S®ESSENTIALS lab power supplies and measuring instruments, showing functional description and instrument compatibility.

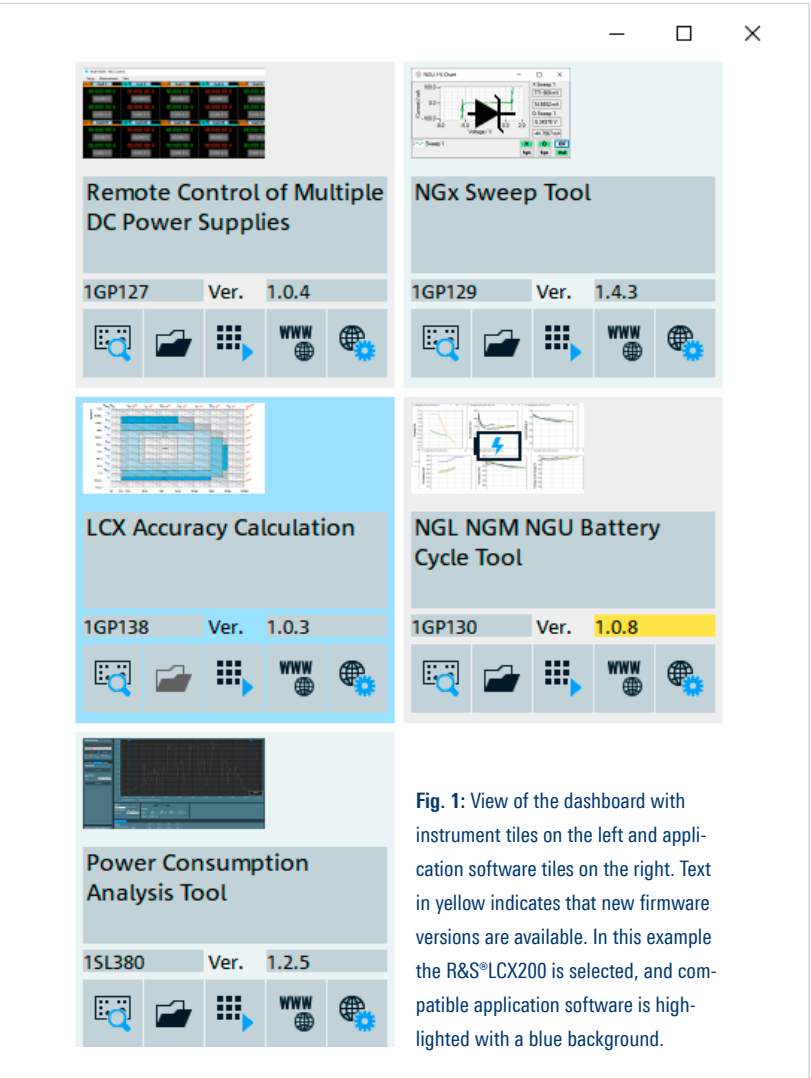


Fig. 1: View of the dashboard with instrument tiles on the left and application software tiles on the right. Text in yellow indicates that new firmware versions are available. In this example the R&S®LCX200 is selected, and compatible application software is highlighted with a blue background.

Application software

The second field is an overview of the application software. Each installed application software program as well as each software program available for download can be seen in a tile. Each tile includes the title, number and version of the application software installed as well as a screenshot. Clicking on the tile can start application software, open the directory in Windows File Explorer or navigate to the website.

Compatibility between application software and instruments in the R&S®ESSENTIALS portfolio is graphically presented. Clicking on an instrument tile highlights the compatible application software tiles and vice versa. If you start application software while an instrument is selected, it will immediately connect to the selected instrument.

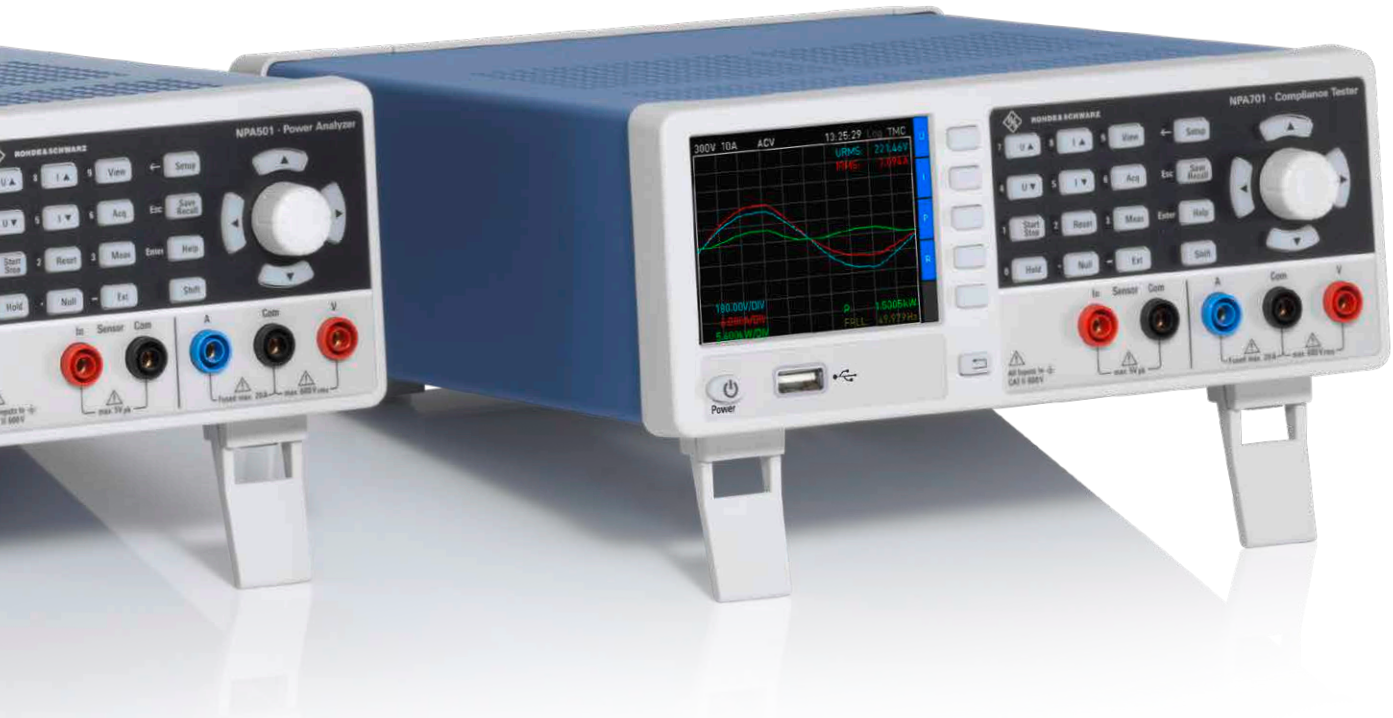
The application dashboard for power supplies and meters makes it easy to manage lab power supplies and measure instruments from a central platform. The application dashboard is available free of charge and accessible to everyone on the Rohde&Schwarz website.

ANJA FENSKE AND THOMAS LECHNER, ROHDE&SCHWARZ

THE NEW R&S®NPA FAMILY

COMPACT ALL-IN-ONE POWER ANALYZERS

The new family of power analyzers measures voltage, current, power and total harmonic distortion from both DC and AC sources. The three R&S®NPA power analyzers meet different power measurement requirements – from versatile power meters to graphical analyzers and compliance testers.



With a wide power measurement range from 50 µW to 12 kW and the ability to measure current in milliamps, measurements with the R&S®NPA series have a very precise basic accuracy of 0.05 percent and sampling frequency of 500 ksample/s for meticulous standby measurements.

The integrated autorange function helps quickly select or adjust measurement ranges. Frequency and adaptive filters also effectively suppress noise for consistent and accurate results. R&S®NPA power analyzers are ideal for labs and integration into test environments. The analyzers can be used in both general measurements and more demanding applications.

Three models for different requirements

All three devices in the R&S®NPA family have 23 standard measurements. Up to ten measurements can be displayed simultaneously on the screen, each with a rapid refresh rate of 100 ms. A choice of crest factors (1, 3 or 6) adds flexibility, ensuring all peak values are captured with a maximum dynamic range.

From FPGAs to drilling machines, virtually every component or device experiences inrush current that is much higher than the normal operating current. This is especially true for switched-mode power supplies. The R&S®NPA501 and R&S®NPA701 can analyze switch-on characteristics, voltage and current waveforms, and frequency domain

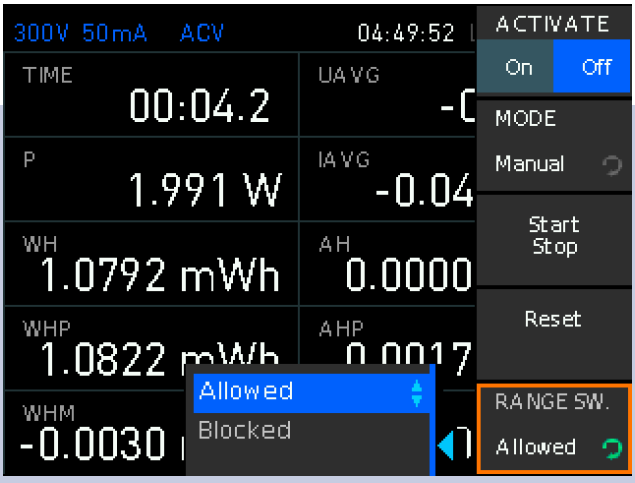


Fig. 1: R&S®NPA101 power meter

Intuitive interface displays up to ten measurement parameters simultaneously.

- 23 standard basic measurements
- Energy meter
- Crest factor values of 1, 3, or 6
- LAN and USB interfaces
- Two compact R&S®NPA can be mounted next to each other in a 19-inch rack
- Simple system integration and remote configuration

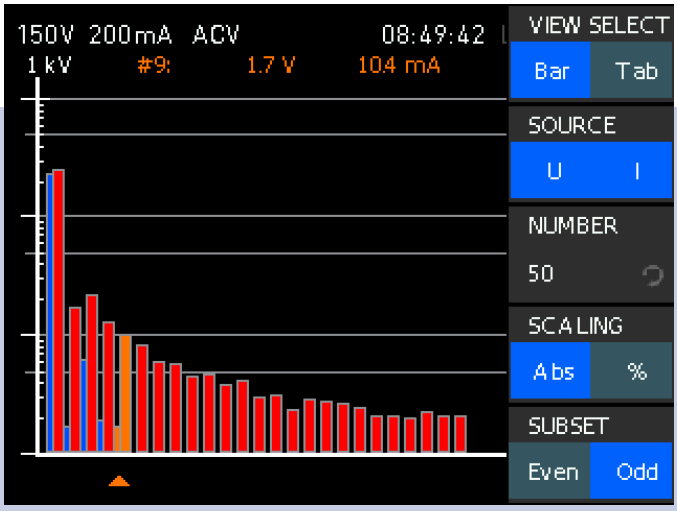


Fig. 2: R&S®NPA501 power analyzer
Graphical display mode includes harmonic analysis.

- R&S®NPA101 specifications and features
- Set maximum and minimum peak values for voltage, current and power
- PASS/FAIL function
- Four graphical display modes
- Four BNC ports for analog and digital inputs and outputs
- R&S®NPA501-G comes with a GPIB interface

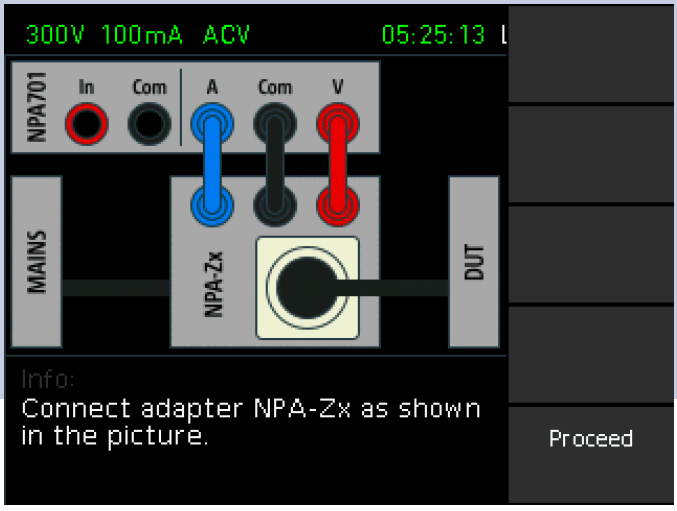


Fig. 3: R&S®NPA701 compliance tester
A user-friendly wizard guides users through the setup process for compliance testing.

- R&S®NPA501 specifications and features
- Wizards for standard compliant measurement of standby power consumption in line with IEC 62301 and EN 50564
- Wizard for standard compliant measurement of EMC harmonic emissions in line with EN 61000-3-2
- R&S®NPA701-G comes with a GPIB interface

parameters up to the 50th harmonic. A PASS/FAIL function also allows users to define thresholds to quickly and easily evaluate the performance of the device under test (DUT). This is crucial in automated test setups and production test systems.

The series flagship is the R&S®NPA701 compliance tester, which includes step-by-step procedures compliant with IEC 62301 and EN 50564 industry standards for power consumption in low-power mode as well as EN 61000-3-2 for EMC harmonic emissions. No additional PC is required, which streamlines testing and ensures accurate and valid results.

Seamless integration for multiple applications

The R&S®NPA seamlessly integrates essential research and development, production line testing and electrical device quality assurance functions. DUTs can be easily and securely connected to the R&S®NPA with R&S®NPA-Z1 and R&S®NPA-Z4 mains adapters. They accommodate various common power plug types. The devices have LAN and USB interfaces while the models R&S®NPA501-G and R&S®NPA701-G also come with a general purpose interface bus (GPIB) interface. A complete set of SCPI commands as well as LabVIEW, LabWindows/CVI and IVI.net drivers help easily integrate the devices into existing systems. The compact form factor means two analyzers can be mounted side by side on a standard 19-inch rack.

R&S®NPA all-in-one power analyzers are very compatible and flexible. Combining precision with space-saving design, they also easily integrate into many application environments. The R&S®NPA family therefore heralds the next evolutionary stage in power analysis technology.

SHIVAM ARORA, ROHDE&SCHWARZ