NEWS

219/18

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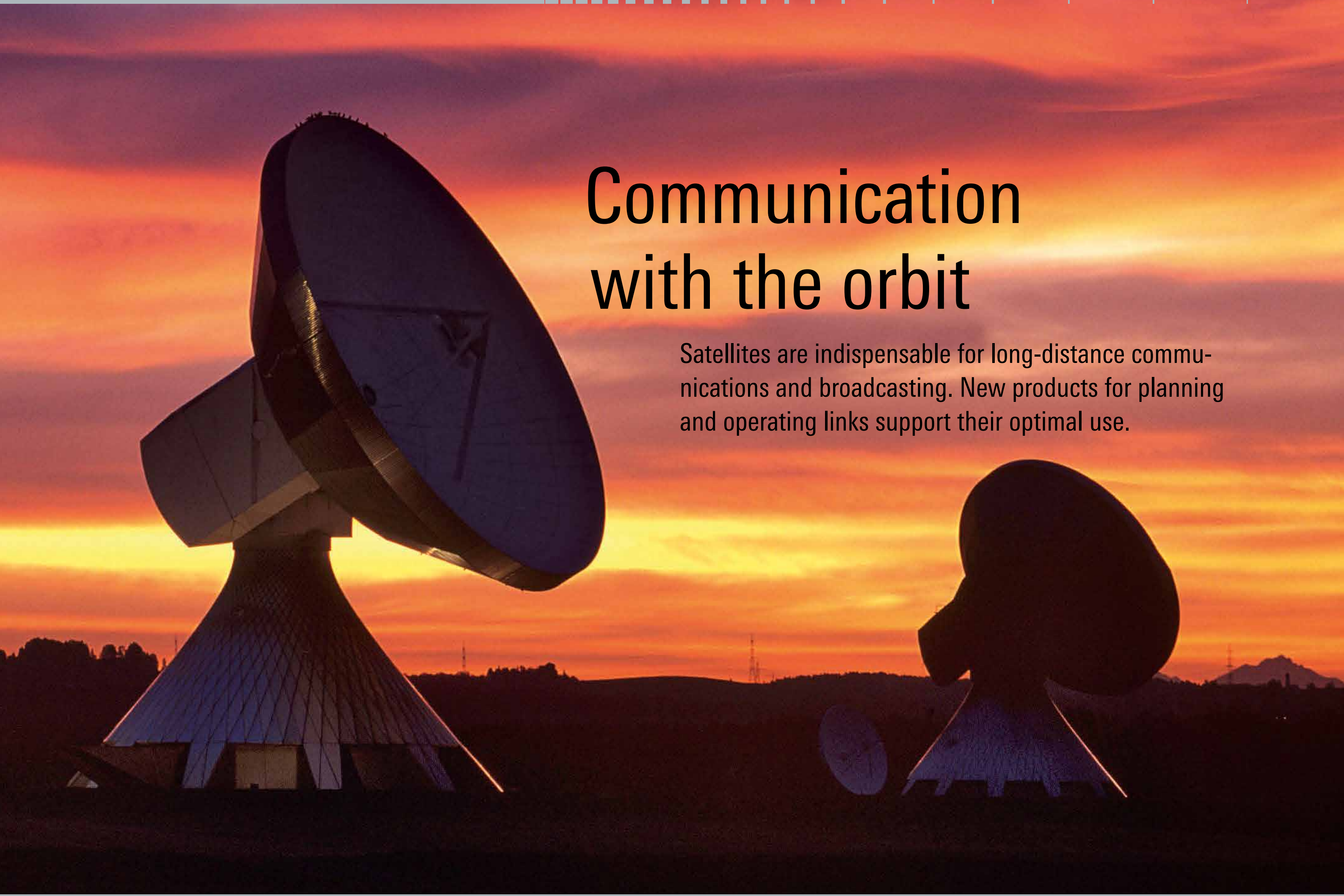

Communication with the orbit

Satellites are indispensable for long-distance communications and broadcasting. New products for planning and operating links support their optimal use.

Wireless

How the ear hears: speech quality measurements in line with ITU-T P.863 POLQA

Automotive

Enabling autonomous driving: new system tests radomes for radar sensors

Monitoring

Compact direction finding system in weatherproof housing for mounting on antenna masts

NEWS

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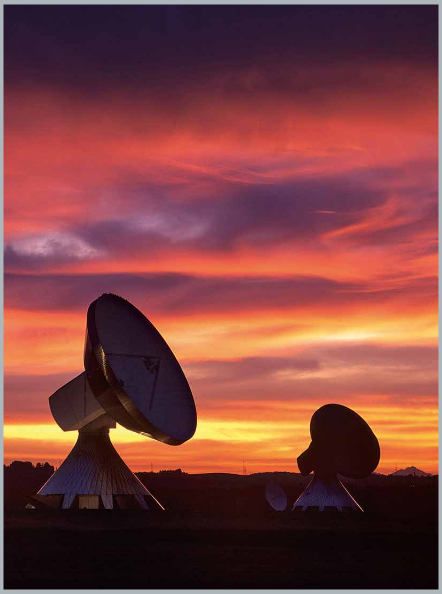
Cover feature

Satellites are extremely practical when it comes to distributing and collecting data over more or less large parts of the Earth's surface with relatively little effort and expense. In the Arctic, in the jungle, in the desert, in the mountains or on the high seas: no place is so remote that a telecommunications satellite cannot establish a link from there to the civilized world. An ambitious project with two features that are distinctly different from ordinary satellite communications scenarios takes advantage of this. Firstly, one of the platforms is none other than the International Space Station (ISS), and secondly, the communicating parties are not members of the human race. ICARUS, a joint venture of the Max Planck Society, the German Aerospace Center and the Russian space agency Roscosmos, is setting up a space based Internet of animals to research their migratory movements and their behavior (page 64). The wireless components were developed and built by Rohde & Schwarz and consume only a very small bandwidth. But even in situations with broader channels due to higher bandwidth consumption, careful link planning is necessary to make optimal use of the limited resources and minimize costs. A software tool that translates performance specifications and user preferences into technical satlink parameters can help (page 71). Once the right configuration has been found, link setup can start. One of the key uplink components is the microwave power amplifier. Due to their energy efficiency and compactness, tube amplifiers still have a large market share in this area despite their other drawbacks. That could change, because new transistorized models are moving in with the full scope of their inherent advantages (page 60). While ICARUS is working on the Internet of animals, the company OneWeb wants to extend the Internet of people to the farthest corners of the world. It intends to launch a large fleet of mini-satellites. Rohde & Schwarz is the sole supplier of the required test and measurement equipment (page 19).



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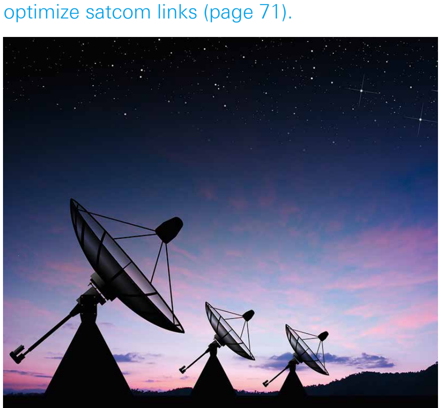
Overview NEWS 219/18

The R&S®SLP satellite link planner helps optimize satcom links (page 71).



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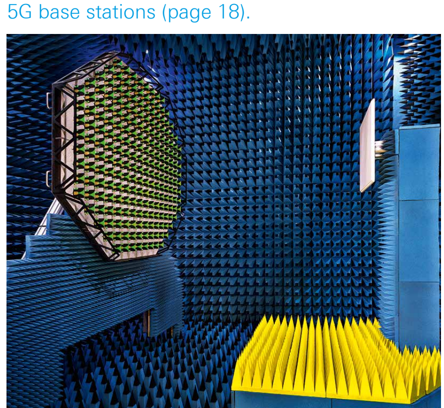
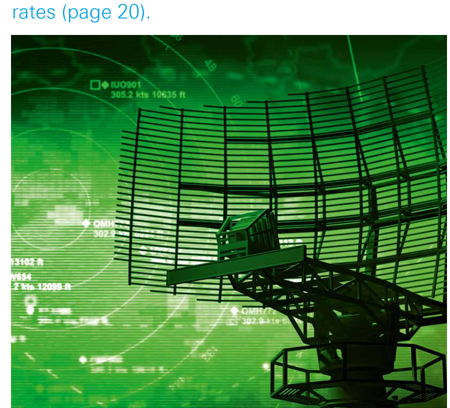
A test system for measuring massive MIMO 5G base stations (page 18).



Testing radar receivers with maximum pulse rates (page 20).



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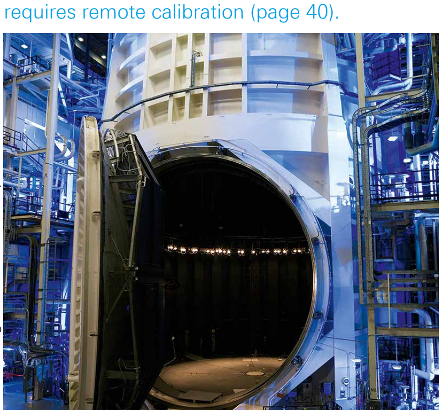
Network analysis of DUTs in vacuum chambers requires remote calibration (page 40).



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New analyzers measure flight navigation systems on the ground and in the air (page 44).

The most powerful solid-state TV transmitter is located in the One World Trade Center (page 54).

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Oscilloscope family updated

With the three new models R&S®RTC1000, R&S®RTM3000 and R&S®RTA4000, and the R&S®RTB2000 introduced in 2017, Rohde & Schwarz has completely updated its portfolio of economical oscilloscopes. The very compact R&S®RTC1000 is especially attractive for the educational and hobby sectors. It can be equipped with numerous accessory functions: eight-channel logic analyzer; four-channel pattern generator; protocol analyzer for I^{2}C, SPI, UART/RS-232, CAN and LIN; digital voltmeter; component tester; spectrum analyzer; counter. Users can also upgrade the bandwidth from 50 MHz to as much as 300 MHz via software license. The models in the 2000, 3000 and 4000 classes are based on the same platform. They all feature a 10-bit A/D converter, and the R&S®RTM3000 and R&S®RTA4000 additionally have a 16-bit high resolution mode as well as an extra-large memory. The specifications and features of the R&S®RTM3000 and R&S®RTA4000 make them ideal for the R&D sector. For example, the standard probe interface supports all Rohde & Schwarz probes. These oscilloscopes cover more than general applications. The R&S®RTM3000 is especially suitable for measurements on power electronics, while the R&S®RTA4000 is ideal for analysis of serial protocols thanks to its higher timebase precision and even larger memory. All models can be upgraded to meet growing demands via keycodes, even after purchase.

Drone warning system enhanced

The R&S®ARDRONIS drone warning and defense system allows sensitive areas to be safeguarded against unwanted airborne visitors. The system monitors the radio spectrum used by drones for telltale remote control signals, classifies approaching drones based on their spectral fingerprints, determines the location of the drone and/or its pilots, and can take countermeasures if necessary by blocking radio contact for remote control. With the release of R&S®ARDRONIS Disruption and R&S®ARDRONIS Protection, all configuration levels of the system are now available. New features are the ability to detect Wi-Fi controlled drones and block their remote control, and to demodulate and display live video streams that drones transmit to ground. This effectively allows monitoring staff to look over the shoulder of the intruder, assess its likely interests, and evaluate whether the drone should be classified as a threat. R&S®ARDRONIS is an open system that system integrators can extend by adding more sensors and defense equipment (www.drohnenabwehr.de/en).

Compact body scanner

Body scanners in airports must reliably detect potentially hazardous objects without impeding security processing. The scan procedure should not unnecessarily annoy passengers and be performed in an ethically correct manner. The R&S®QPS200 introduced in 2016 was the first scanner able to meet all of these requirements. The open portal solution meets the desires of passengers as well as security personnel. Passengers are spared claustrophobic situations and unnatural postures, while security personnel have a clear view of the security area and do not have to provide a separate path for wheelchair users, who can easily pass through the wide, floor-level opening. The new R&S®QPS201 model further enhances the advantages of the R&S®QPS family. The operating principle and technology are still the same: two opposed panels scan the subject by emitting millimeterwave pulses and receiving the reflected pulse echoes. From the billions of amplitude and phase samples, a fast integrated computer reconstructs a millimeterwave image of the person and uses neural networks to detect anomalies, which are presented on an impersonal avatar. Thanks to its high processing power, the R&S®QPS201 is able to do this in less than 4 seconds. Physically, the new model is significantly more slender than its predecessor, making integration into the security area even easier.

Generating customized ATSC 3.0 signals

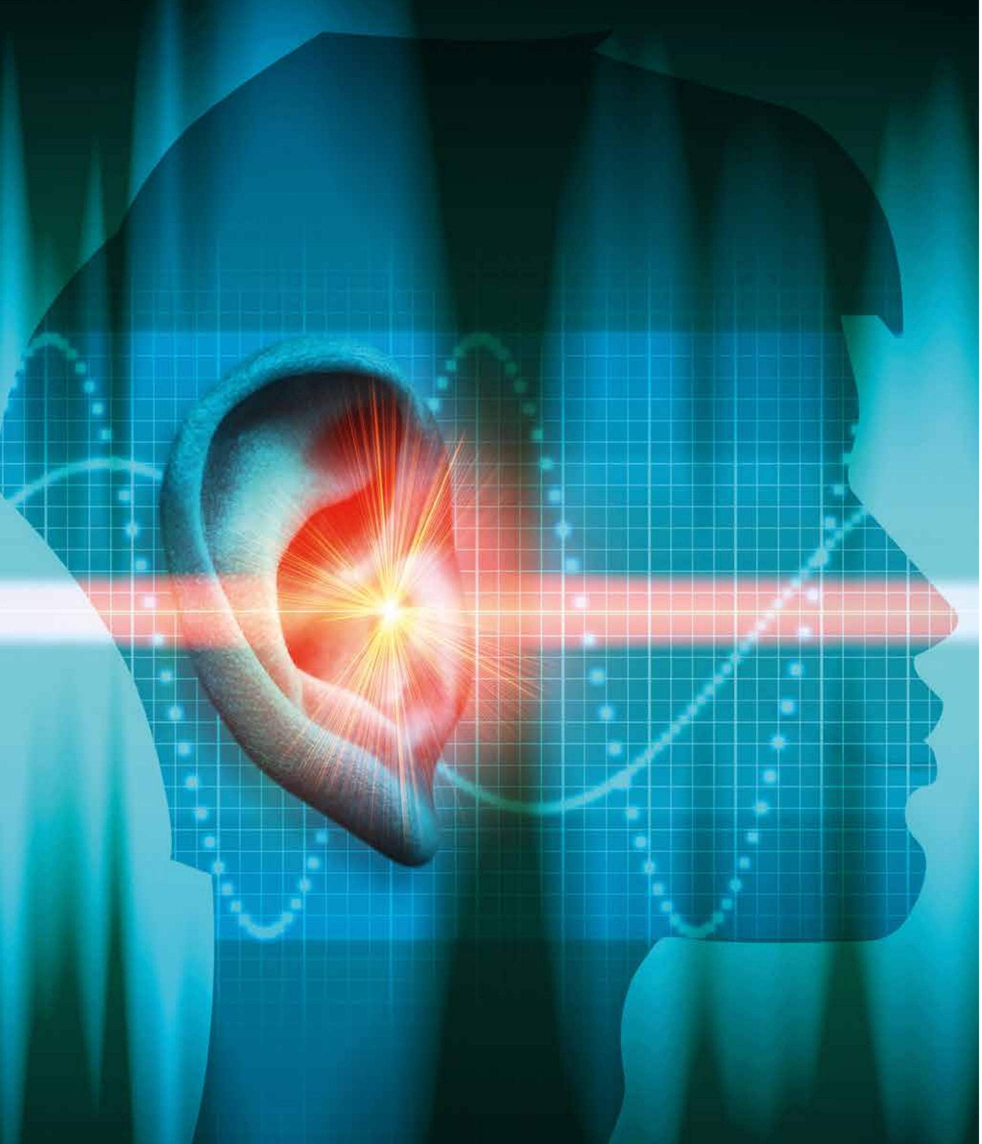
ATSC 3.0 is today's most advanced terrestrial broadcasting standard. It supports video transmissions up to UHD resolution, can work with mobile receivers, and is suitable for single-frequency network architectures. Thanks to its IP baseband architecture, it can be used for a wide variety of applications, including those with return channel capability. Software options for the R&S®BTC broadcast test center enable developers of tuner chipsets and broadcast receivers to fully exploit all the nuances of the standard in their test setups. The R&S®WV-K818 option targets users who test in strict compliance with the specifications of the ATSC organization and want to use the ATSC test cases. The R&S®BTC comes with an I/Q waveform library loaded in memory. The instrument's ARB uses this library to generate the standard-compliant RF signal. The R&S®BTC-K520 realtime coder option opens up the full flexibility of the standard. It supports IP data streams with ROUTE/DASH, MMT and TS formats, implements the STL interface and manages multiple PLPs (up to 64) as well as multiple subframes (up to 256). Users who operate the R&S®BTC with two channels can install the coder option in both channels. To support the official test cases of the ATSC Verification & Validation group, a set of SCPI script files is included that allow the R&S®BTC to easily and quickly be configured for V&V test scenarios.

Smart mobile network testing

Mobile telecommunications networks are constantly monitored for quality. Operators want to know where their networks have weaknesses and how they compare with the competition. Neutral testing bodies consider it their duty to inform the general public about service conditions and carry out nationwide measurements. Mobile vehicle based measuring systems as well as portable measuring systems are used for those purposes. The data from these systems must be merged and made available for efficient evaluation, which makes a web based solution a natural choice. That is exactly what the new Smart platform from Rohde & Schwarz mobile network testing offers. The SmartBenchmarker systems transfer their measurement data to a web database, which is accessed by the equally high-functionality and user-friendly SmartReports analysis tool. Users can configure custom graphic dashboards and include any desired data sets in the analysis. SmartMonitor provides similar capabilities for realtime monitoring of network conditions. Finally, SmartLicenser enables central administration of software licenses for QualiPoc instruments. It allows pooled licenses to be dynamically allocated to measuring systems or withdrawn. All QualiPoc instruments are now available as Smart versions.

Advanced airborne radio for military platforms takes off

The recently launched R&S®SDAR software defined airborne radio from Rohde & Schwarz is the world's most advanced airborne radio for military customers. Designed as an open platform based on the internationally standardized Software Communications Architecture (SCA), it gives customers maximum flexibility and independence. SCA features strict separation of the device platform and the software (waveforms and encryption). This feature enables continued use of existing waveforms and allows waveforms from other manufacturers to be ported to the instrument. To meet a wide variety of deployment requirements, Rohde & Schwarz has developed its own family of network-capable, high data rate waveforms and high-security encryption algorithms. These R&S®HDR waveforms can transfer up to two voice channels and data in parallel at high speed with different priorities. One of the unique features of the R&S®SDAR is its civilian certification capability. It eliminates the need for a second onboard radio certified in compliance with civilian standards as well as the associated expenditures for integration, training and logistics. Thanks to close coordination with government customers and platform manufacturers during development, the first customer contracts are already being implemented.



Measurements that simulate human hearing – psychoacoustics in ITU-T P.863

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Even though telephony now utilizes only a small part of network resources, it remains a core function of telecommunications networks if measured in terms of the actual duration of usage – and speech quality is an important criterion for the acceptance of a service. Automatic measurement procedures can be used to assess just how well an end-to-end connection is performing. These procedures involve meticulously characterizing human hearing based on psychoacoustic models. This is shown here using the state-of-the-art ITU-T P.863 standard as an example.

Almost everyone is familiar with technical parameters such as signal-to-noise ratio, total harmonic distortion and frequency response, which are used to provide insight into the sound quality of high fidelity audio equipment. Until the 1990s, purely physical parameters of this type were used for technically evaluating of the quality of telephone connections. When using analog transmission or simple PCM methods, these types of parameters were also adequate to allow a rough estimate of the transmission quality. Even after the first coding methods came into use – still with the goal of delivering the most exact reproduction possible of the waveform (DPCM, ADPCM) – measurements were still largely restricted to capturing the differences in amplitude between the transmitted signal and the original signal. The channel was simplified by modeling it as a time-invariant, linear system for speech transmission, and any deviation from this assumption was treated as additive distortion.

These assumptions have come under pressure with the introduction of new speech coding methods. Code-excited linear prediction (CELP) as well as frequency-domain coding methods were optimized for high acceptance of the coded audio or speech signal – and no longer necessarily for nearly exact reproduction of the signal as a waveform. Consequently, amplitude differences between the input and output signals could not be generally regarded as perceptible qualitative distortions of the speech signal.

It was at this time that the first psychoacoustic motivated speech quality measurement algorithms were created; the current ITU-T standard P.863 POLQA can be considered the most successful and precise representative of these algorithms.

The goal is to produce technically derived quality assessments of transmitted speech signals that are comparable to estimations obtained in auditory tests using test persons. The speech quality measurement procedure evaluates the quality of a short speech on a scale just like a large group of listeners would. Put simply, the quality is rated using a five-level, one-dimensional mean opinion score (MOS) and the opinions of all test persons are averaged. Now the speech signal has to be technically analyzed in order to calculate this single value for speech quality. Psychoacoustic motivated methods model the auditory situation, human auditory physiology and speech perception in order to attain as precise a result as possible.

The basic structure of ITU-T P.863

ITU-T P.863 approach is called full-reference, which means that the quality prediction is based on the comparison between an undistorted reference (original) signal and the received signal. To evaluate mobile communications channels, a reference speech signal from a preconfigured remote station is received, recorded and compared with a local copy of the reference signal; this is a typical end-to-end measurement. The most common use cases involve test calls between two mobile phones or from a mobile phone to a landline connection (Fig. 1). The measuring systems are designed primarily for mobile use in order to measure the quality of speech connections in real networks while on the move. Of course, P.863 can also be used for evaluation of pure landline or VoIP connections as well as in the lab.

In simplified terms, ITU-T P.863 – like its predecessor ITU-T P.862 – has three aspects:

- Preprocessing and synchronization of the reference and test signals
- Modeling of auditory physiology
- Modeling of speech perception and temporal integration

All of the analyses as well as the calculation of the quality value are based exclusively on the speech signal itself. ITU-T P.863 does not require any additional information or even IP data. This allows very wide-ranging applications since no knowledge is needed about the transmission system at measurement runtime; the transmission channel is treated as a black box (Fig. 2).

Test scenario for speech quality measurements

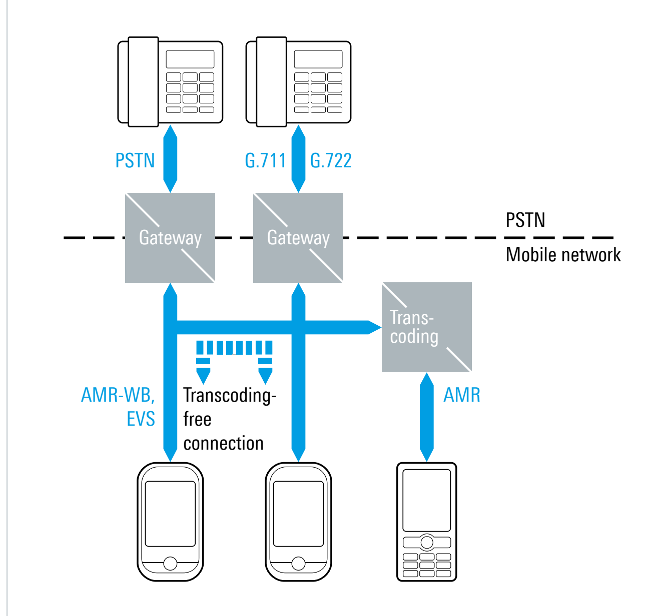

Fig. 1: Typical end-to-end test connections for speech quality measurements.

Transmission path and modeling in ITU-T P.863

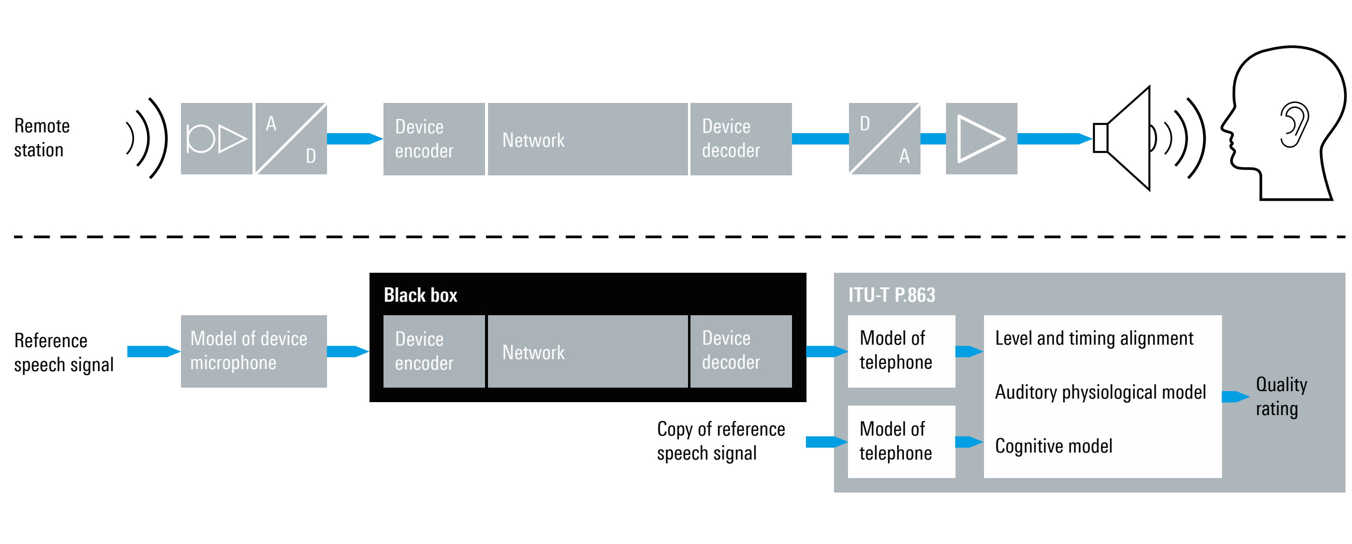

Fig. 2: The transmission channel is treated as a black box.

Preprocessing and synchronization of the reference and test signals

Preprocessing of the signals includes some basic technical aspects such as correcting deviating clock frequencies during transmission, adjusting the signal level and prefiltering the signals as needed in order to model the auditory situation, i.e. with the frequency response of a headset or – in narrowband mode – with the frequency response of a typical telephone receiver. However, the most important and challenging part of preprocessing involves precise synchronization of the reference and test signals to allow subsequent analysis in brief time windows.

The measurement procedure – which will be discussed later – is based on a comparison of the internal frequency-time representations of the reference and transmitted signals. It must be possible to congruently compare the two representations on the time axis, i.e. a certain segment of the signal under evaluation $y(t + \tau)$ must be comparable with the corresponding reference segment $x(t + \tau)$. In the past, it was reasonable to assume a constant delay in the transmission system, i.e. a constant time offset between the two signals $x(t + \tau + c) \sim y(t + \tau)$. In that case, a simple correction using the constant c sufficed to synchronize the representations on the time axis. For largely linear systems, c could be easily determined and with sufficient precision by analyzing the cross-correlation between the input and output signals.

Today's transmission systems no longer meet these prerequisites because they are time-variant and nonlinear. The strong time variance is obvious in popular Internet voice communications services with their perceptible fluctuation in speech rate. At times the speech tempo appears compressed, and at other times elongated. Nevertheless, to be able to precisely compare the short-term spectra of the reference signal and the signal under evaluation, all of the equivalent segments of the two signals must be aligned.

ITU-T P.863 does this with a multi-stage iterative procedure. First, the signals are prealigned in the time domain. The initial delay is eliminated, the signal is divided into long segments such as sentences or word groups, and these are roughly synchronized. Based on this rough alignment, the individual sections are subdivided more finely and then aligned exactly.

It is assumed that the two signals are correlated at least over short time intervals, if not in the time domain then definitely in the frequency domain. Therefore, both spectral similarities and cross-correlations are used as the synchronization criteria. The signal under evaluation is iteratively broken into smaller and smaller segments and matched with the corresponding parts in the reference signal until the synchronization criteria are fulfilled. At the end of the synchronization procedure, each segment in the signal under evaluation has been aligned with the corresponding segment in the reference signal.

Comparison of reference signal and test signal

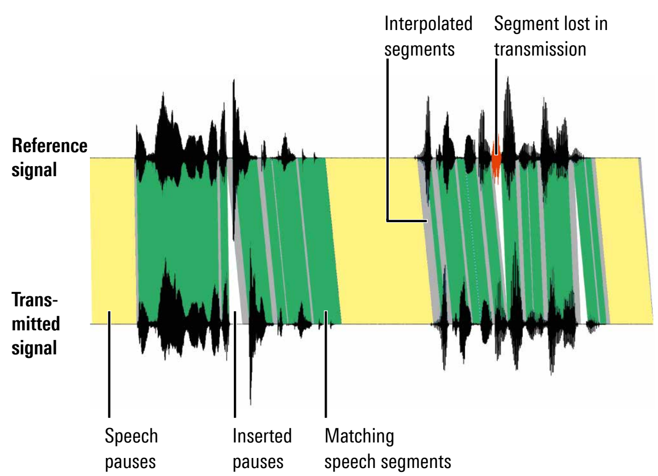

Fig. 3: Example of timing alignment of speech segments in the reference and test signals in case of time-variant transmission.

When all speech segments have been aligned, simple desynchronization is checked by repeatedly and uniformly shifting the signals – such as can occur when there are deviations in the clock frequencies between the transmitting and receiving ends. This type of desynchronization also leads to drift in the frequency domain. If necessary, this is corrected prior to further processing by resampling the signal – a complicated process. The alignment procedure is then repeated to check if the resampling was successful.

In most cases, all of the signal segments can be synchronized. But there can also be highly distorted, missing or inserted (artificial) signal segments. These cannot be reliably aligned with a segment in the reference signal. Such segments are interpolated between accurately assigned segments based on plausibility criteria or they are added to these segments. At the end of the synchronization process, it is ensured that even the tiniest received signal segment can be assigned to a corresponding segment in the reference signal. The signals are not reproduced as a synchronized time domain signal. Instead, the alignment is represented virtually using a correspondence table that contains the start and end points of the matching signal segments (Fig. 3).

Based on this alignment, the two signals are synchronously mapped in overlapping windows (FFT) and psychoacoustically transformed to produce a hearing-oriented, time-frequency representation.

Auditory physiology and speech perception

First, the basics of auditory physiology will be outlined, i.e. the transformation of a sound event into an internal stimulus. This represents the main component of the speech-processing model in ITU-T P.863.

Certain hearing phenomena are generally known. One well-known phenomenon is the absolute threshold of hearing under which sounds cannot be perceived. It is frequency-dependent – as is human perception of sound intensity. An example is the well-known A-weighting curve, which is a frequency weighting for a certain sound intensity. The perception of volume and tone pitch, which is roughly logarithmic, is taken into account by using a decibel scale for the intensity and listing by octave or third-octave bands in the frequency domain. However, the underlying physiology of hearing is much more complex. In simplified terms, the goal of psychoacoustic motivated algorithms is to provide a signal as a starting point for quality estimation – like the signal delivered by the auditory nerve to the speech-processing center in the human brain.

The fundamental idea of the ITU-T P.863 measurement algorithm is not to calculate the difference between the original signal (reference signal) and the transmitted, distorted signal at the level of measurable amplitude values. Instead, it is based on differences in the "internal representation" of the signals, i.e. the actual signal available to the human brain after the speech signal has undergone auditory physiological processing. Simply put, this means masking out signal components that are inaudible.

How is the transformation of the sound signal into an internal stimulus modeled? ITU-T P.863 begins with a short-term spectral analysis. The speech signal is subdivided into overlapping windows with lengths of 30 ms to 40 ms and converted into a spectral display using FFT, whereby the sound pressure level is normalized to what is known as the ear reference point (ear level). The result of the FFT is an equidistant spectral representation of the sound energy in the frequency domain. The spectral resolution of sound events in the inner ear is not constant across the audible frequency range. It becomes less clear as the frequency increases. In physiological terms, this is due to what is known as the frequency-to-place transformation on the basilar membrane in the inner ear. The basilar membrane, which is coiled up in the cochlea of the inner ear and immersed in liquid, is the base for the sensory hair cells. The membrane is stimulated via the ossicles: the stapes, malleus and incus. Depending on the stimulus frequency, vibration maxima are formed closer to the point of stimulus

Anatomy of the human ear

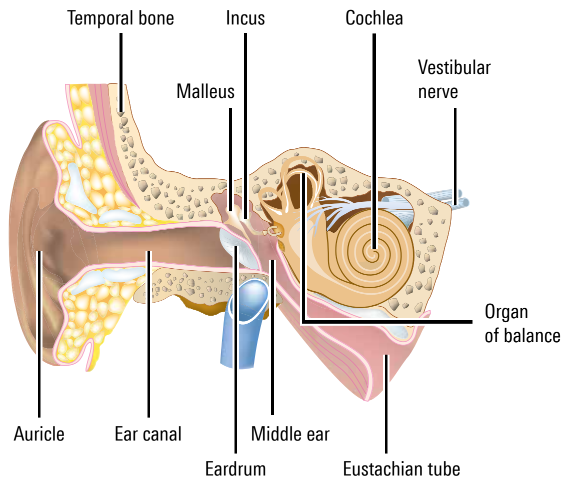

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Fig. 4: The anatomy of the human ear. The frequency range is logarithmized in the cochlea.

Masking phenomena in coding

The phenomenon of spectral and temporal masking was described by Zwicker in the 1950s. This model was not widely used until the development of the MP3 audio coding method, and it was instantly a resounding success. MP3 reduces the signal components that human hearing automatically masks. The coding distortions are hidden below the masking threshold and are therefore imperceptible or barely perceptible. MP3 and later methods such as AAC and WMA exploit the redundancy of human hearing to reduce the amount of information transmitted with the least possible impairment. There is also a distinction between audio and speech coding methods. Speech coding methods exploit the redundancies of speech produced by the human vocal tract. The resulting speech signal is highly correlated and can be characterized reasonably well using simple predictive models. State-of-the-art coding methods model the principle of how the vocal chords and vocal tract produce speech, transmit the model parameters and synthesize the speech signal on the receiving end. This pure vocoder method became commercially viable when, in addition to the original speech signal, the error signal of the synthesized signal was transmitted and used on the receiving end to correct the generated, artificial speech signal. Further development of this coding approach primarily focuses on increasing the efficiency of transmitting as precise an error signal as possible.

or further inside closer to the rear support of the membrane. In this way, the stimulus frequency vibrates at a certain place on the basilar membrane. Since the membrane is narrower towards the inside, it becomes stiffer and adjacent frequencies lead to more closely spaced vibration maxima than at the front end of the membrane. Since the density of the hair cells is approximately constant, the spectral resolution of human hearing decreases at higher frequencies.

This transformation of an air pressure fluctuation by the eardrum and the ossicles into a pressure variation in the cochlear fluid can be interpreted as an acoustic impedance conversion. This is the only way that an acoustic air vibration with a wavelength between 15 m and about 1.5 cm in the range of human hearing can be mapped on a liquid-supported membrane with a length of approx. 7 cm (Fig. 4).

This basic understanding of the transformation of an acoustic sound event into a stimulus of the auditory nerve explains many phenomena related to hearing. The hair cells require a minimum deflection in order to respond. This, in conjunction with a noise floor, forms the resting threshold. The nonequidistant frequency-to-place transformation on the narrowing basilar membrane is responsible for the approximately logarithmic relationship between frequency and perceived tone pitch. The Bark scale, which has been around for a long time, does a good job of modeling this situation.

Considering the described frequency-to-place transformation and the vibration of the basilar membrane, it becomes clear that a single frequency (a sinusoidal oscillation) does not cause a deflection of the membrane at just a single position; instead, a whole region of the membrane is vibrated, whereby only its maximum corresponds to the excitation frequency. This means that adjacent hair cells are also vibrated and stimulated.

This stimulus of an entire region leads to the well-known phenomenon of spectral masking. Weak stimuli in the immediate vicinity of a stronger stimulus do not cause (additional) perceptible excitation of the affected sensory cells. The weak stimulus is masked by the stronger adjacent stimulus and cannot be perceived (or only to a limited extent). One of the achievements of human hearing is that despite the excitation of a whole region on the basilar membrane, a sinusoidal signal can be perceived as such – and not as narrowband noise. However, this comes at the cost of reduced sensitivity in the area of this excitation maximum.

Besides spectral masking, there is another effect known as temporal masking. Following an intensive sound event, the sensitivity of the hair cells in the excited region is reduced for a brief time interval. Weaker stimuli will not be perceived there (or only weakly perceived) for some milliseconds (see box).

Modeling of these spectral and temporal masking effects is the next and most important step in the transformation of the original signal spectrum into a perception-oriented internal representation. The transformed signal can be understood as a special form of a spectrogram in which the frequency-time representation is characterized only by sound intensities that are actually perceptible (sonogram).

The measurement procedure now sees this frequency-time representation as an internal representation of the signal. By comparing the two "spectrograms" of the reference signal and the transmitted signal, a difference representation is obtained that only shows the differences that are actually perceptible. Signal components that are not perceived due to auditory physiology no longer play a role here.

Speech perception and quality modeling

At first glance, it may seem that simply accumulating the perceptible difference vs. frequency and time would lead to a perception-oriented disturbance rating and a valid quality assessment. However, this is not the case.

On the one hand, this "difference" characterizes only the perceptible difference under the remote assumption that both signals can be directly compared and evaluated. However, even a delayed presentation leads to an increased error tolerance since even though acoustic differences lead to different physiological stimuli, they are not remembered as such. The error tolerance for a telephone connection (the case in this model) is higher because the listener can only compare the spoken words with their memory of the speaker as well as their expectations based on their experience of how human speech naturally sounds. Even significant measurable deviations are considered irrelevant, leading to a further masking of errors that is more difficult to comprehend.

As has already been discussed, the goal of the speech quality measurement procedure is to realistically characterize the perception of a speech signal in terms of its naturalness and the influence of disturbances. However, the range of what is acceptable as natural speech is quite large. People are accustomed to perceiving many different voices as natural. People's tolerance to voice is much higher than for a musical instrument. If an instrument is not perfectly tuned, the listener notices immediately. This tolerance in speech perception means that not all theoretically perceptible differences to the reference signal will affect the quality rating equally. Slight shifts in the fundamental frequency and formants tend to be better tolerated than additive distortion caused by noise or interference pulses. There is also a higher tolerance to ripple in frequency responses or even to band restrictions as well as to slow, steady level changes or even to changes in the temporal structure of the signal, i.e. slight elongation or compression on the time axis.

Postprocessing of the calculated, perceptible signal differences is necessary based on the analytical power of the brain. Basically, the auditory physiology only modeled the organic hardware; now the hearing software has to be added to the model. This can be done with a postprocessing cognitive model approach in addition to the described auditory physiological model. In contrast to the precise algorithmic model of the inner ear, the cognitive model is implemented rather coarsely in today's models and is limited to specific weightings of individual error patterns, which in turn are assigned to individual, specific causes (e.g. frequency response, additive noise, etc.).

The model in ITU-T P.863 divides the perceptible signal differences into four categories (indicators), which are analyzed independently and then later weighted and included in the overall assessment:

- (Additive) noise
- Frequency response / timbre
- Reverberation
- Distortions

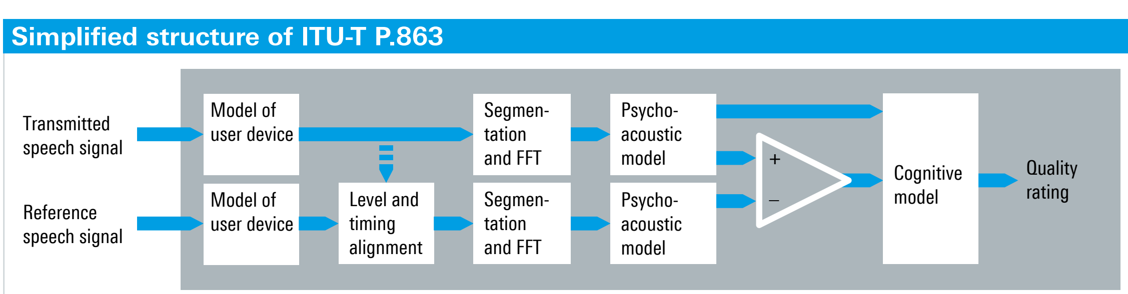


Fig. 5: The structure of ITU-T P.863 POLQA.

Distortions represent the most important branch of analysis. The differences in the sonograms for the reference and test signals over all speech components are used as the basis for calculation. Before these differences are calculated, however, the reference signal representation is aligned with the test signal; level fluctuations and deviations in the timbre are partially corrected in this process. Even though they barely impact the perceived quality, they would dominate the calculated differences. When accumulating the absolute differences, a distinction is made between missing and added elements. Missing signal intensities have a much lower weighting. The accumulated differences over the individual frequency ranges and speech components represent the baseline for the quality rating.

Since the influence of the timbre (frequency response) of the speech signal on the disturbance value was reduced prior to calculation, this indicator is taken into account in a separate evaluation. Reverberation in the speech signal is also quantified separately. Although a certain amount of reverberation in the speech signal hardly leads to lower perceived quality, it does lead to a greater difference in the spectral display and does not correspond to what is perceived. Both indicators – timbre and reverberation – are used to correct the calculated base value for the quality.

This calculated quality base value does a relatively good job of characterizing speech perception, but additive noise is mainly perceptible during speech pauses when there is no speech signal to mask it. This is why background noise is measured separately, weighted and also used to adjust the quality value. The quality model is finalized by transforming the calculated quality value to the MOS scale of 1 to 5. This transformation is based on listening tests with test persons; their MOS values need to be reproduced as precisely as possible by the measured value of the model (see box).

Model development and test data

ITU-T P.863 is the result of a multi-year competition organized by the ITU for a new standard of speech quality evaluation in telecommunications networks. In particular, the advance of IP based transmission and new codecs as well as the extension of the transmitted speech spectrum to HD voice and beyond have necessitated a new measurement method.

Following a complex selection process, the models created by OPTICOM, TNO and SwissQual were chosen as the winners of the competition. Combining the advantages of the three successful candidates into a single model to be standardized led to ITU-T P.863 POLQA. Due to synergy effects, the new model considerably exceeded the accuracy of the individual approaches and was officially approved as a standard in 2010. More than 45 000 spoken and transmitted sentences in ten different languages that were evaluated by listeners were used for the selection and verification of ITU-T P.863.

Today, ITU-T P.863 is the reference method for speech quality measurements. It has been installed on many thousands of measuring instruments worldwide for quality monitoring purposes. The standard is kept up-to-date through regular model maintenance. Published in March 2018, version 3.0 was specially verified for the new EVS coding method. It now also supports the entire audio spectrum audible to humans.

ITU-T P.863 in Rohde & Schwarz products

SwissQual AG – a partner in the POLQA coalition and a co-owner of the rights – has belonged to Rohde & Schwarz since 2012. The long-standing experience of this company in the area of speech and video analysis and quality modeling has been integrated into the Rohde & Schwarz product portfolio. Core products are QualiPoc and Benchmarker – both are smartphone based measuring systems that provide all relevant information at the RF and IP levels and analyze the media signal (audio or video) in real time. Call setup and release, feeding and recording of speech signals, and saving of result structures is automatic. The systems are designed for extensive series measurements in real networks.

After the ITU-T P.863 based algorithm was approved as a standard, it was immediately implemented under Android. Thanks to its own model development, QualiPoc had a head start and was the first commercially available system to run P.863 on a smartphone in real time (Fig. 7).

P.863 POLQA is the core element of an enhanced audio analysis. In addition to the MOS value, other technical parameters such as the speech and noise level, but also important parameters in today's telecommunications channels such as "missed voice" (the percent of lost, unreceived speech) are calculated and output.

Many of the parameters can be visualized over the signal duration. This allows errors in the speech signal to be precisely localized and synchronized with the lower transmission layers, which enables detailed error analysis (Fig. 8).

Fig. 6: Vehicle based test campaigns can be used to prepare comprehensive mobile coverage and quality maps. Speech quality measurements are part of the procedure.

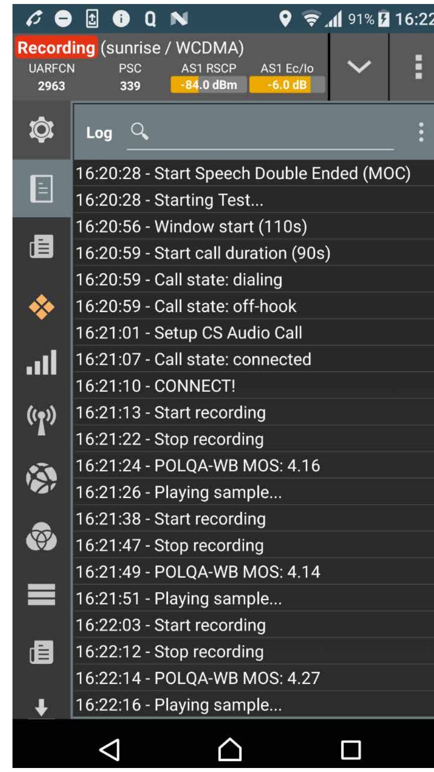
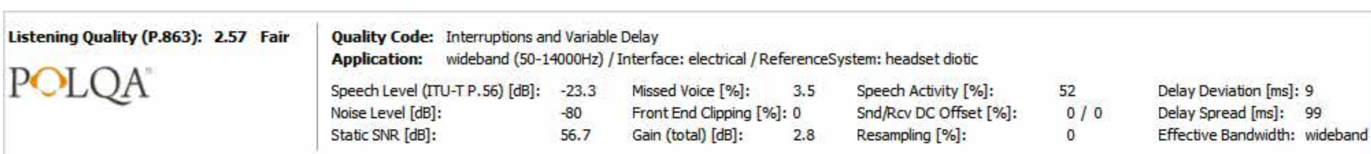


Fig. 7: Real-time evaluation of a speech signal in line with ITU-T P.863 using a QualiPoc measuring system.

Fig. 8: Example of speech quality analysis with P.863. The MOS value for the speech signal is 2.57 (overall rating: "Fair"). Interruptions and variable delay are given as the reason for the rather low score. This score is quantified by the 3.5 % of lost speech signals (missed voice) and a delay spread of 99 ms.



Information about disturbances that influence the quality value allows automatic analysis of the root causes behind a decrease in speech quality. This type of root cause analysis can distinguish among almost 30 different primary sources of problems, including background noise, heavy coding distortion, lost packets, interruptions and more. This auxiliary information is very helpful in pinpointing the problem on the transmission path.

Today, over three quarters of all measuring systems sold include optional audio analysis – a clear indication of the degree of acceptance and success of automated speech quality measurements. However, usage of ITU-T P.863 is not limited to evaluation of classic mobile phone calls. The focus on evaluating the speech signal also allows assessment of OTT services such as WhatsApp Call and Skype. In recent years, it has become increasingly important for network operators to compare these services with their own products in the field, thereby contributing to the high demand for suitable measuring systems.

Dr. Jens Berger

Signal generation and analysis for 5G NR

The future mobile communications standard is ramping up quickly, supported by continuously updated Rohde & Schwarz test and measurement equipment.

5G New Radio (5G NR), the next generation mobile communications standard from 3GPP, promises gigabit connection speeds, lower latency, enhanced reliability, increased connection density and improved energy efficiency compared to LTE. In December 2017, 3GPP completed the first set of implementable 5G NR standards, paving the way for the industry to develop standards-compliant solutions for full-scale trials and commercial deployments starting in 2019.

Key features of 5G NR

Two key features in 5G NR are especially important for the realization of higher data rates than in LTE: the use of millimeterwave frequencies (up to 100 GHz[1)]) and support for significantly higher signal bandwidths. In particular, 5G NR supports signal bandwidths up to 100 MHz for carrier frequencies below 6 GHz and up to 400 MHz for frequencies in the millimeterwave range. Similar to LTE, 5G NR employs OFDM-based waveforms in both the uplink and downlink to utilize the wide carrier bandwidths efficiently, but it allows more flexibility in subcarrier spacing for deployment in different frequency bands. It is expected that up to 16 carriers can be aggregated, making it possible to offer bandwidths in the gigahertz range to a single device. 5G NR also employs massive MIMO and beamforming techniques relying on massive antenna arrays to combat the effects of higher attenuation at higher frequencies.

Major design and testing challenges

These ambitious features bring new challenges for development engineers. Designing power amplifiers that exhibit the necessary characteristics (e.g. linearity) is not trivial and may necessitate new design approaches (e.g. digital predistortion). The circuity needed to generate frequencies in the millimeterwave range requires careful design and selection of components in order to reduce the effects of phase noise introduced by mixers and multipliers. Beamforming also requires very good amplitude and phase synchronization between antenna elements in active antenna systems.

The high frequencies intensify the challenges for test and measurement methods. The short wavelengths and higher losses in circuits necessitate tight integration, making it impractical to supply connector ports for testing. At the same time, the effects of connectors and test fixtures become non-negligible, potentially affecting the validity of conducted measurements. As a result, over-the-air (OTA) testing will play an important role.

Continuously updated test and measurement equipment from Rohde & Schwarz helps the industry quickly bring 5G NR solutions to market. Developers, for example, urgently need suitable signal sources and analyzers.

New software for 5G NR signal generation and analysis

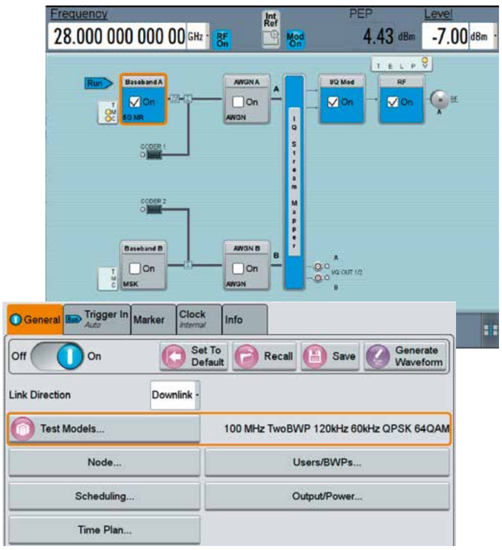
The **R&S®SMW-K144 option** for the R&S®SMW200A simplifies generation of uplink and downlink 5G NR signals for all testing needs. With this option, the generator produces extremely clean 5G NR signals with a flat frequency response and bandwidths up to 2 GHz at frequencies up to 40 GHz. The software supports all waveforms specified in the standards (cyclic prefix OFDM and DFT-s-OFDM[2)]), channel bandwidths from 5 MHz to 400 MHz, modulation formats up to 256QAM, subcarrier spacing (15 kHz to 240 kHz) and numerology options. The intuitive GUI allows users to flexibly configure these and many other parameters, including bandwidth parts (BWP).

The **R&S®FSW-K144 option** for the R&S®FSW signal and spectrum analyzer provides functions for in-depth analysis of 5G NR downlink signals, using standard-compliant parameters such as FFT size, cyclic prefix length, and many more. The option allows configuration of the parameters directly on the instrument or automatic detection of parameters such as the cell ID, which influences other parameters of the signal.

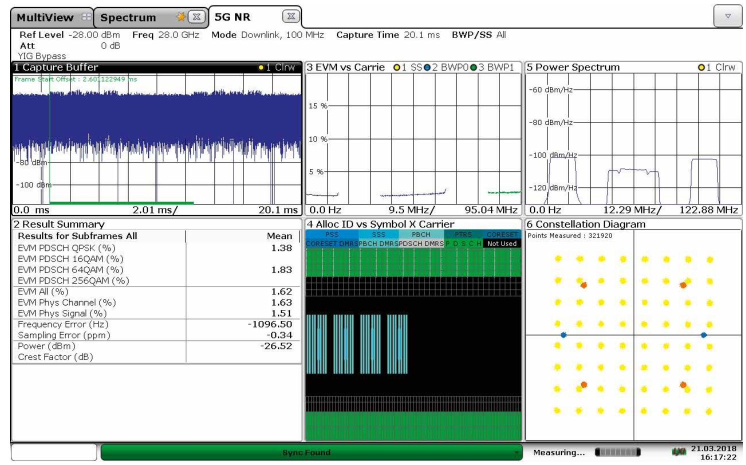
Signal generation with the R&S®SMW200A

A signal generator for 5G NR needs to be able to generate extremely clean wideband signals with excellent EVM over a wide frequency range. This requires the signal generator to exhibit outstanding spectral, phase and amplitude characteristics. To overcome high path loss at millimeterwave frequencies, very high RF output power is also necessary. The R&S®SMW200A vector signal generator fulfills all these and other requirements resulting from 3GPP Release 15[3)]. It generates signals with a bandwidth of 2 GHz for frequency ranges up to 40 GHz internally, eliminating the need for external mixers and upconverters.

Signal generation and analysis for 5G NR



Signal configuration with R&S®SMW-K144 (uplink and downlink)



Signal analysis with R&S®FSW-K144 (downlink)

The R&S®SMW-K144 and R&S®FSW-K144 software options offer presets for all important measurements in the frequency bands below 6 GHz and in the millimeterwave bands.

Automatic internal amplitude correction ensures extremely flat signals (< 0.4 dB measured over a 2 GHz bandwidth) over the entire frequency range. With signal output powers up to +18 dBm, it can be used for OTA testing without an external amplifier. The excellent spectral characteristics also ensure that 5G NR signals with measured EVM of less than 0.3 % for a 100 MHz downlink signal can be generated. With the optional integrated fading simulator, the generator also supports complex applications such as realtime fading for all key MIMO scenarios, another unique feature on the market.

Signal analysis with the R&S®FSW

With 5G NR, signal analysis bandwidths of at least 1 GHz become necessary in order to capture the interaction of multiple component carriers. The R&S®FSW-B1200 option provides 1200 MHz of internal analysis bandwidth for the 43 GHz and 50 GHz models of the R&S®FSW series of signal and spectrum analyzers. The 14-bit A/D converter with its low inherent EVM provides new insight into the design. This internal option also reduces the size of the test setup, reduces the needed cabling between instruments and increases the measurement accuracy compared to systems built with downconverters and separate digitizers.

The **new R&S®FSW-B2001 option** increases the internal analysis bandwidth of the R&S®FSW43 and R&S®FSW50 to 2 GHz, which enables designers of power amplifiers for 5G NR to develop and evaluate predistortion systems, for example. If even larger bandwidths are required, the R&S®FSW85 can be combined with the R&S®RTO2064 oscilloscope to support analysis bandwidths up to 5 GHz for frequencies up to 90 GHz (see article on page 30).

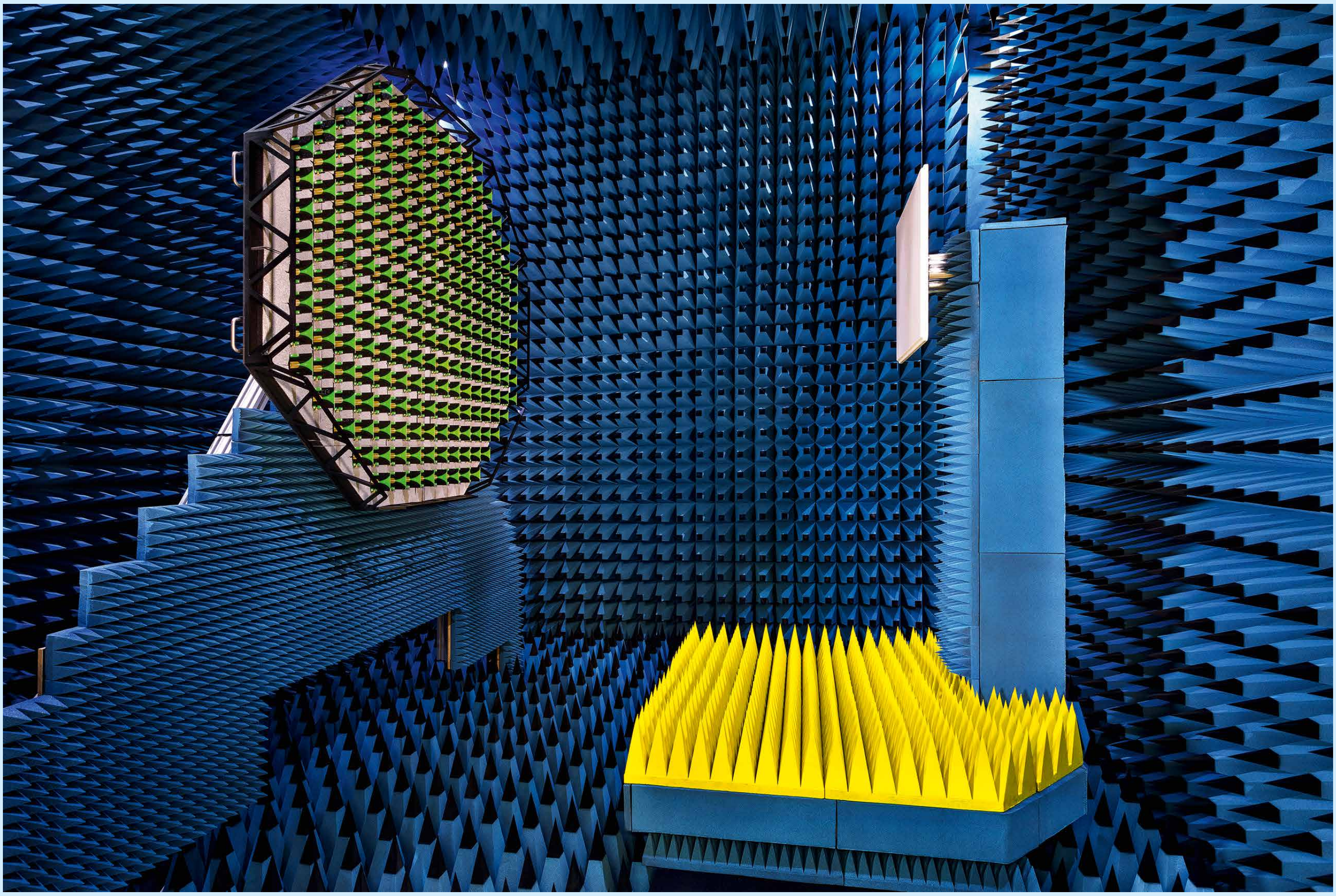
Dr. Patrick Agyapong; Johan Nilsson

1) Rel-15 defines two frequency regions (FR): FR1 (450 MHz to 6 GHz) and FR2 (24.25 GHz to 52.6 GHz). At the time of publication of this article, three bands were specified for FR2 in 3GPP TS 38.101-2 v15.0.0 (official, non-standalone 5G NR specification freeze in December 2017): n257 (28 GHz), n258 (26 GHz), and n260 (39 GHz).
2) Discrete Fourier transform spread OFDM.
3) Official 3GPP Rel-15, frozen non-standalone NR specification dated December 2017 (TS 38.101-1 v15.0.0 and TS 38.101-2 v15.0.0).

In brief

OTA test system for 5G base stations

5G base stations will use massive MIMO antenna arrays to achieve both higher capacity and higher energy efficiency. This base station architecture requires a new measurement paradigm – and T&M equipment such as the R&S®PWC200 plane wave converter.



The R&S®PWC200 plane wave converter (the octagonal array on the left) generates a flat wavefront where the base station under test is located, which will be only 1.50 m away in place of the white reference antenna shown here.

Each antenna in the array of a 5G base station will be a self-contained unit consisting of the frontend (RF transceiver, amplifier, upconverter and downconverter) and the actual antenna elements. Thus future base stations will have to be characterized as a whole, using OTA technology to measure RF parameters. However, it is only possible to obtain conclusive transmitter and receiver measurements under far field conditions at the base station location or with a test setup that simulates the far field. And that is exactly what the R&S®PWC200 plane wave converter does.

The R&S®PWC200 is a bidirectional phased array consisting of 156 wideband Vivaldi antennas in the near field region of the device under test – a base station, passive antenna, or antenna array. Installed in a compact test chamber, which can also be supplied turnkey, the converter enables realtime transmitter and receiver measurements (radiation pattern, gain, EVM, ACLR, etc.) in the frequency range up to 6 GHz. Such measurements previously required a compact antenna test range (CATR) significantly larger than the R&S®PWC200.

Each antenna has a phase shifter and attenuator pad, enabling targeted synthesis of the electromagnetic field where the device under test is located. To feed the signal to the array or to test signal reception, a combiner merges all signal paths to a single port to which the measuring instrument can be connected.

Thanks to their compact dimensions and easy handling, both the R&S®PWC200 and the test chamber can be used in development and for calibration in production.

T&M equipment for OneWeb components

OneWeb wants to use its satellites to make Internet access available in the remotest corners of the world. Rohde & Schwarz provides the necessary test and measurement equipment.

OneWeb is a US company whose mission is to provide fast Internet access to the world's remotest areas via a comprehensive satellite network. The infrastructure is currently being developed. The first of a planned 900 satellites are scheduled to be placed in low-Earth orbit during the course of this year. Renowned companies, including Qualcomm as the chipset supplier, Airbus Defence and Space for satellite development and production, and Hughes Network Systems for the ground stations, are partners in the project. Rohde & Schwarz is the sole T&M manufacturer to provide a package solution for testing the RF components.

OneWeb users will use standard wireless devices that transfer data via terrestrial mobile communications access points known as OneWeb user terminals. These terminals are linked to the satellites that communicate with the Internet via ground station gateways. It is therefore necessary to simulate and test two paths in two directions: user terminal — satellite, and ground station — satellite.

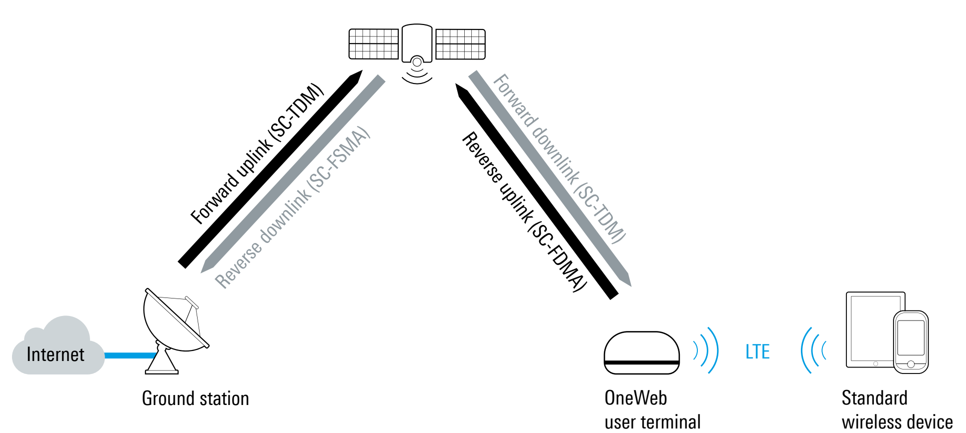
The test signals are generated by the R&S®SMW200A vector signal generator. Two software options support different requirements. The R&S®SMW-K355 option (OneWeb reference signals) contains precalculated, ready-to-use waveforms for physical layer tests on RF components. The R&S®SMW-K130 option (OneWeb user-defined signal generation) provides access to all relevant parameters of the forward and reverse links, e.g. number of subframes, resource block configuration, cell ID and modulation format. All changes to generator settings are immediately applied to the RF output.

Analysis of OneWeb signals is handled by the R&S®FSW signal and spectrum analyzer. Different software options are used depending on whether a forward link or a reverse link is being tested. The reverse link signals are based on a proprietary OneWeb SC-FDMA standard. The R&S®FSW-K201 option can demodulate these signals and analyze all relevant physical layer parameters. The R&S®FSW-K70 vector signal analysis option is sufficient for testing the forward links of both paths. Additional options are available for other measurements, such as R&S®FSW-K18 for characterization of amplifiers, frequency converters and the satellite payload, or R&S®FSW-K17 for group delay measurements.

The OneWeb consortium partners use both instruments with the OneWeb options and recommend them for RF measurements.

Volker Bach

Structure of the OneWeb system



The goal is for OneWeb satellites to provide Internet access even to remote regions.

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The R&S®SMW200A vector signal generator processes PDW streams

Pulse descriptor words (PDWs) describe the parameters of radar pulses. Radar simulators stream these PDWs at high speed to a signal generator that interprets them and converts them into signals for testing radar receivers. A new option enables the R&S®SMW200A to take over this role.

Receivers used for radar electronic support measures (RESM) – e.g. radar warning receivers and receivers for instantaneous frequency measurements (IFM) – are tested in development labs with maximum pulse rates up to their performance limit. To do so, radar development engineers use complex, very long pulse sequences that cannot easily be produced by a signal generator. The pulses are defined by a series of pulse descriptor words (PDWs). Each PDW consists of a set of pulse parameters in coded form (pulse width, pulse repetition interval, time of arrival [ToA, see box], signal level, etc.). A PDW list describes a radar scenario completely, and very compactly in terms of data storage. Typical lists can contain millions of PDWs.

With the new R&S®SMW-K503 interface option, the R&S®SMW200A vector signal generator can interpret PDW streams and convert them into radar signals. The PDW streams are fed in from a customer-provided radar simulator that either calculates them or takes them from a recorded live scenario. The setup in Fig. 1 enables testing of radar receivers and their processing algorithms over extremely long test periods.

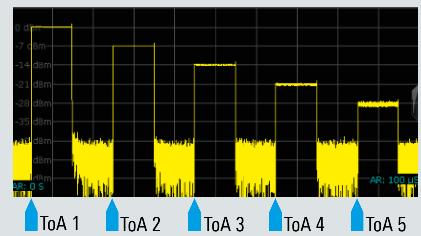
Extremely high pulse rates required

Real scenarios often include several spatially distributed radars (emitters) whose signals must be simultaneously received, separated and evaluated. Due to rotating antennas and directional patterns, these signals have a high dynamic range. The signals generated by the radars have different frequencies and modulations, and pulse rates ranging from a few kilohertz to 100 kHz. The more radars there are in the scenario, the higher the pulse rate the receiver must be able to handle. The maximum pulse rate at which

Fig. 1: A typical setup for testing single-channel radar receivers.

Time of arrival (ToA)

When receiving, classifying and saving pulsed radar signals, a radar warning receiver creates a PDW for each pulse. It assigns each pulse a timestamp at its time of arrival (ToA) and notes this in the PDW. If it is necessary to simulate the pulse for test purposes, the ToA serves as the start time for the signal generator.



individual emitters can still be recognized amid the multitude of pulses is therefore an important performance factor for a radar receiver. Equipped with the R&S®SMW-K503 software option, the R&S®SMW200A is able to generate 1 million pulses per second (1 Mpps) – a market-leading rate for PDW streaming over LAN. For even more demanding receiver tests, the R&S®SMW-K504 software option supports pulse rates as high as 2 Mpps. Users who configure the R&S®SMW200A with two RF paths (possible up to 20 GHz per path), can install both software options twice to enable processing of two independent PDW streams. If these are merged with an RF combiner, the pulse rate can again be doubled.

Arbitrary pulse shapes

In addition to using conventional radar pulses such as Barker coded and unmodulated pulses, many customers want to test with complex pulse shapes such as nonlinear chirps. To achieve this, first an arbitrary waveform segment with the desired pulse shape is stored in the R&S®SMW200. The PDW addresses this segment, and the generator produces the pulse at the time specified in the PDW (Fig. 2). The arbitrary waveform can be created using the R&S®Pulse Sequencer PC software together with the R&S SMW-K300 generator option.

Robert Vielhuber

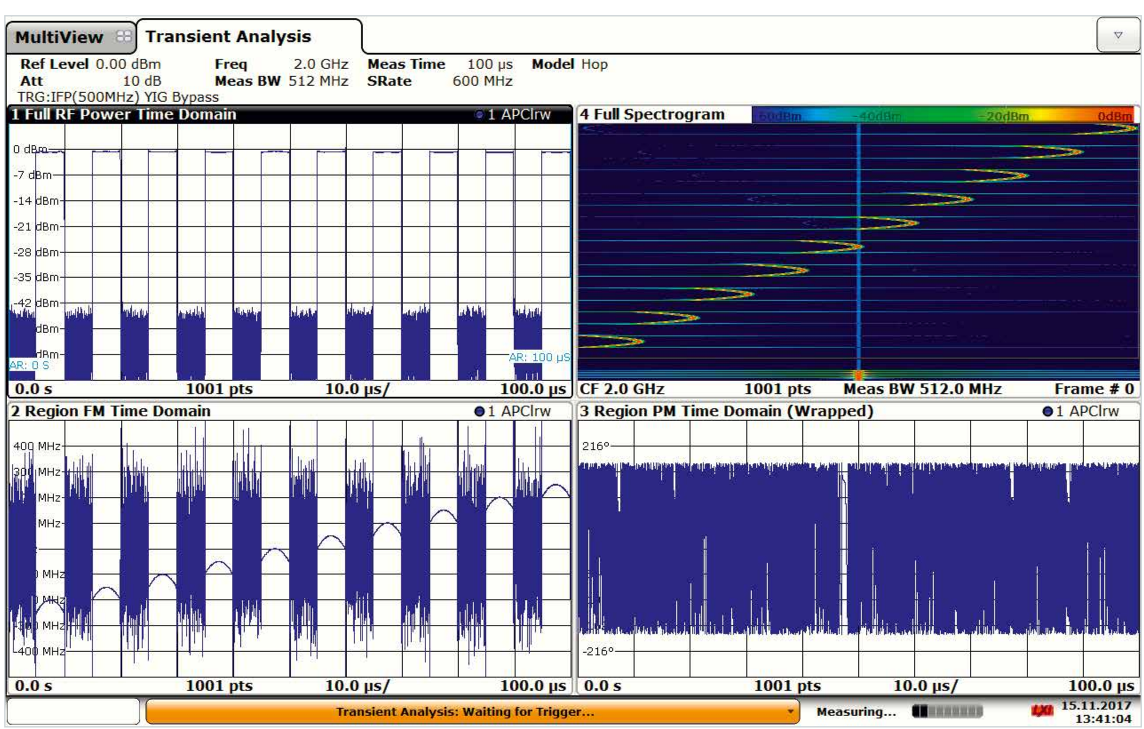


Fig. 2: Plot of a signal generated with PDW streaming and an arbitrary waveform segment: ten pulses, each with its own frequency offset and nonlinear frequency modulation.

Analysis of frequency agile radar systems and ultrashort pulses

Advanced radar systems are able to change the signal frequency and modulation from one pulse to the next. In order to test these frequency agile systems, the test instruments must have a large analysis bandwidth.

Frequency agile radars and jamming systems

Rapid frequency hopping makes radar systems more resistant to atmospheric disturbances, targeted attacks (jamming) and unwanted signals (interference). To increase resolution, these systems additionally alter the modulation, pulse width and pulse sequence depending on the target. Pulses in the nanosecond range are not uncommon. Analysis of such systems typically involves measuring the frequency hops or the modulation quality of pulse compression. That requires a large bandwidth for acquiring the emitted signal.

Jamming systems use targeted interference signals to try to impair the sensitivity of the enemy radar or even make it totally blind. Wideband noise-like signals or frequency agile signals are used for this purpose. These systems may change frequency very often, simply send back the received radar signal or sweep rapidly through a frequency range. That can disrupt even frequency agile radar systems. Wideband signal acquisition during development and verification of radar systems or sophisticated jamming systems enables a detailed analysis of the frequency hops and the effectiveness of various algorithms.

Large internal analysis bandwidth

The R&S®FSW signal and spectrum analyzer with the R&S®FSW-B2001 option provides an internal analysis bandwidth of 2 GHz. That allows the instrument to resolve rise times in the nanosecond range. The A/D converter is integrated into the analyzer, eliminating the need for a wideband oscilloscope for data acquisition. The R&S®FSW-B2001 option features low distortion of input signals with a large dynamic range. The spurious-free dynamic range (SFDR) is an outstanding 60 dBc. These characteristics are important not only for precise determination of signal modulation quality, but also to avoid interpreting internally generated spurious signals as true reflections (“phantom targets”).

In addition, the R&S®FSW signal and spectrum analyzer can be equipped with the R&S®FSW-K60/K60H option to enable automatic analysis of frequency hops. This option detects the initial and target frequencies of a hop, determines the offset, and measures how long a frequency is occupied or how long the system takes to change to the next frequency. The analyzer produces a table listing all frequency hops and time parameters (Fig. 1) Users can display deviations with respect to a predefined list or specify a tolerance range for frequency hop detection.

Analysis of ultrashort pulses

A large measurement bandwidth is not only useful for characterization of frequency agile systems over a broad frequency range. It is also advantageous for measuring ultrashort pulses or wideband modulation of the pulses.

The R&S®FSW-K6 option supports such measurements. It performs detailed pulse analysis, especially for radar applications. The option measures the amplitude, frequency and phase of the pulses and displays them versus time. Pulse rise and fall times, pulse repetition rates and many other parameters are automatically detected and listed in a table (Fig. 2). The option can display trends of parameters, such as the pulse repetition rate, over an extended time period. This can be very useful, for example in scenarios where the aim is to deceive the enemy radar. For this purpose, the targeted aircraft transmits a similar signal in modified form to give the impression that the aircraft is closer to the radar antenna than it actually is. In response, the enemy radar reduces its sensitivity and loses the target. Examination of this type of scenario, which is called range gate pull-off (RGPO), requires trend analysis of several parameters over an extended time period. Segmented acquisition, in which only the pulses are acquired and timestamped, is useful for this purpose. The intervals between pulses are ignored, greatly increasing the number of pulses that can be acquired and used for analysis.

The R&S®FSW-K70 vector signal analysis option is intended for pulses with complex modulation, such as binary phase shift keying (BPSK). It can also be used with an analysis bandwidth of 2 GHz. It does not provide a detailed pulse analysis, but it can analyze the modulation quality of a wide variety of digitally modulated signals.

Ultrawideband (UWB) radar

UWB radar systems use a significantly broader spectrum than conventional systems. They operate with pulses having widths of only a few nanoseconds and low power. The spectrum is very broad and resembles white noise. That makes unwanted interference to other applications unlikely. The spectrum width of a UWB radar is at least 25 % of the transmit frequency, which means 2 GHz with a transmit frequency of 8 GHz. An analysis bandwidth of at least 2 GHz is therefore required for analysis of these systems in the UWB band up to 10.6 GHz. Similar technology is currently used for keyless entry systems in the automotive industry to determine the distance between the key and the vehicle.

Dr. Wolfgang Wendler

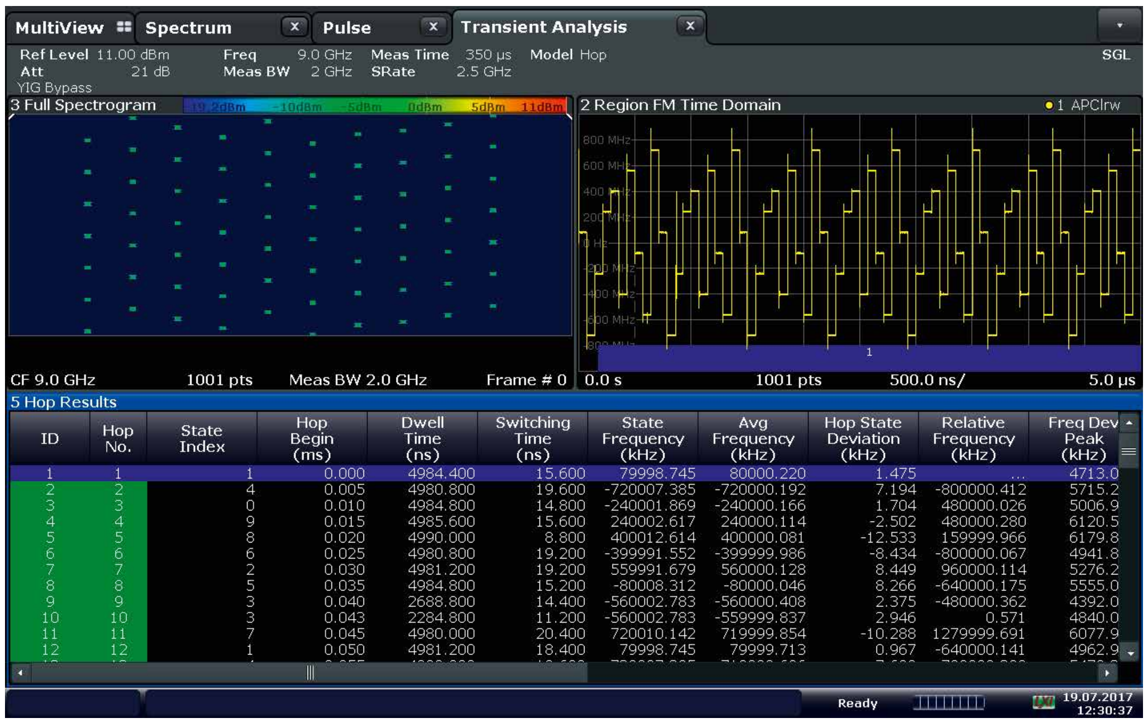


Fig. 1: The 2 GHz spectrogram of a frequency agile signal is shown in the top left window, with a plot of the frequency hops in the time domain to its right and a list of all significant parameters beneath.

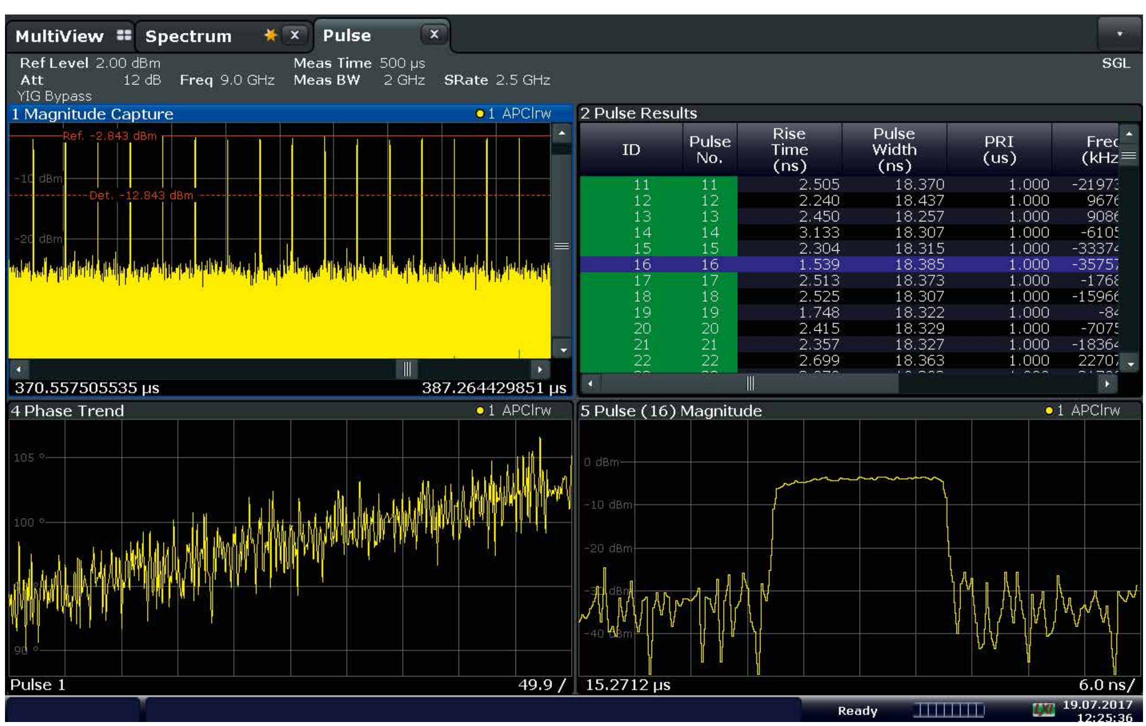
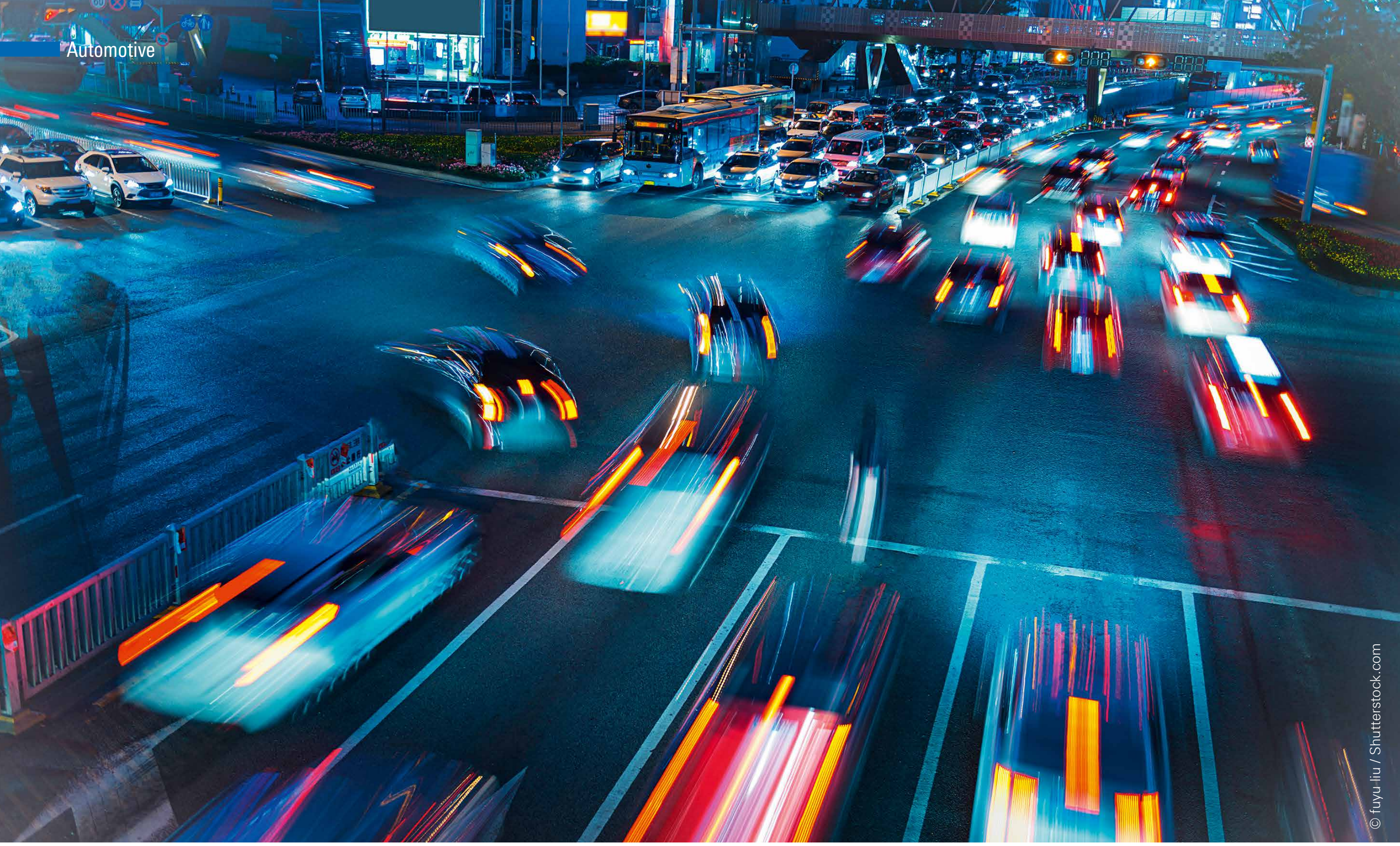


Fig. 2: Time domain analysis of ultrashort pulses (< 20 ns). An enlarged portion of the total acquired signal is shown at the top left, with a list of key parameters to the right (rise time, pulse width, etc.). The amplitude of a selected pulse is shown at the bottom right, with the phase trend to its left.



Enabling autonomous driving

Autonomous vehicles see the world through sensors. The entire concept rests on their reliability. But the ability of a radar sensor to deliver the required performance greatly depends on its installation situation. A new tester provides the necessary insight.

Advanced driver assistant systems that assist the driver and increase road safety are readily available in entry-level vehicles and commonplace in the automotive world. Fully autonomous vehicles (including test vehicles) regularly make the headlines, especially when an incident occurs. These complex systems still have far to go before they are ready for series production, but it is certain that they will become reality in the near future.

Reliable sensors are essential for autonomous driving

Sensors that detect nearby objects are key components for autonomous vehicles. These include cameras and lidar sensors, but especially radar sensors. Millions of automotive radars are produced every year. They are standard equipment in high-end vehicles. Today, automotive radar sensors are mainly used to increase driving comfort and prevent accidents. Most radar sensors that enable adaptive cruise control operate in the 76 GHz to 77 GHz frequency range (1 GHz bandwidth) to sense other vehicles and objects far ahead. Advanced functions, especially those that sense nearby objects – such as lane change assistance and blind spot detection – require larger bandwidths to achieve the necessary high range resolution. This is available in the 77 GHz to 81 GHz frequency range. Additionally, the extended automotive frequency band up to 81 GHz helps mitigate radio interference.

For reasons having more to do with appearance than functionality, automotive radars are covered by a radar dome (radome) constructed from a material transparent to RF signals. The emblem on the grille is often used for this purpose, but plastic bumpers are also good hiding places for radars. In the past, emblems mainly promoted the brand and had no other significant role. However, their use as radomes now makes them more like RF components. If that is not taken into account in their design, it can have a very adverse impact on the detection performance and accuracy of the radars behind the emblems.

In particular, the three-dimensional shape of brand emblems with locally varying material thickness can cause RF performance problems for operation in the millimeterwave band. Bumpers are typically coated with metallic paint, which attenuates high frequencies. To ensure radar reliability, it is therefore essential to validate the material properties of radomes and examine their influence on radar signals. Uncertainties and risks in automotive sensors are unacceptable for autonomous driving because any errors originating here cannot be adequately corrected by postprocessing. Consequently, vehicle manufacturers and their suppliers need new measurement capabilities to be able to evaluate the radar conformity of radomes.

Radomes can significantly degrade radar performance

Automotive radar sensors mainly use frequency-modulated CW (FMCW) signals. Due to the propagation delay and the Doppler frequency shift, the sensors can measure and resolve the range and radial velocity of multiple targets. Depending on the antenna array properties, it is also possible to measure and resolve the azimuth and even the elevation angle. After detection and tracking, the sensor electronics processes the signal to generate a target list that contains the measured positions and velocities of the objects and also type information (pedestrian, car, etc.). This list is sent to the vehicle's electronic control unit where it is used to make realtime decisions for vehicle maneuvers. The accuracy and reliability of this data is extremely important for the safety of the vehicle and its passengers.

The accuracy of a radar depends on many factors, such as hardware components, software processing and the radar echo itself. The parameters of signal echoes with a low signal-to-noise ratio (SNR) cannot be measured as accurately as those with a high SNR. In addition, effects such as multipath propagation and distortion due to radomes greatly impact measurement accuracy. Inaccuracies in the azimuth measurement cause the target to appear misplaced from its actual position. This is illustrated in Fig. 1. An angular measurement error of only 1° at the radar sensor would cause a target that is 100 m away to appear to be laterally displaced by 1.75 m. This displacement could cause the target to be interpreted as being in a different lane. To ensure reliable operation, the angular measurement error at such distances must be significantly less than 1°.

Problems of a standard automotive radar

Fig. 2 shows the effect of azimuth displacement based on measurements on real automotive components. A commercial off-the-shelf automotive radar was presented with a static target at a distance of 12.4 m and an angle of 11.5°. The chart shows how different radomes influence the radar cross section and angle of incidence.

The values shown in blue (without a radome) are provided for comparison. As can be seen, there is no effect on the estimated angle of incidence when a suitable radome (red) is used. However, the radar cross section is reduced by the two-way attenuation (in this case about 2 dB). If an unsuitable radome is used (orange), the average radar cross section drops by about 4 dB relative to the comparison measurement, which can prevent detection of weakly reflecting targets. The effect of the unsuitable radome on detecting the angle of

Incorrectly detected location due to azimuth measurement error

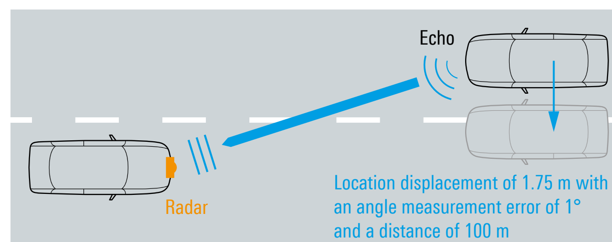


Fig. 1: Location of targets is incorrectly detected due to azimuth measurement errors. The autonomous vehicle controller could respond with a fatal maneuver.

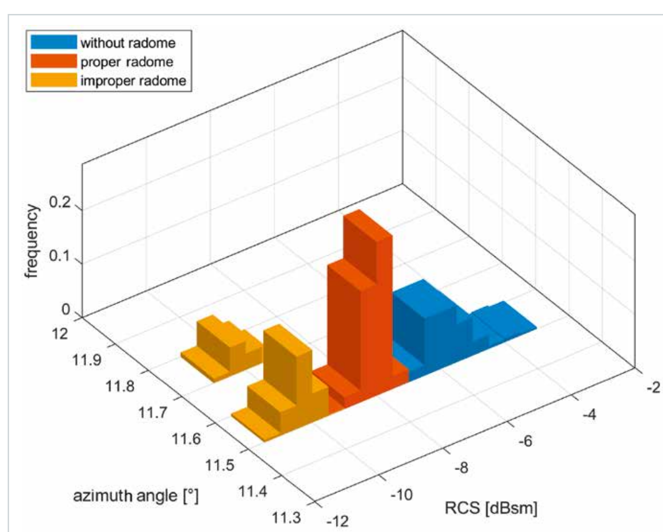


Fig. 2: Influence of different radomes on radar cross section (RCS) and angle of incidence. Unsuitable radomes can cause angle errors.

incidence is also visible. It is no longer seen at a constant 11.5°, but instead as alternating between 11.5° and 11.7°, so the signal processing electronics do not obtain an unambiguous value. With this radome, automotive radars cannot meet the target accuracy of 0.1°.

Radar calibration alone is not enough

A modern radar sensor with an antenna array in the receiver frontend determines the azimuth (and sometimes also the elevation angle) by measuring the phase and amplitude ratios obtained from beamforming with a phased array antenna. For optimal azimuth accuracy, each radar sensor must be individually calibrated. The following procedure is typical for radar calibration. First the sensor is mounted on a turntable in an anechoic chamber. A corner reflector in far field at a known distance is often used as the reference target. The radar pattern is then measured and stored in the sensor memory. This information is used later by the detection algorithm. Correction is calculated during signal processing and takes place during operation.

The vehicle manufacturer integrates the calibrated radar sensors in the vehicle, often behind an emblem or the bumper. The RF transmission loss of the radome material attenuates the signal twice because the signal must pass through the material on the way to the target and on the way back. This reduces the radar's detection range, as can be seen from the following analysis.

According to the laws of signal propagation, the power of the transmitted signal is inversely proportional to the square of the range r, which means it is reduced by the factor $1/r^4$ over the round trip. For a 77 GHz radar with 3 W output power, 25 dBi antenna gain, a target with a 10 m² radar cross section and a signal detection threshold of –90 dBm, the maximum range of this configuration would be 109.4 m using this equation. If the two-way attenuation of the radome is 3 dB, the maximum range of the same radar is reduced by 16 % to just 92.1 m.

But material attenuation is not the only factor that impairs radar performance. The reflectivity and uniformity of the radome material are also important. Reflections, for example from metallic particles in the paint, and RF mismatch of the base material produce interference signals within the radome, i.e. close to the sensor. These interference signals are received and downconverted in the receiver chain, reducing the radar's detection sensitivity. Many vehicle manufacturers try to mitigate this effect by tilting the radome so the emitted radar signal is reflected elsewhere and not directly back into the receiver frontend. This solution is naturally subject to design constraints, and it does not eliminate the parasitic reflections that cause loss of RF energy.

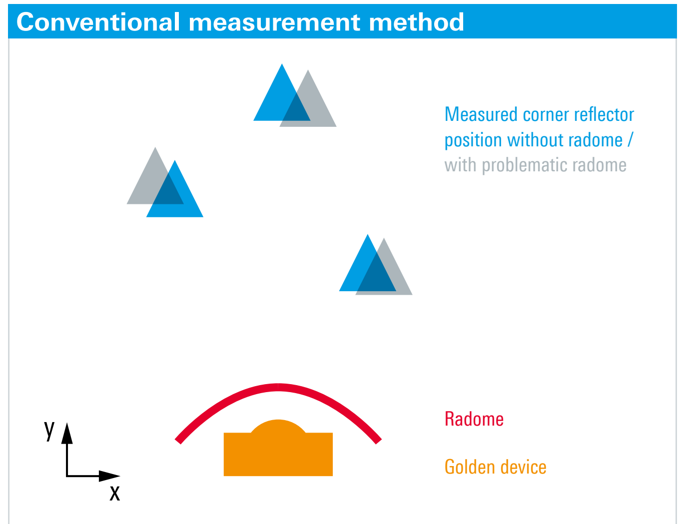


Fig. 3: Typical test setup with a golden device.

Another problem is that material inhomogeneities such as inclusions and density variations disturb the outgoing and incoming wavefront. It is distorted, leading to less accurate angle measurements. Radar sensor calibration cannot compensate for this effect because the calibrated radar may be mounted behind radomes from different manufacturers.

Conventional radome testing

Radome manufacturers typically use a reference radar (golden device) to test their products. For this test, corner reflectors are mounted in front of the radar at predefined distances and azimuth angles (Fig. 3). Differential measurements are conducted with and without the radome and then compared. The radome passes the test when the distances and azimuth angles determined by the radar and the echo signal levels are within specified limits. However, this method only checks specific azimuth angles, making it easy to miss problem areas in the radome.

Another measurement method works in a similar manner but needs only one reflector. In this method, the radar sensor and radome are mounted on a turntable and the measurement is repeated at different angles. The actual angle, which can be read from the turntable (ground truth), and the angle measured by the radar are compared. This method is as accurate as the positioning accuracy of the turntable. However, this test takes a very long time and is therefore not feasible for production line tests.

Conclusive tests at the push of a button with the R&S®QAR radome tester

The R&S®QAR quality automotive radome tester (Fig. 4) overcomes the limitations of traditional methods. Instead of a golden device with a tiny antenna array, it uses a large panel with several hundreds of transmit and receive antennas operating in the extended automotive radar frequency range from 75 GHz to 82 GHz. It "sees" what an automotive radar would see if it also had hundreds of antennas. But thanks to the large aperture, it measures range, azimuth and elevation with a much higher resolution (in the millimeter range). This high resolution allows the measurement results (i.e. reflectivity) to be visualized as an X-ray image, enabling immediate quality assessment even by persons with limited test and measurement experience. Unlike measurements with real radars, time-consuming measurement sequences are not necessary to determine the radome properties – the R&S®QAR obtains results in a one-shot process, similar to taking a picture with a camera.

The radome under test is placed in a specified area in front of the panel. Two measurements are possible – one to determine the reflectivity of the DUT, the other to determine its transmissivity.

First, a reflectivity measurement is made to determine how much energy is reflected by the radome material. This is the energy that does not pass through the radome. It degrades the performance or even, as described above, impairs correct operation. Certain areas can have higher reflectivity for various reasons, e.g. material defects, air inclusions, unwanted interactions between different material layers, or an excessive amount of certain material components. The measurement method delivers spatially resolved measurement results by coherently linking all reflected signals according to magnitude and phase. The visualization of the results allows intuitive and quantitative assessment of the DUT's reflective behavior.

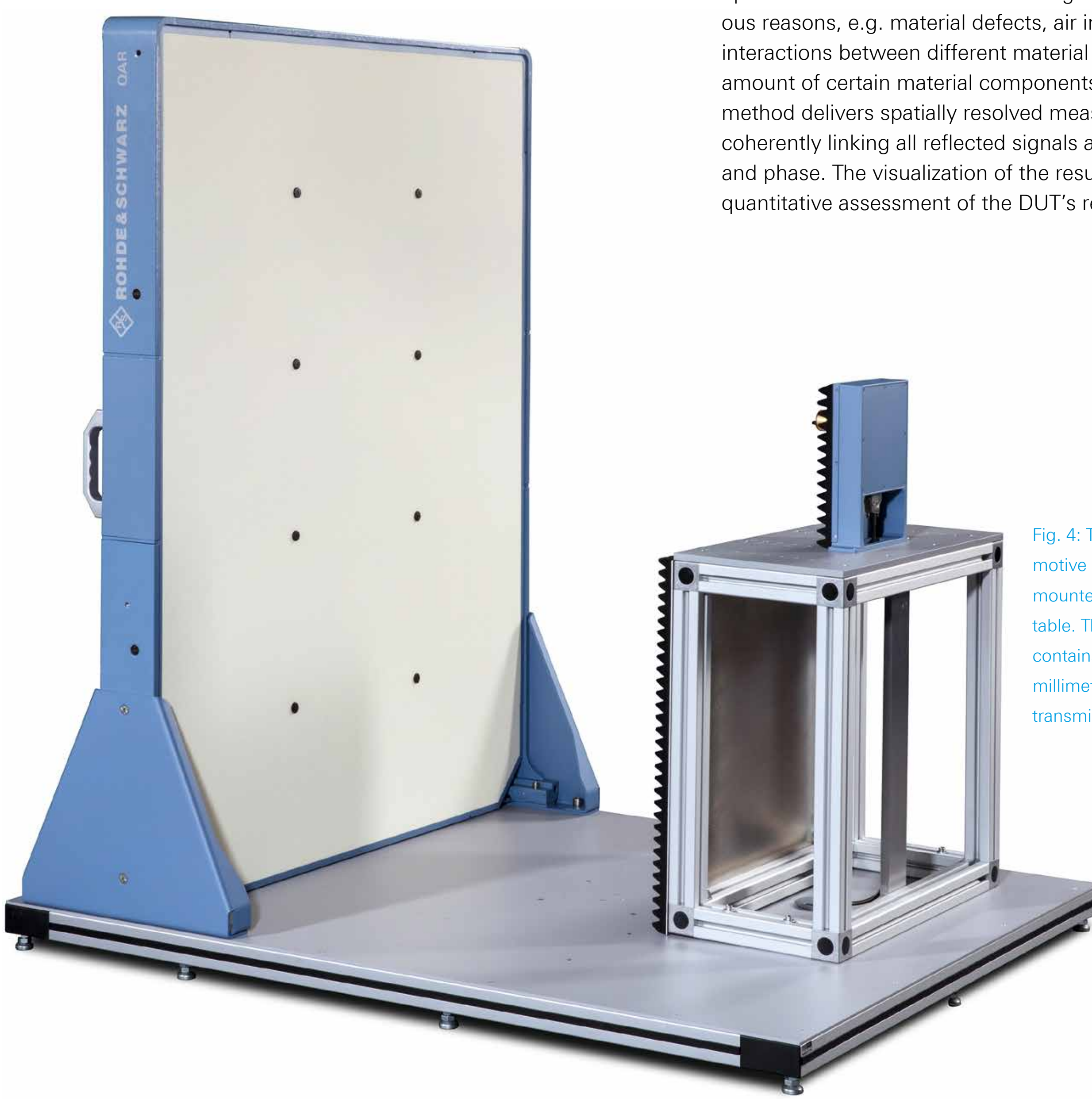


Fig. 4: The R&S®QAR quality automotive radome tester. The DUT is mounted at the front edge of the table. The blue unit on the table contains the optionally available millimeterwave transmitter for transmission measurements.

For demonstration purposes, a demo radome was produced that contains the Rohde & Schwarz logo milled with different thickness (Fig. 5).

The high-resolution radar image in Fig. 6 shows what a radar sensor covered by this radome would see. The brightness levels represent the reflectivity. The brighter an area, the more it reflects the radar signal. Metal objects show up as white (the screws in the four corners). The clearly visible contours of the logo indicate localized high reflectivity and a very non-uniform overall image. The greater thickness of 0.5 mm in the logo area would be enough to considerably degrade radar performance on the road.

In this example, the middle of the radome where the sensor is usually mounted has an average reflectivity of –11.0 dB with a standard deviation of –18.2 dB. In many use scenarios, this is too high to ensure reliable radar operation. In practice, the expected reflectivity depends on the sensitivity of the radar unit and the maximum detection range to be covered.

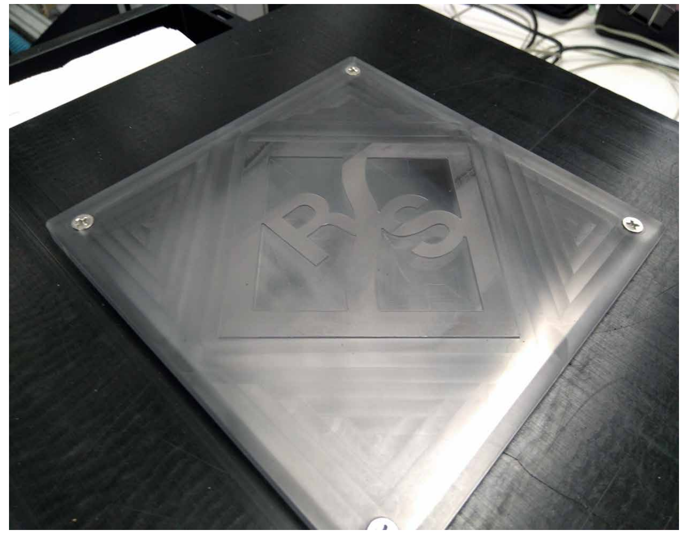


Fig. 5: Demo radome with the Rohde & Schwarz logo protruding only 0.5 mm above the surface of the radome body. Even this small increase in thickness leads to a mismatch at 77 GHz (Fig. 6).

Next, the frequency matching and attenuation of the radome material are measured. A transmitter unit located behind the DUT (Fig. 4) sweeps over a selected frequency span. This allows precise assessment of the radome's transmission frequency response. The frequency response delivers detailed information about the RF matching of the DUT at the exact

Fig. 6: High-resolution millimeterwave image of reflectivity (left) and one-way attenuation (right). The blue outline in the logo indicates the radiation cross section of the test transmitter or radar. This area is used in the assessment.

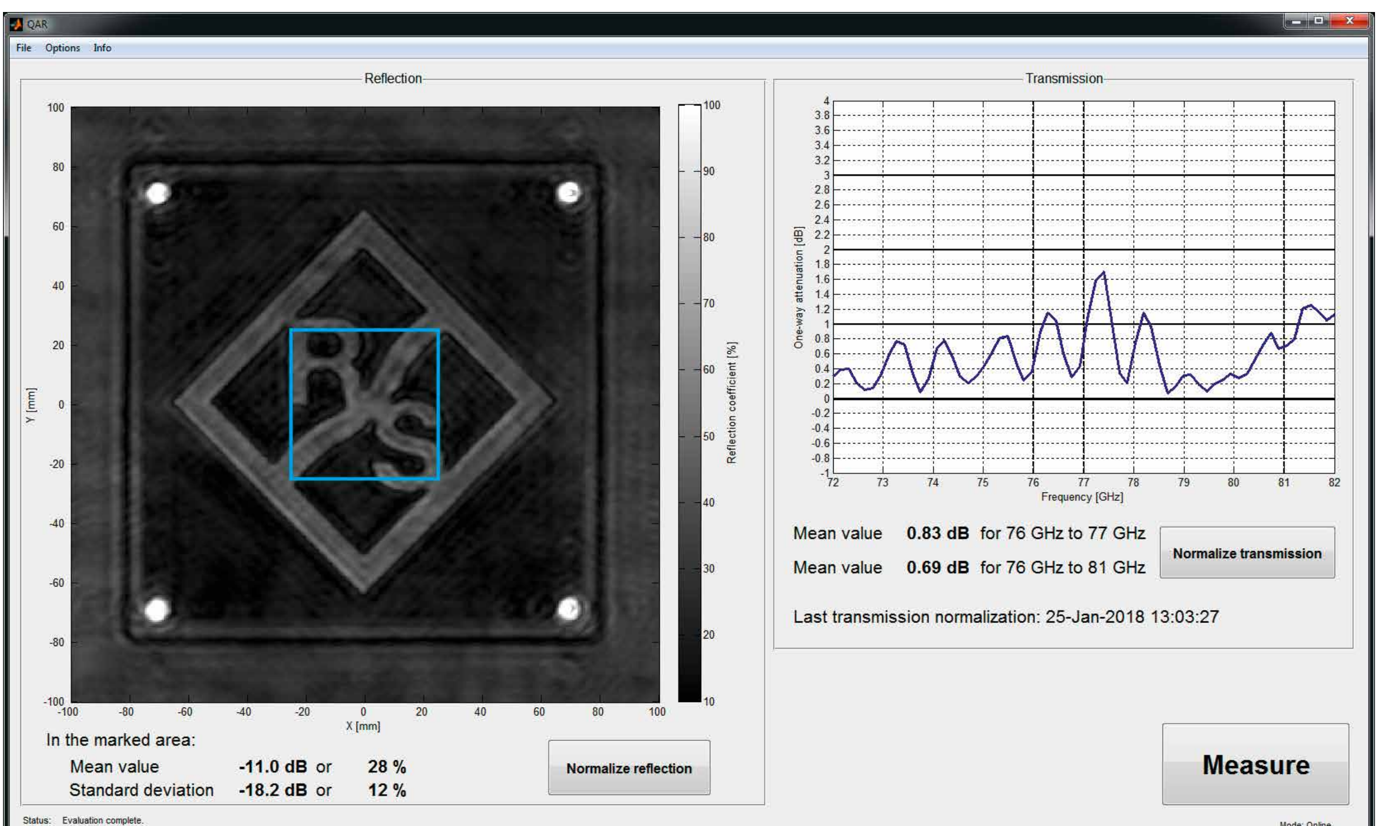
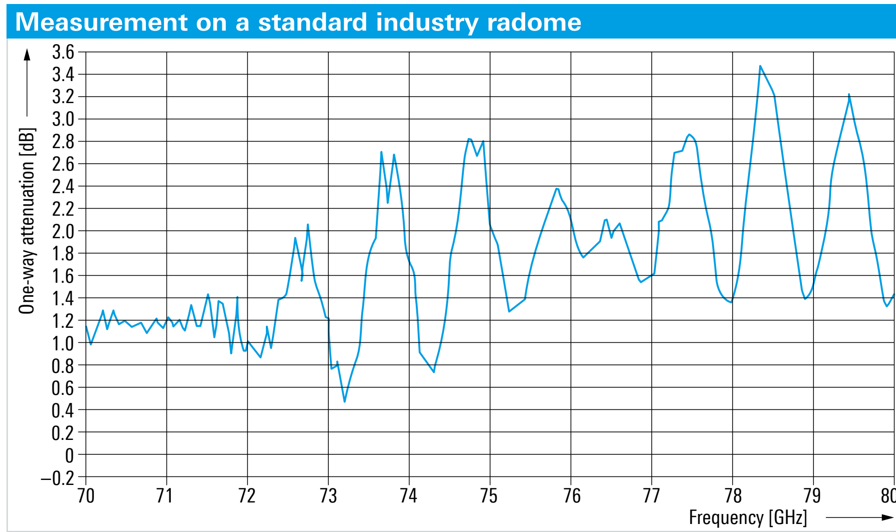


Fig. 7: Transmission measurement on a commercial multilayer radome with a complex 3D design.



frequency band intended for radar operation. This information is independent of the actual signal waveform used by the radar unit and is therefore valid for all types of radars that can be installed behind the radome.

The graph on the right in Fig. 6 shows this measurement for the demo radome. Due to the high waviness between 76 GHz and 79 GHz, this radome would not be suitable for radars in that frequency band.

A transmission measurement on a real 3D radome from the automotive industry yielded the similarly jagged curve in Fig. 7. This radome would have various performance issues:

- The frequency matching is unfavorably located at around 71 GHz instead of 76 GHz. This is often caused by increased thickness of some radome layers.
- The erratic attenuation variations in the 79 GHz band indicate a significant increase in the standing wave ratio. This indicates reflections at the radome boundaries and strong interference effects.
- The overall one-way attenuation is relatively high, which would result in a noticeable reduction in the detection range.

Summary

Autonomous driving requires radars that reliably, e.g. without errors, detect objects in the surrounding area. Whether this is possible depends not only on the quality of the radar, but also on its installation situation. Radars are often installed behind brand emblems or bumpers. These vehicle body parts (radomes) can degrade the signals to the point that objects are not detected or are detected in the wrong places. Today, such parts not only serve their original purpose but also need to have defined RF properties. Accurate and practical measurement methods are needed to verify these properties. The R&S®QAR tester provides a much faster and better method of assessing the quality of automotive radomes than using golden devices. The R&S®QAR measures the RF transmissivity of the DUT, which reveals the basic suitability of a radome design, and also the reflectivity, which is visualized as a type of X-ray image to allow even nonexperts to make a reliable pass/fail assessment, especially in end-of-line tests.

Dr. Steffen Heuel; Tobias Köppel; Andreas Reil; Dr. Sherif Ahmed

5 GHz analysis bandwidth for testing automotive radars in the E band

The R&S®FSW85 signal and spectrum analyzer now supports analysis bandwidths up to 5 GHz together with the R&S®RTO2064 oscilloscope as an external A/D converter. The analyzer controls the oscilloscope and handles all of the steps involved in transferring, processing, equalizing and analyzing data.

Automotive FMCW radars typically operate in the frequency range from 76 GHz to 77 GHz, although some countries have granted approval for operation between 77 GHz and 81 GHz. Since the range resolution is proportional to the signal bandwidth, manufacturers of these components need high bandwidths during the development process in order to achieve the maximum range resolution.

Spectrum measurements in the E band with the R&S®FSW85

The R&S®FSW85 signal and spectrum analyzer is the first choice for measuring radar sensors' RF parameters such as frequency, effective isotropically radiated power (EIRP) and occupied bandwidth and spurious emissions during development, production and verification. The analyzer scans the range from 2 Hz to 85 GHz (up to 90 GHz with the R&S®FSW-B90G option) and analyzes RF signals produced by radar sensors in the E band. No external harmonic mixers are required.

For frequencies between 8 GHz and 85 GHz, the analyzer is equipped with a narrowband YIG filter for hardware preselection in order to suppress unwanted mixing products.

Compared with solutions using harmonic mixers, the R&S®FSW85 has certain benefits:

- Continuous frequency range from 2 Hz to 85/90 GHz
- Suppression of unwanted mixing products by the built-in YIG filter
- Convenient level settings with the built-in RF attenuator
- Simplified setup with no additional cabling
- Wide dynamic range for spectrum emission measurements

The analyzer's already impressive signal-to-noise ratio can be further improved with the optional R&S®HA-Z24E

Fig. 1: The R&S®FSW85 supports an analysis bandwidth of 5 GHz together with the R&S®FSW-B5000 hardware option and the R&S®RTO2064 oscilloscope as an external A/D converter.

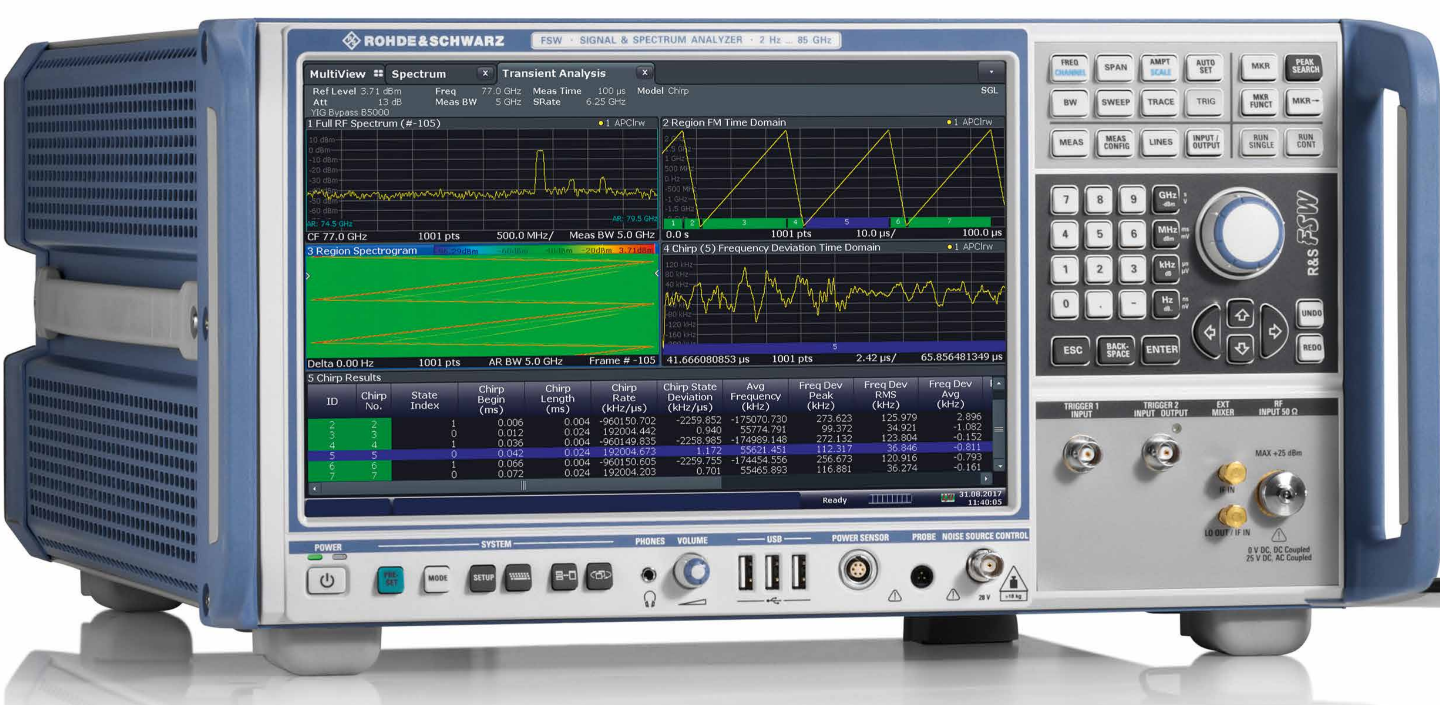


Fig. 2: Using the adjustable legs, the R&S®HA-Z24E external preamplifier can be set to just the right connecting height.

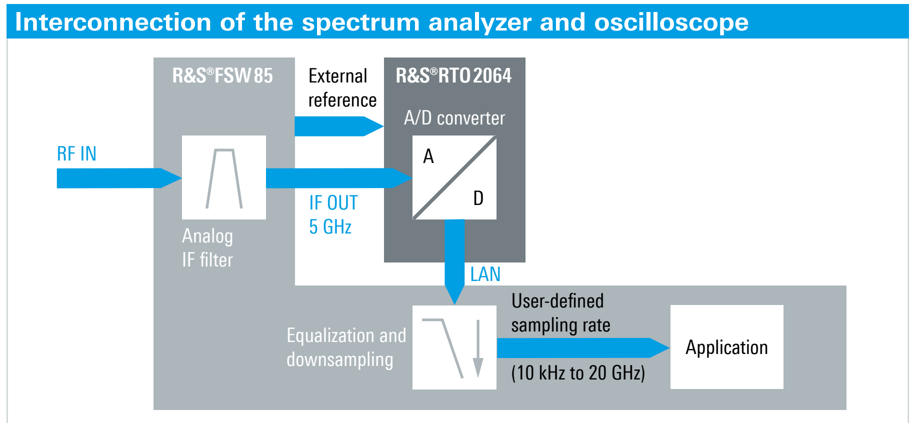
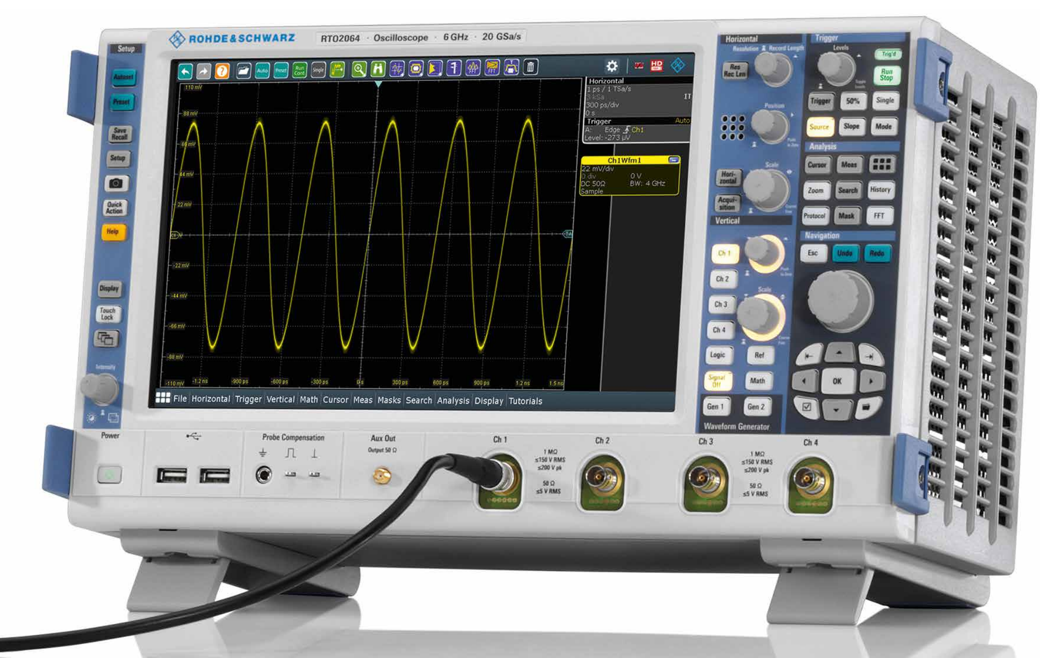


Fig. 3: Signal path for interconnection of the R&S®FSW85 signal and spectrum analyzer with the R&S®FSW-B5000 option and the R&S®RTO2064 oscilloscope for an analysis bandwidth of 5 GHz.

preamplifier between 1 GHz up to 85 GHz (Fig. 2). This is relevant during over-the-air measurements of radar signals.

5 GHz analysis bandwidth

For demodulation and analysis of automotive radar signals in the E band (especially in research and development labs), analysis bandwidths up to 5 GHz are a must. When combined with the R&S®RTO2064 oscilloscope as an external A/D converter, the R&S®FSW85 is capable of supplying these bandwidths (Fig. 1). The analyzer must be equipped with the R&S®B5000 hardware bandwidth option for this application. The R&S®FSW85 mixes the input signal down to an intermediate frequency (IF) of 3.5 GHz, which is digitized by the R&S®RTO and sent back to the analyzer via the LAN (Fig. 3). The analyzer equalizes the signal and mixes it into the digital baseband. The equalized I/Q samples are subsequently fed to the measurement software on the R&S®FSW85. The signal path from the analyzer inputs to the A/D converter in the oscilloscope has been fully characterized in terms of the amplitude and phase response. From the user's perspective, this combination of instruments behaves like a single instrument. The R&S®FSW85 controls the oscilloscope and handles all of the steps involved in transferring, processing, equalizing and analyzing data.



Analysis of FMCW signals

Most automotive radars use chirp sequences consisting of a number of very short linear frequency modulated continuous wave (LFMCW) chirps. A radar's range and speed resolution are dependent on parameters such as the signal bandwidth, chirp duration, chirp rate and signal linearity. Unwanted effects within the radar signal can influence the accuracy and performance of the radar system.

To analyze CW radar signals, the R&S®FSW-K60 transient measurement application can be used. Extensions for

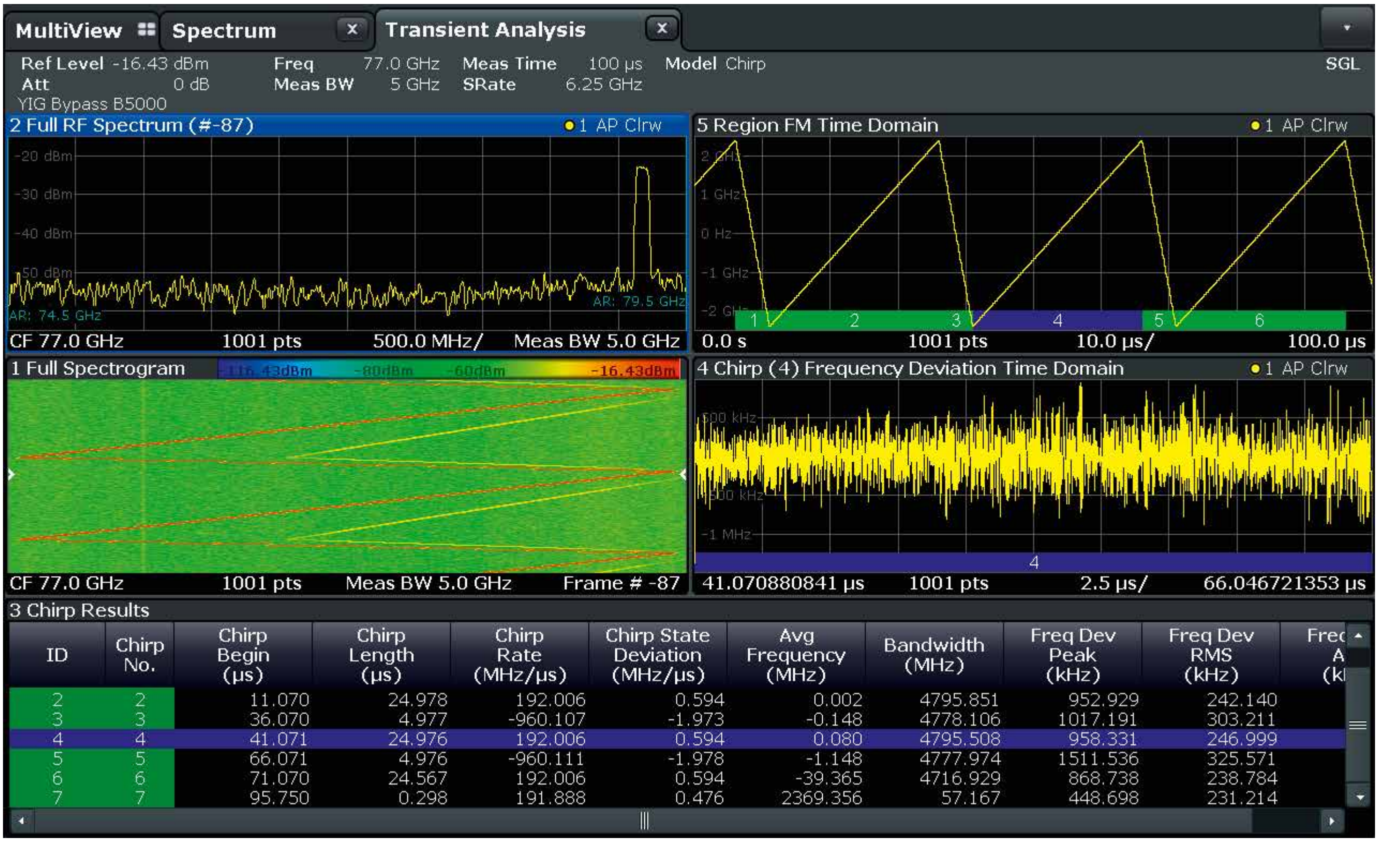


Fig. 4: R&S®FSW-K60 transient measurement application: analysis of chirp signals with the R&S®FSW-K60C extension.

this software support analysis of chirp signals (R&S®FSW-K60C) and frequency hopping signals (R&S®FSW-K60H). The application determines the start and end of individual chirp or frequency hopping signals in the I/Q data acquired by the R&S®FSW. The software calculates all of the performance parameters within a user-defined range, e.g. the measurement bandwidth and time.

Fig. 4 shows the R&S®FSW-K60C measurement application for analysis of chirp signals. In window 1 (Full Spectrogram), the complete content of the I/Q acquisition memory in the time domain (vertically downward) and frequency domain (horizontal) is visible. The color indicates the power level. In this example, six chirps were detected within a measurement interval of 100 µs and a bandwidth of 5 GHz.

Window 2 (Full RF Spectrum) isolates one line from the spectrogram, i.e. the line in the middle that is indicated with two white markers. At this instant, the chirp is just passing a frequency of 79.4 GHz (at the right in the window).

Window 5 (Region FM Time Domain) shows the frequency modulation (FM) vs. time. The green and blue bars indicate the six chirps that were detected. A video filter with 1 % of the demodulation bandwidth (i.e. 50 MHz) suppresses unwanted signals and the noise of the peak detector.

Window 4 (Chirp (4) Frequency Deviation Time Domain) shows the frequency error for one of the detected chirps (4) vs. time. The Chirp Results table lists all relevant parameters for the measured chirps.

Summary

The R&S®FSW85 signal and spectrum analyzer is a user-friendly solution for measuring ultrawide automotive radar signals in the E-band up to 85/90 GHz. Equipped with the 5 GHz bandwidth option, the analyzer uses an R&S®RTO oscilloscope as an external A/D converter. The user operates this combination completely via the analyzer's user interface.

Typical applications include measurements on automotive FMCW radars and on other frequency agile, very short pulse radars. The R&S®FSW-K60 transient measurement option and its extension for chirp signals (R&S®FSW-K60C) as well as the R&S®FSW-K6 pulse analysis option for pulsed radars provide versatile measurement functions for such applications.

Laura Sanchez

Superlative GNSS simulation

The GNSS simulator based on the R&S®SMW200A adds a high-end solution to the Rohde & Schwarz portfolio of satellite navigation system simulators. Its ability to simulate complex interference environments in addition to GNSS signals is unique.

Advanced GNSS receivers are able to receive signals from diverse navigation systems – such as GPS, GLONASS, Galileo and BeiDou – in several frequency bands and in some cases with several antennas simultaneously. Using observations from several frequency bands makes it possible to enhance the position accuracy. Accuracy can be further improved by means of differential GNSS (DGNSS) techniques. They are used in applications such as autonomous vehicles and are indispensable for precise and reliable positioning of aircraft during landing approaches.

Functional and performance tests under the influence of interfering signals are becoming increasingly important in receiver testing. These range from coexistence tests for determining receiver performance under the influence of communications signals such as LTE, to receiver behavior in the presence of intentional interference (jamming) and attempts to mislead the receiver with false position and time information (spoofing). In the latter case, receivers are tested to see how well they detect and respond to spoofing attacks.

Nontrivial lab tests

The large number of tests to be performed, lack of control over the simulation conditions and poor reproducibility prevent testing with live GNSS signals. This is because the conditions are constantly changing under the influence of satellite motion, atmospheric factors and signal reflections on the ground.

By contrast, a GNSS simulator enables comprehensive tests with complete control of the simulation conditions and full reproducibility. Lab simulation is also significantly less

Fig. 1: GNSS simulation with the R&S®SMW200A vector signal generator. To simulate multi-antenna systems, the simulator can be equipped with up to four RF outputs. Two of these are provided by R&S®SGT100A signal generators. The screen shows one of the countless ways to simulate scenarios. Here a lap on the Nürburgring race track is simulated. For each track segment, the simulator generates the position- and speed-dependent signals that would be seen by a GNSS receiver in the vehicle.

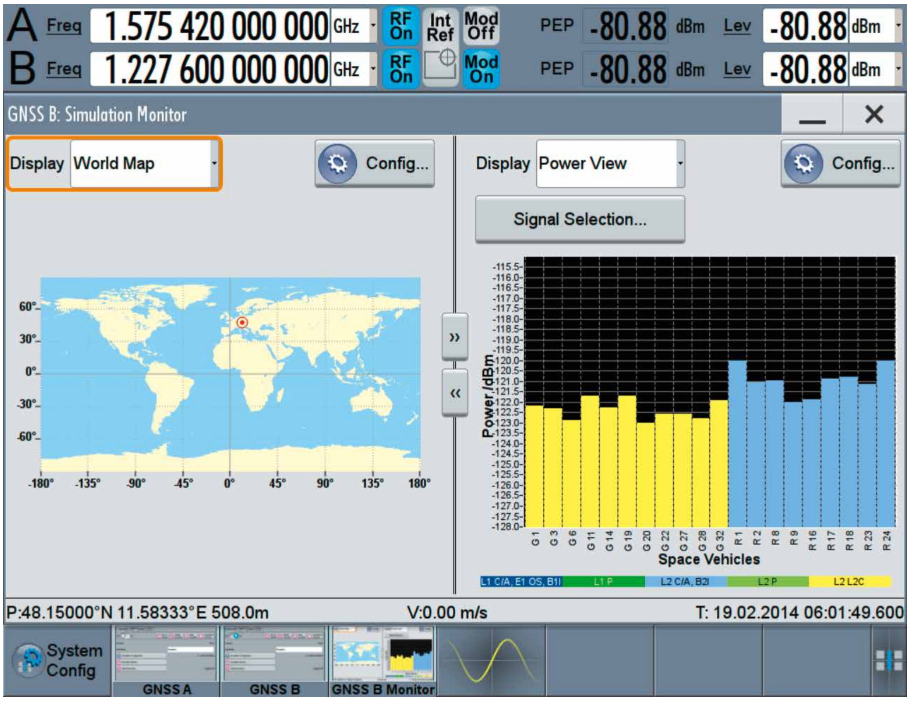


Fig. 2: All settings and status indications can be accessed with just a few touch gestures. The screenshot shows the simulated receiver location on the map and the instantaneous signal levels of the currently visible GPS (yellow) and GLONASS (blue) satellites.

expensive, especially when receivers must be tested under operating conditions that are difficult and time-consuming to implement – such as flight tests and outer-space conditions.

Despite these advantages, lab tests are not trivial. The GNSS simulator must be able to generate complex scenarios incorporating all aspects and properties of a satellite navigation system. In particular, this includes correct simulation of satellite orbits, consideration of signal propagation characteristics and realistic modeling of the receiver environment with signal reflections and obscurations. Furthermore, in many cases the receiver's own motion must be simulated. The system must allow full control over all parameters of these influences.

Additional requirements on the simulation environment arise when the impact of interfering signals on GNSS reception needs to be tested (see box). For example, the relative levels of the GNSS and interfering signals must be user-configurable and alterable during the simulation. To investigate the sensitivity of the receiver to various interferers, a wide variety of interfering signals must be simulated. Ideally, the GNSS simulator should be able to generate them on its own without additional instruments.

Complete simulation of all factors

The R&S®SMW200A vector signal generator's GNSS simulator fulfills all these requirements. It takes into account characteristic effects and error factors such as orbit errors, clock errors, atmospheric factors, multipath propagation and signal obscurations. It models the influence of the receiving antenna and realistically models vehicle movements, including simulation of vehicle orientation angles.

For testing multifrequency receivers or multi-antenna systems, up to 144 GNSS channels are available and can be distributed over several RF outputs. The R&S®SMW200A can be equipped with two RF outputs. If four outputs are required, the user can expand the setup at any time with additional R&S®SGT100A signal generators (Fig. 1). In addition to GPS, GLONASS, Galileo and BeiDou GNSS signals, the system generates signals of the Japanese QZSS system and the satellite based augmentation system (SBAS), with support for the most important implementations of these systems (WAAS, EGNOS, MSAS and GAGAN).

Besides GNSS scenarios, the R&S®SMW200A provides internally generated and user-configurable interfering signals for complex scenarios with multiple interferers. This includes simple CW signals, noise with configurable bandwidth and communications signals such as LTE or WLAN for coexistence tests. Typical GNSS jammers – for example, in the form of frequency sweeps – can also be simulated, as well as pulsed signals e.g. to test the influence of radar signals. Implementing complex jammer scenarios often requires modeling the motion of the GNSS receiver and the motion of the interferer in order to simulate changes in the angle of incidence of the interfering signal. These scenarios are required for testing anti-jamming systems such as controlled reception pattern antenna (CRPA) and can be simulated by the R&S®SMW200A without additional signal sources.

An external computer is not needed for operating and configuring the generator. GNSS scenarios can be configured quickly and easily via the intuitive touchscreen interface, and changes can be made even during a simulation. Convenient visualization functions give users an overview of the situation at all times (Fig. 2). Simulation parameters can be saved during runtime for later data analysis. Operation of the R&S®SMW200A can also be completely automated using the remote control command set.

High-end simulator and generator

The R&S®SMW200A is more than just a GNSS simulator. It can be configured to meet individual requirements and is therefore a universally deployable high-end vector signal generator. The test setup remains compact and simple because no additional instruments are needed to generate the interfering signals. The instrument can be extended with hardware components, for example additional RF outputs, or retrofitted with simulation features by means of software licenses. The GNSS software is continuously adapted to keep pace with technological progress. Users can rely on the instrument's ability to simulate all innovations in this area, now and in the future.

Dr. Markus Irsigler

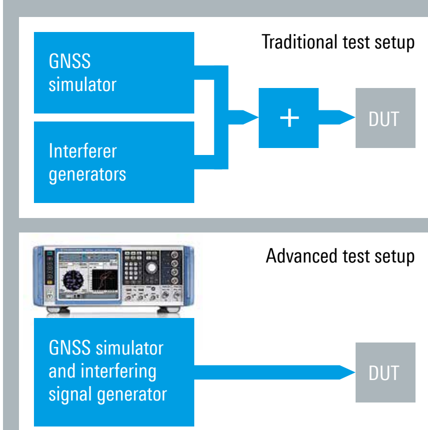
Typology of GNSS interference

Communications signals as interferers
GNSS reception can be impaired by LTE and other communications signals. As part of coexistence tests, receiver performance is determined under the influence of such signals.

Jamming
This refers to intentional interference with GNSS reception. CW signals, wideband noise, frequency sweeps and pulsed signals can be used as interferers.

Spoofing
The aim of this type of interference is to manipulate the position and time information of the receiver in such a way that it is still formally valid but incorrect, thereby making reliable navigation impossible.

Simulation of interference



Complex interference scenarios with the R&S®SMW200A

In this example, an LTE signal, a GNSS jammer (such as a frequency sweep in the L1 band) and a radar signal are simulated in addition to the GNSS signals. Noise is superimposed on the GNSS, jammer and radar signals. Along with the LTE signal, a CW interferer is simulated.

The measurement task

Simulation of interference
To ensure that the simulation of the GNSS reception conditions is as realistic as possible, both the existence of other communications signals and potential jamming or spoofing attacks must be taken into account.

The Rohde & Schwarz solution

GNSS and interfering signals from the same instrument
Along with GNSS signals, the R&S®SMW200A is able to simulate multiple interferers simultaneously. The range of possible interfering signals includes simple CW interferers, a large number of communications signals such as LTE, and pulsed signals. Noise can be superimposed on the GNSS signals and the interfering signals.

The advantages

Simple simulation of interference scenarios
With the R&S®SMW200A, complex interference scenarios for coexistence tests or for testing the impact of jamming attacks can be generated easily. Generating the interfering signals requires no additional instruments.

Squaring the circle

Traditional RF power meters are small and accurate, but they are not very sensitive and have a limited dynamic range. Measurement receivers score well in both disciplines but have disadvantages of their own. Rohde & Schwarz has created a revolutionary new sensor type that combines the strong points of both types of instruments.

Receivers as a fallback solution

It may sound obvious, but for precise power measurements with RF signals the instrument of choice is an RF power meter. Two power detection technologies have become established: thermal measurements and diode measurements. Thermal power sensors determine power based on the heat generated by an input signal in a terminating resistor. Diode based sensors measure power by rectifying the incident RF signal in the square-law region of the diode characteristic. Diode power sensors come in various versions, with multipath and wideband sensors covering the most important applications.

Compared with measurement receivers and spectrum analyzers, which are basically also suitable for RF power measurements, dedicated power meters offer higher accuracy, lower purchasing cost and more compact size. By contrast, receiver based instruments offer higher sensitivity and dynamic range.

The R&S®NRQ6 frequency selective power meter (Fig. 1) was developed to combine the advantages of both types of instruments. It relies on the measurement principle of a receiver, but its hardware concept differs significantly from that of conventional measurement receivers and spectrum analyzers. The key to its exceptional performance is its innovative system concept and smart digital signal processing.

A comparison of typical key data (Fig. 2) demonstrates this quantum leap in RF power meter design. A midrange spectrum analyzer was chosen to represent a typical measurement receiver. The data shows that the R&S®NRQ6 achieves the best performance as it combines the advantages of different measurement concepts. It allows even very low RF powers to be measured fast and accurately. Moreover, it offers

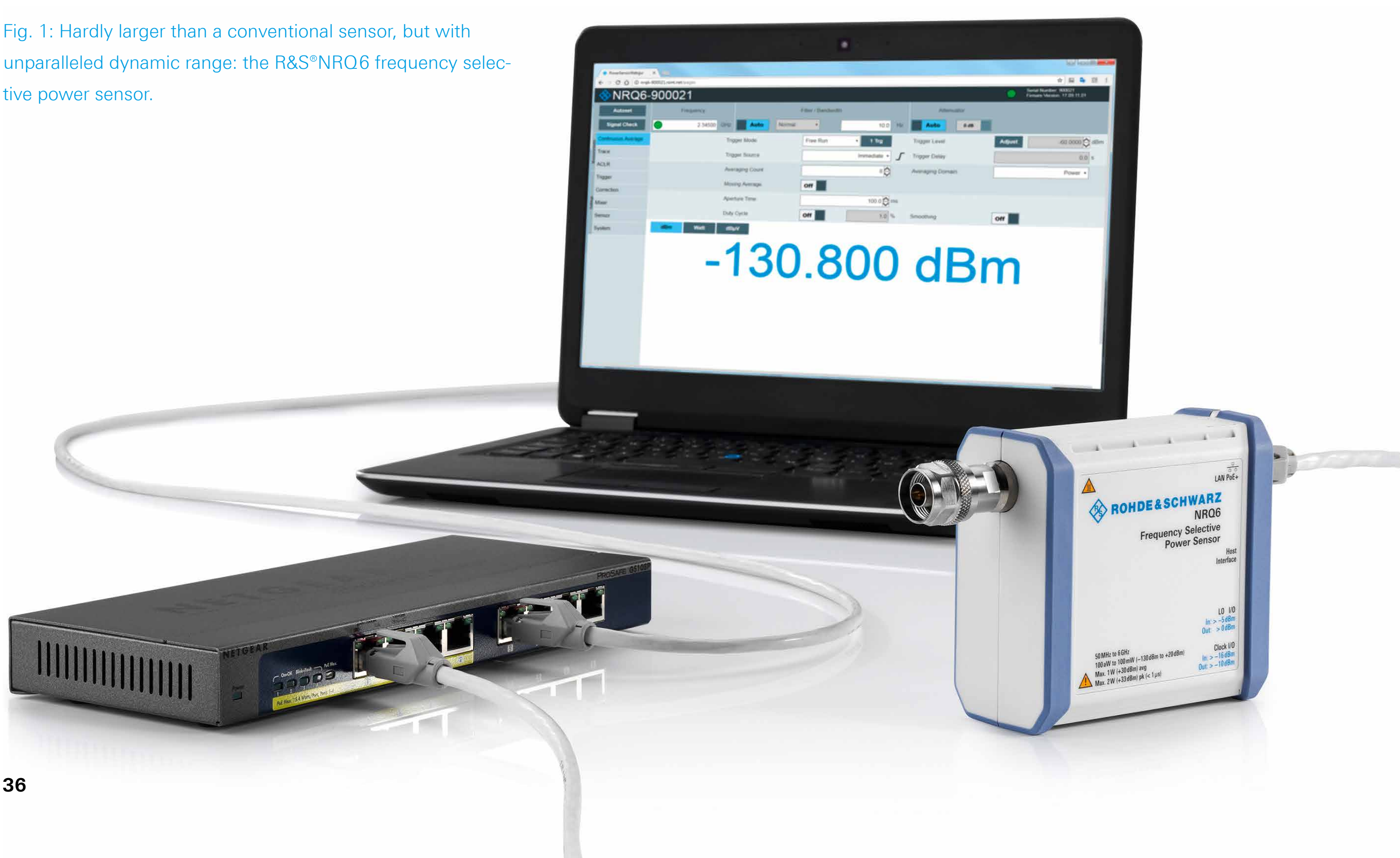


Fig. 1: Hardly larger than a conventional sensor, but with unparalleled dynamic range: the R&S®NRQ6 frequency selective power sensor.

Technology	Lower power measurement limit	Dynamic range	Uncertainty (CW)		Impedance matching (SWR)	Rise time	Lowest power level with a 2σ noise component of ≤ 0.1 dB and 0.1 s measurement time
			Absolute	Linearity			
Thermal (R&S®NRP18T)	–35 dBm	55 dB	0.05 dB	0.01 dB	< 1.13	–	–20 dBm
Three-path diode (R&S®NRP8S)	–70 dBm	93 dB	0.06 dB	0.02 dB	< 1.20	5 µs	–48 dBm
Wideband diode (R&S®NRP-Z81)	–60 dBm	80 dB	0.13 dB	0.04 dB	< 1.20	13.3 ns	–26 dBm
Spectrum analyzer (typ.)	–130 dBm*	160 dB	0.40 dB	0.10 dB	< 1.8	n/a	–104 dBm
R&S®NRQ6	**–130 dBm**	**150 dB**	**0.08 dB**	**0.02 dB**	**< 1.20**	**13 ns**	**–104 dBm**

Fig. 2: A comparison of the key data of different power meter technologies shows the superiority of the new concept.

excellent linearity previously found only in top-class conventional power meters. The sensor can be configured for diverse applications. Depending on the settings, it offers the following:
- A very wide dynamic range that sets a new record among dedicated power meters – outperforming them by several orders of magnitude
- A fast rise time and high video bandwidth previously only achievable with spectrum analyzers and very wideband power sensors

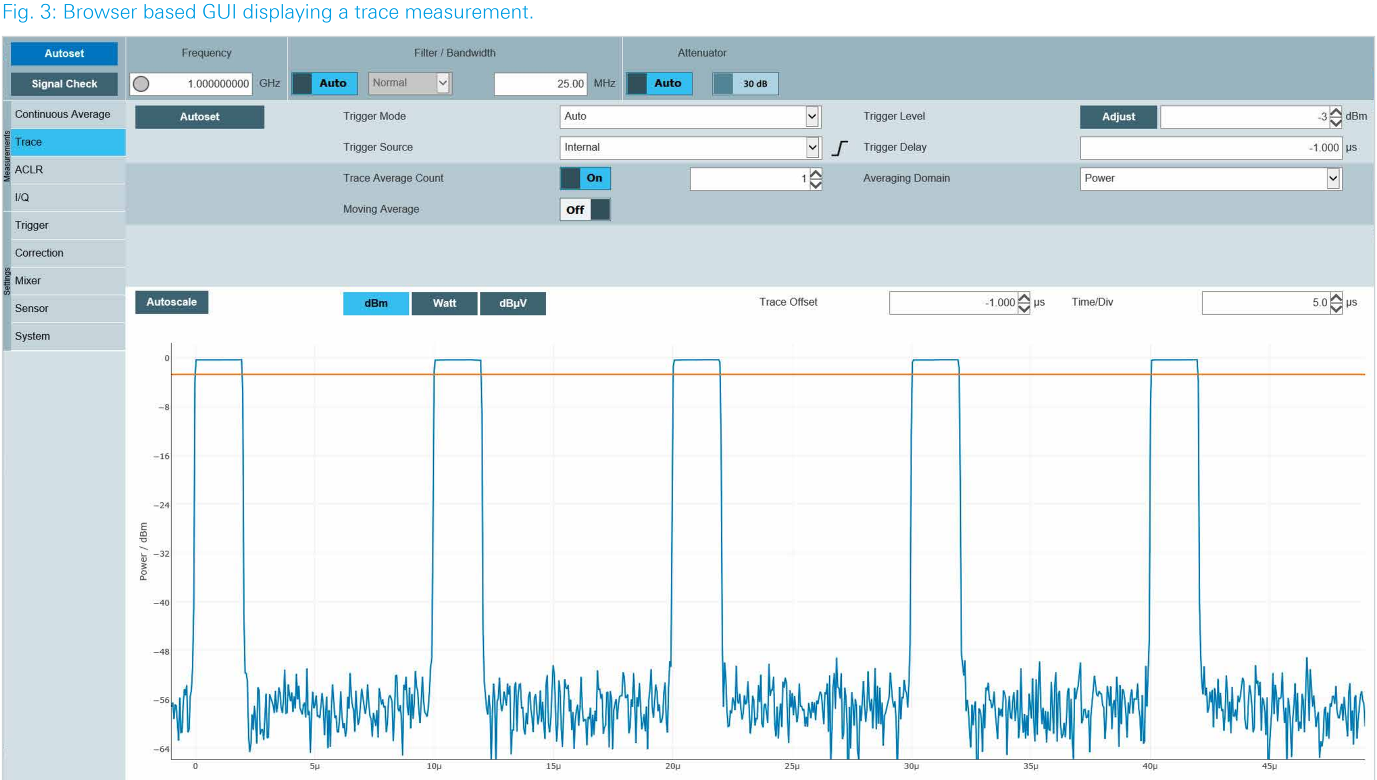
* Typical value for a midrange spectrum analyzer at 100 Hz RBW. The lower power measurement limit is approx. 10 dB above the analyzer's noise floor.

Simple operation as usual

Getting started with the R&S®NRQ6 is very easy. Simply connect the sensor to a LAN via a power over Ethernet (PoE+) switch. The HTML GUI can be accessed from any PC or tablet with a web browser to perform continuous average, trace and ACLR measurements (Fig. 3).

Setting the measurement frequency and signal bandwidth is just as easy. This can be done manually or using the autoset function. Depending on the input level, a 30 dB RF input attenuator is automatically switched on or off to configure the optimal power measurement range.

Fig. 3: Browser based GUI displaying a trace measurement.



Measurement functions

Continuous average power measurements down to –130 dBm

Conventional diode power sensors cannot perform fast and accurate measurements below –70 dBm due to the relatively high inherent noise component measured. The R&S®NRQ6 is based on a receiver architecture which eliminates this problem. Plus, the sensor's ability to perform band-limited measurements reduces the noise power. As a result, the power of narrowband signals can be measured down to –130 dBm, fast and with high precision. As a frequency selective instrument, the R&S®NRQ6 is ideal for measuring intermodulation products, such as harmonics, and for performing measurements on selected transmission channels up to 100 MHz bandwidth. Neighboring channels are not taken into account. This feature is beneficial during measurements on multistandard base stations when users want to measure only one standard (Fig. 4).

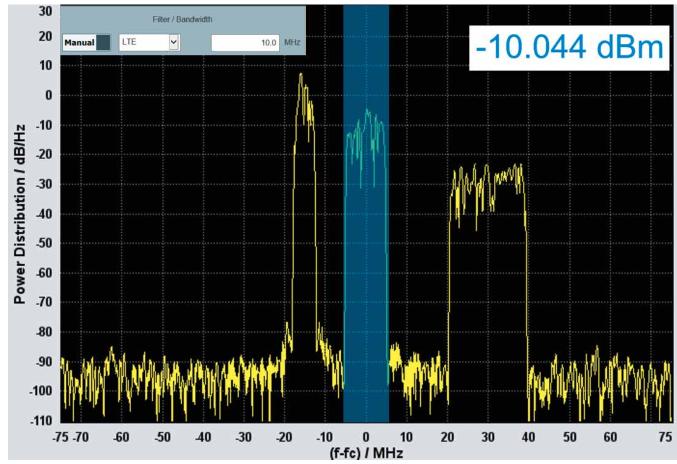


Fig. 4: Selective measurement on a multistandard base station channel – a routine task for the R&S®NRQ6.

Trace measurements

Power measurements on pulsed signals can be carried out in trace mode, which displays signals in the time domain (Fig. 3). With an inherent rise/fall time of 13 ns at a resolution bandwidth of 50 MHz, for example, the R&S®NRQ6 can easily measure steep-edged pulses. The trace mode also offers autoset functions, e.g. to optimally scale the time and power axes. The trigger level is set automatically, ensuring stable display of the measured signal.

ACLR measurements

Adjacent channel leakage ratio (ACLR) is a standard measurement in mobile communications. ACLR measurements can be configured from the web GUI using predefined filters for 3GPP and LTE signals. The filters are set automatically. The R&S®NRQ6 achieves an ACLR performance of typically –63 dBc for a 20 MHz LTE signal at –20 dBm.

When speed is essential: triggered measurements

Triggered measurements call for ever higher measurement speeds over an extended period of time. The R&S®NRQ6 contains a powerful FPGA and a large memory to meet these requirements. More than 100 000 triggered readings can be stored in a buffer in 200 ms – corresponding to a measurement speed of 500 000 readings/s – and transferred to a control PC.

Helpful assistants

Automatic frequency tracking

Drift of the center frequency may occur when measuring power on narrowband signals. If it is not possible to connect the signal source to the R&S®NRQ6 reference frequency input, the frequency tracker will automatically align

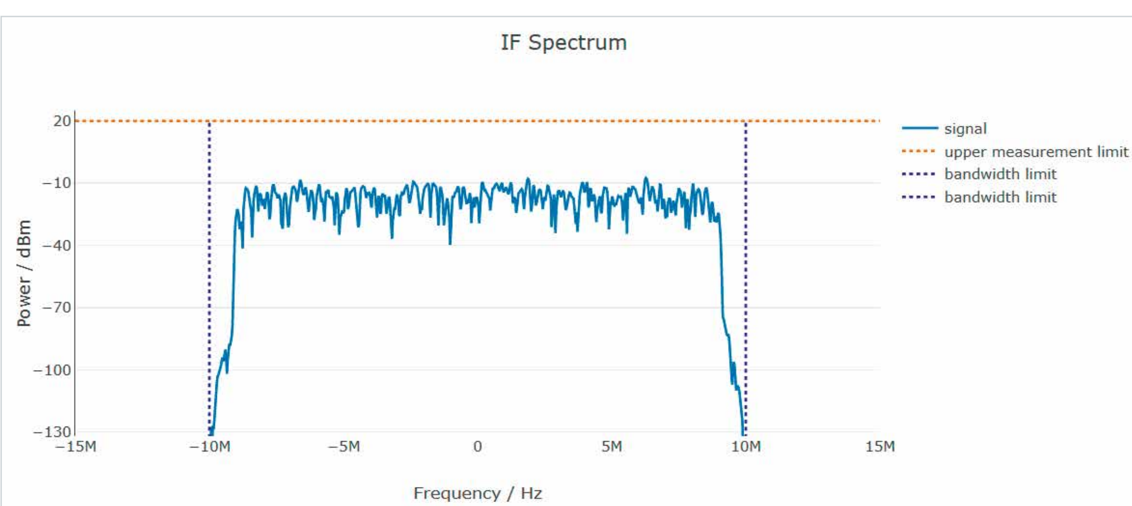


Fig. 5: The signal check function reveals at a glance if the measured signal is within the set frequency range.

the measurement window so that the drifting signal is always within the selected bandwidth.

Spectrum display for signal check

Since power measurements are performed only in the set frequency range (defined by center frequency and bandwidth), the settings must be checked to make sure they are correct. This can be verified at a glance using the signal check function. It graphically displays the test signal, measurement bandwidth and power measurement limit to help avoid any mistakes (Fig. 5).

Applications

The R&S®NRQ6 can be used for all power measurements up to 6 GHz previously accomplished with conventional sensor types. However, its advantages are particularly striking in some applications.

TX power calibration

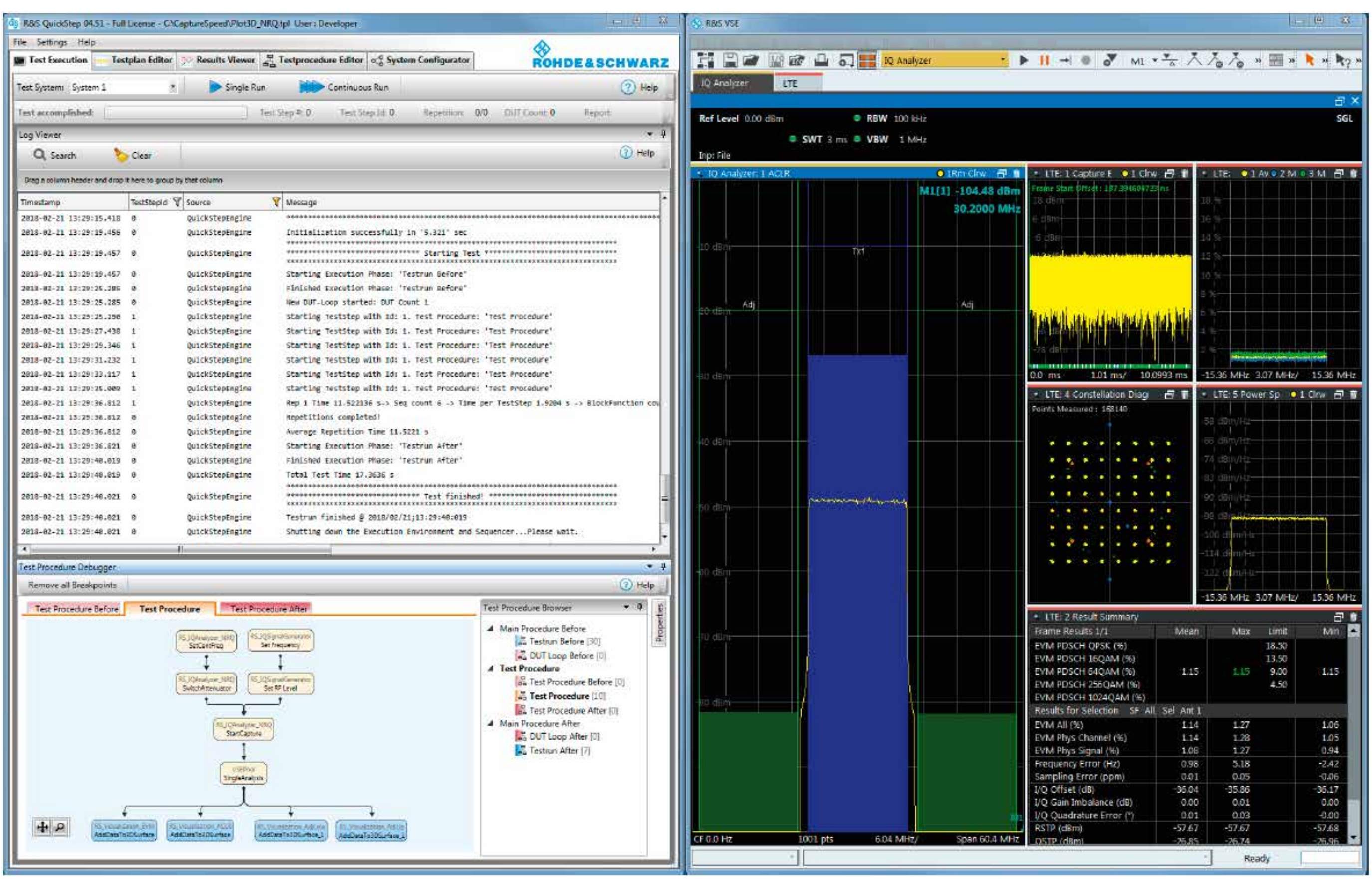
To calibrate a DUT's transmit power, it is necessary to compensate the frequency response at higher levels and measure linearity down to minimum levels. While these tasks previously required several different instruments, the R&S®NRQ6 performs both measurements in a compact, single box. No additional instruments or components such as a splitter and spectrum analyzer are needed. The sensor can be directly connected to the transmitter under test; no cable is required. This solution provides better stability, lower mismatch and higher accuracy.

I/Q data capturing for RF vector signal analysis

The R&S®NRQ6 can be used as a standalone RF frontend to capture vector-modulated I/Q signals. With the optional R&S®NRQ6-K1 I/Q data interface, captured I/Q data can be read out using SCPI commands. The data is demodulated and analyzed using external software. Automated, cloud based signal analysis is also possible using the R&S®Quickstep test executive software. R&S®Quickstep can control any analysis tool to measure error vector magnitude (EVM) and ACLR (Fig. 6).

Dr. Georg Schnattinger; Michael Kaltenbach; Marcel Thränhardt

Fig. 6: The R&S®NRQ6 can be used as a standalone RF frontend for capturing I/Q data. The data is analyzed using external software. Automated data analysis is also possible, for example with the R&S®Quickstep test executive software.



Calibrating network analyzers

Venturing into the vacuum

Fig. 1: Companies in the space industry use thermal vacuum chambers (here at a NASA test facility) to test their components, including entire satellites. During measurements, manual intervention from outside the chamber is not possible. For this reason, test equipment must be calibrated under remote control.

© NASA Image Collection / Alamy Stock Foto

Performing system error correction for network analyzer measurements used to be a tedious task since the calibration units in the test setup had to be connected and disconnected – a time-consuming and error-prone process. Rohde & Schwarz has developed a new series of calibration units that can remain connected to the setup. This increases production throughput and enables automatic testing of spacecraft components under realistic conditions in thermal vacuum chambers.

To make precise S-parameter measurements with network analyzers, system error correction is required before starting the measurements and at defined time intervals. Until now, it was necessary to connect calibration standards to the test cables, disconnect them after calibration and reconnect the DUT. To do so, the user must be able to access the open ends of the test cables, which is not always possible. Moreover, this procedure prolongs test times, increases costs and reduces efficiency on production lines.

Unlike conventional solutions, the new R&S®ZN-Z32/-33 inline calibration units (see details on next page) can remain connected at all times between the ends of the test cables and the DUT. A large number of inline calibration units, and a corresponding number of test ports, can be controlled via the CAN bus, and large distances between the network analyzer and the DUT can be bridged. Users can remotely recalibrate the network analyzer at any time using the R&S®ZN-Z3ASW application software.

Calibration in a vacuum chamber

Inline calibration units are the only solution for tests in thermal vacuum chambers (TVAC), where test sets are not accessible by the user (Figs. 1 and 2). After a base calibration under normal environmental conditions, the T&M components (inline calibration units, cables, auxiliary test equipment, e.g. splitters) are placed in the TVAC. Following evacuation as well as any temperature change in the chamber, recalibration is required due to thermal drift effects in the T&M components. The new solution allows recalibration to be performed at any time.

Efficient multiport calibration in production

During multiport measurements, which are common in production, the limited phase stability of the cables affects the measurement accuracy. A phase change occurs when the cables are moved, e.g. when they are screwed on and off the DUTs or moved with a positioner. Moreover, repeated

Test setup for measurements in a vacuum chamber

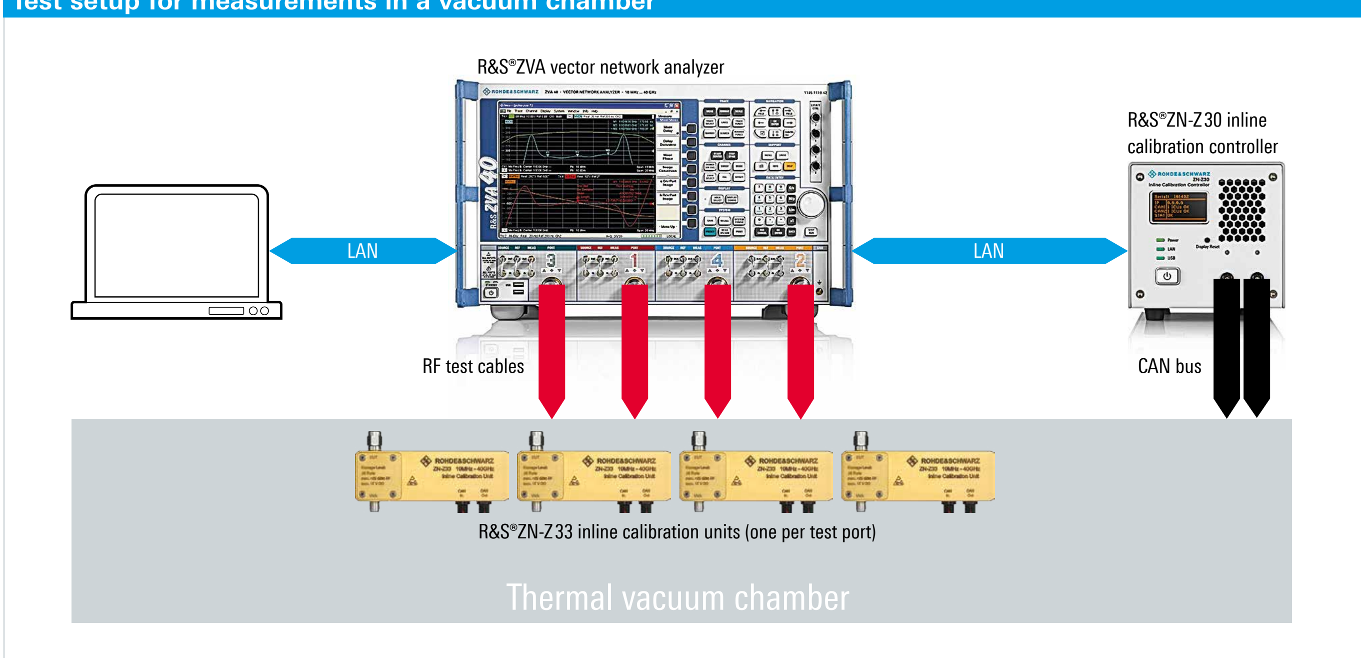


Fig. 2: The control PC, network analyzer and inline calibration controller are located outside the vacuum chamber. For each test port, an R&S®ZN-Z33 inline calibration unit must be connected in the chamber between the test cables and the DUT.

calibration using conventional equipment involves significant effort and time. The new inline calibration units eliminate these drawbacks. They make it possible to calibrate a large number of test ports at the press of a button in the R&S®ZN-Z3ASW application software. Calibration time is typically reduced to a few seconds, boosting production throughput. In combination with an R&S®ZNBT multiport vector network analyzer, for example, these calibration units deliver extremely high efficiency (Fig. 4).

Compact, customized test setups

The R&S®ZN-Z32 inline calibration unit (Fig. 3) operates at frequencies from 10 MHz to 8.5 GHz and at ambient temperatures from +5 °C to +40 °C. The R&S®ZN-Z33 inline calibration unit comes in two models. One model operates in the frequency range from 10 MHz to 40 GHz and at temperatures from +5 °C to +40 °C, whereas the TVAC model can withstand temperatures from –30 °C to +80 °C.

The R&S®ZN-Z30 inline calibration controller can control up to 48 inline calibration units via the CAN bus. With multiple controllers, an almost unlimited number of calibration units – and just as many test ports – can be provided. Users can conveniently configure and calibrate the system via the R&S®ZN-Z3ASW application software, which can be installed on an R&S®ZNB midrange network analyzer, an R&S®ZNBT multiport network analyzer, an R&S®ZVA or R&S®ZVT high-end network analyzer or an external control PC.

Dr. Albert Gleissner

Fig. 3 (from top): Inline calibration units R&S®ZN-Z32 (10 MHz to 8.5 GHz) and R&S®ZN-Z33 (10 MHz to 40 GHz), both with automatic port display, and R&S®ZN-Z33 TVAC model (10 MHz to 40 GHz) for use in thermal vacuum chambers.

Fig. 4: Example of a test setup with the R&S®ZNBT20 multiport network analyzer, R&S®ZN-Z33 inline calibration units and R&S®ZN-Z30 inline calibration controller.

In brief

B class on the starting block

The mid-range class of signal generators is undergoing revision. Analog and vector models up to 6 GHz are now ready.

The mid-range signal generators R&S®SMB100A (analog) and R&S®SMBV100A (vector) have been established on the market for years, but they now have some impressive successors. In the type designations, A has changed to B; the new names are R&S®SMB100B (photo above) and R&S®SMBV100B. However, a lot more has happened with the technology, which was totally redeveloped. Both models have significantly higher output power and better signal quality combined with convenient touchscreen operation. Each signal generator also has its own specific features.

R&S®SMB100B analog RF signal generator

The frequency range of the R&S®SMB100B starts at 8 kHz and extends up to 1 GHz, 3 GHz or 6 GHz depending on the configuration. The base version is configured for CW signals, but the signal generator optionally also supports amplitude, frequency and phase modulation. Other options are available to generate single pulses and complex pulse trains.

The high RF quality of the base version can be further increased if necessary. The OCXO options reduce the aging and temperature dependency of the reference frequency by more than a power of ten and the SSB phase noise by more than 20 dB to –65 dBc (1 GHz, 1 Hz offset). The output power can also be boosted in two stages. The keycode-activated first stage increases the power from 20 dBm to 28 dBm (1 GHz). The ultra high output power option (separate installation required) adds another 6 dB to bring the total output power to +34 dBm – a unique value in this class. The signal generator is attractive in particular for users who want to update an older measuring system with state-of-the-art components. Thanks to the flexible reference frequency inputs/outputs as well as emulation of legacy generators, convenient plug-and-play operation is ensured.

Condensed data

- Frequency range: 8 kHz to 1 GHz, 3 GHz or 6 GHz
- Single sideband phase noise: < –132 dBc (typ.) at 1 GHz and 20 kHz offset
- Wideband noise: < –153 dBc (typ.) at 15 MHz < f ≤ 6 GHz and 30 MHz offset
- Output power: up to +34 dBm (measured) at 1 GHz

R&S®SMBV100B vector signal generator

Like its analog counterpart, the major strength of the R&S®SMBV100B lies in the high signal quality even at high levels. Bandwidth-hungry applications in sectors such as mobile communications and A&D can take advantage of the 500 MHz modulation bandwidth with extraordinarily low modulation frequency response (< 0.2 dB, meas.). The output power can be optionally boosted up to +34 dBm (1 GHz), eliminating the need for external amplifiers, simplifying test setups and improving the specifications. The automatic frequency response correction is also designed to improve overall performance. In this manner, the transmission characteristics of components in the signal path can be dynamically compensated – comparable to de-embedding in network analysis. The new model also delivers impressive flexibility. Many of the options are software-based, i.e. they are dormant in the signal generator and only require a keycode for activation. Time-limited licenses are another attractive possibility. They allow temporary functional requirements to be satisfied without a major capital investment.

Condensed data

- Frequency range: 8 kHz to 3 GHz or 6 GHz
- Output power: up to +34 dBm
- Modulation bandwidth: up to 500 MHz
- EVM (LTE TM 3.1): < 0.4 % at +18 dBm (RMS), ACPR: < –72 dB (WCDMA, 64 DPCH, meas.)

Fig. 1: Measurement flights with drones (here, the R&S®EVSF1000 is installed) are used in ground inspections to reach hard-to-access places (photo: Skyguide).

Fraternal twins on a control mission

Even in the age of satellite navigation, terrestrial flight navigation systems (ILS, VOR, marker beacons) are still indispensable. It is therefore all the more important that these systems function properly. This requires regular testing and verification. Two new analyzers – one for ground use and one for in-flight testing – can handle all of the required measurements.

Regular checking and maintenance of terrestrial navigation systems based on ground inspection as well as flight inspection are key requirements stipulated in ICAO Doc 8071 and ICAO Annex 10. Here, the results of ground and air measurements must be comparable in order to prove the stability and integrity of the systems as well as the measurement procedures. According to ICAO rules and regulations, the level of agreement also determines how frequently the measurements are to be repeated. The R&S®EVSF1000 VHF/UHF Nav/Flight analyzer (Fig. 1) and the R&S®EVSG1000 VHF/UHF Airnav/Com analyzer (Fig. 3) ensure the required level of comparability with their identical signal processing hardware and software. Despite their compact design, these specialized instruments deliver measurement accuracy as good as the best laboratory equipment. Compared with their predecessor, the R&S®EVS300, they offer better handling (e.g. convenient spectrum preview) as well as improved performance (e.g. much higher sensitivity).

A specialist for ground measurements

Although terrestrial flight navigation transmitter systems have integrated monitoring functions, regular inspection and maintenance of these systems using independent measuring instruments is essential. Static analyses as well as dynamic measurements (e.g. runway measurements) are among the tasks that must be performed by officials in charge of maintaining the systems, i.e. airport operators, their subcontracted flight inspection organizations or government agencies. The battery-powered R&S®EVSG1000 was developed precisely for such applications. The analyzer's 6.5" color display is easy to read even in direct sunlight and provides a complete overview of all settings and results. The spectrum preview in particular is very useful for measurements in the field because it displays both the IF spectrum of the measurement signal and the filter bandwidths that are used, so incorrect measurements are virtually impossible. The instrument's functionality is rounded out by numerous features such as integrated recording of all measured values (R&S®EVSG-K21) including GPS position data (R&S®EVSG-K20) and external triggering capabilities (PPS, wheel sensor, etc.).

Fig. 2: When performing ground inspections on localizers, certain antenna heights are recommended that are best obtained using a suitably equipped test vehicle. To perform dynamic runway measurements, such a vehicle is needed anyway. For glide slope measurements, the antenna must be positioned even higher.

Fig. 3: Since their inner workings are largely identical, comparable measurements are no problem with the R&S®EVSF1000 (left) and the R&S®EVSG1000 (right). The R&S®EVSG1000 is built to support ground inspection.

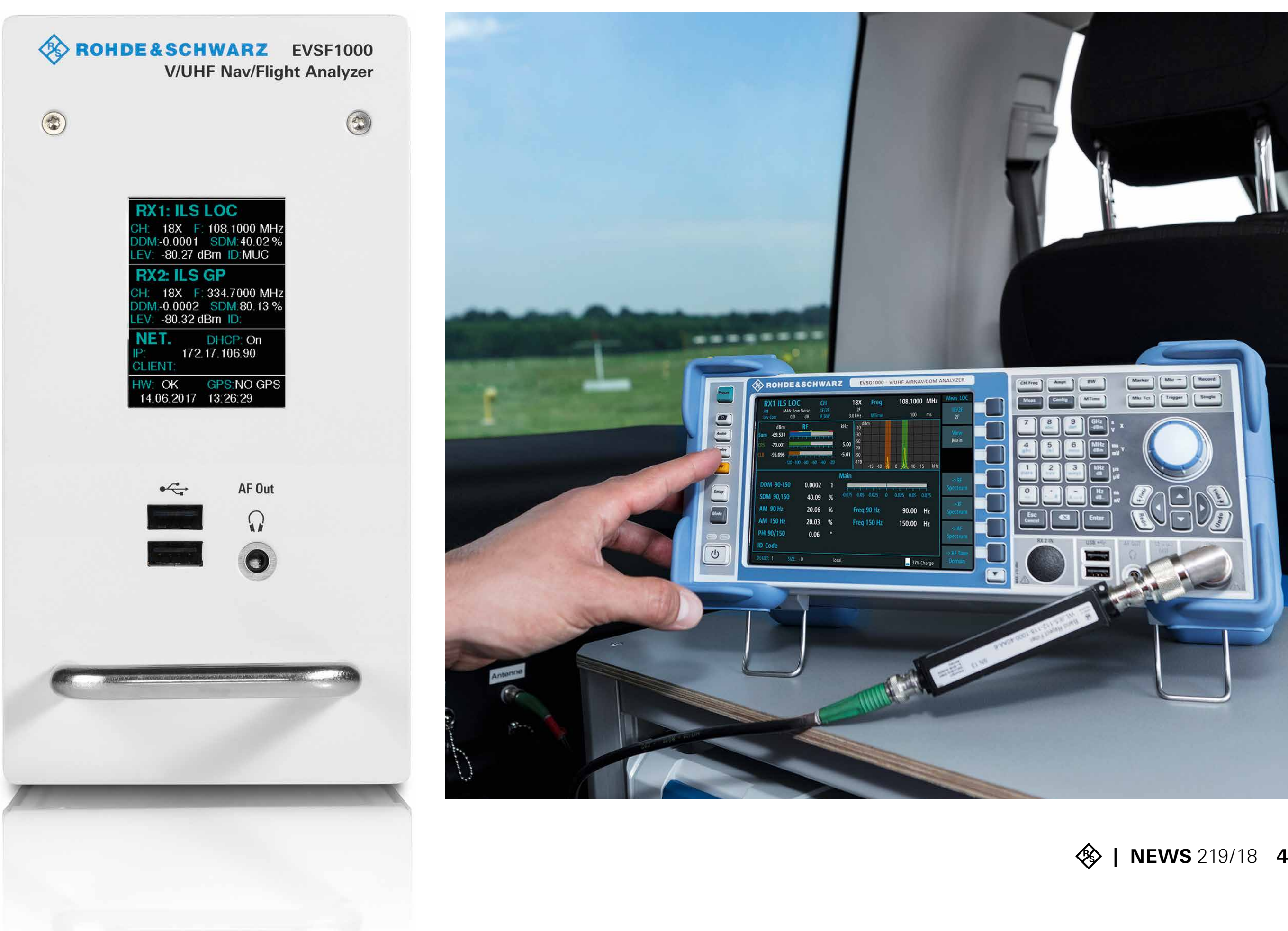


Fig. 4: 2F ILS measurement with IF display of the two carriers (course and clearance), the filter bandwidth settings, the individual measured values (course, clearance) and the sum evaluation.

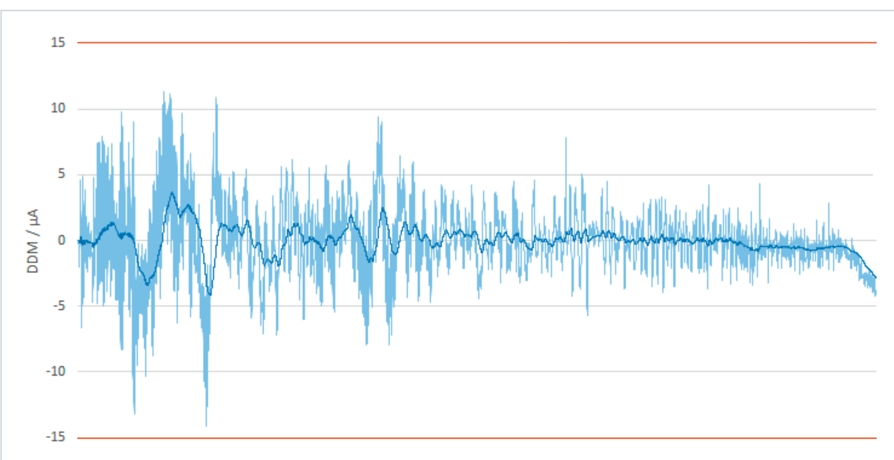


Fig. 5: Unfiltered (light blue) and ICAO filtered DDM curve for a localizer measurement at the center of the runway (course deviation 0). The pronounced scallops in the raw data occur during fast drive tests, but they are removed through ICAO filtering. The curve must not exceed the limit lines after filtering.

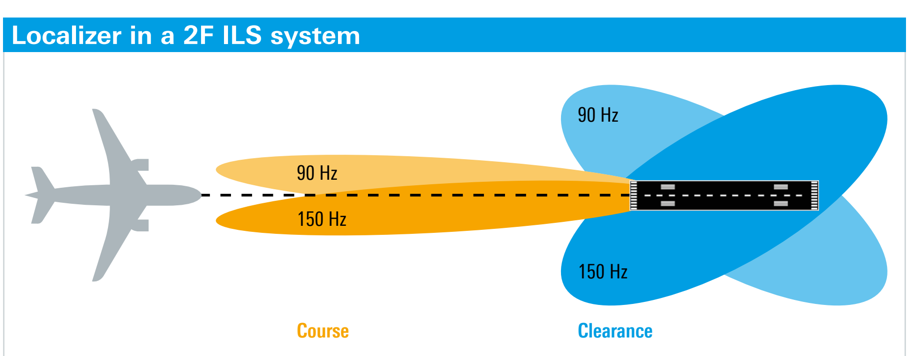


Fig. 6: The course deviation from the center line is obtained from the difference in depth of modulation (DDM) for the 90 Hz and 150 Hz signals at the receiving location.

Runway measurements – a challenge for CAT III systems

For ILS CAT III systems, analysis of the localizer along a runway is one of the most critical ground measurements, requiring a temporary shutdown of the runway to air traffic. To minimize the interruption while still obtaining reliable results, the R&S®EVSG1000 offers high measurement speed (100 measurements/s with R&S®EVSG-K22) and fast data storage (R&S®EVSG-K21). This allows trouble-free drive tests at speeds over 60 km/h without undersampling of high-frequency scallops caused by reflections. The R&S®EVSG-K1 option enables the R&S®EVSG1000 to perform simultaneous and independent measurements of the level and phase relationships between the course and clearance signals of a dual-frequency (2F) ILS system (Figs. 4 to 6).

Time is money – also with measurement flights

Due to their cost, it is important to minimize the number and duration of the required measurement flights (Fig. 7). Of course, to achieve this, a high-performance measuring instrument is needed. Equipped with two signal processing channels, the R&S®EVSF1000 is able to simultaneously perform two independent measurements on any desired frequencies, e.g. measuring the localizer and glide slope signals during the landing approach or simultaneously checking two CVOR/DVOR stations. Steep-edged preselector filters prevent the formation of intermodulation products near powerful FM transmitters so that the measurement is not corrupted. During flights on the edge of the coverage area, the low-noise frontend ensures stable results even when faced with signals well below the specified measurement range. If a GPS receiver with PPS synchronization is connected, each measured value can be correlated to the associated GPS time and position.

Mast too short? Terrain too rough?

Due to its size and weight, the R&S®EVSF1000 is ideal for use on board drones (Fig. 1). Drone flights are obviously no replacement for aircraft-based measurement flights, but they complement ground inspections at locations that are inaccessible with vehicles or masts. Of course, the current position of the drone must be known with high precision at all times (e.g. using RTK GPS or DGPS). Powered by the drone's onboard voltage, the R&S®EVSF1000 delivers extremely stable measurement results in this application. The ILS glide path is typically analyzed in this manner. Using a drone, this measurement can be performed in the far field. Due to the greater distance from the transmit antennas, the results are significantly more reproducible than with mast measurements on the runway (mast measurements are performed at the threshold). The mast is not high enough for measuring the glide path signal further ahead of the touchdown point – a problem that is eliminated by using a drone.

Klaus Theißen

Fig. 7: A typical R&S®EVSF1000 installation in a flight inspection system (photo: Norwegian Special Mission).

Glossary

2F ILS	ILS system with separate carriers for course and clearance
CAT I, II, III	ILS approach categories
CVOR, DVOR	Conventional / Doppler VHF omnidirectional range
DDM	Difference in depth of modulation of the 90 Hz and 150 Hz tones of the localizer signal (0 % DDM [LOC] = center of runway)
DGPS	Differential global positioning system
Glide path	Transmitter that provides a signal used to determine the vertical deviation when landing
ILS	Instrument landing system
Localizer	Transmitter that provides a signal used to determine the lateral deviation when landing
Marker beacon	Used to determine the distance to the touchdown point (outer, middle and inner markers)
PPS	Pulse per second; synchronization signal output by radio beacons, GPS receivers, etc.
RTK GPS	Real-time kinematic global positioning system for determining height and attitude
Scallop	Reflection-induced interference in the DDM curve along a runway
Threshold	Approx. 280 m ahead of the touchdown point (also position of inner marker)

Compact analyzer platform

High-end is not always necessary. In many cases, customers are mainly interested in solid RF performance at an attractive price and versatile and mobile application options. Two new analyzers from Rohde & Schwarz meet these requirements.

Two from the same roots

The R&S®ZNL vector network analyzer and the R&S®FPL1000 spectrum analyzer (Fig. 1) are versatile instruments for key RF measurements. These include the characterization of components such as antennas, attenuators, filters and amplifiers, as well as measurements on signal sources, including spectral measurements, demodulation of analog and digital signals and precise power measurements. The two analyzers are the most compact in their class. With a footprint of just 408 mm × 235 mm, they leave plenty of space on the workbench to accommodate the DUT and accessories. Despite their low height of 186 mm, the analyzers have an integrated 10.1" WXGA touchscreen for the detailed presentation of measurement results. Weighing just 6 kg in the base configuration,

Fig. 1: Not only visually related: The R&S®ZNL vector network analyzer and the R&S®FPL1000 spectrum analyzer are based on the same platform.

they are perfectly suited for mobile deployment in the field. Mobile applications are supported by a specially designed carrying bag and two hot-swappable, rechargeable batteries (Figs 2 and 3). An optional 12 V/24 V DC power supply is available for charging and operating the analyzers in vehicles.

Both analyzers come with an easy-to-use, intuitive graphical user interface. For example, traces can be shifted to a desired position by touching and dragging, and the measurement range can be adjusted using multi-touch gestures. Diverse measurement modes can be activated under several tabs. The MultiView mode displays all active measurements on one screen. The different measurements are performed sequentially in quick succession, providing quasi-simultaneous measurements. Both instruments offer solid RF performance – the R&S®FPL1000 as a pure spectrum analyzer and the R&S®ZNL as a network analyzer with optional spectrum analyzer functionality.

R&S®ZNL vector network analyzer

The R&S®ZNL is a vector network analyzer with a four-receiver test set. In its base configuration, the instrument measures S-parameters, wave quantities and ratios of wave quantities in the frequency range from 5 kHz to 3 GHz or 6 GHz. With a dynamic range of > 120 dB, an output power range from –40 dBm to 0 dBm and trace noise as low as < 0.0025 dB (RMS), the R&S®ZNL is ideal for characterizing passive

Fig. 2: Two optional, rechargeable, hot-swappable batteries are accessible on the rear of the instrument (here R&S®ZNL).

components such as filters. Functions such as embedding/deembedding and trace mathematics are provided as standard. The test setup can be calibrated manually or using an automatic calibration unit. Time domain analysis and distance-to-fault measurements (e.g. to detect cable faults) are available as options; these functions can be enabled via keycodes.

As a special feature, the R&S®ZNL can be equipped with a hardware board that adds a fully integrated spectrum analyzer. As a result, the R&S®ZNL provides both network and spectrum analysis in a compact unit. As the spectrum analyzer is implemented in hardware, it offers performance very close to that of a pure spectrum analyzer. The R&S®ZNL spectrum analyzer function largely corresponds to that of the R&S®FPL1000 in terms of operation, base functionality and performance. Minor limitations arise from the fact that the signal under test, on its way to the receiver, needs to be routed through switches and components to bypass the network analyzer test set. When combined with an R&S®NRP power sensor and the precise power measurements option, the R&S®ZNL turns into a true 3-in-1 allrounder, opening up a wide variety of applications in development, service and university training.

R&S®FPL1000 spectrum analyzer

The R&S®FPL1000 spectrum analyzer operates in the frequency range from 5 kHz to 3 GHz. It has a typical phase noise of –108 dBc (10 kHz offset, 1 GHz carrier), a typical TOI of +20 dBm and a typical displayed average noise level (DANL) of –167 dBm (10 MHz to 2 GHz) with the optional preamplifier switched on. In addition to classic spectrum analysis, the instrument in its base configuration offers a spectrogram function and a wide range of spectral measurements such as channel power, adjacent channel leakage ratio (ACLR), carrier-to-noise ratio, occupied bandwidth, spectrum emission mask, spurious emissions, harmonic distortion, and third-order intercept (TOI). The base unit also offers a gated sweep function for measuring pulsed signals. Further measurement functions can be optionally added, e.g. analysis of analog modulated signals, amplifier measurements (noise figure, gain, Y-factor), and precise power measurements using power sensors.

The R&S®FPL1000 also delivers a detailed analysis of digitally modulated single-carrier signals up to 40 MHz bandwidth using the R&S®VSE vector signal explorer software and the R&S®VSE-K70 option. With the R&S®VSE-K106 option, it can analyze signals conforming to the narrowband Internet of Things (NB-IoT) cellular standard, which is primarily intended for data exchange between machines.

Tanja Menzel; Klaus Theißen

Fig. 3: The specially designed carrying bag protects the instrument during field deployment. The ventilation openings on the sides allow the instrument to be left in the bag during operation. Traces are clearly visible through the transparent cover, and touchscreen operation is also possible.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R&S®TLU9 GapFiller: not just another gap filler – a game changer

Ideally, operators of terrestrial TV transmitter networks would like to deliver proper coverage to their areas using only a few high-power transmitters. Unfortunately, topology considerations can often upset this simple approach. Repeaters are typically required in mountains and valleys. The new R&S®TLU9 GapFiller has completely redefined this class of transmitters.

Fjords and mountain valleys are where the problem is most obvious: Terrestrially broadcast TV signals from a distant transmitter do not make it all the way to the valley floor, leaving the population there without coverage unless additional steps are taken. Installing complete low-power transmitters at such locations with baseband signal feeding (via data network or satellite) is generally not an economically viable option – especially since the number of transmitters required can grow very quickly. Instead, the standard practice is to use repeaters that operate in relay mode: They receive the signal at an elevated position "over the air" – just like a normal TV receiver – and rebroadcast the signal toward the valley floor. Depending on whether the same frequency or a different frequency is used, the following distinctions are made:

- Transposer: A transposer is a repeater that converts the received signal to a different frequency
- Retransmitter: Like a transposer but with signal regeneration; the received signal is demodulated and reconstructed
- Gap filler: A gap filler or on-channel repeater transmits on the same frequency on which it receives the signal (SFN application)

Today's gap fillers are vulnerable to external influences

Because the transmit frequency is the same as the receive frequency, gap fillers suffer from a problem that does not occur when transmitters with independent signal feeding are used: echoes, i.e. disruptive signal feedback to the input. The rugged topology of typical locations where gap fillers are used has many vertical reflecting surfaces, which exacerbates the problem. A compounding factor is the constricted nature of these locations, where everything happens in a relatively confined space. As a result, the distance from the transmitter to the reflecting objects and back is so short that the resulting echo signals are still of significant strength overlaying the actual source signal and disturbing it. Until now, there has been no all-embracing satisfactory solution to this problem. One issue is that echoes are not caused just by natural obstacles but also by moving objects such as vehicles. The Doppler echoes resulting from moving objects are very hard to counteract because of their sporadic and unpredictable nature. Moreover, any structural changes that occurred – for example if a road bridge or a wind farm was built (which invariably causes a change in the echo situation) – meant that the maintenance team had to analyze the new situation and reconfigure the echo cancellation mechanism on site. Unfortunately, the new configuration could also become obsolete at any instant, e.g. at the start of rush hour or when the wind turbines began to turn faster. A poor Doppler echo performance or a generally high noise contribution by signal processing could have consequences ranging from signal degradation to transmission failure. In such cases, the operator was forced to choose between two evils: Either use strict echo cancellation to ensure continuous transmission while accepting permanently poor signal quality, or opt for high quality and live with occasional broadcast interruptions.

Since the vulnerability of gap fillers to external influences made it difficult to predict how they would behave when installed at specific transmitter sites, operators found it impossible to make reliable network planning. For instance, a gap filler from supplier A might never work properly at a certain location despite repeated efforts, while the model from supplier B would not have these problems. At other locations, however, this situation might be reversed. This complicated process of trial and error led to high installation and maintenance costs, offsetting the cost savings generated by the straightforward rebroadcasting concept. Considering the extreme reliability and long-term stability of large transmitters, broadcast network operators have a hard time accepting the apparent discrepancy. While Rohde&Schwarz has sold thousands of gap fillers from its long-established R&S®XLx8000 family, which enjoys a good reputation among network operators, the R&S®TLU9 GapFiller (Fig. 1) has now demonstrated that significant improvement is still possible.

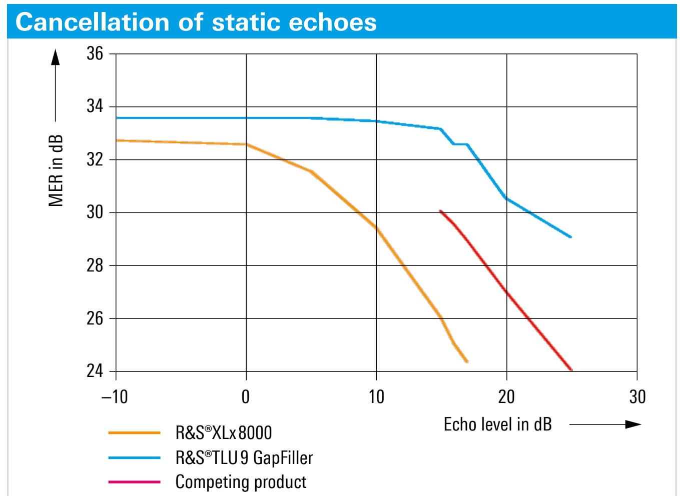
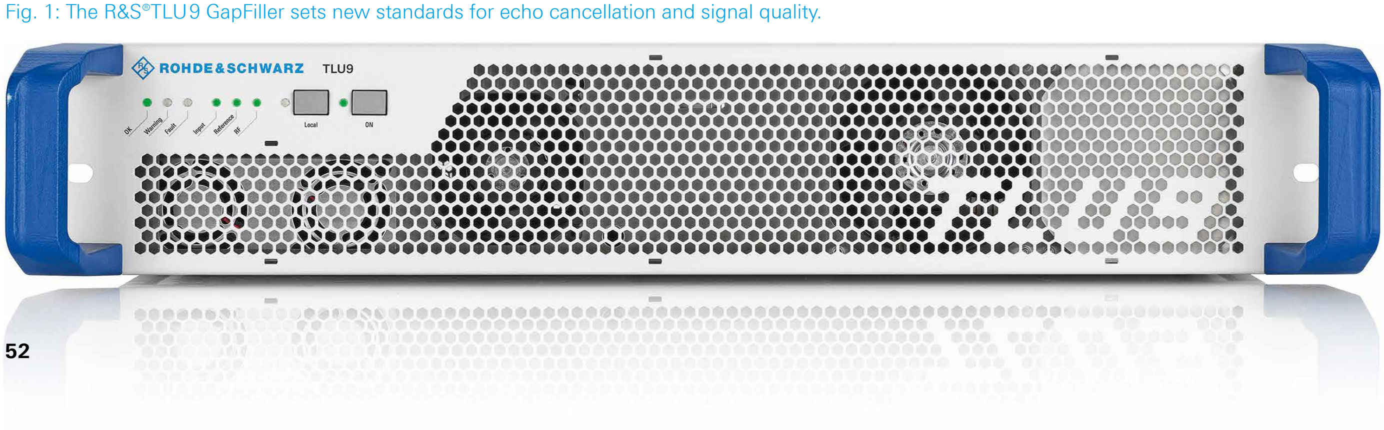


Fig. 2: Static echoes: The R&S®TLU9 GapFiller provides MER values well above any alternative product.

First-time implementation: continuous optimization to changing echoes

The main driver is a technological advance in which a brand-new adaptive self-optimizing function supplements the existing manual and static configuration of the echo cancellation mechanism. The new R&S®smartEC feature analyzes the current echo situation and automatically finds the best echo cancellation setting – anytime and continuously. This ensures maximum signal quality at all times for the given situation. If no significant echoes occur, echo cancellation is unnecessary and the gap filler can operate with focus on maximal signal

Fig. 1: The R&S®TLU9 GapFiller sets new standards for echo cancellation and signal quality.



Cancellation of Doppler echoes

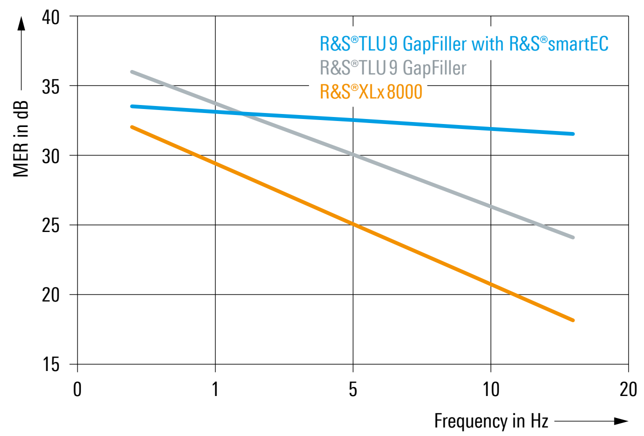


Fig. 3: Doppler echoes: The R&S®TLU9 GapFiller generally provides improved performance compared with the predecessor, the R&S®XLx8000. With R&S®smartEC, it provides optimal echo cancellation with excellent signal quality, anytime and continuously.

quality. On the other hand, coverage interruptions are avoided because the R&S®TLU9 GapFiller can take immediate countermeasures in case of temporary echoes.

The data speaks clearly and shows that the R&S®TLU9 GapFiller works to consistently deliver high signal quality – even in static echo situations where the R&S®smartEC option is not necessarily required. In this manner, echo levels up to 25 dB are canceled most solidly* (Fig. 2). Another key feature is the input sensitivity, which is extremely high at –80 dBm. At 17 µs, the echo window is three times as wide as that of the R&S®XLx8000, which means that echoes from distant reflectors can also be taken into account by the cancellation mechanism. Steep-edged filters attenuate adjacent channels by 80 dB at ±4.115 MHz to eliminate any appreciable influence due to other DTV signals or even mobile network signals.

Ultimately, however, only one thing counts: the measurable and visible signal quality. The modulation error ratio (MER) is one measure of the quality. For static echoes, the R&S®TLU9 GapFiller delivers up to 7 dB higher MER values compared with its predecessor product and up to 5 dB higher MER values compared with recognized competitor products (Fig. 2). The improvement is even more dramatic for dynamic (Doppler) echoes (Fig. 3). Here, MER values of over 30 dB are possible even at a Doppler frequency of 20 Hz on a stable basis – an increase of 10 dB and more compared with conventional products.

* Since a gap filler gets its input signal from a remote terrestrial transmitter and rebroadcasts the signal with significantly higher power in the local environment, thereby producing echoes, the echo level can significantly exceed the received level of the regular signal.

Start gap filling without worrying

On the one hand, network operators have an obligation to their customers, the program providers, who want to make sure their viewers have high-quality coverage. On the other hand, the actual costs required to achieve and maintain high network quality should be as low as possible. All of these issues can be reconciled only if the gap fillers deliver high-quality signals under all operating conditions while supporting the required level of predictability and ensuring low operating costs. The ideal gap filler works according to the motto: install and forget. The R&S®TLU9 GapFiller is the first product of its kind to satisfy this requirement. Network operators can rely on its predictability in deployment scenarios – just like with large transmitters. Thanks to its excellent characteristics and the new R&S®smartEC feature, it fulfills its coverage mandate maintenance-free and with a continuous focus on outstanding signal quality in every environment. As an added bonus, the product is also energy-efficient. Energy cost savings of up to 25 percent can be attained.

In the technology sector, there is a catchy name for innovations such as the R&S®TLU9 GapFiller: a game changer.

Alexandra Stückler-Wede; Maurice Uhlmann

The new R&S®TLU9 GapFiller provides resolutions to many challenging customer situations

Example: High operational cost

Caused by
- Many widely spaced gap filler locations
- Changing echo characteristics

Features of the R&S®TLU9 GapFiller
- Continuous self-optimization based on R&S®smartEC

Resulting customer benefits
- Reduced need for technical personnel
- Significantly reduced operating costs

Example: Interferences from adjacent channels

Caused by
- Adjacent channels with high signal level
- LTE interference
- Dynamic interference from adjacent channels

Features of the R&S®TLU9 GapFiller
- Integrated input filter in a very early stage of signal processing (prior to A/D converter and gain control)
- Suppression of direct adjacent channels by 80 dB

Resulting customer benefits
- Greatly improved robustness against all adjacent-channel and out-of-channel influences
- Better signal quality
- No added costs caused by external input filters

Power for the tower

The world's most powerful solid-state TV transmitter is located in the One World Trade Center in New York.

To meet the high demand for mobile communications frequencies, the US regulatory authority FCC has been implementing a process to reallocate the VHF/UHF spectrum in recent years. The aim of this "spectrum repacking" is to free up the UHF band above 608 MHz, which was previously used for television transmission, shift the affected television stations to the lower UHF and VHF region, and assign the freed-up frequencies to mobile network operators. This process consisted of a multi-stage voluntary frequency auction followed by a regulatory action. Only a few television providers want to completely shut down their operations due to the altered conditions. About 1000 stations have opted for the spectrum move, but they either have to convert their transmitters accordingly or purchase new ones. The migration plan consists of ten phases up to July 2020. It is being precisely orchestrated by the FCC to keep spectral interference as low as possible. New York is among the first regions to make the change. Six of the terrestrial network operators active there have invested in new R&S®THU9evo transmitters. These transmitters are located on the 90th floor (out of 104) of the most prestigious address in the city: One World Trade Center (1WTC). First on air was the transmitter of the Telemundo television network, which started broadcasting in June 2017. With 106 kW transmit power, it is the most powerful solid-state television transmitter ever built. Many other broadcasters from various parts of the country have now become convinced of the advantages of the Rohde&Schwarz transmitter and placed orders.

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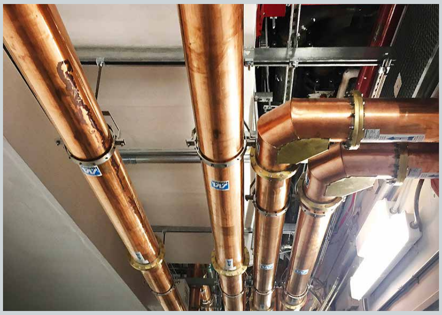


Taking a close look at DOCSIS 3.1 cable networks

The DOCSIS 3.1 extended standard enables cable TV network operators to offer their customers complete multimedia packages with fast Internet, allowing them to compete with telecommunications and mobile phone service providers. The new R&S®DSA realtime DOCSIS analyzer provides comprehensive analysis of the complete transmission path.

DOCSIS 3.1: a quantum leap in performance

The Data Over Cable Service Interface Specification (DOCSIS®) was developed in the mid-1990s for transmission of Internet data over hybrid fiber coaxial (HFC) cable TV networks. Up to version 3.0, single-carrier signals with 6 MHz or 8 MHz bandwidth and modulation up to 256QAM were the norm, but DOCSIS 3.1 [1, 2] changed the game by introducing multicarrier signals with OFDM modulation. They can use bandwidths up to 192 MHz and constellations from 16QAM to 4096QAM. This catapulted the standard into a completely new performance class with downstream rates up to 10 Gbit/s, making it attractive for UHD TV and other data-intensive applications.

Another new feature of DOCSIS 3.1 is that different signal configurations can be assigned to individual areas of the network topology, depending on the quality of the transmission path between the modems and the cable modem termination system (CMTS).

This technological advance requires new T&M equipment for cable network operators and manufacturers of cable network components, because the high data rates in the DOCSIS 3.1 standard can only be achieved if all parts of the transmission path work together with proven high quality.

Fig. 1: The R&S®DSA realtime DOCSIS analyzer enables fast, accurate analysis of DOCSIS 3.0, EuroDOCSIS 3.0 and DOCSIS 3.1 signals.

High-speed Internet over an HFC cable TV network

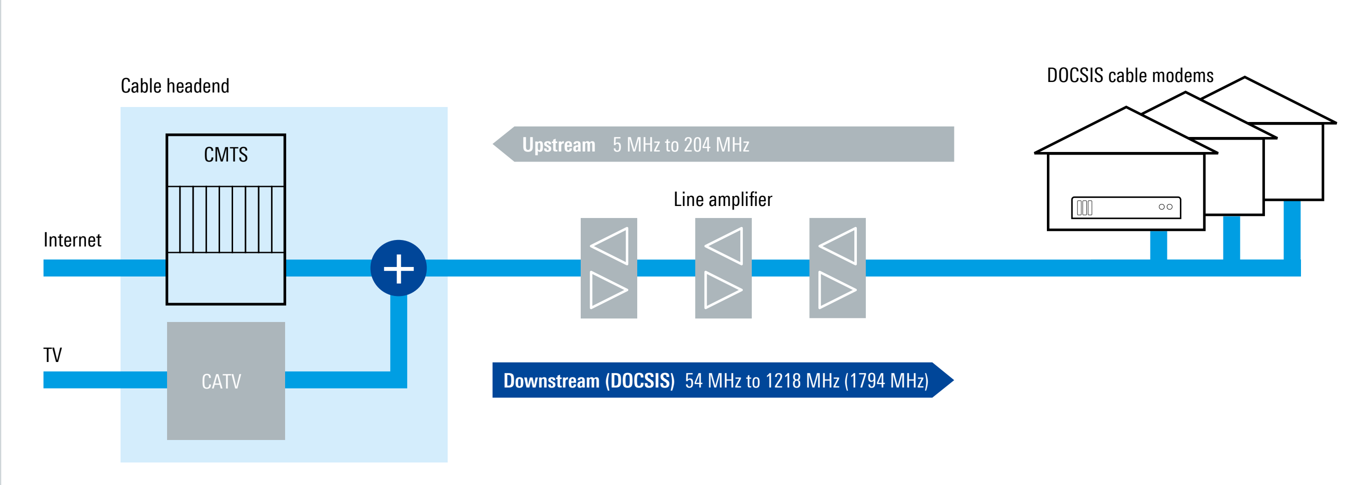


Fig. 2: DOCSIS 3.1 supports bidirectional transmission between the cable headend and the cable modems.

That's where the new R&S®DSA realtime DOCSIS signal analyzer (Fig. 1) comes into play. It is available in two versions – with or without an upstream receiver.

Top-class user interface concept to meet new requirements

A large screen is needed to clearly present the many signal parameters and extensive graphs resulting from DOCSIS 3.1 measurements. The R&S®DSA features a 10.1" touchscreen without mechanical controls. Large icons ensure convenient, ergonomic operation. Measurement results are presented in a clear, well-structured format.

Peak throughput requires top signal quality

The DOCSIS standard specifies bidirectional data transmission between the CMTS and the modems. Downstream signals (toward the modems) and upstream signals (toward the CMTS) are transmitted simultaneously in different frequency bands (Fig. 2). For comprehensive testing of downstream and upstream, the R&S®DSA (version .03) is equipped with two separate RF receivers that can analyze signals with an MER of ≥ 50 dB. Only a few years ago, signals of this quality and analysis of such signals were practically inconceivable. But high signal quality at the CMTS output is essential to provide sufficient margin for unavoidable losses arising from cascaded line amplifiers in the transmission path. With their low inherent noise, both RF receivers can also analyze low-level signals without significant inherent error.

R&S®DSA key features

- 10.1" color TFT LCD touchscreen
- RF frequency range for downstream: 47 MHz to 1794 MHz
- RF frequency range for upstream: 5 MHz to 204 MHz
- Maximum input level: 67 dBmV
- Inherent MER with DOCSIS 3.1 up to 600 MHz: ≥ 50 dB
- Inherent MER with DOCSIS 3.0, J.83: 59 dB
- Weight: 7.5 kg

With realtime signal processing, nothing goes undetected

For maximum data rates in both transmission directions, all components – e.g. power output stages in the CMTS, line amplifiers, optoelectronic converters and cable modems – must be operated within tightly specified ranges. It is crucial to have sufficient signal-to-noise ratios at every point in the network without overdriving the components, while maintaining the smallest possible safety margins.

Safety margins mean additional costs for network operators. Nevertheless, they must be provided because large parts of the cable network are exposed to external interference. This interference includes radiated emissions from terrestrial broadcasters, wireless and mobile services, and household devices with insufficient RFI suppression.

External influences and components operated outside their specifications can lead to interference and degraded performance, which is often only brief and intermittent. Realtime signal processing in the analyzer is needed to reliably detect these types of interference.

DOCSIS 3.1 focuses on proactive network maintenance (PNM), a technique in which chipsets in the modems provide a set of measurement parameters for remote analysis. However, in practice it turns out that the transmitted measurement results have relatively large tolerances and limited in terms of performance.

Unlike many DOCSIS measuring instruments that use these cable modem chipsets, the R&S®DSA circumvents these shortcomings by using fast, high-performance FPGAs for demodulation and signal analysis. It supports the DOCSIS 3.1 standard and optionally the DOCSIS 3.0 standard (R&S®DSA-K1501), the EuroDOCSIS 3.0 standard, and the DVB-C and J.83/A/B/C digital TV standards.

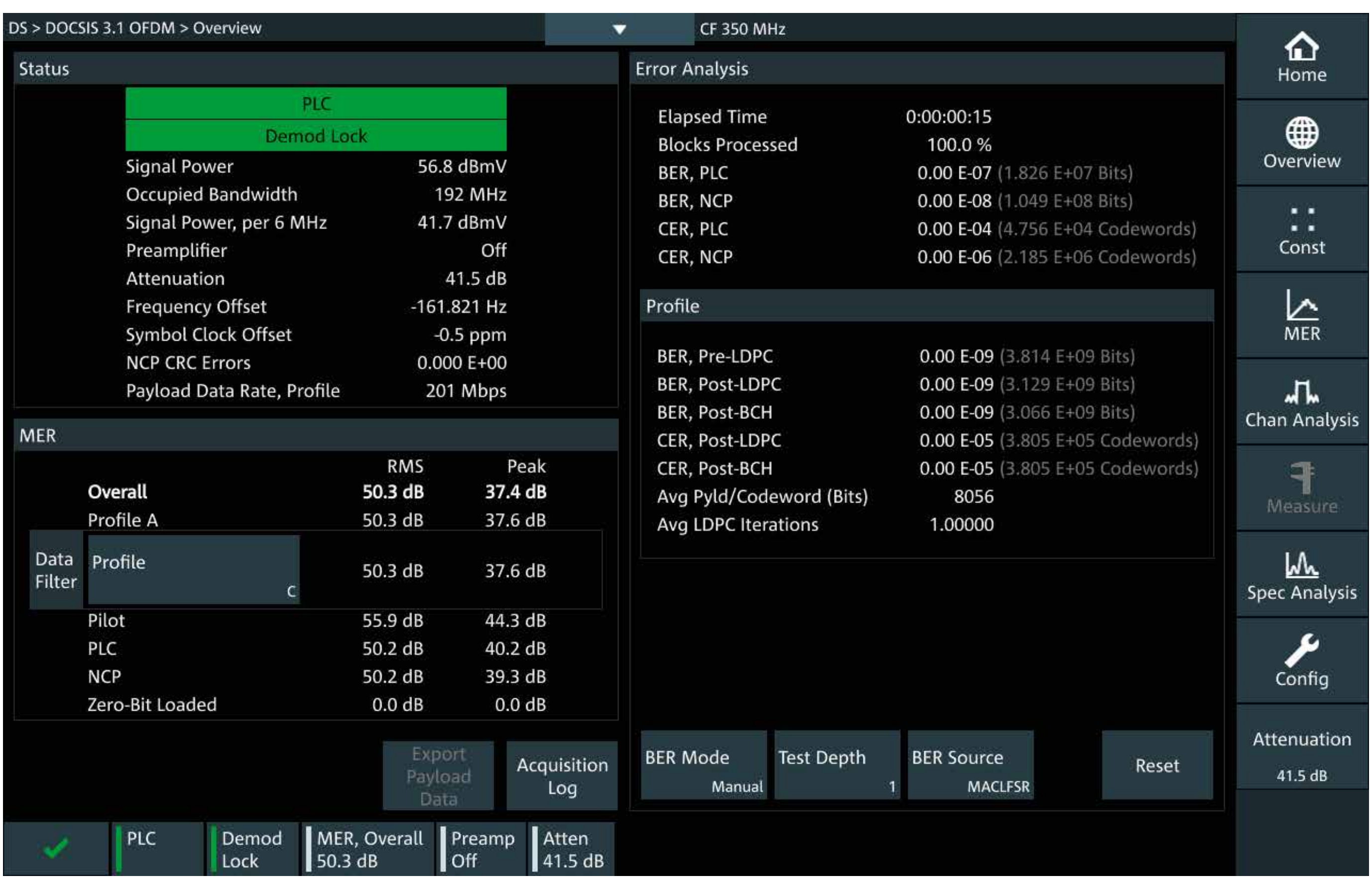
The high processing speed of the R&S®DSA ensures fast signal analysis and high update rates for measured values and traces. These properties are essential for reliable and detailed error analyses at the codeword and bit levels and for detecting brief intermittent errors. Here, the R&S®DSA has an advantage over chipset based instruments, which are limited to the codeword level because no analyses at the bit level are defined in the PNM specification.

Analysis of the physical transmission level

The quality of DOCSIS data transmission depends primarily on the condition of the cable TV network. Typical error sources include faulty connectors, oscillating or overdriven amplifiers and optoelectronic components, inadequate shielding and incorrect signal levels.

To detect such error sources, the R&S®DSA provides a set of measurements for downstream and upstream (R&S®DSA-K1500) that can be selected reliably with a clearly

Fig. 3: Overview window with key parameters of a DOCSIS 3.1 downstream.



structured menu based user interface. They provide conclusive information about the quality of a transmission path and its components.

The overview window (Fig. 3) presents key data on signal status and modulation quality, quantified in MER, and a section with detailed analyses of transmission errors. If any anomalies are visible there, further measurements (echo pattern, amplitude, group delay, phase and constellation) can provide useful clues. For DOCSIS 3.1 signals, the MER versus subcarrier measurement can be used to detect discrete interference signals within a channel (Fig. 4).

The operating modes also include FFT based spectrum analysis. Examination of the entire frequency spectrum is simplified by markers, masks, and frequency and level reference lines that can easily be displayed and modified with touch control.

Also welcome in the lab and in production

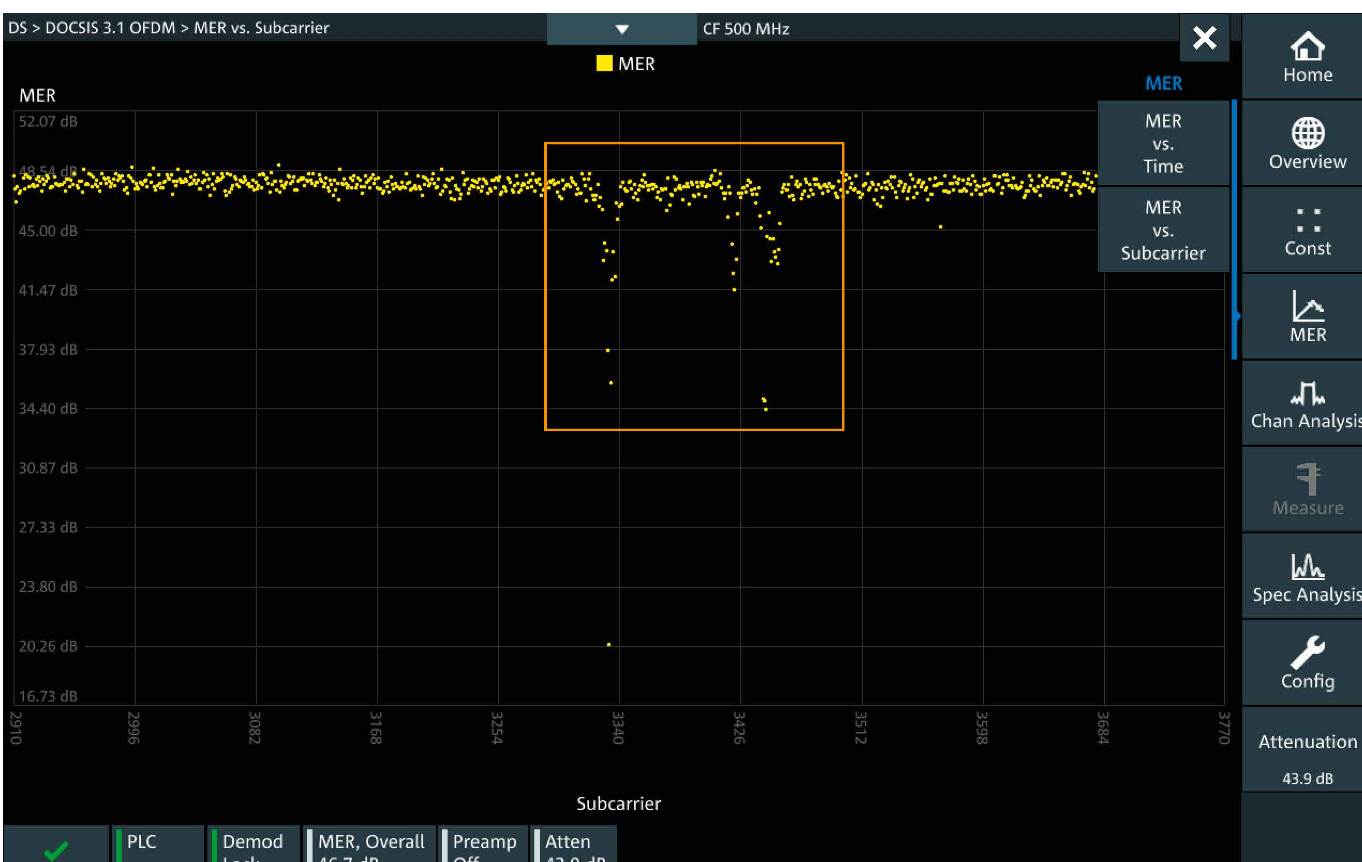
The RF characteristics and extensive analysis functions of the R&S®DSA also make it ideal for use in production and lab environments in situations where realtime capability makes the difference. It is already prepared for the optional extensions defined in DOCSIS 3.1. For example, its RF receiver covers downstream frequencies up to 1794 MHz and can already analyze constellations up to 16384QAM. In combination with the R&S®SFD DOCSIS signal generator, additional operating modes are planned for measuring return channel paths and checking the RF characteristics of cable modems.

All in all, the features of the R&S®DSA translate into a quick return on investment.

Werner Dürport

References
[1] DOCSIS 3.1 – the game changer for cable TV and Internet. NEWS (2015) No. 213, pp. 40–45.
[2] DOCSIS 3.1. Rohde & Schwarz Application Note (download search term: 7MH89).

Fig. 4: MER versus subcarrier measurement for detection of discrete interference signals (orange box).



Better than tubes: solid-state amplifiers for satellite uplinks

Tubes or solid-state? The question is now no longer relevant for RF power amplifiers in the Ku band. New amplifier models have combined the best of both worlds.

Satellite links are known for their independence from terrestrial infrastructure as well as their intercontinental range. In certain applications such as radio links at sea, there are no real alternatives – while in other applications, satellite links are highly attractive. As a result, demand for satellite services is continuously increasing.

In satellite communications, signals are transmitted by uplink stations (earth stations) to the satellite (Fig. 1), where they are converted to a different frequency and rebroadcast for reception on the ground or for other satellites.

Various frequency bands are allocated internationally for satellite communications. Currently, about 25 % of communications takes place in the Ku band between 12 GHz and 18 GHz. Due to the typically demanding requirements for QoS parameters such as availability and signal quality on satellite transmission links, the transmission system must be extremely reliable. Of course, this also applies to the RF power amplifiers that are used.

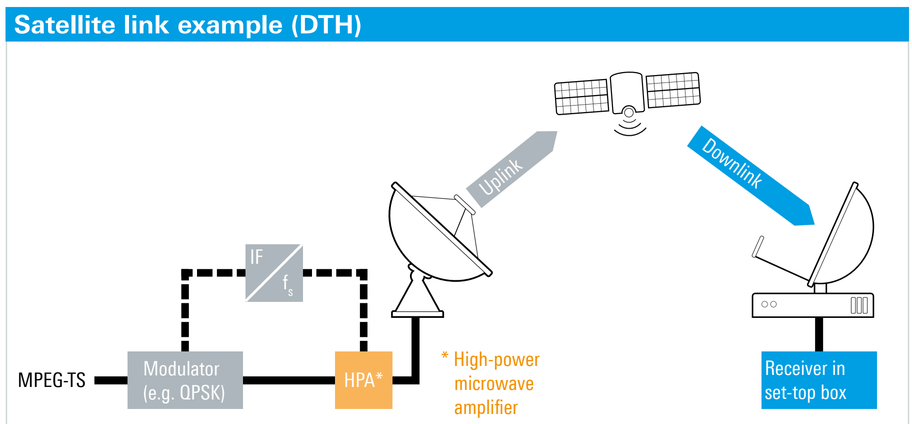
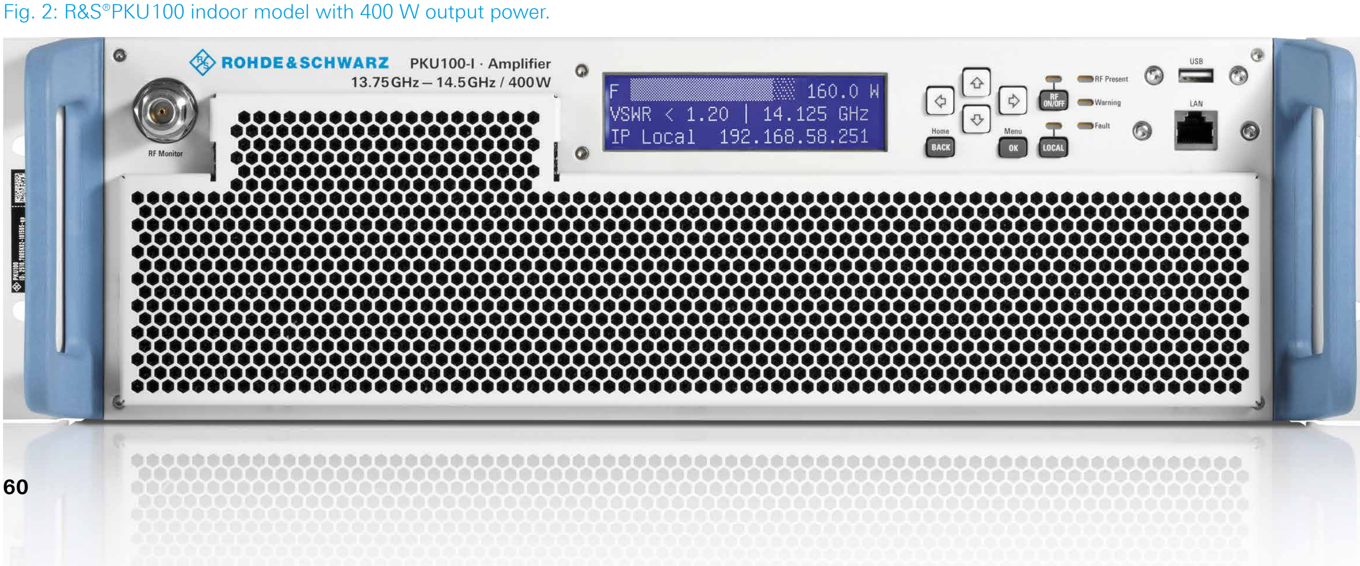


Fig. 1: For example, if a carrier has high power consumption but low bandwidth consumption, this tells the user to reduce the spectral efficiency of the carrier somewhat, i.e. to increase the bandwidth at a constant data rate and to reduce the transmission power.

Tubes or solid-state?

As a result of advances in the field of semiconductor technology, solid-state amplifiers are increasingly found in applications previously dominated by

Fig. 2: R&S®PKU100 indoor model with 400 W output power.



tube amplifiers (mostly traveling wave tube amplifiers, or TWTAs). Currently, tube amplifiers are still widely used to generate high power levels in the Ku band. Compared with conventional solid-state amplifiers, they have high efficiency, which means they consume less power.

However, TWTAs also have disadvantages. The tube needs to warm up before stable RF performance is attained, and this can take a few minutes. As a result, backup systems must be run in hot-standby mode at all times to be able to immediately take over if the primary amplifier fails. Substantial energy costs are the result.

Failure of the tube causes a total breakdown. The amplifier stops producing RF power, and replacing the tube is costly. Furthermore, tube technology is relatively fragile. A change in operating mode (e.g. frequency) can often have undesired consequences for the signal quality. Ambient temperature fluctuations also influence the output power.

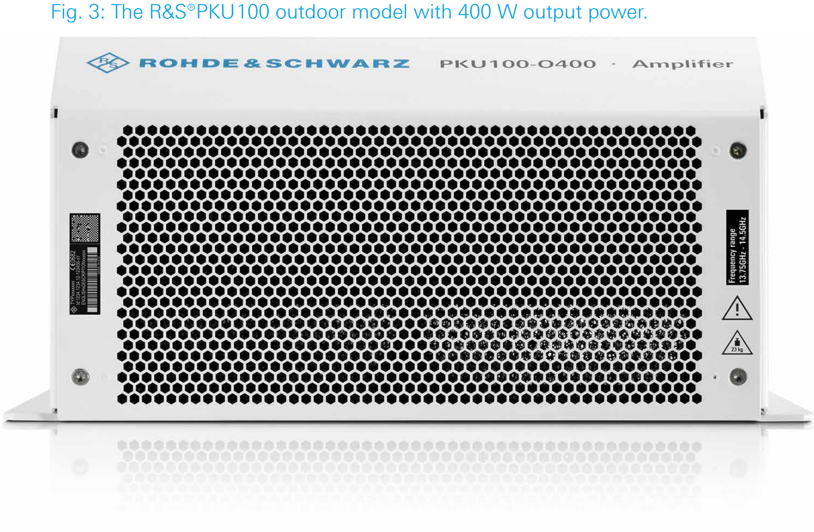
The high noise figure of tube amplifiers does not help the signal quality. In order to achieve good power output, the nonlinear distortion is compensated at a specified operating point using a linearizer. However, if the output power is adjusted, the linearizer must be re-optimized. Maintenance of tube amplifiers is also far from trivial: due to the high tube voltages, experienced personnel is mandatory.

Solid-state amplifiers have many advantages. Currently, gallium nitride (GaN) and gallium arsenide (GaAs) transistors are typically used. Their main benefit is their high failsafety. Since they use a set of single transistors whose power is combined by fully isolated coupling networks to produce the total output power, operation can continue with reduced power in case of failure of a single transistor. Although the lifetime of transistors is also limited due to electromigration, their time-to-failure is typically over 100 years.

Solid-state power amplifiers are immediately operational and do not require any warm-up time. Temperature-compensated control circuits keep the output power constant (< ±0.1 dB) across a wide temperature range.

Weight and size are shortcomings of conventional solid-state power amplifiers. This is due to the combiners needed to interconnect the transistors. As a result, they are typically much larger and heavier than tube amplifiers with comparable output power. In addition, their energy consumption is still significantly higher at the present time.

Fig. 3: The R&S®PKU100 outdoor model with 400 W output power.



R&S®PKU100: the best of both worlds

During development of the R&S®PKU100 high-power RF amplifiers, the goal was to combine the benefits of both worlds while mitigating the weak points. The new amplifiers combine the compactness and other benefits of tube amplifiers with the advantages of solid-state technology. In order to deliver high output power, the final stages are built using interconnected microwave integrated circuits (MIC). If one MIC fails, the R&S®PKU100 continues operation with (reduced) output power – which is often adequate to maintain the uplink.

The amplifiers come in indoor and outdoor versions with 400 W or 750 W peak power. They are available for the frequency ranges from 12.75 GHz to 13.25 GHz and 13.75 GHz to 14.5 GHz (Figs. 2 and 3). Both indoor versions have a height of only 3 HU; the 400 W model weighs only 18 kg. The form factor of the amplifiers is therefore unique among solid-state amplifiers; it is comparable to tube amplifiers with the same output power. In terms of efficiency, the R&S®PKU100 also comes very close to TWTAs with a value of at least 20 % referenced to peak power.

The quality of the RF output signal is critical. It is determined primarily by the amplifier's linearity. Here, a distinction is made between in-band and out-of-band signal quality (Fig. 4):

In-band signal quality

The amplifier output signal must exhibit a certain level of quality as defined by parameters such as the modulation error ratio (MER). The MER represents the sum of all factors that degrade the quality of the wanted signal during digital wireless transmission. It includes noise and nonlinear distortion that yield in-band spectral components. The better the MER for the transmitted signal, the lower the signal-to-noise ratio that is acceptable in the receiver for error-free signal decoding. Another parameter used to characterize the in-band signal quality is the error vector magnitude (EVM). The EVM is a measure of the deviation of the transmitted symbols from the ideal constellation. The lower the EVM, the better the signal quality.

Out-of-band signal quality

The spectral purity of the signal in adjacent channels is another important aspect when selecting an amplifier. Here, the shoulder attenuation of the wanted signal is a good criterion. The higher this value is, the less interference that impacts the adjacent channels. For amplifiers used for satellite uplinks, the third-order out-of-band intermodulation products typically must not exceed –25 dBc. This limit ensures that a DVB-S QPSK signal basically complies with the spectrum mask – although some satellite operators have more stringent requirements.

High signal quality is necessary for new TV standards such as DVB-S2 that define higher-order modulation types (e.g. 64APSK).

Top signals through adaptive linearization

For even higher-quality output signals, automatic adaptive linearization is available for the R&S®PKU100. The input signals are modified to allow optimal compensation of nonlinearities in the amplifier and significantly increase the shoulder attenuation (Fig. 5). Network operators typically specify a value of –35 dB for this parameter, which the R&S®PKU100 easily attains with this option. With conventional amplifiers, the output power must be strongly reduced in order to ensure operation in the linear region and attain the desired shoulder attenuation.

The linearization also improves the MER. A value of 25 dB is attained without linearization and almost 35 dB with linearization. This is an added benefit of adaptive linearization, which significantly increases the signal quality in the uplink and thus creates additional power reserves on the transmission path. If the output power or frequency is changed, the linearization can be automatically

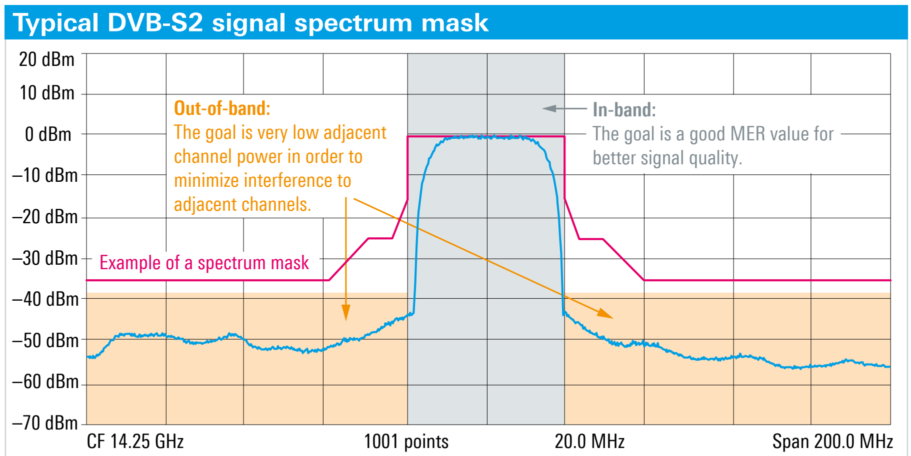
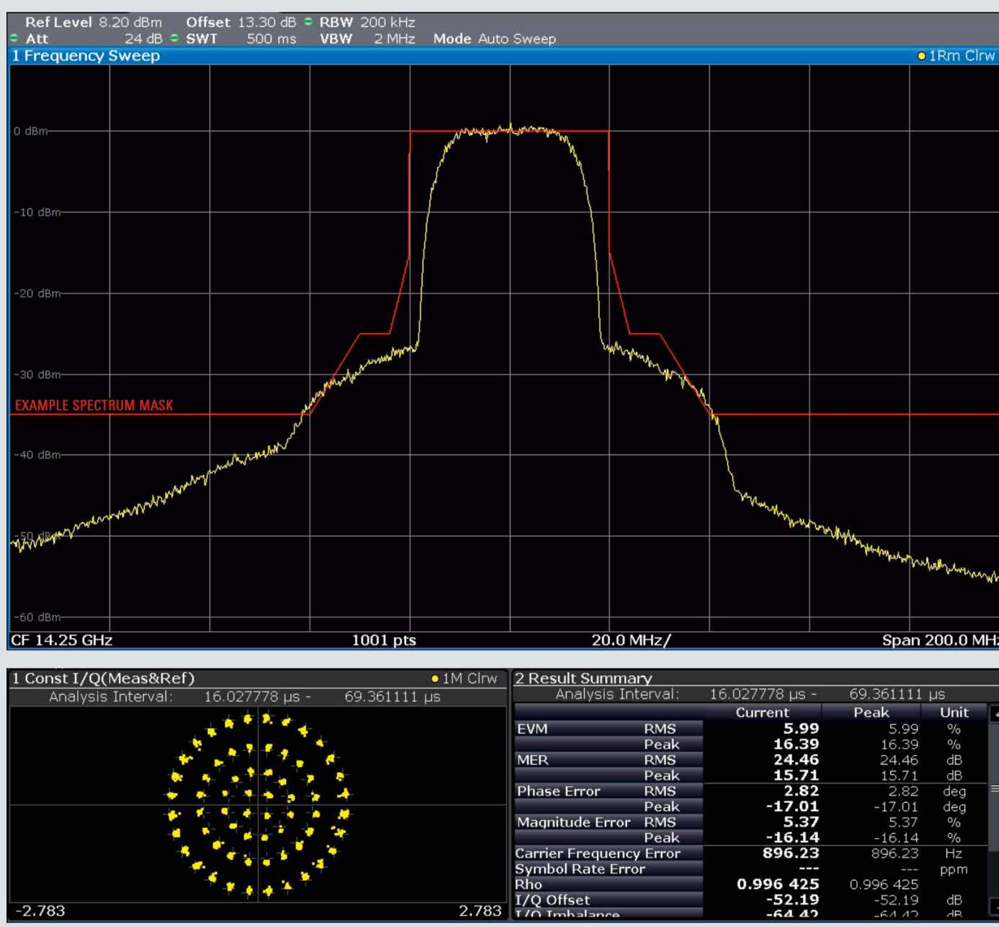


Fig. 4: The greater the shoulder attenuation, the less the adjacent channels are affected by interference.

Fig. 5: Adaptive linearization boosts the signal quality. Spectrum and EVM (or MER) without (left) and with linearization in the case of 64APSK modulation.



adapted. This option is suitable for useful signal bandwidths < 100 MHz.

Integrated block upconverter

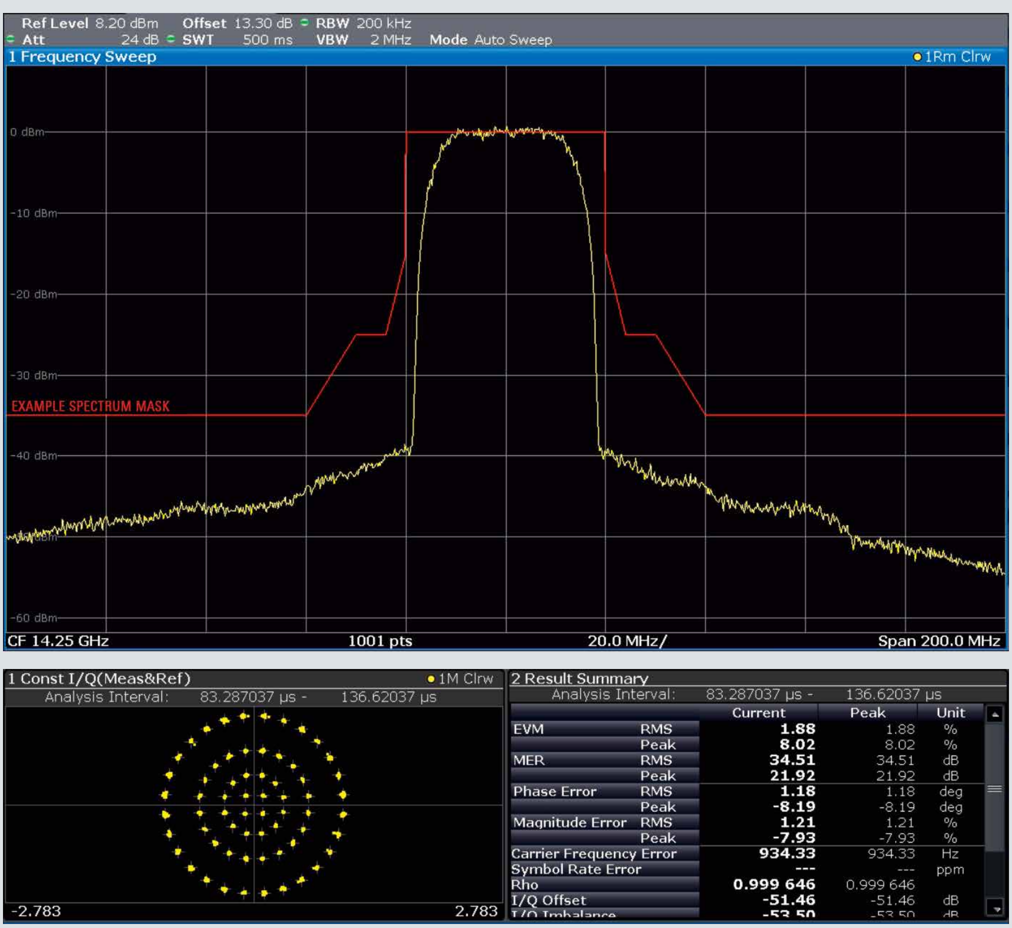
Due to the high frequencies, the cable losses in the Ku band are quite high. That is why the signal is typically fed to the amplifier in the L band, where losses are lower. All of the amplifiers in the R&S®PKU100 family are therefore available with an integrated block upconverter (BUC) as an option.

Fig. 6: The R&S®PKU100 can be operated using any web browser.

Redundant and convenient

Using power supply redundancy, the amplifiers can be fed from two different power networks. If one power network or power supply unit fails, the uplink is not affected. An optional DC supply (48 V) is useful for mobile applications or any other application in which temporary bridging of the backup supply is provided via rechargeable batteries.

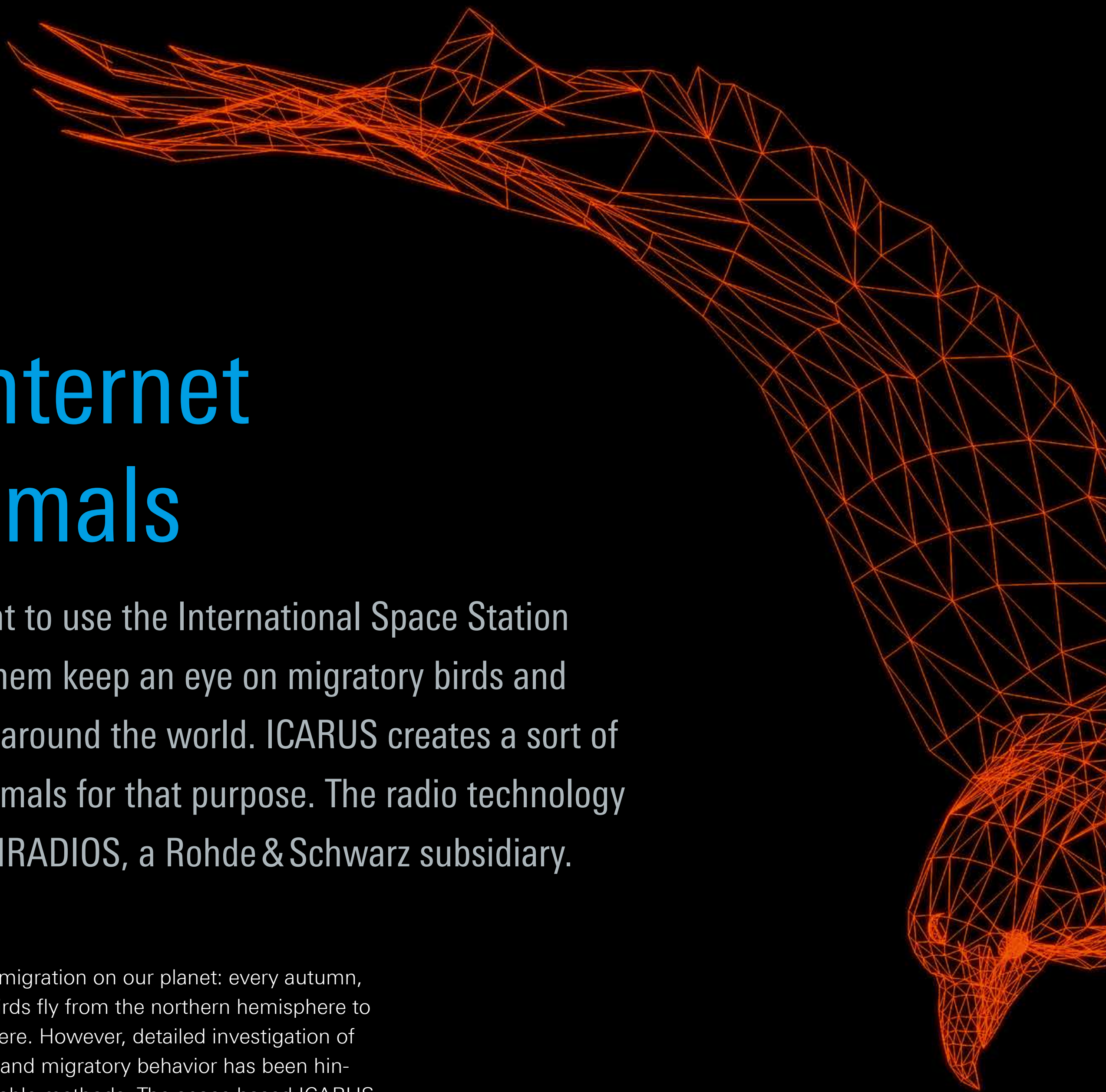
The amplifiers are operated using an intuitive web interface (Fig. 6) or the device user interface. Easy integration into higher-level management systems is facilitated by an SNMP interface accessed via LAN, a serial RS-232/485 interface or a floating parallel interface.



Summary

The RF power amplifiers in the R&S®PKU100 family for the Ku band combine the benefits of tube and solid-state amplifiers. They are compact, lightweight and available in indoor and outdoor models. Using automatic adaptive linearization, the amplifiers produce very high-quality signals and are well-suited for use with higher-order modulation schemes as defined in the DVB-S2 standard.

Dr. Wolfram Titze; Christian Baier; Lothar Schenk



The Internet of animals

Scientists want to use the International Space Station (ISS) to help them keep an eye on migratory birds and other animals around the world. ICARUS creates a sort of Internet of animals for that purpose. The radio technology comes from INRADIOS, a Rohde & Schwarz subsidiary.

The project

It is the biggest mass migration on our planet: every autumn, billions of migratory birds fly from the northern hemisphere to the southern hemisphere. However, detailed investigation of their migration routes and migratory behavior has been hindered by a lack of suitable methods. The space based ICARUS observation system will change that. It allows the routes of individual animals to be followed with GPS precision. And that's not all. Information about the energy consumption and acceleration of the animals can be used to draw conclusions about their life history, their behavior and their community.

ICARUS is a joint project of the Max Planck Society, the German Aerospace Center (DLR) and the Russian aerospace agency Roscosmos. It was initiated and is directed by the Max Planck Institute for Ornithology (MPIO) in Radolfzell (Germany).

The MPIO calls this a new era of behavioral research. Along with birds, this big-data project will observe the behavior of bats, turtles and many other species, so it is of interest not only to ornithologists. It is intended to create a global network – a sort of Internet of animals. The potential applications are manifold and include protection of endangered wild animals as well as prevention of locust plagues. It is even possible for animal behavior to warn of impending natural disasters. The data from the animals (equipped with miniature transmitters) will be processed in a computer on board the International Space Station (ISS)[1] and transmitted to Earth over a radio link[2]. The signals can also be received directly on the ground using mobile or stationary receivers.

Image: © shutterstock (Jovan Vitanowski)

The ICARUS onboard equipment was carried to the ISS by two supply missions in October 2017 and February 2018. Along with the FPGA board, the system consists of three receiving antennas and one transmit antenna. The antennas, which are scheduled to be installed in August 2018, will be arranged to cover a transmission area on the Earth that is oriented forward in the flight direction (with a small rearward extension) and a narrow receiving area oriented slightly to the rear (see Fig. 4).

ICARUS will be the world's first satellite based IoT system. The technology opens up new paths for the remote monitoring of sensors in remote areas. The Dresden based Rohde & Schwarz subsidiary INRADIOS is handling realization of the radio concept, implementation of the firmware for the onboard computer and development of the transmitters for the animals. Rohde & Schwarz is also responsible for developing the ground radios and is producing all components.

The ISS travels in a virtually circular orbit at an altitude of 350 km to 460 km (the altitude only varies within this range in the long term) at an angle of 51.6° to the equator. It circles the Earth 16 times each day. The trajectory of the space station moves 2500 km to the left each time it circles the Earth. In a 24-hour period, the receiving area of the ICARUS onboard antennas covers over 90 % of the Earth's surface between 58 degrees northern and southern latitude.

The components

Bidirectional satcom radio system for sensor data transfer

INRADIOS developed the radio method for data transmission from the animal transmitters (called tags) to the ISS in cooperation with SpaceTech GmbH. They chose CDMA as the channel access method, together with several PSK modulation modes. The biggest challenge was the very low signal power, which the receivers on board the ISS must be able to process. In light of the low data rate (about 1800 bit/s in the uplink), an efficient error correction method had to be developed to make the best use of the available capacity. The expertise of DLR's Institute for Communications and Navigation (ICN) came in helpful.

The signals from the individual animals (transmitted simultaneously) are kept apart by CDMA coding. The receivers can separate up to 120 simultaneous incoming signals. Since the duration of each transmission is only about three seconds, there is potential for data transmission from even more animals in the instantaneous overflight reception area, which is only about 100 km wide. However, to make this possible it must be ensured that they do not all start sending data at the same time (the tags know down to the second when the ISS is accessible). This is done by a

ICARUS at a glance

How does ICARUS work?

- Acquisition of movement data of individual animals by miniaturized data processing sensor and radio modules (tags).
- Individually accessible every day
- Preliminary data processing on the tag, including data compression and transmission management
- Transmission of small data packets to the ISS or to a LEO satellite during each overhead pass (timeslot for this only about 15 s per orbit)
- Supports orbit altitudes from 350 km to 600 km
- Type and quantity of sensor data as well as frequency of its transmission individually configurable on each tag
- Tag energy management with adaptive sleep mode
- Alternative transmission to ground receiving station
- Simultaneous reception in the orbital station of signals from 120 animal transmitters
- Bundled transmission of all new data from the orbital station to the main ground station during overhead pass
- Transmission of data from the ground station to the user data center operated for the project by I-GOS, a company founded by the MPIO
- Data access for scientific users via www.movebank.org

Tasks and benefits of ICARUS

From the behavior of animal populations, it is possible e.g. to draw conclusions about environmental conditions and changes to those conditions:

- Discovery of unknown migratory movements
- Monitoring of environmental changes (habitat shifts, desertification, ice melting)
- Enhanced understanding of ecosystems (pollination, pest control)
- Infectious disease control (avian influenza, hoof and mouth disease, Ebola)
- Protection of endangered species by constant monitoring of individual animals
- Advance warning of natural disasters (floods, volcanic eruptions, earthquakes) from unusual group behavior

Transmission technology

- Uplink
  Frequency range: 401 MHz to 406 MHz
  (licensed for ICARUS)
  Bandwidth: 1.5 MHz
  Net data rate: 520 bit/s
  Transmitted data volume per overhead pass: 1784 bits
  Simultaneously receivable coverage area:
  approx. 100 km (in flight direction) × 1200 km
- Downlink
  Frequency range: 467.5 MHz to 469.5 MHz
  (licensed for ICARUS)
  Bandwidth: 50 kHz
  Net data rate: 656 bit/s
  Simultaneously addressable coverage area:
  1200 km × 1300 km
- Channel access: CDMA
- Modulation: various PSK modes

Animal transmitter (tag)

- Weight: < 5 g
- Volume: approx. 2 cm³
- Antenna length: approx. 150 mm
- Sensors: GPS, magnetic field (compass), acceleration, temperature, humidity, pressure, electrical conductivity (for salinity measurements)
- Data storage: microSD (4 Gbit)
- Processor: microcontroller with hardware-level programming
- Battery capacity: 70 mAh
- Solar cell area: approx. 2 cm²
- Transmit power: approx. 6 mW

randomizer that allocates transmit times within the reception timeslot.

The ISS onboard computer sends commands to individual tags in the downlink. All tags can be uniquely identified and addressed by their ID codes. This allows ICARUS users to send individual behavior patterns to the tags (for example, the type and frequency of sensor data recording) and to merge animals into groups. The net downlink data rate of 656 bit/s is very low for an advanced transmission system. That is due to the narrow licensed bandwidth, but it is sufficient for the needs of ICARUS. Changes to tag configurations occur only rarely and are not time-critical, so it does not matter if the data can only be provided in one of the following overhead passes.

Signal processing board for the space station computer

The FPGA board for signal processing is installed in the Russian module of the ISS. All algorithms for digital signal processing were implemented by INRADIOS on a Xilinx FPGA platform, which essentially consists of two Virtex 5 FPGAs. The radio channel between the ISS and a tag is similar to a conventional wireless channel. It transports direct line-of-sight signal components as well as diffusely scattered components (non-line-of-sight), which combine to form a time-varying (fast fading) signal level as shown in Fig. 1. The demodulators in the ISS on-board computer and the tags equalize the channel situation of each tag individually and adaptively to enable reception even over radio channels with strong dynamic behavior.

Animal transmitters

The animal transmitters/receivers developed by INRADIOS are produced in the Rohde & Schwarz Memmingen plant – a very ambitious undertaking at the limit of current production technology because the total weight of the tag with the antenna, enclosure, processor, memory, radio module, sensors, solar cell, battery and potting compound must not exceed five grams (Figs. 2 and 3). Even relatively small birds such as blackbirds can carry this weight without it hindering them or impacting their behavior.

To prevent the tags from expending their limited resources unnecessarily, data transmission to the ISS takes place in narrow timeslots when the station is

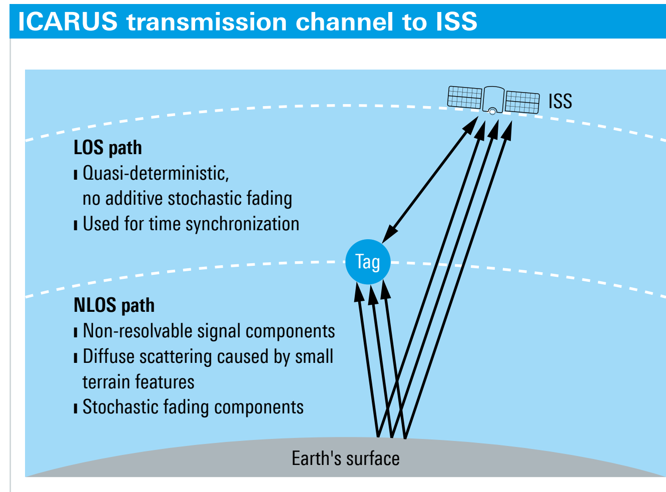


Fig. 1: The radio link between the tag and the ISS is subject to fading, which must be taken into account in signal processing.

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Fig. 2: Blackbirds and larger birds will be able to carry the tags without any hindrance to their daily activities. The final version of the tag (Fig. 3) is even smaller than this early prototype.

Fig. 3: The ICARUS tag (a virtually series-ready prototype is shown here in actual size) was developed jointly by the Max Planck Institute for Ornithology and I-GOS. It is an autonomously operating multisensor device with a radio module (see the overview box on the left for the sensors). The tag communicates with the ISS and with terrestrial base stations.

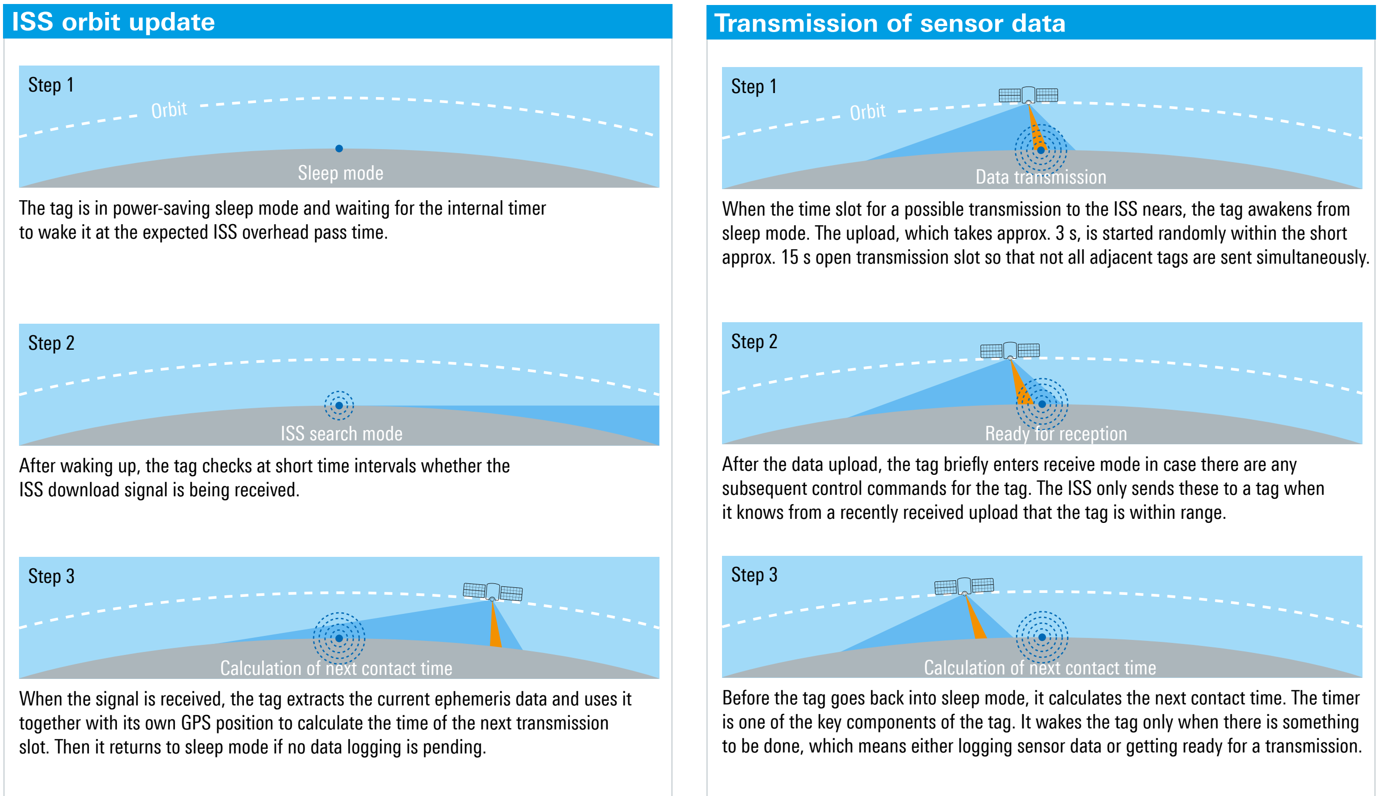

Fig. 4: Data is transmitted between the ISS and the tags in narrow timeslots.

passing over the tags. The tags independently compute these times from the ISS orbit data, which is sent to them at regular intervals (Fig. 4).

The tags are water-resistant and have an operating temperature range from –10 °C to +50 °C. Comparable existing tags for terrestrial animal observation weigh 15 to 20 grams, use the mobile network for data transmission and lack the multiple sensors of the ICARUS tags. Animals that leave the network coverage are irretrievably lost to observation. In addition, mobile networks are not always suitable for monitoring wild animals.

The ICARUS tags therefore fill several capability gaps.

- **Weight:** With a weight of just five grams and very compact dimensions, now even small animal species are available for observation.
- **Accessibility:** The tags can be addressed worldwide via the ISS link, and in the other direction the tags can upload their collected data to the observation network every day via the ISS. In addition, a terrestrial ICARUS infrastructure can be used to establish local acquisition networks with high data rates.
- **Multisensor technology:** ICARUS tags enable access to their GPS coordinates and to various environmental variables (temperature, orientation/compass, acceleration, Earth's magnetic field, humidity, pressure).

Terrestrial infrastructure as an alternative transmission path

Besides the ISS link, ICARUS offers the possibility to read tags through a terrestrial infrastructure. This considerably increases the readout frequency and transmission data rate. The achievable terrestrial data rate is 1 Mbit/s, about 1000 times greater than with the orbit uplink.

The terrestrial infrastructure can be implemented with either handheld mobile devices or stationary base stations. Both types of equipment are developed and produced by Rohde & Schwarz. The tags automatically detect which transmission paths are available and then choose the corresponding default settings for one of these paths (usually the terrestrial connection). With terrestrial readout, an app is used to upload the data to the central database at www.movebank.org.

Dr. Marco Krondorf

1) ICARUS is intended to be used with low Earth orbit (LEO) satellite systems. The ISS is serving as the initial test platform. It is fundamentally conceivable to operate a LEO satellite fleet with ICARUS at a later point in time in order to increase availability or shorten the overhead pass intervals.
2) The ground station will be operated by Roscosmos, the space organization of the Russian Federation. From there the data will be sent over the Internet to the company I-GOS, which will take care of uploading it to www.movebank.org.

A new era in biology: Earth observation by animals

Guest article by Prof. Dr. Martin Wikelski, Director of the Max Planck Institute for Ornithology in Radolfzell, Department of Animal Migration and Immune Ecology; Professor at the University of Constance; Head of the ICARUS project

Scientists have been working on this ambitious project for more than 15 years. The objective of the ICARUS (International Cooperation for Animal Research Using Space initiative) is to explore the global network of the most intelligent sensors available to humanity: wild animals. Animals have a "sixth sense" for events on the Earth. The latest research shows that mutual interactions of animals – often referred to as swarm intelligence – form the basis for incredible sensory performance. Some examples of this are advance warning of natural disasters or the ability of storks to find migrating locust swarms in the deserts of Africa. Locusts are still acting as a sort of Biblical plague that robs one-tenth of the world's population of their basic nutrition.

Now, with the aid of ICARUS technology, we can utilize the information from our animal "sniffer dogs" to launch a new era in Earth observation. At the same time, it makes wild animals so important as information sources for humans that we will want to protect them even better.

The author with a straw-colored fruit bat in Zambia. Fruit bats are useful carriers for ICARUS tags because they perform ecosystem services (seed distribution) and can act as "sniffer dogs" to track down sources of Ebola infection.

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In today's internationally networked world, global data on animal movements and animal behavior is indispensable for understanding how we can safeguard human livelihood while protecting the animal world at the same time. Up to now, scientists have not been able to track small and very small animals on their long journeys. Billions of songbirds migrate from one continent to another every year. Many bat species and countless insect species also cover large distances, possibly crossing continental boundaries as well. We do not have accurate knowledge of this.

However, this knowledge is important, for example for understanding how disease organisms are spread by their hosts, maintaining the ecosystem services of animals or using the distributed intelligent sensory systems of animals to predict natural disasters. To remedy this worldwide lack of knowledge about the distribution and individual migratory behavior of small and extremely small animals, the ICARUS project has been initiated by an international consortium of scientists.

The onboard computer for the ICARUS experimental system was transported to the Russian module of the International Space Station (ISS) by a Soyuz rocket in October 2017, followed by the large ICARUS antenna module on a Soyuz mission in February 2018. This was done in cooperation with the Space Travel Management section of the German Aerospace Center (DLR) and the Russian aerospace agency Roscosmos. The computer was put into operation in April 2018. Startup of the overall ICARUS system will also require a spacewalk lasting about five hours, which is scheduled for August 8, 2018, and will be carried out by two Russian cosmonauts.

The data generated by ICARUS holds the promise of revolutionary insights into the life, behavior and death of animals on our planet. For example, the data collected worldwide will enable us to draw conclusions about the propagation of diseases (zoonoses), climate change and disaster prediction. The anticipated research results will be of invaluable importance to humanity and ultimately for all life on Earth.

ICARUS Global Observation System (I-GOS, www.i-gos.de), a company founded by the Max Planck Institute for Ornithology in Radolfzell on Lake Constance, has been collaborating for many years with the Dresden based Rohde & Schwarz subsidiary INRADIOS to jointly develop the best and least intrusive ways to attach transmitters to various types of animals. Songbirds will carry the tags on their backs like miniature knapsacks, secured by skin-friendly elastic bands. Larger birds, such as storks, cranes and eagles, have been fitted with ankle rings for 100 years, and now these rings will be equipped with advanced ICARUS electronics to transform the birds into in situ Earth observers that will also collect data for weather services from the remotest parts of the world. Mammals such as bears, tigers, zebras, rhinoceroses and elephants can be fitted with small ICARUS ear tags and wear them all their lives virtually unaware of them. The main goal here is animal protection. The large African bats that we hope to use to find the host of the Ebola virus will carry their tags as delicate collars. Eels, whose migrations to their breeding areas in the middle of the Atlantic or Pacific ocean are still largely unknown, will swim with pop-up ICARUS dorsal tags and measure ocean temperatures, currents and salinity, even at great depths. After a predetermined time, the tag will detach from the eel and float up to the ocean surface, where it will establish contact with the ISS and start transmitting the eel's behavior data logged over the course of time. At the same time, the tag will serve as a measurement buoy for surface currents, temperature and salinity. In the future, ICARUS tags will be used to protect fish populations, for example tuna and salmon. The tags will also be attached worldwide to newly hatched sea turtles in order to learn about the "lost years", i.e. the unknown migratory years of young turtles.

ICARUS tags can be regarded as a sort of biodata treasure, which can also be collected with the aid of interested members of the general public (citizen scientists). Via the Animal Tracker app, they will be informed of all places where tags can be found, for example when tag carriers die. Then these interested persons can find the treasure, in the same way as a geocaching treasure hunt, and send it to a participating institution. The stored data can be read like a diary that documents the entire lifetime of the individual animal.

If you want to observe animals yourself, you can download the free *Animal Tracker* app from the Max Planck Institute. This app is not only used by professional scientists, but is also part of a citizen science project. If you contribute photos or observations of animals whose movement data is recorded at movebank.org, you will enliven the data and help the scientists interpret the data.

Reliable planning of satcom links

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Satcom operators and users need connections that are as economical as possible. The R&S®SLP satellite link planner provides precise recommendations to help convert performance specifications into technical parameters.

Transponder planning and optimization

The R&S®SLP satellite link planner is a software tool for satcom analysis and optimization. R&S®SLP assists in system design, transmission planning and transponder usage optimization in all satcom bands (C, X, K, Ka, etc.). The software takes into account all factors that affect link quality. This includes weather conditions as well as atmospheric effects and signal degradation due to intermodulation and power losses from various causes. All of these factors are accurately modeled, verified and calibrated based on measured data from real satellite links.

The link budget – a key element for designing satcom connections

Calculation of the link budget is an important task when operating satellite communications connections. It incorporates all factors in the transmission path that strengthen or weaken the satellite signal. This includes atmospheric effects such as cloud and rain attenuation, as well as absorption by gas molecules. The technical parameters of the satellite concerned (transponder bandwidth, gain and sensitivity) also enter into the link budget. The result is a single number for the uplink or downlink: the carrier-to-noise ratio (C/N). This value determines the data rate that can be achieved over the satcom link with a specified modulation method. Determining this value is a core function of R&S®SLP. In addition to analysis, the software recommends specific link parameters for optimal link design. It automatically calculates which modulation method and which transmit power are the most favorable with regard to the framework conditions in order to establish the link with minimum resource consumption. This is determined by the power consumption of the carrier in the transponder and the bandwidth consumption of the connection. Fig. 1 shows how various user groups can benefit from R&S®SLP.

As mentioned above, the link budget includes both the environmental parameters of the link and the key data of the transmission technology. For consideration of the environmental conditions, the ITU has issued a set of recommendations that are taken into account in R&S®SLP (Fig. 2).

Ground stations can be classified by various parameters, including their antenna gain in the transmit and receive directions, their equivalent isotropic radiated power (EIRP and their output power. The orbit segment is represented by a large database of existing satellites, their transponders and footprints, which simplifies link budget calculation particularly for transponder lessees.

However, an isolated analysis of the link between the satellite and the ground station ignores an important source of interference: interference from signals of nearby satellites and/or ground stations. These external signals can couple significant amounts of power into the link and must therefore be taken into account, which R&S®SLP does.

Another restriction consists of the frequency- and location-dependent limits on transmit power density imposed by the ITU. These specifications are incorporated in the software, which only proposes permissible values for the link parameters.

Fig. 3 shows an example link budget calculation for a multicarrier scenario, taking the previously described factors into account. In a good satellite scenario, all C/N values (dark red) are higher than the specified minimum values (target C/N in orange). The final C/N value is composed of several components.

- Blue: the C/N value of the uplink, which means from the ground station to the satellite
- Green: the carrier-to-intermodulation (C/IM) ratio is the ratio of the carrier power to the distortion power in the transponder
- Yellow: the C/N value of the downlink, i.e. from the satellite transmit antenna to the ground station

Fig. 4 presents a complete numerical overview of the scenario, in particular the carrier-referenced power equivalent bandwidth (PEB).

The statistical analyses of bandwidth and power consumption immediately show the user which carriers need further optimization. For example, if a carrier has high power consumption but low bandwidth consumption, this tells the user to reduce the spectral efficiency of the carrier somewhat, i.e. to increase the bandwidth at a constant data rate and to reduce the transmission power. This is because the signal bandwidth always has a linear effect on the achievable data rate, but the transmit power only has a logarithmic effect (Shannon's definition of channel capacity).

Target group	R&S®SLP application scenario
Satellite operators	Specifying the link budget for customers. The link budget defines the transmit power and occupied bandwidth necessary to fulfill customers data rate requirement.
Transponder lessees	Lessees of transponder capacity use R&S®SLP to plan the ground station parameters necessary for the link, such as antenna diameter and transmit power, with respect to the available satellite modem and the data rate requirement.
Satellite industry and decision-makers for the construction of communications satellites	The satellite industry can use R&S®SLP to check the suitability of the planned communications capacity (transmission technology in orbit) with respect to customer requirements (coverage, data rates, link availability).
Frequency regulation authorities	R&S®SLP can be used to check satellite links for compliance with frequency coordination criteria. For example, this applies to the permissible emitted spectral power density in the uplink and downlink.

Fig. 1: The R&S®SLP satellite link planner software tool is attractive for numerous user groups.

Parameter / title	ITU recommendation
Rainfall rate	ITU-R Rec. P. 837-6
Rain height model	ITU-R Rec. P. 839-3
Specific attenuation model for rain	ITU-R Rec. P. 838-3
Rain attenuation, frequency scaling, scintillation	ITU-R Rec. P. 618-10
Attenuation by atmospheric gases / Water vapor: surface density and total columnar content	ITU-R P. Rec. 676-9 and Rec. P. 836-4
Attenuation due to clouds and fog	ITU-R Rec. P. 840-4
Mean surface temperature	ITU-R Rec. P. 1510
Topography for Earth-to-space propagation modeling	ITU-R Rec. P. 1511

Fig. 2: The ITU recommendations implemented in R&S®SLP to take environment factors into account.

Mastering multicarrier scenarios

The ability of R&S®SLP to calculate multicarrier scenarios is essential for satcom operators (Fig. 5). This is because the carriers in transponders with high carrier density adversely influence each other due to parasitic effects such as power robbing and intermodulation. Scenario optimization in R&S®SLP is able to configure the parameters of each carrier so that as many carriers as possible achieve the required data rate while consuming the least possible bandwidth and signal power. Although the calculation effort rises exponentially with an increasing number of carriers, the optimization can still be run on standard PC hardware even with multicarrier scenarios.

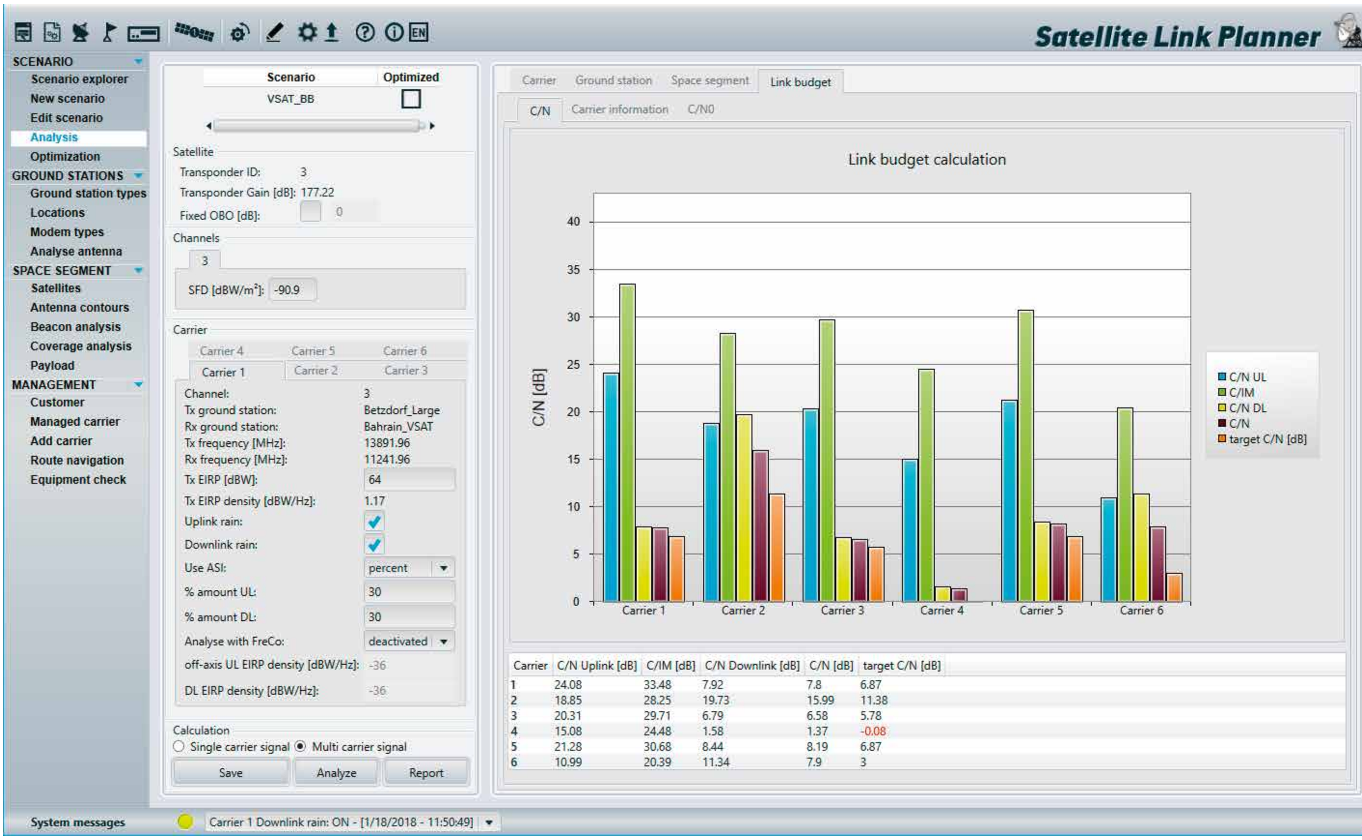
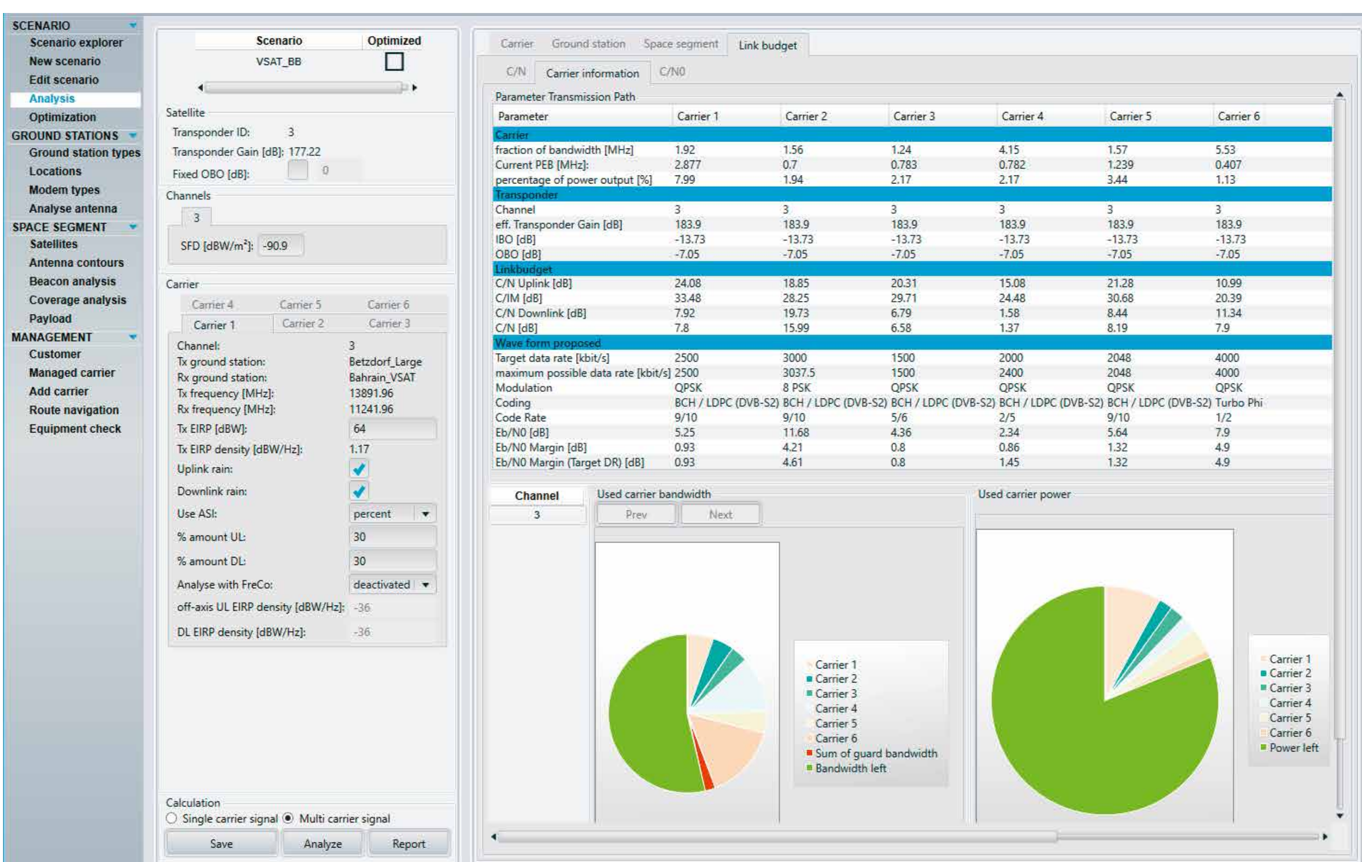


Fig. 3: Calculation of all relevant C/N values after analysis of a multicarrier scenario.

Fig. 4: Detailed carrier-referenced analysis.



Reliable reception is crucial

Ensuring the required link quality is essential for selecting the transmission parameters. As mentioned above, weather conditions play a significant role, especially when it comes to dimensioning power margins.

Fig. 6 visualizes the impact of precipitation on a coverage area. The signal attenuation due to rain is shown in the coverage area by color-coded highlighting, taking into account the framework conditions (frequency, antenna diameter, desired availability, etc.). Based on the coverage map, this shows the

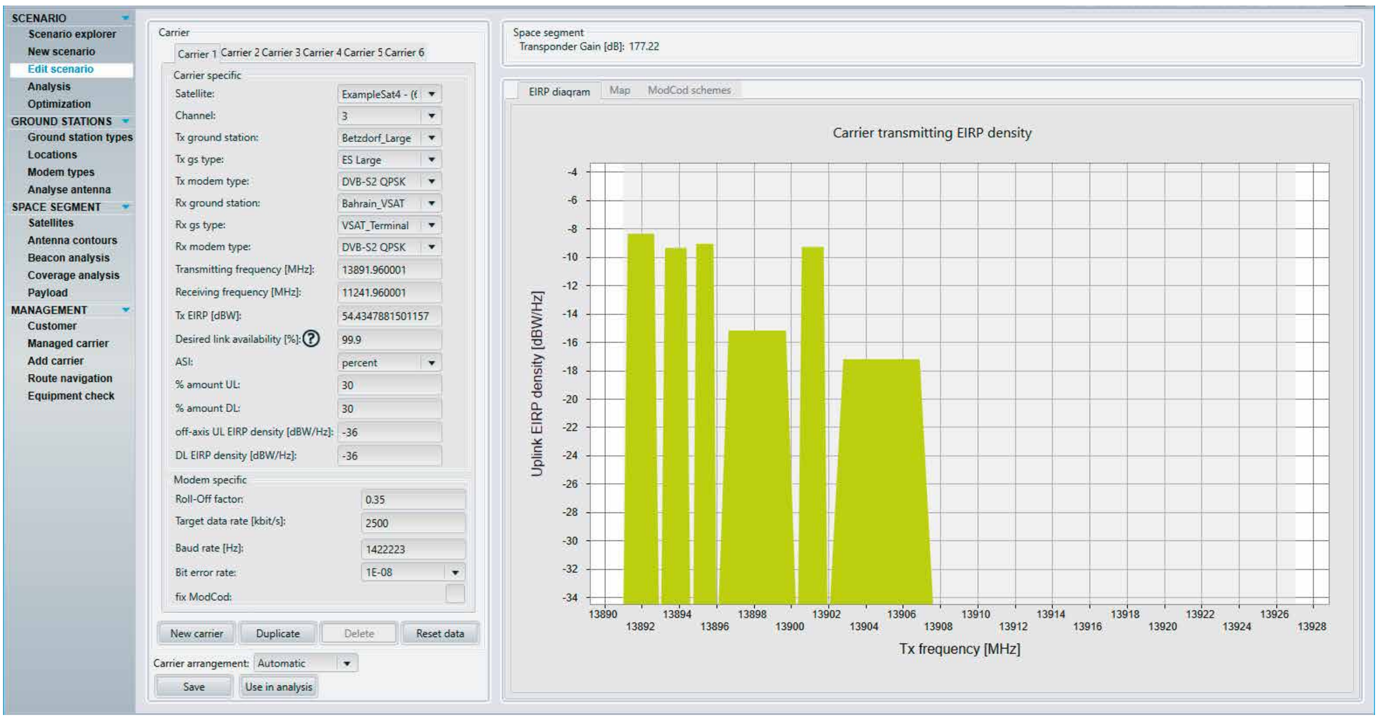
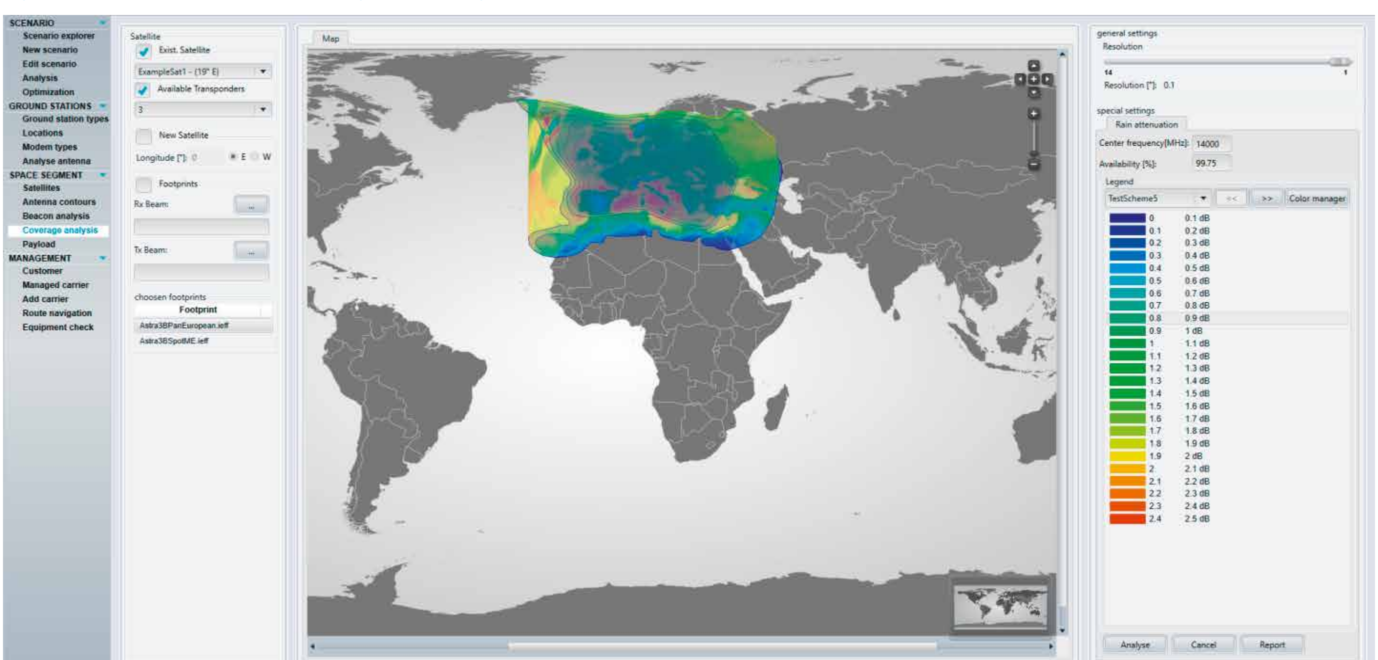


Fig. 5: Multicarrier scenarios can be designed and calculated with R&S®SLP.

Fig. 6: The influence of rain on a coverage area, taking into account the technical link parameters (Astra1KR, European Ku band beam).



operator which geographic areas need a higher power margin. Particularly for mobile satcom terminals on ships, drones, aircraft and so on, this is important to ensure uninterrupted communications.

The transponder simulation module

In the numerical modeling of real satcom links, the power characteristic of the transponder must be incorporated as precisely as possible. That is the task of the transponder module in R&S®SLP. It allows simulation of the power-limiting influence of the transponder electronics on a carrier, which causes degradation of the C/N ratio and capacity losses. This involves both linear and nonlinear effects. The linear effects can be combined in a transponder frequency response characteristic based on the analog circuit components, in particular the IMUX and OMUX filters:

- Gain flatness [dBpp]
- Gain slope [dB/MHz]
- Group delay [ns]
- Group delay slope [ns/MHz]

Nonlinear distortion results from the traveling wave tube amplifiers (TWTA) used in the transponders. The following parameters are taken into consideration:

- AM/AM conversion
- AM/PM conversion
- IBO/OBO curve
- Noise power ratio

R&S®SLP can handle these parameters as follows:

- Import of IBO/OBO curves as text files (usually only the curve shape in single-carrier mode is known)
- Automatic calculation of multicarrier IBO/OBO curves from predefined single-carrier IBO/OBO curves (Fig. 7)
- Application and visualization of IBO/OBO curves for linearized and nonlinearized tubes
- Assignment of a desired IBO/OBO curve to a transponder
- Calculation of IBO/OBO value pairs directly from a given scenario
- Calculation of linear interference from a given gain slope or group delay slope
- Calculation of intermodulation effects

From the available IBO/OBO curves, R&S®SLP calculates the gain of the TWTA for the single-carrier and multicarrier modes (bottom chart in Fig. 7). The lower gain in multicarrier mode is striking. If no IBO/OBO curve is available, R&S®SLP incorporates a set of typical curves for linearized and nonlinearized TWTAs. In addition, users can assign a desired IBO/OBO pair to each transponder if necessary.

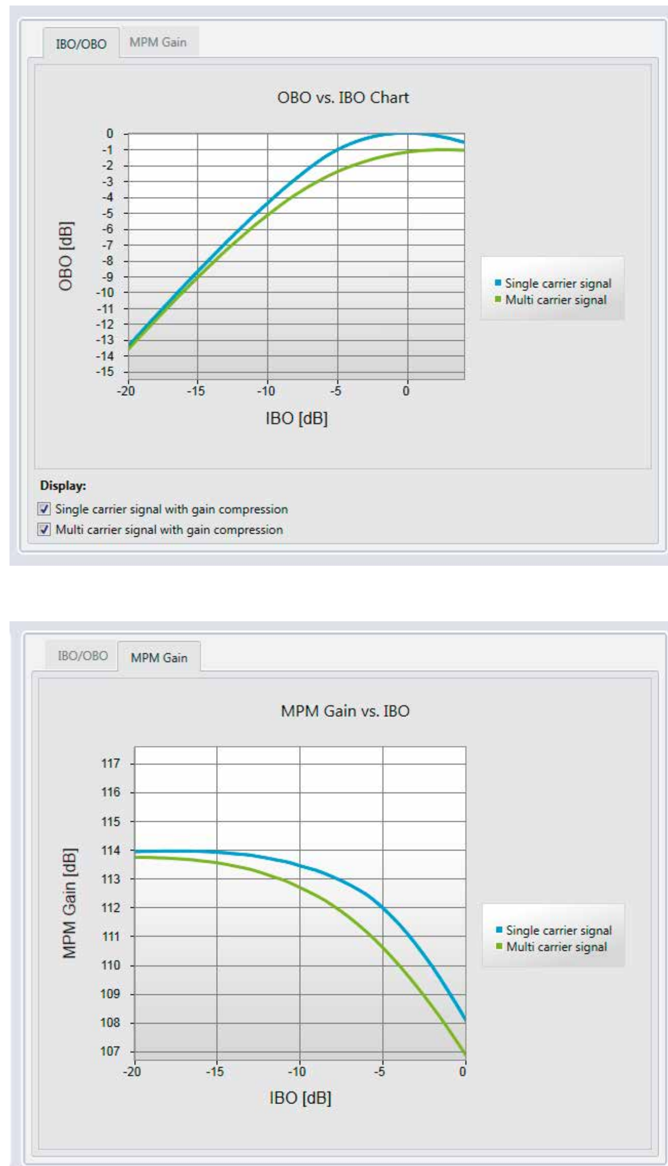


Fig. 7: IBO/OBO ratios and derived gain versus IBO for a nonlinearized TWTA in single-carrier or multicarrier mode.

R&S®SLP satellite link planner in action

The main function of R&S®SLP is transponder optimization. The capabilities of the optimization routine are illustrated below. For this communications scenario example, we consider the occupancy of a 33 MHz Ku band transponder with a footprint covering the Arabian Peninsula (box ❶).

R&S®SLP enables optimization of given scenarios with respect to various operational criteria. The goal is usually minimum PEB consumption, but the optimization goal can also be minimum bandwidth consumption. The two examples below demonstrate the alternatives. The first optimization (box ❷) has very low power consumption, but the bandwidth

❶ Communications scenario example

Parameter	Carrier 1	Carrier 2	Carrier 3
TX ground station	Amman (57 dBi, 35 dB/K)	Riyad (50 dBi, 28 dB/K)	Qatar (50 dBi, 28 dB/K)
RX ground station	Kuwait (57 dBi, 35 dB/K)	Sharam All Sheikh (50 dBi, 28 dB/K)	Kuwait (57 dBi, 35 dB/K)
Modulation	DVB-S2	DVB-S2	DVB-S2
Data rate	5 Mbit/s	6 Mbit/s	6 Mbit/s

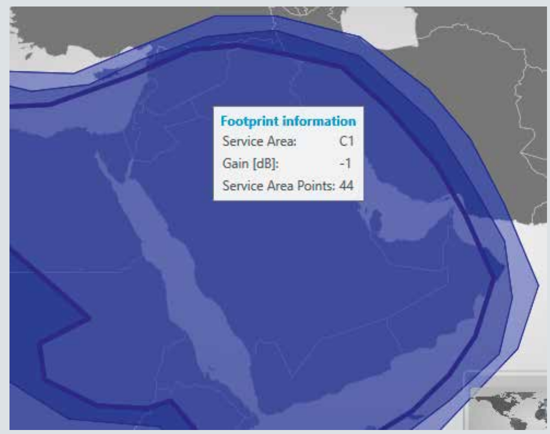


Fig. 8: The footprint of the example scenario.

❷ Optimization 1:

Transponder occupancy for minimum power consumption

With this transponder occupancy, the setting yields a bandwidth consumption of 23.5 MHz (about 71 % of the available transponder bandwidth at 35 % rolloff)* and a power consumption of 6.3 % referenced to the maximum EIRP of approximately 12 dB OBO. That makes the scenario layout extremely power efficient, but at the cost of very high bandwidth consumption. This imbalance can trigger the optimization routine, as can be clearly seen in the second scenario layout.

Parameter	Carrier 1	Carrier 2	Carrier 3
EIRP / baud rate	48 dBW / 5.12 MHz	49.7 dBW / 6.14 MHz	51.5 dBW / 6.14 MHz
Modulation	QPSK 1/2	QPSK 1/2	QPSK 1/2

Fig. 9: The settings proposed by the optimization routine with a target specification of minimum power consumption.

* Sum of baud rates × 1.35. The factor 1.35 comes from the carrier rolloff factor. A rolloff of 35 % is a standard satcom assumption.

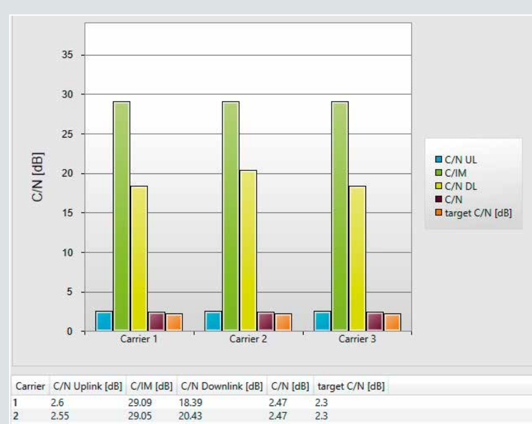


Fig. 10: Optimization means using resources economically. The setting chosen by the optimization routine is closely oriented to the specified minimum C/N value.

requirements are very high. For the calculation in optimization example 2, a low system margin and minimum bandwidth consumption were specified as goals for the routine (box ❸). The system margin usually refers to the power margin on the ground and in the transponder. If a scenario is very bandwidth efficient, this usually is at the cost of the system margin because it is typically necessary to use higher-order modulation methods such as 8PSK, 16APSK or 32APSK. These often require more transmit power in the uplink and downlink to achieve a specific data rate.

Dr. Marco Krondorf

ASI	Adjacent satellite interference; signal interference from adjacent satellite systems, which means satellite systems in adjacent orbit positions
DVB-S2	Digital video broadcasting – satellite, version 2; international transmission standard for satellite signals (not only for TV applications)
EIRP	Equivalent isotropic radiated power; a measure of power (in watts) that characterizes the radiated signal power
IBO/OBO	Input/output (power) backoff; the power or amplitude margin of a power amplifier up to the saturated power point; also often designated as the operating point of the amplifier
IMUX / OMUX	Input/output multiplexer
Link budget	Sum of all amplifying and attenuating factors in the signal transmission path
PEB	Power equivalent bandwidth; a measure of the power or bandwidth consumption of a satcom link
TWTA	Traveling wave tube amplifier; a type of amplifier tube often used in communications satellites

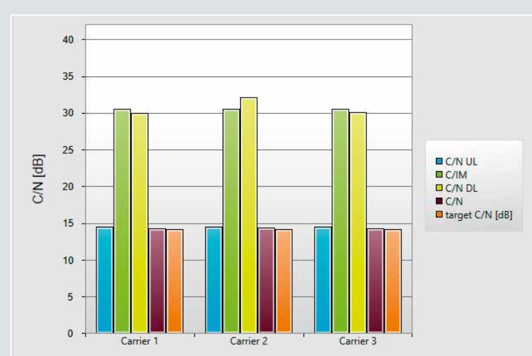
❸ Optimization 2:

Transponder occupancy for high spectral efficiency

With this transponder occupancy, R&S®SLP was able to use all DVB-S2 modulation modes up to 16APSK 3/4. The given setting yields a bandwidth consumption of 7.83 MHz (about 24 %) and a power consumption of 18.2 % referenced to the maximum EIRP of approximately 7 dB OBO. If other modulation modes are included in the optimization*, the tradeoff between bandwidth and power can be pushed further. In this example, the bandwidth consumption drops by about 47 % compared with the first example. By contrast, the power consumption rises by only about 12 %.

Parameter	Carrier 1	Carrier 2	Carrier 3
EIRP / baud rate	55.2 dBW / 2.3 MHz	56.9 dBW / 2.76 MHz	58.6 dBW / 2.76 MHz
Modulation	16APSK 3/4	16APSK 3/4	16APSK 3/4

Fig. 11: Higher-order modulation modes are used when the target specification is high spectral efficiency.



Carrier	C/N Uplink [dB]	C/IM [dB]	C/N Downlink [dB]	C/N [dB]	target C/N [dB]
1	14.5	30.51	30.03	14.27	14.17
2	14.52	30.53	32.15	14.34	14.17
3	14.5	30.51	30.04	14.27	14.17

Fig. 12: Higher-order modulation modes require higher C/N values and therefore more power.

* R&S®SLP incorporates various DVB-S2 modem types – those that support all modulation modes and those that support only a subset. To save on license costs, satcom operators often buy modems that only support a limited number of modulation modes, such as QPSK and 8PSK. R&S®SLP responds to this market situation by offering suitable options.

New radio direction finders boost aviation safety

Fig. 1: Mast with R&S®DF-ATC-S direction finding system in weatherproof housing and R&S®ADD095 DF antenna.

Radio direction finders let air traffic controllers see more. They enhance the situational awareness by adding the dimension of radiocommunications – something that radar cannot detect. The new R&S®DF-ATC-S family of direction finding systems makes life easy for the operators and the ATC organization: All the equipment is mounted at the base of the antenna mast. The only infrastructure needed is the power and network connections.

The typical image of an air traffic control (ATC) workstation has the controller sitting in front of a screen where flight movements are monitored based on information provided by a radar system (Fig. 2). Aircraft in the controlled airspace use a radar transponder to automatically transmit a code that appears as a flight number or aircraft registration identifier at the appropriate position on the radar screen. However, the controller gets no visual identification of the aircraft that is currently calling. Analog aeronautical radio does not transmit any signatures in the background; otherwise, it would be possible to correlate the transponder data with the radio data. This means the identification process must be handled in some other way. For quickly and reliably recognizing the transmitting aircraft, radio direction finders determine its direction or position. They supply the data to the air traffic management system, which then displays it on the radar console – either using a beam if only a single direction finder is involved, or with a circle around the relevant flying object (Fig. 4) if it can be precisely located using a cross-bearing fix. Since the controller can receive a call from only one aircraft at a time, just a single aircraft is highlighted on the screen (assuming a cross-bearing fix), even though dozens of aircraft may be in the air. This allows the controller to immediately identify who is at the other end of the communications.

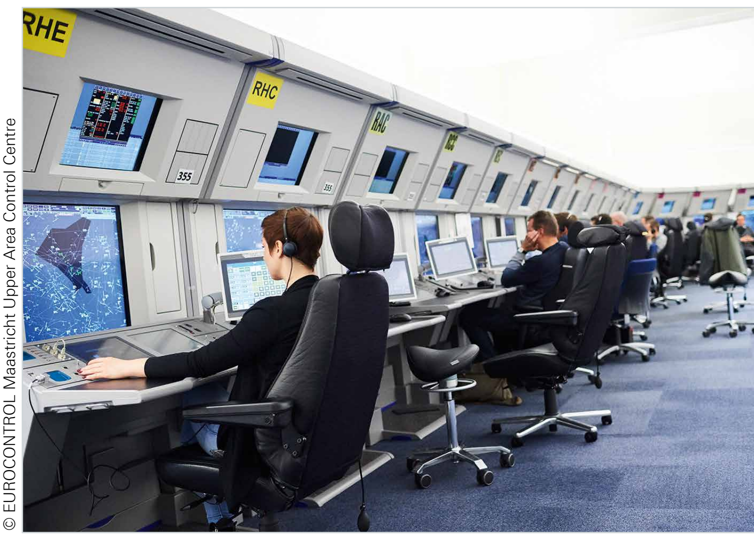


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Fig. 2: Air traffic controllers at Eurocontrol's MUAC (see box on page 81) see radio DF information superimposed on their radar screens.

Rohde & Schwarz has been building radio direction finding systems for over 60 years. One of the first was the NP4, which is seen here in an installation from the early 1960s.

Given that voice radio is used to manage the airspace, this information is critical for overall safety. If there is no radio direction finder to provide the necessary clarity and the controller mixes up the aircraft that is calling, a dangerous situation can quickly arise. This can happen if the call sign is misunderstood during noisy conditions. For example, the controller might give an inappropriate instruction to change flight levels, which in the worst case could have disastrous consequences.

However, radio direction finders not only provide support during arrivals and departures at major airports, they are also part of en-route control at supranational ATC organizations such as Eurocontrol (see box on page 81). At smaller airfields that lack radar systems, ATC direction finders are the only independent source of direction information. They assist flight control, which otherwise would have to rely solely on position reports from pilots in order to keep track of the situation.

Fig. 3: The flat system PC with touch panel is used for configuration and DF display. Flight control at small airfields (typically not equipped with radar) can see the direction of the aircraft that is currently calling on the polar diagram.

Simultaneous direction finding on up to 32 channels

The new R&S®DF-ATC-S direction finding system (Fig. 1) covers all of the aeronautical radio frequencies. It can simultaneously determine bearings on up to 28 VHF channels and four out-of-band channels (up to 450 MHz, including the distress radio beacon on 406 MHz). The channels are easy to select using the software and can be modified at any time, assuming the operator has administrator privileges.

The R&S®ADD095 DF antenna functions on all channels with the same precision and sensitivity. The smaller and more economically priced R&S®ADD317 can even be used in semistationary applications.

If the direction finder is operated as a standalone system instead of with a radar console (e.g. at smaller airfields), the supplied system PC with touch panel is used as the DF display (Fig. 3). The user interface on the antiglare display has been reduced to the essentials to ensure intuitive operation. The display is also built for glare-free night viewing. In cases where the direction finder needs to be integrated into an air traffic management system, the open interfaces help ensure smooth integration.

The most striking feature of the new R&S®DF-ATC-S family is the compact, weatherproof housing. Besides the receiving unit with the DF processor, the housing also contains the DF server, the heating and cooling units, the GPS receiver and an IP switch. The direction finder is simply mounted at the base of the (optionally available) mast and connected to the power grid and data network. Four standard configurations are available to meet the needs of civil and military airfields, major airports and en-route control installations.

Herbert Stärker

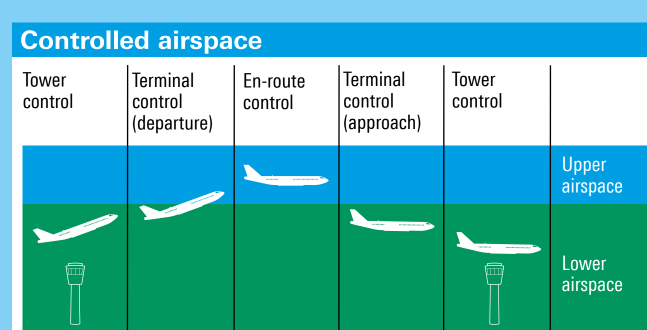
Responsibilities within controlled airspace

Inside controlled airspace, pilots must obey the instructions issued by the ATC center that is currently responsible for their aircraft. However, just who is responsible depends on the flight phase and altitude. The actual structure and designations for the different ATC centers vary from country to country and region to region, but the rules are standardized worldwide.

Aircraft take off from civil or military airfields and airports. There, the pilots receive information, instructions and clearances from tower control. Tower control monitors take-offs and landings and manages all of the air traffic within its area of responsibility. As aircraft fly away from the airport or descend from cruising altitude, terminal control takes over coordinating them. Different frequencies, areas of responsibility and designations are often used for the approach and take-off as well as for the different directions to the airport.

Finally, area control centers guide aircraft along their designated route through upper airspace. Since aircraft typically pass through airspace managed by different area control centers, they are handed over from one ATC center to the next along their route.

The different air traffic controllers in charge of this process use voice radio to coordinate the traffic. Normally, they can determine the position of aircraft near the airport using approach radar and further away using en-route radar. During each flight phase, controllers must manage the separation between aircraft in compliance with the applicable minimum horizontal and vertical distances. The radio direction finders help by providing additional information.



More safety above the clouds

To improve safety in air traffic control, Eurocontrol – a European organization with 41 member states working in the area of air traffic safety – uses seven radio direction finders from Rohde&Schwarz. Air traffic controllers at the Maastricht Upper Area Control Center (MUAC) have been using this technology since 2017 to help them keep better track of current flight movements. MUAC is operated on behalf of four countries. It monitors the upper airspace (over 24500 feet or about 7500 meters) of Belgium, Luxembourg, the Netherlands and northwest Germany. With more than 1.77 million flights passing through the area controlled by MUAC annually, the organization handles the third-largest traffic volume in Europe.

The direction finders are distributed across northwest Germany, Belgium and the Netherlands. Their multichannel design allows them to simultaneously cover all of the frequencies in use and continuously supply DF data to MUAC. There, triangulation software is used to determine the positions of the transmitting aircraft. The results are shown to the responsible controllers along with the data from the radar system in the form of a circular mark on the screen (Fig. 4).

The locations of the direction finders were determined with the aid of the R&S®PCT propagation calculation tool (Fig. 5). This simulation software calculates the optimal direction finder locations, taking into account the required coverage and the propagation conditions. For reliable position fixing, it must be ensured that at least two direction finders can simultaneously receive each aircraft in the area of responsibility in a reliable manner.

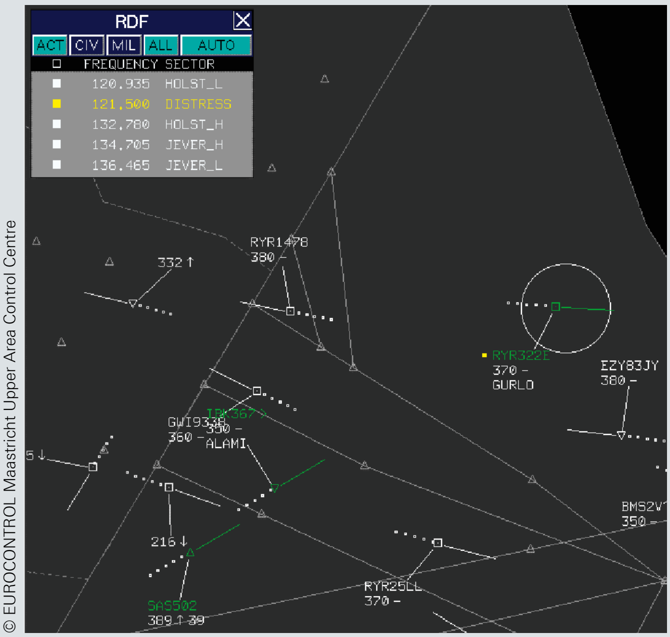


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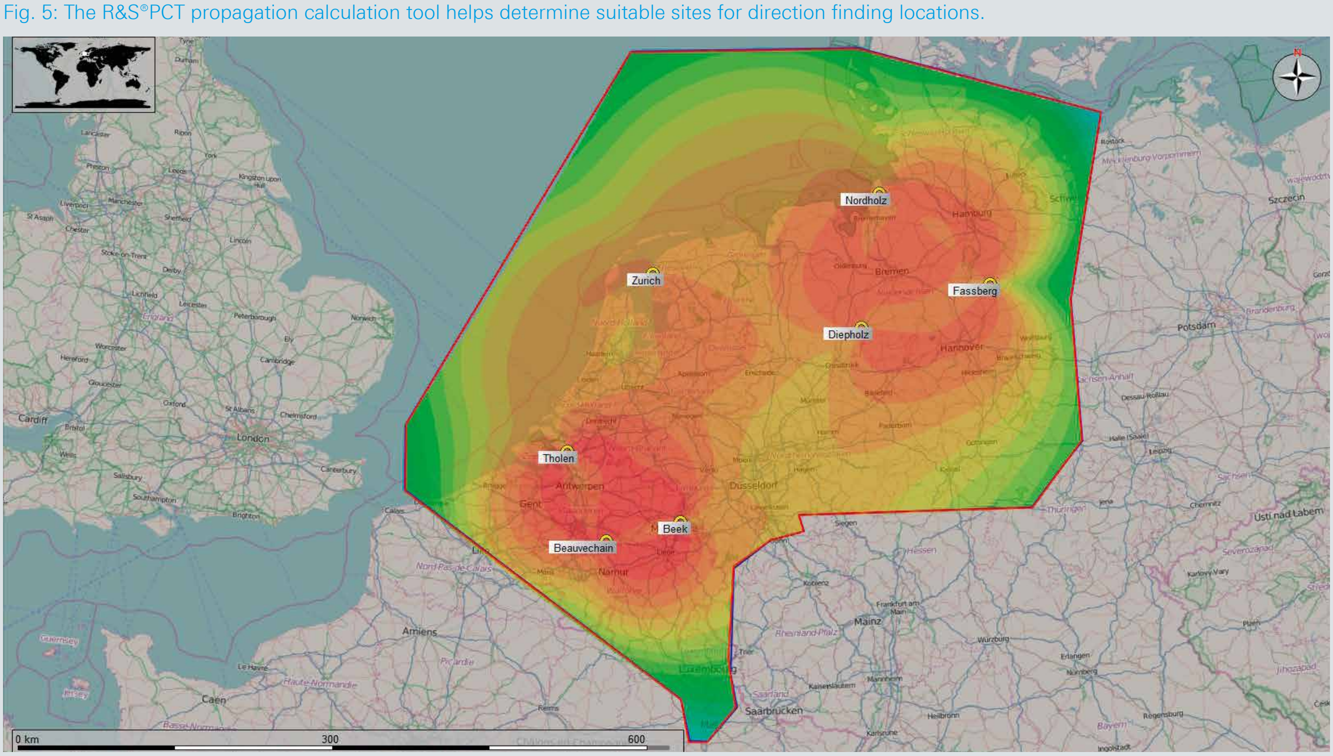
Fig. 4: The aircraft that is currently calling is marked on the radar screen with a circle for reliable identification.

Fig. 5: The R&S®PCT propagation calculation tool helps determine suitable sites for direction finding locations.



Rohde & Schwarz and Unigroup Spreadtrum & RDA expand collaboration

Adam Zeng (left), CEO of Unigroup Spreadtrum & RDA, and Christian Leicher, President and CEO of Rohde & Schwarz, ratify the new collaboration agreement.

Rohde & Schwarz and Unigroup Spreadtrum & RDA, a leading fabless semiconductor company with advanced technology for mobile communications and IoT, have signed an MoU for collaboration in five key areas: 5G communications, network operator tests, automotive electronics products, broadcasting products and IoT applications. The agreement includes setting up a joint operator test lab in China.

Unigroup Spreadtrum & RDA previously chose Rohde & Schwarz as a partner for 2G, 3G and 4G, and now the two companies are expanding their collaboration with current key technologies. For instance, Rohde & Schwarz will support Spreadtrum in the design of chipsets for the 5G mobile communications sub 6 GHz and millimeterwave bands and employ its test solutions to accelerate the development of a 5G test platform.

Rohde & Schwarz Italia opens a test lab in Rome

Not every Rohde & Schwarz customer has their own test lab or T&M instruments for special requirements. Rohde & Schwarz Italia is helping by setting up a lab that is also open to customers. They can perform spectrum, network and time domain analyses as well as power measurements and signal generation. After registering online and specifying the requirements, customers can start measurements. A Rohde & Schwarz employee can provide any needed assistance. The lab is also open to students to enable them to become familiar with various types of T&M instruments.

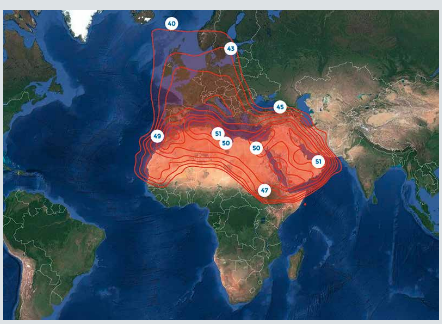
Research project for TV transmission over 5G networks

The Wendelstein transmitter is one of the test transmitters for 5G broadcasting mode FeMBMS.

As part of the Bavarian 5G Today project, research is being conducted to determine how 5G technology can be used in the future for large-scale, economical transmission of broadcasting content. A 5G test range is presently being set up in Upper Bavaria. Under the leadership of the Institut für Rundfunktechnik (IRT) – the research institute for public broadcasters in Germany, Austria and Switzerland – project partners Rohde & Schwarz and Kathrein are researching large-scale TV transmission in 5G further evolved multimedia broadcast multicast service (FeMBMS) mode. They are supported by associate partners Telefónica Deutschland and Bayerischer Rundfunk, which operates the 5G FeMBMS transmitter network as a test range at its transmitter sites. The research project has a duration of 28 months. The first transmissions from the Wendelstein transmitter station and other sites are planned for late 2018.

DTH platform for satellite operator Arabsat

Arabsat, the leading satellite operator for the Arabian world, and Rohde & Schwarz have jointly implemented an IP-based broadcast platform for Tunisian broadcaster ONT. The platform, based on the R&S®AVHE100 head-end solution for encoding and multiplexing, will initially provide signals for ten TV channels in standard definition (SD) quality, two HD TV channels and 24 radio stations, which will be relayed by the BADR-4 satellite to enable reception in all of northern Africa, the Middle East region and western Europe. It is possible to economically upgrade to UHD TV at a later date. Rohde & Schwarz was chosen based on its technologically leading products and its full range of services, including system design, project management, installation, commissioning and training.



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The new DTH platform services the entire EMEA region via the BADR-4 satellite.

Swisscom transmits FIFA World Cup with an IPTV UHD coding solution from Rohde & Schwarz

After extensive research and testing of various offerings, Swiss telecommunications service provider Swisscom has chosen Rohde & Schwarz as the UHD coding solution supplier for the upcoming 2018 FIFA World Cup in Russia. The redundantly configured R&S®AVHE100 system will transmit the live program over three IPTV channels as well as Swiss broadcaster SRG's recorded broadcasts in UHD resolution. Rohde & Schwarz will also handle technical and operational support during the four-week tournament.

"It was not just the outstanding image quality that led us to choose Rohde & Schwarz, it was also the lowest possible bit rate, which has major operational advantages," says Bruno Haug, Head of TV Development at Swisscom. "This efficiency enables us to reach a larger audience with the UHD programs."

Wireless Innovation Forum honors SVFuA and Professor Rohde

The Wireless Innovation Forum has chosen SVFuA, the software defined radio (SDR) system for joint operations developed for the German armed forces, as the winner of the *Technology of the Year Award*. This award honors breakthrough products and technologies in the field of software defined radio and cognitive radio. Rohde & Schwarz is the lead industry partner in the SVFuA project and made this approach possible with its waveform development environment.

The Leadership Award went to Prof. Dr.-Ing. habil. Dr. h.c. mult. Ulrich L. Rohde. This award recognizes individuals or organizations that have made especially significant contributions in advancing the global mission of the Wireless Innovation Forum. According to the WIF, Professor Rohde has done this as an academic and technical author, engineer and businessman.

Popular airborne radio

In the spring of 2018, Rohde & Schwarz marked a milestone with the delivery of the six-thousandth R&S®XK516 airborne radio. The shortwave radio, deployed by more than 50 airlines, is used in passenger aircraft for data and voice communications during long-distance flights.

For transoceanic flights, shortwave radio is still the standard as the only independent wide-range medium. All aircraft are therefore equipped with shortwave radios, mainly the market-leading R&S®XK516. Since more batches have been ordered, the success story of this model will continue in the coming years.

The R&S®XK516 (right) with the R&S®FK516 antenna coupler.

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