RF SIGNAL ANALYSIS WITH ROHDE & SCHWARZ SPECTRUM ANALYZERS AND OSCILLOSCOPES

Choosing the right instrument for your application





Application Brochure Version 01.00

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Nowadays, real-time oscilloscopes feature bandwidths that allow them to acquire microwave and even millimeterwave (mmWave) signals directly. While providing many new possibilities for RF engineers, the overlapping capabilities offered by spectrum and signal analyzers might cause confusion when choosing the right instrument for a specific application. Our focus here will therefore be the differences between both instruments and the use cases for which these instrument are ideally suited to meet the typical requirements of the measurements concerned.

Spectrum and signal analyzers

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SPECTRUM AND SIGNAL ANALYZERS

One of the most frequent measurement tasks in radio engineering is the examination of signals in the frequency domain. Spectrum analyzers required for this purpose are therefore among the most versatile and widely used RF measuring instruments. Covering frequency ranges up to 85 GHz and beyond, they are used in practically all applications involving wireless, cellular or satellite communications, radars or IoT devices for development, production, installation and maintenance activities. For these applications, parameters such as displayed average noise level (DANL), dynamic range and frequency range, and other exacting requirements regarding functionality and measurement speed come to the fore. Moreover, spectrum analyzers are also used for measurements in the time domain, such as measuring the transmitter output power of time multiplex systems as a function of time.

SPECTRUM OVER A WIDE SPAN

The spectrum analyzer shows the level versus frequency at a selected resolution bandwidth. It can be used to measure basic signal parameters such as signal level or bandwidth. The signal shape visible on the screen allows an estimation of further parameters such as the filter settings or a frequency response.

Other measurements in the spectrum include the detection of spurious emissions, the measurement of the signalto-noise ratio (SNR) or the detection of unwanted spurious emissions.

Spectrum analyzers are frequency-selective, i.e. only part of the spectrum is considered at a time. This frequency selectivity enables the spectrum analyzers to achieve a high dynamic range. Even very small signals can be displayed in the vicinity of a strong carrier signal.

With modern signal and spectrum analyzers such as the R&S*FSW, the entire spectrum from 2 Hz to 85 GHz can be measured and displayed in a single measurement. And with external mixers, the displayable frequency range can be expanded by hundreds of gigahertz.

IMPORTANT FOR CONFORMITY

Many standards and regulations require spectrum measurements for conformity. In mobile radio, these are the adjacent channel power ratio (ACLR), spectrum emission masks (SEM), spurious emissions over a large frequency range, etc. These measurements require very small levels to be measured in the immediate vicinity of a strong signal. Spectrum analyzers are the measuring device of choice because the frequency selectivity achieves the necessary dynamics that these standards require.



Fig. 1: Measurements of the spectrum emission mask (SEM) with a spectrum analyzer.

The ACLR measurement is similar to the SEM. Unlike the SEM, however, it is not individual spurs that are of interest, but rather the integrated power over frequency of the neighboring channels of a communications signal. Such power leakage into neighboring channels is a common challenge in the design of highly efficient power amplifiers. Spectrum analyzers provide the dynamic range required to perform such measurements according to the respective standards.



Fig. 2: Measurements of the adjacent channel leakage ratio (ACLR) require a high dynamic range and are performed using a spectrum analyzer.

Conformance is also required with respect to electromagnetic interference (EMI). The respective EMI standards require a minimum number of spurs to be measured with the appropriate EMI detectors (quasi-peak, CISPR-Average and RMS-Average (CISPR-RMS)). Spectrum analyzers are typically used to carry out corresponding precompliance measurements.



Fig. 3: EMI precompliance measurement with a spectrum analyzer.

FREQUENCY SELECTIVITY

A fundamental aspect of spectrum analyzers is their frequency selectivity. This differentiates spectrum analyzers from other RF measurement instruments such as power sensors or oscilloscopes. A spectrum analyzer in swept spectrum mode only considers a small part of the spectrum at a time.

At the lower frequency end, DC components in the signal are removed. At frequencies from typically 7 GHz to 8 GHz, a tunable bandpass filter called a preselector removes signal components from its passband. The bene-fit of frequency selectivity is an increase in dynamic range so that small signals can be detected even in the presence of a higher power signal.

SIGNAL ANALYSIS

In addition to spectrum analysis, today's analyzers also support signal analysis. The signal is mixed to a low intermediate frequency via one or two mixer stages and sampled over a wide bandwidth with an A/D converter. Then it is digitally downconverted to the baseband and equalized. Signal analysis bandwidths up to 1 GHz are now commonplace. Modern spectrum analyzers, like the R&S°FSW, even support up to 8.3 GHz analysis bandwidth. The digital I/Q values obtained in this way contain all signal information within the bandwidth and dynamic range to allow the signal to be further processed.



Fig. 4: Digital signal analysis with a signal and spectrum analyzer

With the appropriate application-specific measurements, the signal can now be analyzed in detail. Important parameters of communications signals are, for example, modulation quality, typically error vector magnitude (EVM), I/Q offset or imbalance as well as the level ratio of pilot-to-data channels. With pulsed signals for radar applications, it is phase, frequency, modulation and level over the entire pulse duration.

The corresponding measurement applications are either available on the device or via PC software such as the R&S[®]VSE.



Fig. 5: Signal analysis of a 5G NR signal. The measurement application displays key parameters such as the EVM, the power spectrum and the constellation diagram.

FURTHER MEASUREMENTS

From predevelopment to series production of highfrequency devices, many measurements take place at component, module and, finally, device level. Measurement of the noise figure and gain is essential in the case of amplifiers, and measurement of the phase noise in the case of oscillators. Today, these measurements are usually carried out with signal and spectrum analyzers and the corresponding measurement applications.



Fig. 6: Noise figure and gain measurement of a low-noise amplifier with a spectrum analyzer and a dedicated measurement application. Using the Y-factor method enables very precise measurements almost down to the thermal noise floor because the inherent noise of the analyzer is cancelled out.



Fig. 7: Phase noise measurement with a spectrum analyzer. While phase noise measurements are often conducted in spectrum mode, more sophisticated measurements are possible in I/Ω mode, which enables separation of AM and PM noise or frequency tracking of drifting sources.

High-end signal and spectrum analyzers support further measurements, e.g. uninterrupted real-time spectrum analysis and uninterrupted streaming of digital I/Q data.

OSCILLOSCOPES

OSCILLOSCOPE BASED APPROACH FOR RF SIGNAL ANALYSIS

Wide analysis bandwidth

Modern high-end oscilloscope architectures contain highspeed A/D converters allowing them to cover frequency ranges which, until recently, were ranges that could only be measured using a spectrum analyzer. In combination with high bandwidth analog frontends, these oscilloscope architectures make it possible to perform direct sampling of high-frequency signals without any need for analog downconversion.

This approach allows unprecedented analysis bandwidth ranges. For instance, using the R&S®RTP high-performance oscilloscope with 16 GHz bandwidth and assuming a center frequency of 8 GHz, it is possible to acquire RF signals with up to 16 GHz bandwidth. This analysis bandwidth cannot be reached by conventional spectrum and signal analyzers.

Such a large analysis bandwidth is playing a more and more important role, especially for radar research applications, since the radar range resolution is directly proportional to the available bandwidth. Moreover, even if the bandwidth of the signal of interest is lower, a high analysis bandwidth allows out-of-band signals to be covered, e.g. harmonics, neighboring channels and interference signals.

User-defined digital filters

While having multiple advantages as stated above, a high analysis bandwidth may also have a number of caveats if narrowband signals have to be acquired. Let us consider, for example, a 2 MHz wide Bluetooth[®] Low Energy signal at a center frequency of 2.4 GHz. The signal can, of course, be acquired easily using an R&S®RTP (as explained above), but if no filters are applied, all possible interferers from DC to the maximal frequency within the oscilloscope bandwidth will be acquired in addition to the signal of interest, which unnecessarily increases the noise level when focusing on the Bluetooth® Low Energy signal. To avoid this, Rohde&Schwarz high-end oscilloscopes allow users to design digital filters using their preferred filter design tools and import the filter coefficients to the instrument. By doing so, they can limit the analysis window to the signal of interest.

Digital downconversion

As just explained, applying an appropriate digital filter improves the signal-to-noise ratio (SNR). However, the question arises whether the achievable capture time can still be improved for such a narrowband signal. Even if we reduce the sample rate to be just as high as stated by the Nyquist theorem, the maximal capture time is namely less than 1 s when proceeding as described above.

Rohde & Schwarz was the first on the market to introduce a digital downconversion solution for its high-end oscilloscopes. This powerful option takes all appropriate steps to downconvert the signal and stores the converted I/Q data for further analysis, either with the R&S®VSE vector signal explorer software or with a third-party tool such as MATLAB®. In our Bluetooth® Low Energy scenario, applying the digital downconversion leads to a capture time of approx. 500 s.

Advanced trigger system

Oscilloscopes are typically equipped with a much more advanced trigger system than spectrum and signal analyzers. This allows very accurate detection of short, intermittent, burst or pulsed signals – a major advantage especially for radar applications where precise detection of a pulse/chirp start is essential.

A special feature of Rohde & Schwarz oscilloscopes is that their trigger system is fully digital, i.e. it operates directly on the samples of the A/D converter. The measurement signal is not split up into two paths as is the case for conventional analog triggers. This solves the problems associated with an analog trigger system and results in a lower trigger jitter and a flexible trigger sensitivity that can be optimized depending on the actual needs.

Furthermore, the digital trigger system provides Rohde&Schwarz oscilloscopes with the unique property that all trigger types support the full bandwidth of the oscilloscope.

Fig. 8 shows the difference between the oscilloscope architecture with a conventional analog trigger and with the Rohde&Schwarz digital trigger system. To better understand the digital trigger concept, read the application note "Benefits of the Oscilloscope's Digital Trigger" (1ER04).

Fig. 8: Simplified oscilloscope architecture with a) a conventional analog trigger

b) the Rohde & Schwarz digital trigger system





PHASE-COHERENT MULTI-CHANNEL ACQUISITION

In many wireless applications, multi-antenna designs are gaining more and more importance for multiple reasons. For radar applications, for example, a common requirement on radar systems is determining the direction from which the surrounding objects are coming. For this purpose, multi-antenna systems became the state-of-the-art technology to estimate the angle of arrival (AoA) of an object based on the phase difference between multiple receive paths.

To characterize these types of systems, test equipment must exhibit multichannel capabilities and ensure that all channels are constantly phase-coherent. Oscilloscopes are very well suited in this case because they typically provide multiple channels which are by design tightly aligned and do not need any additional enhancements such as timebase and LO sharing to perform phase-coherent measurements, as is the case for spectrum analyzers. Therefore, oscilloscopes represent a cost-effective and easy-to-use solution when it comes to multi-antenna system design tests.

The R&S®RTP, for example, has an analysis bandwidth that goes up to 16 GHz and thus covers the entire X band and a large part of the Ku band. Multichannel acquisition is possible in these frequency ranges without any need for external downconverters. This is particularly useful for radar and electronic warfare (EW) applications. One of the most prominent examples is the digital radio frequency memory (DRFM) jamming technique. There the jammer is capable of receiving the original radar signal and creating a fake radar echo representing a false target that the transmitting radar cannot distinguish from other legitimate



signals. For this purpose, the retransmitted false targets have to maintain coherence with the original signal. This can only be validated when both the original and retransmitted pulses are analyzed in relation to each other. The R&S®RTP allows phase-coherent analysis of both signals in the time and frequency domains. It even allows for frequency agile radar and RF hopper analysis over a relatively wide bandwidth in order to verify whether the DRFM is following that agility.

Even for standards using frequency ranges beyond the oscilloscope bandwidth capabilities, it is still possible to acquire the corresponding signals by combining the oscilloscope with external mixers such as the R&S*FS-Zxx. This makes the multichannel acquisition and analysis of well-established as well as novel radar signals possible, such as automotive radar in the 77 GHz to 81 GHz range and the new radar technology for gesture sensing at 60 GHz. The real-time deembedding capabilities of Rohde&Schwarz oscilloscopes allows the compensation of losses induced by the additional components across the entire signal path.

The acquired signals can be analyzed using either the oscilloscope's built-in measurement tools for basis analysis or the pulse and transient analysis options of the R&S®VSE software, which provides a more comprehensive functionality. Fig. 11 shows examples of both approaches for an automotive radar signal.



Fig. 11: Screenshots of automotive radar signal analysis using a) the oscilloscope onboard tools and b) the R&S[®]VSE.

Fig. 10: Phase-coherent multichannel signal analysis setup for automotive radar applications



Modern wireless standards such as 5G NR rely on a similar approach of using multiple antennas to transmit the signal in a desired direction, so-called beamforming. Beamforming is achieved by generating a well-defined phase shift of each adjacent input signal stream. The introduced phase shift is kept constant so that the generated beam consistently points in the desired direction.

Fig. 13 shows an example of 5G NR MIMO signal analysis with the R&S®RTP and the 5G analysis options of the R&S®VSE. The multichannel capability of the R&S®RTP allows phase-coherent measurement of up to four input streams. By doing so, it expands all measurements supported for a single 5G NR channel to up to four input channels. In addition to this, it adds MIMO-specific measurements such as the phase difference between the input signals, which is an important metric to characterize the beams when performing transmitter tests on 5G NR base stations or small cells.

Fig. 12: Typical setup for 5G NR MIMO TX measurements on base stations/small cells





Fig. 13: 5G NR MIMO measurements with the R&S®VSE vector signal explorer software.

MULTI-DOMAIN ANALYSIS FOR SYSTEM-LEVEL DEBUGGING

Unlike spectrum and signal analyzers, which are dedicated instruments for RF signal analysis, oscilloscopes are by definition general-purpose instruments that allow multiple measurements besides the acquisition of RF signals. They namely provide a variety of bus trigger and decode, power, time and frequency domain measurement options. Therefore, it is possible to correlate the acquired RF signals with other signals, such as the supply voltage or digital bus signals, since the time-alignment between all these measurements is constantly ensured.

For example, simultaneously acquiring CAN bus or automotive Ethernet signals together with radar signals is particularly helpful during the development and debugging of automotive radar modules. The analysis time of the radar sensor can be determined from the delay between the radar signal and the bus protocol signal. If the measured delay exceeds a specified time, deployment in autonomous vehicles is not acceptable.

Powerful FFT functionality

Powerful FFT capabilities are particularly helpful in the initial design and prototyping phases where correlation to time domain is important. If we consider, for example, the UWB 802.15.4z standard, which is attracting increasing interest in automotive applications, the oscilloscopes multidomain capability makes it possible to examine the UWB signal in both the time and frequency domain at the same time. So the measurement settings can be adjusted if need be. As shown in Fig. 15, it is possible to use the gated FFT feature provided by Rohde&Schwarz oscilloscopes to define a signal portion in the time domain and plot the spectrum of this specific portion. In addition to that, Rohde&Schwarz oscilloscopes provide a variety of fast and easy-to-setup spectral measurements such as the channel power and the occupied bandwidth. This can be very useful when focusing on the spectral properties of a specific pulse or when debugging unexpected behavior of a device under test.

The same approach can be applied when debugging the electromagnetic interference (EMI) behavior of electronic designs. For this purpose, Rohde&Schwarz oscilloscopes provide dedicated near-field probes that can be used in conjunction with the FFT and trigger capabilities.



Fig. 15: Time and frequency domain measurements of UWB signal.



Fig. 14: Multi-domain capabilities of Rohde & Schwarz oscilloscopes

Zone trigger

Another example of a useful cross-domain feature is the zone trigger. Using Rohde & Schwarz high-end oscilloscopes, up to eight zones can be graphically defined in the time and frequency domain and combined through logical operators to define a condition as well as the device reaction when this condition is met. This can be particularly useful for EMI debugging purposes by giving the user the flexibility to define forbidden areas in both domains and be warned if these areas are violated, even by a short or intermittent interferer. As shown in Fig. 16, zones from both domains can be combined for defining the condition to detect any fading effects on a WLAN signal.



Fig. 16: Using zone triggers in time and frequency domain to detect fading effects on a WLAN signal.

SUMMARY

WHEN TO CHOOSE A SPECTRUM AND SIGNAL ANALYZER OR AN OSCILLOSCOPE?

Advantages of a signal and spectrum analyzer

The main differences result from the frequency selectivity of the signal and spectrum analyzer:

- High dynamic range through frequency selectivity: low-level signals can also be analyzed in the vicinity of a strong signal: standard-compliant ACLR and SEM measurements are usually only possible with a spectrum analyzer
- With signal demodulation, the great dynamic range is reflected in the quality of the measurement results: particularly with signals with a large bandwidth and a high crest factor, significantly better results, i.e. better EVM values, can be achieved
- ► High maximum frequency and continuous sweep from minimum to maximum frequency
- Depending on the bandwidth, very long, seamless recording times are possible
- Measuring applications for phase noise and noise figure/gain
- Measurement applications for real-time spectrum analysis with uninterrupted analysis

Advantages of an oscilloscope

The main advantages of an oscilloscope result from full signal capture including DC components and the availability of several, typically two or four phase-coherent inputs:

- Measurement of signals with DC components is possible
- Unrivalled analysis bandwidth, usually up to the maximum frequency of the oscilloscope
- Wideband measurement of signals in the analog baseband, four-port instruments even allow differential I and Q capture
- Phase-coherent measurements of several sources are possible
- ► Time-correlated multi-domain measurements

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Summary

The table represents a short summary of the topics discussed above. It focuses on the strengths of the high-end Rohde&Schwarz spectrum and signal analyzers and Rohde&Schwarz oscilloscopes for RF measurements.

ROHDE & SCHWARZ ROHDE & SCHWARZ SPECTRUM AND SIGNAL OSCILLOSCOPES ANALYZERS Wide analysis bandwidth Wide analysis bandwidth (up to 8.3 GHz) (up to 16 GHz) High dynamic range Advanced triggering Phase-coherent multichannel Optimized architecture for excellent RF performance up to 85 GHz capability **Comprehensive RF measurement** Time-correlated multi-domain functionality measurements

Which device for which application?

The table below shows whether a Rohde&Schwarz spectrum and signal analyzer or a Rohde&Schwarz oscilloscope is most suitable for the required measurements, depending on typical requirements in multiple RF applications.

Requirements	Rohde&Schwarz spectrum and signal analyzer	Rohde & Schwarz oscilloscope
Standard-conformant spectral measurements of ACLR, SEM or spurs of cellular or wireless standards like LTE, 5G NR or WLAN	•••	•
Seamless, long-time recordings	•••	•
Signal demodulation and EVM analysis of cellular or wireless standards like LTE, 5G NR or WLAN	on device or R&S®VSE	only with R&S®VSE
Phase difference measurements between 5G NR base station/small cell outputs for beam characterization	-	•••
Accurate detection of DRFM jammer retransmitted echo and phase- coherent analysis in relation to the original pulse	-	•••
EMC precompliance measurement with CISPR detectors and 6 dB filters	•••	only EMI debugging with advanced FFT capabilities
Trigger on a very sporadic spur with 100% probability of detection	•••	•
Analysis of bus and high-speed interface signals	-	•••
Multi-domain measurements to determine causes of unexpected behavior	-	•••
Analysis of wideband automotive radar signals in the E band	one-box solution or with external mixer	possible with external mixer and LO
Versatile test equipment that can handle both RF and digital measurements when debugging radar sensors	-	•••
Measurement of phase noise	•••	-
Measurement of noise figure and gain of an amplifier	•••	-

• The higher the number of points, the higher the performance.

Service that adds value

- ► Worldwide
- Local and personalized
- Customized and flexible
 Uncompromising quality
- Long-term dependability

Rohde & Schwarz

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