RADAR TESTING

Analyzing automotive radar signals with an oscilloscope

Automotive radar sensors require detailed characterization in the lab. Oscilloscopes are ideal for this because they can simultaneously analyze multiple signals and precisely compare them.

Compact radar sensors with long range and high resolution are currently being developed for driver assistance systems and future fully autonomous vehicles. Operating in the frequency range from 76 GHz to 81 GHz, these sensors use phased array antennas to obtain location information. The accuracy of the obtained data is directly correlated to the accuracy of the relative phase angles of the emitted signals, making precise adjustment of the antenna system a crucial factor for precision.

Characterization of these sensors in the development phase requires sophisticated T&M equipment due to the high frequencies. For many of these measurements, the R&S®FSW85 spectrum analyzer with its large measurement dynamic range and sophisticated analysis features is an excellent choice*, but it has only one input channel and is therefore not able to measure the phase differences of multiple signals. Oscilloscopes have an advantage here. The four-channel R&S®RTP, for example, can act as a phase coherent receiver and simultaneously analyze and compare up to four signals.

* 5 GHz analysis bandwidth for testing automotive radars in the E band. NEWS (2018) No. 219, pages 30 to 32.

Test setup

External mixers are used to downconvert the radar signals to the oscilloscope's frequency range (Fig. 1). The R&S®FS-Z90 mixers in this example use the sixth harmonic of a local oscillator (LO) to generate the desired output frequency. An R&S®SMA100B signal generator (see page 50) serves as the LO, while the evaluation board of a commercial radar sensor acts as the radar signal source.

The radar system uses a chirp sequence signal consisting of several high frequency pulses in direct succession. Each of these pulses is a chirp with a bandwidth of approximately 4 GHz. The sensor is configured so that the frequency of the radar signal rises linearly from 77 GHz to nearly 81 GHz (up chirp). The end of the sequence is followed by a break of several milliseconds (interframe time). During this time, the radar processor calculates the locations and speeds of the detected objects.

Test setup

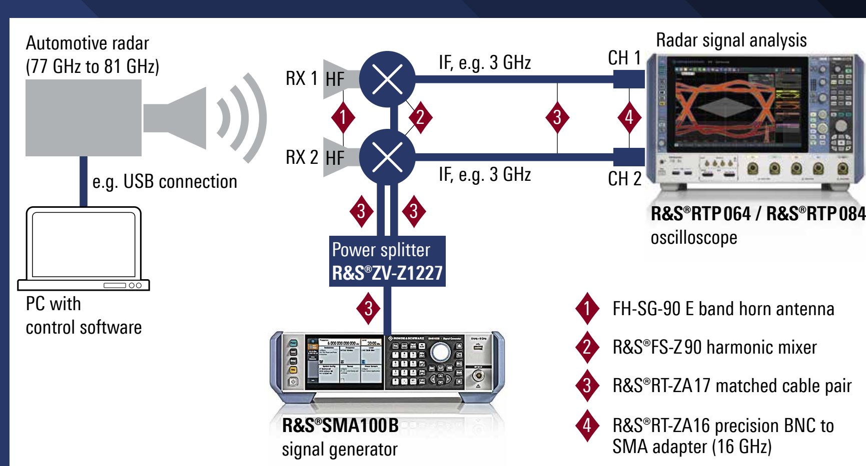


Fig. 1: Test setup for multichannel radar analysis with an oscilloscope. The radar signal is downconverted to an IF frequency of 3 GHz by the harmonic mixers and fed to the oscilloscope. The power splitter and one mixer are not needed for a test setup with only one channel.

The IF signals from the mixers are fed to the oscilloscope inputs. The attenuation and S-parameters of the individual components in the signal path can be taken into account by the hardware and software deembedding functions of the R&S®RTP. The impact of deembedding is illustrated in Fig. 2. The received signal is attenuated over the entire frequency range and detected with decreasing amplitude as the frequency increases (upper screenshot). Deembedding compensates for these losses (lower screenshot), enabling the oscilloscope to analyze the actual signal.

Single-channel analysis

Trigger

Stable trigger conditions are essential for reliable signal analysis with an oscilloscope. Oscilloscopes usually offer advanced trigger options in addition to traditional edge triggering. However, these options can only be used up to a certain bandwidth, depending on the manufacturer. Thanks to its digital triggering, the R&S®RTP can use the entire range of trigger options up to the maximum bandwidth.

Simple edge triggering is not useful for these measurement tasks since the oscilloscope will trigger on virtually any point of the signal due to the nature of the radar pulse. A pulse width trigger, which can be used to trigger on the interframe time between pulses, is more useful because it allows individual pulses or entire pulse sequences to be detected and analyzed. The trigger condition can be configured for specific radar signal parameters, for example to only display pulses with a specific duration (see the application note at the end of this article).

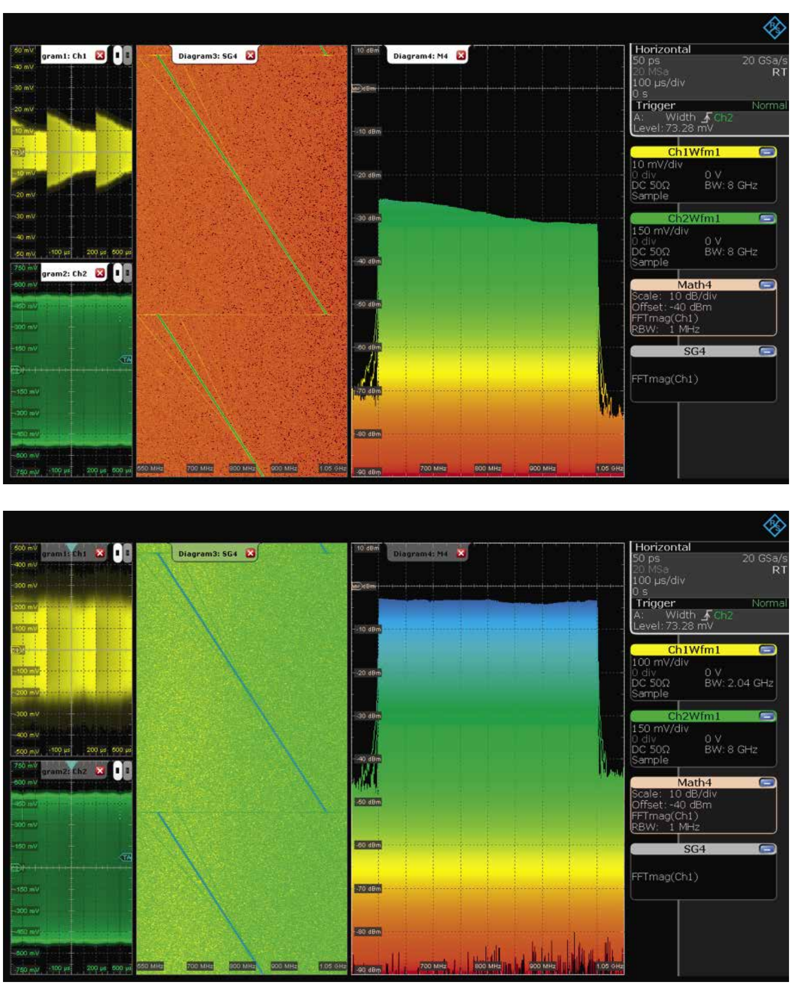


Fig. 2: An FMCW signal with deembedding disabled (top screenshot) and enabled (bottom screenshot). The frequency response correction reconstructs the signal in its original frequency range.

Demodulation

For the best possible spatial resolution, current automotive radars operate with bandwidths up to 4 GHz. The R&S®RTP meets the associated T&M requirements. With its high sampling rate and large memory, it captures the downconverted radar signal with a sufficiently high sampling frequency. The analysis tools included in the base configuration are sufficient to check the modulation in the radar signal. The signal used starts at 1 GHz and rises linearly to 5 GHz. An initial check of these frequencies starts with a frequency measurement that is configured to perform many frequency measurements within one acquisition (frequency tracking). The result is a display of the downconverted frequency versus time $f_{IF}(t)$.

At higher frequencies, the data points are closer together, making the measurement more difficult. Noise often increases, but can be filtered out by the oscilloscope's lowpass filter math function. It is possible to change the scaling of $f_{IF}(t)$. (increase the frequency axis) to display the radar signal in its original frequency range $f_{HF}(t)$ (Fig. 3).

Other measurement functions help users quickly determine important parameters such as the rise time of the linear frequency modulation. For example, the oscilloscope's FFT function creates a spectrogram that shows how the radar signal changes over time. These two analysis methods (Figs. 2 and 3) allow users to perform an initial check of the bandwidth and the modulation.

Pulse analysis with the R&S®VSE software

The R&S®VSE vector signal explorer software offers advanced analysis tools for investigating radar signals, for example to check the linearity of a frequency modulated continuous wave (FMCW) radar signal, which has a large influence on the Doppler properties of a target. The software's R&S®VSE-K60c transient analysis option performs this measurement with high accuracy (Fig. 4). The R&S®VSE-K60c displays the frequency response $f_{IF}(t)$ and calculates the deviation from the ideal linear phase. The software can be installed directly on the oscilloscope, but also on an external PC. In this case, the data is transferred for example via Ethernet for analysis.

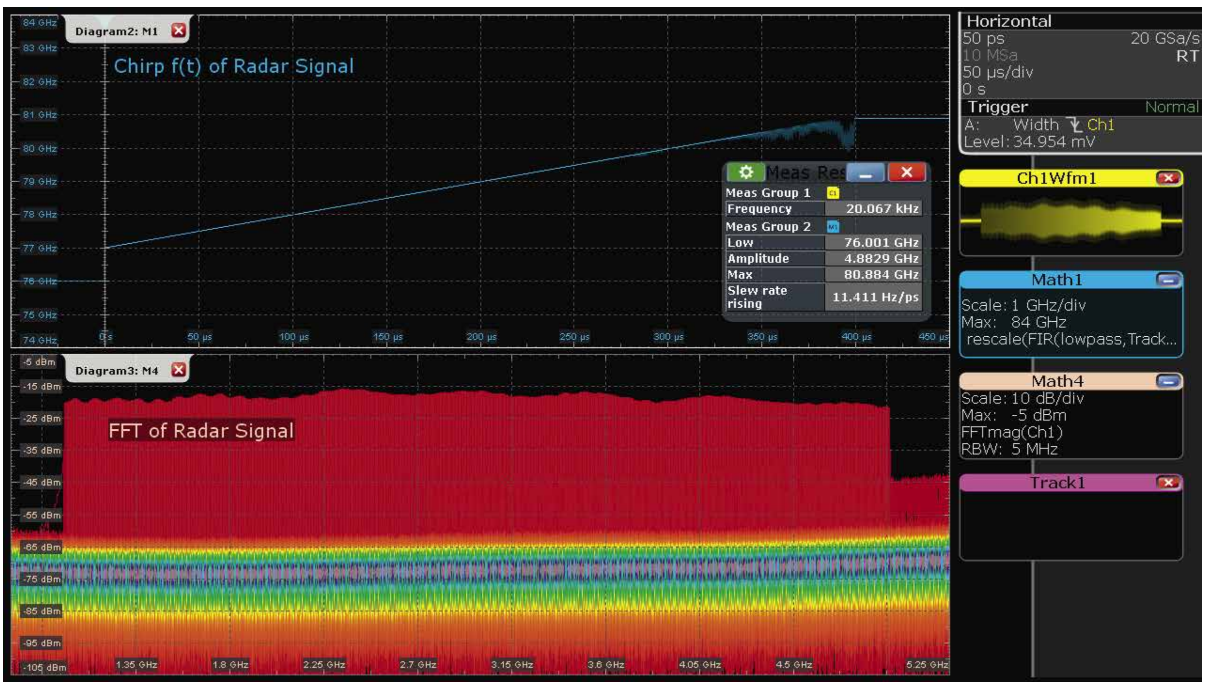


Fig. 3: Top: With suitable scaling and filtering, the radar signal can be displayed in its original frequency range $f_{HF}(t)$. Measurement functions provide important parameters, such as the slew rate of the chirp. Bottom: The FFT shows the power profile of the chirp.

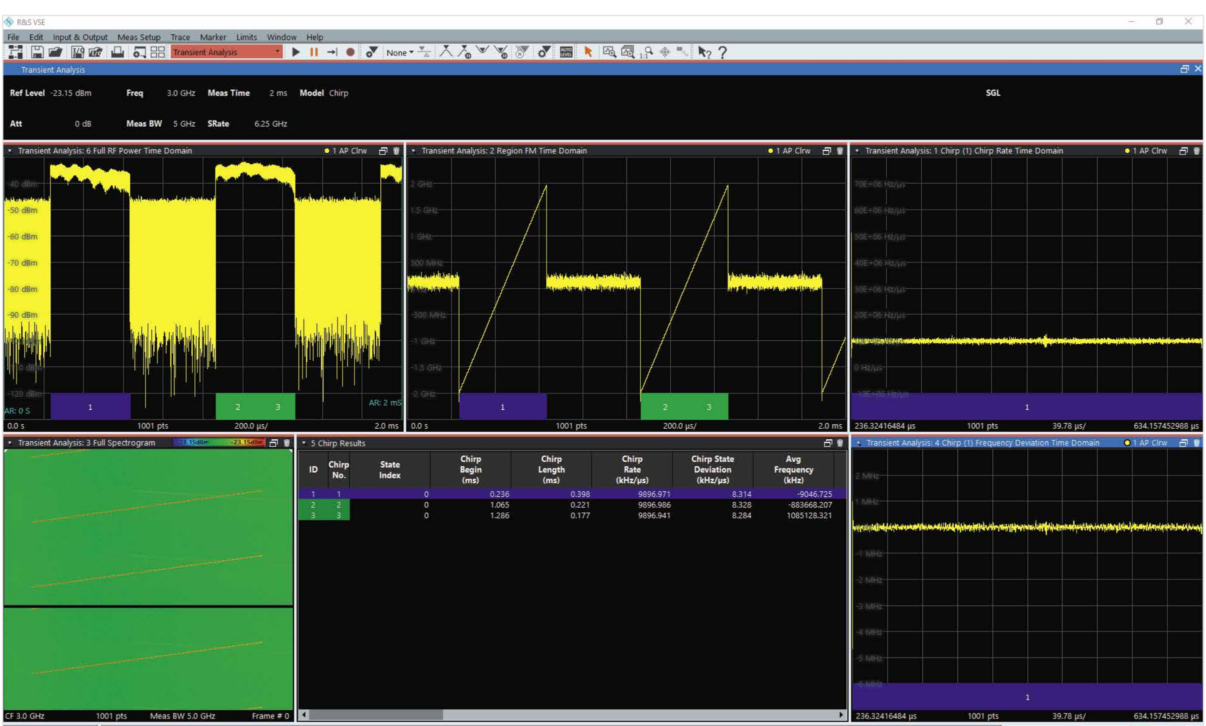


Fig. 4: Transient analysis of a chirp sequence signal with the R&S®VSE-K60c transient analysis option. The pulse power versus time is shown at the top left. The linear frequency response can be seen in the top middle and in the spectrogram on the bottom left. The software lists the properties of the detected pulses in a table (bottom middle). The properties can also be investigated in detail in graphical form. The chirp rate and frequency deviation are shown on the right.

Measuring phase and amplitude differences with multichannel analysis

Many automotive radars are equipped with multiple transmit and receive antenna arrays. These determine the directivity of the antenna and allow beamforming and detection of the direction of the target. To specifically investigate the transmit properties, for example, multiple mixers can be operated simultaneously on the oscilloscope. The setup is similar to that for single-channel analysis; the LO signal simply has to be distributed to all the mixers (Fig. 1).

When used as a phase coherent receiver, the oscilloscope analyzes multiple signals relative to each other. Typically, the phase differences and difference between the two spectra are analyzed. The FFT function of the R&S®RTP is also helpful. It is used to calculate the amplitude spectra of the signals in the two channels. The difference is then calculated with another math function and displayed.

For the phase measurement, the analysis range is limited to a narrow time corridor, and the phase difference of the two input channels is calculated from the phase properties determined by FFT (Fig. 5). The advantage of the indirect method using FFT is the larger time analysis range. Whereas a single measurement of the phase difference in the time domain can be strongly dominated by noise, in the frequency domain multiple signal periods are compared with each other, resulting in a significantly smaller measurement uncertainty.

Debugging by correlating radar signals with other signals

The R&S®RTP can measure the amplitude and phase differences of multiple antenna paths simultaneously and correlate the radar signals with other signals, such as the supply voltage or digital bus signals (Fig. 6). Simultaneously acquiring CAN bus or automotive Ethernet

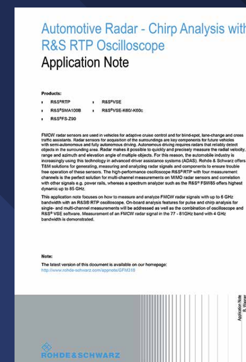
Fig. 5: Multichannel measurement of a chirp sequence. The pulses are shown in the time domain (top), the spectra of the individual channels in the middle, and the amplitudes and phase difference are shown on the bottom left and bottom right, respectively.

signals together with radar signals is particularly helpful during development and debugging. 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.

Summary

The R&S®RTP oscilloscope is ideal for characterizing the new generation of radar sensors. The radar signals are either acquired directly from the radar sensor as baseband signals or downconverted by a mixer to the oscilloscope's bandwidth. The oscilloscope's advanced trigger and analysis tools and the powerful R&S®VSE pulse analysis software facilitate characterization and debugging.

Dr. Ernst Flemming, Dr. Andreas Ritter



Analysis of radar signals is described in detail in the application note "Automotive Radar – Chirp Analysis with R&S®RTP Oscilloscope".

Fig. 6: Measurement of the delay between the radar signal (left) and the CAN protocol frame (right). The oscilloscope triggers on the radar signal and, using the "Trigger to Frame" function, measures a delay of 9.54 ms from when the radar signal is transmitted to when the protocol transfer starts (bottom).