Microwave Journal

eBook

Oscilloscope Measurement Guide

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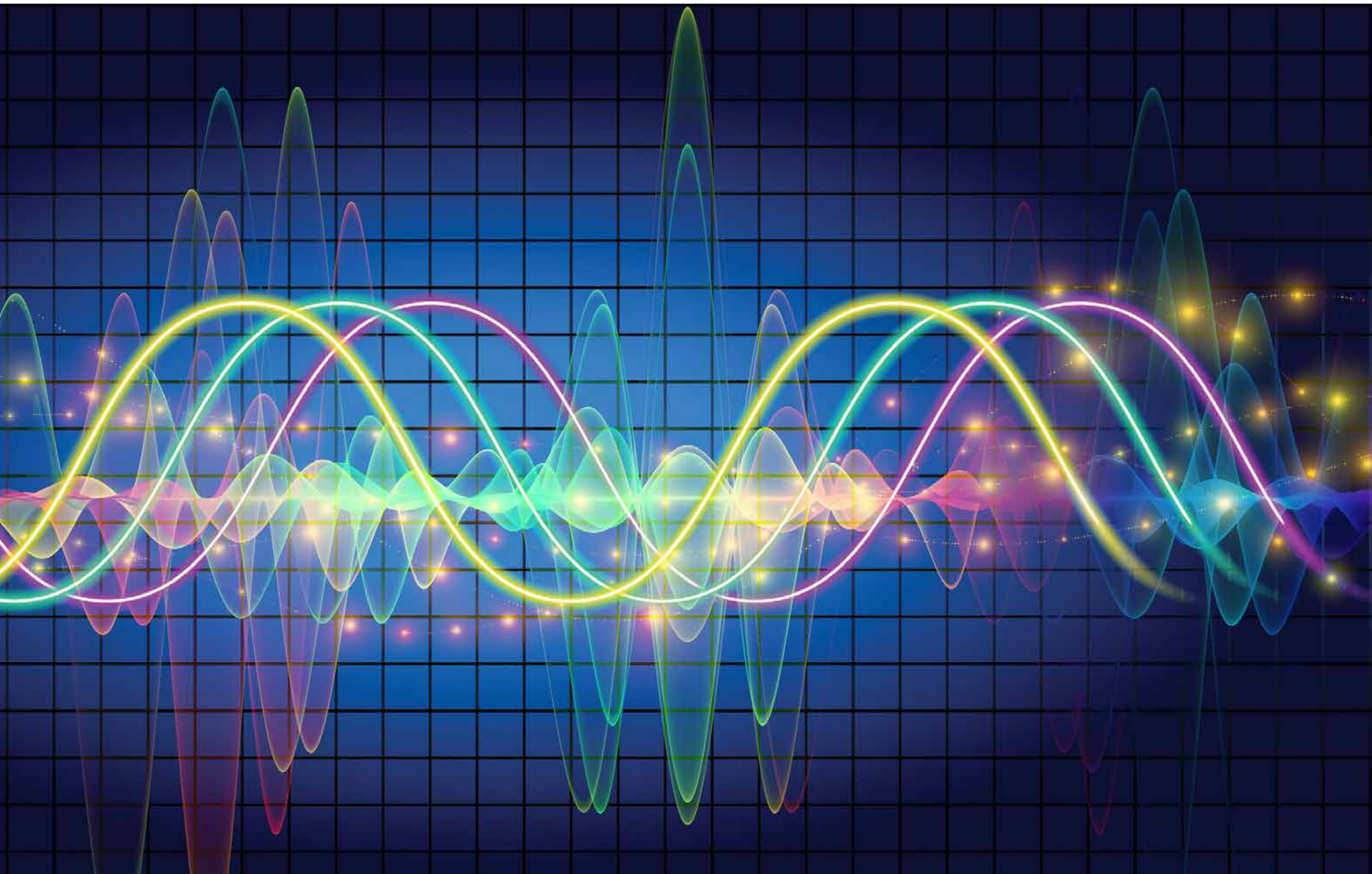

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Introduction

Oscilloscope Measurement Guide

If you need to uncover information like frequency, noise, amplitude, or any other characteristic that might change over time, you need to use the swiss army knife of electronics, the oscilloscope. New oscilloscopes have user friendly touch screens, very broad frequency bands and high resolution. There are a wide variety of models from many manufacturers to fit your budget and performance needs.

This eBook takes a look at some key applications where oscilloscopes are best suited to make the key measurements to evaluate your designs. The first article examines practical printed circuit board design and manufacture to reduce noise by comparing two simple circuits and the resulting difference in their performance. The next article looks at triggering on radar RF pulses with an oscilloscope. It reviews how to measure radar RF pulses with respect to frequency, modulation, rise/fall time and pulse repetition interval (PRI), duration and amplitude to see if they fulfill your needs. And another article follows covering demodulating radar RF pulses with an oscilloscope. It reviews how to measure radar RF pulses with respect to frequency, modulation type (linear up/down, exponential, phase) chirp rate, modulation sequence, pulse repetition interval (PRI) and amplitude to judge if they fulfill your requirements.

Then the eBook shares some tips about how to successfully perform low noise, sub-milliOhm measurements in very small circuits, followed by making power integrity measurements with R&S®RTP oscilloscopes. Measuring noise and ripple on power rails with small voltages and increasingly tighter tolerances are a challenge for oscilloscopes so this steps through how to make accurate measurements.

The last article is about how Rohde & Schwarz has expanded its high-performance R&S RTP oscilloscope family in terms of both bandwidth, and functions for debugging and analysis. The latest models support up to 16 GHz bandwidth, support four channels to 8 GHz, or two channels interleaved for the respective higher frequencies. Additional new highlights are powerful debugging functions such as the high-speed serial pattern trigger using hardware-based clock-data-recovery (CDR) up to 16 Gbps, or the DDR4 signal integrity and compliance test.

This eBook provides practical measurement advice for using Rohde & Schwarz oscilloscopes for various radar and power integrity measurements. We thank Rohde & Schwarz for sponsoring this eBook so that we can provide it to you.

Pat Hindle, Microwave Journal *Editor*

We Live in the White Space

Eric Bogatin, Joshua Lynn Biggio, and Allison Roney

Evidence that the schematic is not enough.

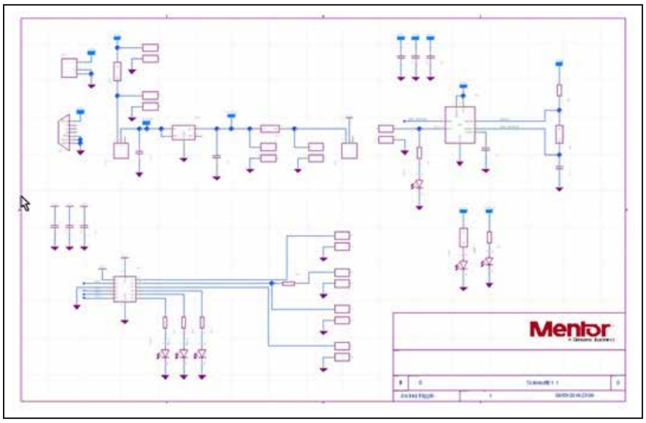
A schematic tells us what components are used in the circuit and how they connect. It tells us nothing about signal integrity, power integrity, or EMI. These important properties live in the ideal wires connecting each component and in the white space of the schematic. All the important design information about high-speed performance is hidden and can only be seen in the mind of the engineer. This is one of the most important lessons engineers can learn when they start out designing circuits and boards.

In the mixed undergraduate/graduate course taught at the University of Colorado, Boulder, "Practical Printed Circuit Board Design and Manufacture," students learn this important lesson in their first board design project.

A SIMPLE BOARD PROJECT

The circuit design is very simple. A 5 V power plug supplies power to the board. It drives a 555 timer designed for a 10 kHz square wafer with a 90% duty cycle. A simple LDO converts the 5 V into a 3.3 V rail which powers a hex inverter chip. One of the inverters has its input tied high so it is always producing a low. Four other drivers have inputs connected to the output of the 555 timer so they switch with the square wave, but invert the 90% duty cycle to a 10% on duty cycle. The simple schematic is shown in ***Figure 1.***

One of these switching signals makes its way to a test point where the signal can be measured. This is used to trigger an oscilloscope so we have a reference for the switching edge. When the scope is set for 50 Ohms input, the current draw is 3.3 V/50 Ohms = 66 mA. When a 10x probe is used, the load impedance on the output of the inverter is much higher than 50 Ohms, and less than 10 mA switches on each edge.



▲ Fig. 1 Schematic for the first design assignment board. It contains 5 V in, a 3.3 V LDO, a 555 timer and a hex inverter with LED indicators and test points.

The other three switching signals drive 50 Ohm resistors in series with red LEDs. The current through each LED is estimated as about (3.3 V – 1.8 V)/50 Ohms = 30 mA. This means when the hex inverter chip switches, as much as 100 mA will flow on each edge and can be as much as 150 mA when 50 Ohms is used in the scope input.

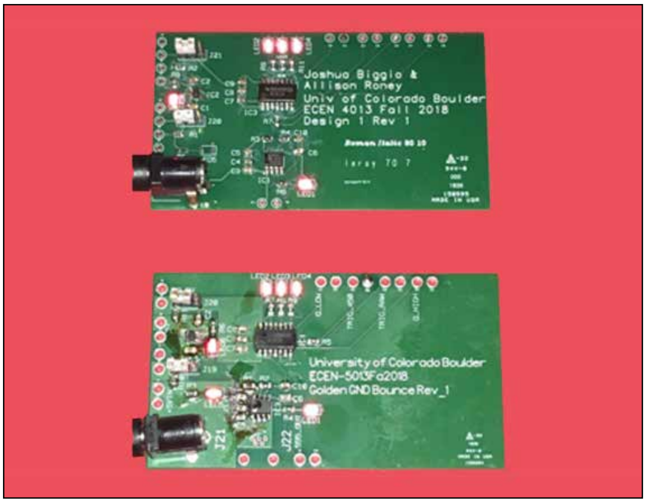


Fig. 2 Two boards with the same schematic but very different layout and different performance.

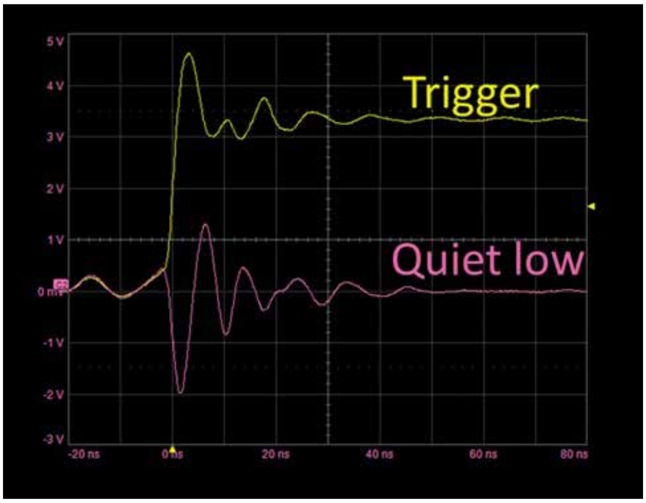


Fig. 3 Signals from the student board measured with a Teledyne LeCroy HDO8108 scope showing a peak-to-peak ground bounce of more than 3 V.

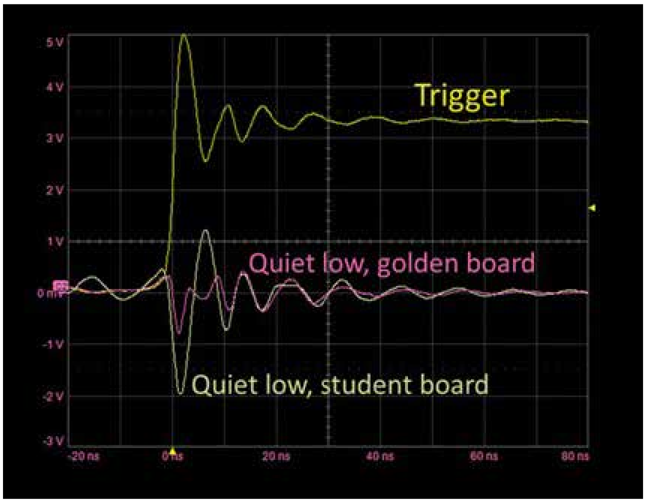


Fig. 4 Good layout practices dramatically reduce the ground bounce noise to less than 1 V peak-to-peak.

TRANSLATING SCHEMATIC TO LAYOUT

In the first class exercise, this schematic is translated into a 2-layer circuit board layout in two forms. On the first day of class, students are given the board with the parts placed in specific locations. Their first assignment is to route the traces taking into consideration ONLY the connectivity. This uses all the information in the schematic, implemented however they want. Since few students come into this class with experience in best design practices, most of the boards are routed with signal, power, and ground traces all over the place, going back and forth between the two layers.

Their boards are sent out to fab and students assemble and test these boards. In parallel, another version of this board, a "golden board," is fabricated that uses a ground plane and all signals and power traces routed on the top layer.

An example of these two different boards are shown in ***Figure 2.***

It should be noted that each board came from exactly the same schematic. The difference is that the golden board layout was based on best design practices while the student board was not. They both have a 10 kHz, 90% duty cycle square wave, with a hex inverter switching about 100 mA on each edge. These two boards have a radically different noise levels.

MEASURING GROUND BOUNCE WITH A QUIET LOW LINE

We use the hex inverter output pegged low as a sense line to transmit the voltage on the die's ground rail, compared to the board level ground, through the signal path to a probe point on the edge of the board. We call this sort of pin a "quiet low" pin. This is a very common technique to measure the ground bounce on the ground rail of the die.

This voltage is a direct measure of the noise on the ground rail of the die, which all the other I/O drivers see. The difference in these two boards is the ground bounce noise generated because of the layout of the signals and return paths.

In the student board version, the signal path (between the I/O pin to the test point and their return path from the ground pin of the hex inverter and the ground connection on the edge of the board) makes really big loops. Since these loops overlap, there is a huge mutual inductance between them. When currents switch through one of these loops, as when the I/O switches, the dI/dt generates a large voltage in the quiet signal-return path loop.

This is the most common cause of ground bounce. The more I/Os switch simultaneously, each of their dI/dt's generating induced voltage noise in the quiet loop, the larger the ground bounce noise.

COMPARING THE MEASURED GROUND BOUNCE

We use the signal coming out of one of the switching hex inverters as the trigger. ***Figure 3*** is an example of the trigger signal and the quiet line on the student board measured with a scope.

This is not a typo or mis-print. The ground bounce voltage, measured on the quiet line, when the four I/Os switch simultaneously really is more than 3 V peak to peak. If you don't pay attention to the layout, ground bounce can get very large.

To reduce this problem, use a return plane in close proximity to the signal lines. This forces the return currents to flow directly under the signal lines, creating very small signal-return loops, with no overlap between them.

In the golden board, we use a solid ground (return) plane and route all the signal lines on the top layer. There is very little overlap of the signal-return loops. The noise on the quiet line on the golden board compared to the ground bounce on the student board, is shown in ***Figure 4.***

Even though there are no overlapping signal-return path loops on the board, there is still a long, common ground lead in the package. The inductance of this lead will generate some residual ground bounce, which is what we see in this scope measurement. It is less than 1/3 of the noise when layout is not optimized.

BEST DESIGN PRACTICE

These boards were designed from exactly the same schematic. They differed only in the layout. Nowhere on the schematic is information about where noise might come from. It is hiding in the white space between the components.

This example illustrates one of the most important best design practices: keep a continuous return path under the signal lines using a solid return plane. If you don't use a continuous return path, it doesn't mean your design won't work, it just means you will have more ground bounce noise generated. Sometimes this noise is enough to kill your product.

Trigger on radar RF pulses with an oscilloscope

Analyzing RF pulses is a key aspect of pulsed radar applications, e.g. in air traffic control (ATC), maritime radar or scientific measurements of the ionosphere. Analyzing the envelope and the modulation of the pulse is essential, because they contain important information to characterize the application. The R&S®RTO and R&S®RTP oscilloscopes are capable of triggering precisely on a pulse as a prerequisite for time domain and frequency domain analysis. This document describes the use of the R&S®RTO and R&S®RTP to trigger exactly on pulses in preparation for further in-depth measurements such as RF pulse measurements on an ATC signal.

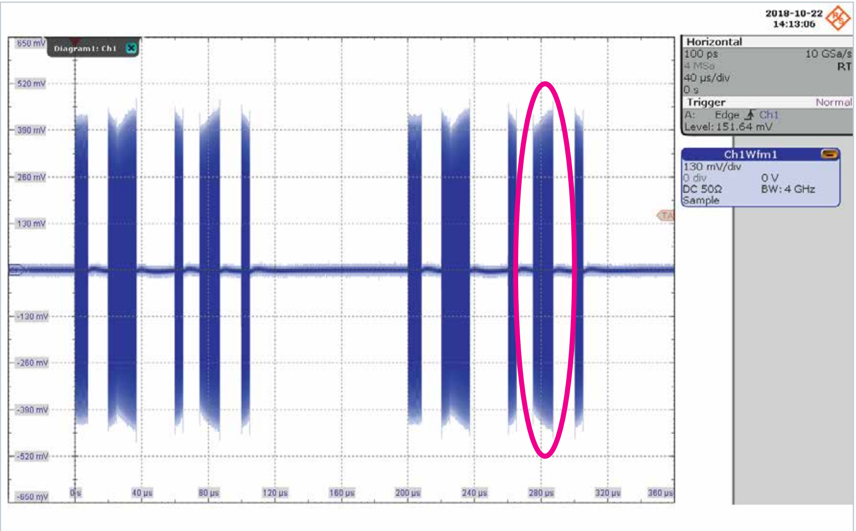
Your task

You have to measure radar RF pulses with respect to frequency, modulation, rise/fall time and pulse repetition interval (PRI), duration and amplitude to judge if they fulfill your requirements [1]. So you need to trigger on a pulse in a reproducible manner to position the pulse correctly for the measurements and to efficiently store only pulses and not the pause. A conventional edge trigger will not create a stable display since a pulse typically contains multiple edges where a trigger can be positioned. In a complicated scenario (see screenshot below) where multiple pulses with different pulse widths (5.0/10.0/3.0/7.5/3.0 µs) and modulations are present, the edge trigger cannot be used.

Rohde & Schwarz solution

The R&S®RTO and R&S®RTP oscilloscopes can analyze RF pulses with frequencies up to 6 GHz/8 GHz. The most important feature for pulse analysis is the precision digital trigger. Compared to an analog trigger, the digital trigger has much better trigger sensitivity and no bandwidth limitation for an advanced type of trigger. To analyze the RF pulse, the trigger must always appear in the same position relative to the pulse. As an example, a pulse train is used to set up a trigger specifically on the 7.5 µs pulse (circled in red) with a power level of 5.0 dBm (= 400 mV) and a carrier frequency f_c of 2.8 GHz.

[1] Richard, Mark (2013): Fundamentals of Radar Signal Processing. 2. Edition: McGraw-Hill Companies.



Sequence with multiple pulses

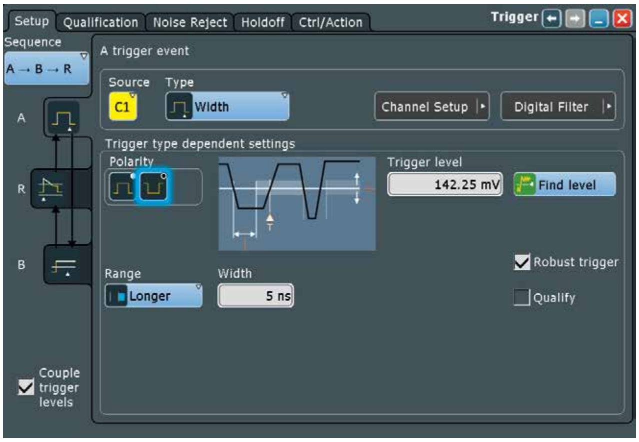
ROHDE&SCHWARZ

Application Card | Version 01.00

For this acquisition, an A-B-R trigger is used. While the pulse start triggers condition A, the B trigger is released by the end of the pulse after the specified pulse duration. The R trigger is then used to reset the condition for pulses that have either a too long pulse duration or a too high pulse power.

A trigger

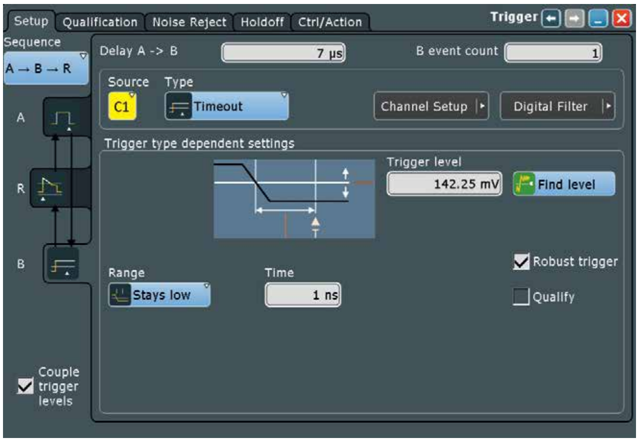
The A trigger uses the trigger type "Width" with negative polarity. This trigger focuses on the pause between two consecutive pulses. The width should be larger than a few periods of the carrier (360 ps), in this example 5 ns. The level is set to the minimum accepted power level of –3.9 dBm (= 142.25 mV). Since the width trigger triggers on the radar pulse, the robust trigger option should be enabled (see screenshot below). This setting is sufficient for an A trigger for stable triggering on the start of every pulse.



A trigger setup for the start of the pulse

B trigger

The B trigger (see following screenshot) uses the trigger type "Timeout" with the same power level as the A trigger. Coupled trigger levels are used. Analog to the A trigger, the timeout time should be larger than a few periods of the carrier (360 ps), in this example 1 ns.

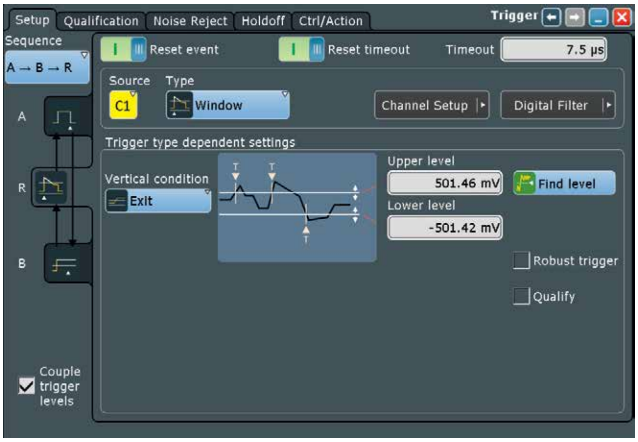


B trigger setup up for the end of the pulse

Smaller pulses are ignored by setting the delay from A to B to the lowest acceptable pulse length of 7 µs. The robust trigger option is enabled.

R trigger

Pulses that are longer than 7.5 µs or exceed 10 dBm should be discarded. This is accomplished by applying the R trigger (see screenshot below). This resets the A trigger condition. Enabling the reset timeout and setting the timeout to the maximal allowed pulse length (7.5 µs) will discard longer pulses. Pulses with higher pulse power will be ignored due to the window trigger. Therefore, the type is set to "Window" with the vertical condition "Exit". The levels are set symmetrical to 7.0 dBm (= 501.46 mV).



R trigger setup up to reset the trigger condition

As a result, pulses with a pulse duration between 7.0 µs and 7.5 µs and a power level between –3.9 dBm and 7.0 dBm are acquired out of a sequence of different pulses. These pulses are stored with a low percentage of off-time always in the same trigger position at the end of the frame (indicated by the red triangle in Diagram 1 in the upper section of the screenshot on the next page).

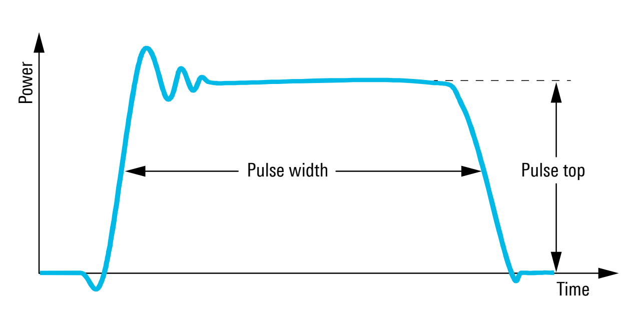
In this example, the R&S®RTO equipped with 1 Gsample memory size can store about 36 000 consecutive pulses. The history mode allows access to all acquisitions for a detailed analysis of each pulse as well as pulse-to-pulse analysis.

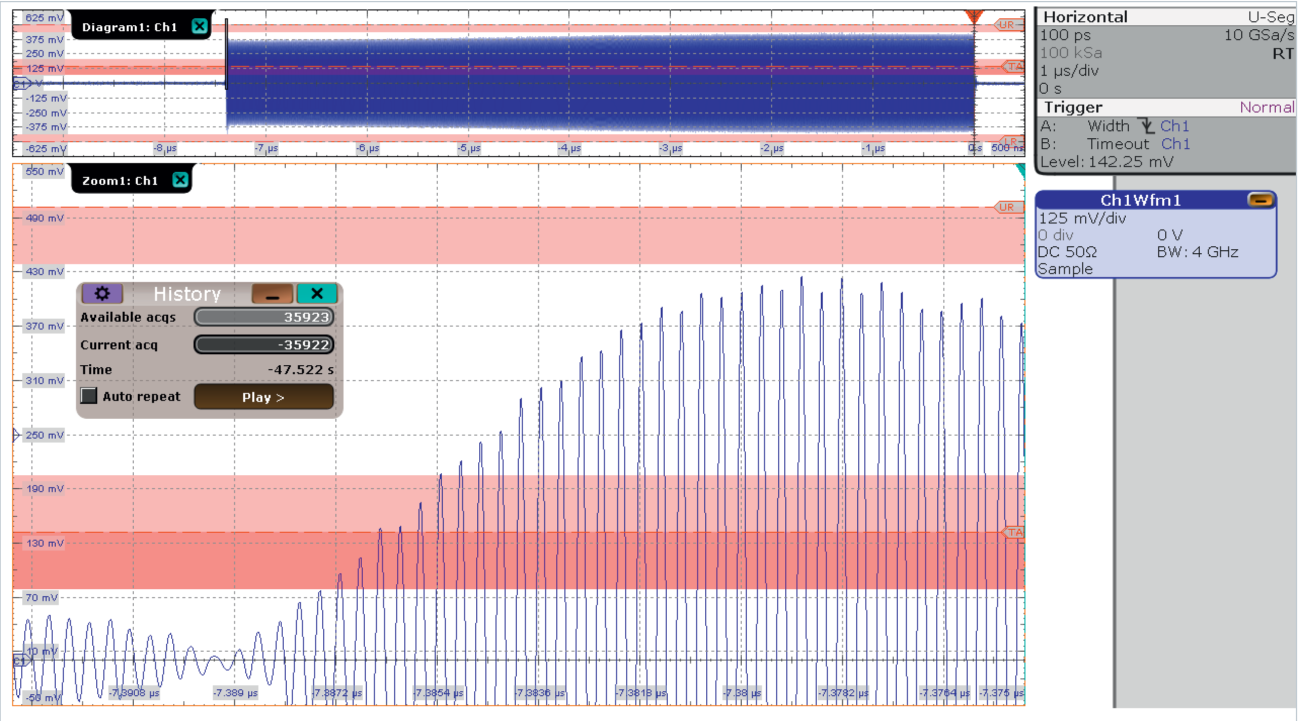
The table gives an overview how the pulse parameters translate into oscilloscope trigger parameters:

Parameter translation

Pulse parameter	Oscilloscope parameter
Pulse top (min.)	(A) trigger level
Pulse top (max.)	(R) exit upper/lower level
Pulse width (min.)	(B) delay A ▷ B
Pulse width (max.)	(R) timeout

Parameter translation





Captured 7.5 µs pulse using the A-B-R trigger

Summary

The R&S®RTO and R&S®RTP oscilloscopes analyze RF pulses to the maximum bandwidth of the model used. To perform detailed analysis, the R&S®RTO and the R&S®RTP trigger precisely on pulse characteristics such as pulse width and power level, similar to an IF power trigger in spectrum analysis. The digital trigger works to the full bandwidth and is a key feature. Once the pulse is acquired, the R&S®RTO and R&S®RTP allow accurate characterization of envelope[2] and modulation since the pulse is well positioned within the acquisition. Pulse-to-pulse analysis on consecutive pulses is also possible.

[2] Analyzing RF radar pulses with an oscilloscope (Application card, PD 5215.4781.92, Rohde & Schwarz GmbH & Co. KG).

Demodulating radar RF pulses with an oscilloscope

Analyzing RF pulses is a key aspect of pulsed radar applications, e.g. in air traffic control (ATC), maritime radar or scientific measurements of the ionosphere. Analyzing the modulation of the pulse is essential, because it contains important information to characterize the application. The R&S®RTO and R&S®RTP oscilloscopes can precisely trigger on and analyze RF pulses. This document describes the use of the R&S®RTO and R&S®RTP to demodulate RF pulses for further measurements.

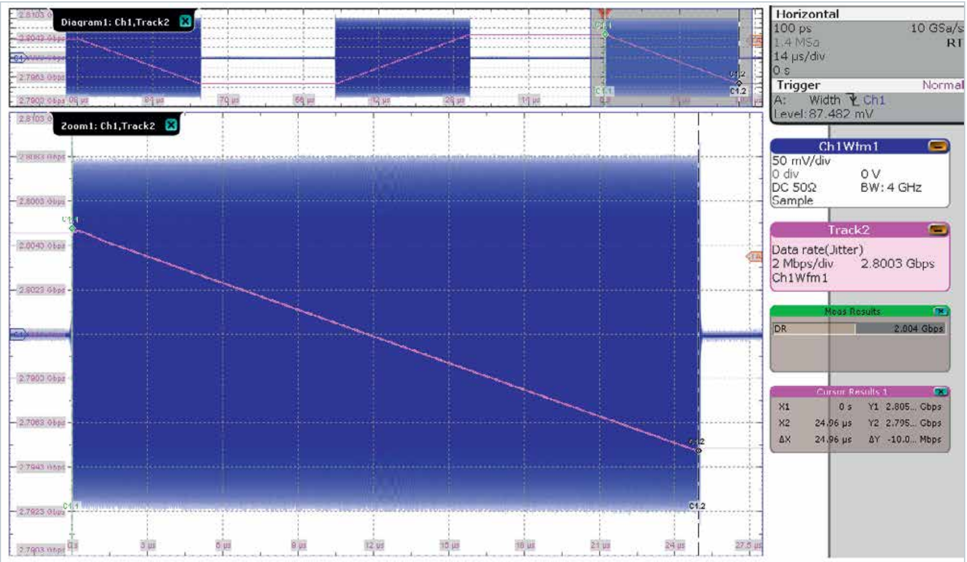
Your task

You have to measure radar RF pulses with respect to frequency, modulation type (linear up/down, exponential, phase) chirp rate, modulation sequence, pulse repetition interval (PRI) and amplitude to judge if they fulfill your requirements [1]. So you need to trigger on a pulse in a reproducible manner to position the pulse correctly for the measurements. Once triggered, you can demodulate the pulses, which are either frequency modulated or phase modulated.

Rohde & Schwarz solution

The R&S®RTO and R&S®RTP oscilloscopes can analyze RF pulses with frequencies up to 6 GHz/8 GHz. The most important feature for pulse analysis is the digital trigger. Compared to an analog trigger, the digital trigger has much better trigger sensitivity and no bandwidth limitation for an advanced trigger type. To analyze the RF pulse, the trigger must always appear in the same position relative to the pulse. As an example, a pulse train is used with a pulse duration of 25 µs and a PRI of 50 µs (see screenshot below). A zoom shows the third pulse in greater detail at the trigger position (t = 0 s).

[1] Richard, Mark (2013): Fundamentals of Radar Signal Processing. 2. Edition: McGraw-Hill Companies.



Sequence with multiple RF pulses

Application Card | Version 01.00

For this acquisition, a width trigger is used. The trigger setup [2] and envelope analysis [3] are described in separate documents. The horizontal scale is set to 14 µs/div so that three pulses are captured to analyze the modulation sequence.

Now, the pulse is demodulated. The example pulse train is frequency modulated and is demodulated using one of the oscilloscope's automated frequency measurements. Using this measurement together with the track functionality, frequency results are displayed as a function of time. This approach works well for wideband radar signals such as automotive radars. For narrowband signals such as ATC radars where the carrier frequency is large relative to the occupied bandwidth ($f_C >> f_B$), the track function looks quite noisy. This noise limits the accuracy of the chirp rate measurement and requires additional noise reduction.

The noise reduction of the signal is not straightforward. A simple bandpass filter cannot be used due to the changing carrier frequency. The filter bandwidth must be quite large. In a conventional, coherent radar system, the RX and TX paths share a stabilized local oscillator. For an oscilloscope, downconversion with the local TX oscillator is impossible because this signal is unavailable. Utilizing a phase locked loop (PLL) [1] to demodulate the signal is another approach.

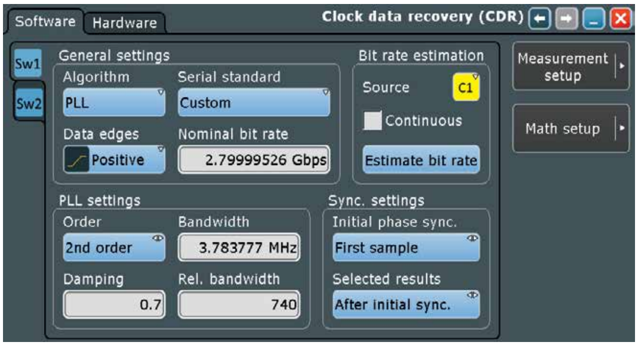
The R&S®RTO and R&S®RTP oscilloscopes have a software-based clock data recovery (CDR) that is equivalent to a PLL. Using the automated measurement function, the data rate essentially measures the instantaneous frequency of the pulse. When the track function of the data rate is turned on, the instantaneous frequency is displayed over time (see Track 2 on the right side of the screenshot on the previous page). Due to the use of the data rate function, the vertical unit of the displayed track is gigabit per second (Gbps), which is equivalent to GHz since the bit period and the sine period are the same.

Diagram 1 (upper section of the screenshot on the previous page) shows the modulation sequence of down-up-down chirps within the pulse train of three pulses. For a more detailed analysis, the cursor on the track in the zoom window can be used to measure the chirp rate.

[2] Trigger on radar RF pulses with an oscilloscope (Application card, PD 3609.2000.92 Rohde & Schwarz GmbH & Co. KG).

[3] Analyzing RF radar pulses with an oscilloscope (Application card, PD 5215.4781.92, Rohde & Schwarz GmbH & Co. KG).

This measures the frequency change of the pulse over time. For the given example, Cursor Results 1 (lower right of screenshot on the previous page) shows 10 MHz in 25 µs for the down chirp.



CDR setting to demodulate the RF chirp

The data rate function requires the CDR configuration. The screenshot above shows the CDR menu, where the algorithm is set to PLL, and the data edges are set to positive edges. Define the order of the PLL as second order since only a second order PLL will display the correct time track of the frequency [1] with respect to the data rate. Estimating the bit rate will set the nominal bit rate to the expected value.

The damping factor and the sync settings do not need to be modified. The bandwidth is important only for the measurement. The PLL bandwidth allows a tradeoff between the visible noise and the settling time for the initial pulse. A large bandwidth settles fast but will not attenuate the noise efficiently, whereas a small bandwidth will efficiently attenuate the noise on the track but takes more time to settle. With the displayed PLL bandwidth setting of 3.8 MHz, the noise is barely visible on the track and the effect of settling is minimal, which improves the accuracy of the chirp rate measurement.

Summary

The R&S®RTO and R&S®RTP oscilloscopes analyze RF pulses to the maximum bandwidth of the used model. To perform a detailed analysis, the R&S®RTO and R&S®RTP trigger precisely on the pulse. The stable captured waveform can be demodulated to analyze important characteristics such as modulation sequence and chirp rate. The R&S®RTO and R&S®RTP can also accurately characterize the pulse envelope [3].

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Demodulating radar RF pulses with an oscilloscope

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Measuring Sub-milliOhm PDN Impedance

Steve Sandler

High speed and portable electronics are still shrinking while power integrity demands continue to require lower power distribution network (PDN) impedance. Measuring sub-milliOhms is difficult. Getting low noise, sub-milliOhm measurements in very small circuits is a bit more difficult. We recently had the opportunity to support R&D Altanova[1] in performing this difficult measurement. We are grateful that they allowed us to use their measurement to help others facing this challenge. The final result, shown ***Figure 1,*** shows low noise even as low as 150 uΩ.

The purpose of this article is to share some tips with you so that you can successfully perform these measurements, too.

SIMULATIONS GENERALLY COME FIRST

R&D Altanova is an expert at projects like this and uses simulation tools to optimize the PCB and decoupling before fabricating an expensive multilayer PCB. Simulation is a much faster, and less expensive method of optimizing the PCB decoupling than multiple circuit board revisions. The simulation results can also provide insight for the measurement setup as well.

The simulated VDDO PDN bulk capacitor and decoupling impedance is shown in ***Figure 2.***

The simulation results show the impedance measurement range to be between 150 uΩ and 20 mΩ. The typical impedance ranges for the three S-parameter based impedance measurements are summarized in ***Table 1***[2]. Much of the impedance range falls below the recommended minimum, suggesting a difficult measurement, though the best option is the 2-port shunt thru measurement.

The measurement setup for the 2-port shunt thru measurement is shown in ***Figure 3.***

The 2-port shunt through measurement includes an unwanted DC ground loop, due to the RF connection of the two port grounds at the instrument panel and the

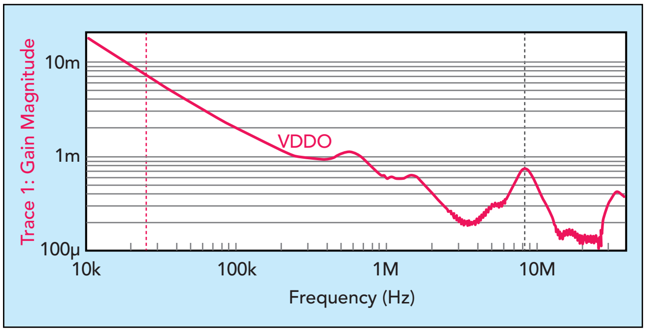

Fig. 1 This off state measurement of the bulk caps and decoupling shows good fidelity even as low as 150uΩ. This is the final result.

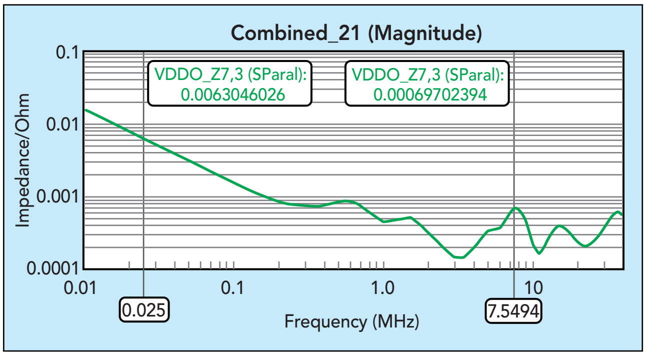

Fig. 2 The VDDO power rail impedance without the VRM indicates the impedance is below 1 mΩ from 150 kHz to 40 MHz and less than or equal to 200 uΩ at several frequencies.

TABLE 1

HIGH FIDELITY MEASUREMENT RANGES OF VNA BASED IMPEDANCE MEASUREMENTS

	Minimum	Maximum	Dynamic Range
1-Port	1 Ω	2 kΩ	66 dB
2-Port Series	10 Ω	2.5 MΩ	108 dB
2-Port Shunt	1 mΩ	225 Ω	108 dB

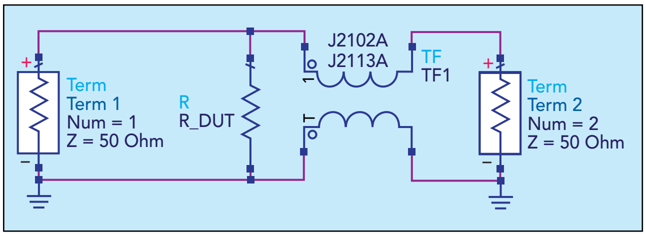

Fig. 3 Typical 2-port shunt thru transfer impedance measurement setup showing the DUT, the VNA ports and the required coaxial transformer (see text).

Fig. 4 The UFL micro-cox connectors and lead wires require much less circuit board space than the more common SMA connectors. The micro-coax is a good solution for compact spaces.

DUT ground connection located remotely at the DUT. This DC ground loop is well-documented [3] and is resolved by the introduction of a coaxial, common mode transformer as depicted in Figure 3. (Both passive and active off-the-shelf 50Ω matched coaxial transformers are available from Picotest.) The solid-state device yields the best performance, allowing measurement down to DC while the passive solutions are generally limited to several kHz. The active solutions are also usable to higher frequency than the passive solution.

Physical access is also a common limitation, with circuits continually shrinking and increasing in circuit board density. One good method of dealing with the physical aspect is to use UFL type micro-coax connectors rather than the more common SMA connectors. The UFL connector requires much less physical circuit board space as shown in ***Figure 4.***

The measurement setup, including the VNA, coaxial transformer (passive J2102A), connector lead-wires and the DUT, is shown in ***Figure 5.***

After calibration of the setup, an initial measurement is performed and the measurement result is shown in ***Figure 6.*** The measurement has the correct general shape, but for much of the frequency span, the measurement is significantly degraded by noise.

To be fair, this impedance magnitude is below the common recommended limit of 1millOhm. The S21 measurement at 150 uΩ is

$$S21_{150u\Omega} = 20 \cdot log\frac{150u\Omega}{150u\Omega + 25\Omega} = -104dB$$

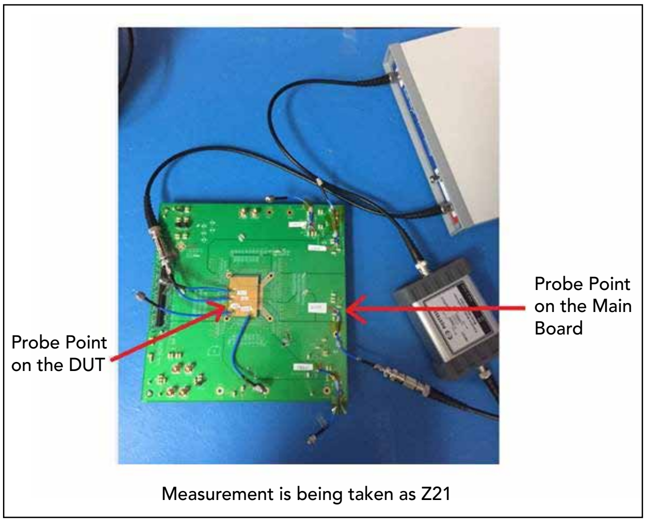

Fig. 5 The 2-port shunt thru measurement setup, including the VNA, passive coaxial transformer (J2102A), connector lead-wires and the DUT. This particular circuit board is a 20 layer, Nelco N4800-20 PCB, 0.127" thick.

And assuming the maximum +13dBm (1Vrms) source signal, the receiver signal is 6uVrms. The Bode 100, and most other quality VNA's can measure a dynamic range of 104 dB and have a receiver sensitivity of less than 3 uV, so it is possible to make this measurement. Most VNAs, including the Bode 100, offer several methods of noise management. The five common methods are source amplitude, attenuators, receiver bandwidth, number of points, and trace averaging.

SOURCE AMPLITUDE

In order to maximize the signal to noise ratio, it is desirable to set the source amplitude to the maximum level. This results in the largest signal at the receiver.

ATTENUATORS

Attenuators reduce the signal and also add a finite amount of noise due to the attenuator resistors. If the DC voltage of the measurement is zero, then the CH2 port will likely not require any attenuation. It is possible that CH1 will require an attenuator, and the instrument will warn of a signal overload if this is the case.

RECEIVER BANDWIDTH

The receiver noise is generally white noise with a finite noise density. The receiver noise is a function of the noise density and the square root of the receiver bandwidth. The narrowest receiver bandwidth results in the lowest noise, but this also corresponds to a longer sweep time, so consider the tradeoff between noise and sweep time, especially if you will be performing many measurements.

NUMBER OF POINTS

The VNA, like other instruments required distinct datapoints. The trace is completed by interpolating between the datapoints. While the natural tendency is to increase the number of datapoint to reduce noise, this is often counterproductive. Fewer datapoint result in more interpolation, resulting in more "smoothing" of the data.

TRACE AVERAGING

Most VNAs, including the Bode 100, can also include trace averaging. The selected number of traces are averaged, reducing gaussian noise by the square root of the averaging depth. Like the receiver bandwidth, this comes at the expense of sweep time. An averaging depth of 10, for example, requires 10 sweeps to maximize the averaging. I rarely use this feature, mostly for this reason.

EXTERNAL OPTIONS

There are also a few external options for improving the signal to noise ratio, including external signal amplifiers for both the source and the receiver ports and the cables themselves.

SOURCE AMPLIFIER

The Bode 100 already offers a larger signal than many VNAs, but this can be increased using an external power amplifier. In many cases the VNA manufacturer offers signal source power amplifiers.

RECEIVER AMPLIFIER

The receiver signal level can be increased using a low noise preamplifer (LNA). Many companies offer LNAs, including Picotest's J2180A with 2nV/rt-Hz input side noise density and 20dB signal gain.

CABLES

Whether you use SMA or micro-coax connectors, choose cables carefully. Choose a cable with good shield efficiency, which often means multiple shield layers. These are available in both SMA and micro-coax forms. Also, get these cables from a quality manufacturer. Even a good shield cable can be compromised by a poor connector attachment. These cables do tend to be expensive, but with good care they'll last a long time. Also, be careful how you dress these cables. Try to keep them away from noisy areas of the circuit board.

THE IMPROVED MEASUREMENT

Applying just a few of the noise management techniques can result in much better fidelity. The impedance measurement results using a 30 Hz receiver bandwidth, no attenuation on CH2 and 20 dB attenuation on CH1

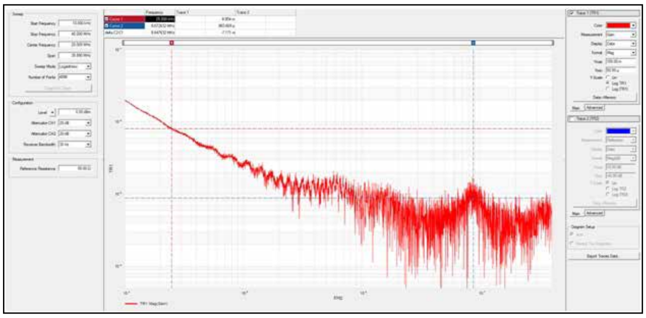

Fig. 6 A first measurement attempt shows has the correct general shape, but the measurement is significantly degraded by noise.

are shown in Figure 7. The improved measurements are low noise even at the 150uΩ magnitude. Further noise reduction can be achieved by applying more of the internal and/or external improvement options.

ASSURING THE DATA IS VALID

There is always the remaining question regarding how we can be confident that the measurement is accurate. There are two recommendations for this. First, we can compare the measurements with the simulations. Agreement between the measurement and the simulation increases confidence in the measurement, however this does not guarantee the measurement is precise.

Another way to assure the measurement accuracy is to always measure a known quantity, and preferably in the same magnitude of the measurement you are making. For example, a mounted, 250 uΩ current sense resistor could provide a good indication of accuracy. Taken together, these two methods provide very high confidence in the accuracy of the measurement.

Comparisons between the measured results of ***Figure 7*** and the simulation results are shown in ***Figure 8.***

CONCLUSIONS

It is possible to perform accurate, low-noise impedance measurements even below 1 milliOhm. Numerous noise management techniques were presented, both internal and external to the VNA, and only several of them were necessary to achieve a reasonable fidelity measurement at 150 uΩ.

Special thanks to R&D Altanova for sharing their measurement and excellent correlations with us for your benefit.

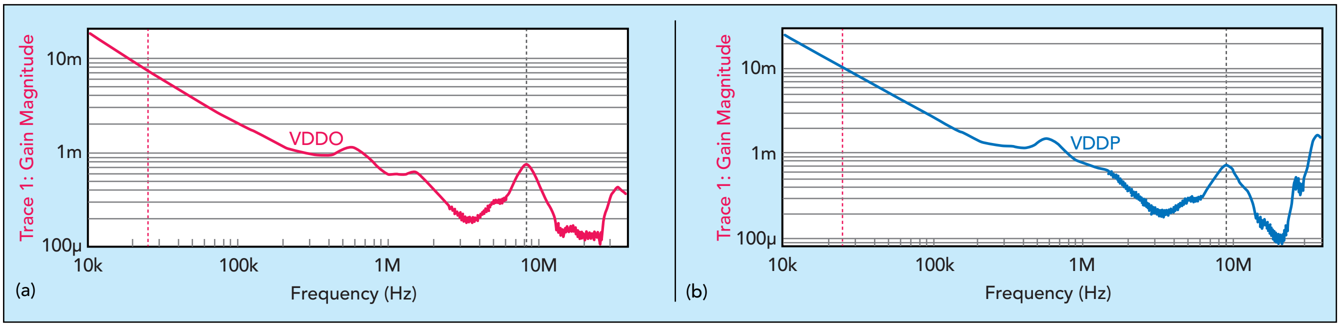

Fig. 7 Reducing the receiver bandwidth, increasing the signal source amplitude and optimizing the attenuators results in much lower noise measurements.

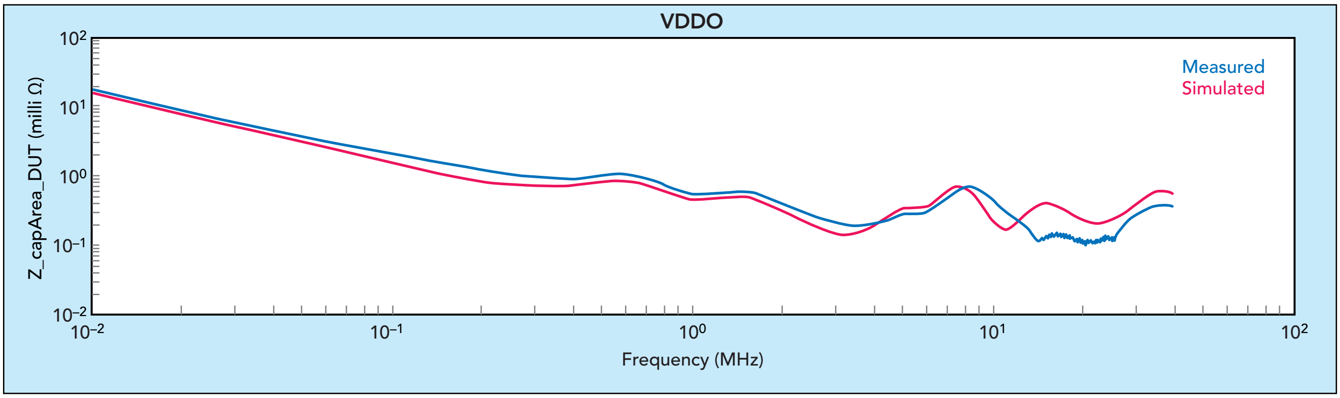

Fig. 8 **The VDDO measurement and simulation are in good agreement, resulting in a high confidence in the accuracy of the measurement results.**

References

1 R&D Altanova is the leading provider of full turn-key test interface solutions specializing in Advanced Technology Printed Circuit Board Engineering, Design, Fabrication, Assembly and Manufacturing services. Technology solutions for the ATE industry include; fine pitch interface board fabrication, Burn-in Boards, embedded component solutions for interface boards and daughter-cards, Conductive Bridge™ and Coaxial Via™ technologies, elastomer interconnects and test sockets, as well as Signal Integrity and Power Integrity engineering and manufacturing services.

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Power integrity measurements with R&S®RTP oscilloscopes

Make more accurate power rail measurements.

Your task

Measuring noise and ripple on power rails with small voltages and increasingly tighter tolerances is a challenge for oscilloscopes. Fast clock and data edges can be coupled onto rails, requiring higher bandwidth oscilloscopes for power integrity measurements.

Using a standard 500 MHz passive probe with a 10:1 attenuation results in additional measurement noise, causing overstated peak-to-peak voltage measurements and masking signal details.

Such a probe does not have sufficient bandwidth to isolate coupled signals. The higher bandwidth of R&S®RTP oscilloscopes allows isolation of coupled signals as shown in the gated FFT image.

Measurement of a 1.5 V power rail using an R&S®RT-ZP10 10:1, 500 MHz passive probe (50 mV (V_{pp}), noise masks signal detail).

Measurement of a 1.5 V power rail using an R&S®RT-ZPR20 1:1 active power rail probe (–38.3 mV (V_{pp})). The captured waveform includes higher frequency transients riding on the rail.

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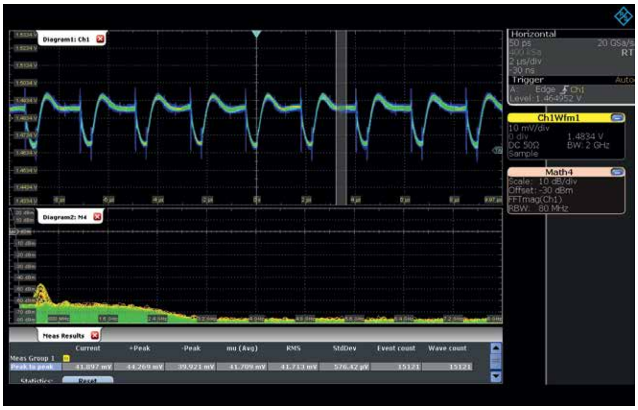
Application Card | Version 02.00

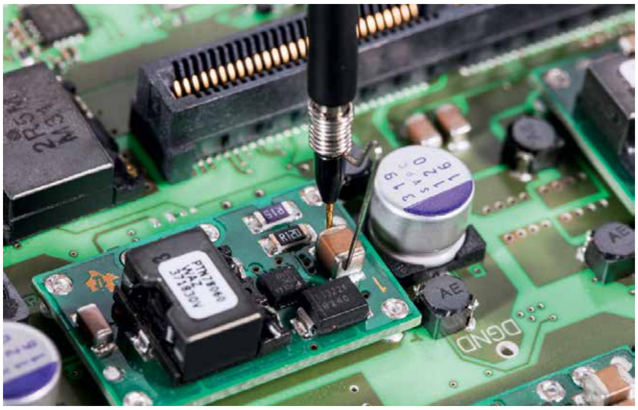
Our solution

The R&S®RT-ZPR20 and R&S®RT-ZPR40 power rail probes with a 1:1 attenuation ratio have very little noise and sufficient bandwidth to not attenuate critical signal content. Both probes are compatible with R&S®RTP oscilloscopes. The combination results in a measurement system that delivers high-bandwidth, accurate measurements:

- The probe's 1:1 attenuation provides minimal noise for a system noise of less than 500 µV (at 1 GHz bandwidth and 10 mV/div)
- With ±60 V of built-in offset, users can center and zoom in a wide variety of DC rail voltage standards without worrying about how much built-in offset the scope has. Increased vertical sensitivity means less noise and that more of the oscilloscope's ADC bits are used, resulting in a more accurate measurement. The offset eliminates the need to use AC coupling or DC blocking capacitors, which impede the ability to see true DC values and drift.
- High-frequency transients and coupled signals are isolated. The R&S®RT-ZPR40 has a typical 3 dB bandwidth of 4 GHz
- 50 kΩ DC input impedance minimizes loading, so DC values remain accurate
- An integrated 16-bit R&S®ProbeMeter provides a simultaneous five-digit readout of each power rail's DC value, even if the waveform is not on the oscilloscope display

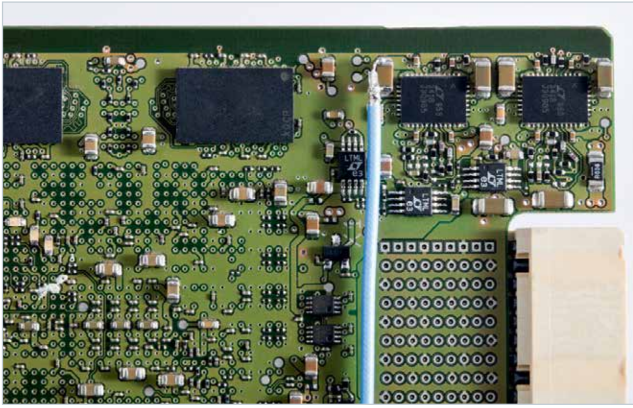


Gated FFTs let user zero in on disturbances in the time domain, and see associated tones.



Use the supplied 350 MHz browser with a variety of probing accessories.

R&S®RT-ZPR20 power rail probe.



Easily connect using an SMA or solder-in coax pigtail.

Power integrity tools	
R&S®RTP high-performance oscilloscope	4 channels, 4 GHz to 8 GHz bandwidth; power rail probes work all models
R&S®RT-ZPR20	2 GHz power rail probe
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R&S RTP High-Performance Oscilloscope

Rohde & Schwarz, Munich, Germany

With new 13 GHz and 16 GHz models, the R&S RTP high-performance oscilloscope family, the most compact multi-purpose lab instrument available, is now scalable from the 4 GHz minimum up to the full 16 GHz bandwidth. Additional new highlights are powerful debugging functions such as the high-speed serial pattern trigger using hardware-based clock-data-recovery (CDR) up to 16 Gbps, or the DDR4 signal integrity and compliance test. The R&S RTP oscilloscope now also provides time domain reflection (TDR) and transmission (TDT) analysis to characterize and debug signal paths.

Rohde & Schwarz expands its high-performance R&S RTP oscilloscope family in terms of both bandwidth, and functions for debugging and analysis. The new R&S RTP134 with 13 GHz, and R&S RTP164 with 16 GHz bandwidth, support four channels to 8 GHz, or two channels interleaved for the respective higher frequencies. For all R&S RTP models, update options support bandwidth increases right up to 16 GHz.

The new R&S RTP models support all functions already introduced for models up to 8 GHz, including the high acquisition and processing rate, and the realtime deembedding. The bandwidth of the industry-leading digital trigger is extended to 16 GHz to provide the highest precision for detecting very small and intermittent signals. The R&S RTP triggers on realtime deembedded signals and supports all trigger types including pulse width, setup and hold, or runt, up to the full instrument bandwidth.

Fig. 1 RTP High-Performance Oscilloscope

Ideal for debugging high-speed differential signals and available for both data acquisition and trigger functions, the new math module introduced directly after the realtime deembedding block supports addition or subtraction for any two signals, plus signal inversion and common mode operations.

R&S RTP users can now analyze high-speed serial signals at data rates up to 16 Gbps with the serial pattern trigger options R&S RTP-K140/K141, which include hardware-based clock data recovery for extracting the embedded clock signal as trigger reference. The trigger supports bit patterns up to 160 bits in length, plus decoding schemes such as 8B/10B, or 128B/132B. Eye diagrams for signal integrity debug, based on the embedded clock, for at-a-glance analysis with the fastest mask test or histogram function provide results within seconds.

The R&S RTP supports debug and compliance test on DRAM memory interfaces using DDR4, DDR4L, and LPDDR4 with the new option R&S RTP-K93. It combines multiple functions such as READ/WRITE decoding, up to four DDR eye displays and automated compliance testing in line with the appropriate JEDEC standards.

The new I/Q mode option R&S RTP-K11 converts modulated signals to I/Q data for analysis, saving acquisition memory, and extending the maximum acquisition time. The [R&S VSE] vector signal explorer is the right tool for in-depth analysis of wideband radar signals, or demodulating wireless communication signals including 5G NR. The I/Q data can also be used with any suitable external tool for proprietary signal analysis.

The R&S RTP now also provides all the functions required as a time domain reflection (TDR) and transmission (TDT) analysis system to characterize and debug signal paths, such as PCB traces, cables and connectors. The new option R&S RTP-K130 combines the highly symmetrical differential pulse signals from the R&S RTP-B7 pulse source with the analog input channels to provide TDT/TDR analysis for both single-ended and differential signals. The software guides the user through setup, calibration and measurement.

No oscilloscope is complete without suitable probes. The R&S RT-ZM family of modular probes featuring interchangeable probing tips and instantaneous mode switching, as well as excellent RF performance, is extended to include the R&S RT-ZM130 with 13 GHz bandwidth, and the R&S RT-ZM160 with 16 GHz bandwidth.