ROHDE&SCHWARZ
Make ideas real

POWER ELECTRONICS T&M SOLUTIONS

Component testing, product design, production and compliance testing

Flyer | Version 02.00

YOUR CHALLENGE

Among the most significant challenges in contemporary power electronics is testing systems that utilize wide-bandgap (WBG) semiconductors such as silicon carbide (SiC) and gallium nitride (GaN). The incorporation of these materials into power devices, like converters, leads to higher operating frequencies, voltages and temperatures. This results in numerous advantages in converter design, including improved power efficiency, reduced size and weight, and lower manufacturing costs. WBG materials have been adopted in certain applications where power density and size are critical, including solar energy, electric vehicles, electric vehicle (EV) chargers and consumer electronics, among others.

Despite the numerous benefits that SiC and GaN provide, it is critical to be aware of the unique challenges faced when testing circuits that employ these technologies:

- Electromagnetic interference:
  Higher switching frequencies, steeper edges and higher voltages lead to higher levels of frequency harmonics due to higher overshoots and ringing. Consequently, higher conducted and radiated emissions are expected in the converter designs.
- Parasitics:
  At higher frequencies, the parasitic behavior of passive components can negatively impact the performance of a power device. Thus, proper identification of these parasitics is required.
- Dynamic range:
  Power electronics devices operate in wide ranges of current and voltage, which can be challenging to measure accurately.
- Quantification of losses:
  Fast slew rates pose challenges when estimating the switching losses of transistors. Factors such as the effect of parasitics, propagation delays and the bandwidth of the test and measurement equipment impact the calculation of losses.

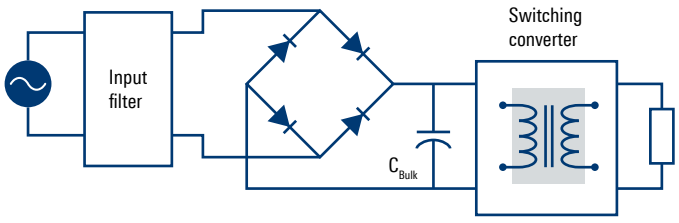
In addition to the new challenges that have arisen due to the use of WBG materials, design engineers perform various tests to verify and validate a power device as a switched-mode power supply (SMPS). These tests include efficiency, ripple, start-up and shut-down behavior, power quality, inrush currents, input harmonics, simulation of real scenarios (e.g. battery cells in an EV), stability and more.

Furthermore, engineers conduct detailed battery modeling and simulations, essential for predicting battery performance and lifespan in real-world applications. Such simulations provide data for optimizing battery designs and developing efficient battery management systems (BMS).

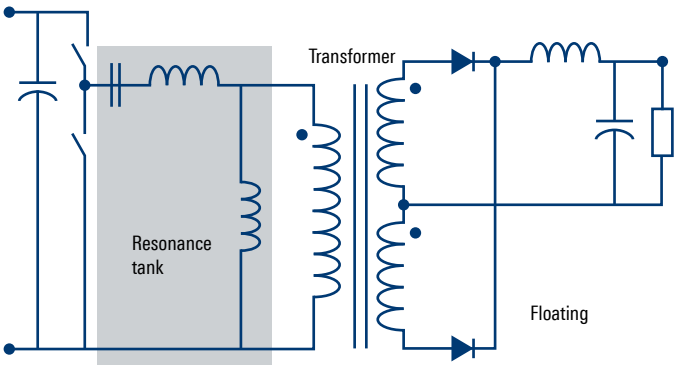
Likewise, monitoring of a device's power consumption plays a crucial role throughout the development process. This information is vital for evaluating device efficiency and ensuring regulatory compliance.

Each of these tests presents its own challenges and requires appropriate test and measurement equipment to obtain precise and reliable results throughout all stages of the design process, from debugging a prototype to validating the SMPS.

Boost converter



LLC converter



OUR SOLUTION

Rohde&Schwarz provides high-quality test and measurement (T&M) equipment for all phases of power electronics equipment measurements. Our products cover everything from design to delivery and beyond, including testing of both passive and active components along with complete device service and maintenance.

Different solutions are offered to address the testing requirements of power devices that use WBG materials. These solutions aim to overcome the main challenges faced in the design process for a converter or SMPS that uses SiC or GaN.

First of all, Rohde&Schwarz provides solutions for EMC requirements that range from initial EMI investigations in early-phase development to full EMC compliance measurements. The powerful and fast FFT supported by Rohde&Schwarz oscilloscopes makes them the perfect tool for debugging EMI problems in the early stages of the design while saving costs. Once the performance of the prototype has been verified, Rohde&Schwarz spectrum analyzers and EMI receivers are used for compliance measurements.

When selecting suitable passive and active components in the early development phases and identifying their parasitic elements, LCR meters are an excellent option. They can assess a component's performance by mimicking the actual operating conditions of the circuit itself (e.g. frequency, voltage/current level and DC bias). This reduces the uncertainty in the converter's behavior due to parasitics that appear at high frequencies, making the measurements more closely resemble simulations.

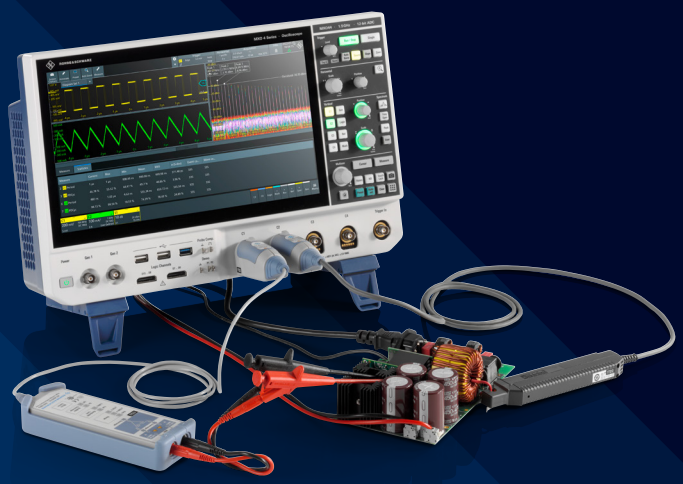
Furthermore, Rohde&Schwarz oscilloscopes and high voltage differential probes allow accurate measurement of small signals in the presence of a large offset due to their wide dynamic range. This makes them the perfect combination for measuring low ripples when high output voltages are measured in a converter. The capabilities of Rohde&Schwarz oscilloscopes are invaluable. It is possible to test a prototype and obtain its main parameters with high accuracy, including switching losses, efficiency, ripple, semiconductor behavior and more.

Developing converters and inverters requires test and measurement equipment that is both flexible and accurate. In addition to oscilloscopes and LCR meters, Rohde&Schwarz power supplies emerge as a solution to emulate the real conditions of a power device, such as different input and load scenarios. For instance, bench power supplies with dual quadrant operation are the preferred choice in applications where both a source and an electronic load are needed. This simplifies the setup and saves costs and space.

Moreover, our power supply portfolio adapts to different devices under test (DUTs) and applications, ranging from basic models to high-performance options. Additionally, Rohde&Schwarz provides specialty power supplies designed for specific applications, such as emulating battery management systems.

Rohde&Schwarz oscilloscopes and power analyzers are suitable for the production environment. The instruments can be used for typical manufacturing verification tests on major home appliances too. These pieces of equipment include automated measurements that allow the user to characterize the SMPS in an easy and quick manner.

For installation and service, Rohde&Schwarz offers handheld oscilloscopes with the performance of laboratory instruments, making them ideal for all test requirements in the field.



COMPONENT CHARACTERIZATION

Passive components

The real-life behavior of passive components has an essential impact on the design and achievable performance of power electronics designs. Verification of component behavior is thus an important step in the selection process for use in production. In particular, it is necessary to characterize the parasitic behavior of components at high frequencies, especially when using WBG semiconductors.

Verifying the real-life behavior of passive components

The effective capacitance of a capacitor is highly dependent on its DC offset voltage during operation, while the effective inductance of an inductor depends on the average DC current flowing through the inductor. In addition, the properties of passive components fluctuate depending on the frequency. Hence, it is crucial to utilize an LCR meter that allows control over these parameters and has a suitable range for the intended application.

The R&S®LCX100/LCX200 LCR meters can be used to measure the frequency-dependent complex impedance of passive components to derive accurate values for the equivalent circuit diagram of the component. This enables testing of components under DC bias voltage or current.

Key features

- Very high basic accuracy of 0.05 %
- Frequency range from 4 Hz to 10 MHz
- DC bias up to 10 V/200 mA (internal) or 40 V (external)
- Multiple test fixtures to select depending on the component

R&S®LCX200 LCR meter

Rohde&Schwarz has rounded out its portfolio with the Zurich Instruments MFIA impedance analyzer. This device covers a measurement range from 1 mΩ to 1 TΩ, which makes it ideal for measuring materials with low ESL/ESR such as DC link capacitors.

MFIA impedance analyzer from Zurich Instruments

Semiconductors

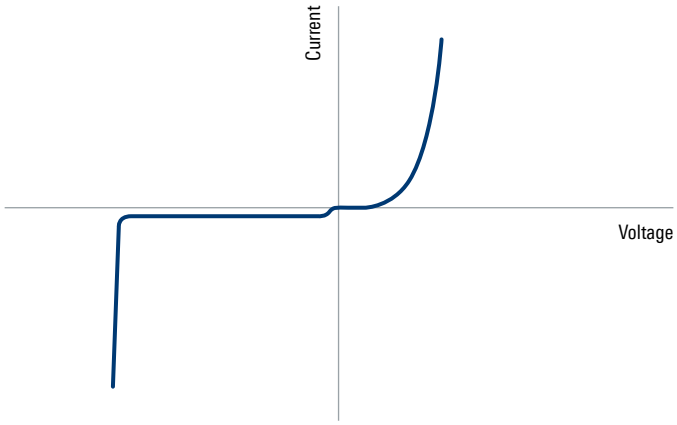
Similar to transistors, two-terminal semiconductors are widely used in power electronics applications. These can be found in power factor correction power supplies, such as SiC Schottky diodes, other types of converters which use free-wheeling diodes, LEDs and solar cells.

It is crucial to understand and characterize these types of semiconductors in order to determine their key properties. This is typically done by obtaining their I/V curve, which is the basis for derivation of various parameters.

The R&S®NGU source measure unit (SMU) can precisely measure from the sub-microampere to the ampere range. Its sweep tool, arbitrary function and fast logging allow execution of precise I/V sweeps that provide valuable information regarding the semiconductor.

R&S®NGU411 source measure unit

Semiconductor I-V characteristic curve



BATTERY SIMULATION

Battery cell emulation

Bidirectional converters are used together with batteries in order to enhance the efficiency of the power transfer and simplify the charging and discharging process. Here, it is important to have T&M equipment that is capable of reproducing the behavior of batteries in order to test the bidirectional converter under realistic conditions.

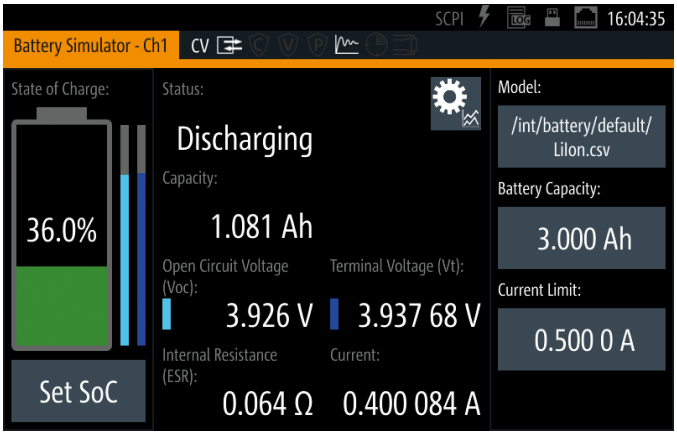
The battery simulation function of the R&S®NGM200 power supply series makes it possible to simulate the real battery output performance. Testing can be based on a selected battery model. Battery capacity, state of charge (SoC) and open circuit voltage (Voc) can be set to any state to test the device under specific conditions. The charging behavior of a battery can also be simulated. This is particularly important when designing battery chargers.

How to get the right battery model:

1. Use one of the predefined models available on the instrument
2. Program an individual model based on the manufacturer's data or measurements
3. Use the battery modeling tool

This option provides dynamic simulation, meaning Voc, equivalent series resistance (ESR) and SoC change according to charging/discharging conditions like a real battery.

Battery simulation: The main parameters that characterize a battery's condition are summarized in one display.



Battery management systems

Larger batteries are typically built by connecting multiple cells in series and parallel. Since the same charge and discharge current flows through all cells, individual differences in battery capacity, self-discharging, aging, etc. would lead to differing states of charge (SoC) over time and consequently limit the capacity and lifetime of the battery. Battery management systems (BMS) actively monitor, control and manage various battery cell parameters.

The R&S®NGL200 and R&S®NGM200 support two-quadrant operation as source and sink. All outputs are fully isolated against ground. They can be connected in series to emulate battery packs on a single cell level up to a maximum voltage of 250 V against ground. The adjustable output impedance can be set between –50 mΩ and 100 Ω. Current and voltage measurements at the power supply output deliver high-resolution values. These features allow the cell properties to be simulated and varied over time with high accuracy and high time resolution.

DESIGN IN POWER ELECTRONICS

Verifying converter behavior

Designing power converters involves a great deal of testing, both during the design and the production phases. This typically means balancing conflicting design goals. A key consideration is usually efficiency, but compliance to different standards is also essential. Another important aspect is safety: Testing must sometimes be carried out using hazardous voltages that necessitate a strict safety policy during measurements.

To overcome these challenges, Rohde&Schwarz offers solutions based on its oscilloscope capabilities for all phases of converter development from design through compliance and production testing.

Automated measurements

The power analysis software option of Rohde&Schwarz oscilloscopes provides essential measurement functions for analyzing power electronics, including inrush current, output spectrum and safe operating area. A measurement wizard with detailed instructions guides the user through the test setup. The oscilloscope configures itself automatically and delivers quick results.

Measurement functions:

- Current harmonics
- Input (power quality)
- Output (ripple)
- Power path (efficiency)

Results can be added to the test report simply by pressing a button. This report documents the current setup and configuration.

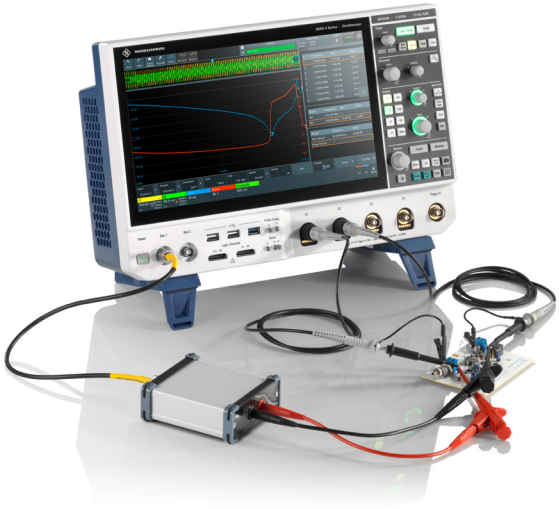
Multiple channel measurements

An 8-channel oscilloscope becomes handy when investigating power electronics designs. Considering that there could be different stages in a power device (e.g. input filter, rectifier, DC link, DC/DC converter, inverter), it is important to measure multiple signals to verify the overall behavior of the design. For example, when analyzing the start-up process of a converter, it is necessary to verify that the power sequencing is working as expected and that there are no timing issues between the different stages.

For applications that include three-phase signals, an 8-channel oscilloscope like the MXO 5 is the perfect tool. Multiple signals can be measured in a three-phase system using just a single oscilloscope.

Control loop response

At the core of each power converter or inverter, a control loop makes sure the output voltage stays stable independent of input voltage variations or load jumps at the output. Verifying stability of the control loop at different operating points of the system is an essential test during design. The R&S®RTx-K36 frequency response analysis (Bode plot) option allows you to perform this test directly with the oscilloscope, providing essential features such as direct plotting of the phase and gain margin as well as amplitude profiling.



High voltage and current measurements

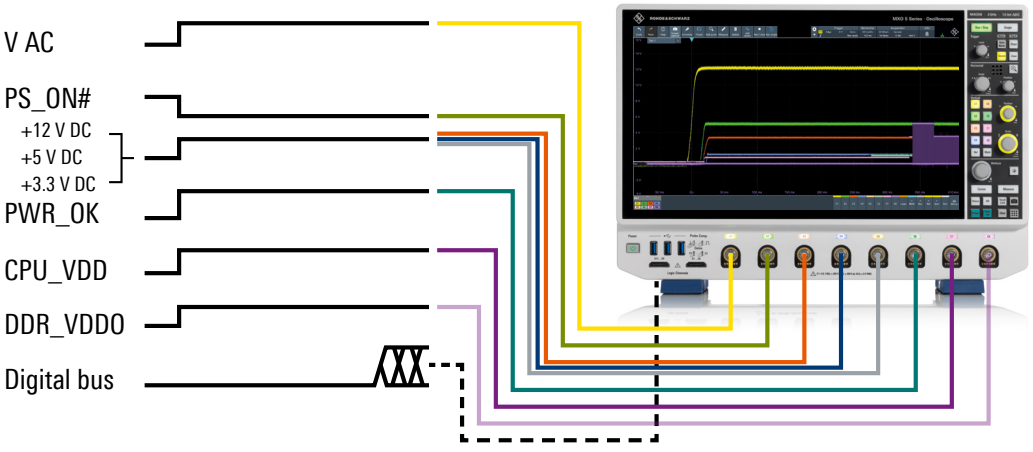
Accurate oscilloscope measurements require the right probes for the application. The R&S®RT-ZHD high-voltage differential probe family offers a bandwidth of up to 200 MHz, high common mode rejection ratio, low drift and low noise. Passive high-voltage probes from Rohde&Schwarz are excellent for ground-referenced measurements. R&S®RT-ZCxx clamp-on current probes allow current measurements over a broad range of parameters.

Isolated measurement systems

When working with the new WBG technology, the fast switching requires high voltage probes with enough speed to capture the details of the rising and falling edges. The R&S®RT-ZISO isolated probing system offers a solution with high common mode rejection up to 60 kV at 1 GHz. This makes it ideal for applications such as high-side gate measurement, isolation of three-phase inverter noise, as well as fast shunt current sensing.

Power sequencing and integrity

The MXO series oscilloscopes precisely measure power rail ramp-up and ramp-down. The oscilloscopes have advanced capabilities that can be used to correlate power sequencing events with other system activities. With its 8 channels, the MXO 5 allows measurement of multiple rails. An additional 16 logic channels let you include key timing signals for further analysis. The deep memory feature ensures that the oscilloscope maintains sufficient bandwidth throughout sequences that last tens of milliseconds.



SWITCHING ANALYSIS

Measuring switching behavior of converters

To maximize a power converter's performance and efficiency, a common practice is to increase the switching frequency. When increasing a power design's switching speed, the timing characteristics, interactions between high and low side transistors, and undesired outcomes such as shoot-through and excessive EMI must be accounted for.

High voltage measurements are another critical aspect. Precise measurement of these high voltages is crucial in order to verify that the system operates within its specifications and to ensure safe operation.

Rohde&Schwarz supports engineers working in the field of power electronics with solutions that enable testing, measurement and analysis of switching behavior in low, medium and high voltage converters.

The MXO 4 and MXO 5 series oscilloscopes are the perfect tool for these purposes. They meet the bandwidth, resolution, memory, noise, offset and trigger requirements needed to carry out comprehensive switching analysis.

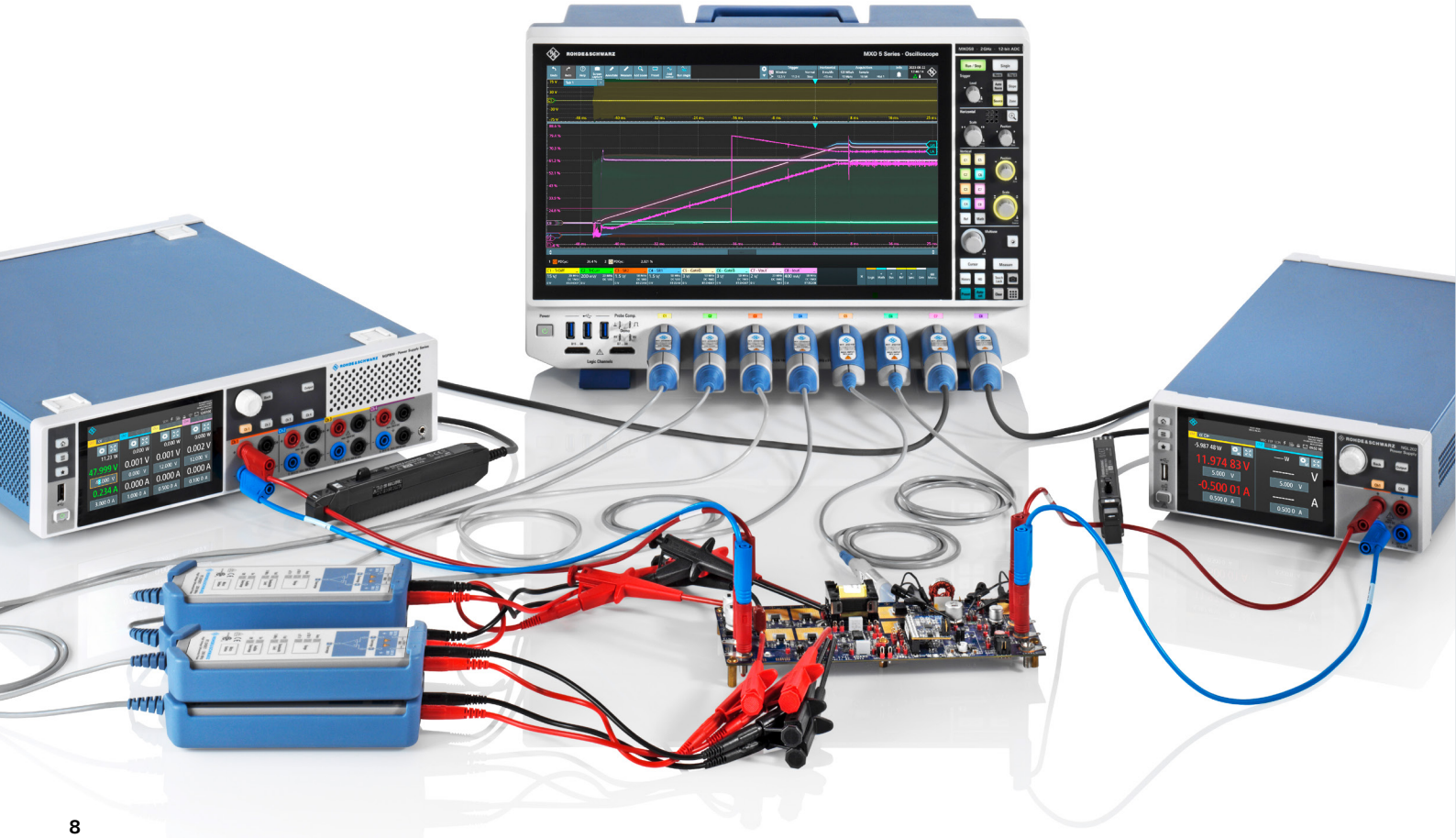
R&S®RT-ZHD probes can perform accurate measurements up to 6000 V. The R&S®RT-ZISO isolated probing system provides excellent CMRR up to 1 GHz when measurements requires isolation and fast switching. These probes offer high bandwidth and low loading impact, thus leading to accurate high voltage measurements without influencing the natural behavior of the circuits under test.

With these advanced tools, Rohde&Schwarz supports engineers when tackling the challenges of WBG semiconductors, offering the instruments needed for in-depth analysis of designs.

Double pulse tests

Knowledge about the switching behavior of power semiconductor devices is crucial when it comes to the design of power converters. Double pulse tests are carried out to determine the switching times and switching losses as well as to ensure proper switching behavior.

Together with PE-Systems, Rohde&Schwarz offers a solution that eases the process of characterizing the dynamic switching behavior of power semiconductors. This solution combines the necessary hardware and software to deliver accurate and repeatable results.



EMI DEBUGGING

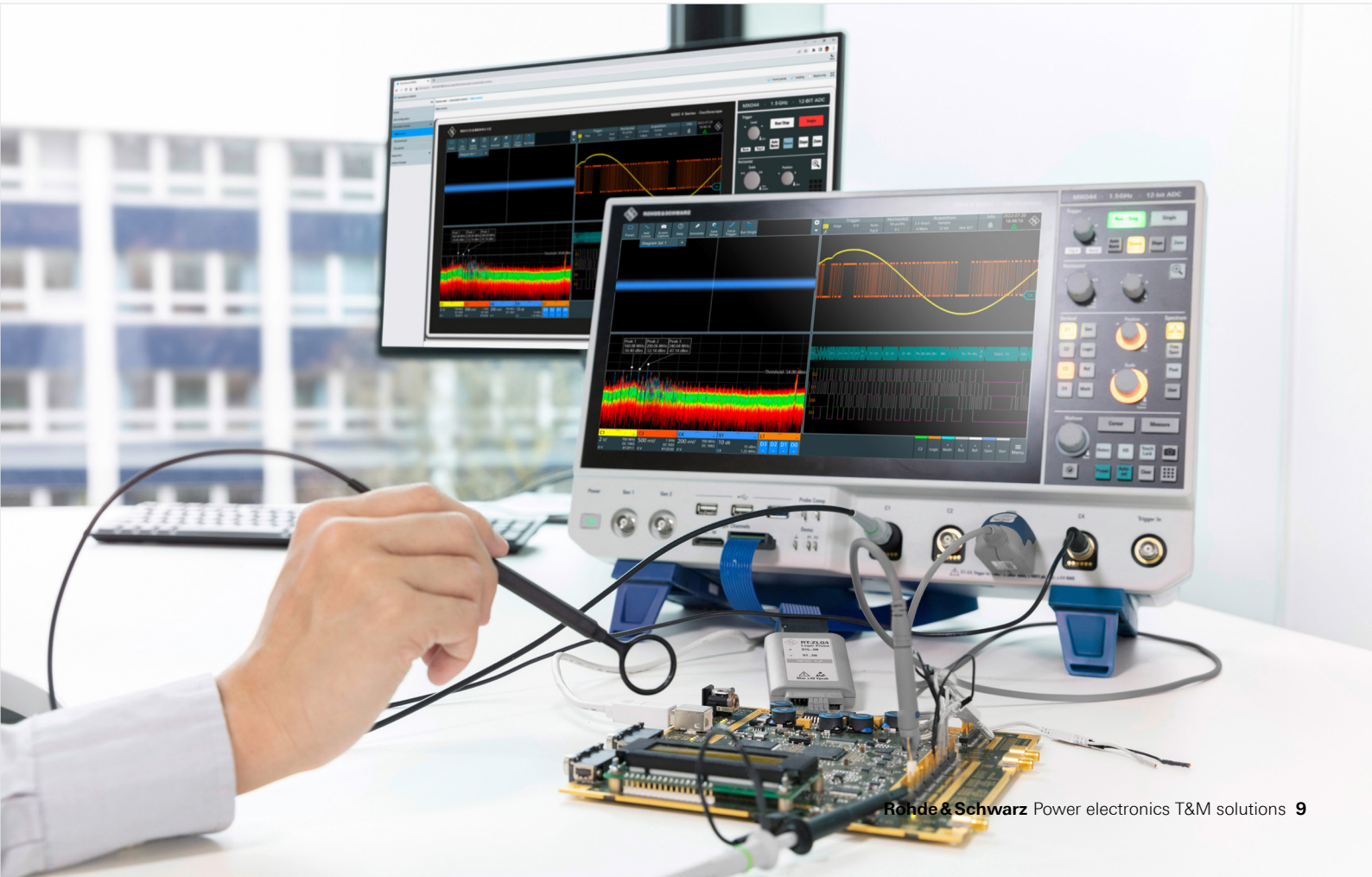
Compliance with electromagnetic interference (EMI) standards has to be taken into account in the early concept phase of a product. The later that EMI compliance is considered in the design phase, the more expensive the countermeasures.

Rohde&Schwarz provides T&M tools for EMI debugging during the design phase, for precompliance measurements on prototypes, and for full compliance testing at the end of the development cycle.

Rohde&Schwarz oscilloscopes provide fast, responsive and easy-to use FFT analysis functionality to measure the magnitude of the frequency component. Users are able to simultaneously view related signals in the time domain in order to correlate unwanted spectral emissions with time domain events. This makes these oscilloscopes powerful standalone instruments for performing early emission tests on power electronics designs.

The streamlined user interface allows FFT settings to be configured and changed with just a few gestures on the large touchscreen of the MXO 4, MXO 5 and R&S®RTO6 oscilloscopes. These instruments include zone triggering on spectrum waveforms, which is unique in the industry and extremely beneficial for finding spurious EMI events. In combination with near-field probes and high voltage differential or current probes, power electronics circuits can be fully optimized without additional test tools. This speeds up power electronics development during the device design phase and helps devices to pass EMC qualification testing.

This is particularly relevant when no dedicated equipment such as an EMI receiver is available in the R&D lab to support precompliance testing during the design phase.



VERIFICATION AND PRODUCTION TESTING

Starting from the early prototype phase, performance verification and preproduction testing are necessary steps towards mass production. Rohde&Schwarz provides both multipurpose as well as specialized test equipment for these applications.

Power converter verification and production testing

Verification and production testing of AC/DC or DC/DC power converters requires high vertical resolution, deep memory and dedicated analysis capabilities. The MXO 5 and MXO 5C oscilloscopes are ideally suited for this task.

Key benefits

- Native 12-bit ADC resolution with ENOB of > 10 bit
- Deep memory of up to 1 Gsample
- Up to 0.5 mV/div hardware input sensitivity
- Advanced analysis capabilities

Major home appliance efficiency and conformance testing

Energy efficiency, current harmonics and inrush currents must all be verified as part of the standard tests that electronic consumer durables are required to undergo.

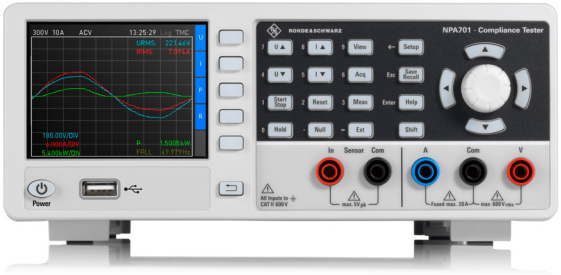
The R&S®NPA power analyzer series is a single-box solution that supports testing in compliance with standards such as IEC 62301, EN 50564 or IEC EN 61000-3-3.

Key benefits

- Measurement range: 50 µW to 12 kW with 0.05% basic accuracy
- 100 kHz bandwidth
- Pass/fail production testing and automated policy testing in line with EN and IEC standards
- Data logging, waveform view and energy meter functionality

MXO 5 (above) and MXO 5C (below) oscilloscopes

R&S®NPA power analyzer series



The R&S®NPA-Zx mains adapters are available in versions for the EU, UK, China/Australia and the US.

STANDARD LAB EQUIPMENT

Power supplies

On a bench or in a test system, our versatile DC power supply portfolio covers a wide range of power ratings, features and accuracy levels to provide the right choice for your application.

Key benefits

- Multiple independent outputs with separate power levels and characteristics, saving cost and space on the bench or in system racks
- Both parallel and serial operation to provide higher currents or voltages, covering more applications
- Remote control supported by a variety of interfaces
- Intuitive operating concept, large high-resolution touchscreen
- Programmable safety functions to protect the DUT and instrument
- Sophisticated features, such as battery simulation, output delays, remote sensing and data logging, to speed up everyday measurements

Multimeters

Accuracy and speed are the most important characteristics of multimeters, while usability comes in a close third. With the R&S®HMC8012, Rohde&Schwarz offers a powerful 5 ¾ digit multimeter for laboratory use.

Key benefits

- Measurement range from DC to 100 kHz
- Up to 200 measurements/s
- High basic accuracy of 0.015%
- Simultaneous display of up to three measurement functions; DC + AC + statistics, for example

POWER SUPPLY PORTFOLIO




	Basic units			Performance units
	R&S®NGE102B/103B	R&S®NGC101(-G)/ NGC102(-G)/NGC103(-G)	R&S®NGA101/102/141/142	R&S®HMP2020/2030
Electrical specifications				
Number of output channels	2/3	1/2/3	1/2	2/3
Maximum output power	66 W/100 W	100 W	40 W/80 W	188 W
Maximum output power per channel	33.6 W	100 W/50 W/33 W	40 W	80 W, except R&S®HMP2020, CH1: 160 W
Output voltage per channel	0 V to 32 V	0 V to 32 V	R&S®NGA101/102: 0 V to 35 V R&S®NGA141/142: 0 V to 100 V	0 V to 32 V
Maximum output current per channel	3 A	10 A/5 A/3 A	R&S®NGA101/102: 6 A R&S®NGA141/142: 2 A	5 A, except R&S®HMP2020, CH1: 10 A
Voltage ripple and noise (RMS) (20 Hz to 20 MHz)	< 1.5 mV (typ.)	R&S®NGC101: < 1 mV (meas.); R&S®NGC102/103: < 450 µV (meas.)	R&S®NGA101/102: < 0.5 mV (meas.); R&S®NGA141/142: < 1.5 mV (meas.)	< 1.5 mV (meas.)
Current ripple and noise (RMS) (meas.) (20 Hz to 20 MHz)	< 2 mA	R&S®NGC101: < 1.5 mA; R&S®NGC102/103: < 1 mA	< 500 µA	< 1 mA
Load recovery time [1] (meas.)	< 200 µs	< 1 ms	R&S®NGA101/102: < 100 µs; R&S®NGA141/142: < 50 µs	< 1 ms
Programming/readback resolution				
Voltage	10 mV	1 mV	programming: R&S®NGA101/102: 1 mV R&S®NGA141/142: 10 mV readback: 1 mV	1 mV
Current	1 mA	< 1 A: 0.1 mA (R&S®NGC101: 0.5 mA); ≥ 1 A: 1 mA	readback: 10 µA low-current measurement range: 1 µA	< 1 A: 0.1 mA (10 A CH: 0.2 mA); ≥ 1 A: 1 mA
Readback accuracy (± (% of output + offset))				
Voltage	< 0.1% + 20 mV	< 0.05% + 2 mV	R&S®NGA101/102: 0.02% + 5 mV R&S®NGA141/142: 0.02% + 10 mV	< 0.05% + 5 mV
Current	< 0.1% + 5 mA	R&S®NGC101: < 0.2% + 10 mA; R&S®NGC102: < 0.1% + 5 mA; R&S®NGC103: < 0.05% + 2 mA	< 0.05% + 500 µA low-current measurement range: < 0.15% + 40 µA	< 0.1% + 2 mA
Special functions				
Measurement functions	voltage, current, power	voltage, current, power, energy	voltage, current, power	voltage, current
Protection functions	OVP, OCP, OPP, OTP	OVP, OCP, OPP, OTP	OVP, OCP, OPP, OTP	OVP, OCP, OTP
FuseLink function	●	● (R&S®NGC102/103)	● (R&S®NGA102/142)	●
Fuse delay	●	●	●	●
Remote sensing	–	●	●	●
Sink mode	–	–	–	–
Output delay	–	● (R&S®NGC102/103)	–	–
Trigger input/output	○/○	●/–	○/○	–
Arbitrary function	● (CH1: EasyArb)	● (EasyArb)	● (CH1: EasyArb)	● (EasyArb)
Analog/modulation interface	–	●	–	–
Channel fusion	–	–	●	–
Data logging	–	● (standard mode)	● (standard mode)	–
Display and interfaces				
Display	3.5" QVGA	3.5" QVGA	3.5" QVGA	240 × 64 pixel LCD
Rear panel connections	–	16-pin connector block	8-pin connector block	4-pin connector block per channel
Remote control interfaces	standard: USB; optional: LAN	standard: USB, LAN; R&S®NGC10x-G models with IEEE-488 (GPIB)	standard: USB, LAN	optional: USB, LAN, IEEE-488 (GPIB), RS-232
General data				
Dimensions (W × H × D)	222 × 97 × 310 mm	222 × 97 × 291 mm	222 × 97 × 448 mm	285 × 93 × 405 mm
Weight	4.9 kg/5.0 kg	2.6 kg (R&S®NGC10x-G models: 2.7 kg)	6.6 kg/7.0 kg/6.9 kg/7.3 kg	7.8 kg/8.0 kg
Rack adapter	R&S®HZC95 option	R&S®HZC95 option	R&S®HZN96 option	R&S®HZ42 option

[1] 10% to 90% load change within a band of ±20 mV of set voltage.
[2] In the most sensitive measurement range.





		High-precision power supplies		
R&S®HMP4030/4040	**R&S®NGP802/822/804/814/824**	**R&S®NGL201/202**	**R&S®NGM201/202**	**R&S®NGU201/411/401**
3/4	2/4	1/2	1/2	1
384 W	400 W/800 W	60 W/120 W	60 W/120 W	60 W/20 W/60 W
160 W	200 W	60 W	60 W	60 W/20 W/60 W
0 V to 32 V	0 V to 32 V (32 V channels); 0 V to 64 V (64 V channels)	0 V to 20 V	0 V to 20 V	R&S®NGU201: 0 V to 20 V R&S®NGU411/401: –20 V to +20 V
10 A	20 A (32 V channels); 10 A (64 V channels)	≤ 6 V output voltage: 6 A; > 6 V output voltage: 3 A	≤ 6 V output voltage: 6 A; > 6 V output voltage: 3 A	≤ 6 V output voltage: 8 A; (R&S®NGU411: ≤ 10 V: 2 A) > 6 V output voltage: 3 A (R&S®NGU411: > 10 V: 1 A)
< 1.5 mV (meas.)	< 3 mV (meas.)	< 500 µV (meas.)	< 500 µV (meas.)	< 500 µV (meas.)
< 1 mA	< 3.5 mA	< 1 mA	< 1 mA	< 1 mA
< 1 ms	< 400 µs	< 30 µs	< 30 µs	< 30 µs
1 mV	1 mV	1 mV/10 µV	1 mV/5 µV[2)]	50 µV/1 µV[2)]
< 1 A: 0.2 mA; ≥ 1 A: 1 mA	0.5 mA	0.1 mA/10 µA	0.1 mA/10 nA[2)]	100 nA/100 pA[2)]
< 0.05 % + 5 mV	< 0.05 % + 5 mV (32 V channels); < 0.05 % + 10 mV (64 V channels)	< 0.02 % + 2 mV	< 0.02 % + 500 µV[2)]	< 0.02 % + 500 µV[2)]
< 0.1 % + 2 mA	< 0.1 % + 5 mA	< 0.05 % + 250 µA	< 0.05 % + 15 µA[2)]	< 0.025 % + 15 nA[2)]
voltage, current	voltage, current, power, energy	voltage, current, power, energy	voltage, current, power, energy	voltage, current, power, energy
OVP, OCP, OTP	OVP, OCP, OPP, OTP	OVP, OCP, OPP, OTP	OVP, OCP, OPP, OTP	OVP, OCP, OPP, OTP
●	●	● (R&S®NGL202)	● (R&S®NGM202)	–
●	●	●	●	●
●	●	●	●	●
–	–	●	●	●
–	●	● (R&S®NGL202)	● (R&S®NGM202)	–
–	o/o	o/o	o/o	o/o
● (EasyArb)	● (QuickArb)	● (QuickArb)	● (QuickArb)	● (QuickArb)
–	o	–	–	R&S®NGU411/401: modulation interface
–	–	–	–	–
–	● (standard mode)	● (standard mode)	● (standard and fast mode)	● (standard and fast mode)
240 × 128 pixel LCD	TFT 5" 800 × 480 pixel WVGA touch	TFT 5" 800 × 480 pixel WVGA touch	TFT 5" 800 × 480 pixel WVGA touch	TFT 5" 800 × 480 pixel WVGA touch
8-pin connector block per 2 channels	8-pin connector block per 2 channels	8-pin connector block per channel	8-pin connector block per channel	8-pin connector block
optional: USB, LAN, IEEE-488 (GPIB), RS-232	standard: USB, LAN; optional: IEEE-488 (GPIB)	standard: USB, LAN; optional: IEEE-488 (GPIB)	standard: USB, LAN; optional: IEEE-488 (GPIB)	standard: USB, LAN; optional: IEEE-488 (GPIB)
285 × 136 × 405 mm	362 × 100 × 451 mm	222 × 97 × 436 mm	222 × 97 × 436 mm	222 × 97 × 436 mm
12.4 kg/12.8 kg	7.5 kg/8.0 kg	7.1 kg/7.3 kg	7.2 kg/7.4 kg	7.1 kg
R&S®HZP91 option	R&S®ZZA-GE23 option	R&S®HZN96 option	R&S®HZN96 option	R&S®HZN96 option

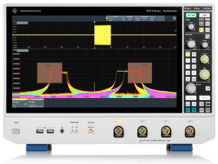
All data valid at +23 °C (– 3 °C/+ 7 °C) after 30 minutes of warm-up time. ● yes – no ○ optional

OSCILLOSCOPE PORTFOLIO




	R&S®RTH1000	R&S®RTC1000	R&S®RTB2000	R&S®RTM3000
Vertical system				
Bandwidth [1]	60/100/200/350/500 MHz	50/70/100/200/300 MHz	70/100/200/300 MHz	100/200/350/500 MHz/1 GHz
Number of channels	2 plus DMM/4	2	2/4	2/4
Vertical resolution; system architecture	10 bit; 16 bit	8 bit; 16 bit	10 bit; 16 bit	10 bit; 16 bit
V/div, 1 MΩ	2 mV to 100 V	1 mV to 10 V	1 mV to 5 V	500 µV to 10 V
V/div, 50 Ω	–			500 µV to 1 V
Digital channels	8	8	16	16
Horizontal system				
Sampling rate per channel (in Gsample/s)	1.25 (4-channel model); 2.5 (2-channel model); 5 (all channels interleaved)	1; 2 (2 channels interleaved)	1.25; 2.5 (2 channels interleaved)	2.5; 5 (2 channels interleaved)
Maximum memory (per channel; 1 channel active)	125 kpoints (4-channel model); 250 kpoints (2-channel model); 500 kpoints	1 Mpoints; 2 Mpoints	10 Mpoints; 20 Mpoints	40 Mpoints; 80 Mpoints
Segmented memory	standard, 50 Mpoints	–	option, 320 Mpoints	option, 400 Mpoints
Acquisition rate (in waveforms/s)	50000	10000	50000 (300000 in fast segmented memory mode [2])	64000 (2000000 in fast segmented memory mode [2])
Trigger				
Types	digital	analog	analog	analog
Sensitivity	–	–	at 1 mV/div: > 2 div	at 1 mV/div: > 2 div
Analysis				
Mask test	tolerance mask	tolerance mask	tolerance mask	tolerance mask
Mathematics	elementary	elementary	basic (math on math)	basic (math on math)
Serial protocols triggering and decoding [1]	I²C, SPI, UART/RS-232/RS-422/RS-485, CAN, LIN, CAN FD, SENT	I²C, SPI, UART/RS-232/RS-422/RS-485, CAN, LIN	I²C, SPI, UART/RS-232/RS-422/RS-485, CAN, LIN	I²C, SPI, UART/RS-232/RS-422/RS-485, CAN, LIN, I²S, MIL-STD-1553, ARINC 429
Applications [1, 2]	high-resolution frequency counter, advanced spectrum analysis, harmonics analysis, user scripting	digital voltmeter (DVM), component tester, fast Fourier transform (FFT)	digital voltmeter (DVM), fast Fourier transform (FFT), frequency response analysis	power, digital voltmeter (DVM), spectrum analysis and spectrogram, frequency response analysis
Compliance testing [1, 2]	–	–	–	–
Display and operation				
Size and resolution	7" touchscreen, 800 × 480 pixel	6.5", 640 × 480 pixel	10.1" touchscreen, 1280 × 800 pixel	10.1" touchscreen, 1280 × 800 pixel
General data				
Dimensions in mm (W × H × D)	201 × 293 × 74	285 × 175 × 140	390 × 220 × 152	390 × 220 × 152
Weight in kg	2.4	1.7	2.5	3.3
Battery	lithium-ion, > 4 h	–	–	–

[1] Upgradeable. [2] Requires an option.



MXO 4	MXO 5/MXO 5C	R&S®RTO6	R&S®RTP
200/350/500 MHz/1/1.5 GHz	100/200/350/500 MHz/1/2 GHz	600 MHz/1/2/3/4/6 GHz	4/6/8/13/16 GHz
4	4/8	4	4
12 bit; 18 bit	12 bit; 18 bit	8 bit; 16 bit	8 bit; 16 bit
500 µV to 10 V	500 µV to 10 V	1 mV to 10 V (HD mode: 500 µV to 10 V)	
500 µV to 1 V	500 µV to 1 V	1 mV to 1 V (HD mode: 500 µV to 1 V)	2 mV to 1 V (HD mode: 1 mV to 1 V)
16	16	16	16
2.5; 5 (2 channels interleaved)	5 on 4 channels; 2.5 on 8 channels (2 channels interleaved)	10; 20 (2 channels interleaved in 4 GHz and 6 GHz model)	20; 40 (2 channels interleaved)
standard: 400 Mpoints; max. upgrade: 800 Mpoints[2)]	standard: 500 Mpoints max. upgrade: 1 Gpoints[2)]	standard: 200 Mpoints/800 Mpoints; max. upgrade: 1 Gpoints/2 Gpoints	standard: 100 Mpoints/400 Mpoints; max. upgrade: 3 Gpoints
standard: 10000 segments; option: 1000000 segments	standard: 10000 segments; option: 1000000 segments	standard	standard
> 4500000	> 4500000 on 4 channels	1000000 (2500000 in ultra-segmented memory mode)	750000 (3200000 in ultra-segmented memory mode)
advanced (includes zone trigger), digital trigger (15 trigger types)	advanced (includes zone trigger), digital trigger (15 trigger types)	advanced (includes zone trigger), digital trigger (15 trigger types), high speed serial pattern trigger including 5 Gbps clock data recovery (CDR)[2)]	advanced (includes zone trigger), digital trigger (14 trigger types) with real-time deembedding[2)], high speed serial pattern trigger including 8/16 Gbps clock data recovery (CDR)[2)]
0.0001 div, across full bandwidth, user controllable	0.0001 div, across full bandwidth, user controllable	0.0001 div, across full bandwidth, user controllable	0.0001 div, across full bandwidth, user controllable
		user configurable, hardware based	user configurable, hardware based
advanced (formula editor)	advanced (formula editor)	advanced (formula editor, Python interface)	advanced (formula editor, Python interface)
I²C, SPI, UART/RS-232/RS-422/RS-485, CAN, CAN FD, CAN XL, LIN, SPMI, 10BASE-T1S, ARINC, SPMI, QUAD-SPI	I²C, SPI, UART/RS-232/RS-422/RS-485, CAN, CAN FD, CAN XL, LIN, SPMI, 10BASE-T1S, 100BASE-T1, ARINC, SPMI, QUAD-SPI	I²C, SPI, UART/RS-232/RS-422/RS-485, CAN, LIN, I²S, MIL-STD-1553, ARINC 429, FlexRay™, CAN FD, MIPI RFFE, USB 2.0/HSIC, MDIO, 8b10b, Ethernet, Manchester, NRZ, SENT, MIPI D-PHY, SpaceWire, MIPI M-PHY/UniPro, CXPI, USB 3.1 Gen 1, USB-SSIC, PCIe 1.1/2.0, USB Power Delivery, Automotive Ethernet 100/1000BASE-T1	I²C, SPI, UART/RS-232/RS-422/RS-485, SENT, CAN, LIN, CAN FD, MIL-STD-1553, ARINC 429, SpaceWire, USB 2.0/HSIC/PD, USB 3.1 Gen 1/Gen 2/SSIC, PCIe 1.1/2.0/3.0, 8b10b, MIPI RFFE, MIPI D/M-PHY/UniPro, Automotive Ethernet 100/1000BASE-T1, Ethernet 10/100BASE-TX, MDIO, Manchester, NRZ
power, digital voltmeter (DVM), frequency response analysis	power, digital voltmeter (DVM), frequency response analysis	power, advanced spectrum analysis and spectrogram, jitter and noise decomposition, clock data recovery (CDR), I/Q data and RF analysis (R&S®VSE), deembedding, embedding, equalization, PAM-N, TDR/TDT analysis, advanced eye diagram	advanced spectrum analysis and spectrogram, jitter and noise decomposition, real-time deembedding, embedding, equalization, PAM-N, TDR/TDT analysis, I/Q data and RF analysis (R&S®VSE), advanced eye diagram
–		see specifications (PD 5216.1640.22)	see specifications (PD 3683.5616.22)
13.3" touchscreen, 1920 × 1080 pixel (Full HD)	for MXO 5 only: 15.6" touchscreen, 1920 × 1080 pixel (Full HD)	15.6" touchscreen, 1920 × 1080 pixel (Full HD)	13.3" touchscreen, 1920 × 1080 pixel (Full HD)
414 × 279 × 162	MXO 5: 445 × 314 × 154 MXO 5C: 445 × 105 × 405	450 × 315 × 204	441 × 285 × 316
6	MXO 5: 9 MXO 5C: 8.7	10.7	18
–	–	–	–

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