High definition oscilloscopes: signal analysis with 16-bit vertical resolution

For oscilloscopes, vertical resolution is increasingly being counted as a key parameter alongside other such as bandwidth, sampling rate and memory depth. This development is being driven by the heightened demand for more signal details in applications from the consumer goods sector as well as in medicine and R&D. The particular challenge here is to measure low-voltage components with an order of magnitude of only a few hundred mV on a signal that also exhibits high-voltage components.

Front page: See more with up to 16-bit vertical resolution: R&S RTO and R&S RTE oscilloscopes with high definition option increase the vertical resolution by a factor of 256.

Increasing vertical resolution with filter gain

The vertical resolution of an oscilloscope determines how accurately signals are displayed and is responsible for the precision of the achieved measurement results. Just a few years ago a typical oscilloscope had a vertical resolution of 8 bit. However, when the signal under test has a high dynamic range – i.e. low-voltage components are to be analyzed in detail on a signal that also exhibits high-voltage components – 8-bit resolution might not be precise enough to meet the measurement requirements. This is why high definition oscilloscopes with a higher vertical resolution have become available in the interim.

One option for increasing the vertical resolution is to use A/D converters with more than 8 bit. Another option is to use digital postprocessing algorithms. Rohde & Schwarz has embraced the second approach in its R&S RTO and R&S RTE oscilloscopes with the R&S RTO-K17 or R&S RTE-K17 high definition option. As a result, the resolution is increased to a maximum of up to 16 bit – a 256-fold improvement over 8-bit resolution in standard mode. This is achieved by means of a digital lowpass filter that is implemented directly after the A/D converter in the oscilloscope's ASIC (Fig. 1).

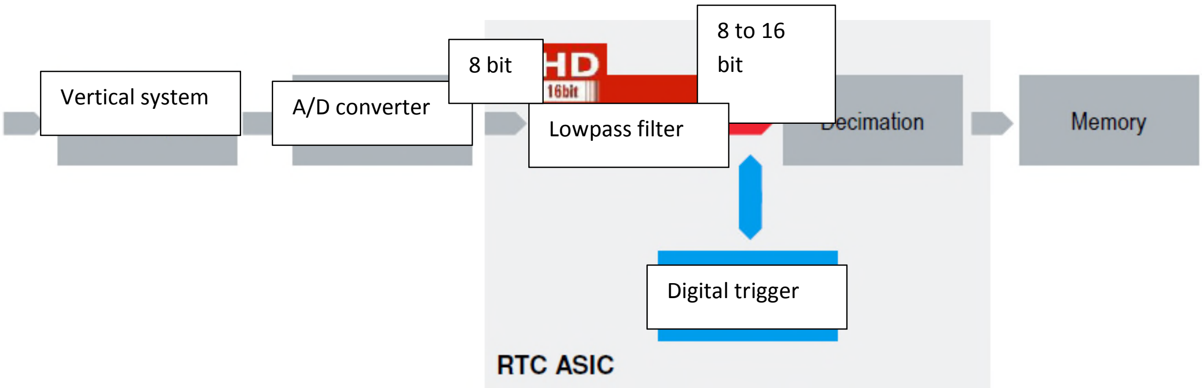

Fig. 1: Excerpt from the block diagram in the R&S RTO and R&S RTE oscilloscopes. The lowpass filter is positioned directly after the A/D converter, which increases the vertical resolution.

The filter reduces the noise, thereby increasing the signal-to-noise ratio and the vertical resolution. Users can adjust the bandwidth of the lowpass filter from 10 kHz to 1 GHz as needed to match the characteristics of the applied signal. The associated filter bandwidth determines the nominal resolution (table 1). The lower the filter bandwidth as compared to the instrument bandwidth, the higher the resolution and noise reduction (Fig. 2). This is illustrated by the spectrum in Fig. 3, where f_a is the sampling rate of the oscilloscope, f_B is the bandwidth of the lowpass filter and $S(f)$ is the wanted signal. Assuming pure white noise (AWGN), which is a good approximation for a high-quality A/D converter, and assuming an ideal lowpass filter, the gain in the signal-to-noise ratio is as follows:
$SNR_{gain} = 10log(f_a/2f_B)$.

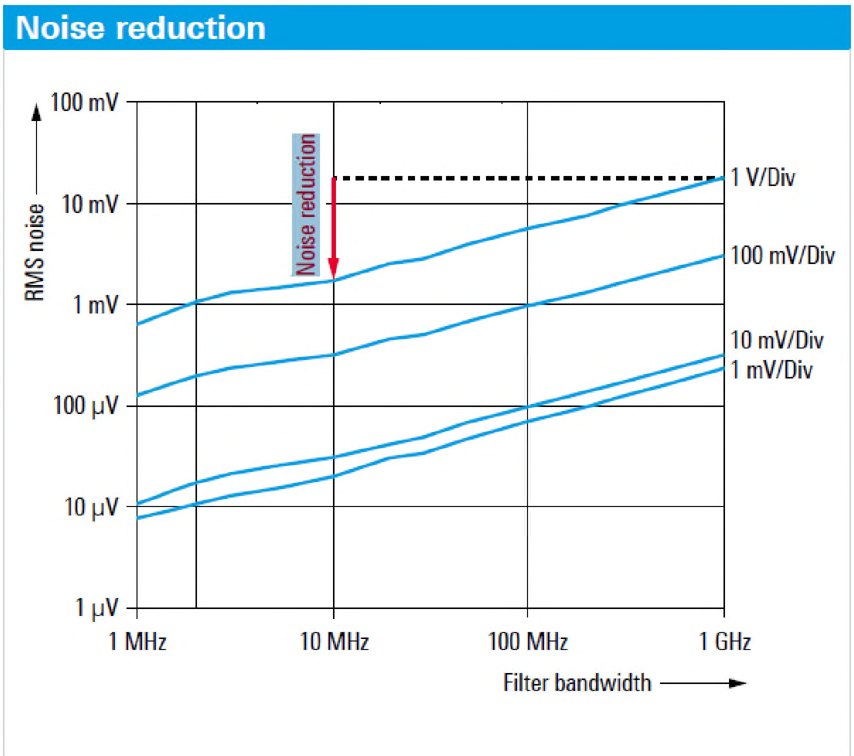

Fig. 2: Noise of the R&S RTO1044 oscilloscope (4 GHz model) as a function of the filter bandwidth set in high definition mode; a reduction in noise leads to an increase in the signal-to-noise ratio, which improves resolution.

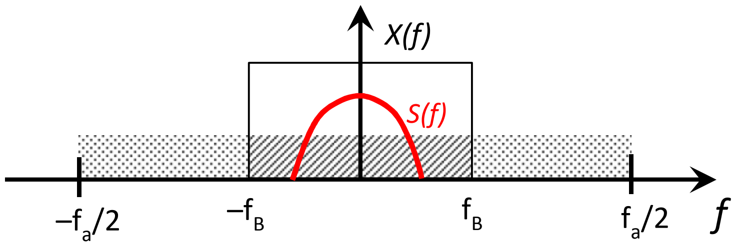

Fig. 3: Noise reduction in the spectrum using a lowpass filter, where f_a is the oscilloscope sampling rate, f_B is the bandwidth of the lowpass filter and *S(f)* is the wanted signal.

Filter	Vertical resolution
inactive	8 bit
1 GHz	10 bit
500 MHz	12 bit
300 MHz	12 bit
200 MHz	13 bit
100 MHz	14 bit
50 MHz to 10 kHz	16 bit

Table 1: Vertical resolution of the R&S RTO oscilloscope as a function of the selected filter bandwidth in high definition mode.

More signal details and more accurate measurement results

The increase in resolution leads to sharper waveforms, showing signal details that would otherwise be masked by noise, leaving them undetected. To allow detailed analysis of these small signals, the R&S RTO and the R&S RTE oscilloscopes offer an increased input sensitivity of 500 µV/div. Thanks to the low-noise frontend and the highly accurate single-core A/D converter, the R&S RTO and R&S RTE oscilloscopes have an excellent dynamic range and measurement accuracy. Switching on high definition mode allows users to benefit from even more precise measurement results, as seen in Figs. 4 and 5.

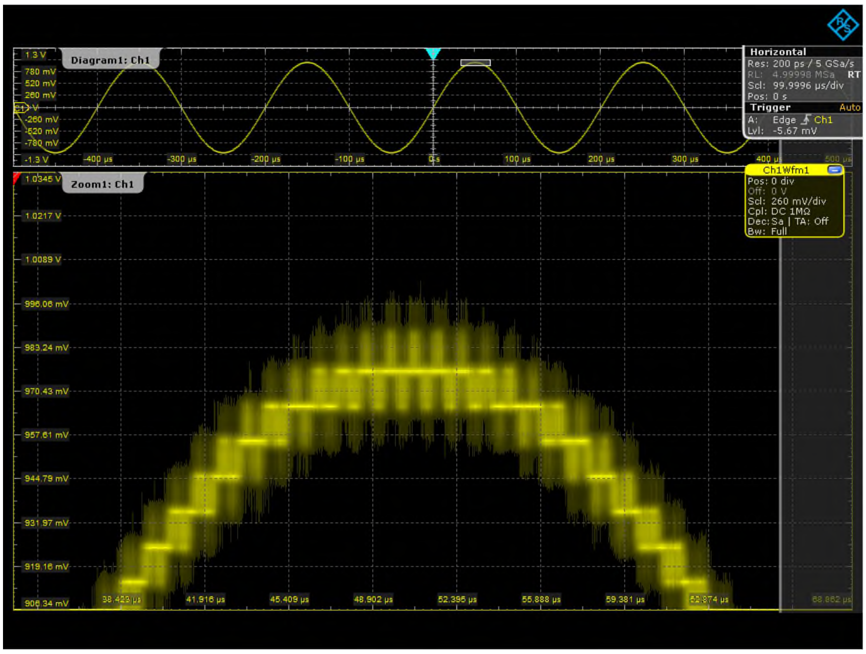

Fig. 4: Zoomed-in peak of a sine wave. High definition mode is not activated. Only the quantization levels can be seen in the zoom window.

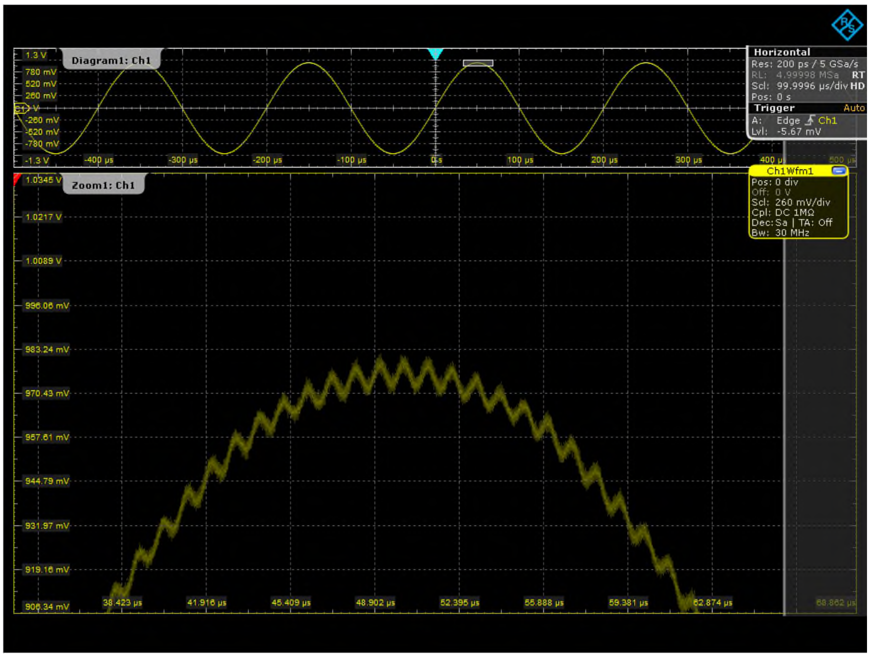

Fig. 5: When high definition mode is switched on, the zoom window shows that another very low-amplitude sine wave is superimposed on the signal.

Realtime triggering on the smallest signal details

The increased resolution in high definition oscilloscopes makes it possible to reveal even the smallest signal details. The ability to trigger on these details so that they can be reliably displayed on the monitor depends strongly on the capabilities of the trigger system. The digital trigger system from Rohde & Schwarz has the sensitivity required to benefit from the high-resolution signal. Each of the up to 16-bit samples is checked against the trigger condition and can initiate a trigger (see Fig. 1). As seen in Fig. 6, the oscilloscopes are able to trigger on even the smallest signal amplitudes and isolate relevant signal events in order to permit more detailed analysis. In contrast, a traditional analog trigger system cannot trigger on the high-resolution signal details because they are masked in the trigger path by the hysteresis of the analog components.

Fig. 6: The high sensitivity of the Rohde & Schwarz digital trigger makes it possible to trigger on signal overshoots of less than 9 mV, as can be seen in this example. At a vertical scale of 130 mV/div, this corresponds to only a fraction of one display division.

High definition mode versus HiRes decimation

The Rohde & Schwarz oscilloscopes' high definition option offers significant advantages over the high resolution (HiRes) decimation mode supported by most oscilloscopes on the market. First, the user knows exactly what signal bandwidth is available due to explicit lowpass filtering. Second, there are no unexpected aliasing effects. High definition mode is not based on decimation. This means that even in high definition mode, R&S RTO oscilloscopes still maintain a sampling rate of 5 Gsample/s, or 2.5 Gsample/s for R&S RTE oscilloscopes, ensuring the best possible time resolution. Moreover, the high definition mode permits users to trigger on the signals with increased resolution, whereas HiRes decimation takes place only after the trigger unit.

High acquisition rate and functional range for fast measurement results

Even in high definition mode, R&S RTO and R&S RTE oscilloscopes do not compromise on measurement speed and options. Since the lowpass filtering, which improves resolution and noise reduction, is implemented in realtime in the oscilloscopes’ ASIC, the acquisition and processing rates remain high. The oscilloscopes enable smooth operation and measurement results are available quickly. All analysis tools, including automatic measurements, FFT and the history mode, remain available in high definition mode.

Application example: Measuring $R_{DS(on)}$ of a DC/DC converter

Switched-mode power supplies are an integral part of modern electronic devices. They transfer electrical power from a source to a drain and at the same time convert the current and voltage characteristics so that the correct voltage is supplied to the components. A possible criterion for classification of switched-mode power supplies is the type of input or output voltage. For example, a DC/DC converter converts one DC voltage at the input into a different DC voltage with either a higher (upconverter) or a lower (downconverter) voltage level. There are many applications for DC/DC converters, ranging from PC or laptop power supplies to mobile phones to automobiles. Because of their switching speed, metal oxide semiconductor field effect transistors (MOSFET) are typically used as switches, although the efficiency of the transistor is naturally a key factor. The power loss must be as low as possible, regardless of type. A key parameter in this respect is $R_{DS(on)}$. When switched on, the transistor acts as a resistor between the drain and the source. The value of this resistance, which differs depending on the operating point, determines the power loss of the converter.

$R_{DS(on)}$ of a DC/DC converter is calculated from the drain current and the drain-source voltage. Both must therefore be measured accurately. The measurement of the drain-source voltage is particularly challenging with an oscilloscope. When the transistor is switched on, the voltages are very low, i.e. in the range of a few hundred mV. Conversely, very high voltages are present when the transistor is switched off. In extreme cases, the voltage variation between the transistor when switched on and the transistor when switched off can be several hundred volts. As seen in Figs. 7 and 8, a high resolution of more than 8 bit is necessary for a precise measurement of the low voltages.

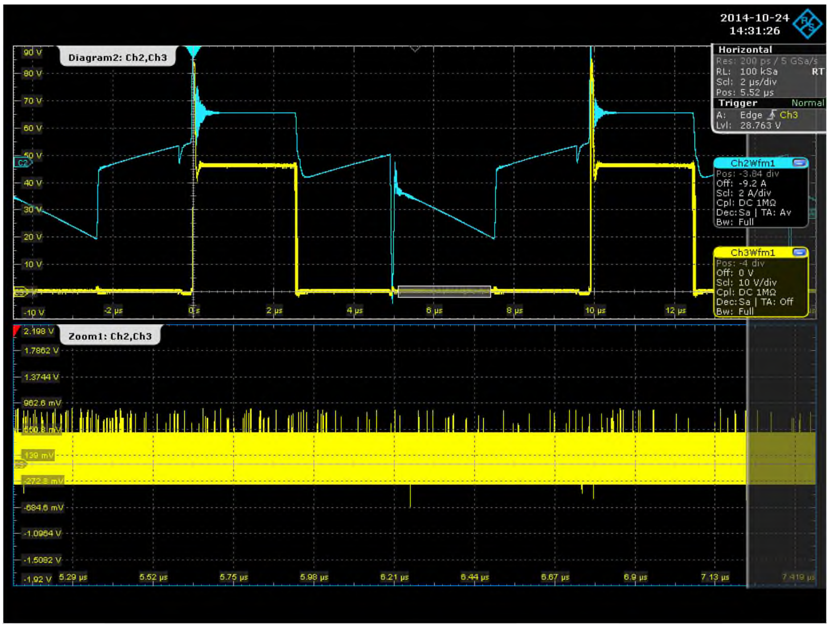

Fig. 7: Measurement of the drain-source voltage of a DC/DC converter without high definition mode. The large noise component in the signal makes reliable results impossible.

The top half of Fig. 7 shows a complete switching cycle of a MOSFET transistor, while the lower half shows a zoomed view of the drain-source voltage being measured. The waveforms were recorded with a vertical resolution of 8 bit. The noise component of the signal is too large to permit a reliable measurement of the drain-source voltage. On the other hand, switching on high definition mode in the R&S RTO oscilloscope and using a vertical resolution of 16 bit reduces the noise significantly, providing sharper waveforms and showing more details (Fig. 8). This ensures precise measurement results and makes it possible to calculate $R_{DS(on)}$ of the converter.

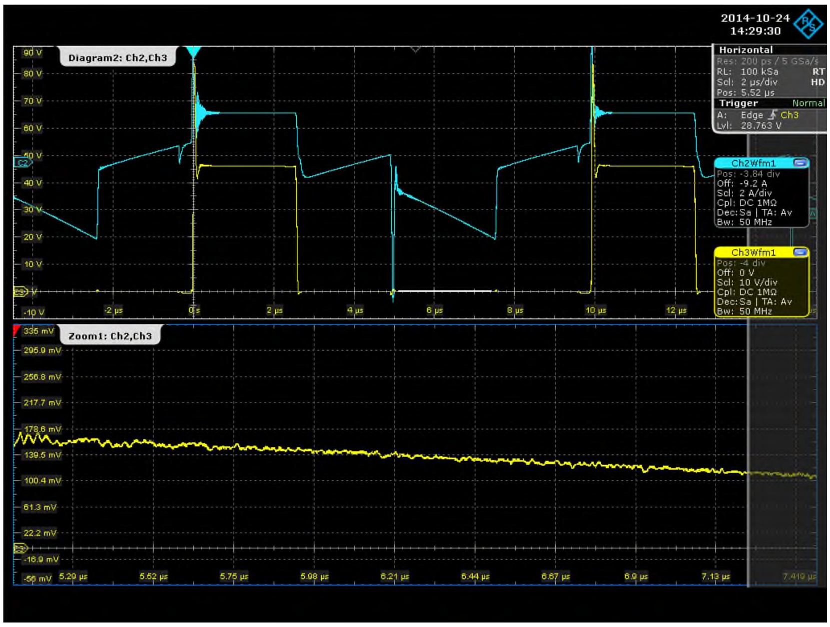

Fig. 8: Measurement of the drain-source voltage of a DC/DC converter with high definition mode. Increasing the vertical resolution to 16 bit make the signal details visible.

For the sake of completeness, it must be pointed out here that a Rogowski coil was used to measure the drain current in this example. Rogowski coils capture only the AC components in the signal, which means that the current waveform on the oscilloscope display must include a DC offset. Therefore, to obtain an accurate result for $R_{DS(on)}$, it is not sufficient to simply divide an individual voltage value by the associated current value. A differential approach must be used instead. While the transistor is switched on, both the drain-source voltage and the drain current increase almost continuously within a defined time period. As seen in Fig. 9, $R_{DS(on)}$ is therefore calculated based on Δu_{DS} and Δi_D within this time period.

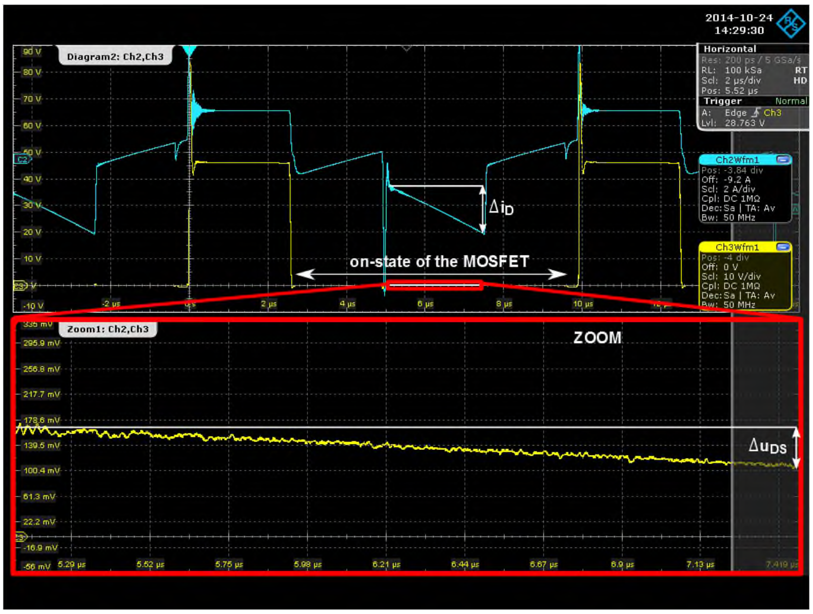

Fig. 9: $R_{DS(on)}$ is calculated differentially from Δu_{DS} and Δi_D.

Summary

High definition oscilloscopes are used for applications that require an increased vertical resolution. This is the case primarily when the signals under test have a high dynamic range. A flexible method of achieving high definition is through digital postprocessing. The R&S RTO and R&S RTE high definition mode allows a resolution of up to 16 bit. Signal details that would otherwise remain undetected due to noise are now visible, providing more accurate measurement results. The digital trigger system even permits triggering on signal details in order to isolate individual events. Each base unit is equipped with the R&S RTO-K17 or the R&S RTE-K17 high definition option. The solution can be adapted flexibly to meet the needs of specific tasks. Users benefit both from the high bandwidth (up to 4 GHz for the R&S RTO and up to 2 GHz for the R&S RTE) and from the increased vertical resolution in high definition mode.

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