Optimize differential measurements on high-speed interfaces

High-speed serial interfaces often transmit data with differential signaling. For probing on the signal, trace differential probes are used. Besides the differential inputs, these probes often provide an additional connection for ground – especially the higher bandwidth models. The ground connection on the R&S®RT-ZMxx modular multimode probes can be used to improve measurements on high-speed differential interfaces.

Your task

Your task is to measure high-speed interfaces such as PCIe, USB 3.1 and 10 Gbit Ethernet, which use differential transmission. Differential signal lanes use a positive and a negative line referenced to each other instead of one signal line to ground (single-ended transmission). The measured differential signal is the difference between the negative and positive input. Because of their high impedance inputs, differential probes can measure signals between any two potentials as long as they are within the dynamic range of the probe. The differential probe measures and amplifies the voltage difference of the two signal levels.

T&M solution

To analyze high-speed interfaces accurately, it is important to carefully select the differential probe. Fig.1 shows the simplified measurement setup of a differential probe with positive (V_P) and negative (V_N) input voltages measuring a USB 3.1 Gen1 signal. In this example, the USB drive is connected to a laptop that is not connected to the mains. It shows the differential voltage ($V_{DM} = V_P - V_N$) and the common mode voltage ($V_{CM} = ½(V_P + V_N)$).

The probe also has a connection to ground. This connection has a parasitic and usually unknown inductance $L_{parasitic}$ that depends on the ground quality and properties, e.g. the distance to ground. A high ground inductance results in a deterioration in the quality of the measured high-speed signal due to the frequency dependence of the common mode rejection. A ground connection is necessary to improve the common mode rejection ratio (CMRR) of the probe.

Application

The influence of the ground connection on differential measurements can be analyzed based on the setup in Fig.1:

- The USB drive is connected to the laptop
- The transmitting signal is detected by the R&S®RT-ZM60 modular probe, which is connected to the R&S®RTO2064 digital oscilloscope

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The first setup uses the ground connection in the tip module. In the second setup, no ground connection is made for comparison reasons to show the effect of this additional ground connection.

First the common mode of both setups (with/without ground connection) is measured, afterwards the differential voltage. The R&S®RT-ZM modular probe is an ideal choice because it allows you to switch between differential mode (DM) and common mode (CM) measurements without reconnecting or resoldering the probe.

Fig. 2 shows the CM voltage measurement result. The blue waveform represents the measurements with a ground connection (setup 1). The yellow waveform shows the measurements without a ground connection (setup 2). The peak-to-peak (PTP) and root mean square (RMS) voltage of the CM voltage are shown in the measurement result box "Meas Results" on the right, making it possible to compare the CM voltage of both measurements.

Comparison of CM voltage measurement results

Measurement type	With ground connection	Without ground connection	Ratio
Peak-to-peak (mean)	95 mV	123 mV	1.29
Root mean square (mean)	9 mV	12.3 mV	1.37

The PTP and the RMS measurement results of the CM voltage with a ground connection (PTP = 95 mV, RMS = 9 mV) are much lower than the measurement results without a ground connection (PTP = 123 mV, RMS = 12.3 mV). This means that a ground connection is necessary for accurate CM measurements.

The purple waveform in Fig. 3 is an example of the unpredictable and unknown influence if the ground of the probe is not connected. It represents the measurement without a ground connection (yellow waveform in Fig. 2) when the laptop is connected to the mains via the power supply. The purple waveform shows that now the switching frequency (approx. 55 kHz) of the power supply unit is also measured, which impacts the measurement result. The peak-to-peak measurement of the CM triples to 298 mV (PTP value in the 'Meas Results' box).

Fig. 1: Example of a differential probe measuring the transmitted USB 3.1 Gen 1 signal

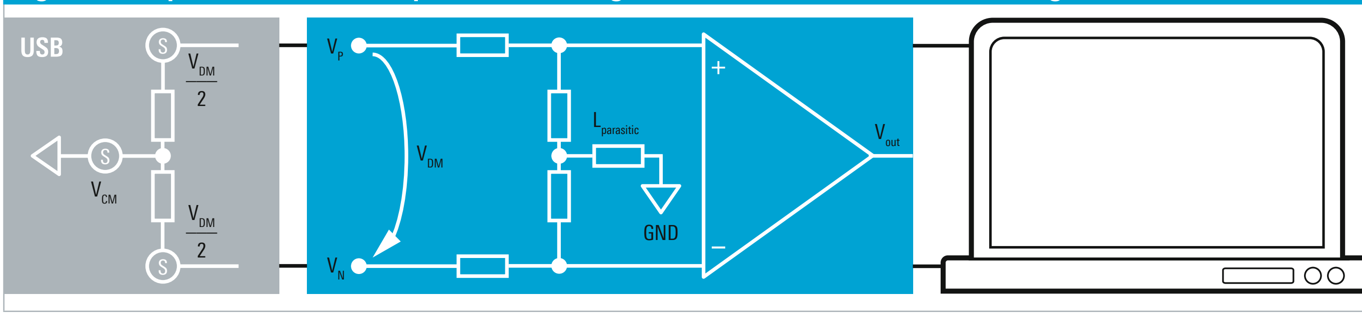
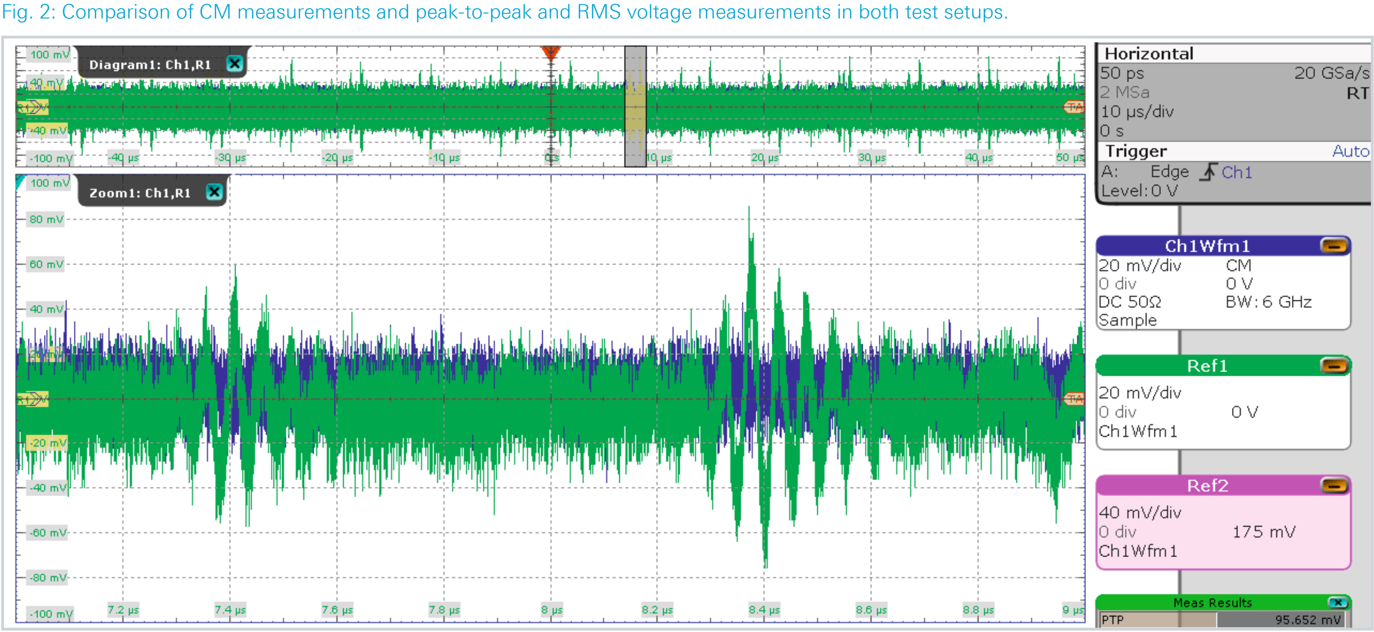


Fig. 2: Comparison of CM measurements and peak-to-peak and RMS voltage measurements in both test setups.



When the ground of the probe is connected, the mains connection of the laptop has no impact on the measurement results.

The results indicate that the probe ground connection also influences the differential voltage measurements.

To compare the same data pattern of both measurements, a protocol trigger for a serial bus is used. The blue waveform in Fig. 4 represents the measurement results with a ground-connected probe. The yellow waveform represents the measurement without a ground connection. The TIE jitter of the blue waveform is displayed in the green histogram at the bottom.

The RMS jitter of the setup with a ground connection corresponds to the standard deviation of the histogram σ = 10.8 ps (red arrow). Carrying out the same measurement on the yellow waveform results in an RMS jitter of σ = 14.5 ps, which is 34% higher. This correlates to the overshoots of the yellow waveform seen in the zoom window. These results show the better signal fidelity of the measurements when using a probe with a ground connection.

Summary

The R&S®RT-ZM modular probe offers special functions to perform DM, CM and single-ended measurements. Using a ground connection is essential for DM measurements because it prevents the circuit from floating and ensures stable and reproducible signals in the measurement range of the differential probe – especially for high frequencies. The ground connection also decreases the parasitic inductance, which should be as small as possible in order to maintain high signal integrity. Differential probes with connected ground can ensure high immunity to interference.

Fig. 3: CM voltage measurement without connection to ground when the laptop is connected to the mains.

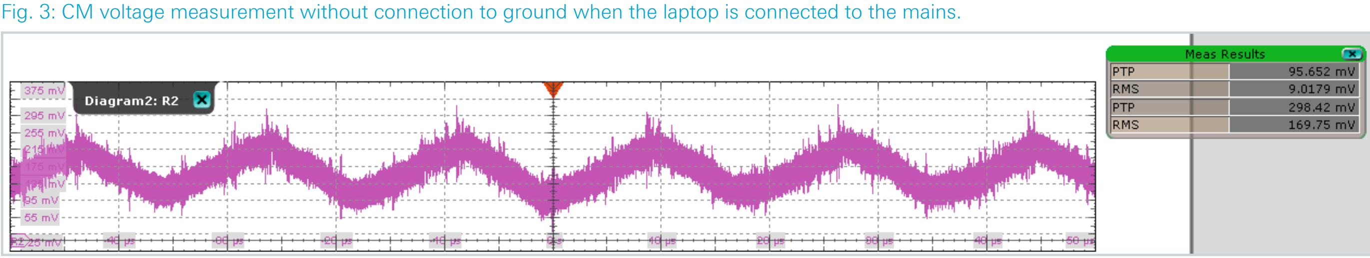
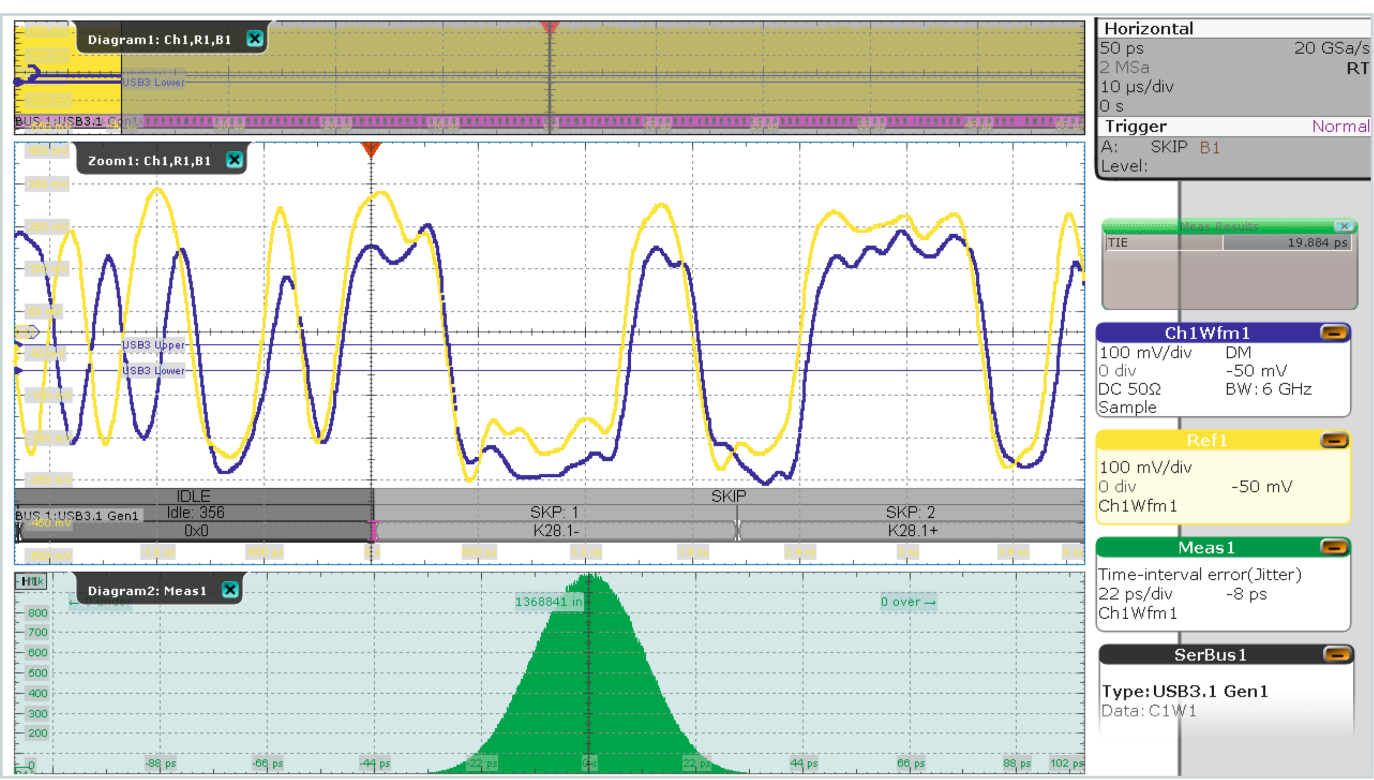


Fig. 4: Comparison of DM measurements.



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