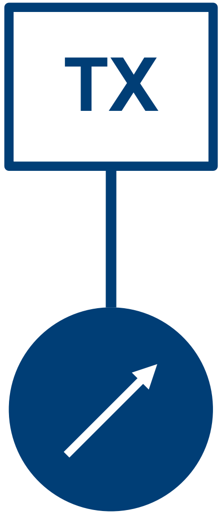
FUNDAMENTALS ON LOW- AND HIGH-VOLTAGE PROBING

ROHDE&SCHWARZ

Make ideas real

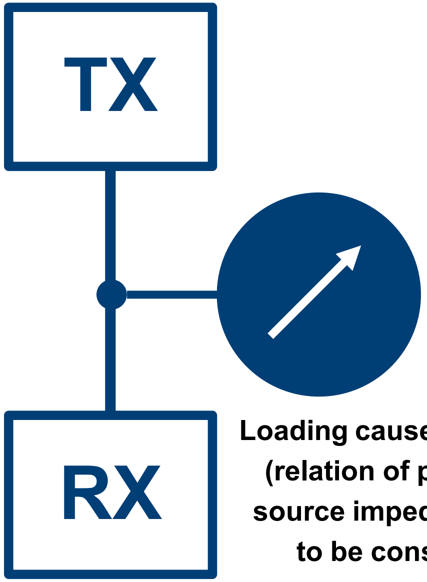
SCENARIOS OF SIGNAL CONNECTIONS

Scope connected directly



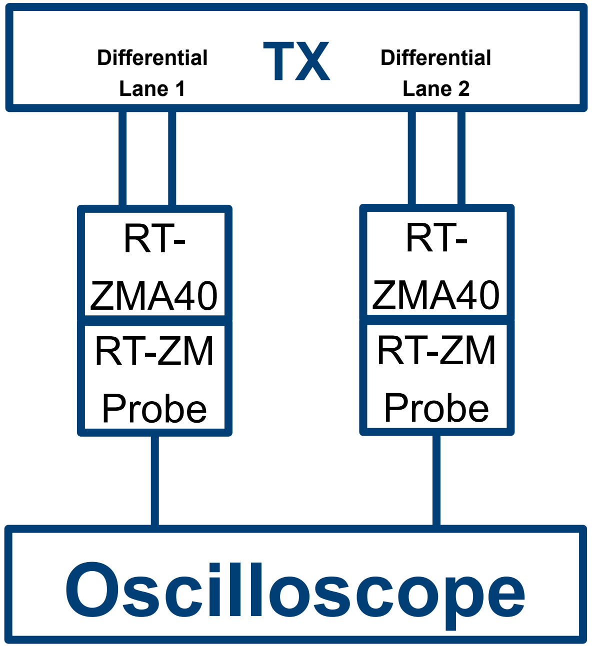
Oscilloscope terminates the signal

Probe used as midbus sniffer

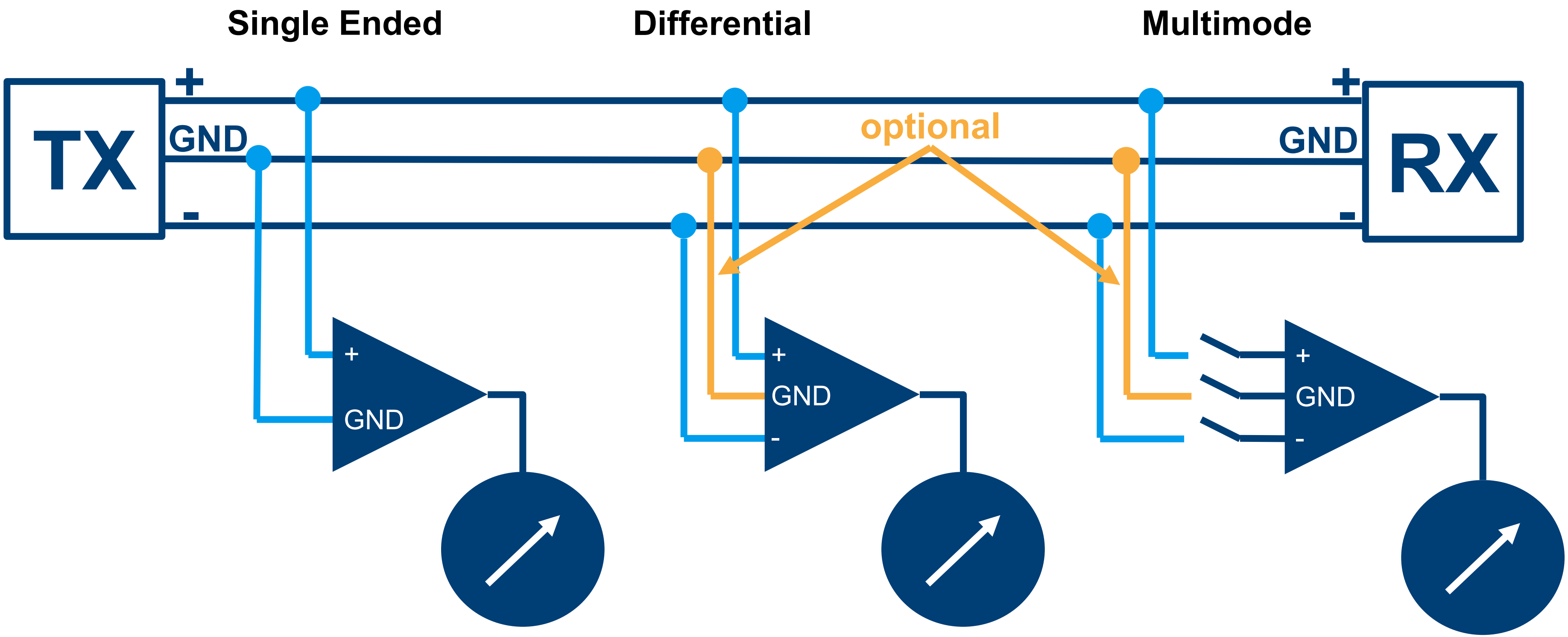


Loading caused by probe (relation of probe and source impedance) has to be considered

Probe used to terminate bus (Multilane differential signals)

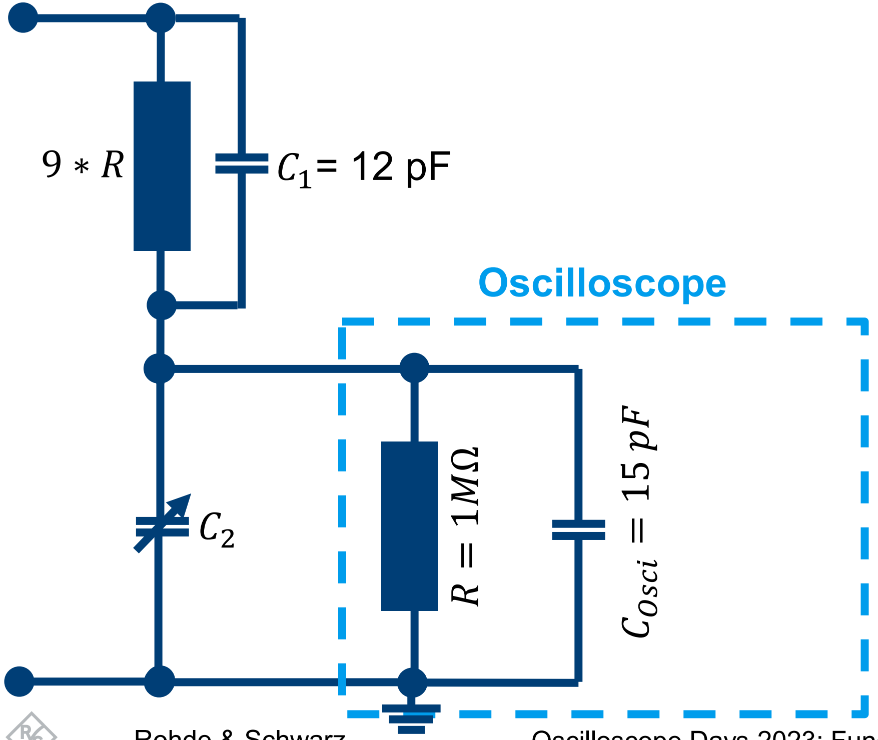


WHAT DOES SINGLE ENDED, DIFFERENTIAL AND COMMON MODE MEAN?

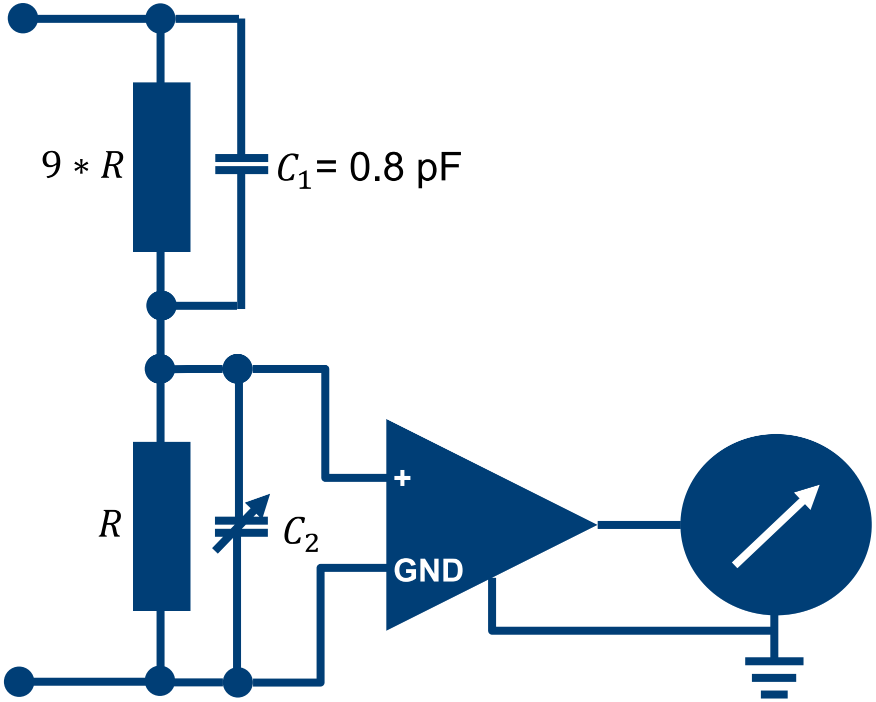


VOLTAGE PROBES
CAPACITIVE LOADING BY PROBE

10:1 Passive Probe e.g. RT-ZP10

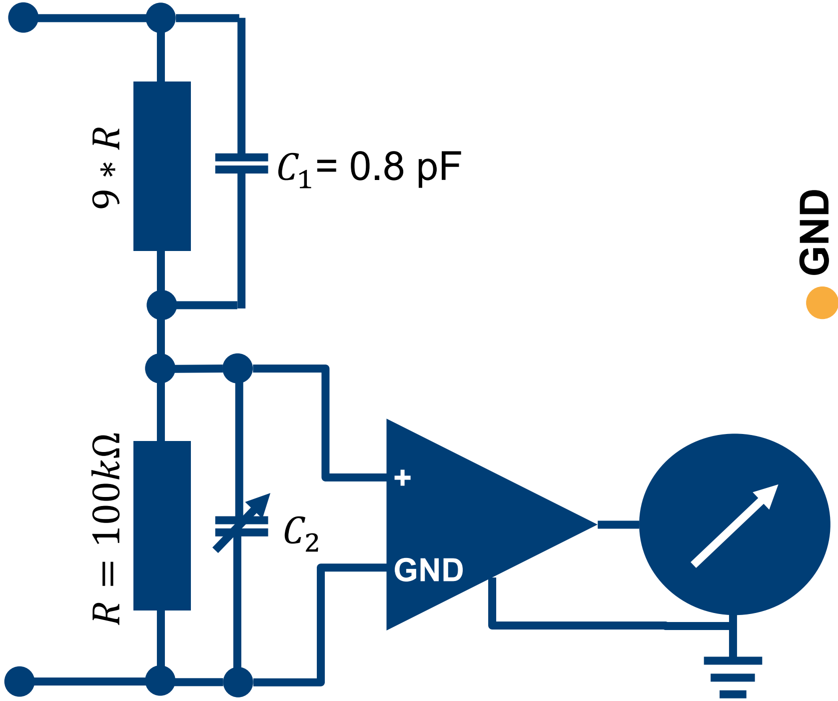


10:1 SE Active Probe e.g. RT-ZS10

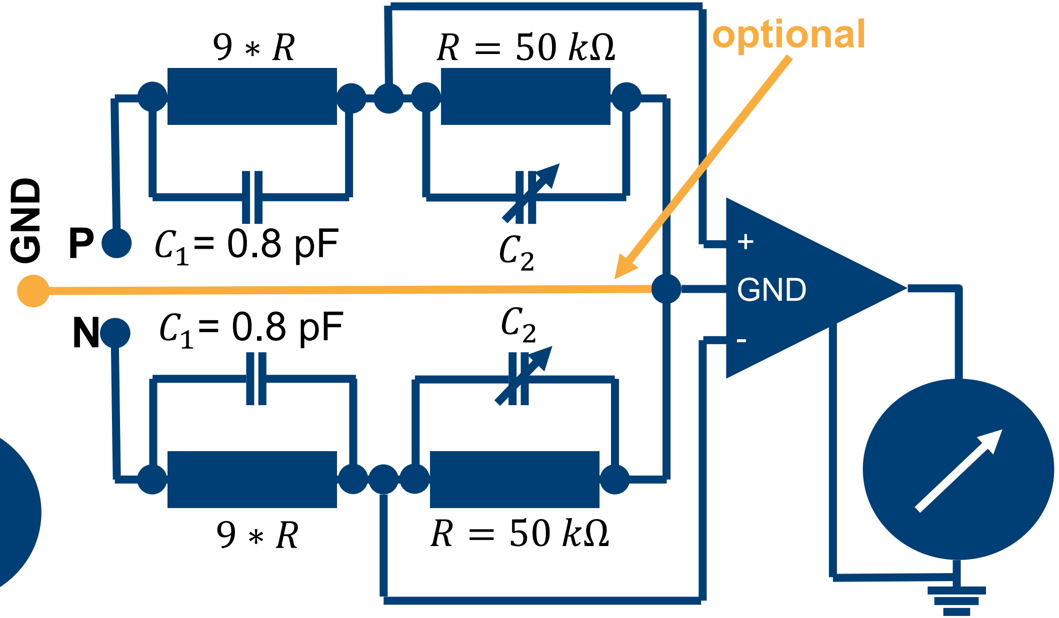


VOLTAGE PROBES
CAPACITIVE LOADING BY PROBE

10:1 Single Ended Probe e.g. RT-ZS10

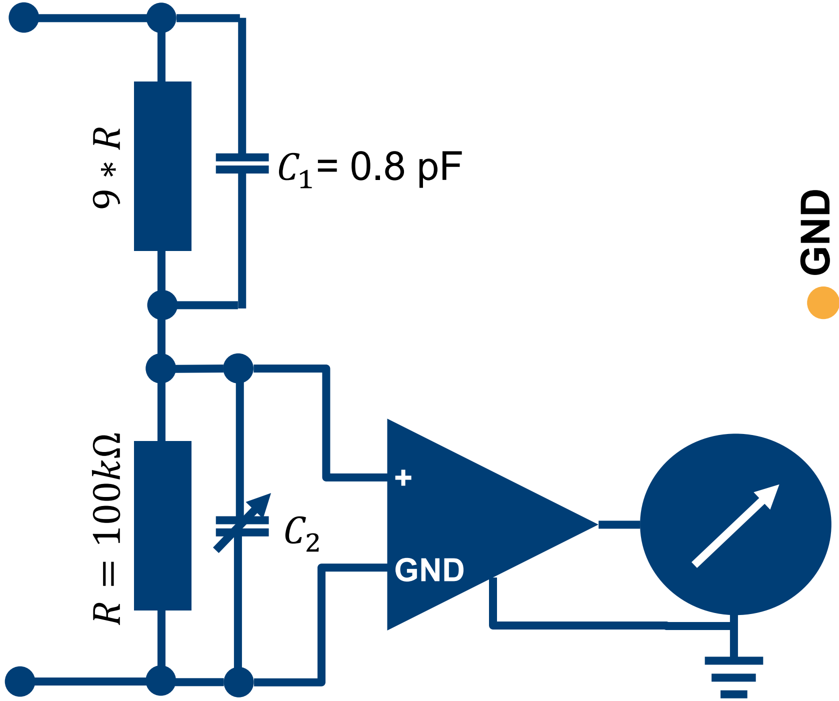


10:1 Differential Probe e.g. RT-ZD10

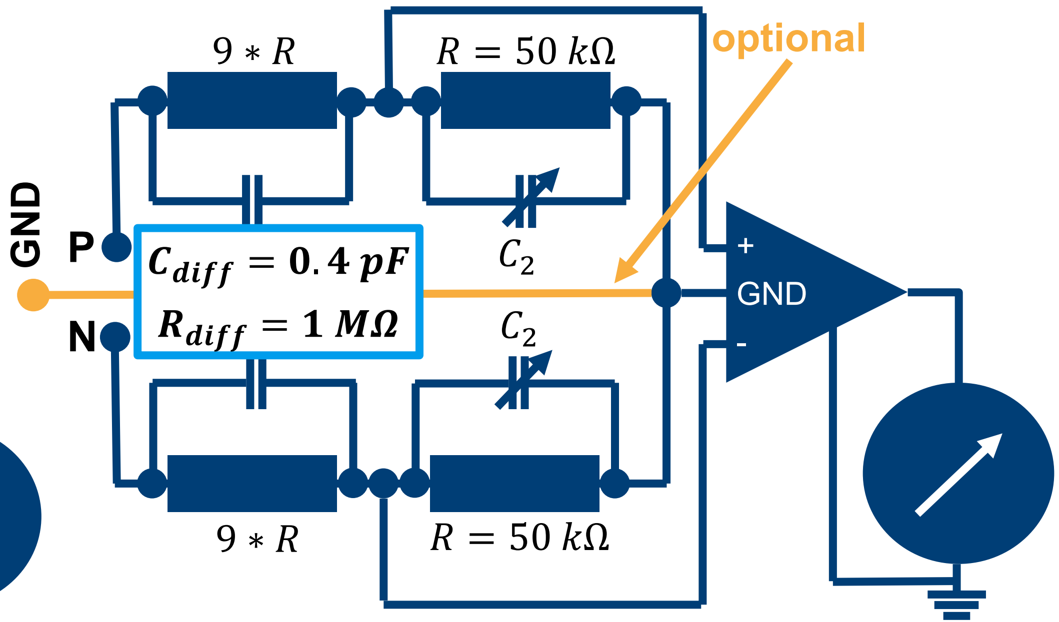


VOLTAGE PROBES
CAPACITIVE LOADING BY PROBE

10:1 Single Ended Probe e.g. RT-ZS10



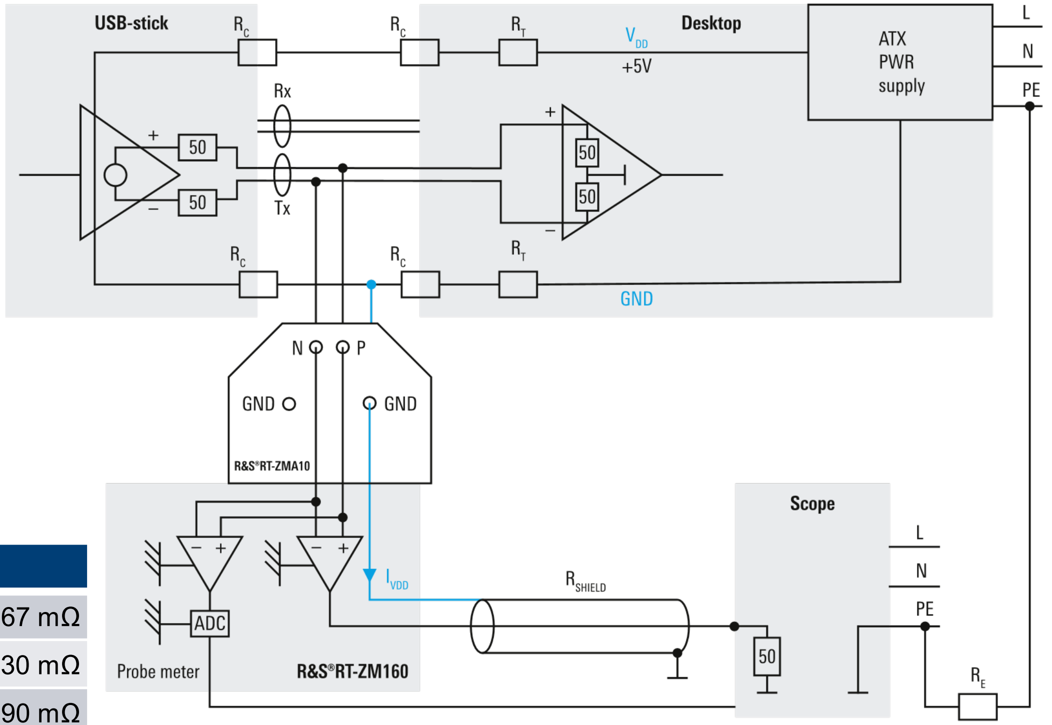
10:1 Differential Probe e.g. RT-ZD10



TO GND OR NOT TO GND?
EXAMPLE: ANALYSIS ON USB3 STICK

- Equivalent circuit diagram of scope, desktop and USB stick incl. Power Supply
- The USB spec gives an estimate about the GND resistance R_C and R_T in the desktop circuitry
- The probe shield R_{shield} can be estimated with 30 mΩ
- R_E is the resistive loading via PE

USB max supply resistance (ch 11.4.2)		
Host trace resistance	R_T	167 mΩ
Mated Connector resistance	R_C	30 mΩ
Cable resistance	R_W	190 mΩ



LIMITATIONS

- The probe amplifier need sufficient common mode range to tolerate this mode
- Inductive loading in the supply didn't play a role in this case, but might be significant
- Without GND, signal acquisitions of P, N, CM are impossible
  - Example – DDR memory measurements
  - For single ended measurements a kludge exists, connecting P to signal and N to GND
- Measuring the resistance between scope GND and USB shield with a DMM is problematic
  - Low resistance (<10mΩ) might move the DMM out of the defined measurement range
  - Potentially opens up a new path for the GND current
  - Disconnect the probe during the DMM measurement of R_E

TO GROUND OR NOT TO GROUND, THAT IS HERE THE QUESTION – HOW TO CONNECT YOUR PROBE

High-speed serial interfaces often transmit data with differential signaling and differential probes can be used to access signal traces. In addition to differential inputs, these probes have a ground connection.

One important question when connecting R&S®RT-ZMxx modular multimode probes is whether or not to connect the probe ground (GND) to the device under test (DUT).

Rohde & Schwarz solution
The R&S®RTP high-performance oscilloscope is an ideal, one-box solution for high-speed digital interface testing. R&S®RT-ZMxx modular probes together with a wide range of probe tips (R&S®RT-ZMAxx) and accessories can help you easily access data signals and master mechanical and electrical connection challenges for increased measurement confidence.

Application
When testing high-speed digital interfaces, the circuit connection is crucial to measurements. First you need to decide whether to analyze a host-to-device (or vice versa) data signal or to test for compliance. When a[illegible]zing a host-to-device data signal, a R&S®RT-ZM160 [illegible] can be used to tap the live signal. Complian[illegible] [illegible]ting [illegible]quires a standard-complaint test fixture tha[illegible] signal using standard 50 Ω e[illegible] [illegible]able, connector, balloon, …).

This app card looks at data signal analysis for a conventional USB 3.2 generation 1 memory flash drive. After checking all the parameters, such as bandwidth, operating voltage window and loading, take the R&S®RT-ZM160 and a R&S®RT-ZMA10 probe tip and solder the probe tip (see Figure 1) with P, N, GND to the USB interface on [illegible] memory flash drive (TX port) and connect the flash drive [illegible] a desktop computer.

Figure 1: R&S®RT-ZMA10 solder-in [illegible]

N
P
GND
5 mm

Application Card
Version 01.00

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Make ideas real

IMPEDANCE PROFILE OF A PROBE

- For low frequencies R_{Source} dominates
  → For amplitude error at DUT smaller 10%

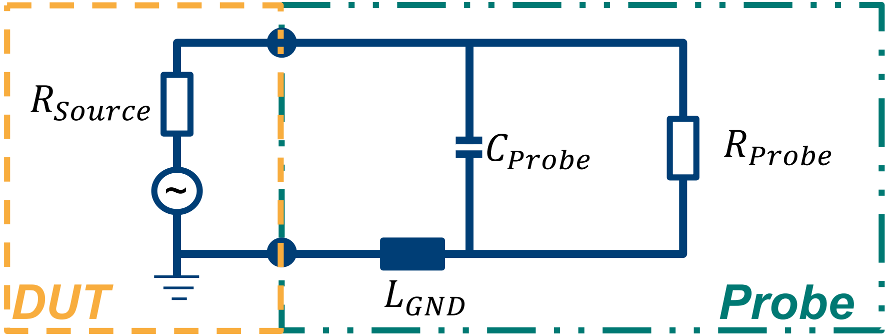
$$R_{Probe} \geq 10 \times R_{source}$$

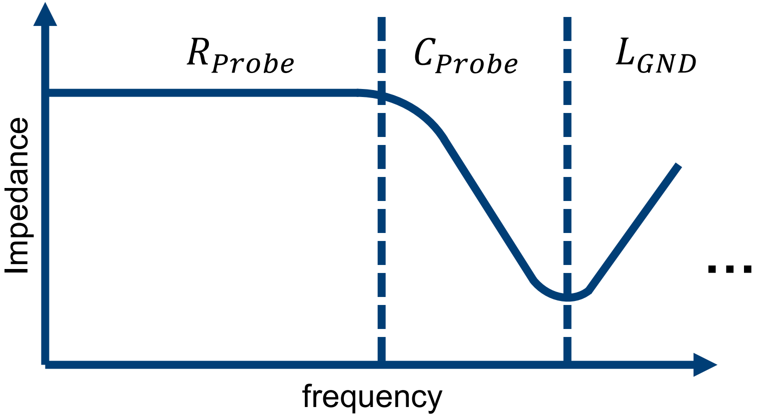
- For mid frequencies C_{Probe} dominates:
  - 1st resonance frequency will be reached at

$$f_{res} = {}^{1}\!/_{2\pi\sqrt{L_{GND}C_{Probe}}}$$

  - Reduce (stray) capacitances for high bandwidth probes

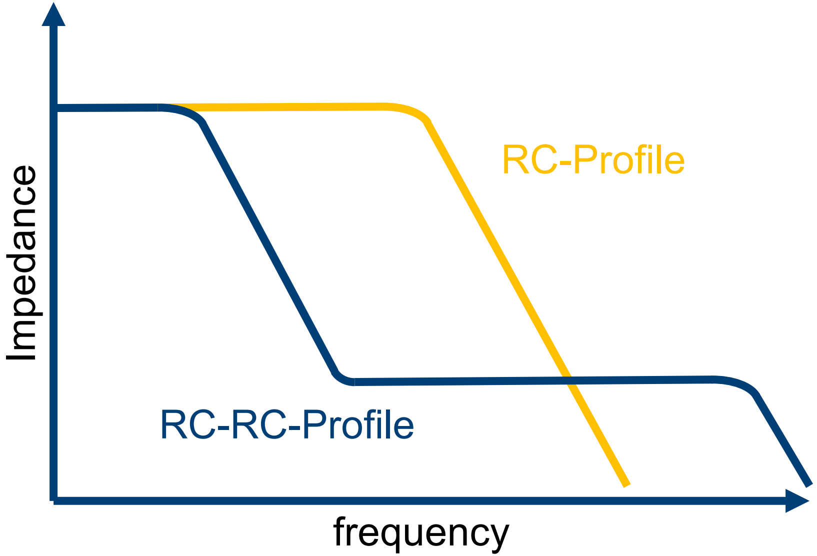
- For higher frequencies L_{GND} dominates:
  → Ground loops shall be as short as possible.
  → As rule of thumb, each mm additional GND loop length adds 1 nH mutual inductance.





RC- VS. RC-RC-IMPEDANCE PROFILE

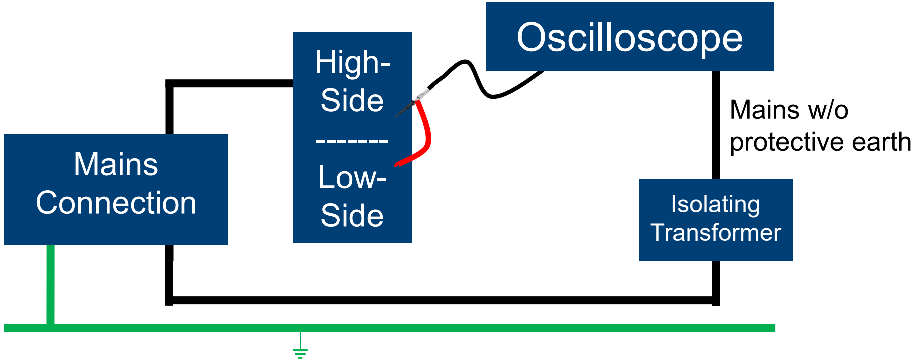
- Loading of the DUT is directly related to the probes input impedance profile.
- If DUT switches between low and high impedance states, loading will vary in dependency of probes input impedance profile.
- RC-Profile:
  - High impedance for low and mid frequencies.
  - Frequency range is limited by 1^{st} f_{res}.
- RC-RC-Profile:
  - High impedance for low frequencies.
  - Second resistive plateau for mid frequencies.
  - Higher impedance than RC for high frequencies.
  - Typical characteristic for high bandwidth probes.

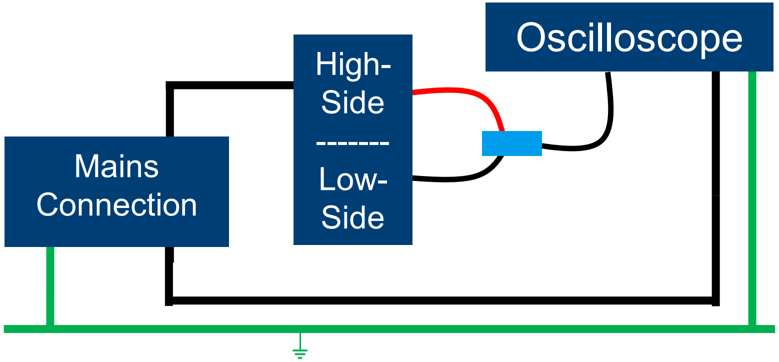


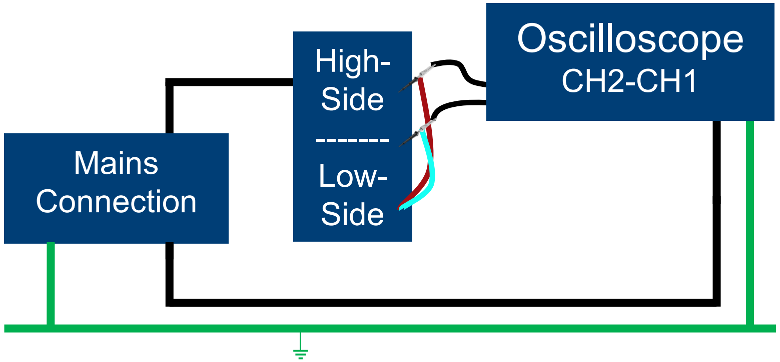
How to connect and what can you expect?

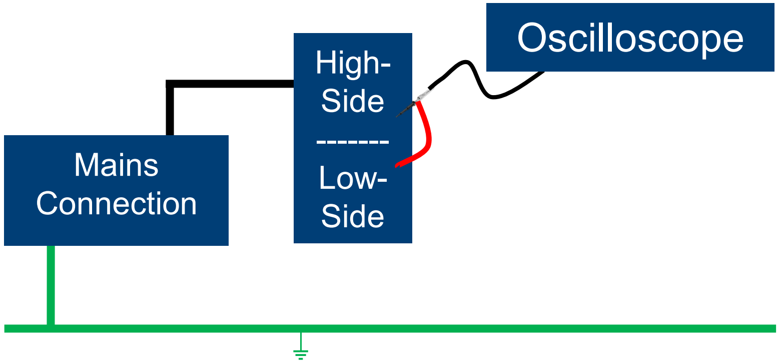
PROBING IN HIGH VOLTAGE POWER APPLICATIONS

FLOATING MEASUREMENT TECHNIQUES









FLOATING MEASUREMENT TECHNIQUES

Floating Scope using isolating Transformer:

- Oscilloscope Ground provided by DUT and can differ from 0 V.
- All grounds are at the same level.
- Potential risk for electrical shock when touching the system.
- Stray capacitances and inductances of the setup can influence measurement results

High-Voltage Differential Probe:

- Can accurately measure small differential voltages in the presence of large common-mode voltages up to thousands of volt.
- High input impedance on both inputs to minimize loading and measurement errors.
- Bandwidth limited to typ. 200 MHz

2 Single-ended Probes + Math-function:

- Scope inputs can be overdriven easily.
- Vertical resolution is limited by offset range and divider ratio of the probe.
- Probes must be compensated against each other to achieve good results.
- In most cases: 2 probes of the same type have to be used, otherwise no compensation possible.

Isolated Channel oscilloscope:

- Isolated input has no direct electrical connection to earth ground.
- Great DC & low frequency CMRR.
- Bandwidth up to 500 MHz.
- Isolated probes are not true differential

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Not recommended

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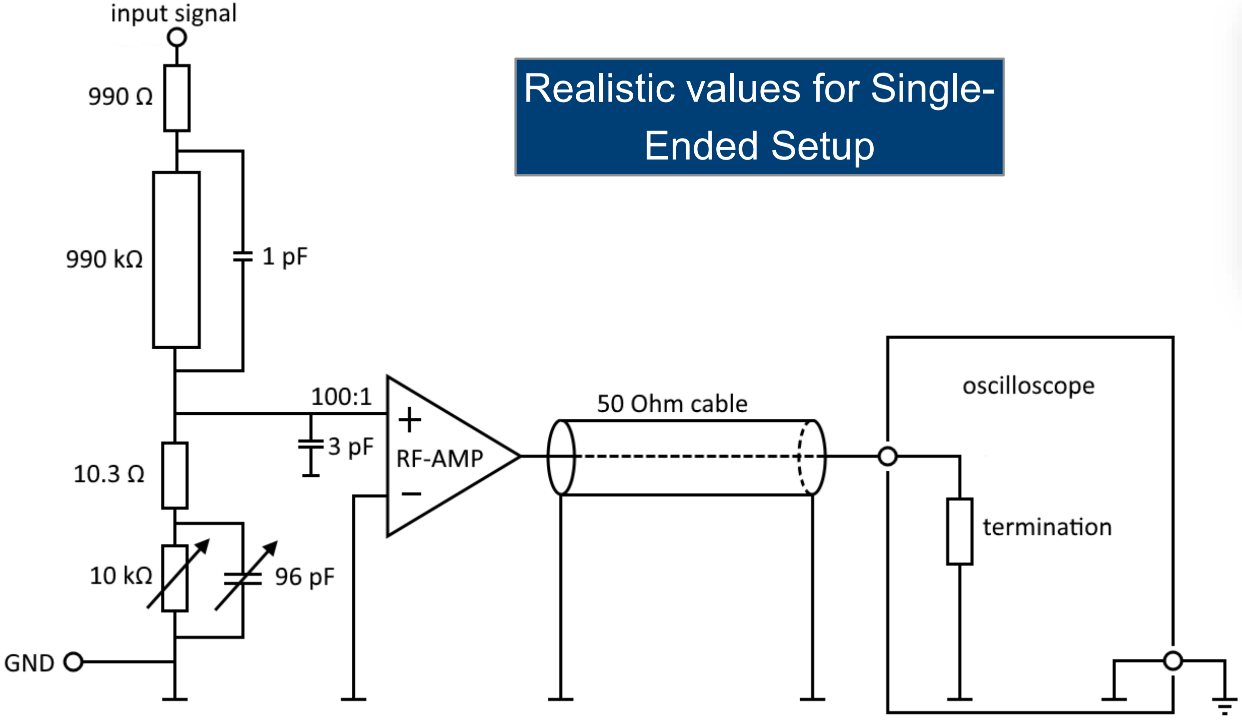
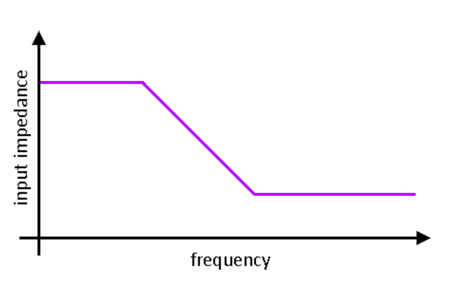
CONSTRUCTION OF A HIGH VOLTAGE DIFFERENTIAL PROBE

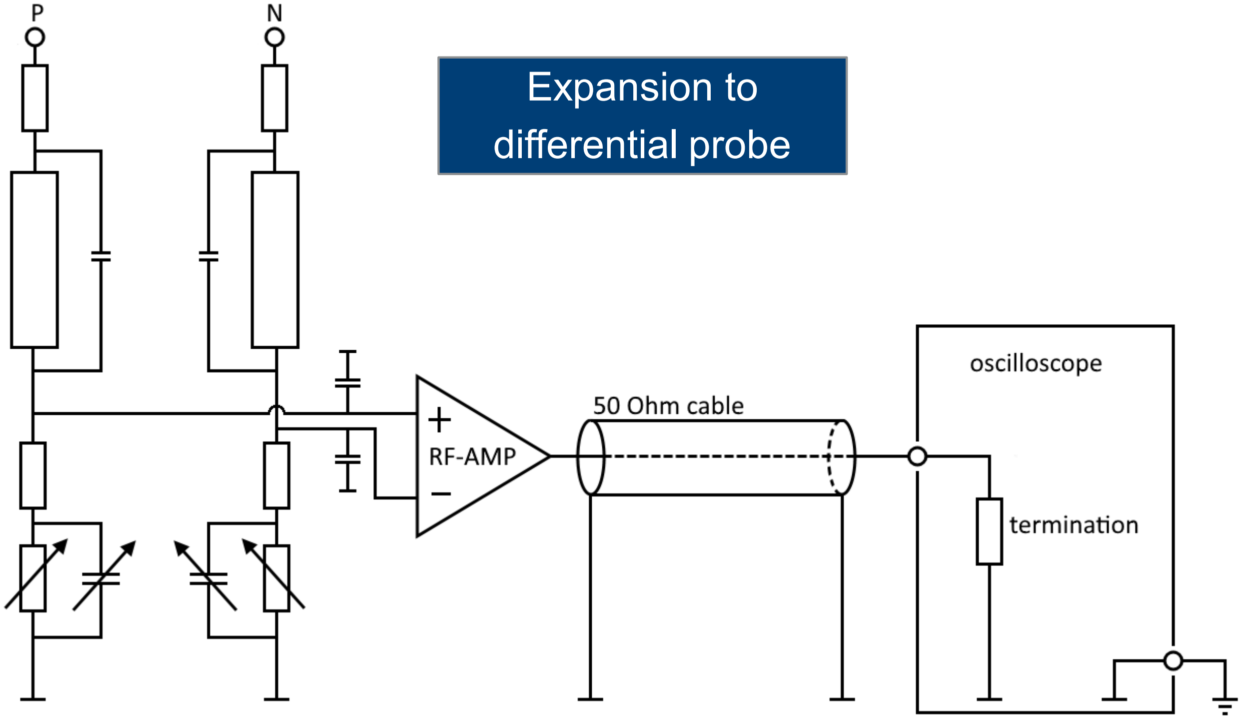


Realistic values for Single-Ended Setup



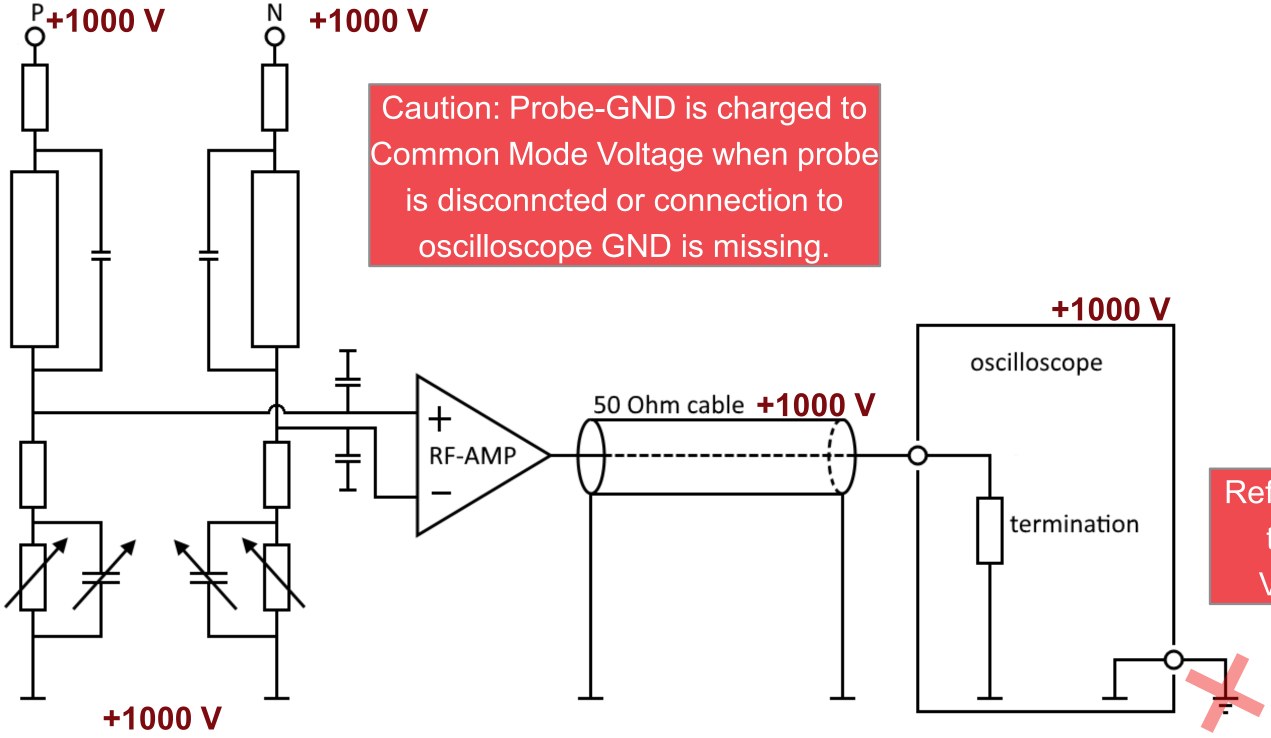
CONSTRUCTION OF A HIGH VOLTAGE DIFFERENTIAL PROBE

Expansion to differential probe



SECURITY AND DATASHEET VALUES

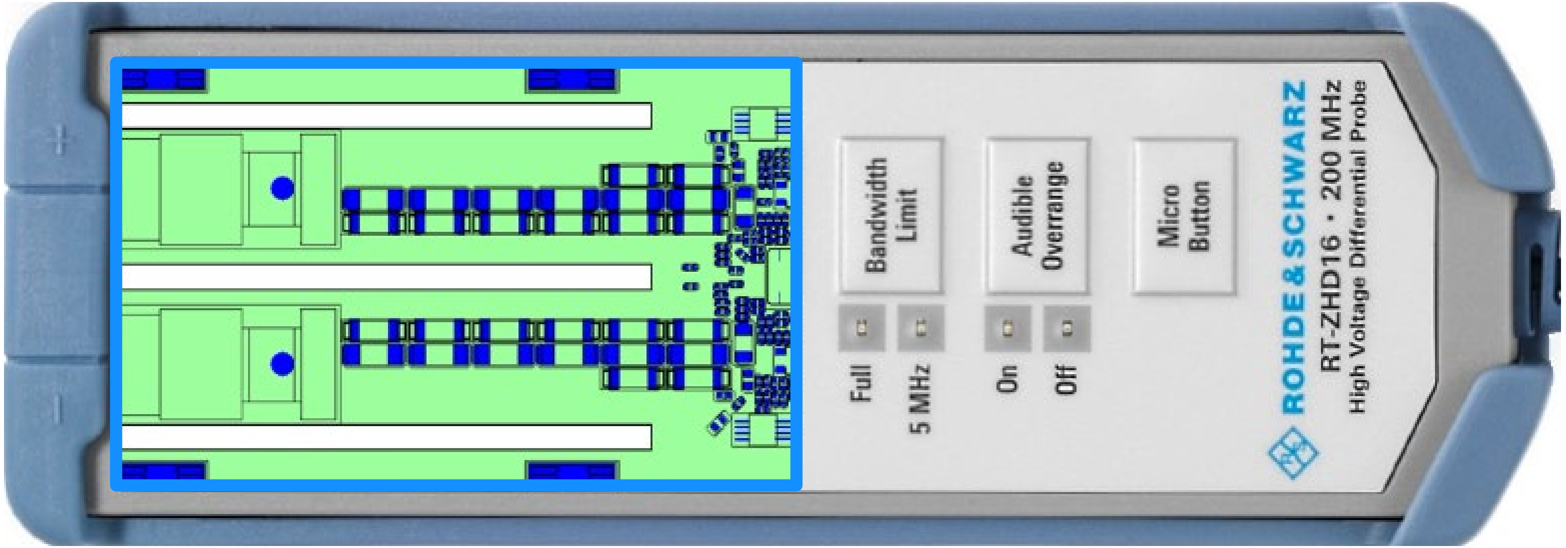
WHY IS IT IMPORTANT TO GND YOUR OSCILLOSCOPE?



Caution: Probe-GND is charged to Common Mode Voltage when probe is disconncted or connection to oscilloscope GND is missing.

Ref-Potential is charged till Common Mode Voltage is reached.

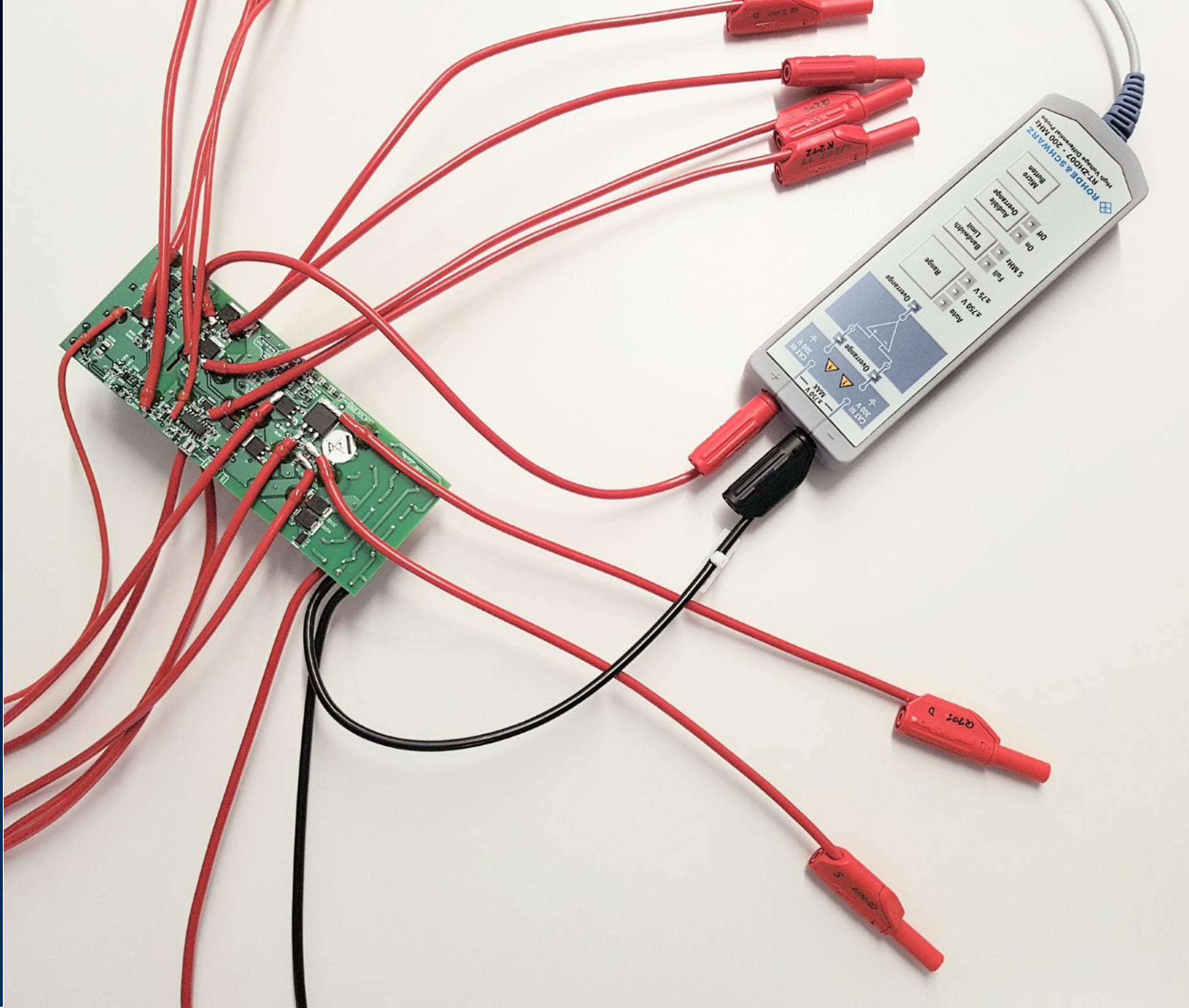
CONSTRUCTION OF A HIGH VOLTAGE DIFF PROBE



Approx. Half of the PCB area is needed to ensure safety and prevent discharges inside the probe

HOW TO CONNECT

- Twisted or untwisted
- Length of meas. leads
- Type of accessory



HOW TO CONNECT

Twisted or untwisted

Usually the best option

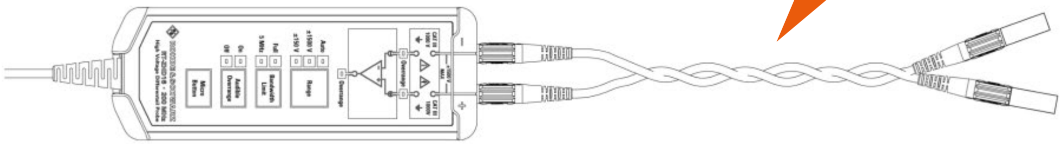


Figure 2-5: Leads, twisted

pro	interferers are minimized
con	greater load on the measuring point

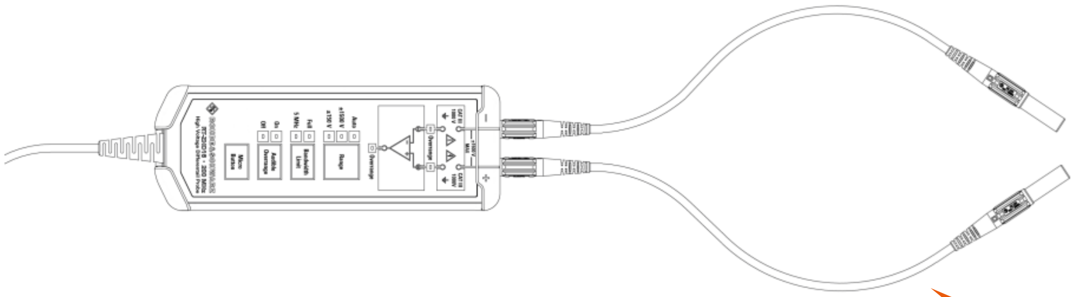


Figure 2-4: Leads, untwisted

pro	minimizes the capacitive load on the measuring point
con	interferers are looped in

Only recommended if the loading of probe is the biggest problem

HOW TO CONNECT

Twisted or untwisted

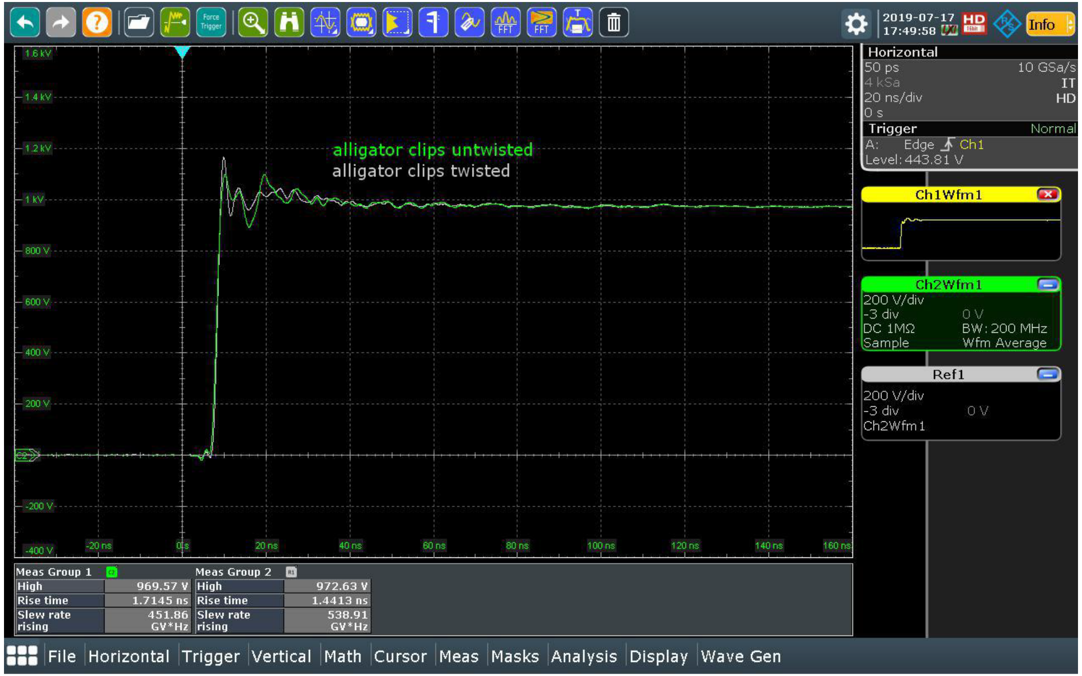
single ended input capacitance of an RT-ZHD16
P or N to GND without meas. lead: **3.5 pF**

	RT-ZHD16 + meas. leads	**RT-ZHD16 + meas. leads + alligator clips**
untwisted	9 pF	10 pF
twisted	12 pF	15 pF

Rule of thumb:
The differential input capacitance is approx. half the single ended capacitance.

HOW TO CONNECT

Twisted or untwisted with BW = 200 MHz



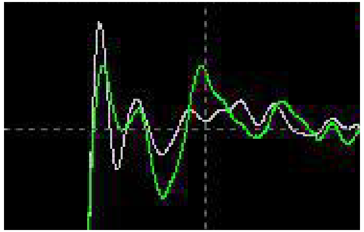
Input signal:

Vin = 970 V / tr =100 ps

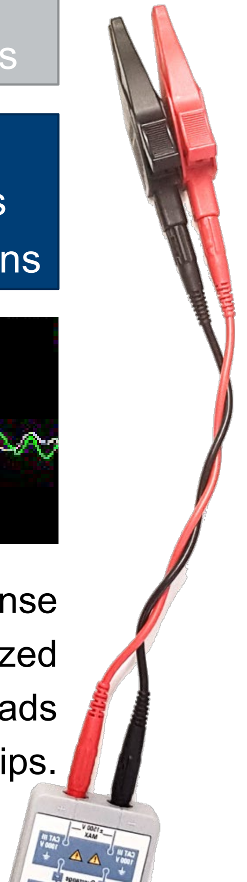
Output signal:

rise time = 1.4 - 1.7 ns

slew rate = 452 - 540 V/ns

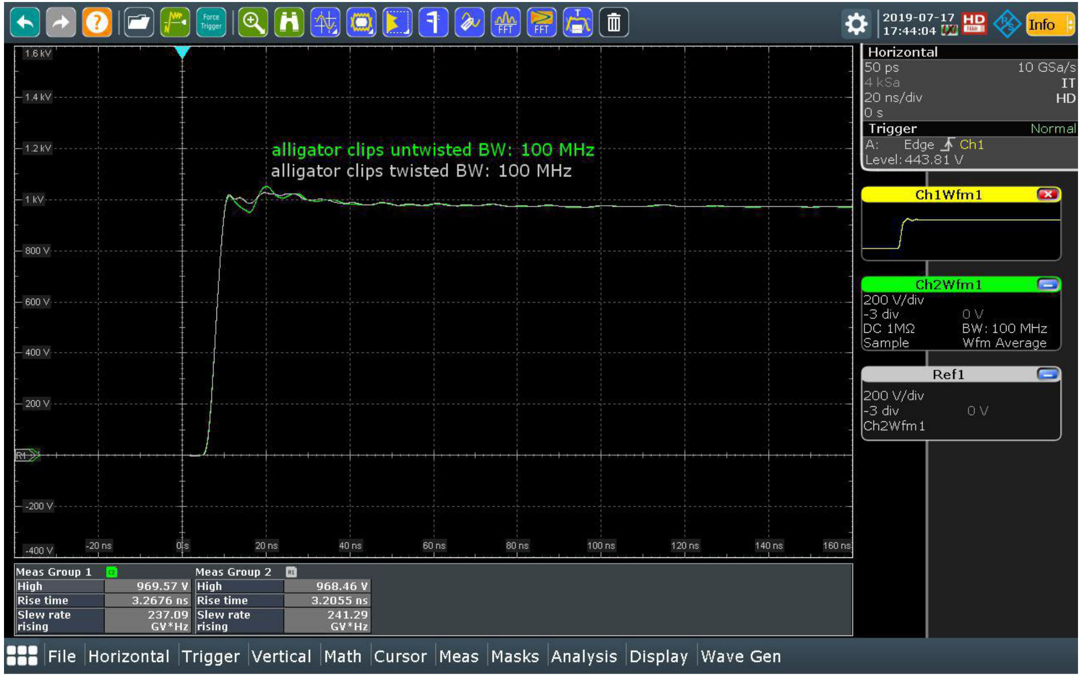


The impulse response of the probe is optimized for twisted test leads with alligator clips.



HOW TO CONNECT

Twisted or untwisted with BW = 100 MHz



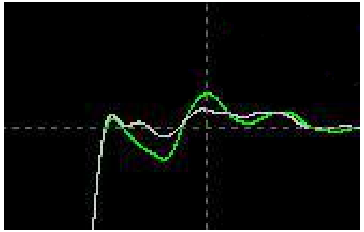
Input signal:

Vin = 970 V / tr =100 ps

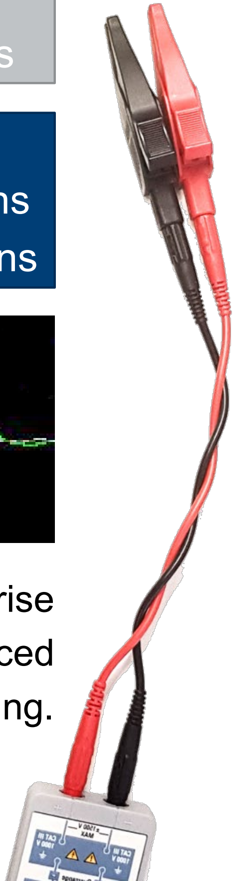
Output signal:

rise time = 3.20 – 3.27 ns

slew rate = 237 - 241 V/ns



Signals with slower rise times are less influenced by the type of probing.



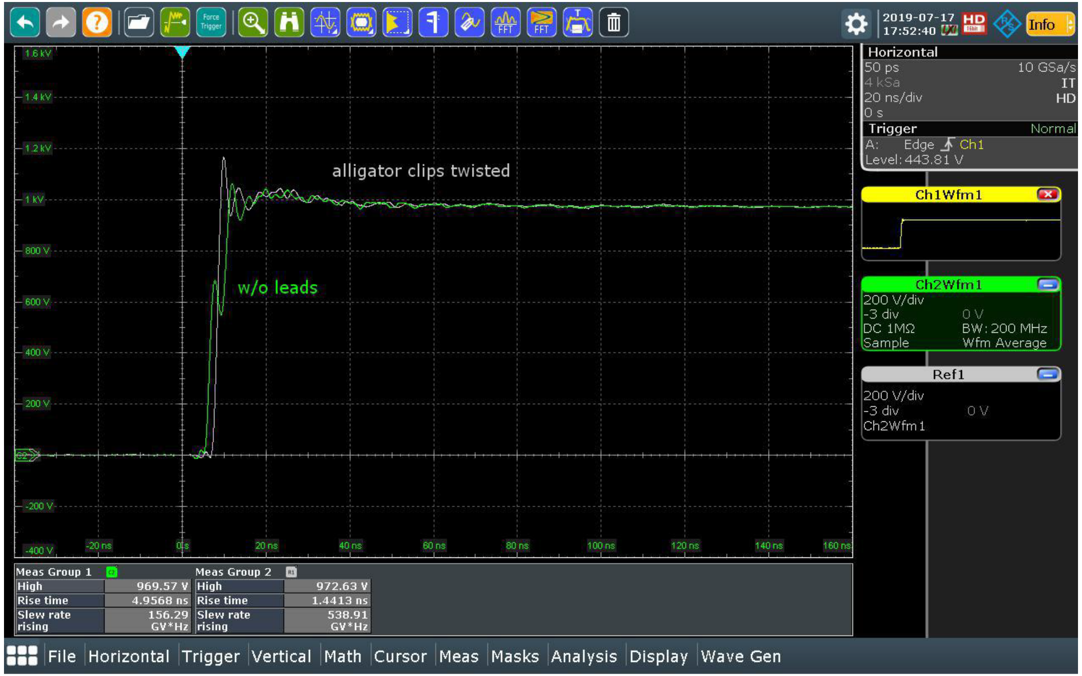
HOW TO CONNECT

Bananas are not suitable for RF, but

Input signal:

Vin = 970 V / tr =100 ps

Length of measurement leads 200 MHz



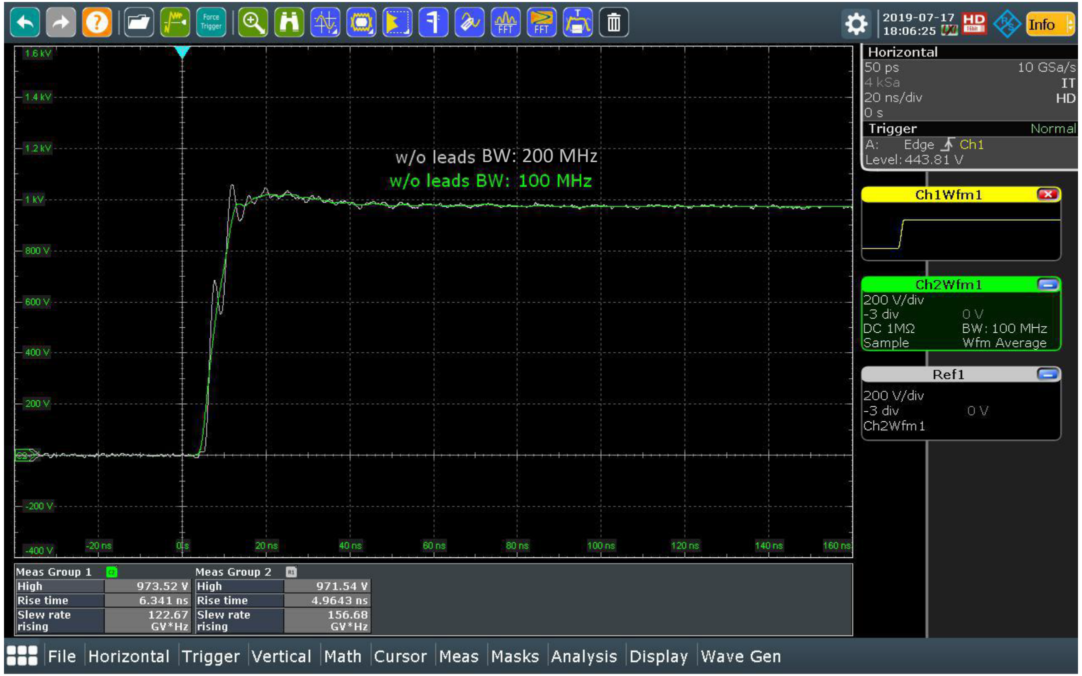
The standard test leads (17 cm) are compensated in the probe head!

Shorter or longer meas. leads cause measurement errors.

RT-ZHD w/o leads

HOW TO CONNECT

Length of measurement leads 100 MHz



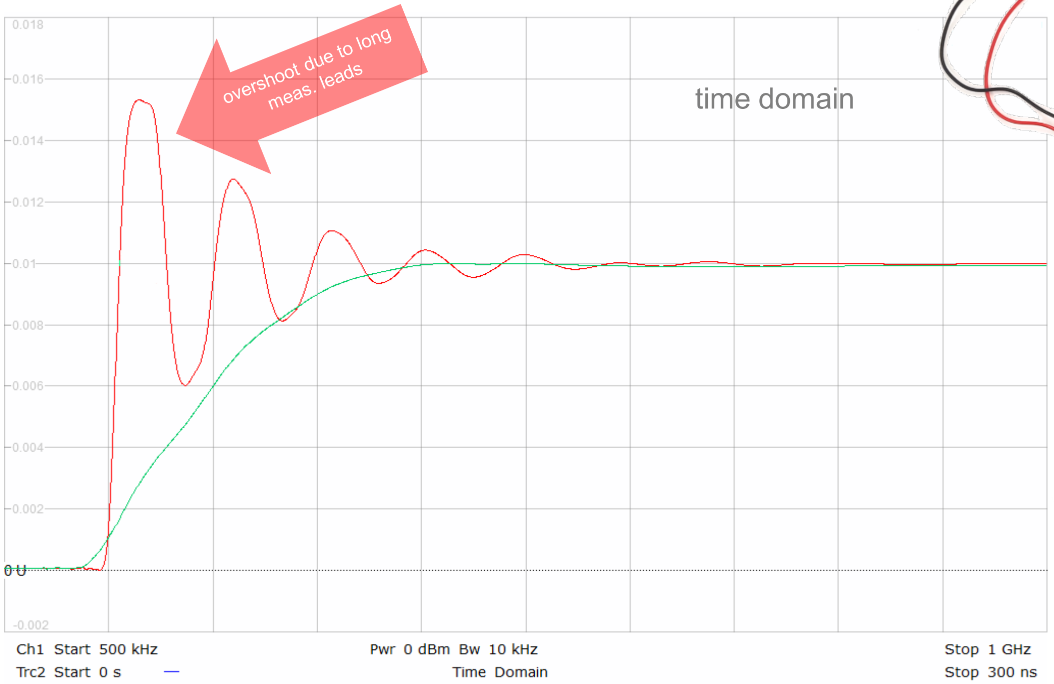
Input signal:
Vin = 970 V / tr =100 ps

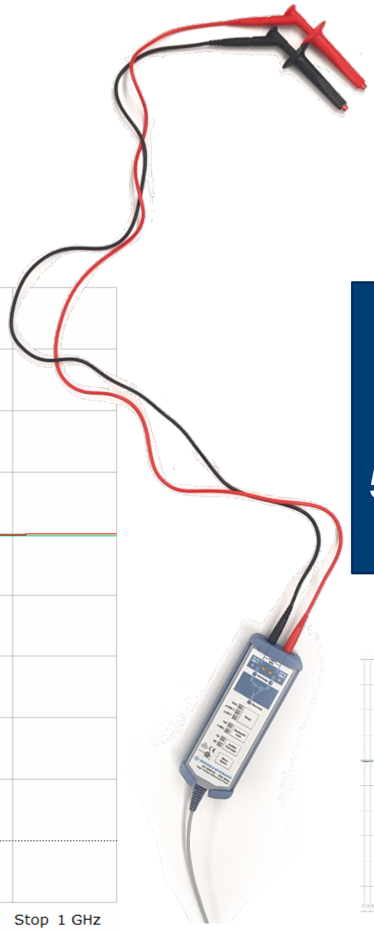
For input signals with a rise time slower than 6 ns, longer or shorter test leads can also be used

RT-ZHD w/o leads

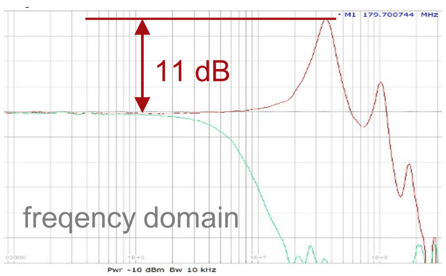
HOW TO CONNECT

Length of measurement leads 1 m



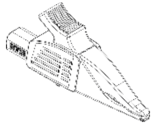


But:
When using very long test leads (1 m), the 5 MHz low pass should be switched on.



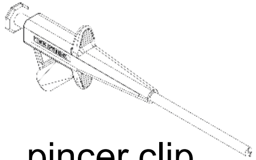
HOW TO CONNECT

Type of accessory



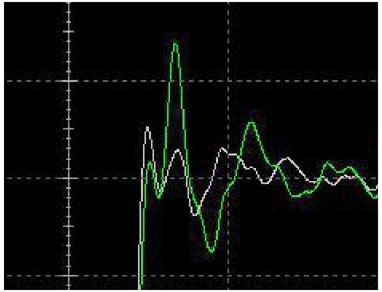
alligator clip

VS



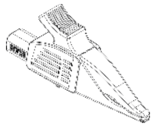
pincer clip

Accessory definitely has an influence on measuring accuracy (at full bandwidth, i.e. 200 MHz)



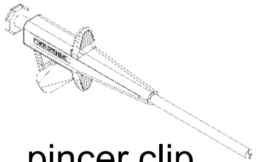
HOW TO CONNECT

Type of accessory

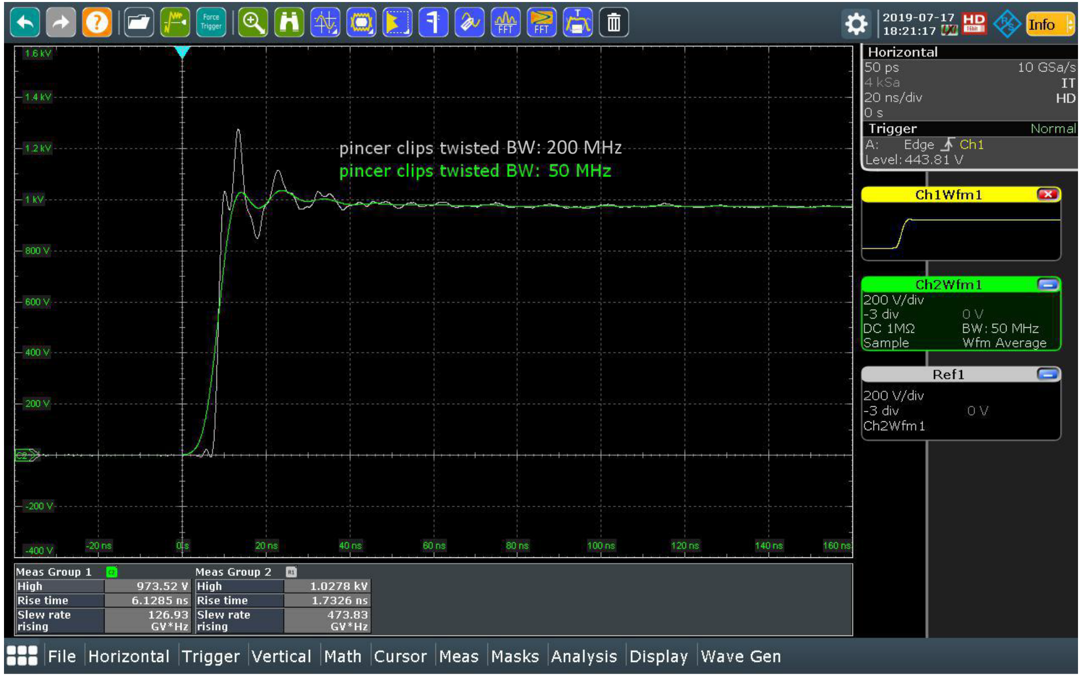


alligator clip

VS



pincer clip



However, the influence only becomes visible when the input signal has the necessary rise time.

For an input signal with a rise time of 6 ns the influence of the pincer clips are negligible.

WHAT CAN YOU EXPECT

- CMRR
- Noise
- DC accuracy
- Overshoot and slew rate

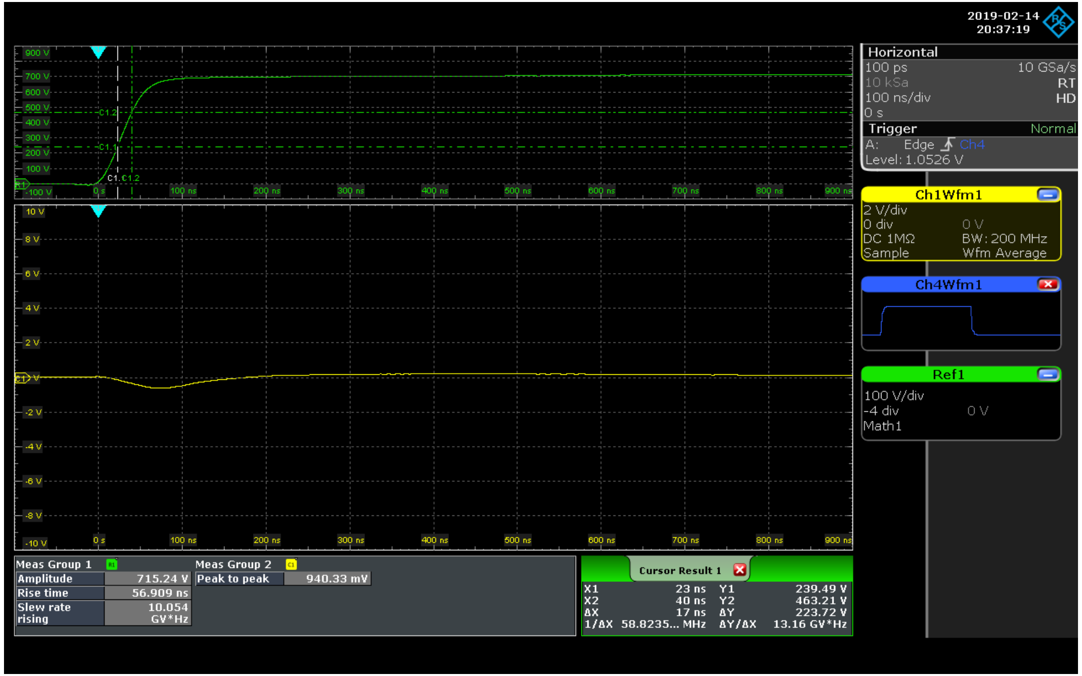
WHAT CAN YOU EXPECT

CMRR (Common Mode Rejection Ratio) up to 200 MHz

Signal on both inputs:
0 V -> 1000 V in 1.9 ns
measurement error ±10 V

WHAT CAN YOU EXPECT

CMRR (Common Mode Rejection Ratio)

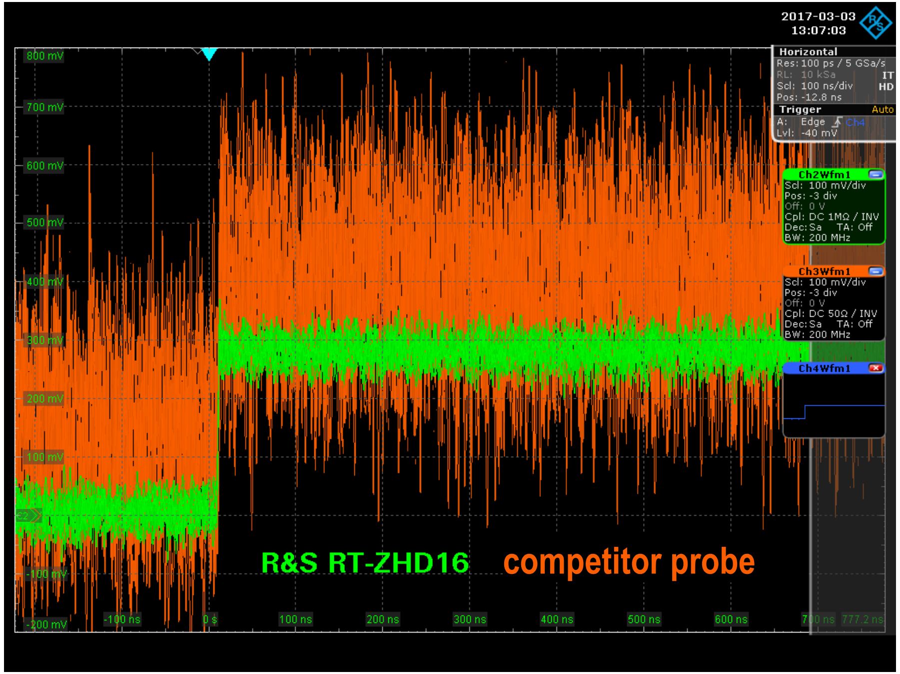


Signal on both inputs:
0 V -> 700 V in 60 ns
measurement error
lower than 1 V

Suitable for high side gate measurements in applications with slew rates up to 10 V/ns

WHAT CAN YOU EXPECT

Noise



Input noise
(RMS, BW = 200 MHz)
Competitor = 117 mV
RT-ZHD16 = 23 mV

Enables a stable trigger on a 300 mV signal with a 1.5 kV probe and 200 MHz bandwidth

THANK YOU FOR YOUR ATTENTION

For questions please come back to us using
Sales.germany@Rohde-Schwarz.com

ROHDE & SCHWARZ

Make ideas real