TIPS AND TRICKS FOR ACCURATE HIGH VOLTAGE MEASUREMENTS

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ROHDE&SCHWARZ
Make ideas real

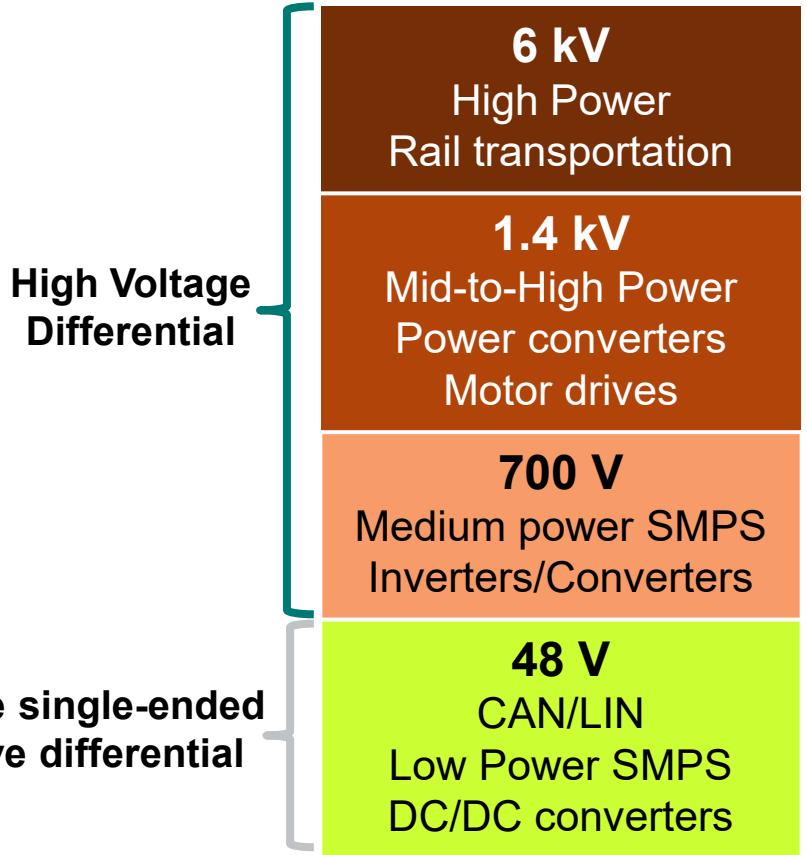
OBJECTIVE

- Overview of voltage probes including pros and cons
- Key characteristics for selecting a high voltage differential probe for power applications
- Understanding the effects of cabling and connectors on power measurements

INTRODUCTION TO VOLTAGE PROBES

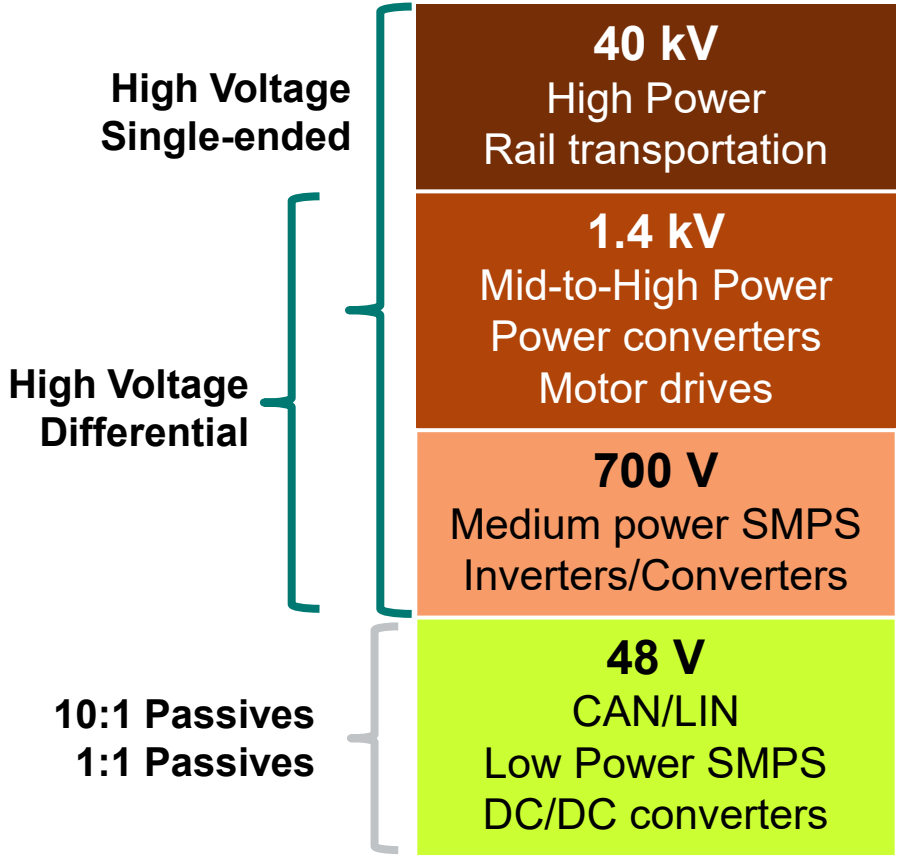
MEASURING VOLTAGE WITH ACTIVE PROBES

- Measurements
  - Gate drives, switchers, current sense, filters, and transformer
  - Applications such as inverters, converters, transportation, LED's, motor drives, and more
- Lower voltage applications have 50Ω input
  - Typically higher bandwidth
  - Lower probe loading
- High voltage differential probes with native interface are 1 MΩ
- Differential and single-ended
- Typically higher cost
- Scope vendor specific
  - Minimal setup is required



MEASURING VOLTAGE WITH PASSIVE PROBES

- 1 Meg Ohm input
  - Typically lower bandwidth
  - Higher probe loading
- Differential and single-ended
- Lower cost
- Typically scope agnostic
  - May require more setup time
- Connecting to the DUT is typically more convenient

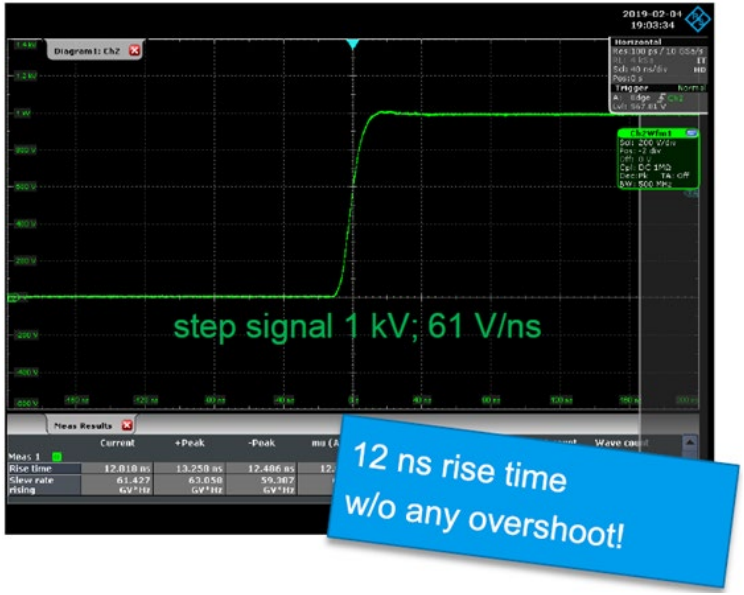


HIGH-VOLTAGE DIFFERENTIAL PROBES: RT-ZHD FAMILY

- **One of two major T&M vendors that designs and manufactures their own high voltage differential probes**
  - Not artificially peaked to get the performance
  - R&S is the only vendor to warrant their specifications using high voltage test signals
    - Other vendors use small signals and list the spec as typical
- Up to **200 MHz** models and **6000 Vpeak**
- Lowest **noise** in industry
- **Up to 2000 V Offset Compensation**
  - Independent of probe attenuation factor or vertical scale
- **Excellent DC Accuracy: 0.5%**
  - Integrated DC Voltmeter with 0.1% Accuracy
  - Very low drift
- **High CMRR**
- **Overrange Indicator**

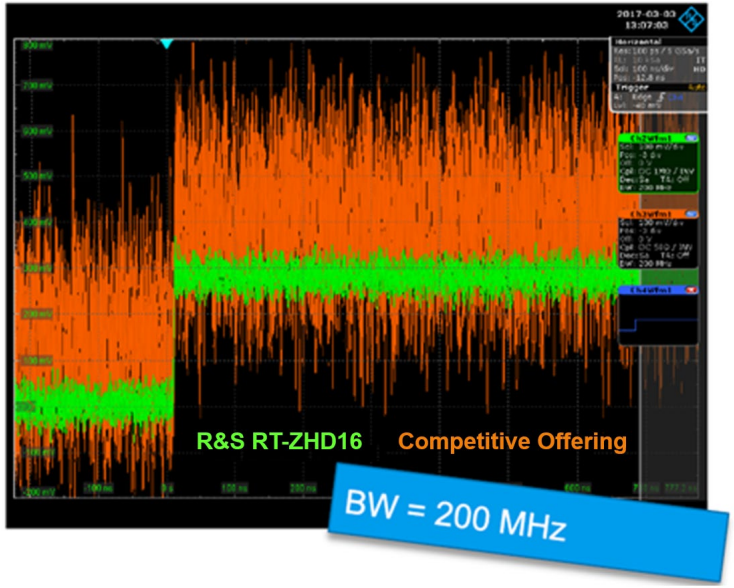
SOURCES OF MEASUREMENT ERROR
PEAKED STEP RESPONSE

- R&S tests and documents rise time using a 1 kV step response signal with 20 ns rise time
- Be cautious about how T&M vendor's specify rise time
  - Vendors will test and document the probe's rise time using a small signal (generally less than 20 V)
    - Why don't they use a fast, high voltage step?
  - Artificially peaking the front edge to get the rated performance
    - The "hump" at the front corner is an artifact of artificially increasing the gain to "boost" the performance.
  - The signal content of interest is at the front edge
    - Manipulating the front corner decreases accuracy



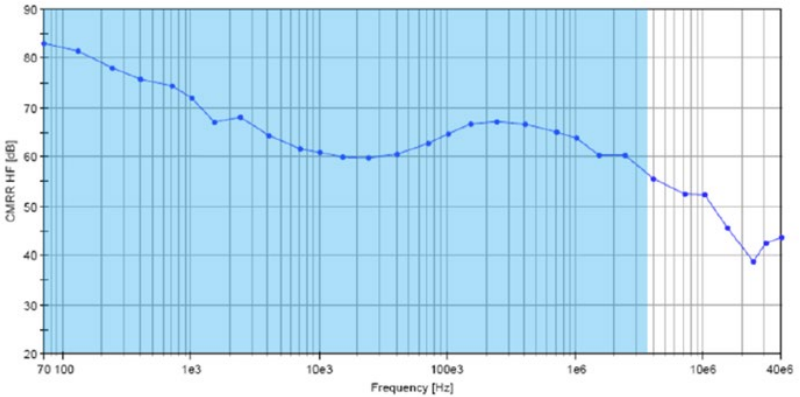
SOURCES OF MEASUREMENT ERROR
PROBE NOISE

- Operate the probe within the right attenuation setting
  - Signals are attenuated and re-amplified
  - Noise is part of what gets amplified
- The lower noise of an RT-ZHD series probe against other competitor's probes is clearly seen in Figure 2.



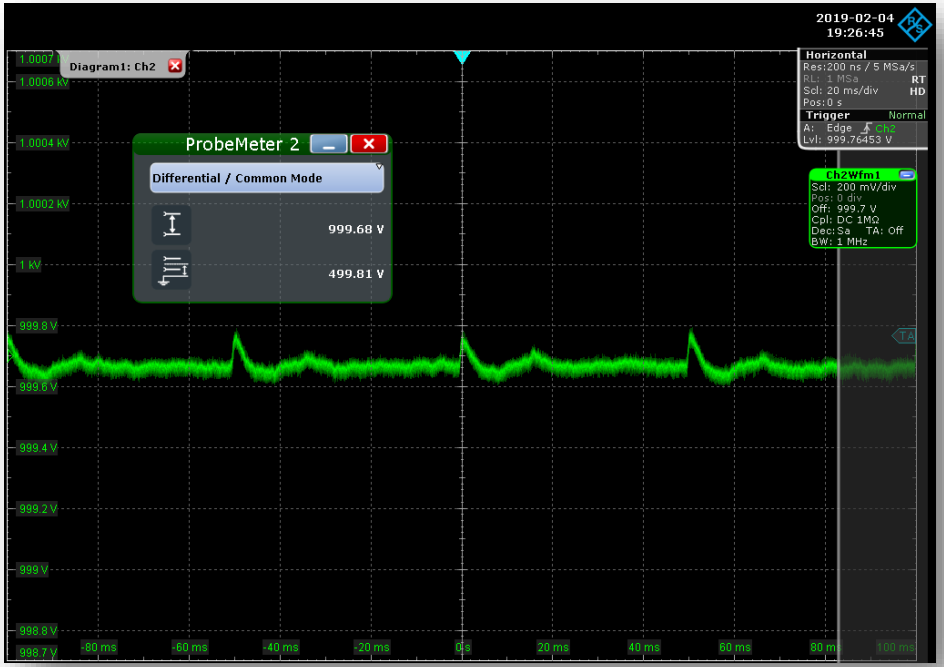
SOURCES OF MEASUREMENT ERROR
POOR COMMON MODE REJECTION (CMRR)

- CMRR specifies a probe's ability to reject common mode signals
- CMRR is frequency and dynamic range dependent
- It's critical to refer to the CMRR plot in the user's manual to understand how the probe's CMRR will affect your specific measurement



OFFSET COMPENSATION
CHARACTERIZE SMALL VARIATIONS IN HIGH DC VOLTAGES

- Application
  - Ripple voltage detection on DC link
- Signal characteristics
  - 1000 V DC
  - ± 100 mV variations
    - High vertical measurement resolution required, e.g. 200 mV/div
- RT-ZHD: Differential offset up to 2000 V
- Most differential probes cannot compensate a DC offset



6 ½ Digit Multimeter: 

Deviation: -0.15 ‰

PROBES FOR MEASURING HIGH VOLTAGE LEVELS
GENERAL PURPOSE HIGH VOLTAGE DIFFERENTIAL PROBES

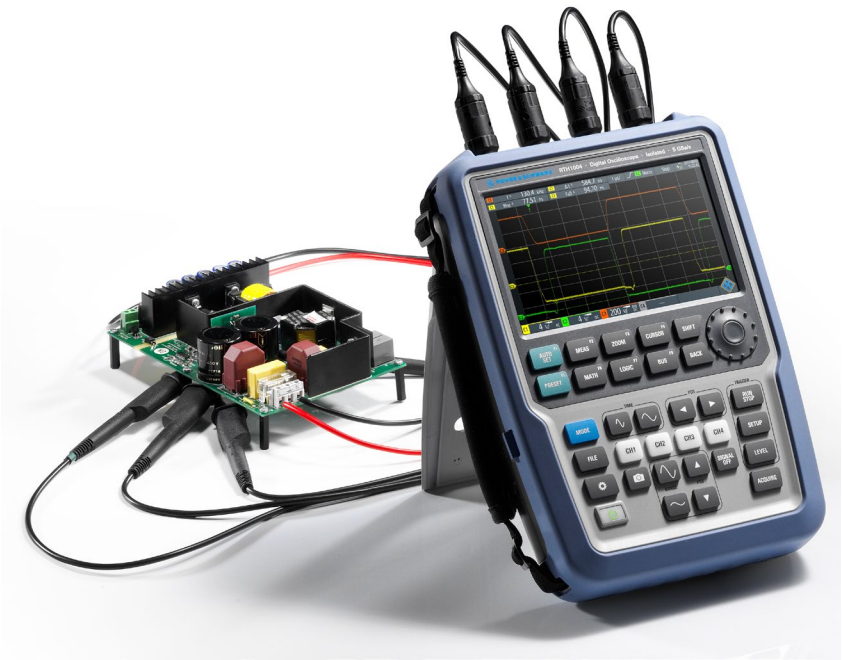
- 25 MHz and 100 MHz bandwidth
- 750 Vpeak and 1400 Vpeak input voltage
- BNC Interface
- BNC interface fits to all scopes / applications
- Cost-effective differential solution

PROBES FOR MEASURING HIGH VOLTAGE LEVELS
SINGLE-ENDED PASSIVE PROBES

- 250 MHz and 400 MHz
- Single-ended passive probes
- Up to 1000 V (RMS) and 6000 V (peak)
- BNC Interface
- BNC interface fits to all scopes / applications
- Cost-effective solution

PROBES FOR MEASURING HIGH VOLTAGE LEVELS
ISOLATED CHANNEL OSCILLOSCOPE – RTH FAMILY

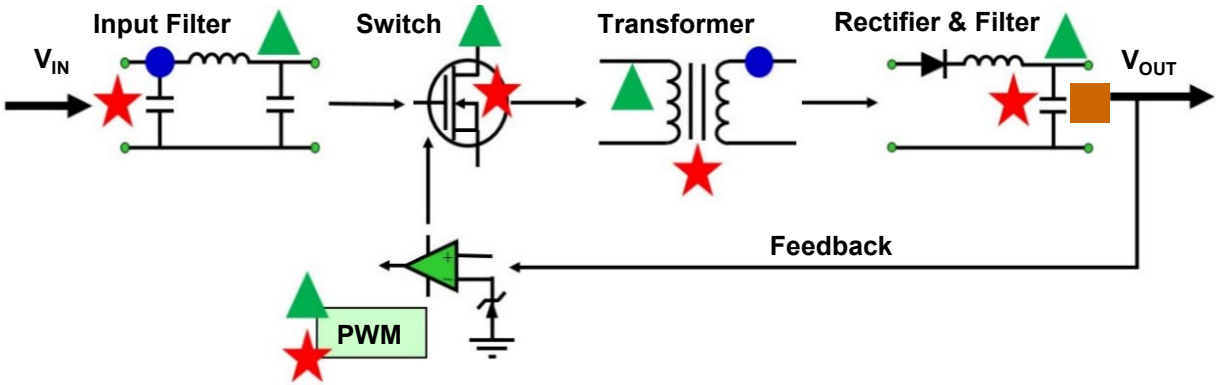
- 60 MHz, 100 MHz, 200 MHz, 350 MHz and 500 MHz models
- Channel isolation for up to 1000 Vrms and 500 MHz bandwidth
- Isolated channels → no need for differential probes
- CAT IV 600 V, CAT III 1000 V with R&S®RT-ZI10 or R&S®RT-ZI11 probes
- High CMRR > 100 dB @ DC – 100 kHz
- Up to 16-bit vertical resolution with high resolution mode



APPLICATIONS

SMPS

- Measurements
  - Switch
    - Switching Loss
    - Safe Operating Area
  - Output
    - Ripple
  - Input
    - Harmonics
    - Power quality
- Probe requirements
  - Fast rise time
  - Attenuation to evaluate both turn on and turn off
  - Low noise
  - Sufficient CMRR
  - Offset adjustment and control
  - RTH may be used in lieu of a differential probe where applicable



RT-ZHD High Voltage Differential Probe

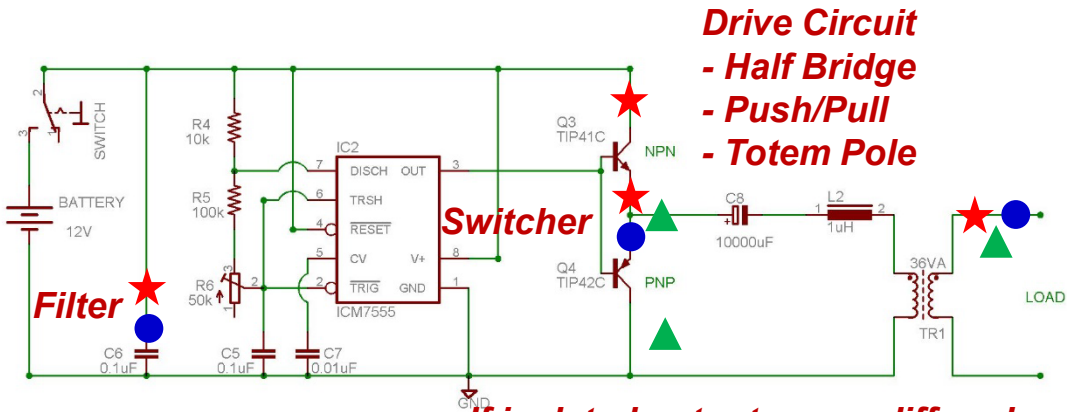
Ground Referenced Probe

Current Probe

Rail Probe

INVERTER

- Industry trends
  - Higher power ratings. Inverter cost per watt decreases as inverter power increases.
  - Higher system voltages in order to reduce power losses and cost
  - Higher efficiencies
- Probe needs
  - Sufficient CMRR over bandwidth
  - Low noise
  - No artificial peaking to get probe performance
    - Measure your probe with a fast, high voltage step



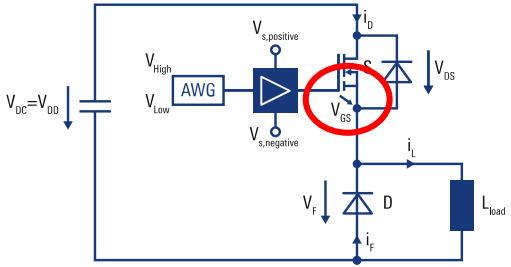
DOUBLE PULSE TEST
VOLTAGE PROBING

- Passive probes are sufficient for floating setups
  - Possible for device characterization setups
  - Care has to be taken on any (unintentional) grounding

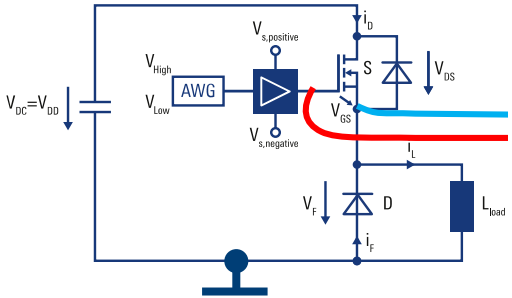
- Broadband differential probes are an attractive alternative for floating setups
  - Very high bandwidth of up to 1 or 2 GHz
  - Very low loading (~ 1pF)
  - Input voltage range of +/-50V DC with 10:1 attenuator

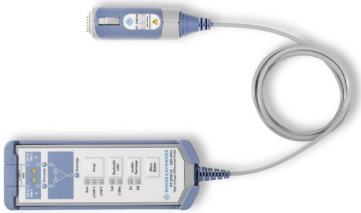
- High-voltage differential probes are necessary if system-under-test is grounded
  - Typically the case for prototypes
  - Provide CMRR to suppress switch-node signal

Floating High-side DUT



Grounded High-side DUT



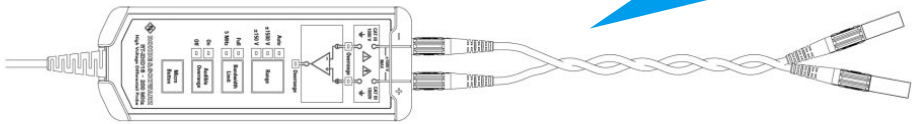


EFFECTS OF CABLES AND CONNECTORS ON HIGH VOLTAGE DIFFERENTIAL PROBES

TWISTED OR UNTWISTED CABLES

Leads twisted

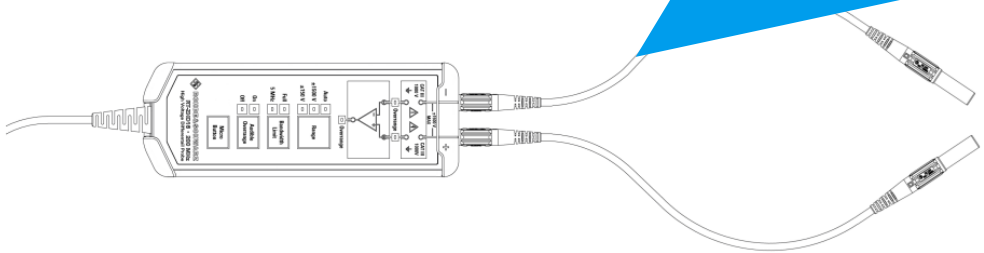
Usually the best option



pro	interferers are minimized
con	greater load on the measuring point

Leads untwisted

Only recommended if the loading of probe is the biggest problem



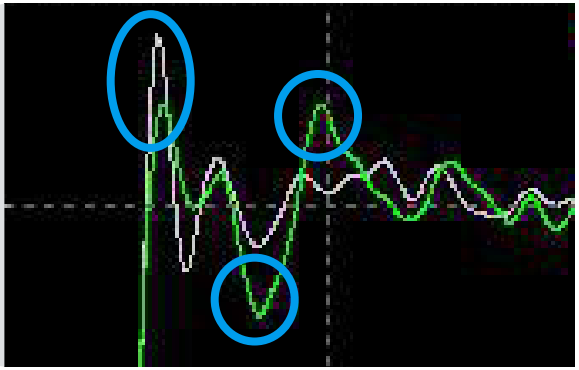
pro	minimizes the capacitive loading
con	interferers are looped in

Rule of thumb:

Diff input capacitance is ~half the single ended capacitance

	ZHD probe + meas. leads
untwisted	9 pF
twisted	12 pF

TWISTED OR UNTWISTED CABLES
200 MHZ BANDWIDTH



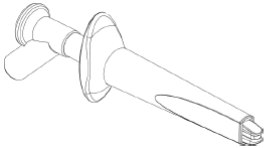
The impulse response of the probe is optimized with twisted test leads

Higher overshoot due to twisting

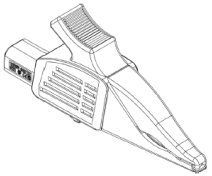
Untwisted: high lower frequency ringing

INFLUENCE OF CLIPS

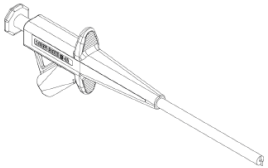
- **Test Clip**: Max. rating 1000 V (RMS) CAT IV

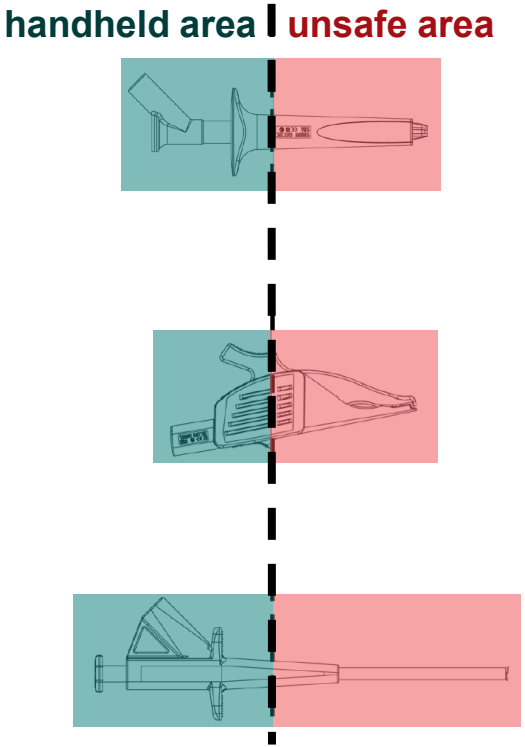


- **Safety Alligator Clip**: Max. rating 1000 V (RMS) CAT III

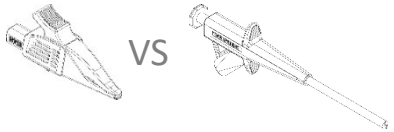


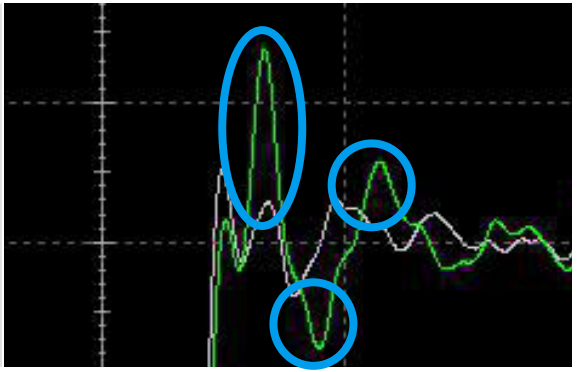
- **Pincer Clip:** Max. rating 1000 V (RMS) CAT III





ALLIGATOR VS PINCER CLIPS
200 MHZ BANDWIDTH





Clips have an influence on accuracy especially at full bandwidth (e.g. 200 MHz)

Find out more

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Thank you!

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