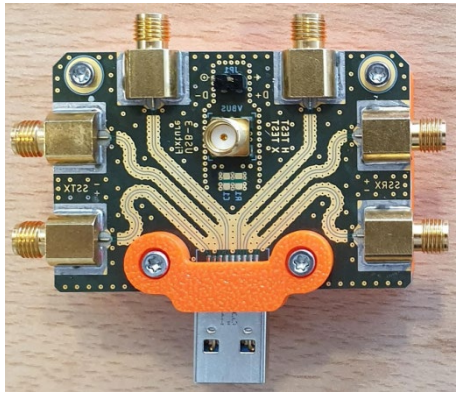
Oscilloscope Probes

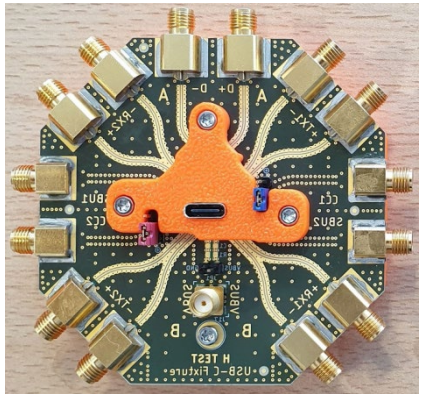
Oscilloscope probing

- three ways how to connect an oscilloscope to a signal source:
  1) direct connection to the coaxial input
     - typically used in 50 Ω signal paths with 50 Ω termination selected
     - preferred method (high signal quality; works well to high frequencies)
     - limited to **5 Vrms into 50 Ω** and to **tens to hundreds of V** into 1 MΩ
     - channel **grounds are connected together** and with the power cord ground – users need to be careful when using single-ended probes

Oscilloscope probing

2) fixtures
   - adapter between some specific connector/interface and one or more coaxial connectors - USB, LAN, HDMI, PCIe .....



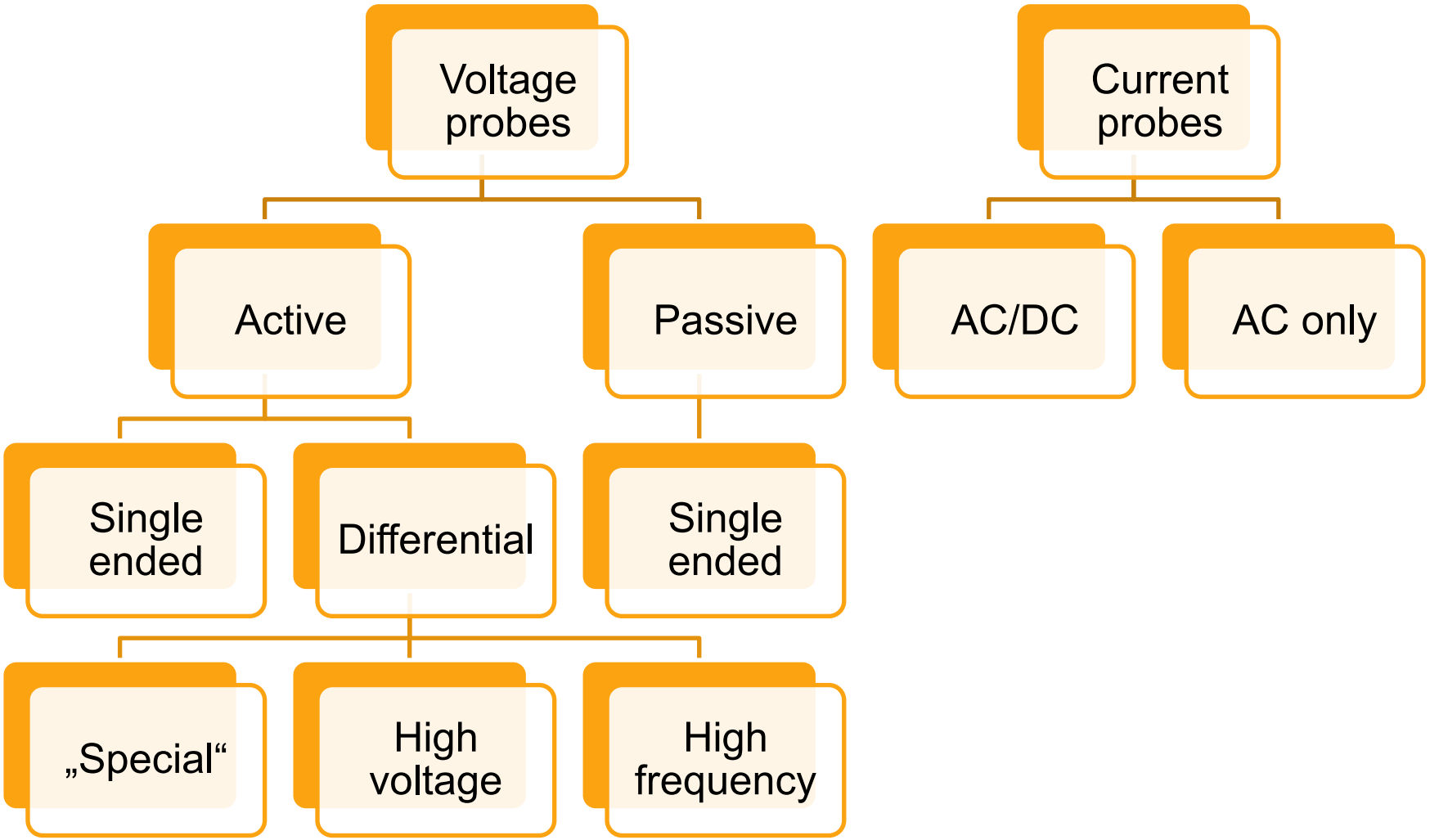


3) probes
   - probes facilitate the connection between the measured circuit and the oscilloscope; many kinds of probes for different measurement needs
   - power measurements are generally not possible without special voltage and current probes

Oscilloscope probing

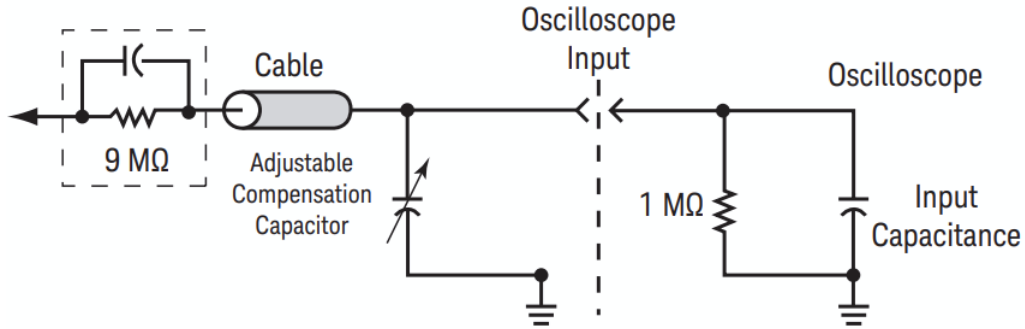
- an ideal probe would:
  - be able to reach any point of the DUT
  - present a perfect replica of the measured signal
  - have an infinite range and would not add any noise
  - would not affect the probed circuit
- unfortunately, ideal probes do not exist:
  - probes influence the measured circuit and change the signal shape
  - at the same time, they are not able to reproduce the measured signal 100 % correctly – non ideal frequency response; noise, ...
  - it can be difficult to reach and contact the measurement point

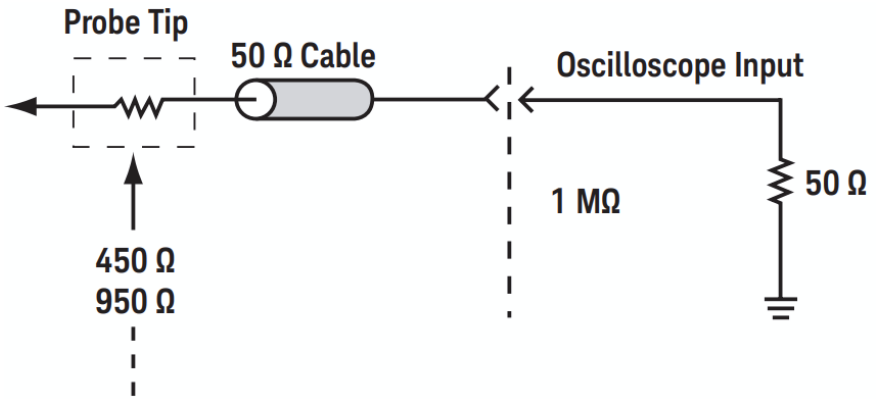
Types of probes



Passive voltage probes

- rugged, inexpensive, wide dynamic range; only single-ended
- high impedance
  - relatively high bandwidth – 500 MHz ~ 1 GHz
  - 10:1 – most common; ~ 400 V rms
  - 100:1 – ~ 2 to 3 kV rms
  - high capacitive loading
- low impedance
  - requires 50Ω scope input
  - low C/high R loading
  - up to 1,5 GHz



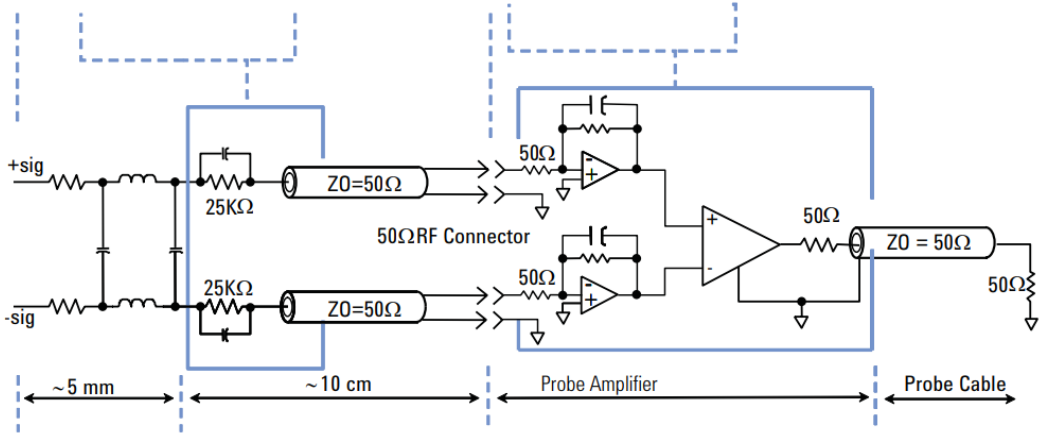


Active voltage probes

- better signal integrity (less parasitics), lower circuit loading
- differential or single-ended
- more expensive

„high speed“

- higher bandwidth (52 GHz)
- low input voltage (diff/common)
- in circuit testing on digital buses

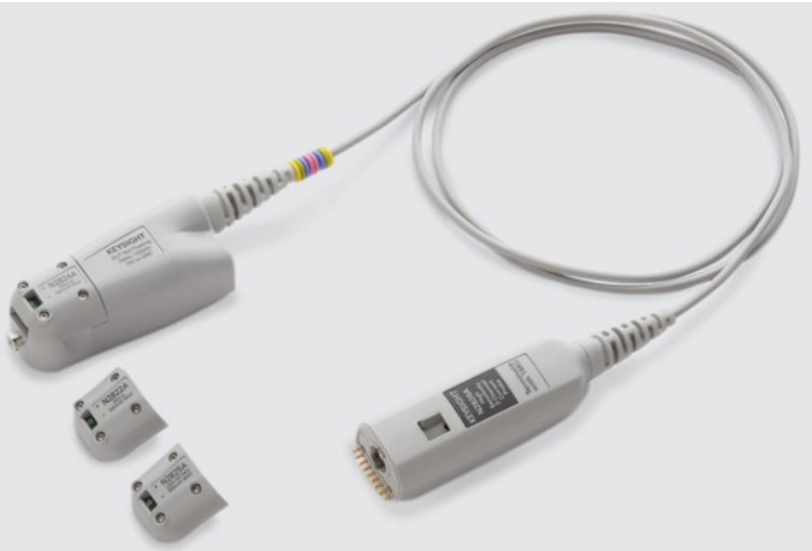


„high voltage“

- lower bandwidth (hundreds of MHz)
- higher input voltage
- general purpose or special high voltage measurements

Current probes

- current → voltage converters
- AC/DC probes:
  - Hall-Effect clamp-on probes
    - bandwidth up to 150 MHz
    - currents of up to 700 A
    - can be easily connected to the measured conductor
  - probes with resistive shunt
    - Keysight N2820A / N2821A
      special high-sensitivity probes
    - measurement on internal or external
      shunt resistors



Current probes

- AC only probes:
  1) current transformers with magnetic core
     - higher sensitivity, electrical isolation
     - prone to DC saturation, lower bandwidth, bulky, not easy to connect to the circuit, higher insertion inductance, worse linearity
     - from low to very high currents (tens of kA peak)
     - bandwidth of up to 60 MHz (for lower current versions)

Current probes

2) Rogowski coil probes (with air core)

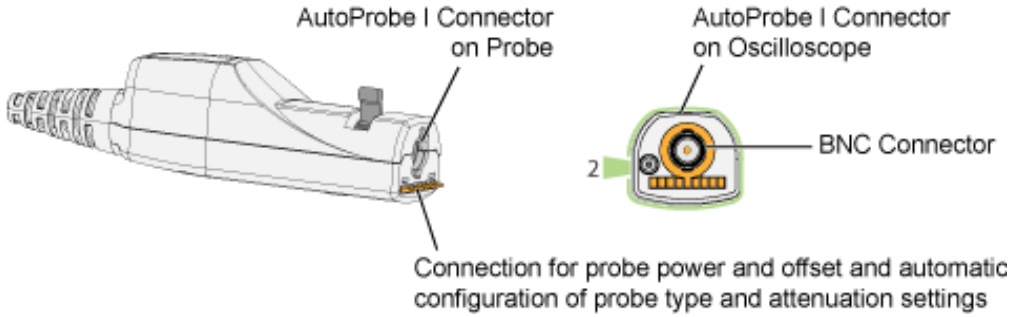
- low insertion impedance, higher bandwidth, great linearity, no magnetic saturation, electrical isolation
- very flexible to use – coil is easy to wrap around a conductor
- affected by external magnetic fields, worse sensitivity
- sensitive to fast electric field changes (solved by shielding)
- 100 MHz BW; up to 120 kA peak

Probe interfaces

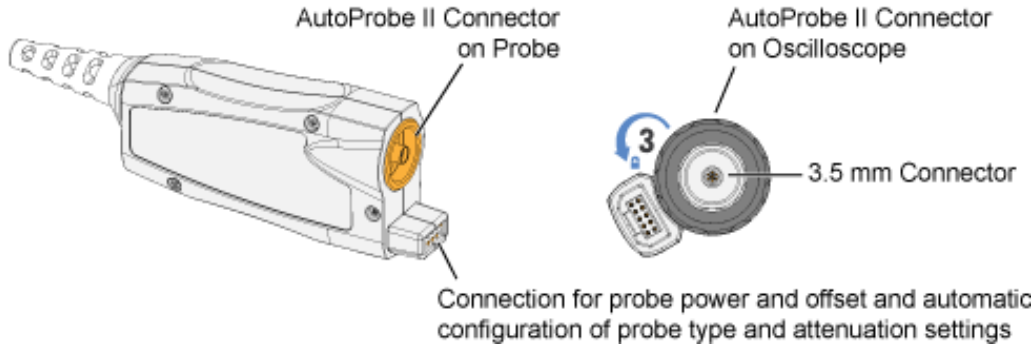
- oscilloscope probes can have a universal BNC interface
  - expects a 1 MΩ or a 50 Ω input on the oscilloscope
    - in case that 50 Ω is required on a 1 MΩ only scope; a 50 Ω feed-thru load can be used
  - active probes need to be powered and in this case, the power can be supplied from a battery or an external power adapter
  - probe parameters need to be configured manually in the scope
- some active probes use special interfaces proprietary to a specific oscilloscope manufacturer
  - probe interface supplies power to the probe and provides communication; probe setup is done automaticaly

Keysight probe interfaces

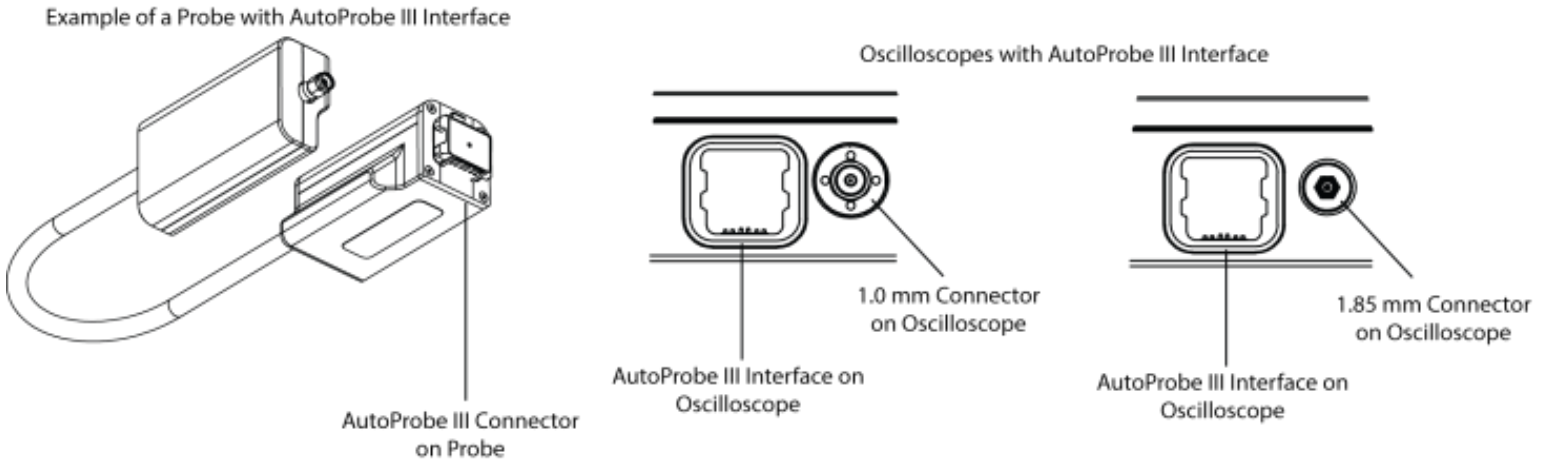
- AutoProbe I:



- AutoProbe II:



- AutoProbe III:



PMK oscilloscope probes

- PMK is a German manufacturer of a wide range of oscilloscope probes:
  - passive single-ended
    - **MMCX** series - probes with coaxial connection and low capacitive loading
    - **ENVI** series - high temperature probes – 500 MHz, 400 V
    - **PHV(X)** – high voltage passive probes
  - active differential
    - **HSDP** series – high speed probes up to 4 GHz and 42 V
  - active single-ended
    - **Sonic**, **Tetris** series – high speed up to 4 GHz and 20 V
  - current probes – Hall efect, Rogowski, current transformers, ...

PMK BumbeBee and HORNET

- industry leading high voltage differential probes
  - for less demanding applications than the FireFly, but still very good
- up to 500 MHz BW (depending on the model and selected range)
- five models; up to 200 / 400 / 1000 / 2000 / 4000 V
  - each model has four selectable ranges with different division factor
- high CMMR – 80 dB (DC) to 35 dB (400 MHz) to 80 dB (DC)
- up to 7 m cable length
- universal BNC interface; usable with any oscilloscope
- very wide selection of connection accessories (standard)

PMK FireFly probe

+

PMK FireFly probe

- special differential high voltage optically isolated probe
- 1.5 GHz BW; ± 60 kV common mode and 2.5 kV differential input
- unmatched CMMR (> 180 dB up to 500 kHz; 80 dB at 1 GHz)
  - the probe is able to resolve high bandwidth and small amplitude differential signals in presence of large common mode voltages
- ideal for GaN / SiC high side V_{GS} measurements
- wide range of input tips and other connection accessories
- universal BNC interface – can be used with any oscilloscope
- probe head is battery powered
  - there will be a „power over fibre“ option soon

PMK FireFly probe

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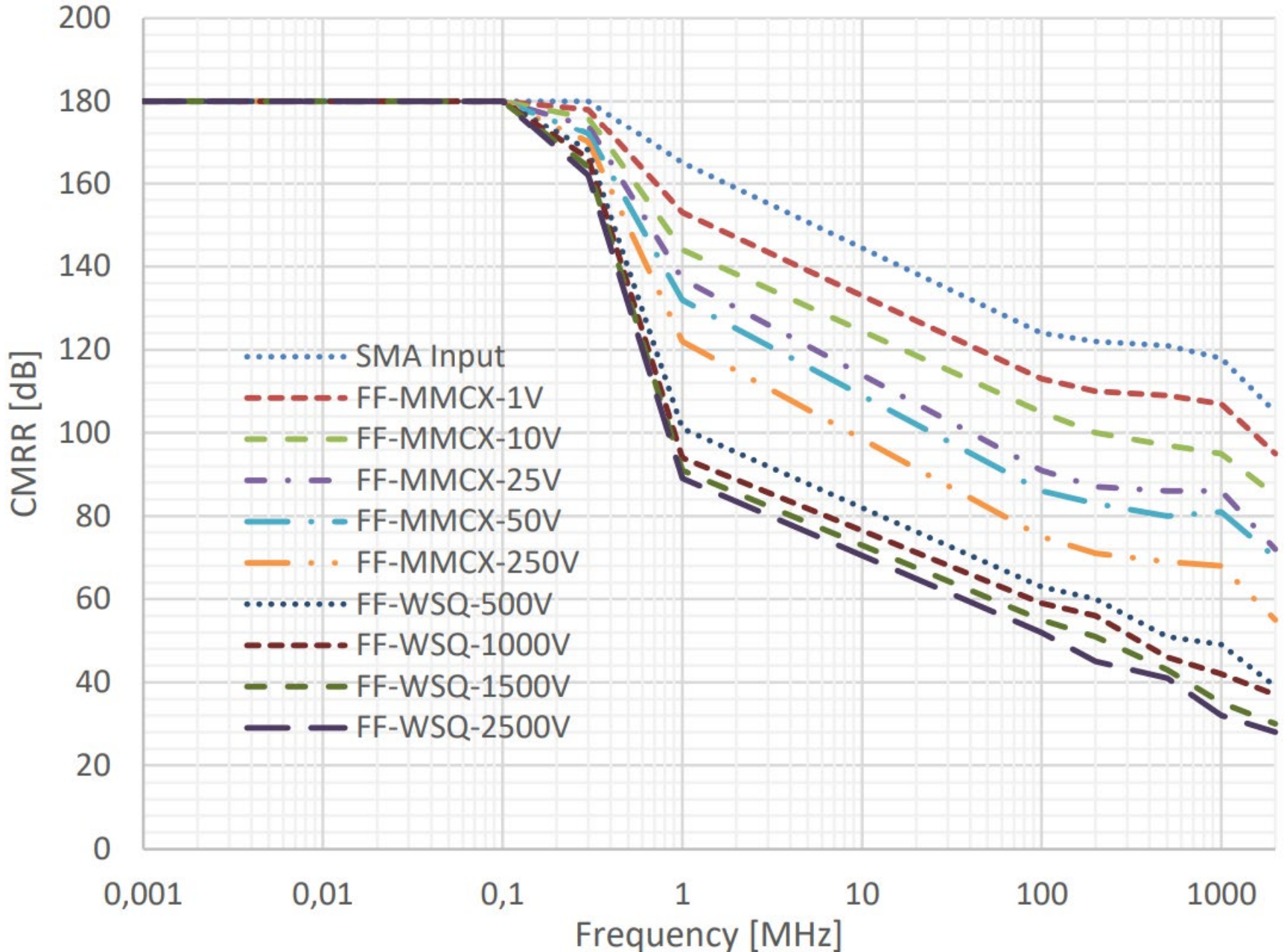
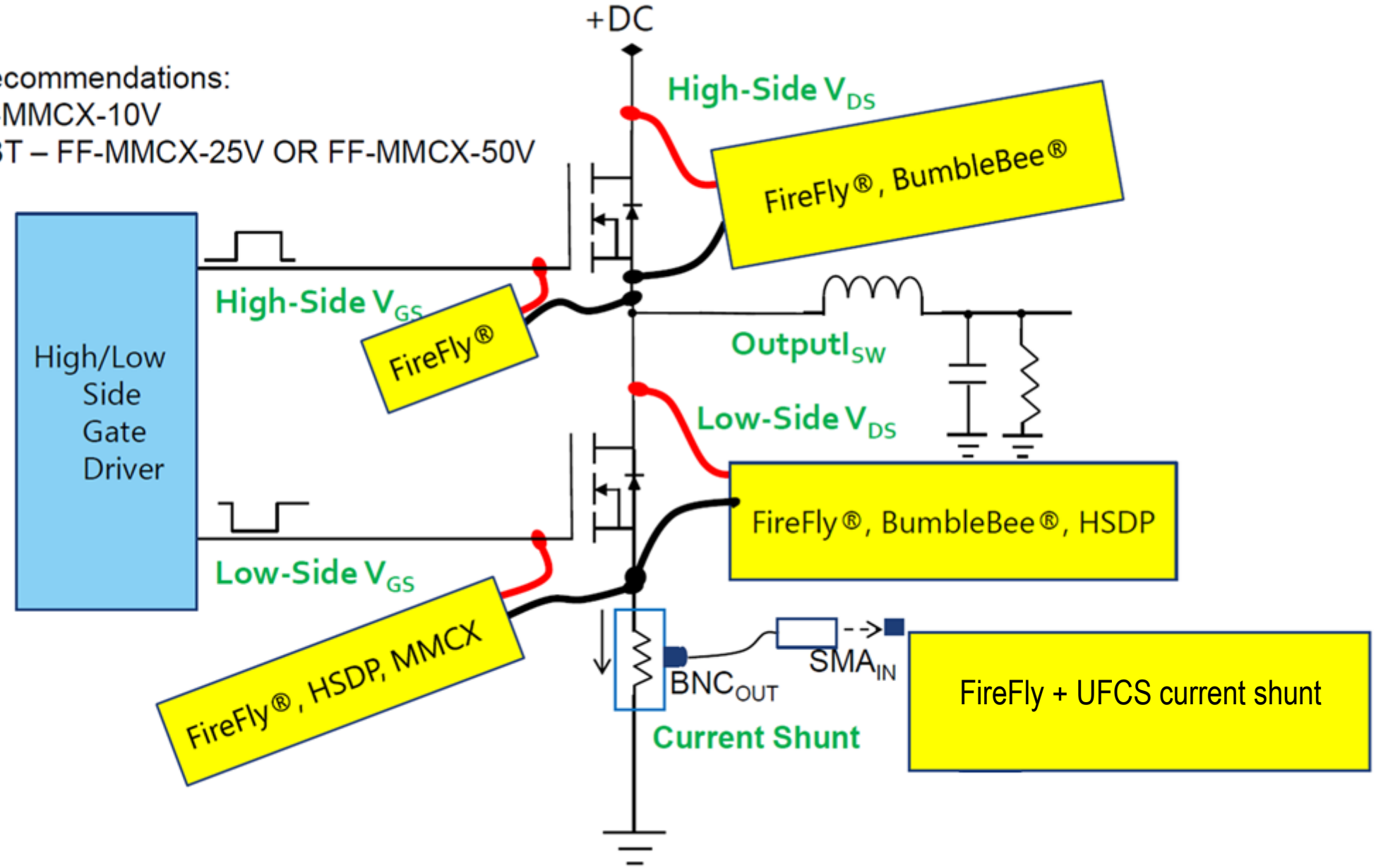
PMK FireFly probe

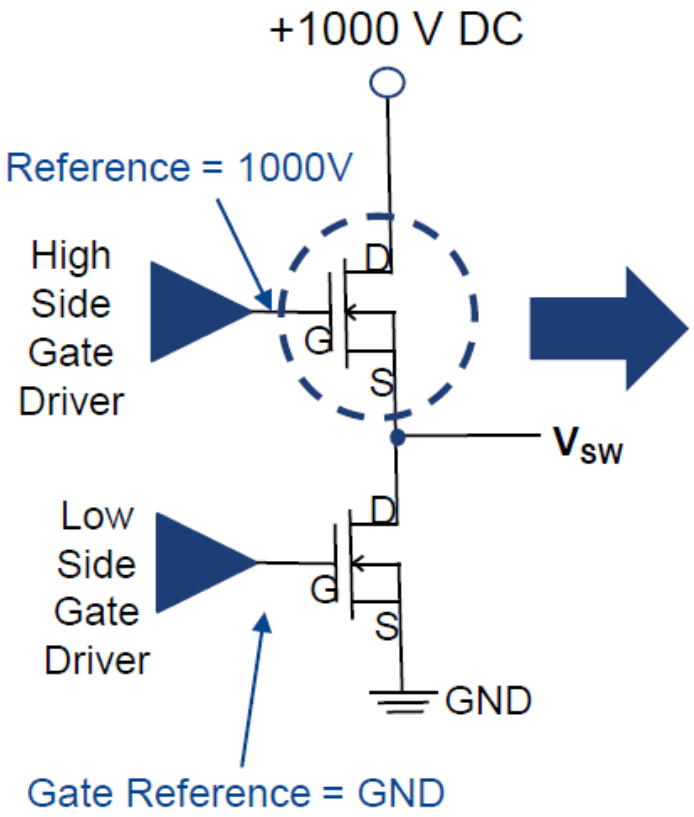


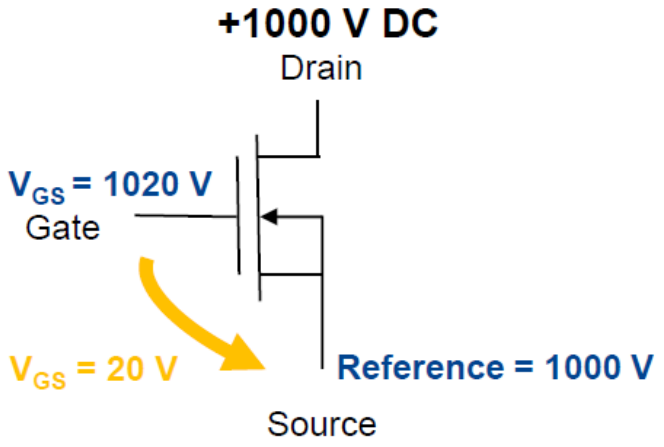
Typical measurement setup

V_{GS} Tip Recommendations:
GaN – FF-MMCX-10V
SiC/Si/IGBT – FF-MMCX-25V OR FF-MMCX-50V



High-side measurement





The voltage at the switch node (V_{SW}) swings between the supply voltage (1000V) and the low-side reference voltage (GND).

Common Mode Voltage = 1000 V
Diff. Voltage (HS V_{GS}) = 1020 - 1000 = 20 V

High-side V_{GS} measurement

- resulting common mode error - FireFly with the 25V Input Tip vs. the BumbleBee 1000 V differential probe:

Frequency	CMMR FireFly		CM Error FireFly	CMMR BumbleBee		CM Error Bumblebee
	(dB)	linear		(dB)	linear	
DC	180	1,000,000,000	1 µV	80	10,000	100 mV
1 MHz	137	7,079,458	141 µV	70	3,162	316 mV
100 MHz	91	35,481	28 mV	40	100	10 V
200 MHz	87	22,387	44 mV	40	100	10 V
500 MHz	86	19,952	50 mV	35	56	18 V
1 GHz	86	19,952	50 mV	---	---	---

PMK UFCS (Ultra-Fast Current Shunt)

- solder-in fast current shunts with small form factor, high current capabilities and coaxial output
  - for WBG (SiC/GaN) switching loss and pulse current measurements
  - ideal in combination with the FireFly probe
- very high bandwidth > 1 GHz
- ultra low insertion impedance < 200 pH
- available in different resistance versions (5mΩ, 11mΩ, 24mΩ, 52mΩ)

PEM CWT Rogowski current probes

- Power Electronic Measurements (PEM) company specializes in the design and manufacture of current probes based on Rogowski technology
- very wide range of probes with different sizes and parameters
  - some models offer electrostatic shielding which increases the immunity to fast voltage transients or large AC voltages
  - bandwidth of up to 50 MHz

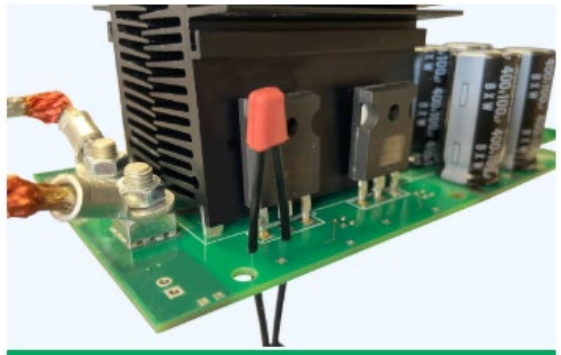
SCREENED

CWTMini50HF

Clip-around Rogowski current probe with 50MHz bandwidth and superior dV/dt immunity

CWTUM-S

Clip-around Rogowski current probe with 30MHz bandwidth and ultra-thin 1.2mm coil cross-section



SCREENED COMING SOON

CWTUMHF-F

Novel 'forked' Rogowski current probe with 30MHz bandwidth, superior dV/dt immunity and 1.7mm coil cross-section