OSCILLOSCOPE FUNDAMENTALS

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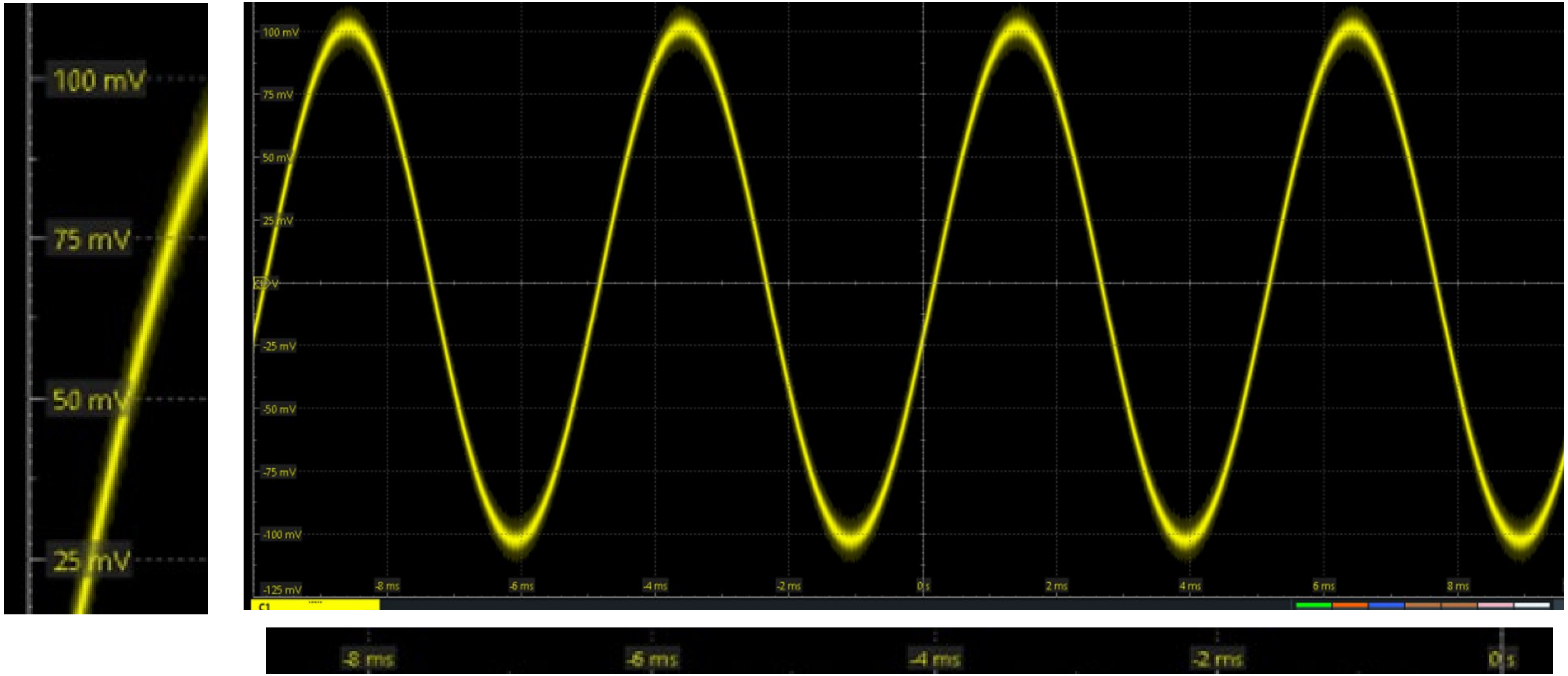
Application Engineer Digital Debug Tools

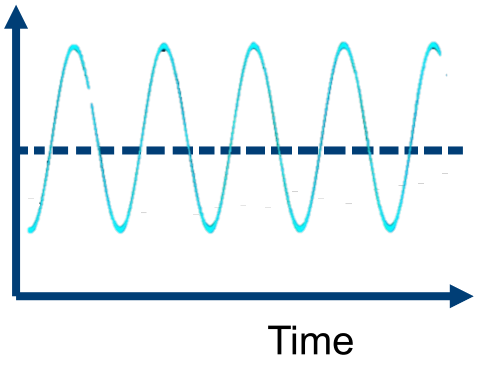
ROHDE&SCHWARZ
Make ideas real

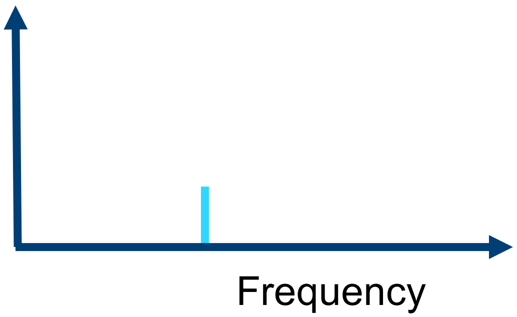
WHAT IS AN OSCILLOSCOPE?

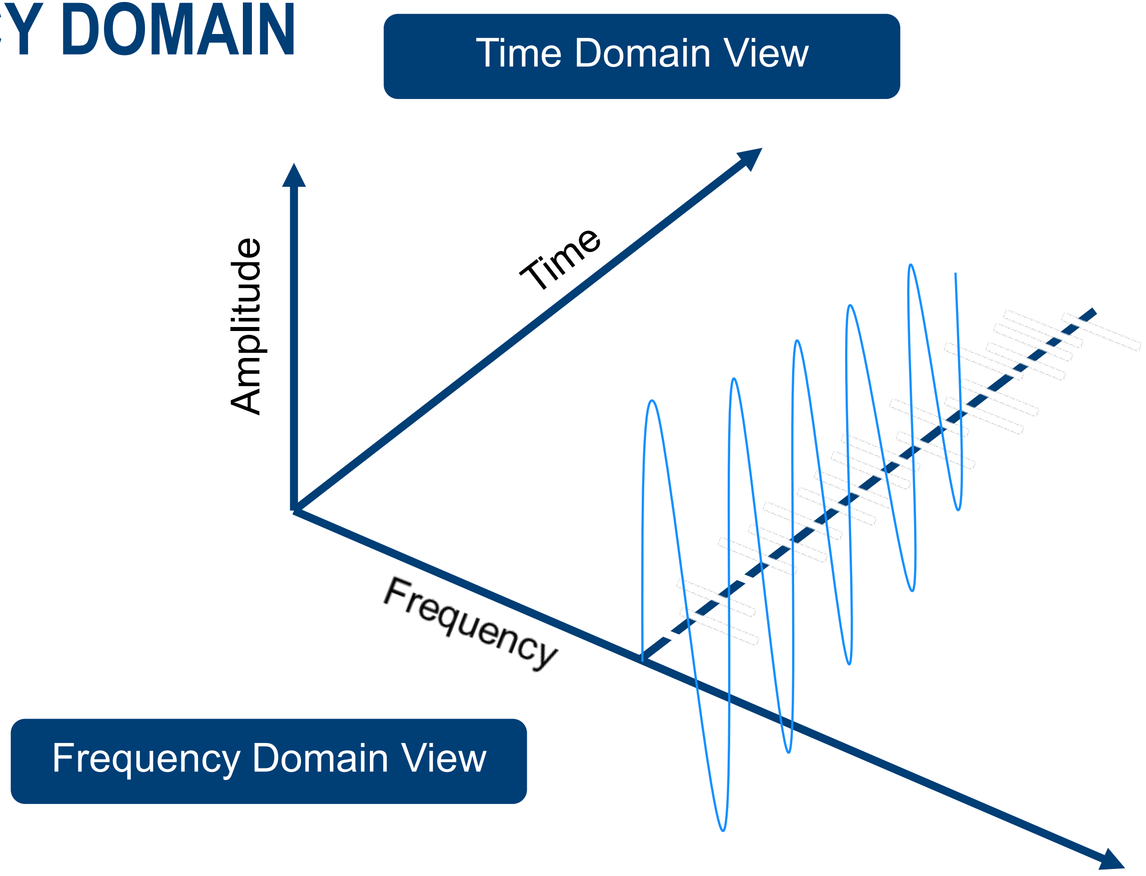


► **An oscilloscope is a device that allows you to see how voltage changes over time by displaying a waveform of electronic signals**

WHAT IS AN OSCILLOSCOPE?
- TIME VS FREQUENCY DOMAIN

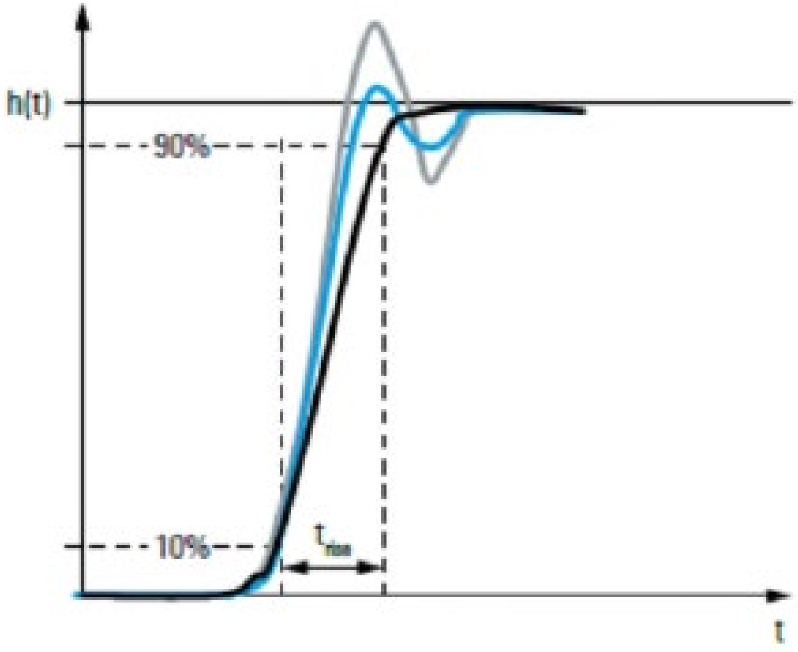




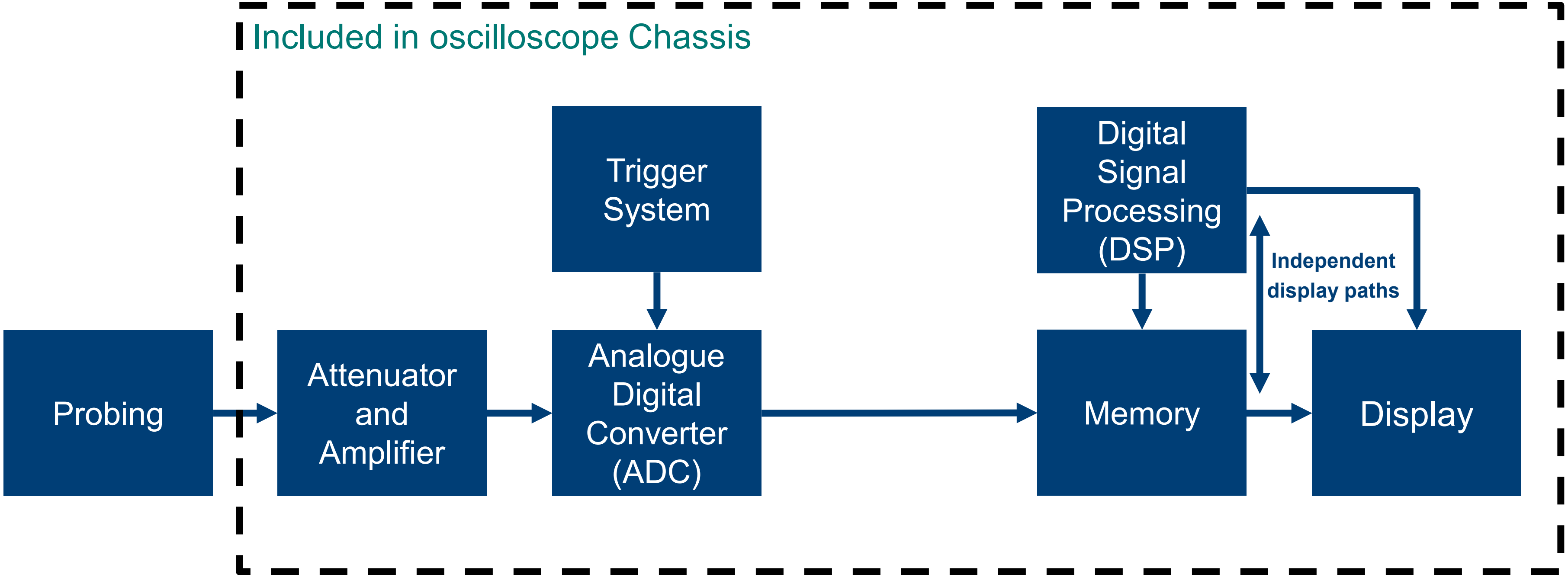


TYPICAL MEASUREMENTS WITH AN OSCILLOSCOPE

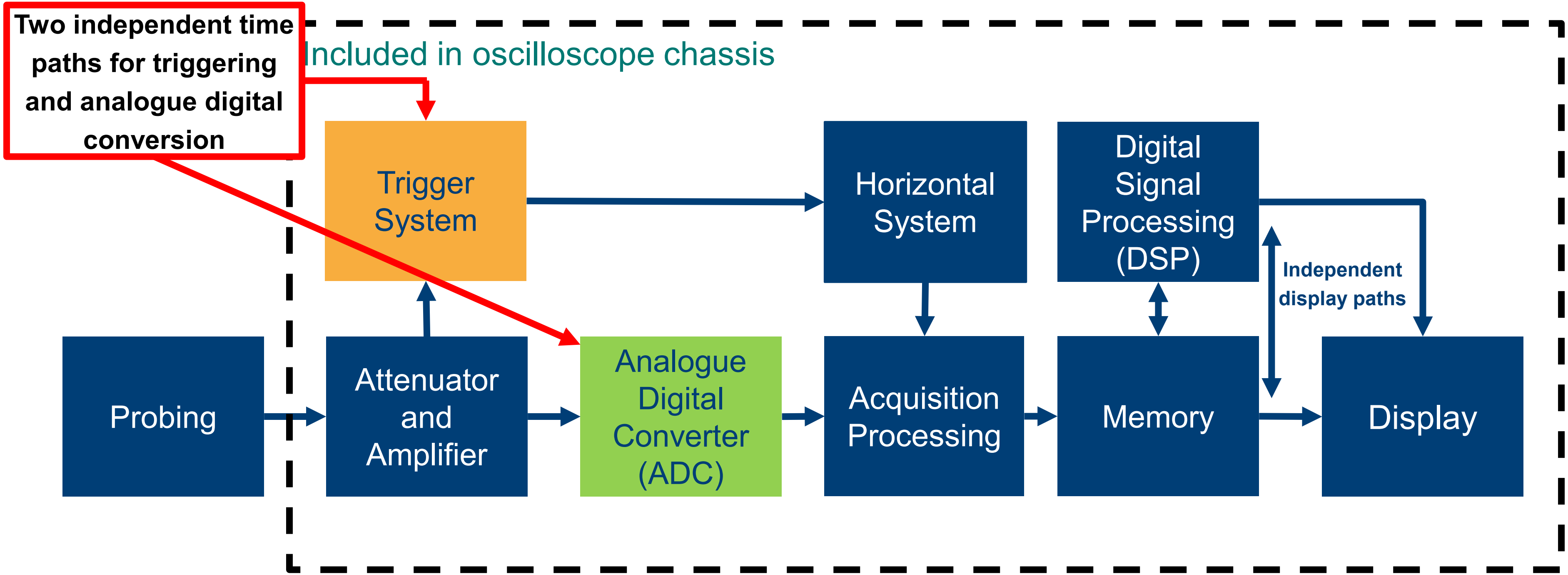
- Rise time / fall time
- Overshoot
- Ringing
- Voltage drop



WHAT IS AN OSCILLOSCOPE?
- DIGITAL OSCILLOSCOPE BLOCK DIAGRAM



DIGITAL OSCILLOSCOPE ANALOGUE TRIGGER UNIT



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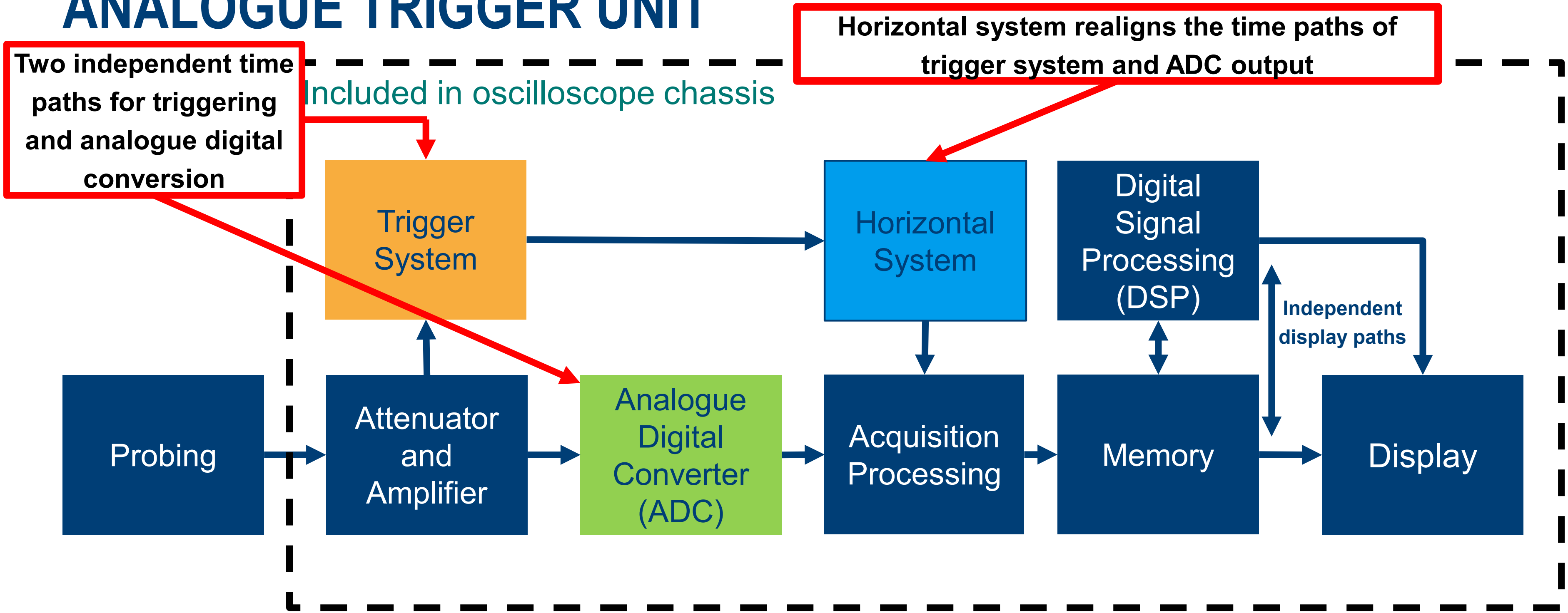
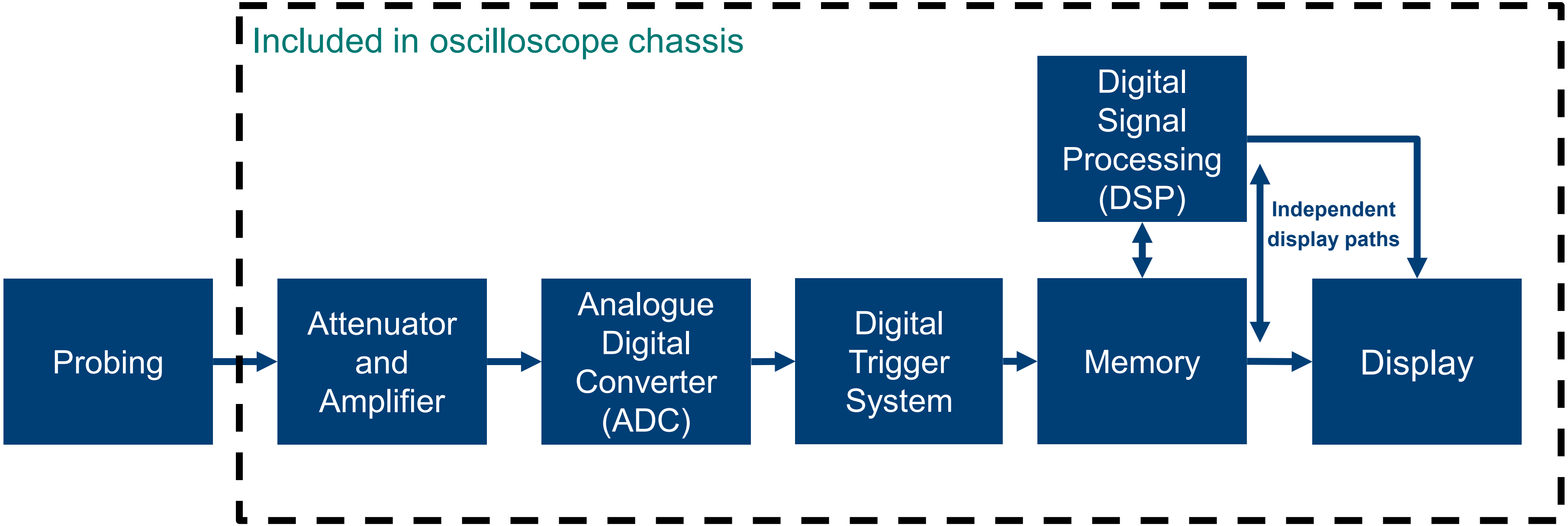
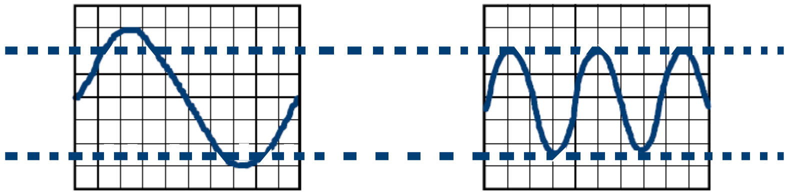


DIGITAL OSCILLOSCOPE
DIGITAL TRIGGER UNIT



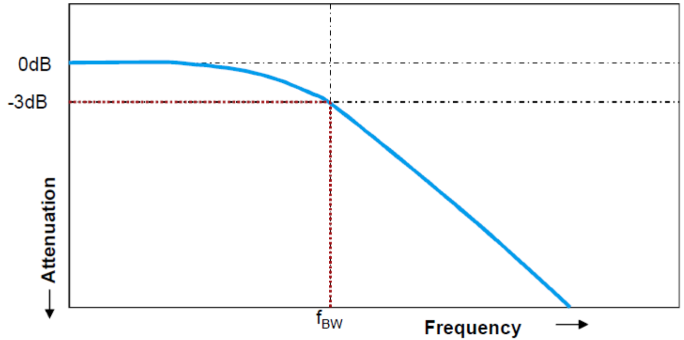
WHAT IS ANALOG BANDWIDTH

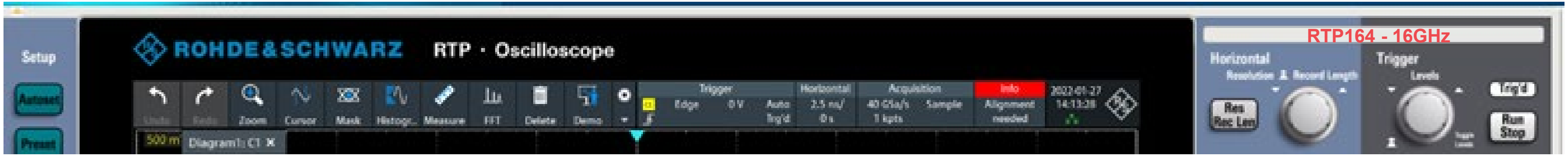
- Bandwidth: is The most Crucial parameter when choosing an Oscilloscope
- Specified Bandwidth is equal to the frequency of the input sinusoidal signal attenuated by 3dB



0 dB
6 div at low frequency

- 3 dB
4.2 div at bandwidth limit





HOW MUCH OSCILLOSCOPE BANDWIDTH DO I NEED?

- Required scope bandwidth depends on test signals frequency components

- Bandwidth relates to rise time $\mathbf{t_r}$
- If only a max. slew rate is given the rise time is calculated accordingly: $t_r = \frac{\Delta Voltage}{Slew\ Rate}$

- Estimating the Bandwidth needed

  Investigating the units:

  Rise time t_r is expressed in [s]
  Frequency is expressed in [Hz]

  $$f_{max} = 1/t_r$$

  - **As a rule of thumb $\boldsymbol{f_{max}}$ can be estimated by using the equation $\boldsymbol{f_{max} = 0.5/t_r}$**

BANDWIDTH
TEST SIGNAL REQUIREMENTS

- Data rate of typical I/O interfaces

Interface	Data Rate	Clock Frequency	Oscilloscope Bandwidth Requirement	
			3rd harmonic	5th harmonic
I2C	3.4 Mbps	3.4 MHz	10.2 MHz	17 MHz
LAN 1G	125 Mbps	62.5 MHz	187.5 MHz	312.5 MHz
USB 2.0	480 Mbps	240 MHz	720 MHz	1200 MHz
SATA I	1.5 Gbps	750 MHz	2.25 GHz	3.75 GHz
DDR4	3.2 Gbps	1.6 GHz	4.8 GHz	8 GHz
PCIe 2.0	5.0 Gbps	2.5 GHz	7.5 GHz	12.5 GHz
PCIe 3.0	8.0 Gbps	4 GHz	12 GHz	20 GHz

BANDWIDTH
TEST SIGNAL REQUIREMENTS

► Data rate of typical I/O interfaces

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PCIe 2.0	5.0 Gbps	2.5 GHz	7.5 GHz	12.5 GHz
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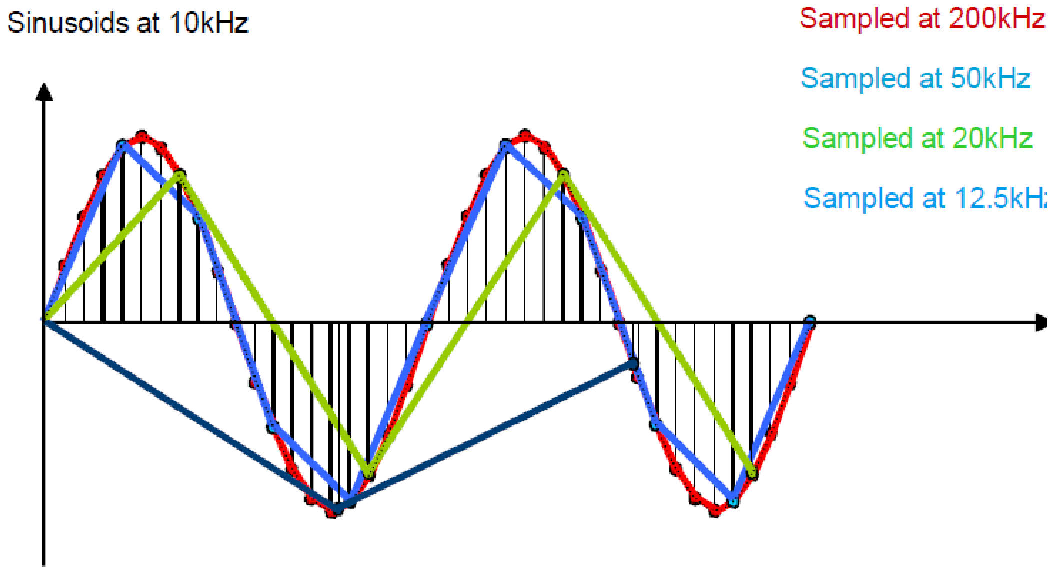
Always remember the “3 to 5 times Rule”

SAMPLING RATE

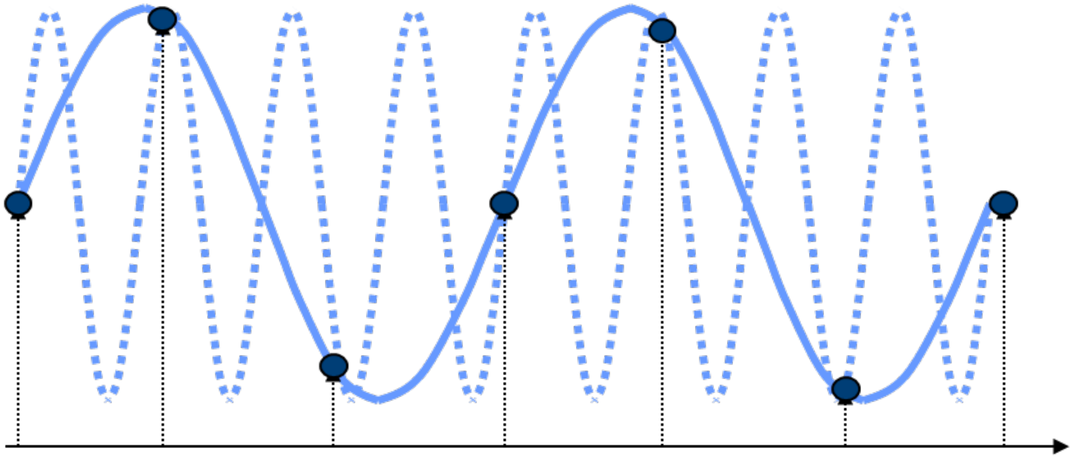
► What is sample rate?

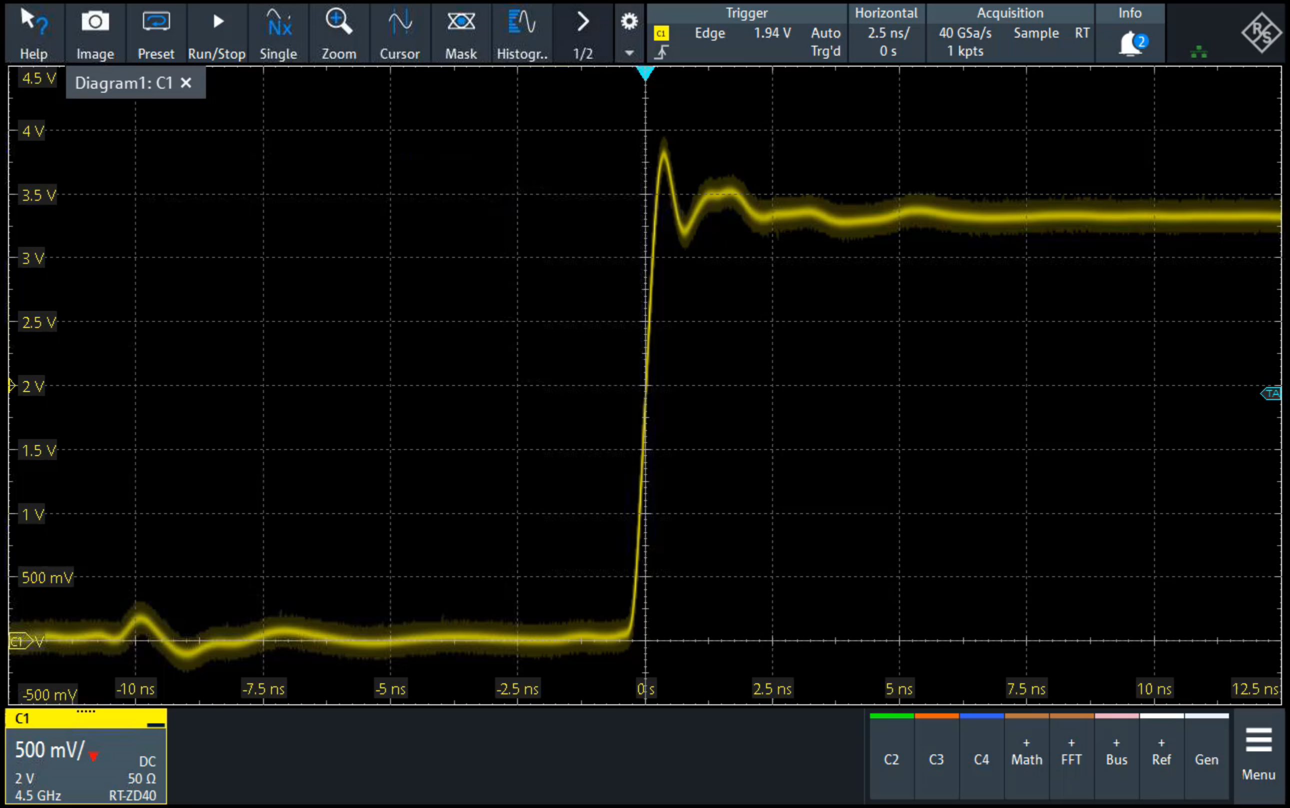


Sample rate is the number of samples (i.e. discrete values) a digital oscilloscope can acquire per second.

SAMPLING RATE

- Sampling rate is smaller than 2 x highest signal frequency
- Signal is not sampled fast enough -> aliasing
- False reconstructed (alias) waveform is displayed!!




Help
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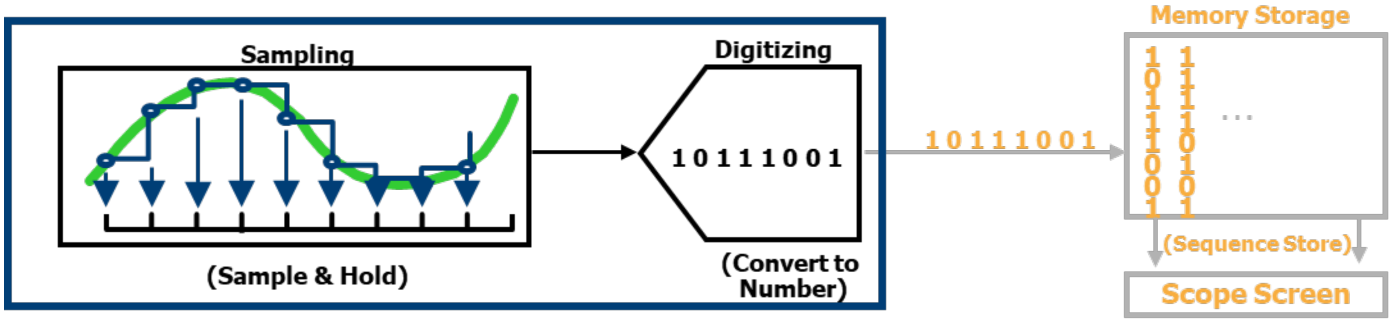
Trigger
Edge
1.94 V
Auto
Trg'd
Horizontal
2.5 ns/
0 s
Acquisition
40 GSa/s
Sample
RT
1 kpts
Info
Diagram1: C1
4.5 V
4 V
3.5 V
3 V
2.5 V
2 V
1.5 V
1 V
500 mV
-500 mV
-10 ns
-7.5 ns
-5 ns
-2.5 ns
0 s
2.5 ns
5 ns
7.5 ns
10 ns
12.5 ns
C1
500 mV/
DC
2 V
50 Ω
4.5 GHz
RT-ZD40
C2
C3
C4
Math
FFT
Bus
Ref
Gen
Menu

RECORD LENGTH

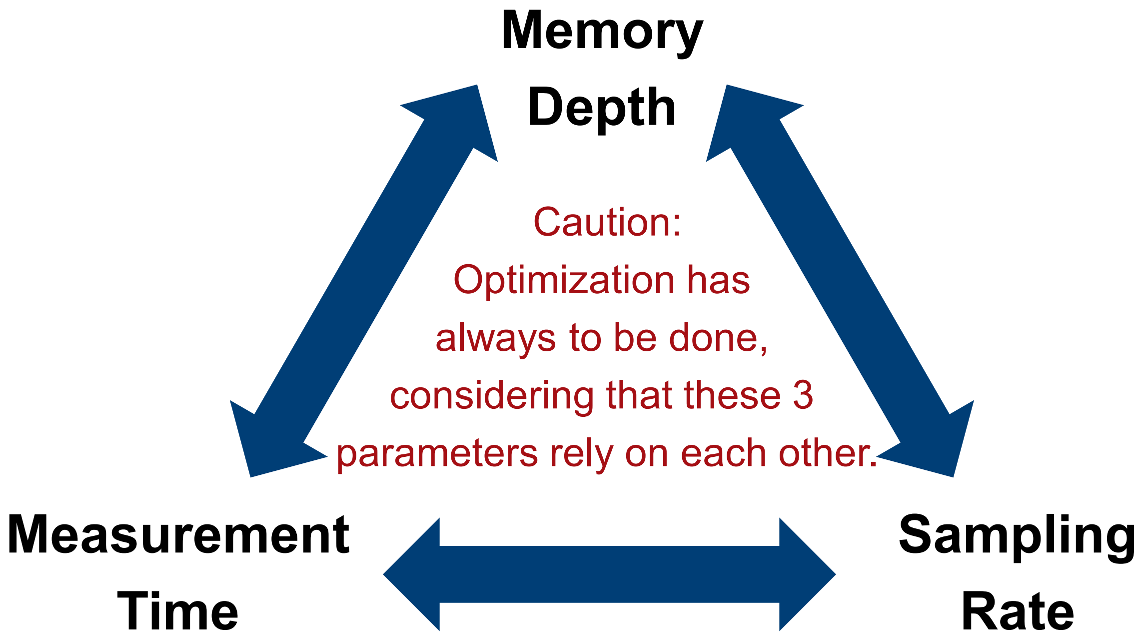


$$Sample\ Rate\ x\ Acquisition\ Time = Record\ Length$$

$$f_{sample}\ x\ t_{meas} = n_{samples}$$ with $$t_{meas} = [Time\ scale]\ x\ [\#\ of\ Divisions]$$

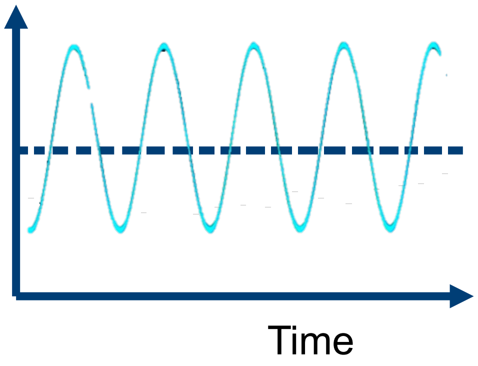
e.g. Sample Rate = 10 GSa/s: $$10\,\frac{GSa}{s} \times 100\,\frac{ns}{div} \times 10\ \text{div} = 10\ \text{kSa}$$

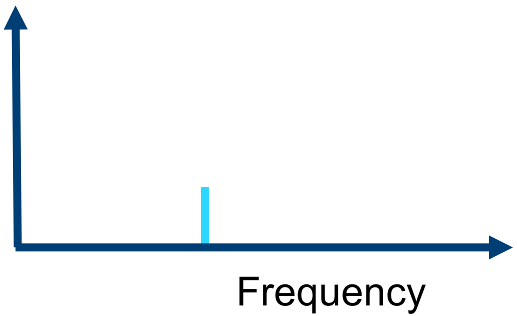
$$10\,\frac{GSa}{s} \times 100\,\frac{\mu s}{div} \times 10\ \text{div} = 10\ \text{MSa}$$


Memory
Depth
Caution:
Optimization has
always to be done,
considering that these 3
parameters rely on each other.
Measurement
Time
Sampling
Rate

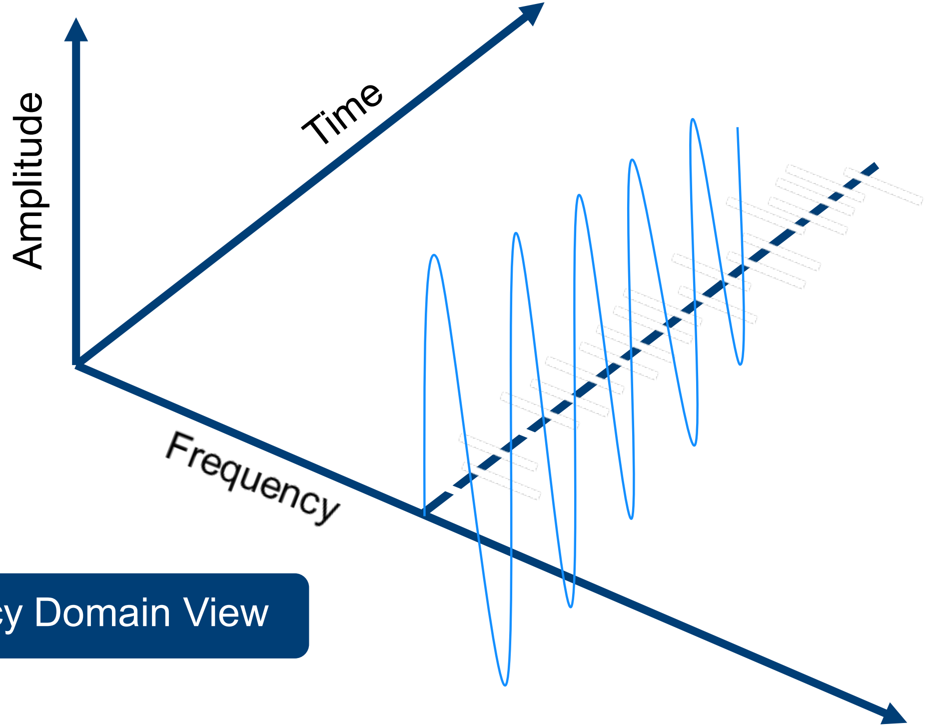
EMC – FAULT HUNTING:
WHY IS AN OSCILLOSCOPE A GOOD CHOICE?

WHAT IS AN OSCILLOSCOPE?
- TIME VS FREQUENCY DOMAIN





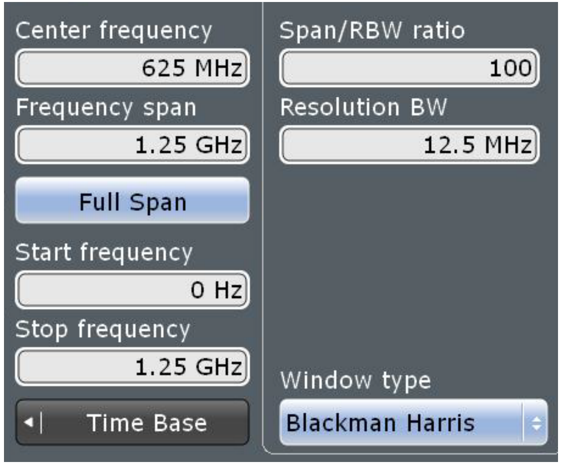
Time Domain View



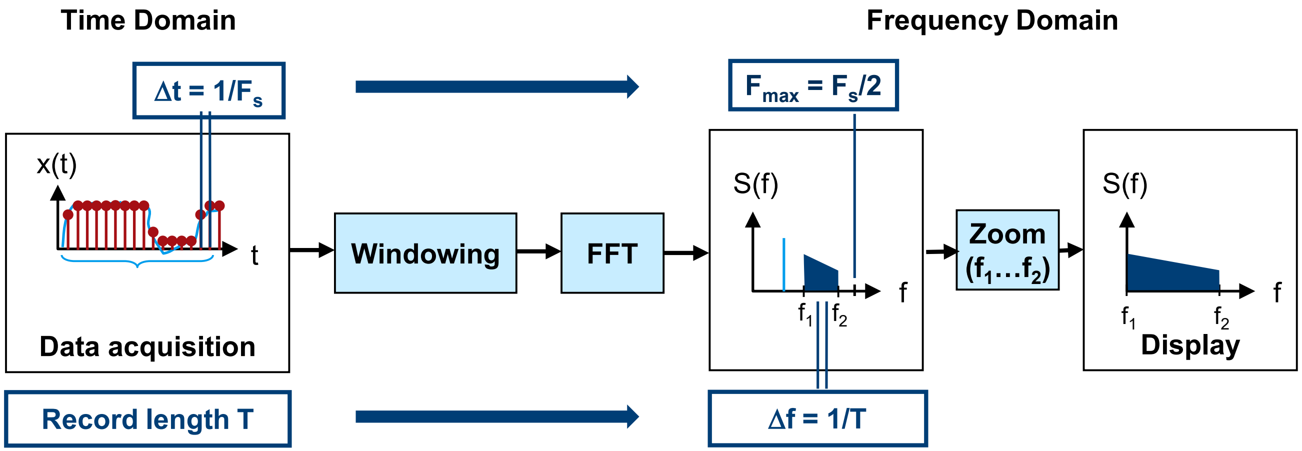
Frequency Domain View

EMI ANALYSIS WITH OSCILLOSCOPES?
USUAL OBJECTIONS

- **… but is the scope sensitive enough?**
  - Yes: 1mV/Div gives **DANL** of ~0 dBµV (@500 MHz, 120 kHz RBW, 50 Ω)
- **… but isn‘t it difficult to use?**
  - No: spectrum analyzer use model
- **… but what about a (6 dB) EMI filter?**
  - Not necessary for EMI debugging
- **… and what about limit lines?**
  - The mask tool includes limit line functionality



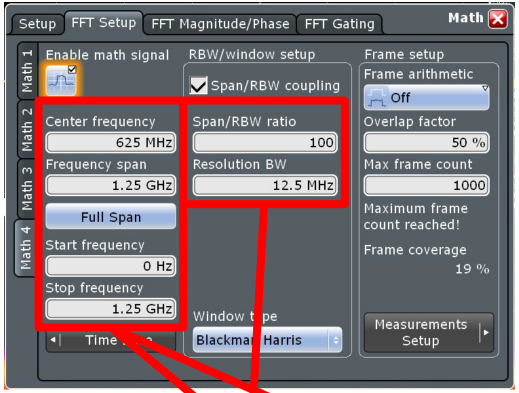
FFT AS BASIS FOR EMI DEBUGGING WITH OSCILLOSCOPES
CONVENTIONAL FFT IMPLEMENTATION ON A SCOPE



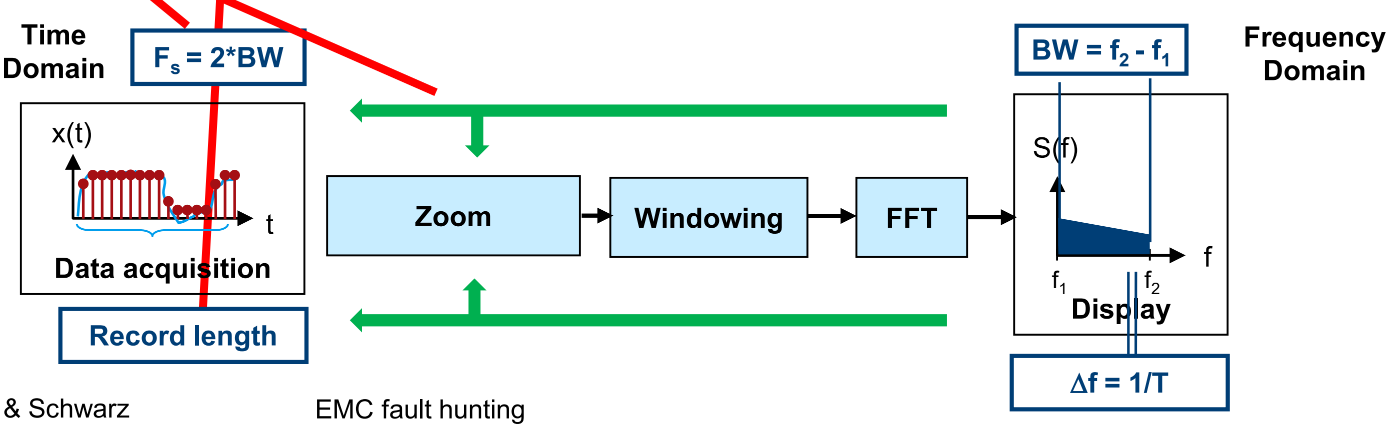
Disadvantages:

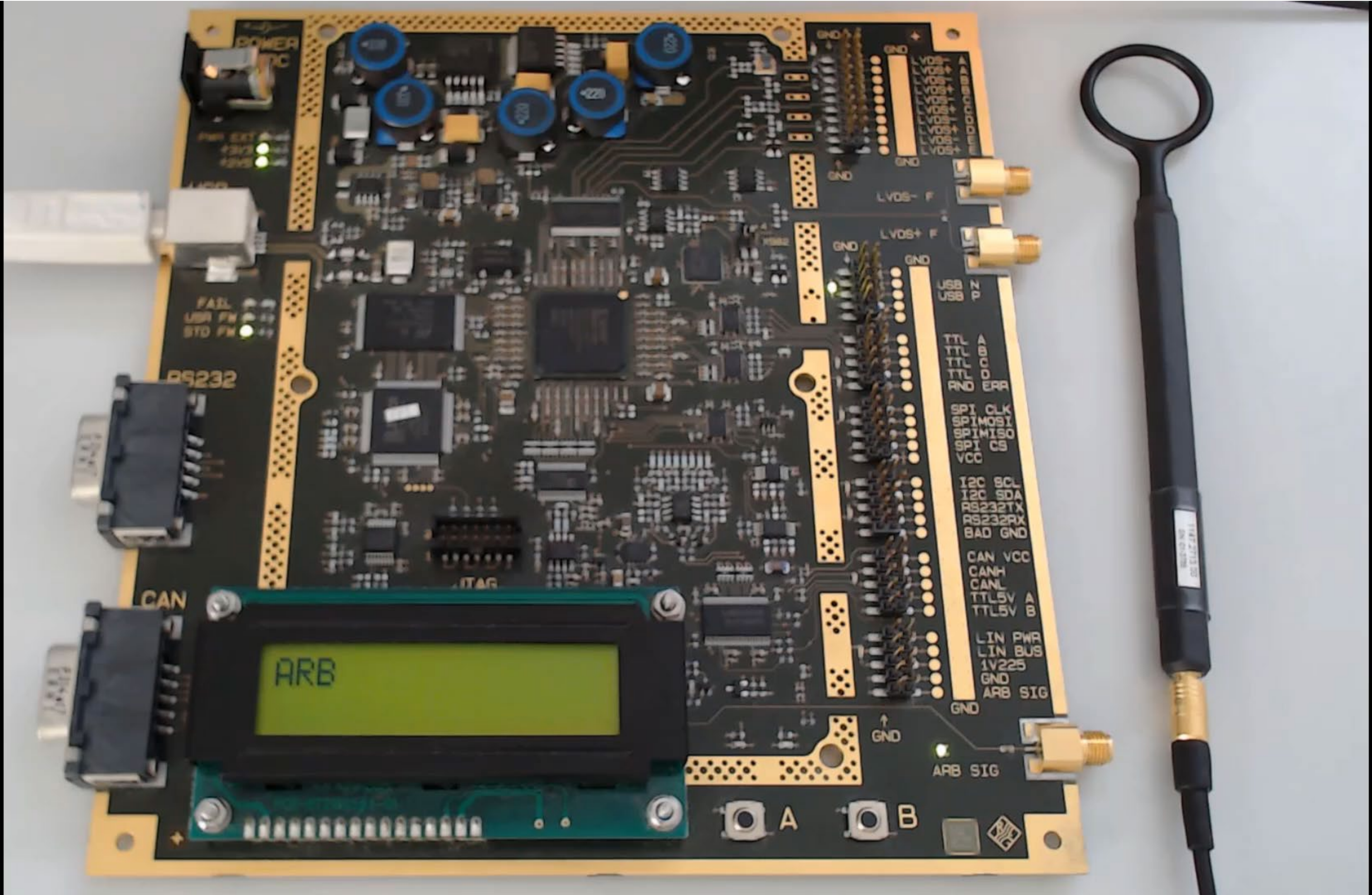
– Time domain settings define frequency domain
– Zoom in frequency domain does not give more details
– Correlated time-frequency analysis not possible

R&S RTE/RTO/RTP – HIGH-PERFORMANCE FFT IMPLEMENTATION WITH SPECTRUM ANALYZER USE MODEL



- **Spectrum Analyzer Use Model**
  - Frequency domain controls time domain: Record length and sampling rate are updated automatically
- **FFT for maximum performance**
  - Frequency zoom *before* FFT: e.g. 500 MHz center / 10 MHz span: 20 MS/s instead of 1 GS/s





POWER
RS232
CAN
JTAG
FAIL
USR FW
STD FW
ARB
LVDS- A
LVDS+ A
LVDS- B
LVDS+ B
LVDS- C
LVDS+ C
LVDS- D
LVDS+ D
LVDS- E
LVDS+ E
GND
LVDS- F
LVDS+ F
USB N
USB P
TTL A
TTL B
TTL C
TTL D
AND ERR
SPI CLK
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SPI CS
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I2C SCL
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RS232TX
RS232RX
BAD GND
CAN VCC
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CANL
TTL5V A
TTL5V B
LIN PWR
LIN BUS
1V225
GND
ARB SIG
GND
ARB SIG
A
B

WHEN TO USE WHICH INSTRUMENT? FROM COMPLIANCE TO EMI DEBUGGING

EMI Receiver

- 6 dB Filters
- Preselector available
- Highest selectivity
- CISPR compliant detectors
- Demodulation of signals possible
- Time domain scan reduces sweep time to a minimum

Spectrum-/ Signalanalyzer

- 3 dB Filters
- High selectivity
- High sensitivity
- Analysis on wide frequency range possible (today up to 8 GHz internal analysis BW available)
- Demodulation of signals possible

Oscilloscope

- 3 dB Filter
- One shot analysis of whole frequency range
- Measures down to DC
- Trigger capabilities for signal separation
- Mask testing in frequency and time domain
- Gated FFT possible
- Multichannel coherent receiver

WHEN TO USE WHICH INSTRUMENT?
FROM COMPLIANCE TO EMI DEBUGGING

EMI Receiver

- 6 dB Filters
- Preselector avial
- Highest selec
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Full Compliance

Spectrum-/ Signalanalyzer

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- High sensitivity
- Analysis on quency range pc day up to 8 GHz i nalysis BW av
- ulation of signals sible

(Pre-) Compliance

Oscilloscope

- 3 dB Filter
- One shot analysis frequency ranc
- Measures C
- Trigger ies for signal sep
- ting in frequency ne domain
- ated FFT possible
- Multichannel coherent receiver

EMI Debugging

Find out more

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For further questions please contact
sales.germany@rohde-schwarz.com
with subject “Oscilloscope Fundamentals”

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Make ideas real