Oscilloscope Basics

What my Digital Oscilloscope is capable of …

TELEDYNE LECROY
Everywhereyoulook™

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Overview

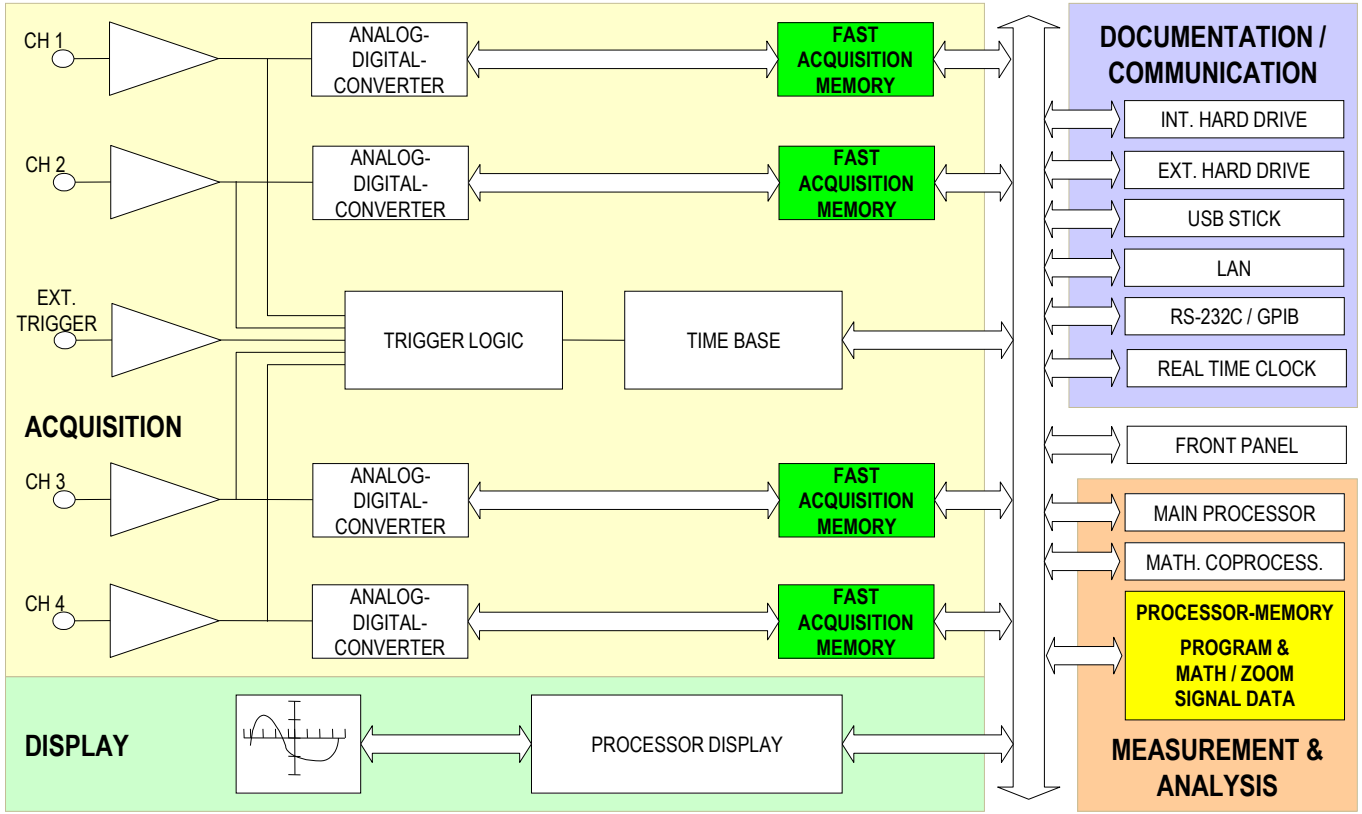
- Fundamentals
  - Scope general architecture
  - Analog and Digital BandWidth
  - Sample rate, Time Windows, trigger time
  - Aliasing
  - Vertical resolution
- Screen display
  - How can 1.000.000 points be represented with 1000 pixels?
  - How to use all available vertical bits
  - YX display

oversview

- Trigger
  - Trigger modes
  - Trigger definition
  - Trigger rate
  - Sequence Mode

Oscilloscope Fundamentals

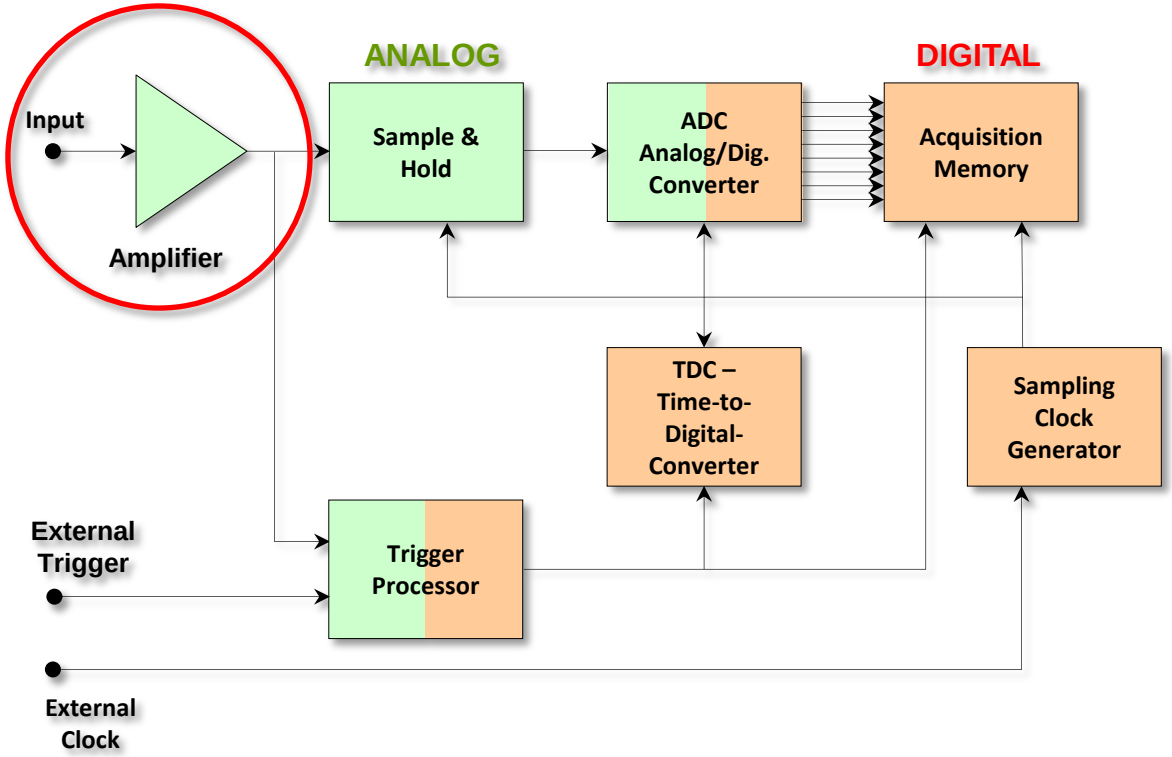
Basic Setup of a Digital Oscilloscope



- **ACQUISITION**
  - Input Amplifier
  - Analog/Digital Converter
  - Acquisition Memory
  - Trigger-Logic
  - Time Base
- **DISPLAY**
  - Display Processor
  - Display Grid
- **MEASUREMENT/ ANALYSIS**
  - Processor
  - Math Co-Processor
  - Processor Memory
- **DOCUMENTATION**
  - Hard Drive(s)
  - USB-Stick
  - Interfaces

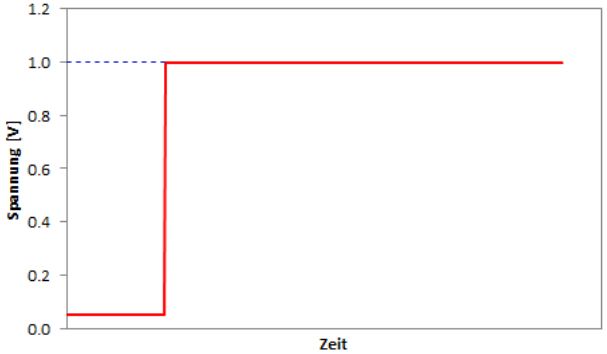
Analog Bandwidth

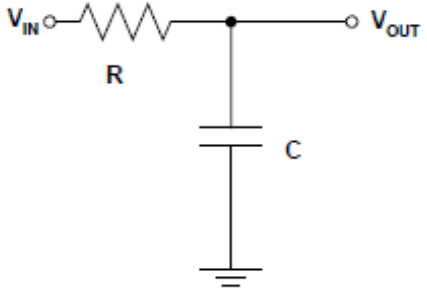
- Frequency at which a sinusoidal input signal is attenuated to 70.7% of the true signal amplitude (-3dB-bandwidth)
- This figure generally depends on the analog bandwidth of the input amplifier
- The bandwidth can be limited depending on the software (software filter); upgrade options can be available

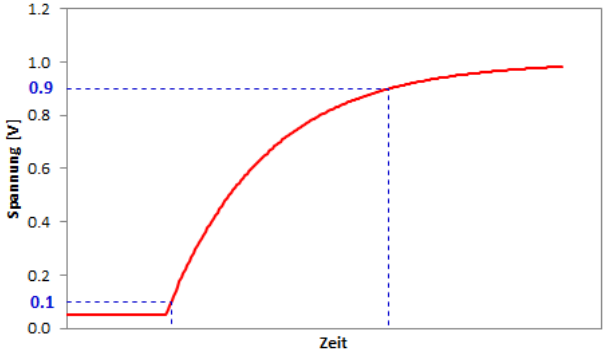


Rise Time

- For oscilloscopes up to 2 GHz: Rise time (10% .. 90%) is described as follows







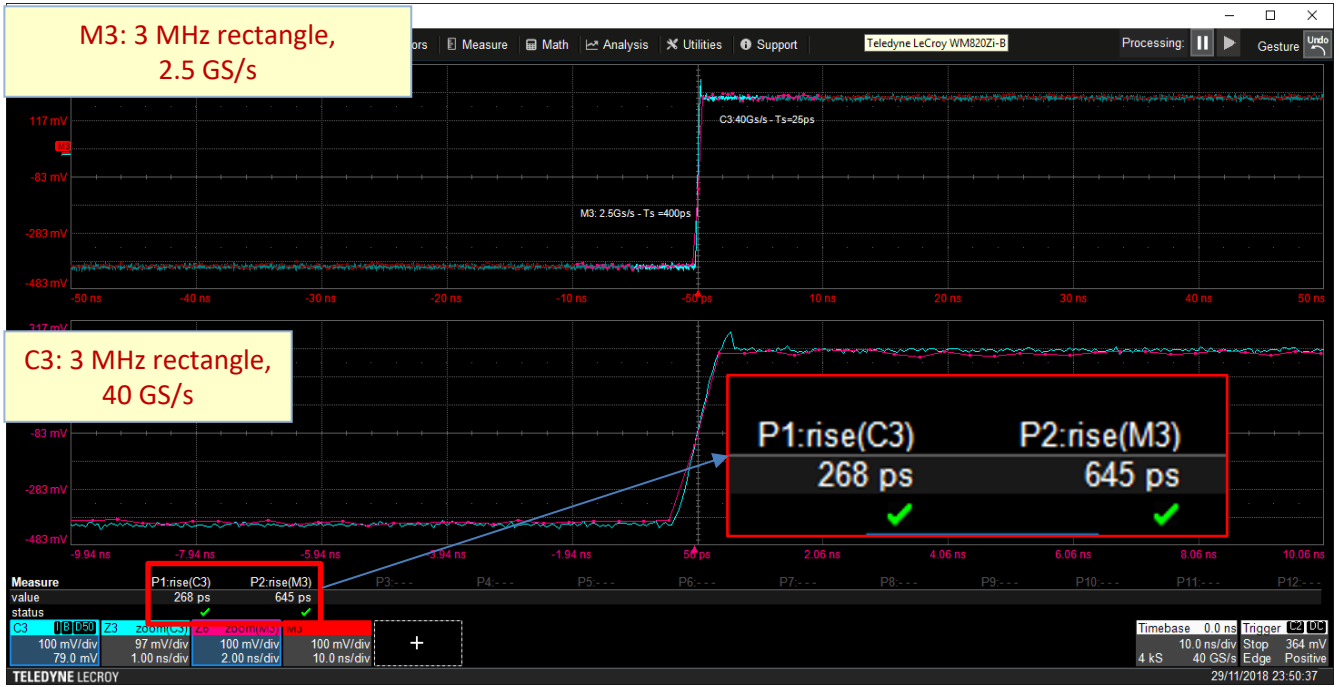
Rise Time = 0.35 / Bandwidth

- For oscilloscopes with higher bandwidths this factor is approximately '0.4/Bandwidth' and depends on the slope of the filter in the input amplifier

$$
\begin{aligned}
V_{OUT} &= V_{IN}\left(1 - e^{-\frac{t}{RC}}\right) \\
e^{-\frac{t}{RC}} &= 1 - V_{OUT}/V_{IN} \\
-t/RC &= ln(1 - V_{OUT}/V_{IN}) \\
t &= -RC \times ln(1 - V_{OUT}/V_{IN}) \\
\Rightarrow\ t_{10\%} &= 0.1\ RC \quad and \quad t_{90\%} = 2.3\ RC \\
\Rightarrow\ t_{RISE} &= t_{90\%} - t_{10\%} = 2.2\ RC \\
&= 2.2/2\pi f_{BW} \\
&= 0.35/f_{BW}
\end{aligned}
$$

But there is also a digital bandwidth depending on the sampling

- Analog Bandwidth
  - Bandwidth of the analog amplifier



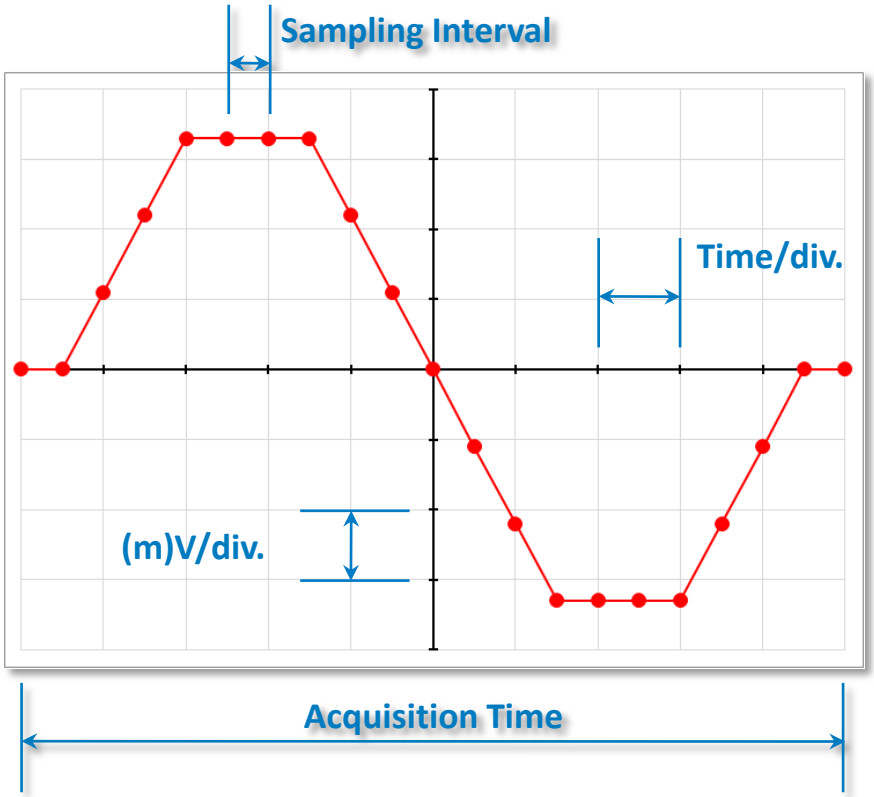
- Digital Bandwidth
  - Depends on the real time sampling rate
  - Frequency response of the analog/digital converters
  - Memory depth and sampling rate define the time that can be captured

Sampling Rate

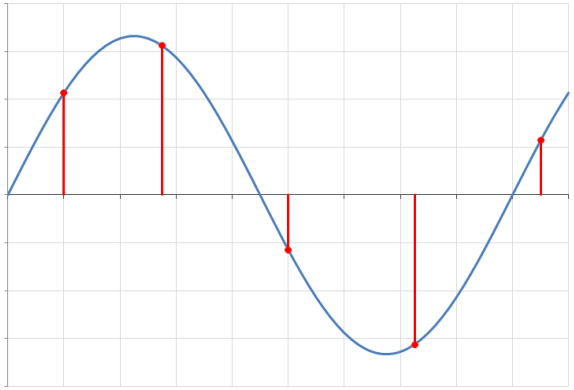
- Maximum Sampling Rate, shown in Samples/Sec. [S/s], refers to the frequency at which the A/D Converter samples the signal per second

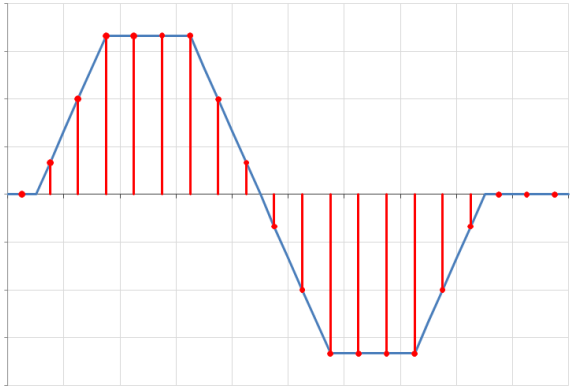
We distinguish between:

- *Single Shot:*
  Maximum sampling rate for single signals
- *Random Interleave / Equivalent Time Sampling:*
  Repeated sampling of a periodic signal with a stable trigger point



Real Time Sampling

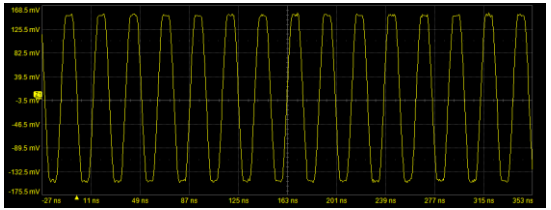




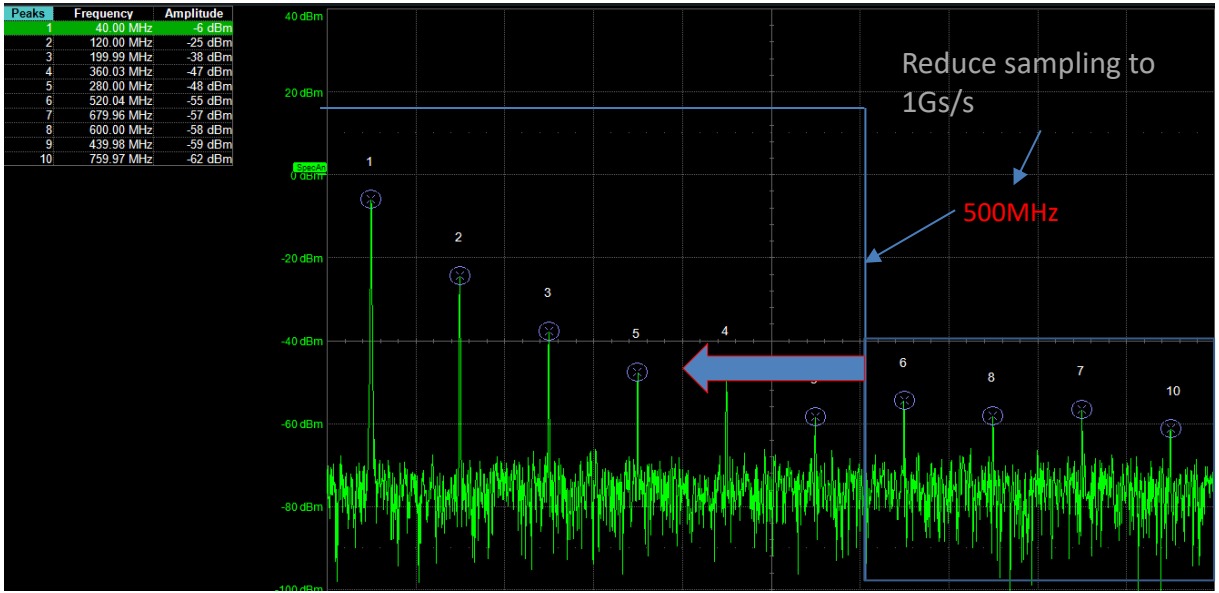
- Sine Wave:
  - Single frequency
  - Sampling rate > 2 x max. frequency
  - 'Nyquist-Theorem'
- Pulse, Rectangular Waves
  - Broadband
  - Sampling rate > 10 x Max. frequency
- Realistically:
  - 10-fold oversampling

Sampling at 1.6GHz

All harmonics are included…Signal perfectly reconstructed



Peaks	Frequency	Amplitude
1	40.00 MHz	-6 dBm
2	120.00 MHz	-25 dBm
3	199.99 MHz	-38 dBm
4	360.03 MHz	-47 dBm
5	280.00 MHz	-48 dBm
6	520.04 MHz	-55 dBm
7	679.96 MHz	-57 dBm
8	600.00 MHz	-58 dBm
9	439.98 MHz	-59 dBm
10	759.97 MHz	-62 dBm



All harmonics above 500MHz
Will be flipped like in a mirror in the 500MHz-DC band

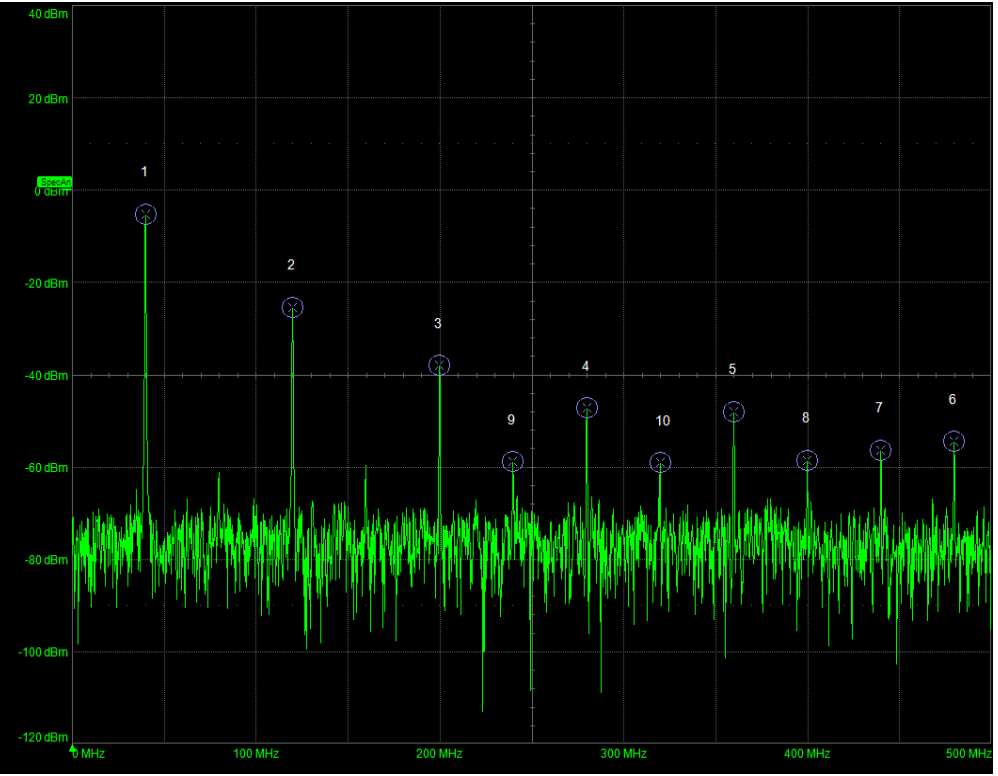
F6 = 520 -500 = 20 will be flipped at 500-20= 480
F8 =600 -500 = 100 will be flipped at 500-100 = 400
F7 = 680 -500=180 will be flipped at 500-180 =320

Without antialising filter we are supposed to have harmonics components not really present in the original signal

Folded spectrum…the signal reconstructed is not my signal

Peaks	Frequency	Amplitude
1	40.00 MHz	-5 dBm
2	120.00 MHz	-26 dBm
3	200.00 MHz	-38 dBm
4	280.00 MHz	-48 dBm
5	359.99 MHz	-48 dBm
6	480.01 MHz	-55 dBm
7	439.98 MHz	-57 dBm
8	400.03 MHz	-59 dBm
9	239.99 MHz	-59 dBm
10	320.00 MHz	-59 dBm

New peaks at
480
400 MHZ
320



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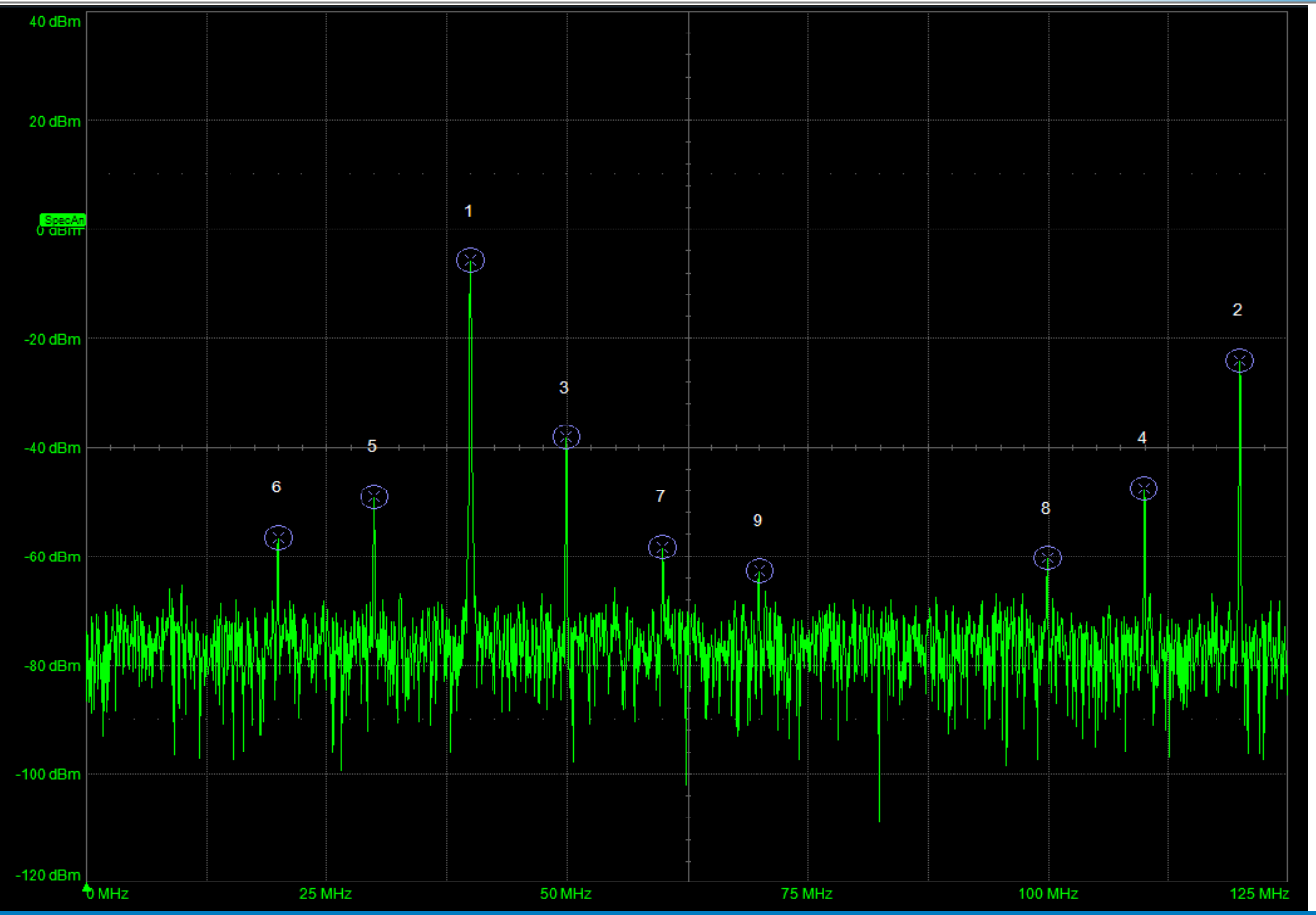
9	239.99 MHz	-59 dBm
10	320.00 MHz	-59 dBm

Folded spectrum…the signal reconstructed is not my signal

Peaks	Frequency	Amplitude
1	40.000 MHz	-6 dBm
2	120.000 MHz	-24 dBm
3	50.000 MHz	-39 dBm
4	110.001 MHz	-48 dBm
5	30.005 MHz	-49 dBm
6	19.994 MHz	-57 dBm
7	59.998 MHz	-59 dBm
8	99.976 MHz	-61 dBm
9	70.007 MHz	-63 dBm

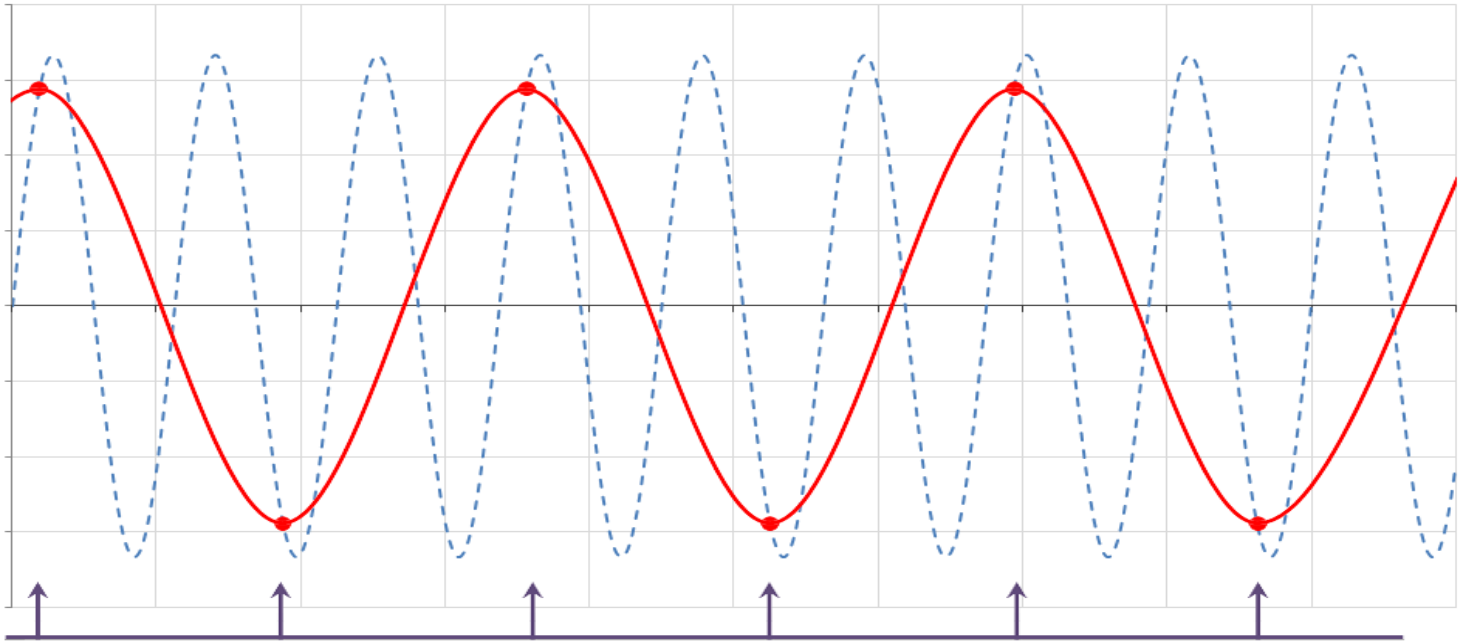
At 250MS/s
We have harmonics below the fundamental



Aliasing

Reason: Sampling rate too low

Consequence: wrong unstable waveform, wrong measurements, false artifacts and frequency components…



Aliasing

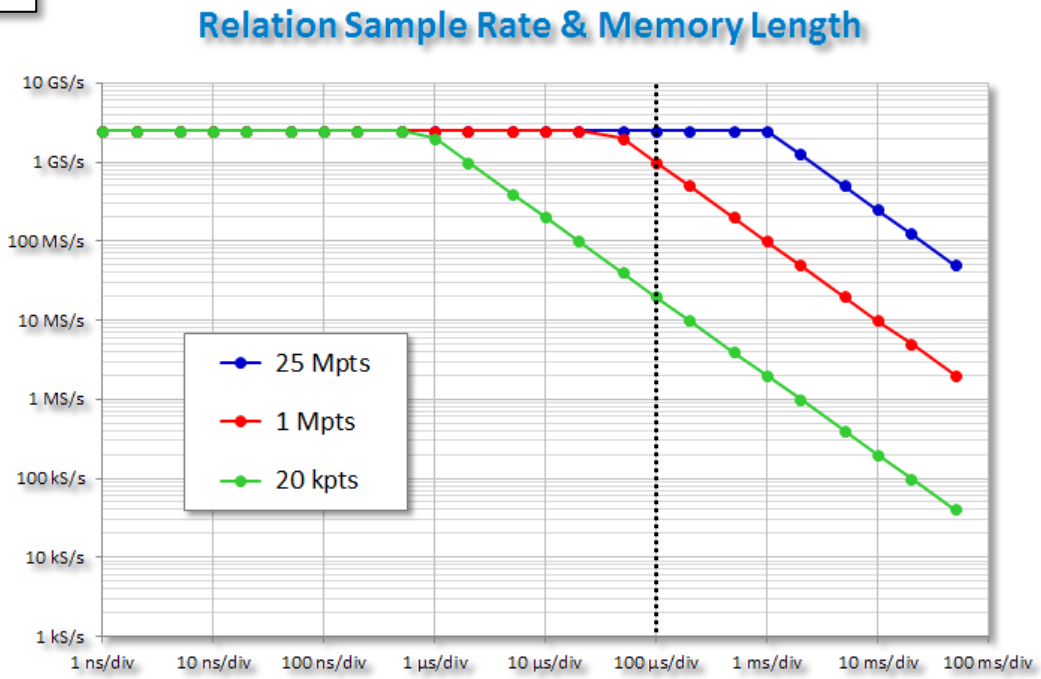
- Real Example of a rectangular wave with aliasing

Relationship between Memory Length & Sample Rate

$$Sample\ Rate = \frac{Memory\ Length}{Time\ Base\ * 10\ div}$$

- A larger memory enables longer recording at a higher sampling rate
- Examples (at 100 µs/div):

20'000 points / 1 ms	=	20 MS/s
1'000'000 points / 1 ms	=	1 GS/s
25'000'000 points / 1 ms	=	25 GS/s



Vertical Resolution of an Oscilloscope

- The number of Bits of the ADC determines the vertical resolution of the oscilloscope
- A higher vertical resolution means that smaller details are visible and more precise measurements are possible
- An improvement of the accuracy is essential to be able convert the higher resolution in higher precision of measurements

Teledyne LeCroy
HDO Series
with 12-Bit A/D converter

16x higher Resolution

What Does the Vertical Definition Mean in Practice?

- Available quantization levels of the ADC = 2^N (N = Number of Bits)

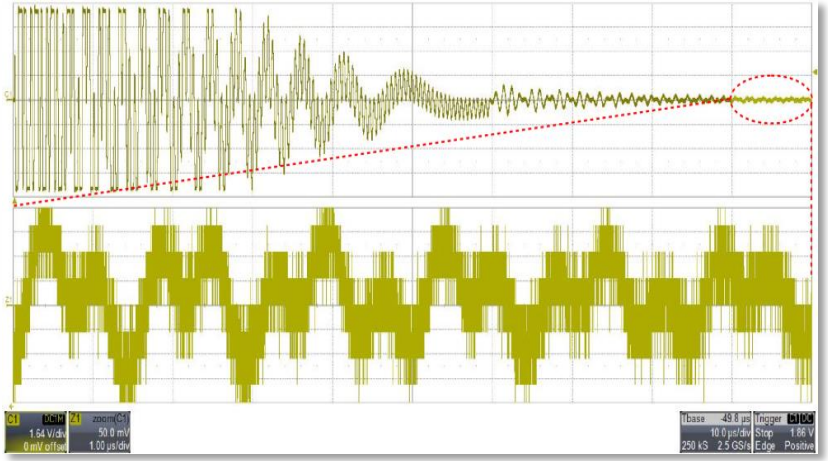
ADC resolution	Amount of possible values	Dynamic
8 Bit	256	~48 dB
12 Bit	4'096	~72 dB

- This means that a 1.0 V measurement window can be resolved as follows:
  - 8 Bit with 256 levels ⇒ 3.91 mV resolution
  - 12 Bit with 4'096 levels ⇒ 0.24 mV resolution

HD4096 Advantages – More Signal Details

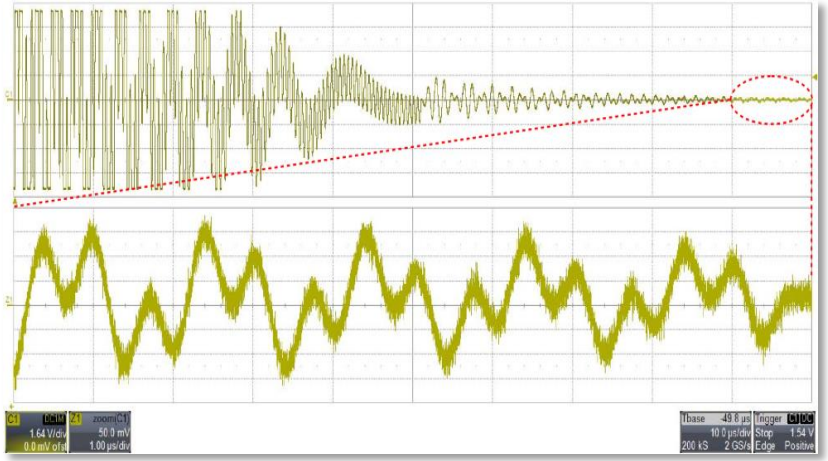
- Shutdown processes can be better evaluated with real 12-Bit resolution
  - Averaging cannot be used because it is an isolated event

Shutdown process recorded with an 8-Bit oscilloscope



The oscillation disappears in the noise

Shutdown process recorded with a 12-Bit oscilloscope



The oscillation is clearly visible

Screen display

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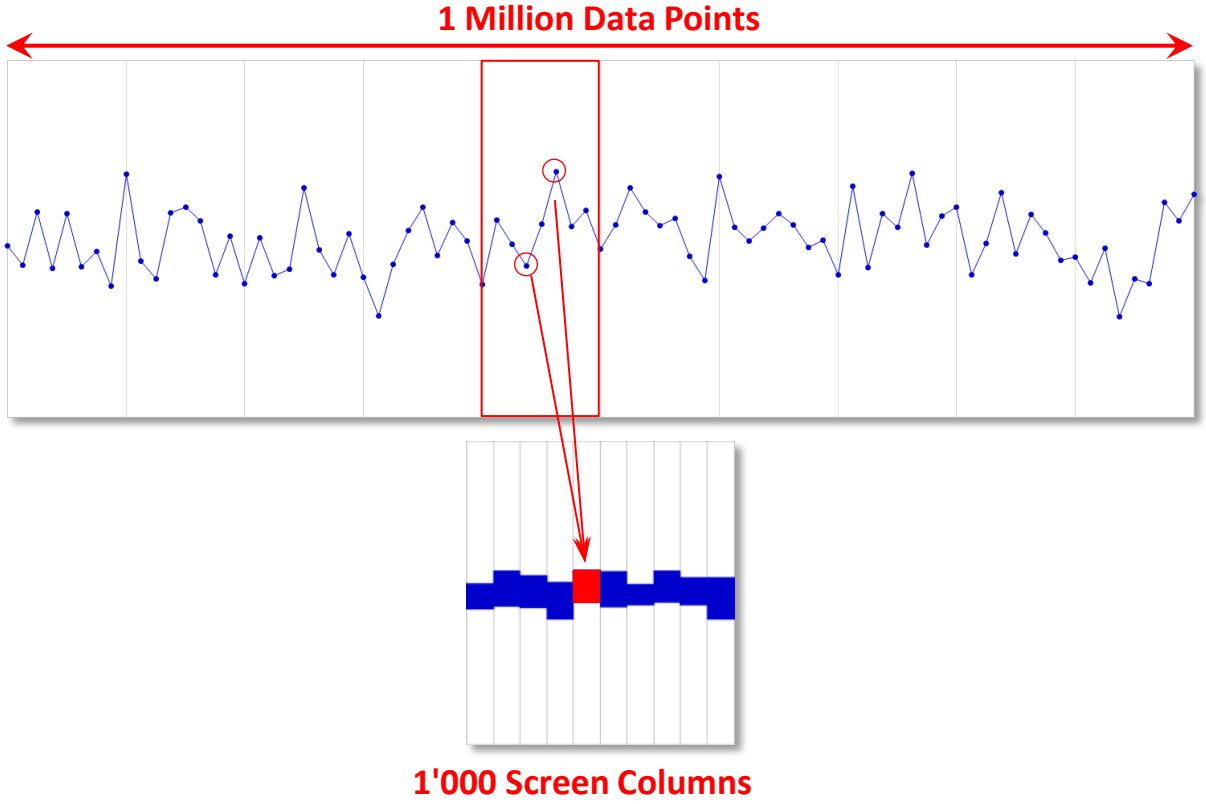
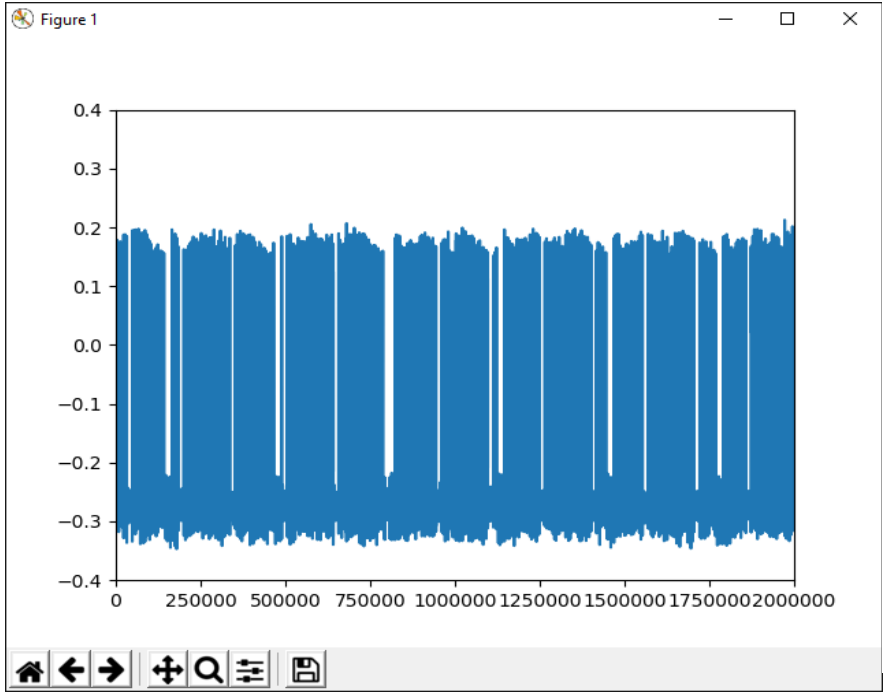
Screen Display

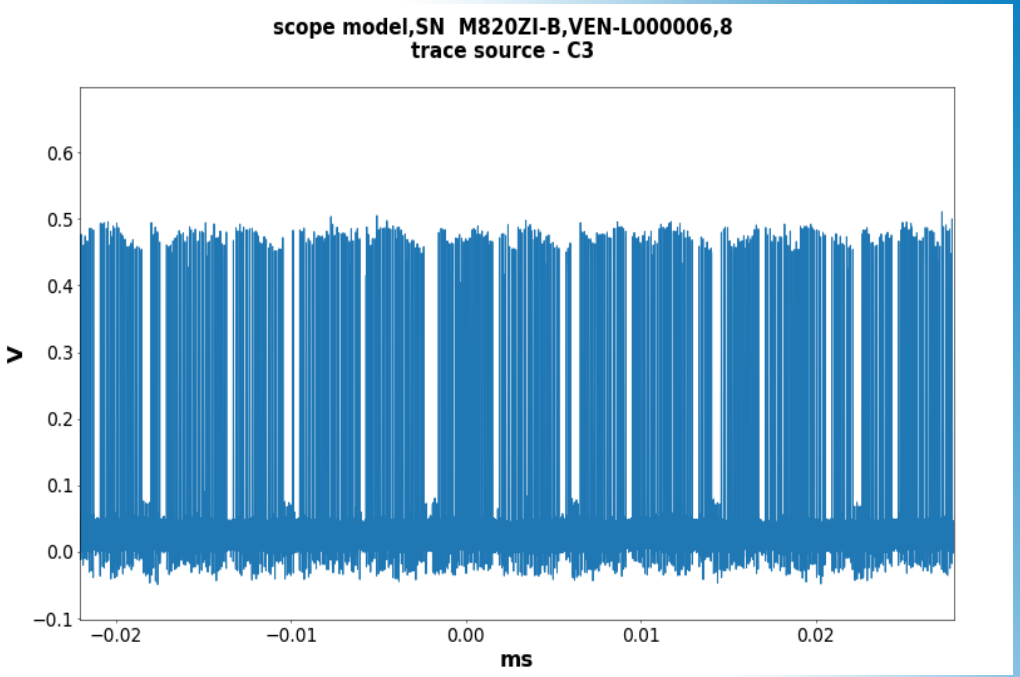
- Data reduction for display ⇒ max/min display

- Grouping of the raw data
- Determine of max/min values
- Display the max/min values in the form of a vertical bar in the screen columns
- 'Visual noise' by displaying all acquired data points

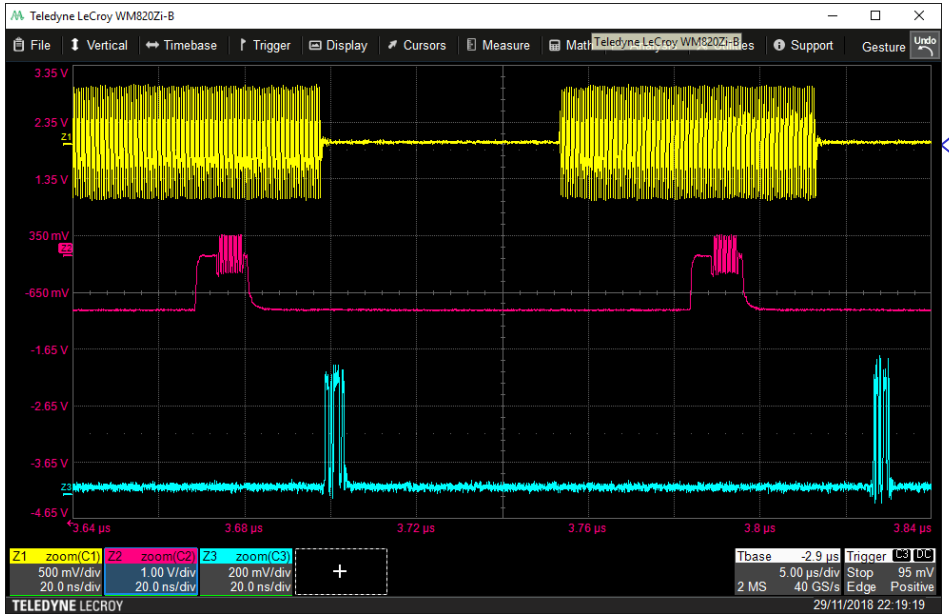


Trace 2Ms – pixels on screen less than 1000

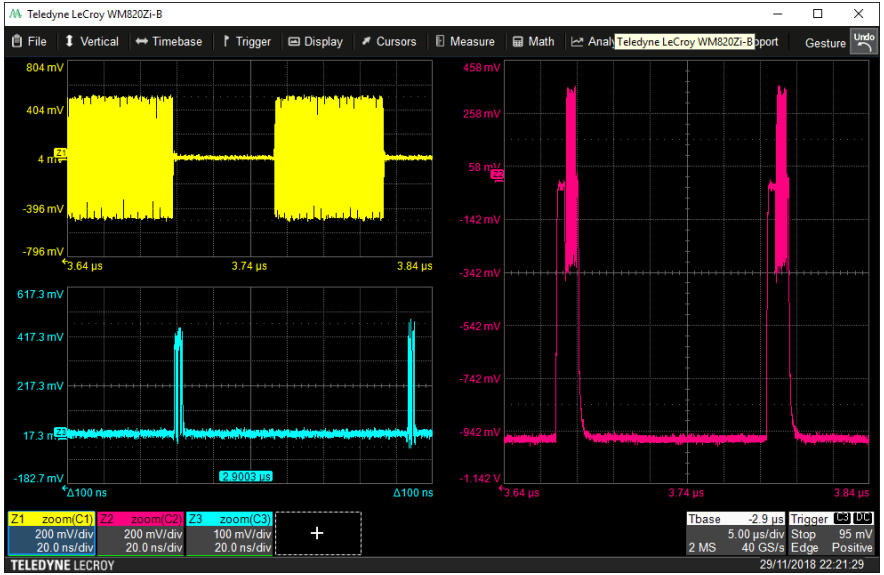




Vertical Resolution: how to use full vertical dynamic range



If the signal is scaled to ¼th of the grid, the vertical resolution of an 8 Bit scope is reduced to 6 Bit. If the ADC is 12 bit then you can still count on full 10 bit/sample

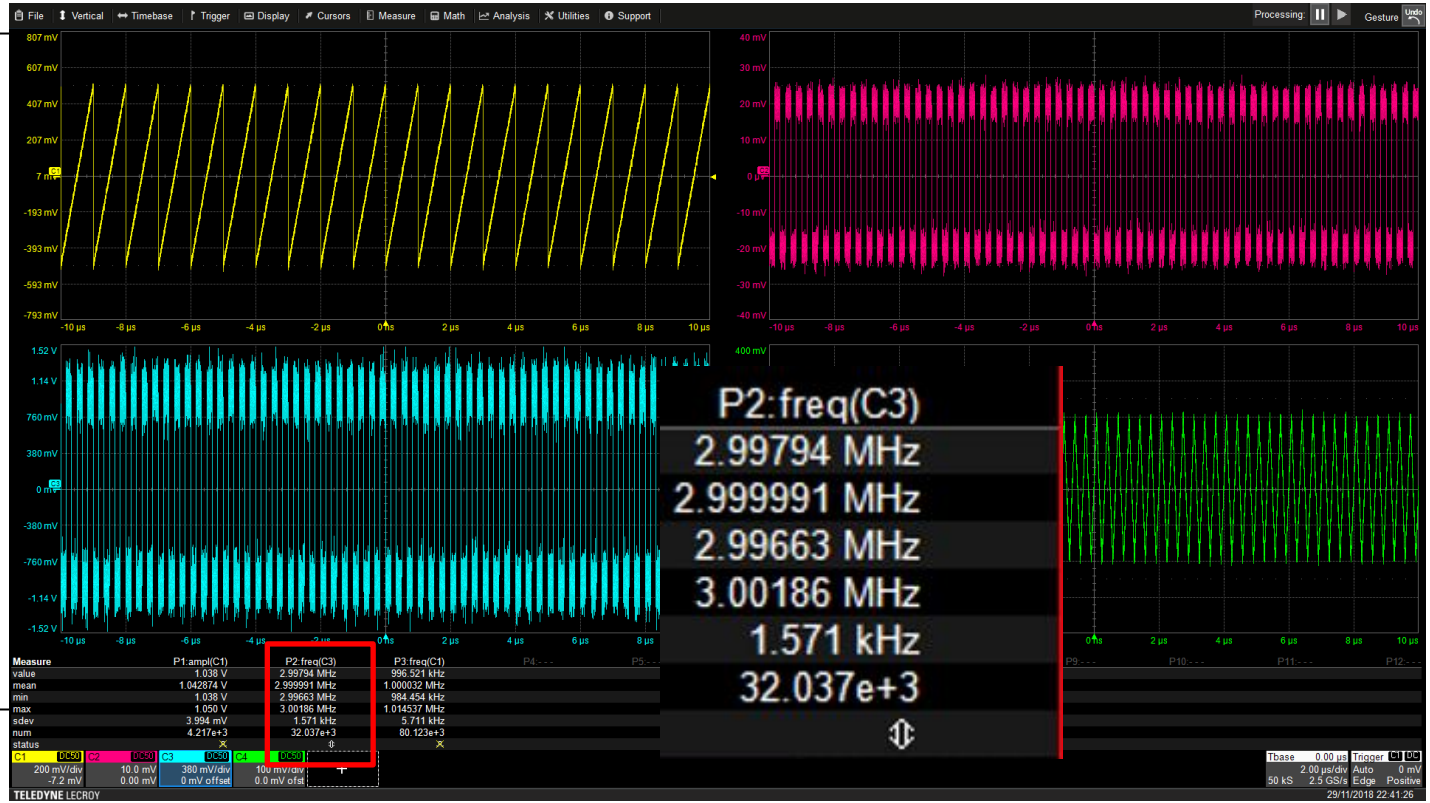


bits (8 or 12) of the A/D converter are used on the full vertical scale…setting the trace to occupy at least 80% of the vertical grid helps using as many bits as possible…using the 100% of the scale can create problems because of clipping

Avoid signal clipping: the scope gives you warnings

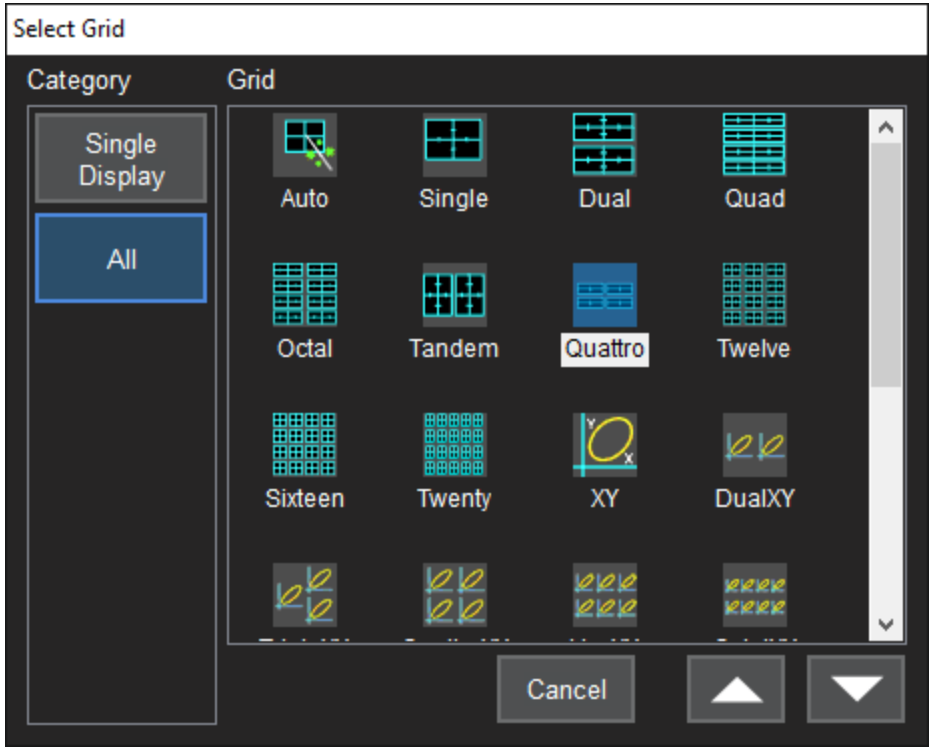
Multi-Grid Display

- The mult-grid allows independent optimal scaling of different signals without overlap.
- Use all vertical bit
- Better accuracy
- More room for vertical zoom
- Make sure noise is not clipping the signal

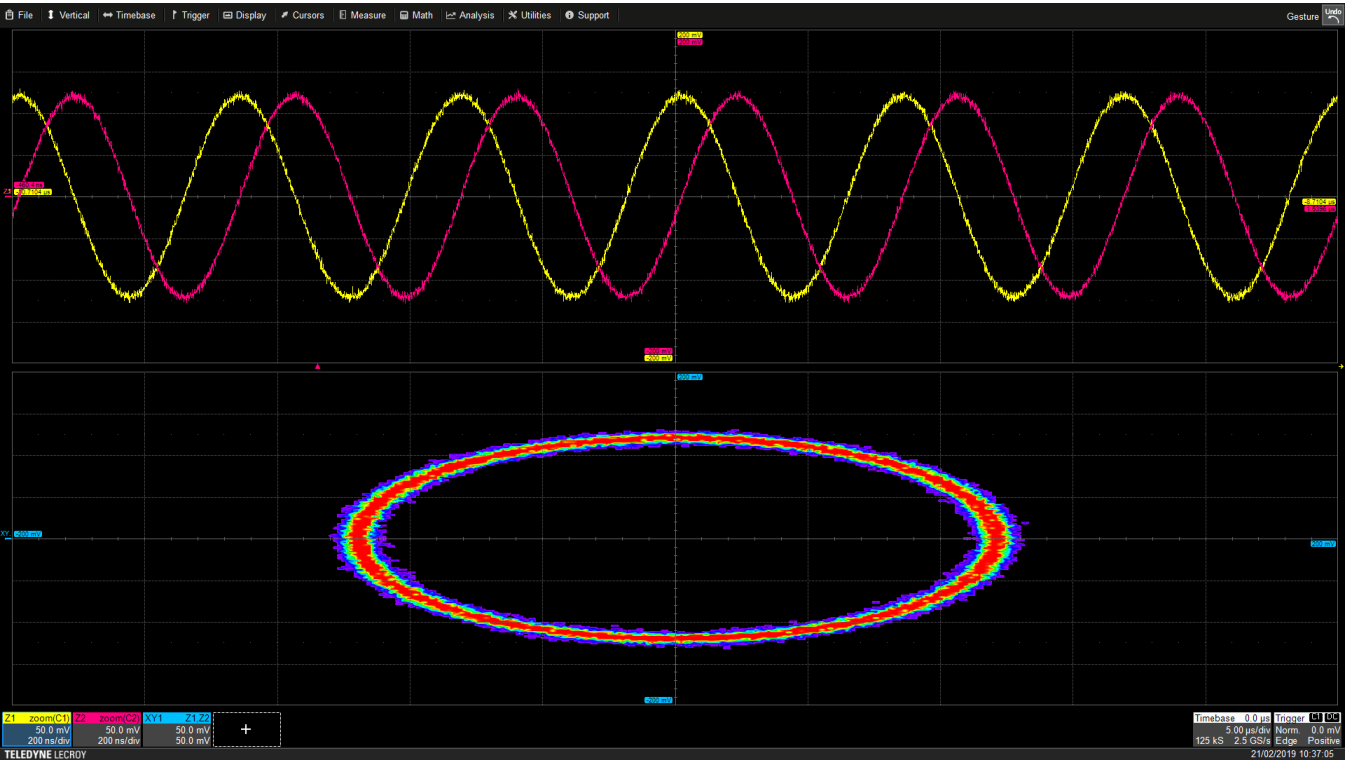


Grids / Display

- Depending on the oscilloscope model and installed options, several display (grid) settings are available.
- Example: display split horizontally or vertically into 2 grids.
- Depending on the model, up to 32 different display modes are available.



XY Display



Both traces must have the same number of samples

X has 10 grids
Y has 8 grids
H and V scales still have the same V/div, X axis is only using 4 grids

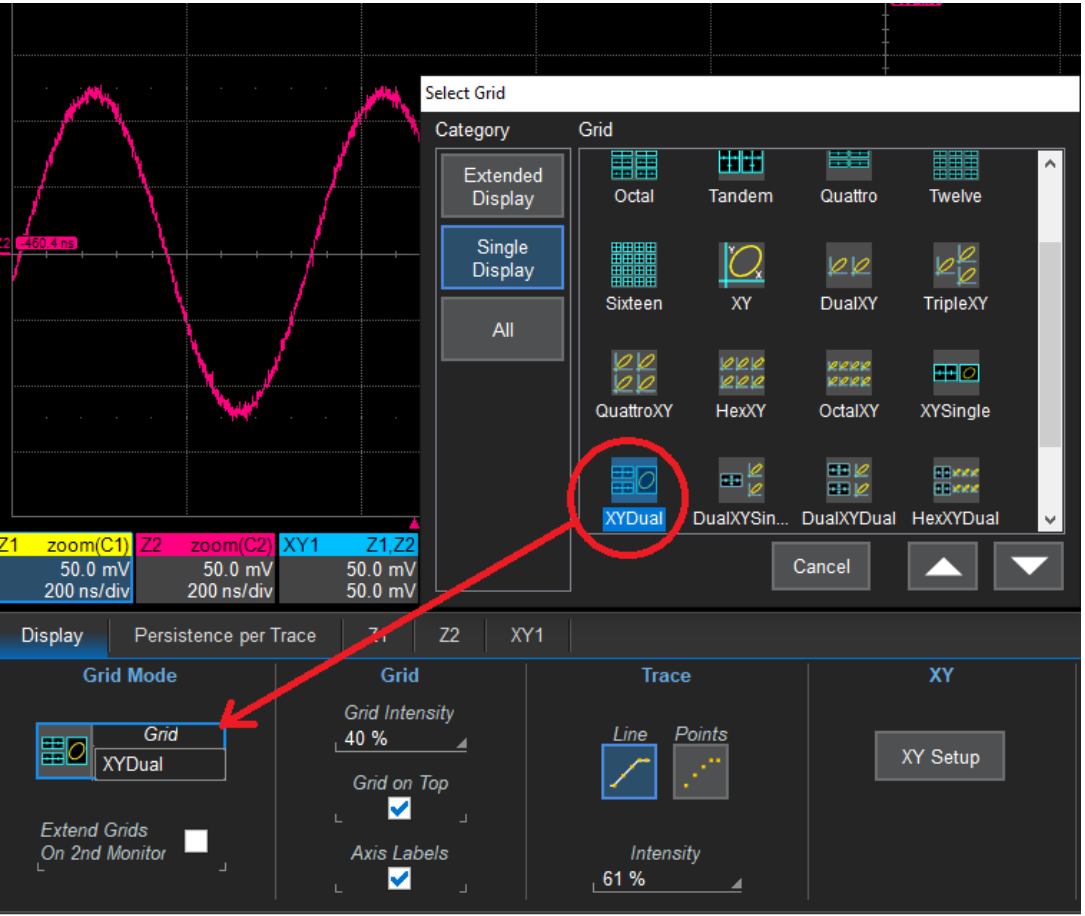
The ellipse is caused by rectangular and not square grids

Select Display, Display Setup, XY setup

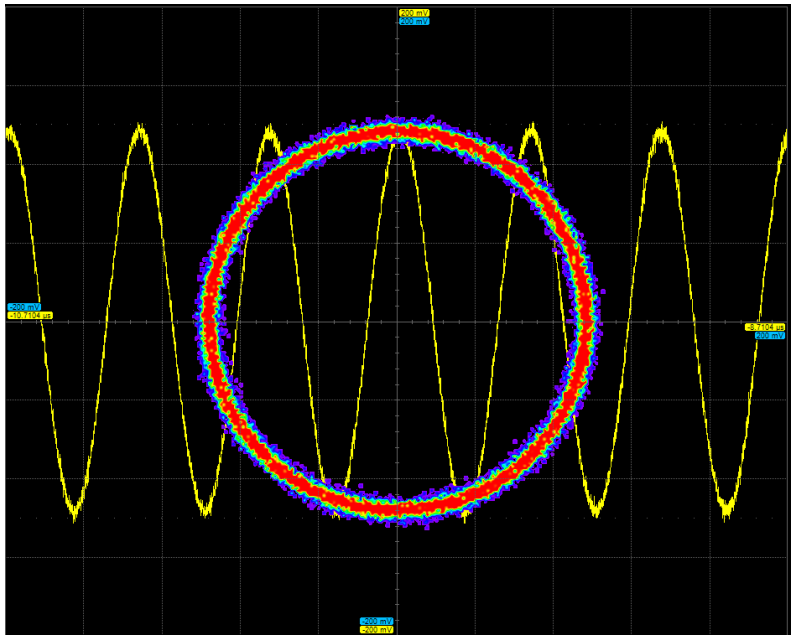
XY setup

Ye, we are Limited to 12 XY plots

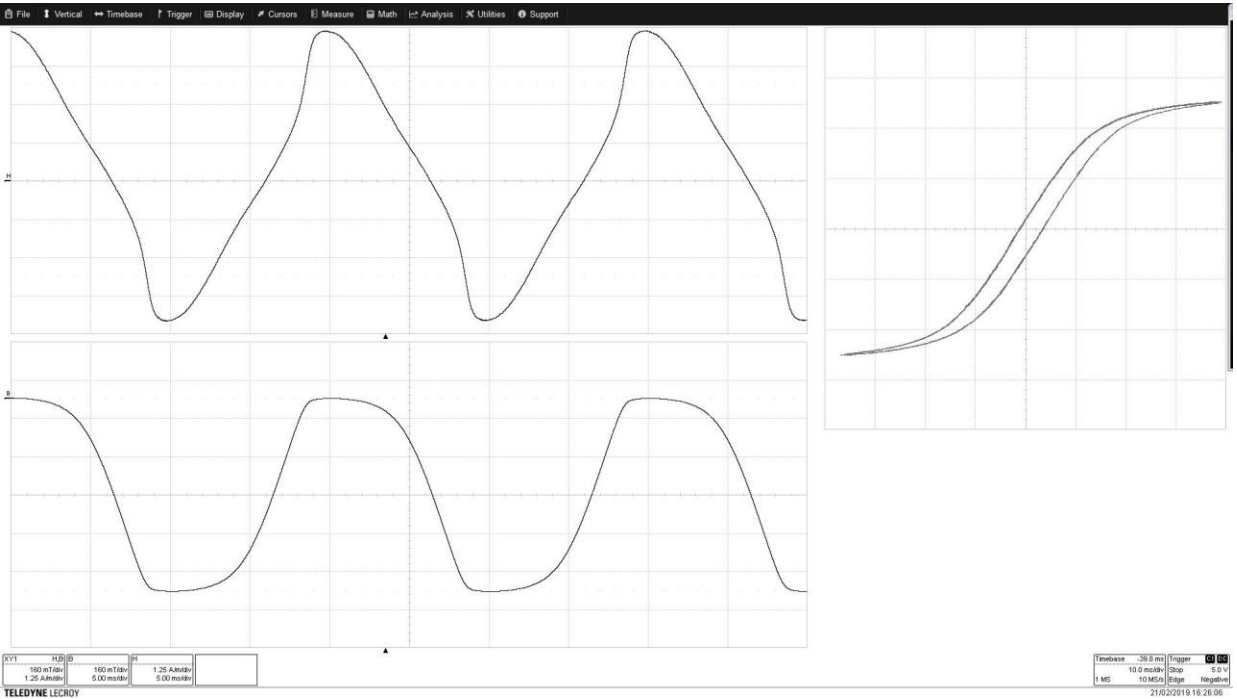
Predefined XY displays



Predefined XY displays are available but not mandatory, you can display and overlap V/t with XY traces. Any grid can be used for an XY plot



XY display one of many applications: B-H Curve



Power analysis SW package

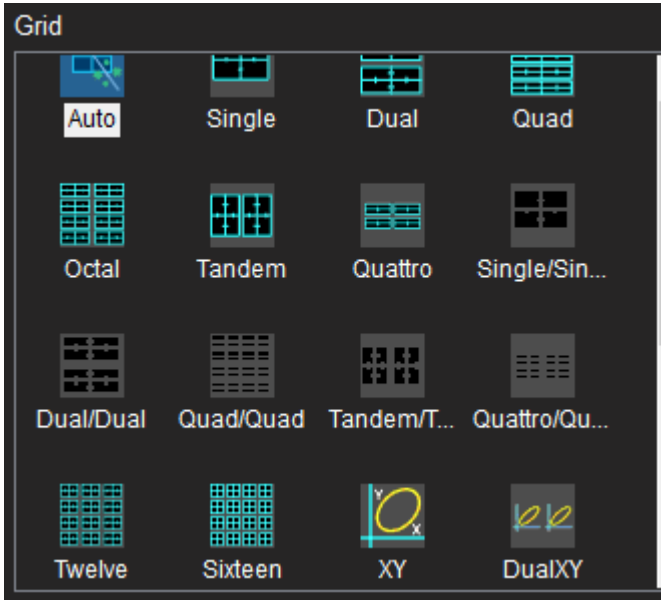
Traces captured are Voltage and Current
At the inductor

$$B(t) = \frac{A}{N}\int V(t)\,dt$$

$$H(t) = \frac{N}{L_e}I(t)$$

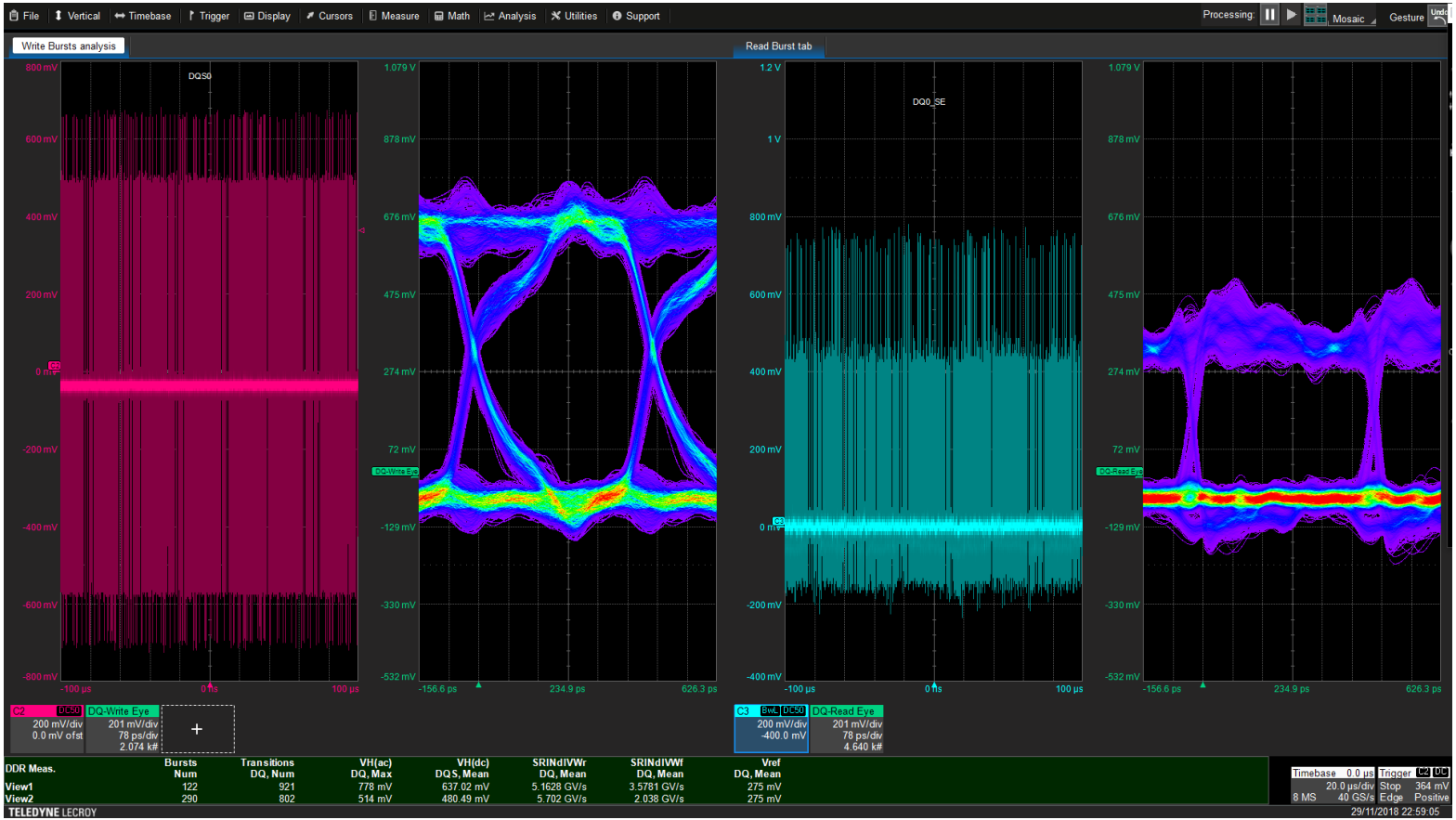
How many grids are available?

- Depends on the scope model, number of channels, applications



These are present on HDO6K

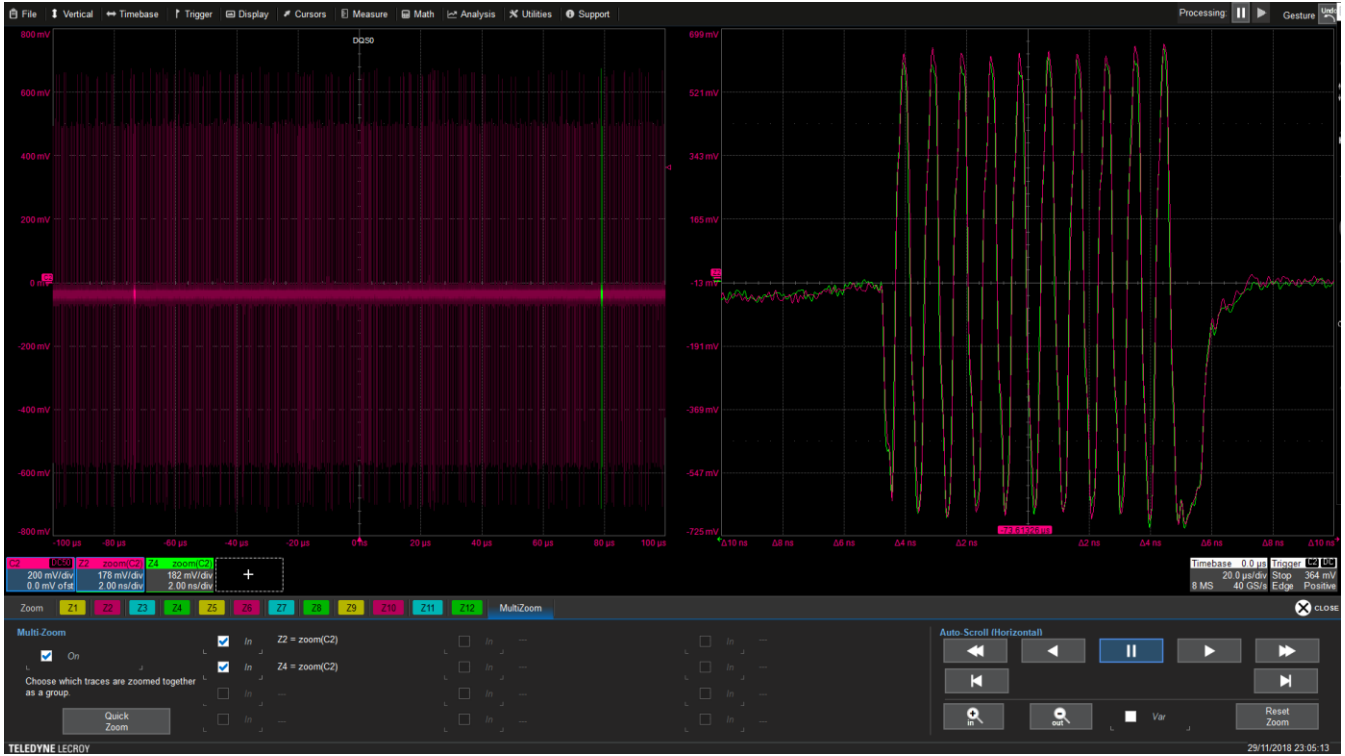
Some models offer Q-Scape Display



Screen Display – Zoom

Zoom Functions are never enough…

Any trace can have as many zoom as available across the entire acquisition, it can be a captured trace a zoom or any math function…no restriction



Multizoom can link multiple zoomed traces together for faster signal analysis

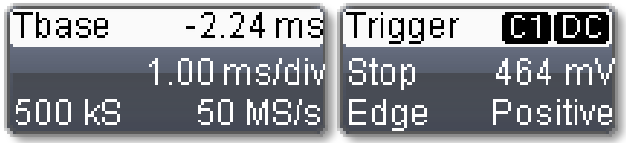
Number of ZOOM traces depends on the scope model as well

HDO6K has 8
HDO4K has 4
Higher level Model have 12

Trigger

Trigger – Main purpose and overview

- Start of Acquisition for Single Events
- Synchronizing the Acquisition ⇒ Stable Image
- Trigger Modes
  - **AUTO Trigger:** continuous triggering on internal time base
  - **NORMAL Trigger:** continuous triggering on defined event (edge, pulse width, logic, smart, …)
  - **SINGLE Trigger:** single triggering on defined event (edge, pulse width, logic, smart, TV, …)
- Trigger Sources:
  - Analog Channels 1-4
  - Digital Channels
  - External Trigger Input



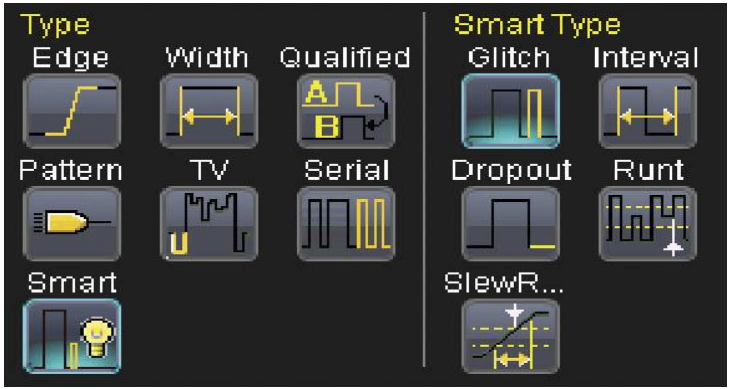
Trigger – Modes

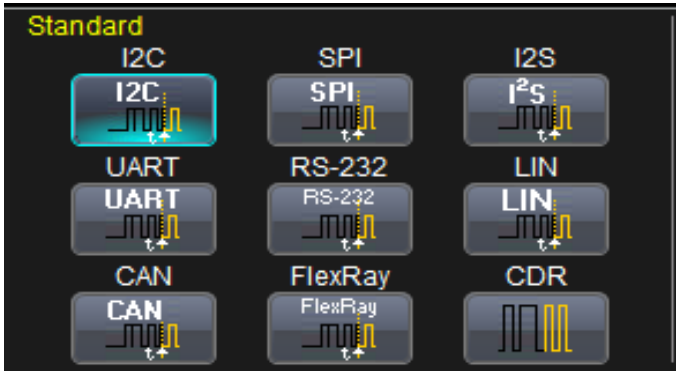
Oscilloscopes have 4 trigger states

- Auto-Trigger
  - If the preset trigger condition is not met within a defined time window, an automatic trigger event is generated regardless
- Normal-Trigger
  - The trigger event only takes place if the preset trigger condition is met
- Single-Trigger
  - There will be one trigger event at the first time the preset trigger condition is met, after this the stop-mode is activated
- Stop-Mode
  - No further trigger events, the last capture is shown on the screen

Triggers in Modern DSOs

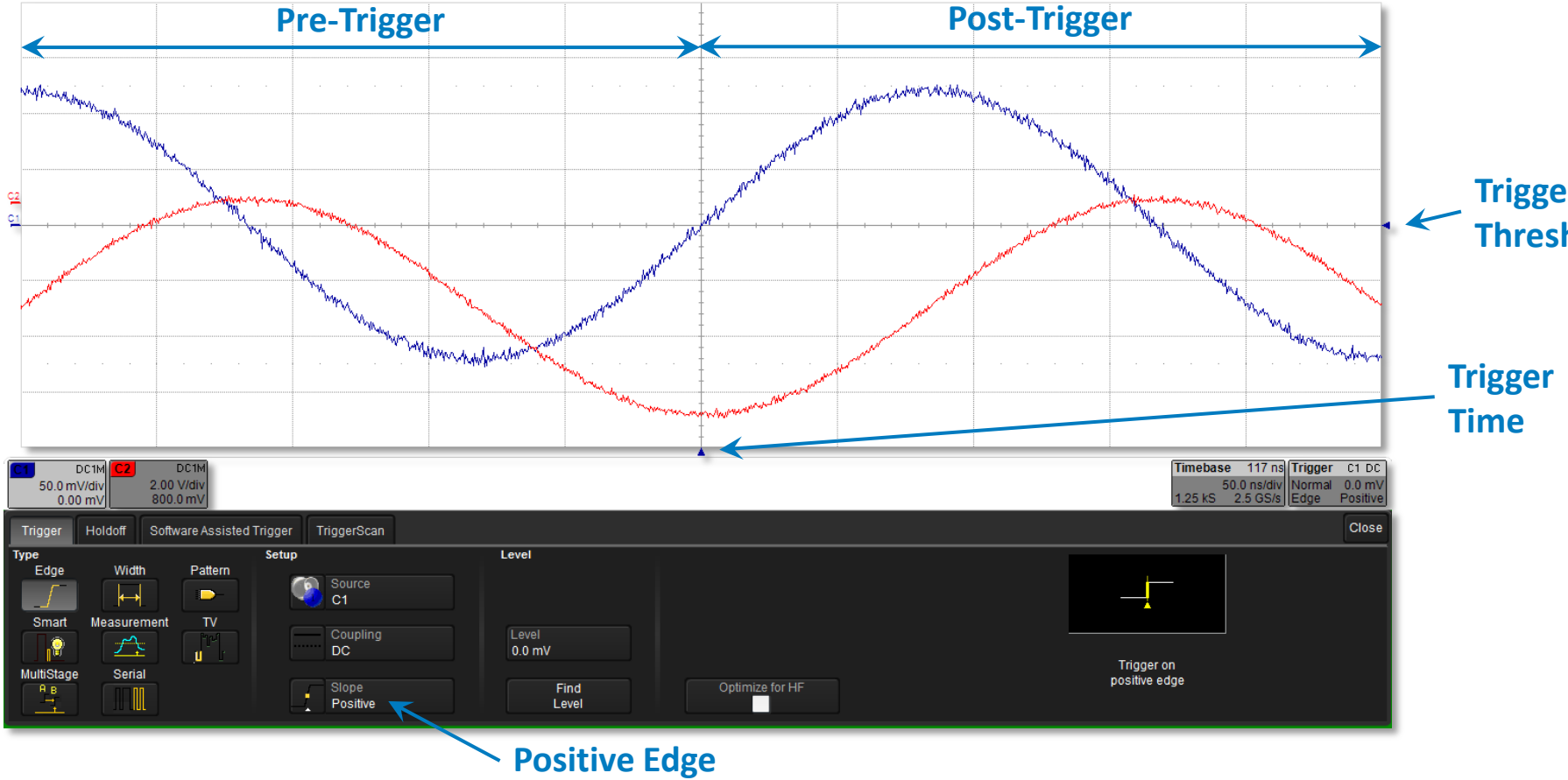
- The bandwidth of the edge trigger should be ≥ the analog bandwidth of the DSO
- The DSO can be equipped with many trigger functions*. Most common are:
  1. Edge
  2. Width
  3. Qualified
  4. Pattern
  5. TV
  6. Smart
  7. Serial



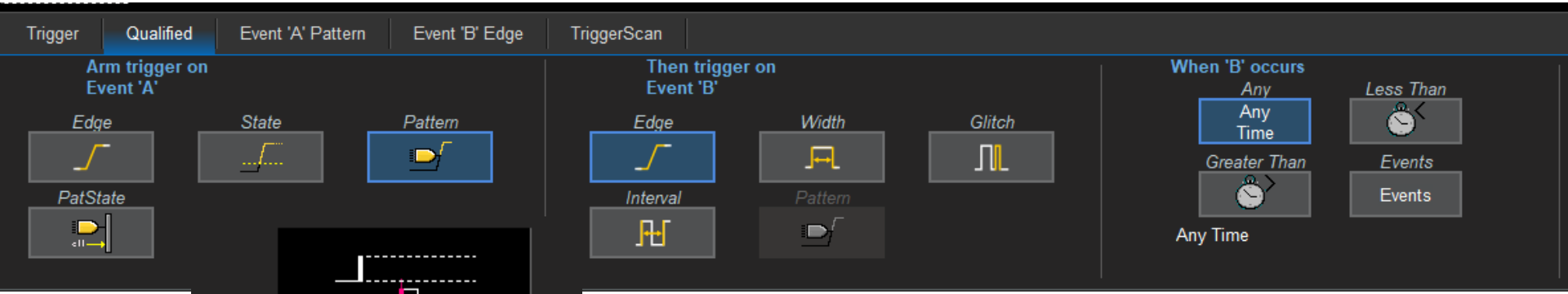


* Trigger functions are covered in more detail in the advanced scope seminar

Trigger – Example Edge Trigger

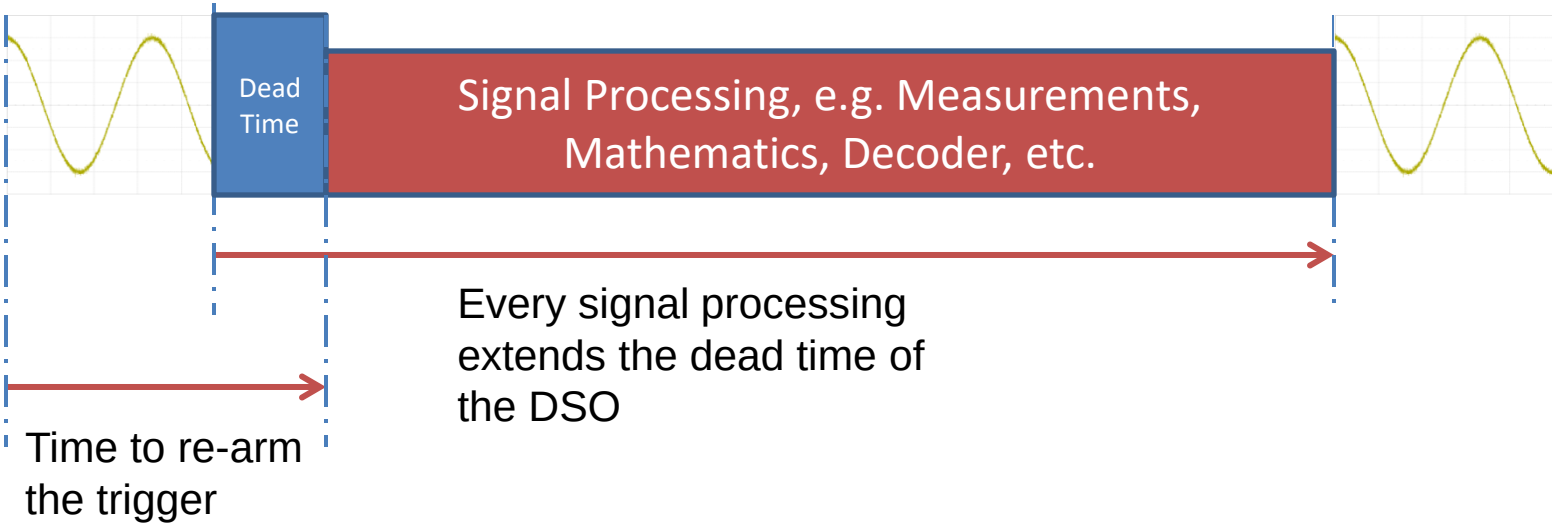


Trigger: pulse Width - Qualified



Trigger with edge trigger settings only after a second qualifying condition is satisfied once.

Trigger Rate



Although the trigger has been re-armed, a new acquisition cannot be started because the signal processing is not yet complete.

Sequence mode*

- Fastest trigger mode
  - Acquisition memory is divided in segments
  - At each new trigger event a new segment is filled with samples and a trigger time stamp is saved
  - Scope will show the captured segments only when all segments are captured or STOP trigger is pressed

*Topic fully covered in the advanced Scope seminar