Oscilloscopes, accessories, applications

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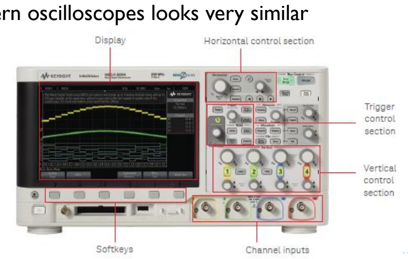
What is oscilloscope?

- The main purpose of an oscilloscope is to give an accurate visual representation of electric signals. By viewing signals displayed on an oscilloscope you can determine whether a component of an electronic system is behaving properly. So, to understand how an oscilloscope operates, it is important to understand basic signal theory.
- Signal Integrity - oscilloscope's ability to reconstruct (show) the waveform so that it is an accurate representation of the original signal. The waveform on an oscilloscope will never be an exact representation of the true signal - this is because when you connect an oscilloscope to a circuit, the oscilloscope becomes part of the circuit.
- Types of osciloscopes
  - CRO = cathode ray oscilloscope - analog principle with cathode tube, obsolete, now not used
  - DSO = digital storage oscilloscope, digitizing scope, ...)
  - MSO = mixed signal oscilloscope - combination DSO + simple logic analyzer for measurement of digital signals (logic circuits)
  - (DPO = Digital Phosphor Oscilloscopes - real time digitizing scope,
  - ...)

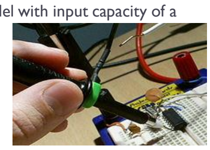
What an oscilloscope looks like

- Modern oscilloscopes looks very similar



Connection scope to circuit - probes

- Scope inputs for measured signals
  - Single ended (BNC connector,) sensing voltage with input impedance typically 1Mohm in parallel with input capacity of a few pF (5-25pF)
- Oscilloscope probes:
  - comfortable and reliable mechanical connection and fixing in circuit
  - Signal preprocessing:
    - None, only electrical connection by wires (1:1)
    - **Attenuation of sensed voltage** (**1:10**, 1:100, …)
    - Amplification, galvanic isolation conversion from differential to single ended, conversion current to voltage, …



Some examples

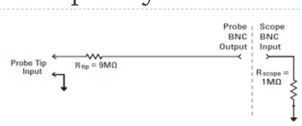
Active differential probe

Current probes

Differential probe

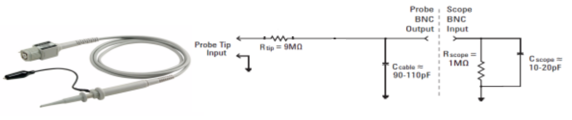
High voltage active differential probe

Probes10:1 – low frequency model



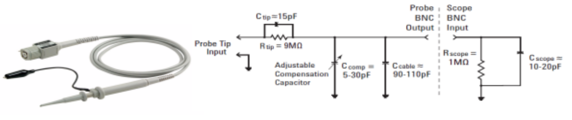
- Probes attenuate signal 10 times (they can protect the scope input but it is not the main reason to employ them)
- Be careful:
  - Some have switch 1:1 - 1:10 - check the switch position
  - Remember the attenuation and recalculate voltage read from scope screen or set up type of probes in scope for automated recalculation

Probes10:1 – high frequency model



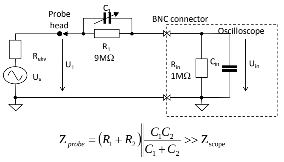
- Input capacity of scope and parasitic capacity of cable creates low pass filter with resistors (high frequency spectral components of measured signal are attenuated more than low frequency component - low signal integrity)

Compensation



- Adding capacitors we can compensate the effect

Compensation model



Frequency response is required to be frequency independent

$$\frac{U_{in}(j\omega)}{U_1(j\omega)} = \frac{\frac{1}{1/R_{in} + j\omega C_{in}}}{\frac{1}{1/R_{in} + j\omega C_{in}} + \frac{1}{1/R_1 + j\omega C_1}}$$

$$Z_{probe} = (R_1 + R_2) \| \frac{C_1 C_2}{C_1 + C_2} >> Z_{scope}$$

$$if \quad R_{in} C_{in} = R_1 C_1$$

$$\frac{U_{in}(j\omega)}{U_1(j\omega)} = \frac{R_{in}}{R_{in} + R_1}$$

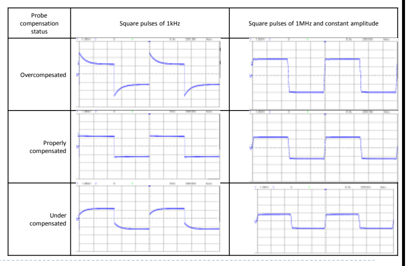
$$C_i = \frac{C_{in} C_1}{C_{in} + C_1} < C_{in}$$

Resulting effects:

- Increasing input resistance
- Decreasing input capacity

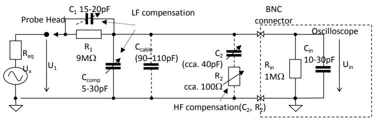
How to do it?

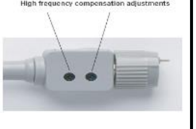
*We speak here about "low frequency" because there could be still another high frequency compensation - see the following slide



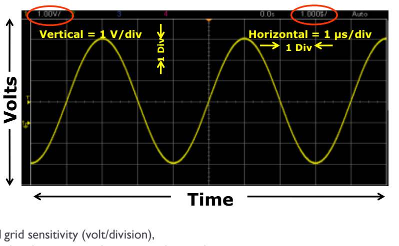
Addition high frequency compensation

- Some probes have also additonal high frequency compensation



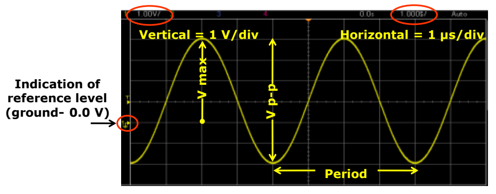


Reading from screen



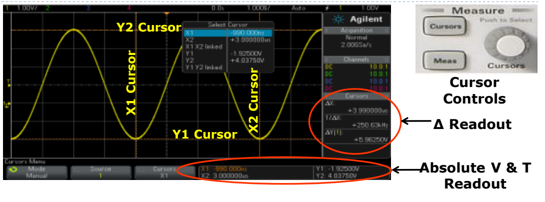
- Grid:
  - vertical grid sensitivity (volt/division),
  - horizontal grid - a time per division given by time base setting

Direct reading



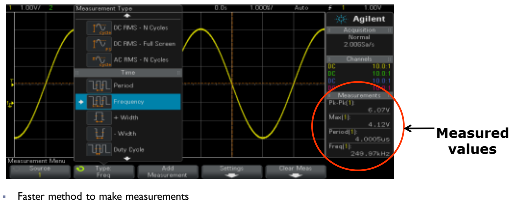
- Period (T) = 4 divisions x 1 µs/div = 4 µs, Freq = 1/T = 250 kHz.
- V p-p = 6 divisions x 1 V/div = 6 V p-p
- V max = +4 divisions x 1 V/div = +4 V, V min = ?

Cursors



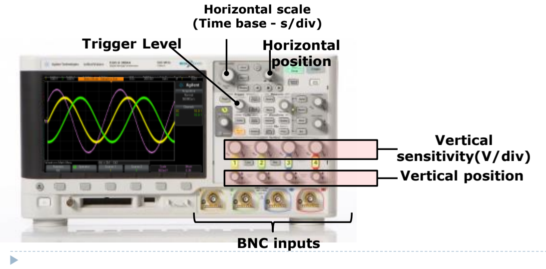
- Set cursors X & Y on required position.
- Scope displays cursors' absolute positions and difference between them

Scope's automatic parametric measurements

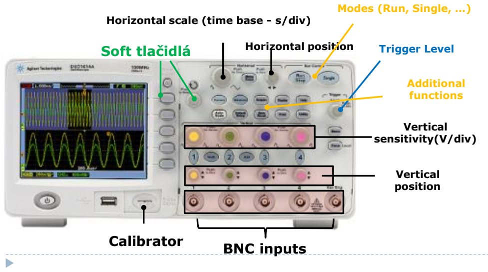


- Faster method to make measurements
- Today's oscilloscopes have the ability to automatically measure voltage and timing parameters such as Vpp, Vmax, Vmin, Period, Frequency, Rise Time, Fall Time, etc.
- Based on digital signal processing

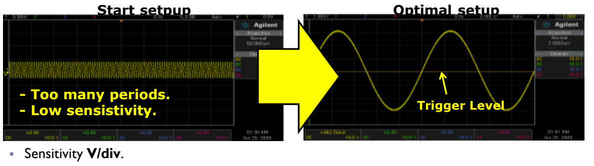
Basic control buttons



Oscilloscope for excercises (DSO1004)



Right setup



- Sensitivity **V/div**.
- Vertical position
- Horizontal (Time) resolution **s/div**.
- **Trigger Level** to stabilize picture.

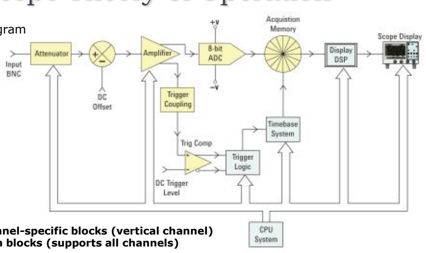
Usually iterations.

Preparation of scope for measurement

- Autoscale, autosetup, … – if this is implemented in the scope
- General instructions to set up the oscilloscope in standard positions are as follows:
  - Set the oscilloscope to display channel 1
  - Set the vertical volts/division scale and position controls to mid–range positions
  - Turn off the variable volts/division
  - Turn off all magnification settings
  - Set the channel 1 input coupling to DC
  - Set the trigger mode to auto
  - Set the trigger source to channel 1
  - Turn trigger holdoff to minimum or off
  - Set the intensity control to a nominal viewing level, if available
  - Adjust the focus control for a sharp display, if available
  - Set the horizontal time/division and position controls to mid-range positions

Oscilloscope Theory of Operation

DSO Block Diagram



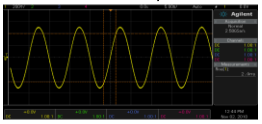
Yellow = Channel-specific blocks (vertical channel)
Blue = System blocks (supports all channels)

Vertical channel

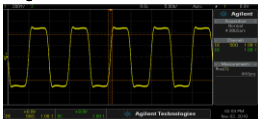
- To adjust the input measured voltage for internal processing - attenuation, amplification, removing DC component
  - Remember, that input impedance (capacity) restricts effective bandwidth
  - Typical range of sensitivity> 10mV/div – 100V/div
- Frequency bandwidth:
  - Low costs: do 20MHz – 50MHz
  - Middle class 100MHz - 500MHz
  - Wideband, above 1GHz, up to tens GHz)
  - BW limit - see the next slide
- Vertical position: adding variable DC voltage

Selecting the Right Bandwidth

Input = 100-MHz Digital Clock



Response using a 100-MHz BW scope



Response using a 500-MHz BW scope

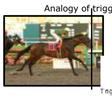
- Required BW for analog applications: ≥ 3X highest sine wave frequency.
- Required BW for digital applications: ≥ 5X highest digital clock rate.
- More accurate BW determination based on signal edge speeds

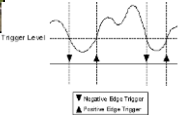
$$t_{r\ osc} \cong \frac{0.35}{f_{osc\ max}}; \quad t_{r\ screen} = \sqrt{t_{r\ osc}^2 + t_{r\ inp}^2}$$

Triggering

- Triggering is oscilloscope function, which helps provide a stable, usable display.
- Triggering allows to synchronize scope's acquisition on the part of the waveform you are interested in viewing
- Triggering is one of the most important part of oscilloscope but often not much known to user

Analogy of triggering



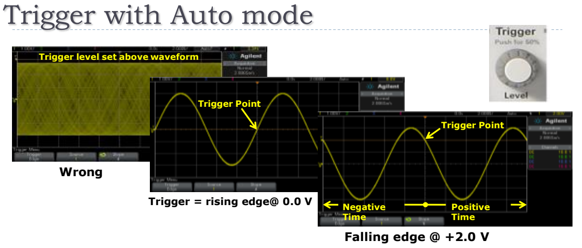


- Triggering is analogy of live picture taken in sport to determine the winner.
- The acquired waveform consists of amount of samples taken from the waveform
- Taking "picture" of repetitive signal = to show a "live" picture must be synchronized to an unique point on the repetitive signal to show a stable picture.
- **The basic edge triggering: the trigger occurs when the voltage surpasses some set threshold value (trigger level) on a rising or a falling edge.**

Trigger modes and source

- "Auto" trigger mode: the scope generates "automatic" asynchronous triggers if a real trigger event doesn't occur after a specified time-out period
  - The displayed picture may be not be synchronized if condition for trigger are set wrongly
- "Normal" trigger mode: the scope waits for a real trigger event for unspecified time-out period (infinity). After acquisition scope hunts for equal following trigger event.
  - If trigger condition are set wrong, the picture will never be acquired.
- "Single" trigger mode: after Reset (Arming, …) the scope waits for a real trigger event for unspecified time-out period (infinity). After acquisition scopes stops hunting for next trigger until next Reset (Arming, …)
  - If trigger condition are set wrong, the picture will never be acquired.
- Source:
  - Measured signal - internal synchronisation
  - External source:
    - Power (50/60Hz)
    - Input for external trigger signal

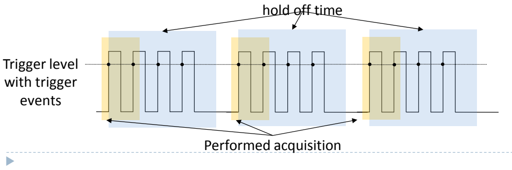
Trigger with Auto mode



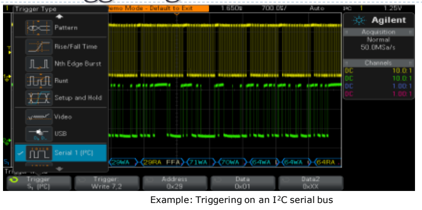
- **Default position of trigger event for DSO is the screen center**

Hold-off function

- The holdoff time is the oscilloscope's waiting period before starting a new trigger.
- The oscilloscope will not trigger until the holdoff time has expired.
- Convenient for comples signals, e.g. burst - digital data train with long period



Advanced triggering in DSO

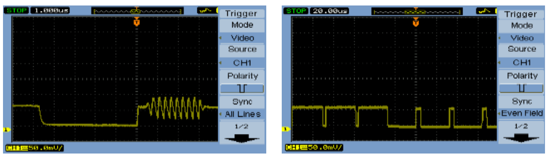


Example: Triggering on an I^2C serial bus

- Edge triggering is satisfied triggering method for the most of common simple measurements
- DSOs offer much more sophisticated advanced triggering based on digital signal processing, which are highly needed and useful for measurement complex signal (e.g. busses, modulated signals, video, …)

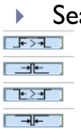
Triggering I - video

- Triggering on fields or lines for standard video waveforms (PAL, NTSC, SECAM):
  - Line number
  - Odd/even field



Triggering II - pulse width triggering

- Search fol pulse with specific parameters

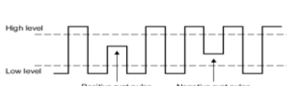


Positive pulse greater than the width setting
Positive pulse less than the width setting
Negative pulse greater than the width setting
Negative pulse less than the width setting

  - Pulse width in or out of set width, rise or fall time, …
- Detection of glitch,

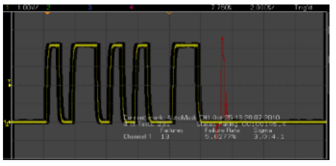
Triggering III – digital levels(pattern)

- Level H, L or edge and their combinations on channels
- Derived from digital inputs in MSO – hexa code, decoding bus status (I²C, SPI, RS 232, CAN, LIN, ...)
- Pulse amplitude error (runt) – off-limits of H a L
- ...



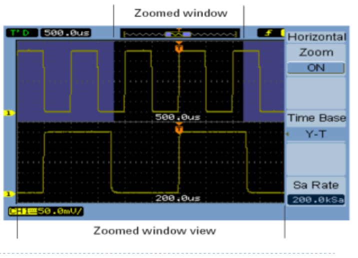
Triggering IV – mask

- The mask test function monitors waveform changes by comparing the waveform to a predefined mask.
- The mask is usually created by catching the reference signal and setting vertical and horizontal tolerance.
- Signal is caughted and displayed only if it crosses the mask.



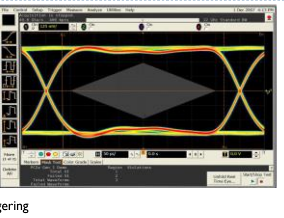
Zooming - delayed sweep time base

- Magnifying a portion of the original waveform display and displays it in a zoomed time base
- A portion of signal captured in memory is marked for zooming (zoomed window) and displayed as a new waveform on screen (zoomed window view)
- Based on fact that in the memory is captured much more samples than shown in screen



Displaying data, Persistence

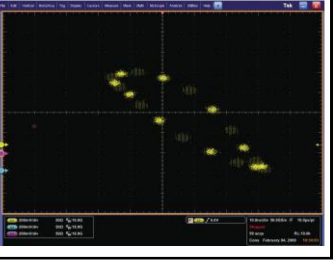
- Displaying data
  - Dots
  - Connected dots - interpolation (almost continuous curve on the screen)
    - Line
    - Sinx/x (oversampling and low pass filtering)
    - …
- Persistence - keeping history (statistics) of signal on the screen
  - Signal quality in digital communication systems - Eye diagram - evaluation of clock jitter, noise, distortion, etc.



- Synchronization of clock or dual slope triggering
- Evaluation of width and height of eye, jitter, rising and falling, …
- http://www.youtube.com/watch?v=my7CI84le5g

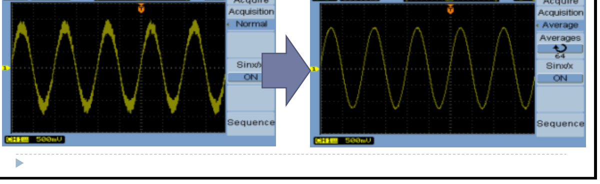
Displaying data - XY mode

- Both X and Y axis display acquired signal (no time division on X axis)
- Displaying some relation between signals (e.g., Lissajous curves)



Capturing data - averaging

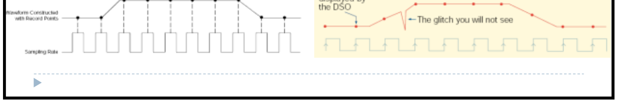
- Continual repetitive averaging and displaying the average of last N captured records
- Application: evaluation of noisy periodical signals



Sampling in real time (Shannon)

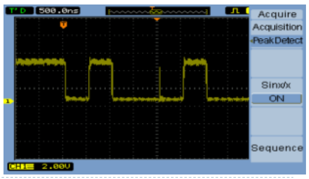
- A minimal number of samples per period is required to achieve an acceptable signal integrity (12 - 15 in dependence on signal shape)
- Effective sampling rate in common mode changes with horizontal time division and depends also on memory depth to be displayed on screen (rate decreases as you increase the range of time).
  - Memory of scope (record length) may be many times longer
  - Maximum rate is achieved only at some circumstacies, e.g. only one channel is on

$$f_s = \left(\frac{C_{mem}}{N_d T_d}\right)$$



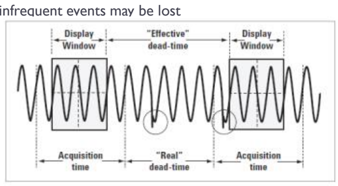
Capturing data - modes

- **Sample mode** (standard) - sampling rate is changed by setting horizontal division and addapted to set horizontal division
- **Peak detect mode** - maximal sampling rate with following decimation based on saving sample with most extremal value
- **High resolution mode** - maximal sampling rate with followed decimation based on averaging of captured samples
- **Envelop mode** - repetitive capturing with memorizing and displaying only maximum and minimum waveform points
- XY mode -



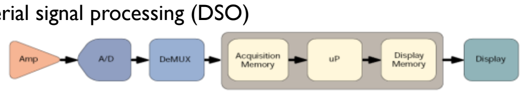
Update rate

- A pause (dead time) is is inserted between following acquisitions in common DSO
  - Caused by signal processing
  - Some rare infrequent events may be lost

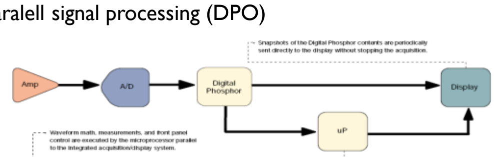


Signal processing

- Serial signal processing (DSO)

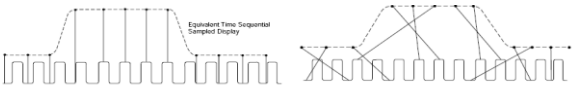


- Paralell signal processing (DPO)



Sampling in equivalent time

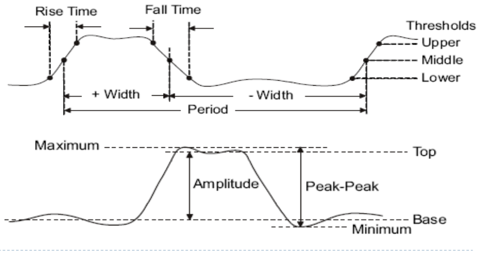
- Sampling is the first operation on signal in the scope
- Sampling rate is lower (much) than nyquist frequency
- Applicable only for periodical signals
- Low cost solution for ultra high frequencies



Other properties and trends

- Increasing capacity of memory and segmentation
- Mathematical function (advanced signal processing, e.g., filtering, FFT, integration, …)
- Combining with other instruments, e.g. generator, logic analyzer (MSO), spectrum analyzer, etc.
- Improving signal integrity by improving vertical resolution (12 - 16bits ADC)and widening bandwidth (tens GHz)
- Connectivity (USB, LXI, GPIB, …) - Remote control, build in web server. …
- Storing data and control (USB host)
- User friendly, e.g., touch screen
- ...

Pulse parameters I



Overshoots

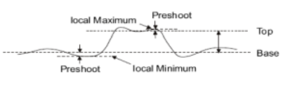
$$\text{Rising edge overshoot} = \frac{\text{local Maximum} - \text{D Top}}{\text{Amplitude}} \times 100$$

$$\text{Falling edge overshoot} = \frac{\text{Base} - \text{D local Minimum}}{\text{Amplitude}} \times 100$$

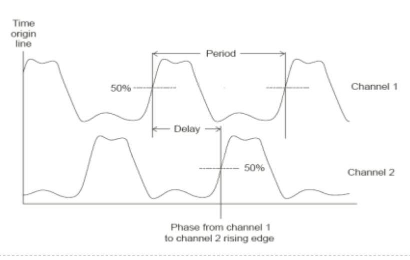
Preshoots

$$\text{Rising edge preshoot} = \frac{\text{local Maximum} - \text{D Top}}{\text{Amplitude}} \times 100$$

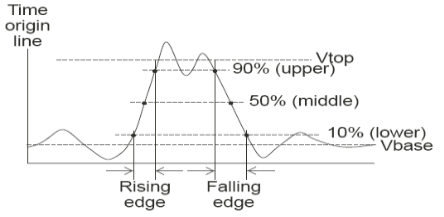
$$\text{Falling edge preshoot} = \frac{\text{Base} - \text{D local Minimum}}{\text{Amplitude}} \times 100$$



Period, delay



Použitie osciloskopu - meranie parametrov impulzov – časové parametre



Frequency ratio and phase shift

Lissajous curves (today rarely used)