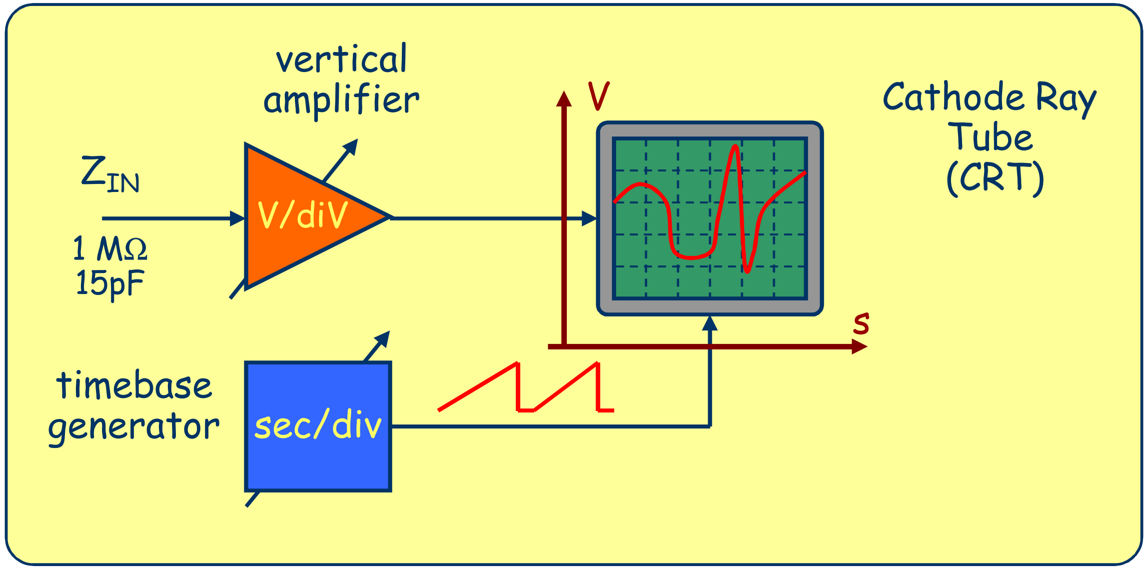
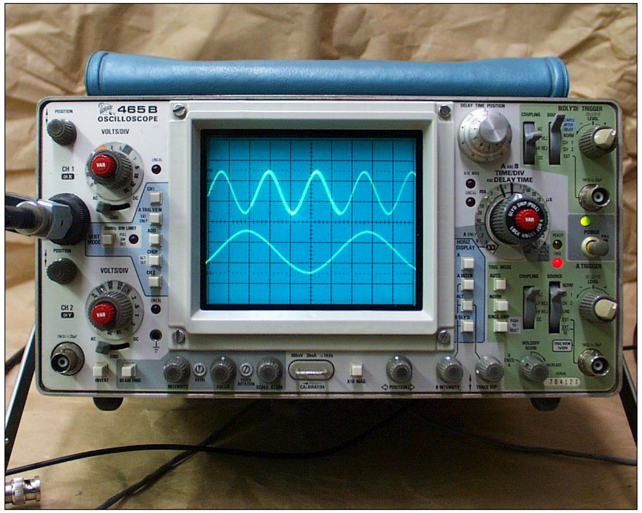
Oscilloscopes

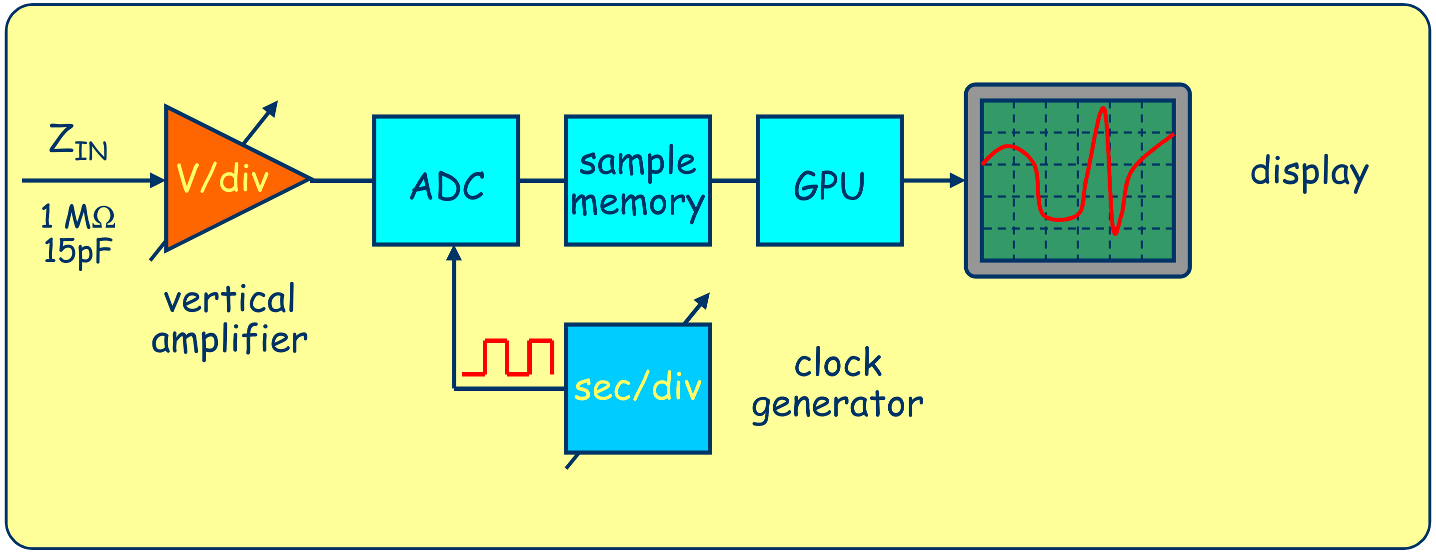
and oscilloscope measurements

Analog oscilloscope



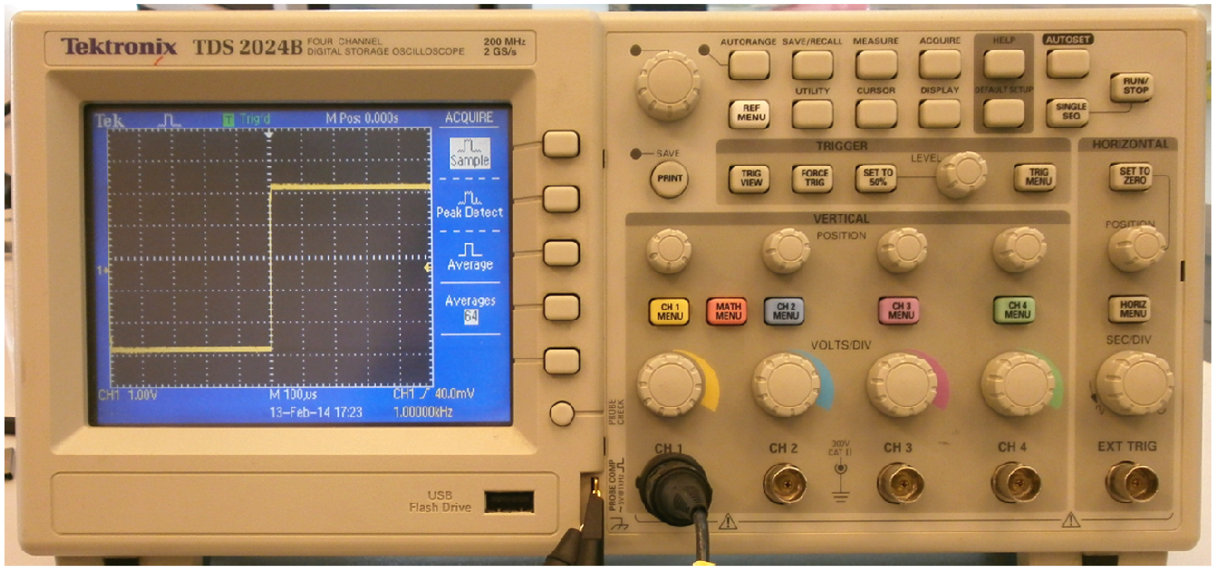


Digital oscilloscope



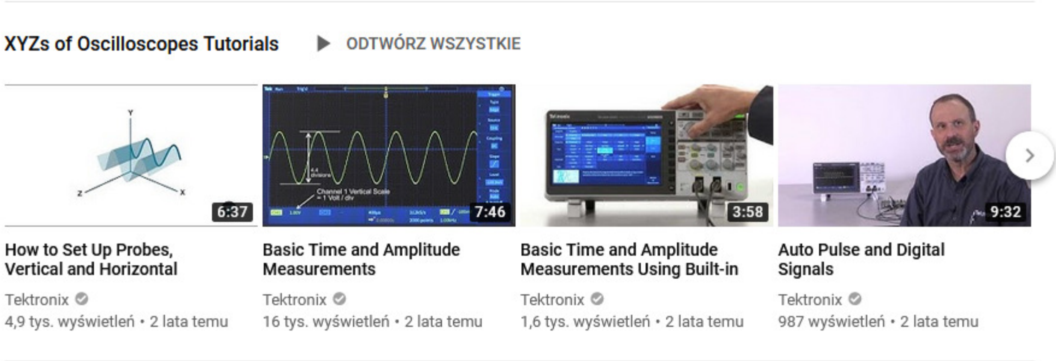
DSO
- Digital Storage Oscilloscope
- Digital Sampling Oscilloscope

MSO
- Mixed Signal Oscilloscope



There is a number of YouTube resources

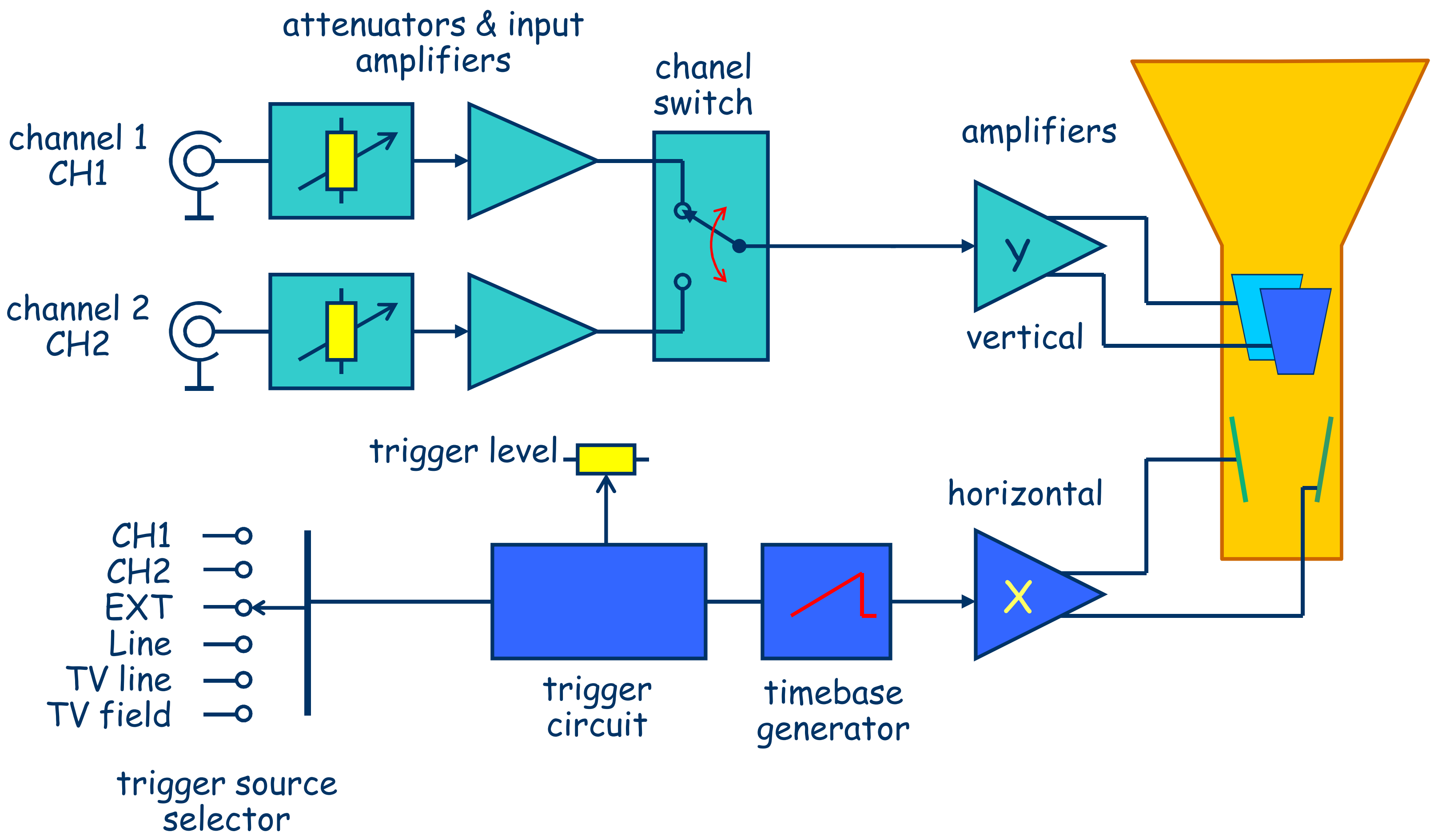
if one is unhappy with my explanations



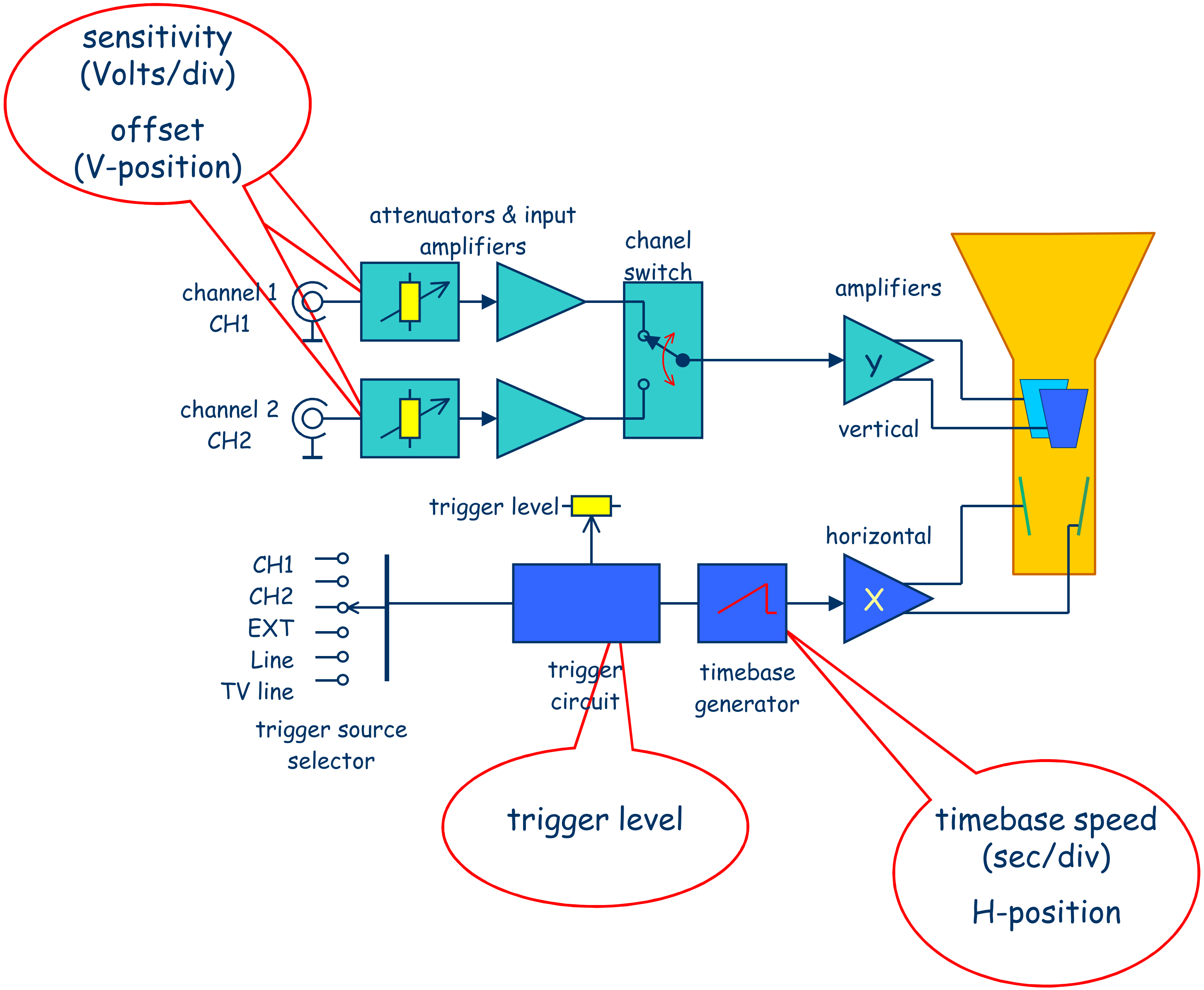
E.g. from Tektronix:
How to use an oscilloscope
https://www.youtube.com/watch?v=tzndcBJu-Ns
How to set up oscilloscope triggering:
https://www.youtube.com/watch?v=uZuL6QUTe_w
How to set up probes, vertical and horizontal settings
https://www.youtube.com/watch?v=ykRTsDdQAWE
Basic time and amplitude measurements:
https://www.youtube.com/watch?v=ry8TJFQuP3E

and from others:
How to use O'Scope (Tektronix TDS2024B)
https://www.youtube.com/watch?v=vIXiHTxiYCA
Tektronix oscilloscope tutorial
https://www.youtube.com/watch?v=7nwIIPN9QEY
How to use an oscilloscope
https://www.youtube.com/watch?v=u4zyptPLlJI

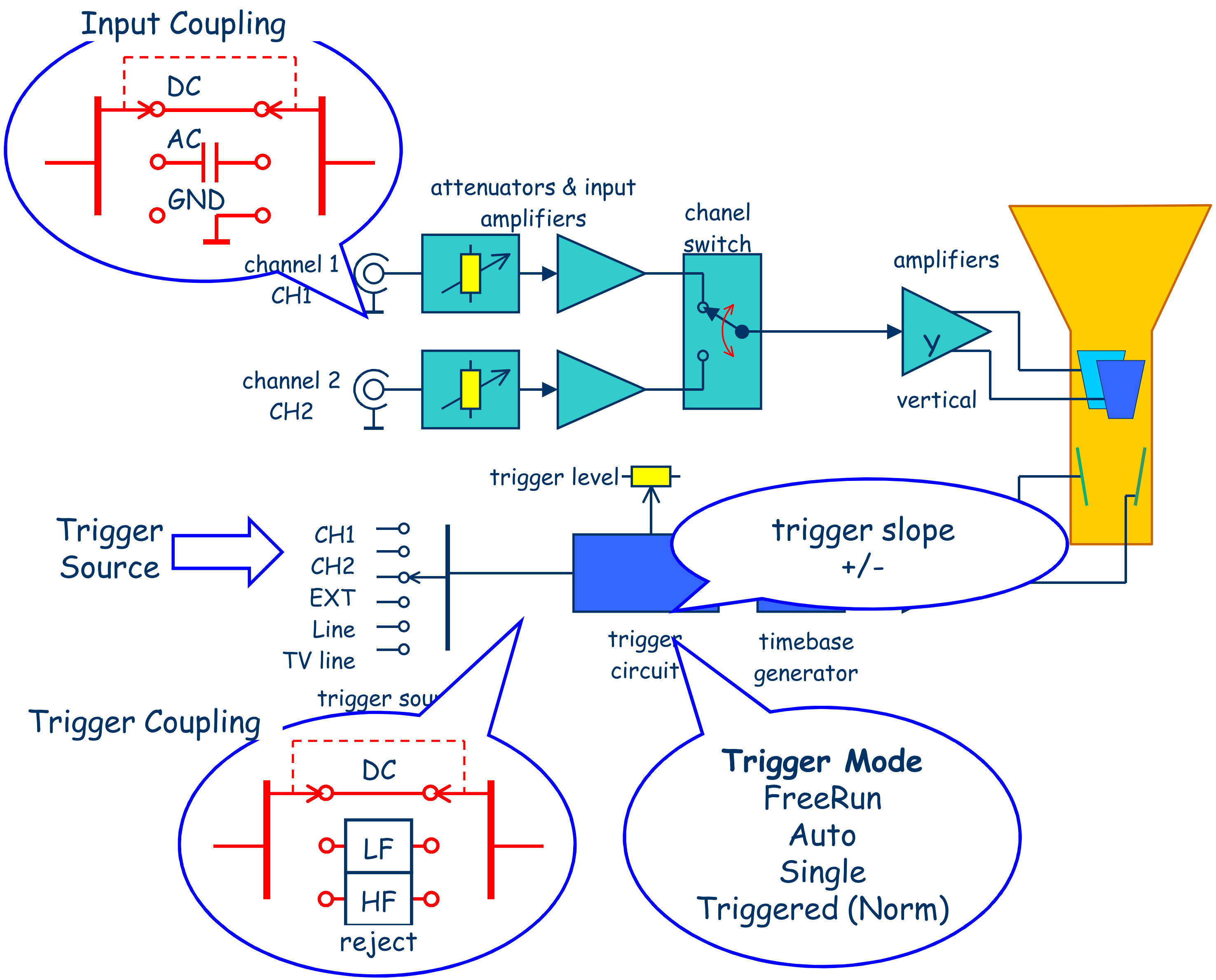
Analog oscilloscope structure



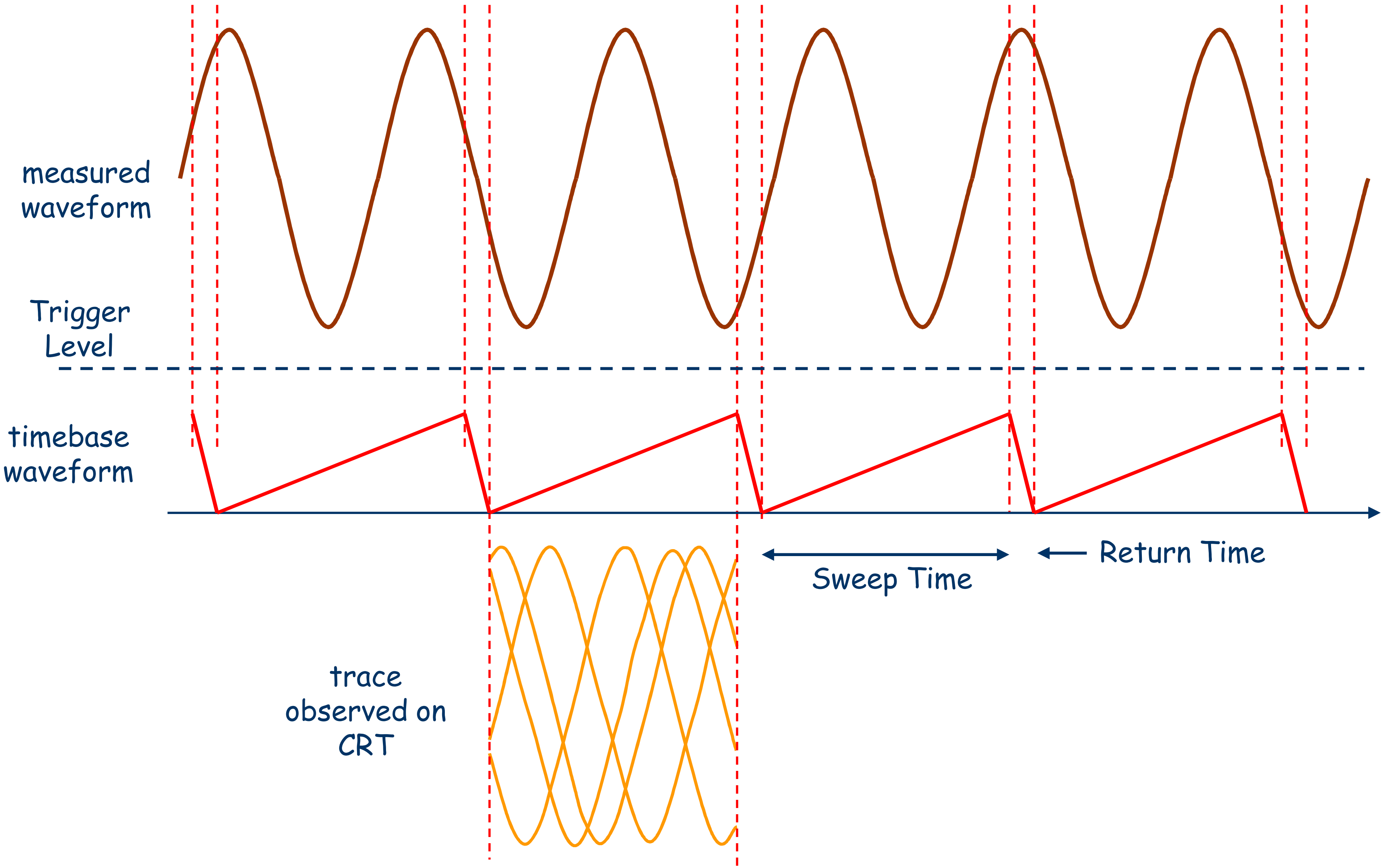
Basic control elements



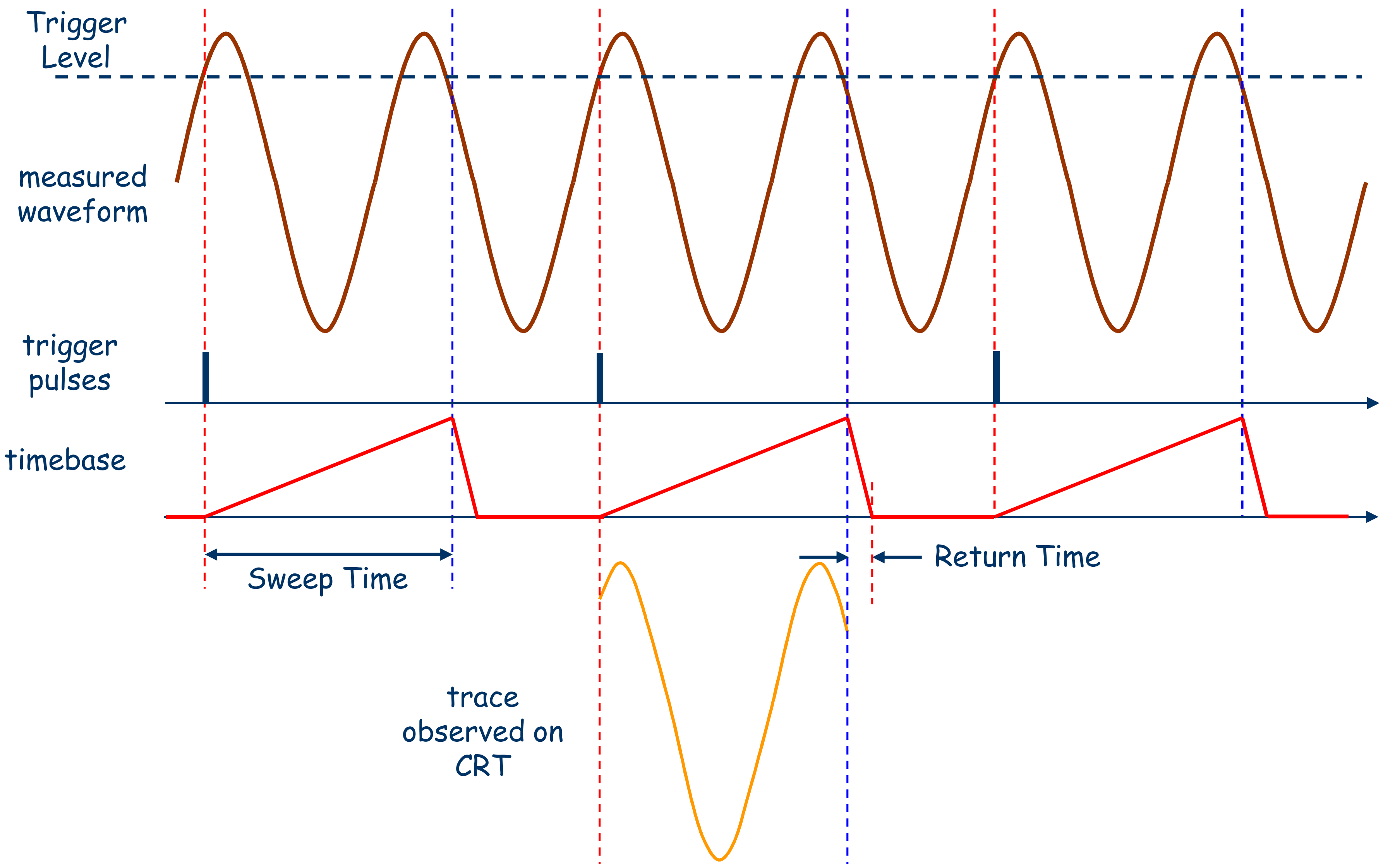
Basic operation modes



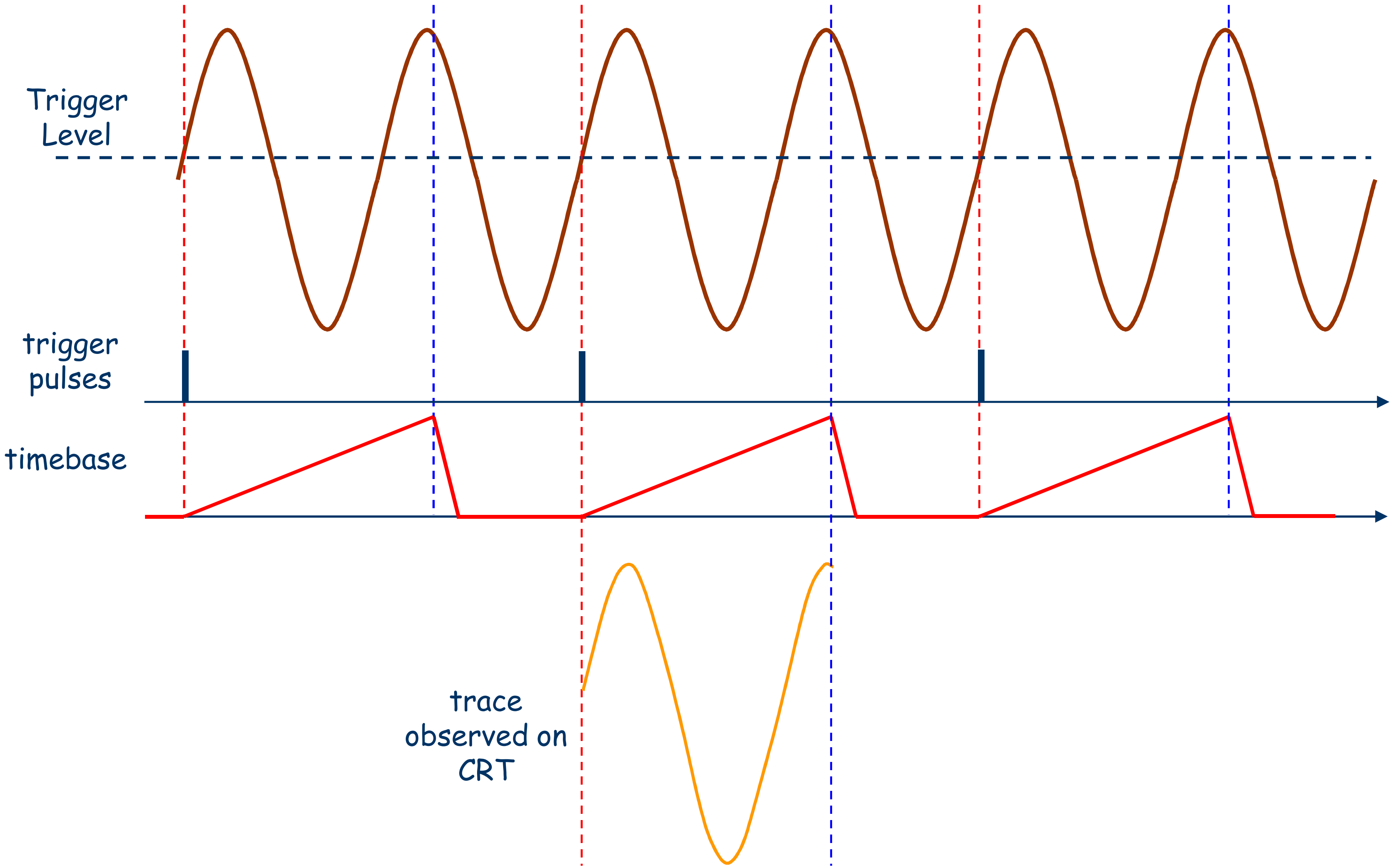
Trigger Mode „Auto" (FreeRun)



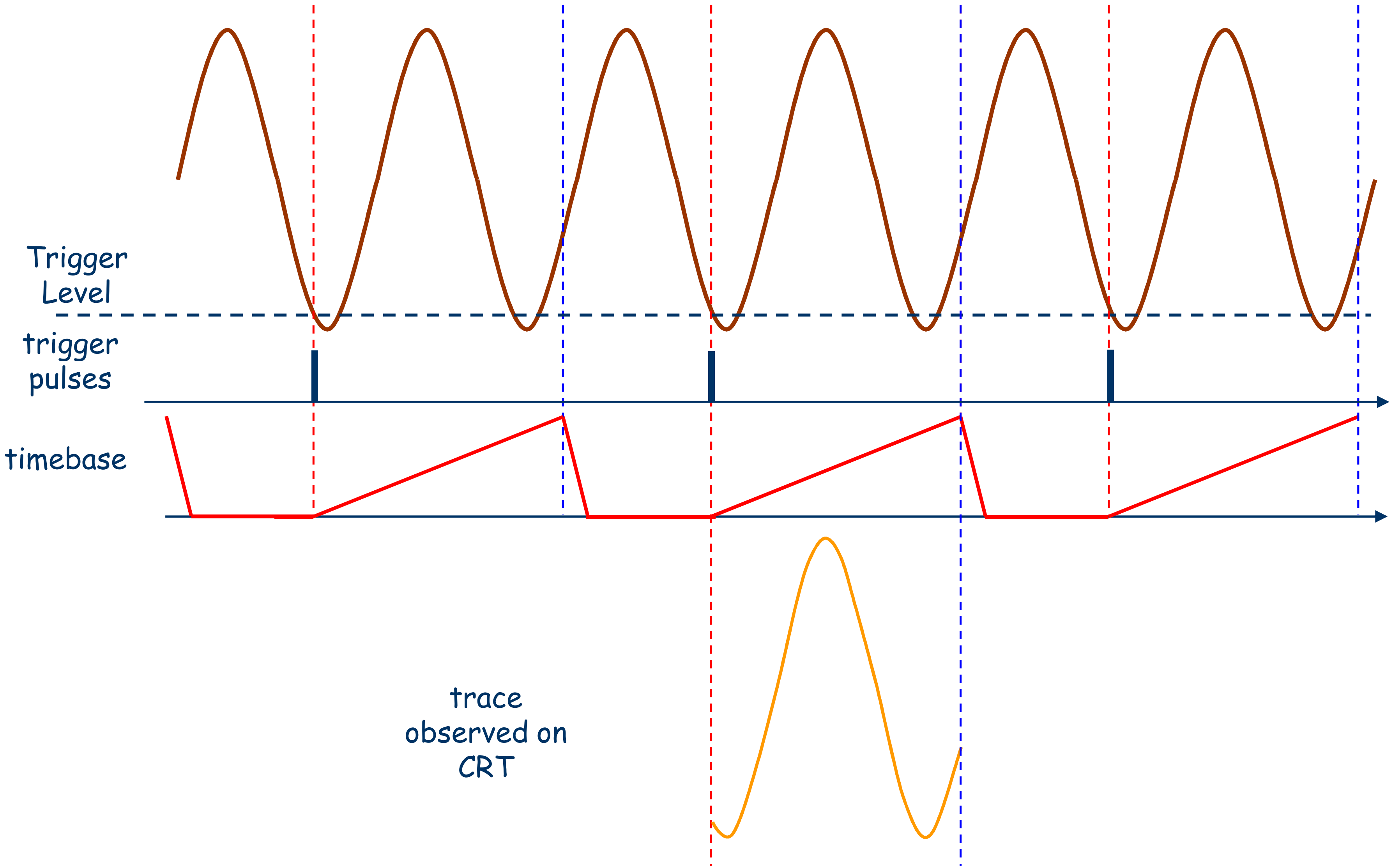
Triggered Timebase (1)



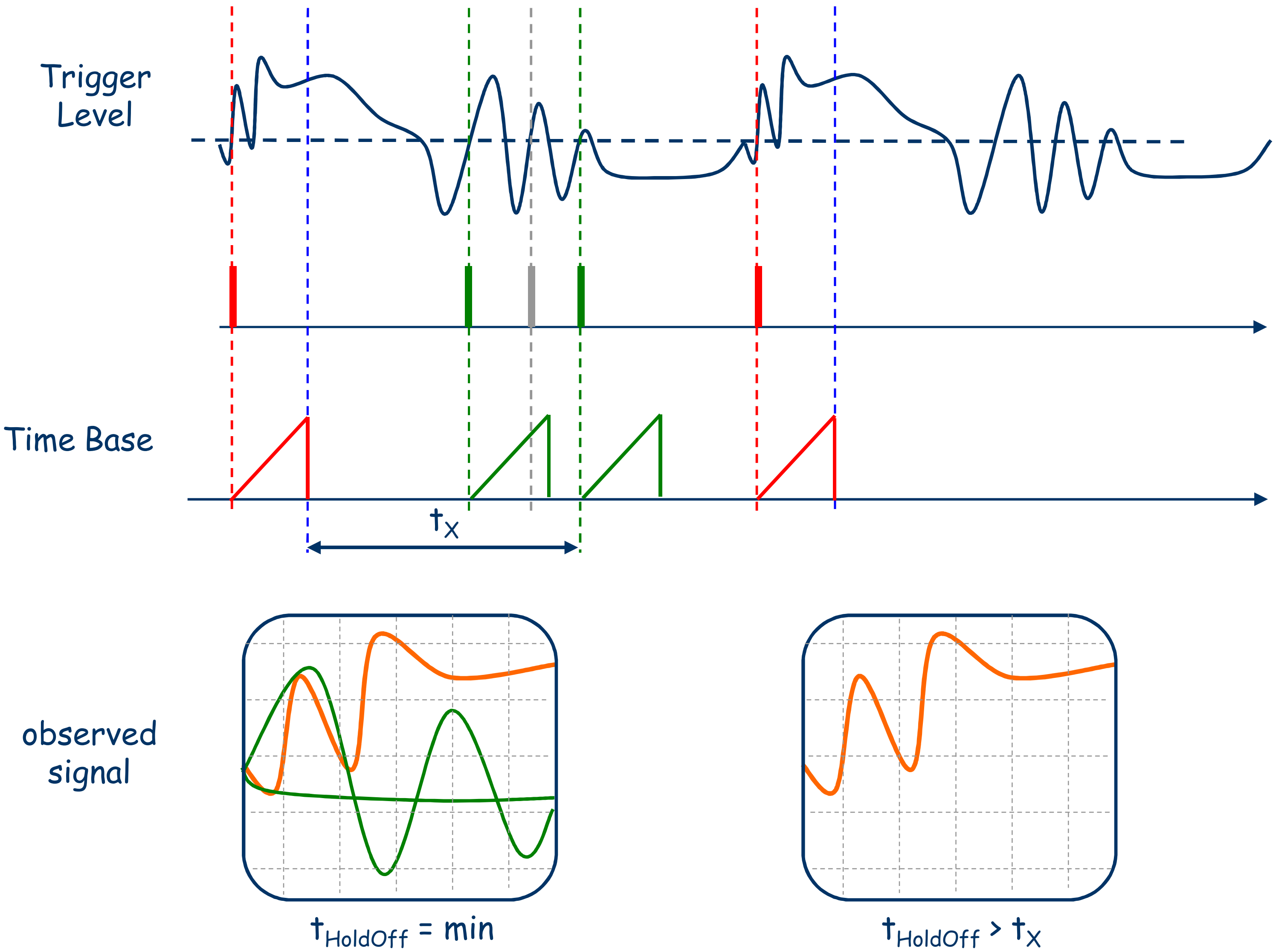
Triggered Timebase (2)



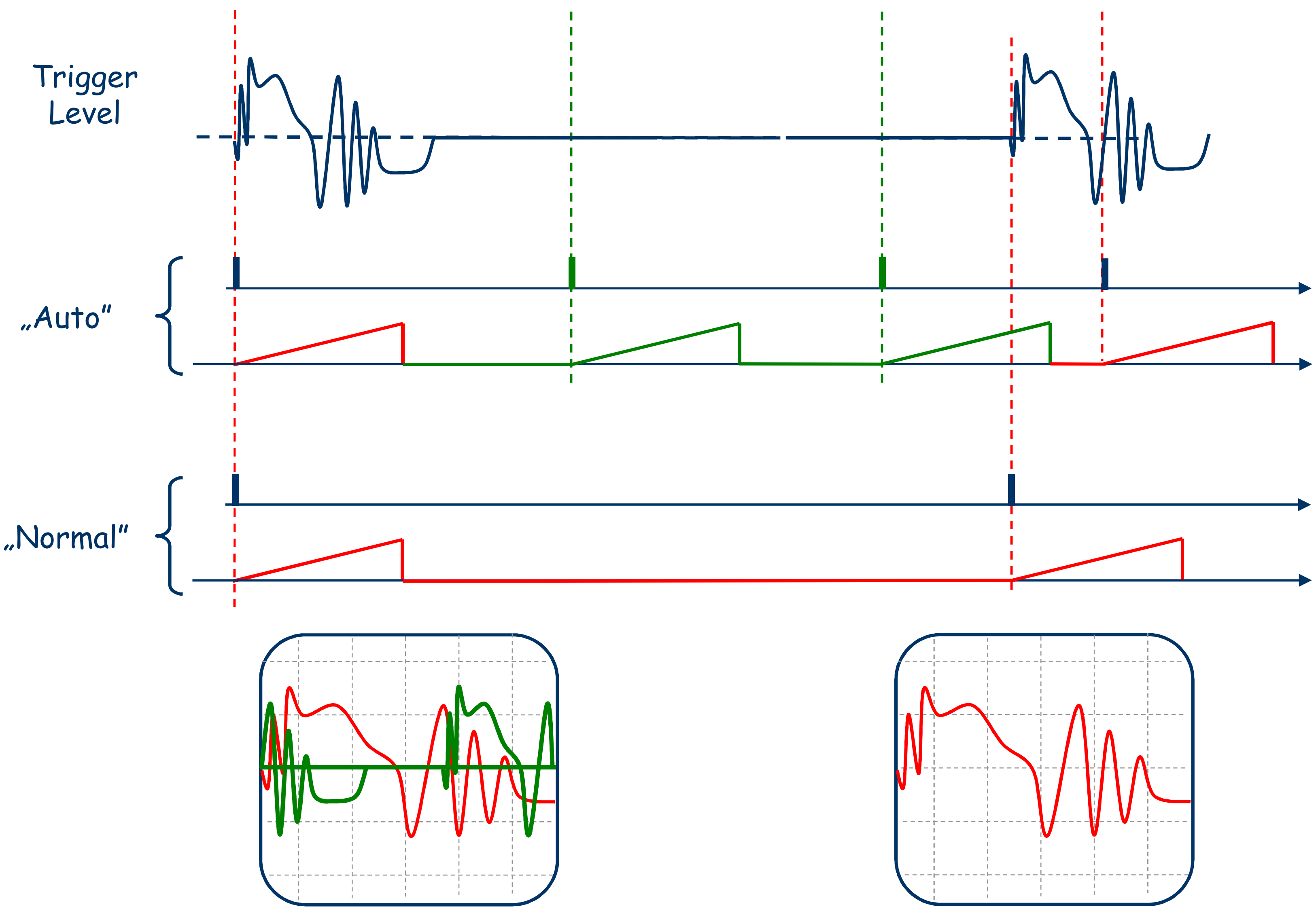
Triggered Timebase (3)



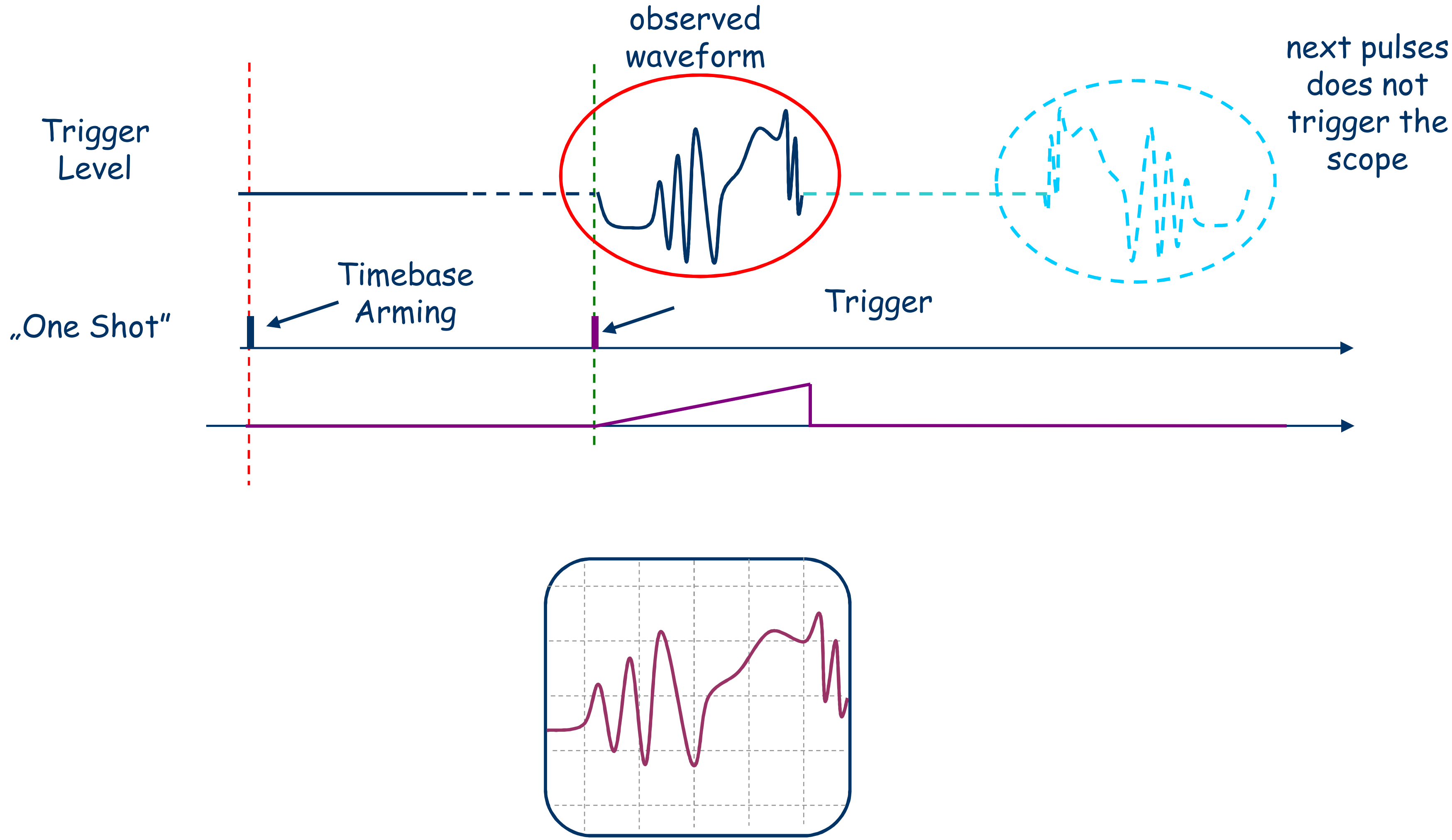
Some more complex cases...



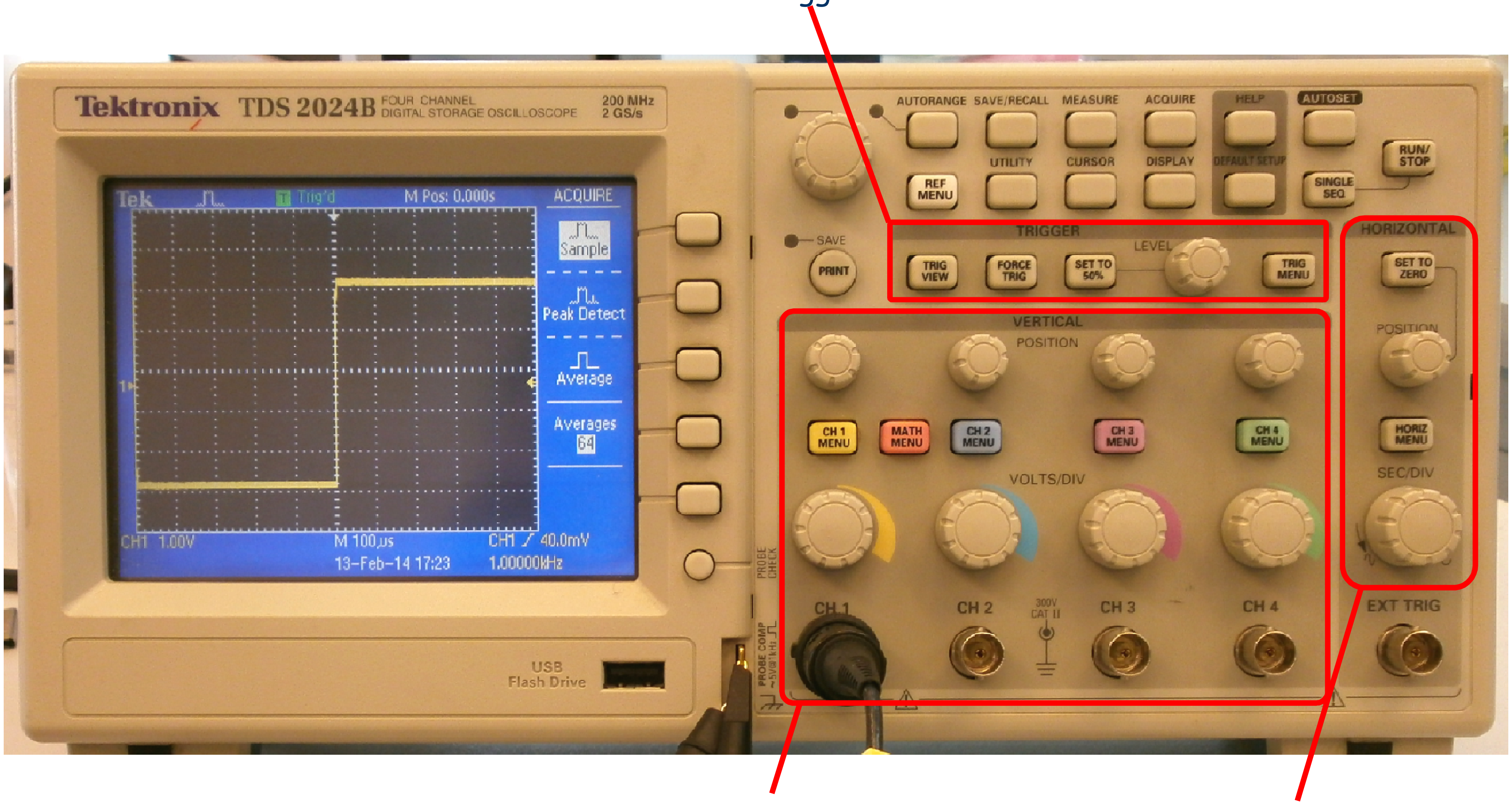
Trigger Mode „Normal" – rare events



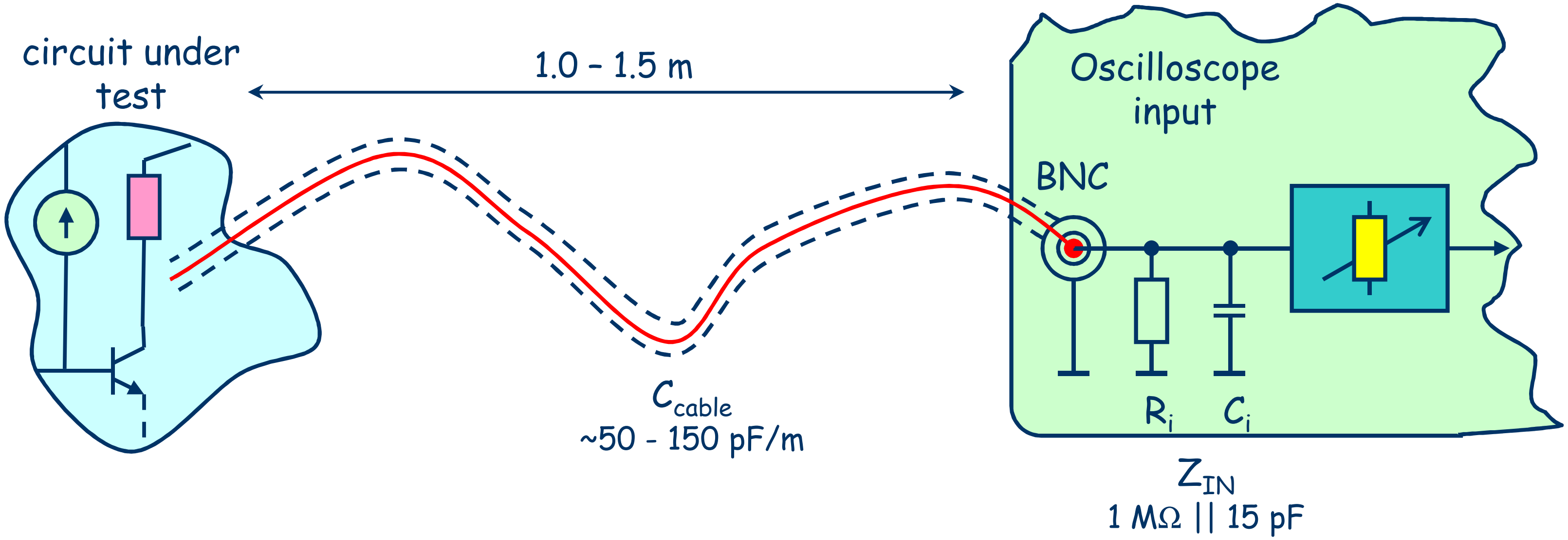
Trigger Mode „One Shot”



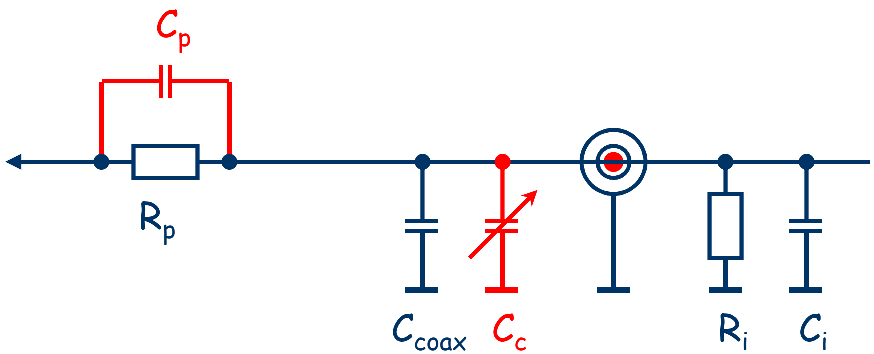
Accessing control switches and knobs



Oscilloscope probe

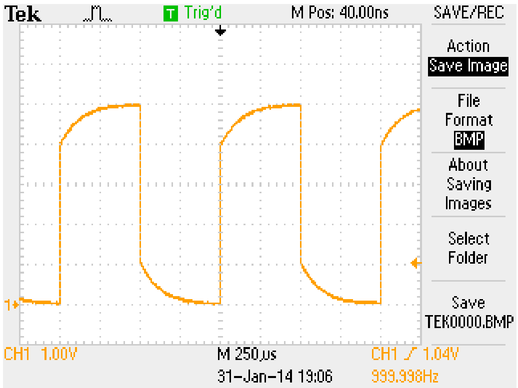


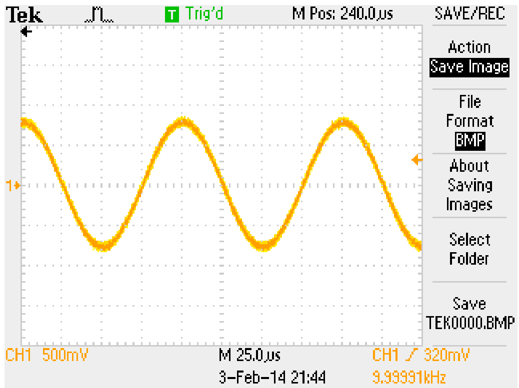
compensated voltage divider



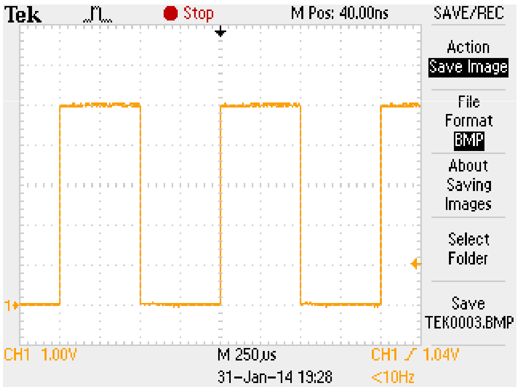
$$\frac{R_i}{R_i + R_p} = \frac{C_p}{C_p + (C_i + C_{coax} + C_c)}$$

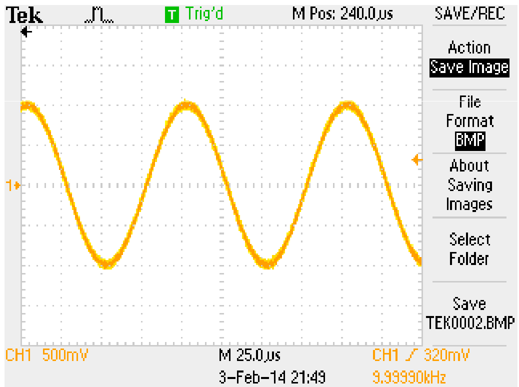
Probe compensation



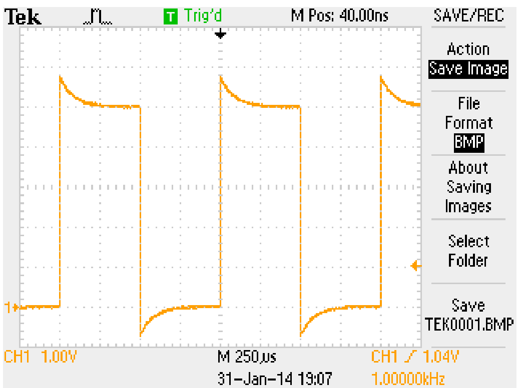


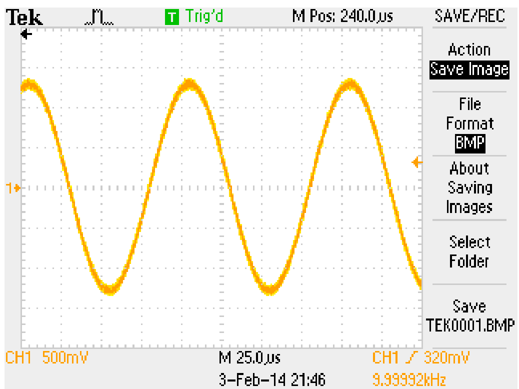
probe undercompensated





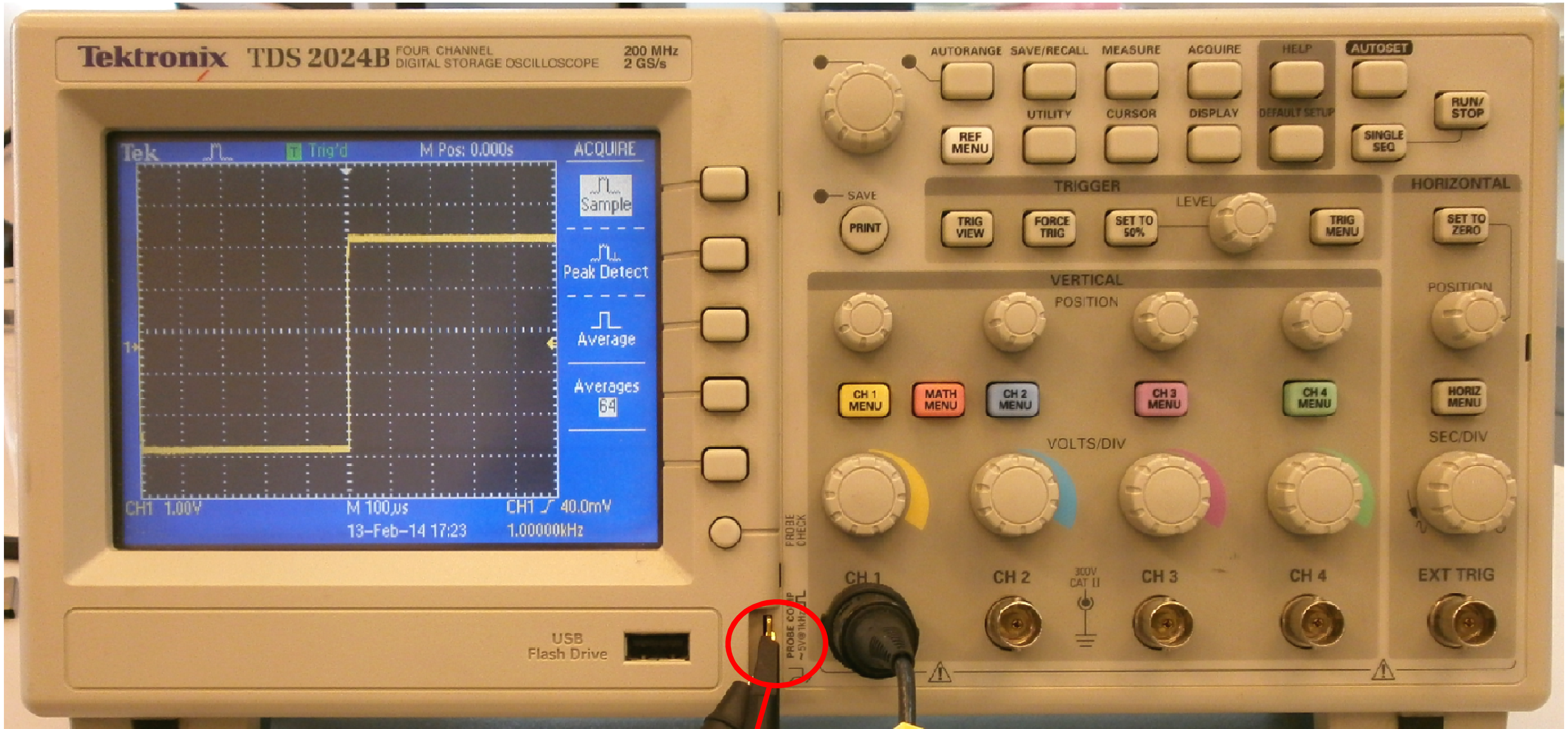
probe O.K.





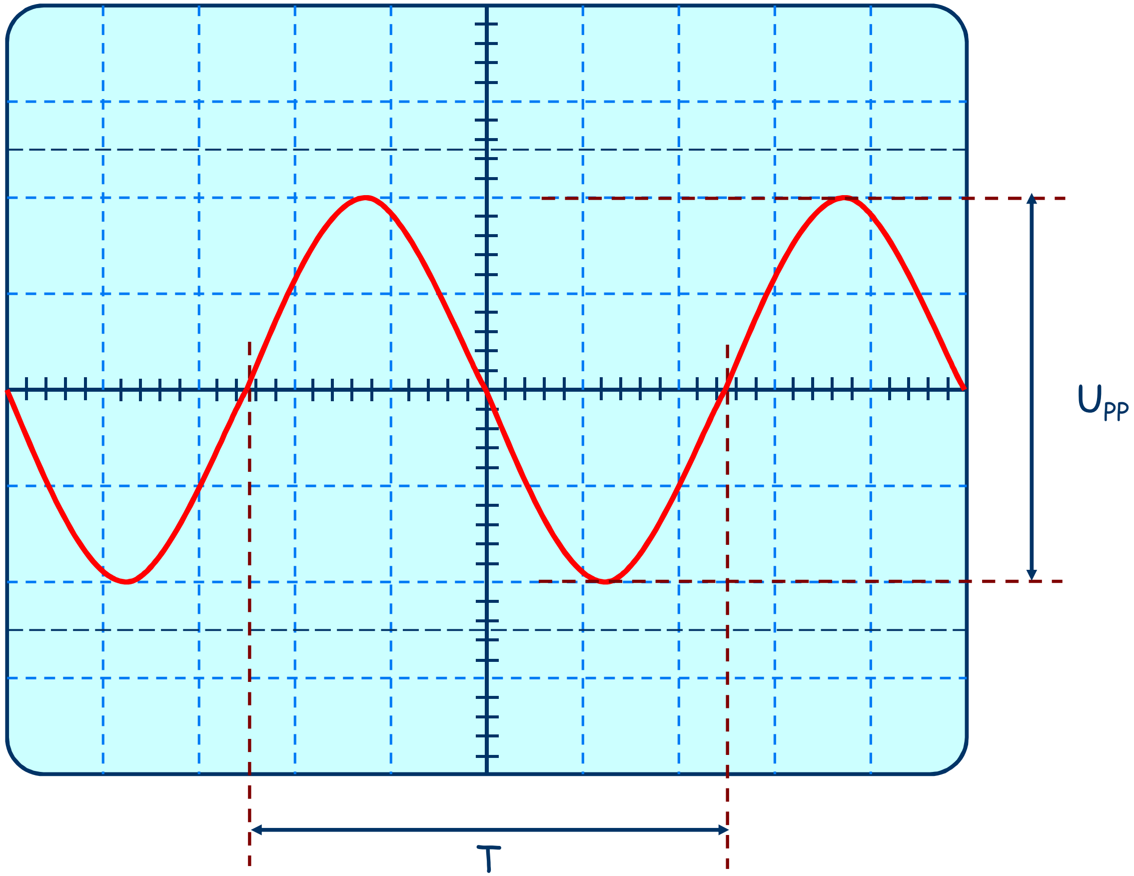
probe overcompensated

Probe compensation



calibrator output

oscilloscope measurements: amplitude, period, frequency



U_{PP} = 4 div × V/div

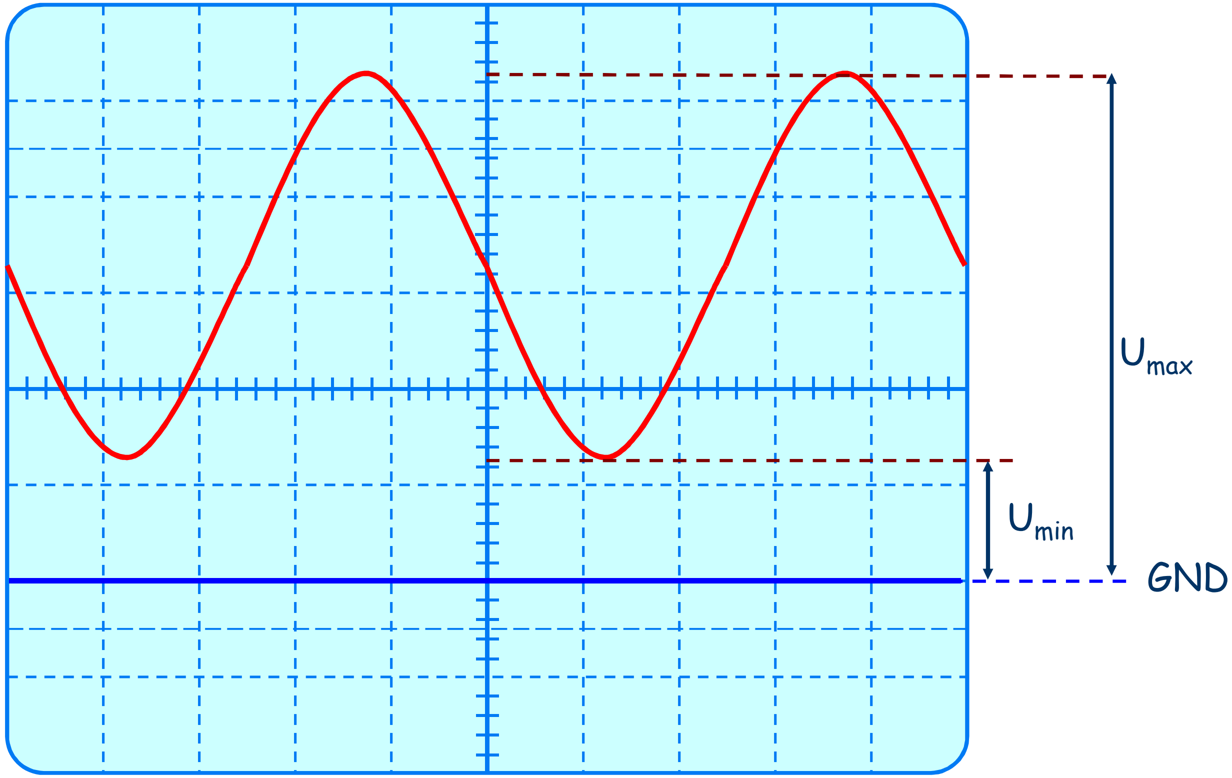
T = 5 div × sec/div

f = 1/T

oscilloscope measurements: absolute voltage level

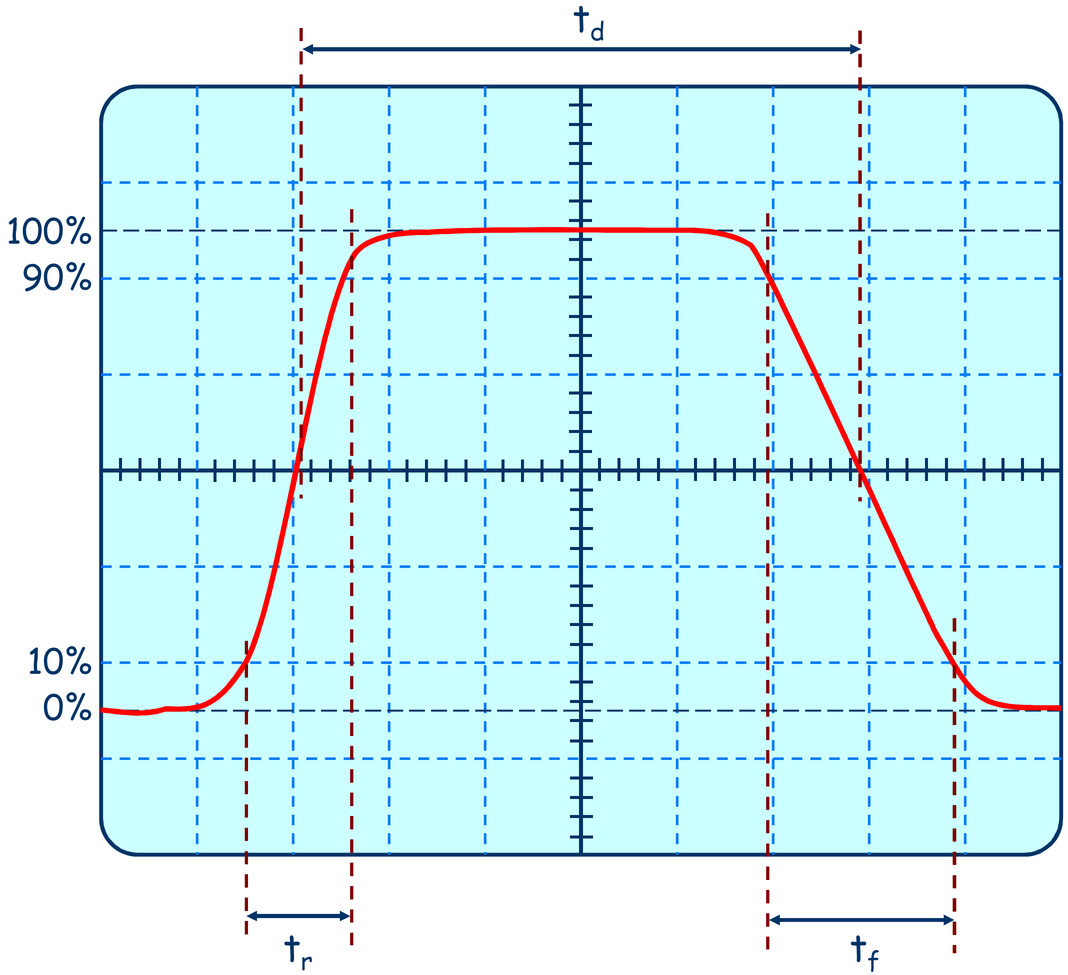
It's a three-step procedure:

1. Disconnect the input signal or ground the input (AUTO trigger is helpful)
2. Set the line visible on the screen in some convenient location
3. Apply the input signal



U_{min} = 1.3 div × V/div
U_{max} = 5.3 div × V/div
U_{PP} = 4 div × V/div

Oscilloscope measurements: rise time, fall time, pulse duration



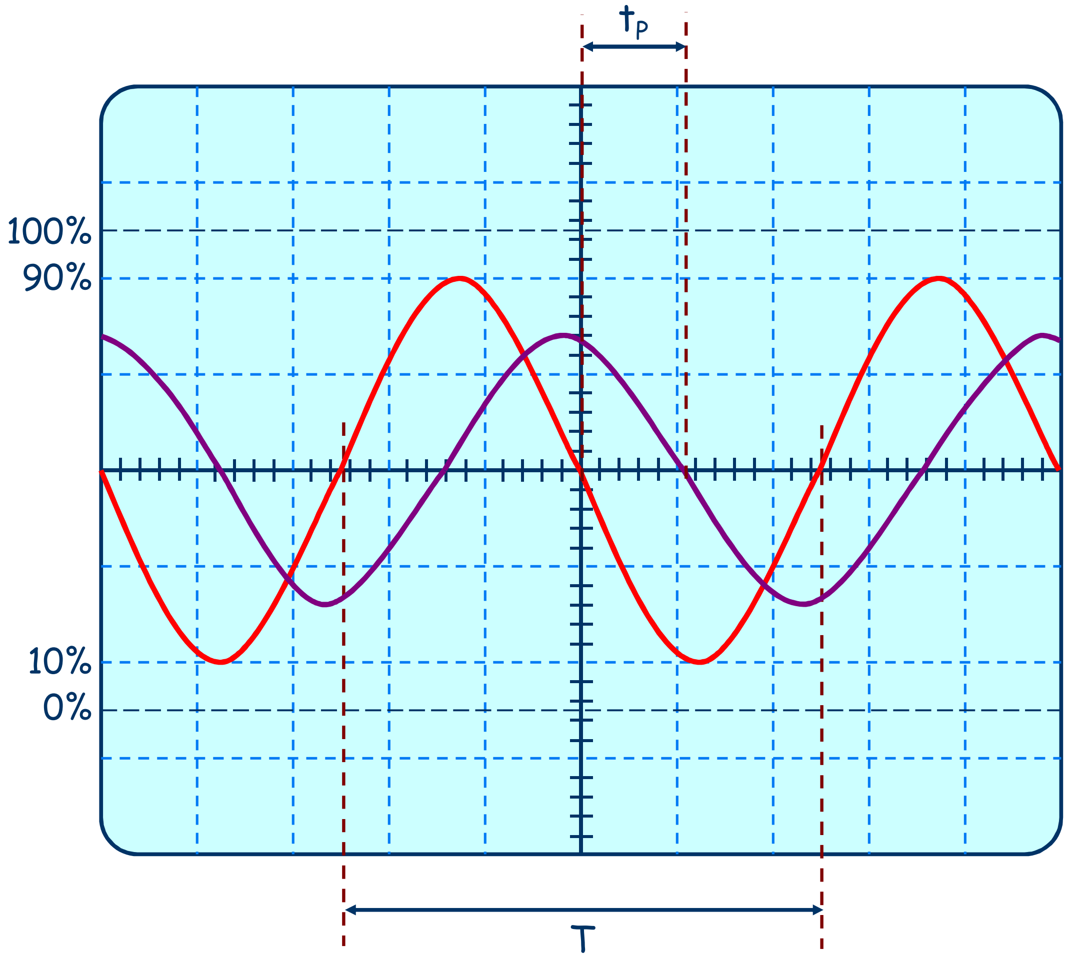
t_r = 1.1 div

t_f = 1.95 div

t_d = 5.8 div

} × sec/div

Oscilloscope measurements: phase shift

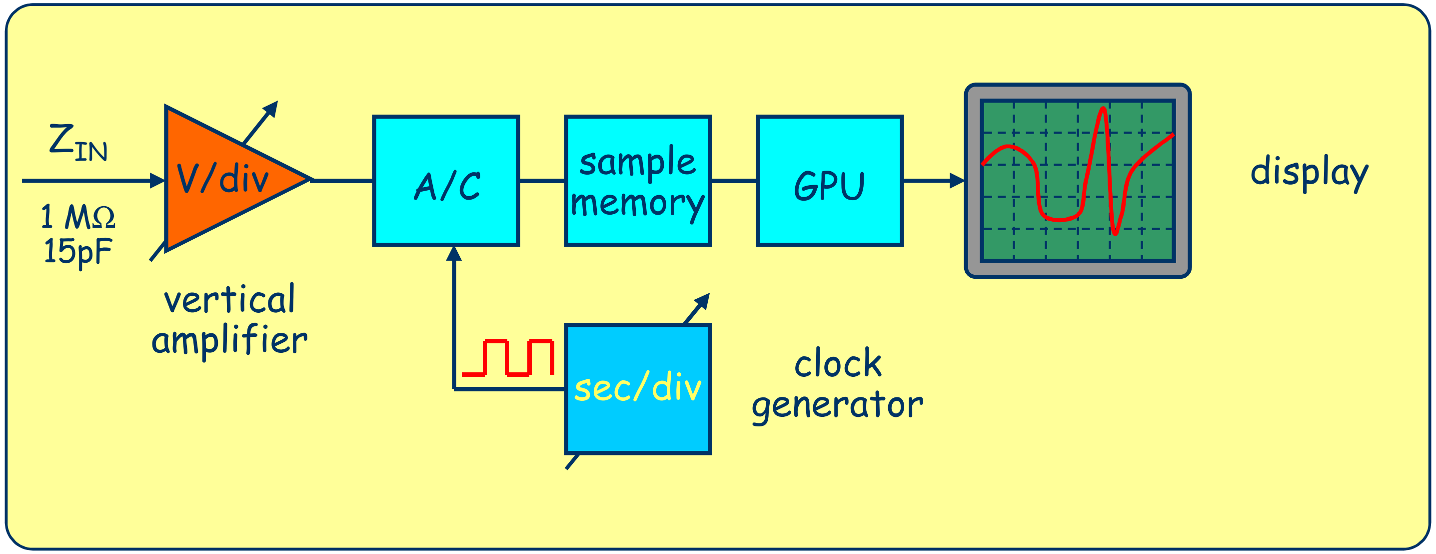


t_P = 1.05 div

T = 5 div

$\varphi = 2\pi \times t_P/T$ [rad]

Digital oscilloscope



DSO

- Digital Storage Oscilloscope
- Digital Sampling Oscilloscope

MSO

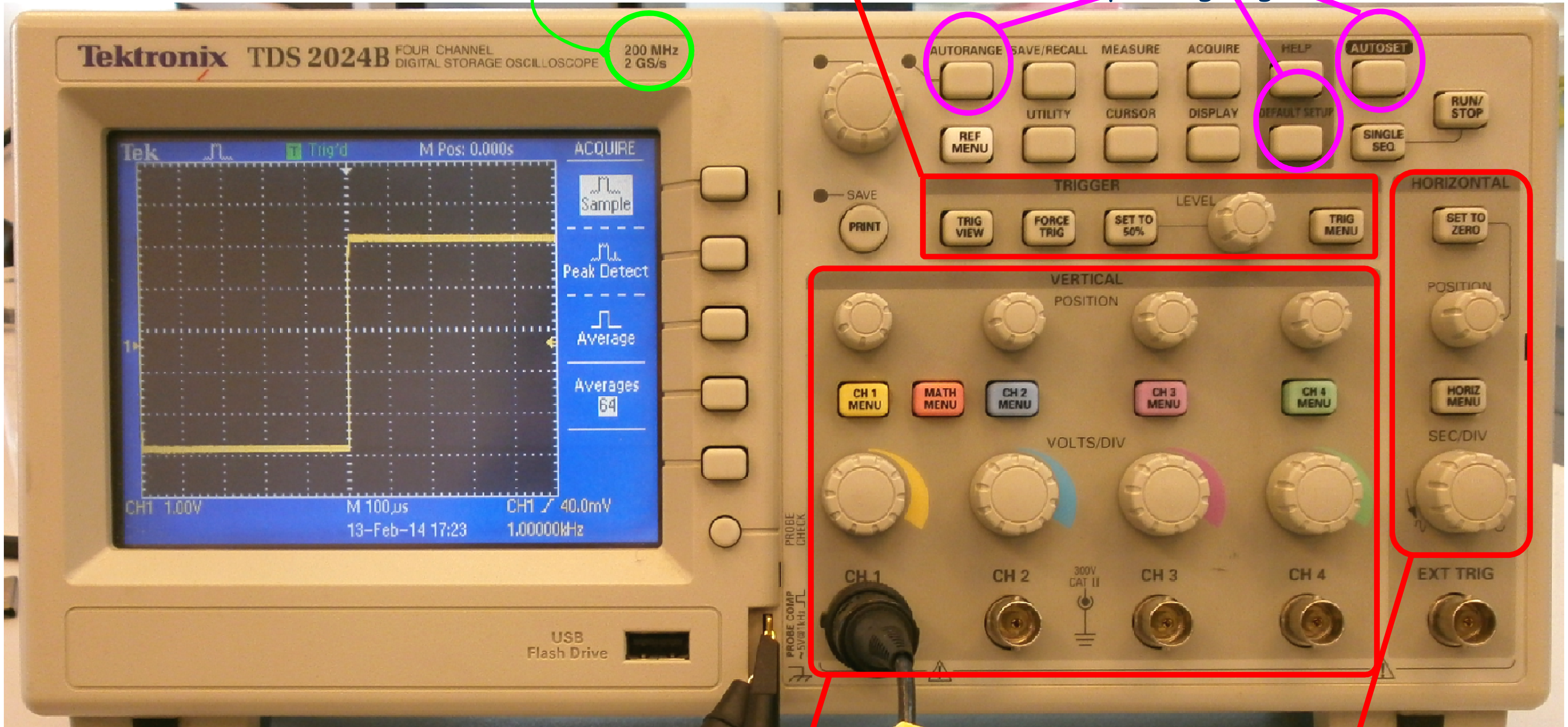
- Mixed Signal Oscilloscope

Digital oscilloscope:
basically everything is the same...

analog bandwidth: 200 MHz
sampling: 2 GS/s

trigger

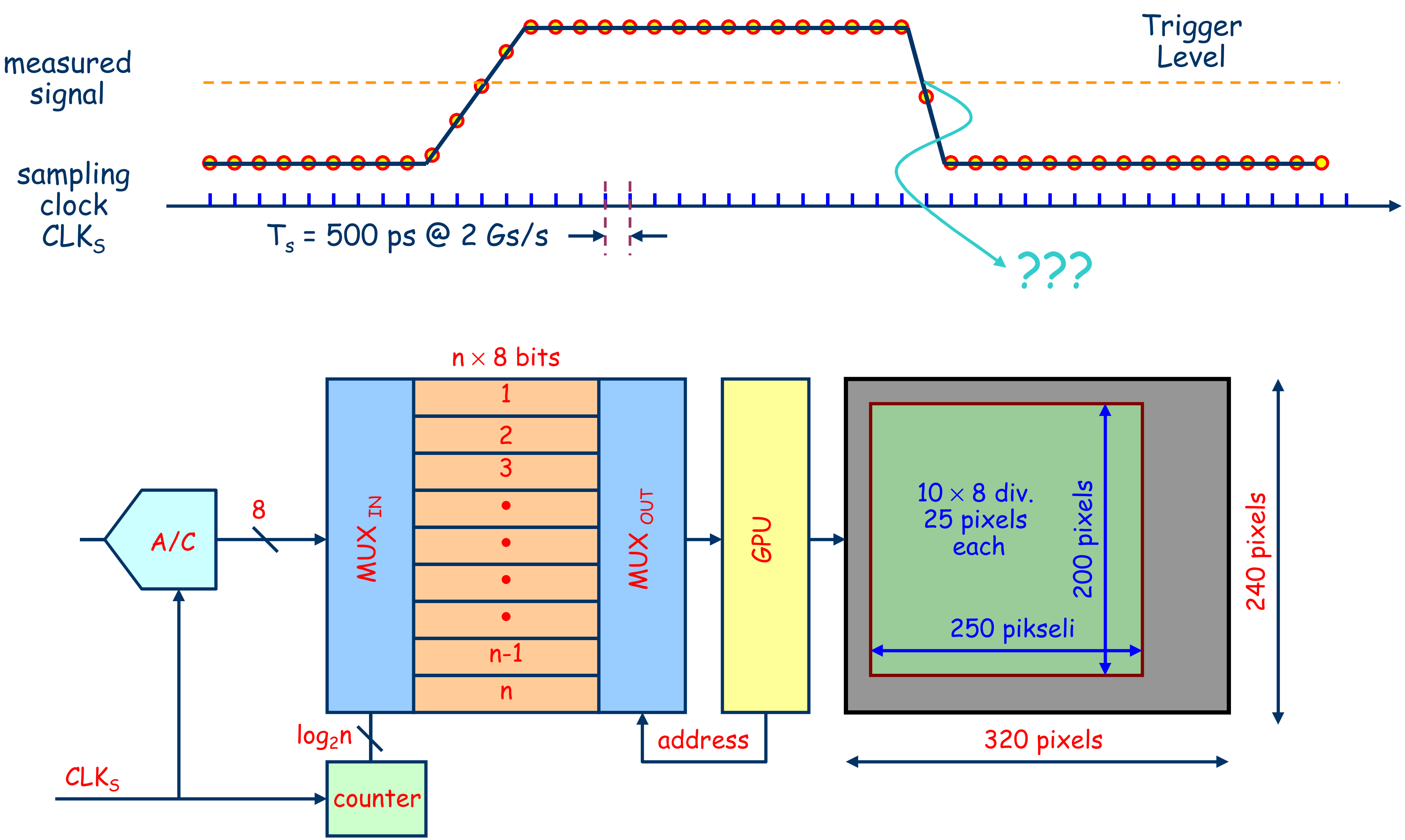
buttons for helpless (i.e. not for self-respecting engineers)



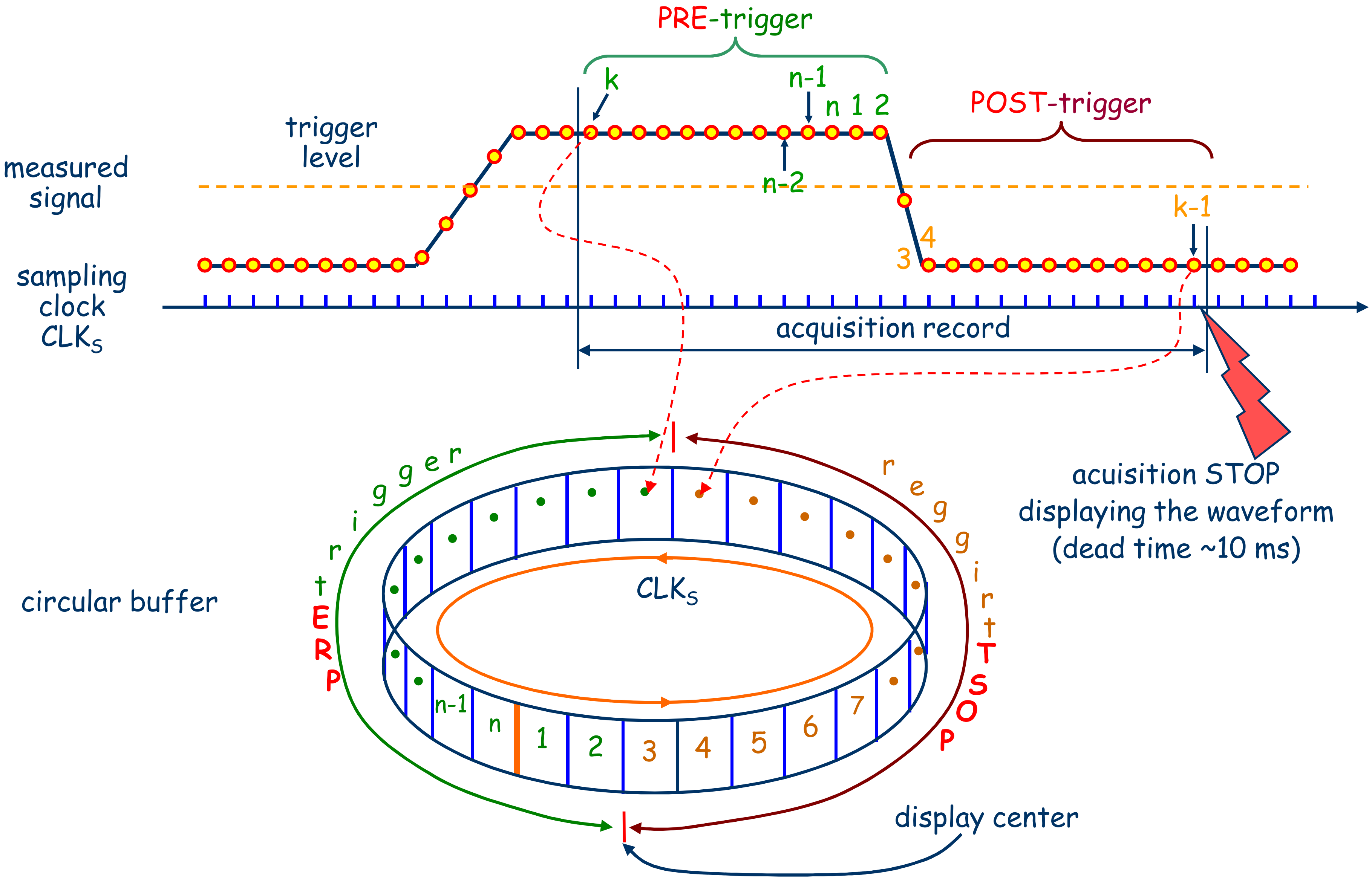
4 measurement channels

timebase

...but operates substantially different...

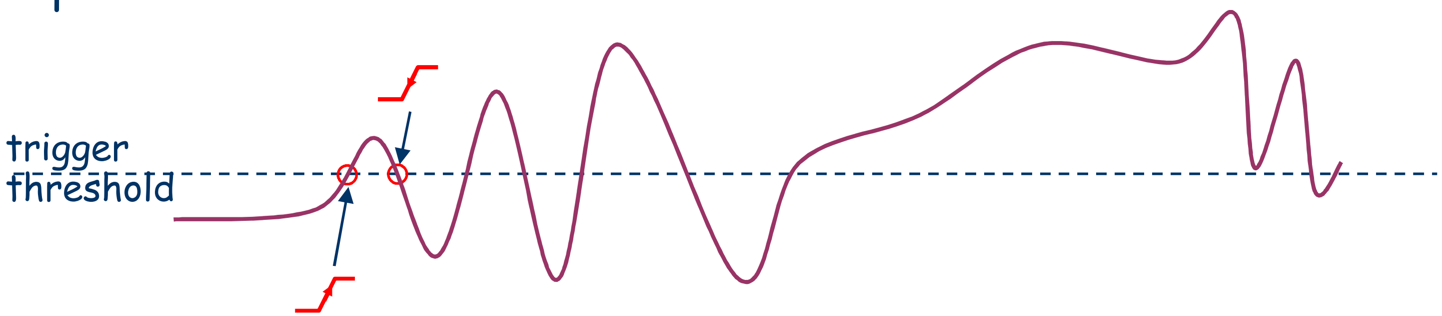


Trigger


PRE-trigger
k
n-1
n 1 2
n-2
trigger level
measured signal
POST-trigger
k-1
3
4
sampling clock CLKS
acquisition record
acuisition STOP
displaying the waveform
(dead time ~10 ms)
circular buffer
PRE trigger
POST trigger
CLKS
n-1
n
1
2
3
4
5
6
7
display center

Trigger types

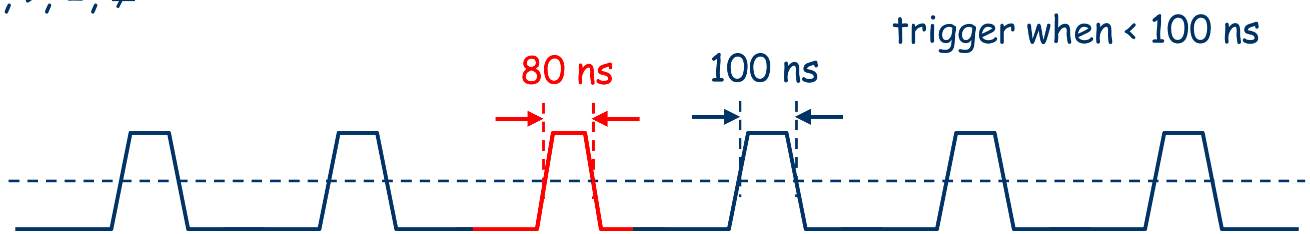
slope



pulse width or glitch

pulse duration

<, >, =, ≠

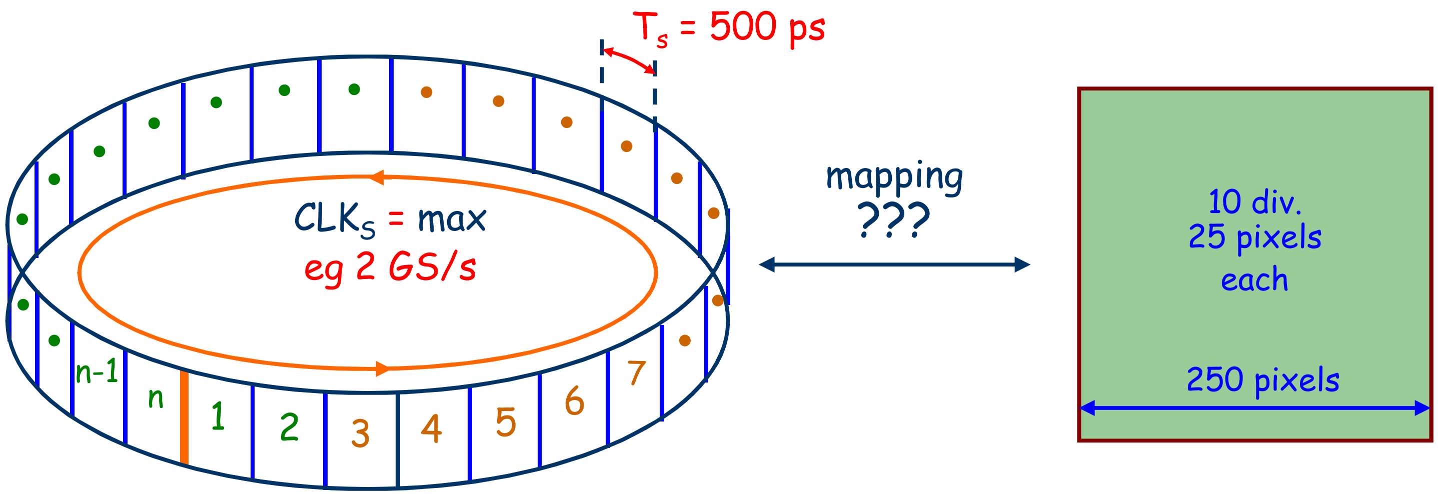


pattern

trigger when pattern 1000110010101000

DSO Timebase operation (I)

„high" timebase speed („low" S [sec/div] values)



samples/div:

$$x = S \cdot f_S = S/T_S \text{ [sec/div} \cdot \text{samples/sec]}$$

S = 10 ns/div → x = 20 ← interpolation (GPU) acquisition record full, not enough samples
S = 100 ns/div → x = 200 ← decimation acquisition record full, too many samples

DSO Timebase operation (II)

„low" timebase speed („large" S [sec/div] values)

observable time interval:

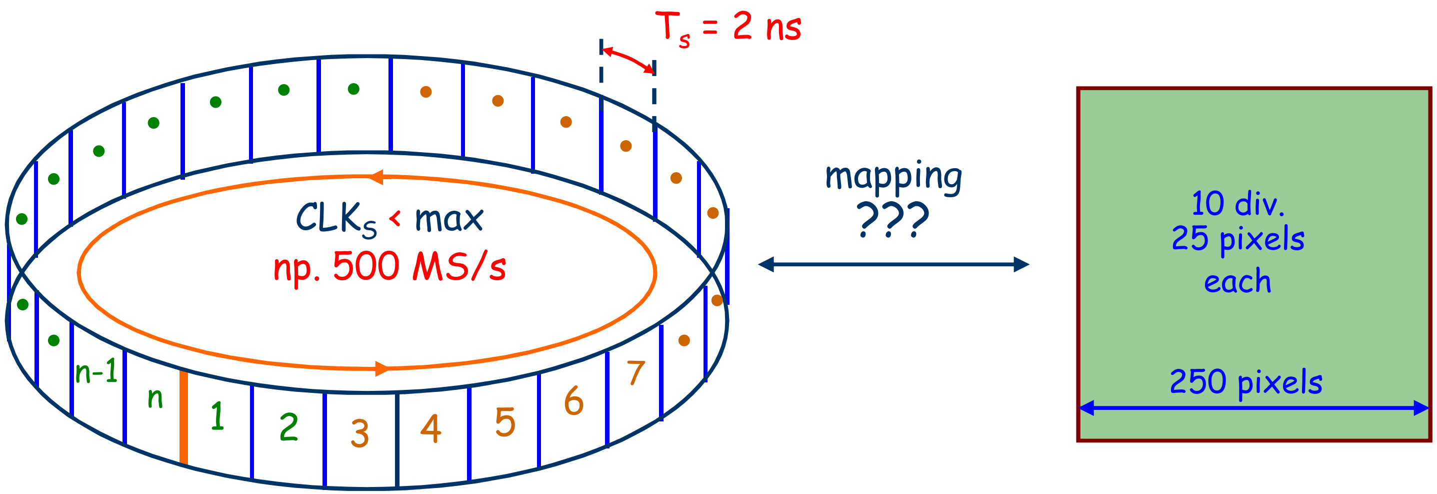
$$\Delta t = L_A \times T_s = L_A / CLK_S$$

L_A – length of acquisition record

eg: for L_A = 2500 samples

CLK_S = 2 GS/s → Δt = 1.25 μs
CLK_S = 500 MS/s → Δt = 5 μs
Δt = 1 s → CLK_S = 2.5 kHz !!!

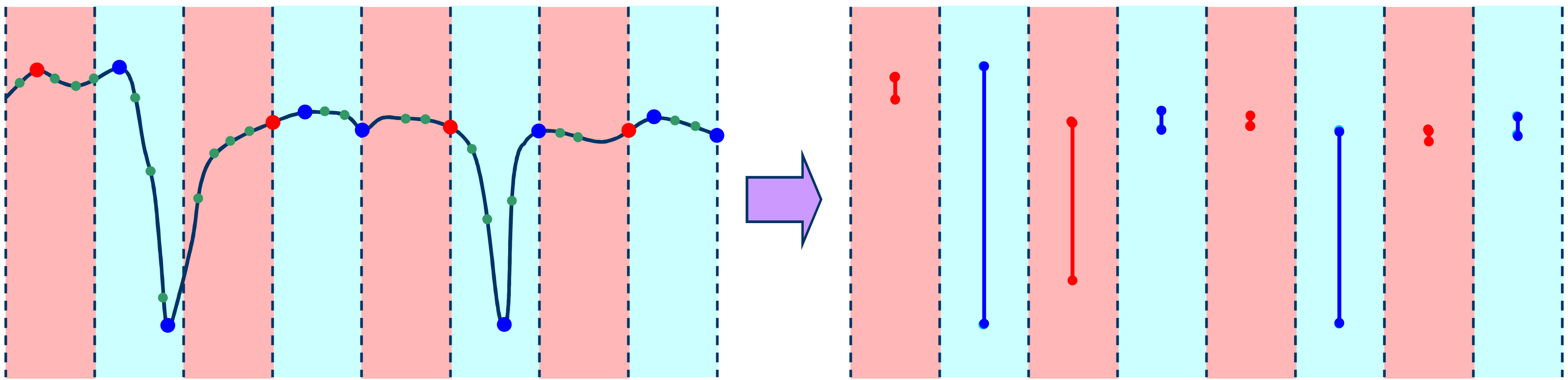
acquisition record always full
CLK_S < CLK_{max} (decimation)



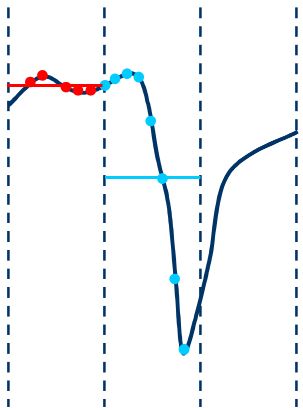
In practice it is more convenient to have the rate of CLK_S constant:
⇒ in the memory only every *k* sample is stored

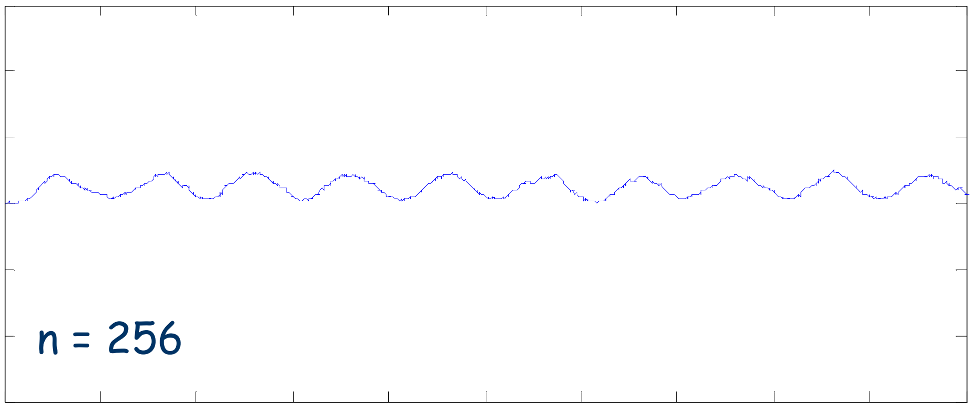
DSO opeartion modes with low timebase speed

Peak Detect

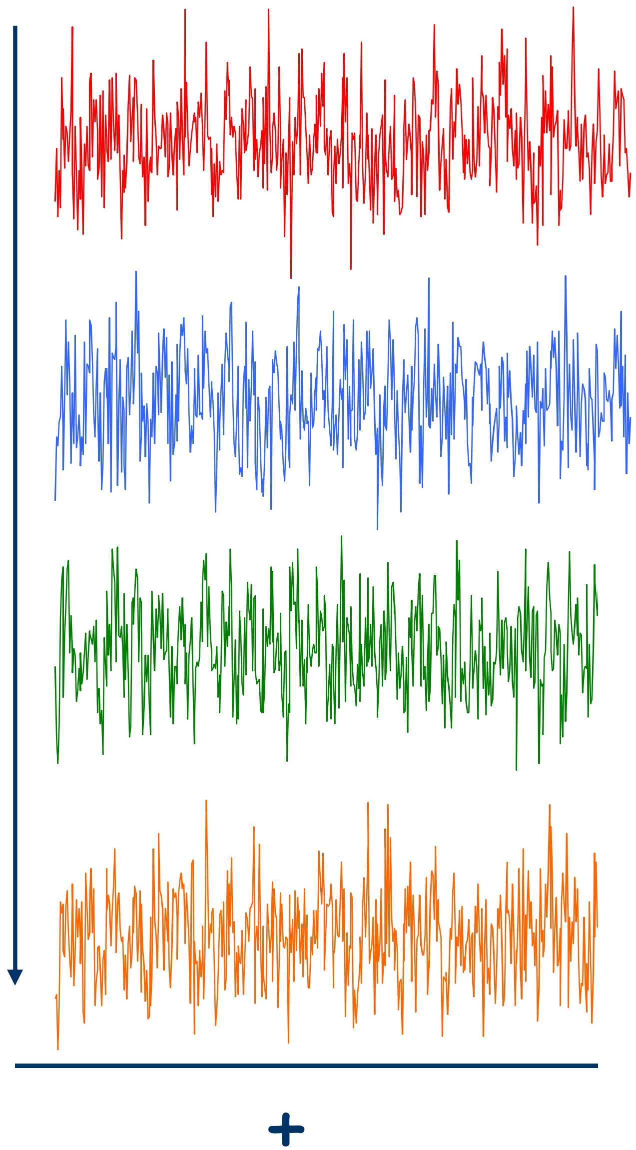


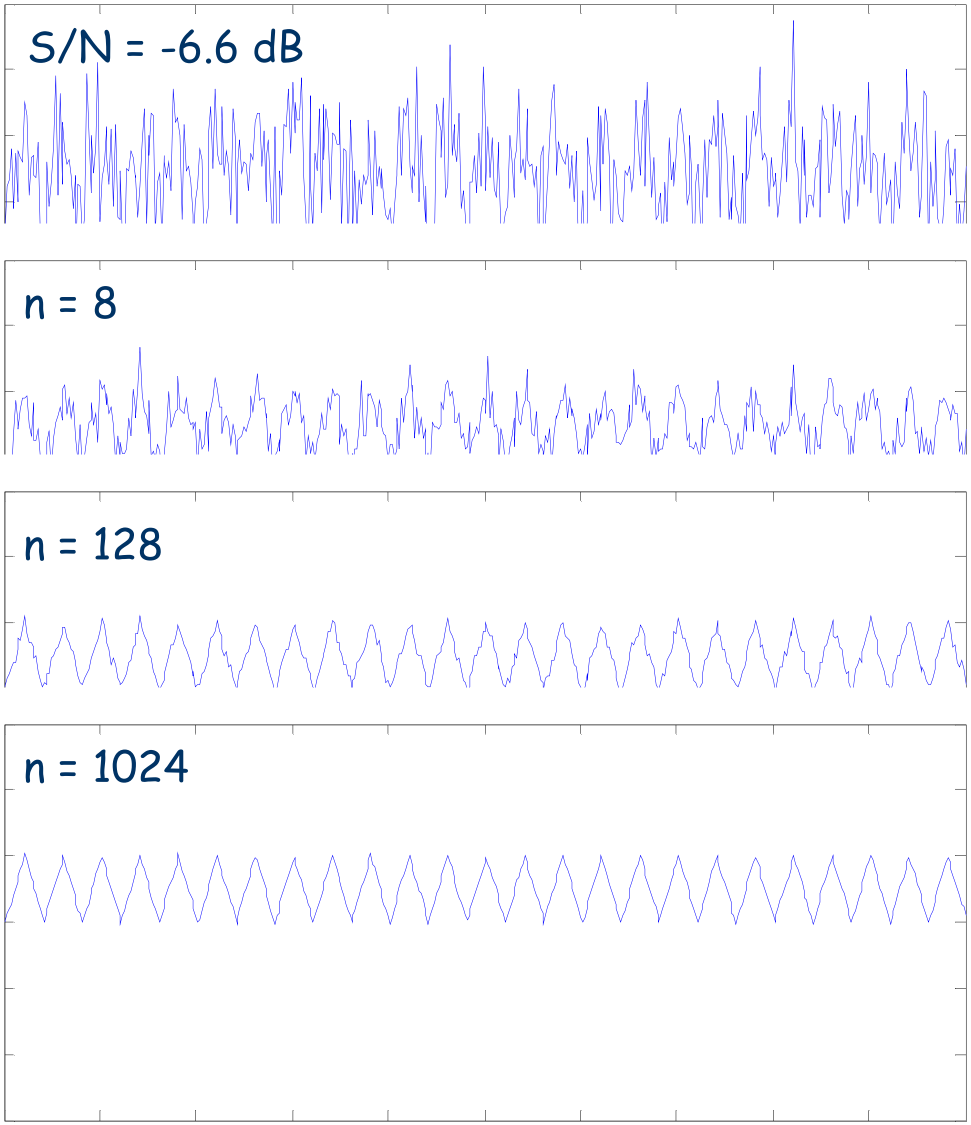
HiRes, ERes, Smoothing





Averaging



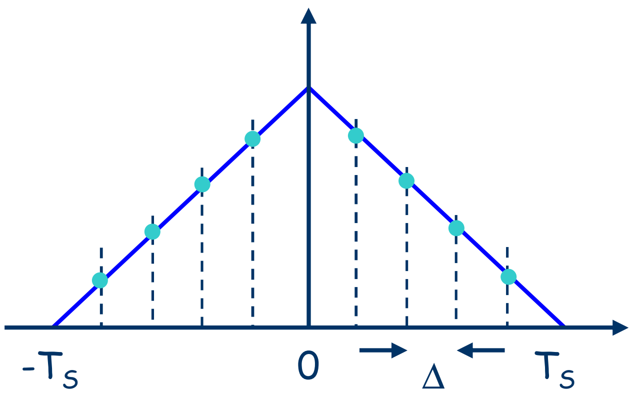


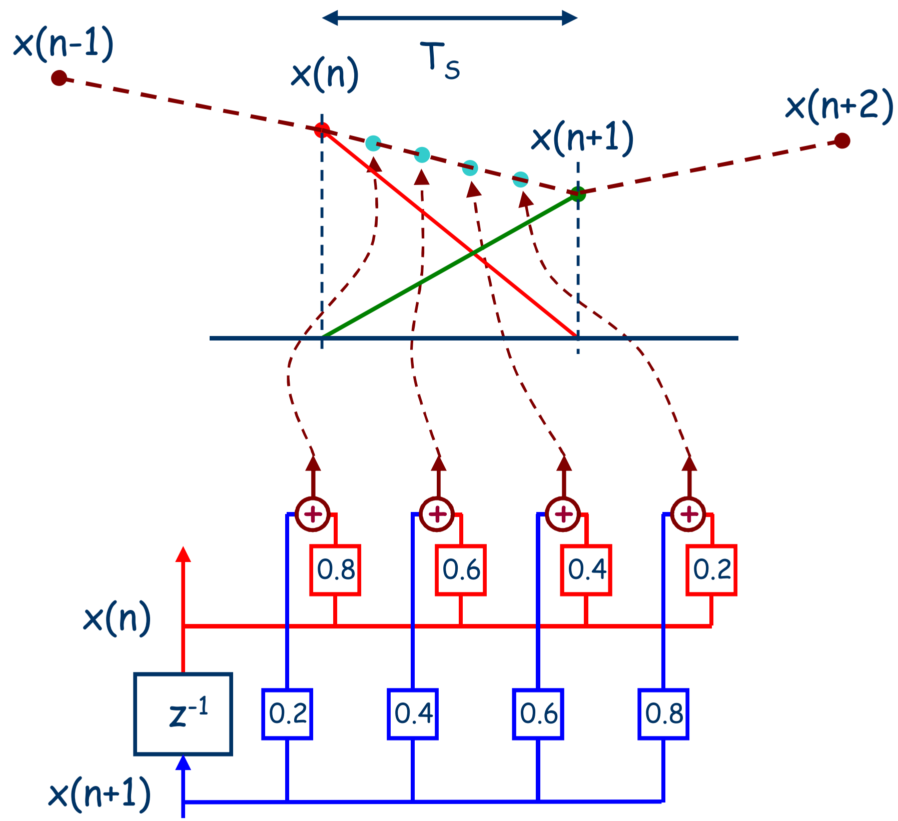
There are not only „dots": interpolation

1. Dots
2. Vectors (Connect Dots)
3. Sin(x)/x

$$x(t)=\int_{-\infty}^{+\infty}\sum_{i=-\infty}^{+\infty}x(i\cdot T_s)\cdot\delta(\tau-i\cdot T_s)\cdot I(t-\tau)d\tau=$$

$$=\sum_{i=-\infty}^{+\infty}x(i\cdot T_s)\cdot I(t-i\cdot T_s)$$





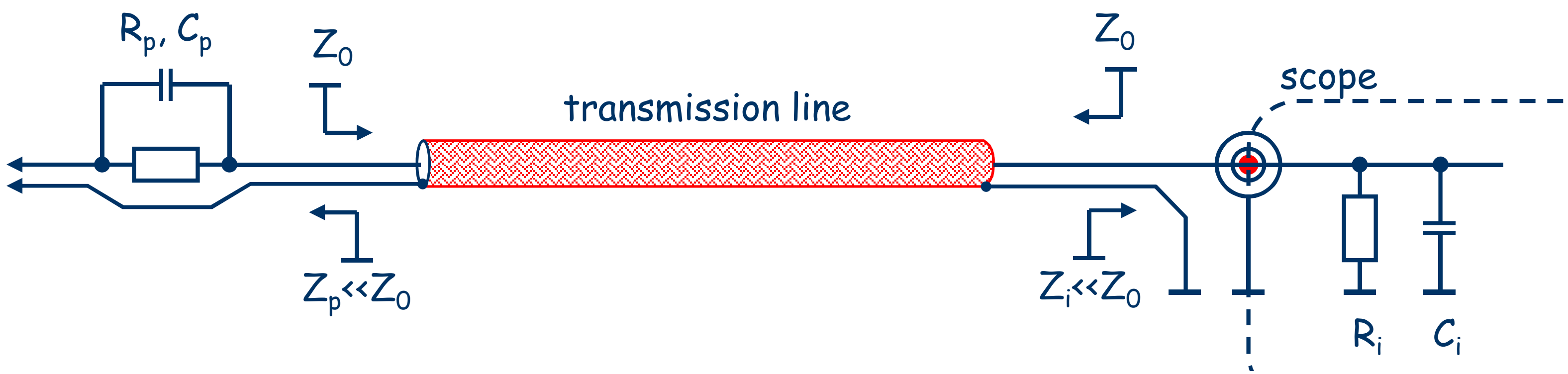
$$t=n\cdot T_s+k\cdot\Delta$$

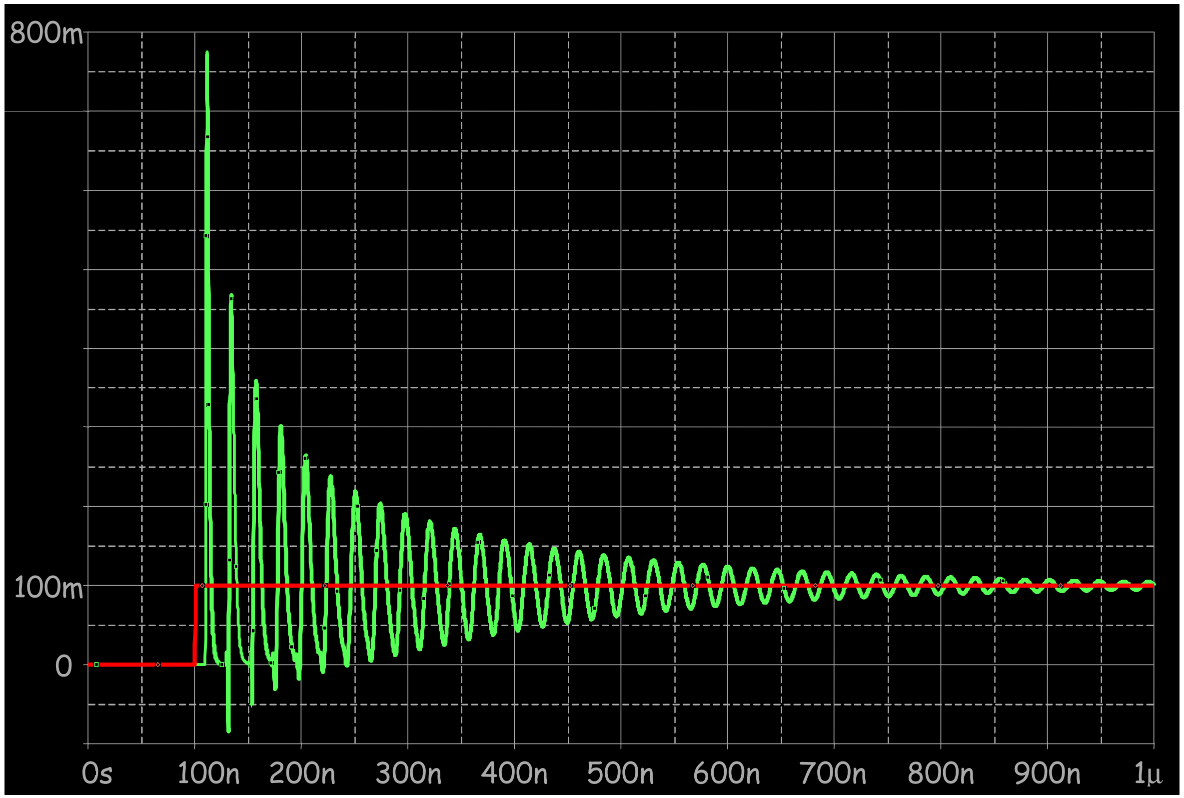
$$x(n\cdot T_s+k\cdot\Delta)=\sum_{i=-\infty}^{+\infty}x(i\cdot T_s)\cdot\Lambda(k\cdot\Delta+(n-i)\cdot T_s)$$

$$i=n \quad \to x(n\cdot T_s)\cdot\Lambda(k\cdot\Delta)$$

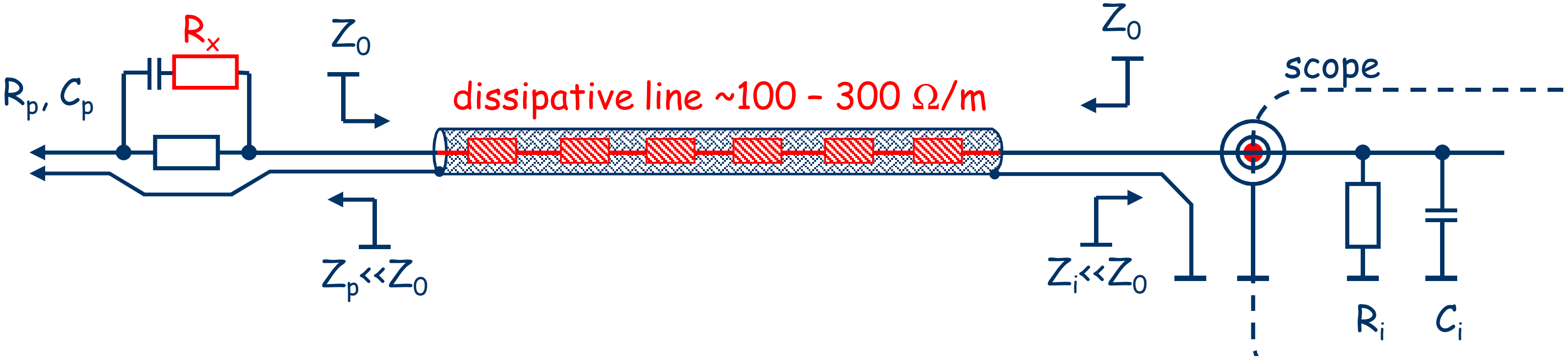
$$i=n+1 \quad \to x((n+1)T_s)\cdot\Lambda(k\cdot\Delta-T_s)$$

Oscilloscope probe for curious...

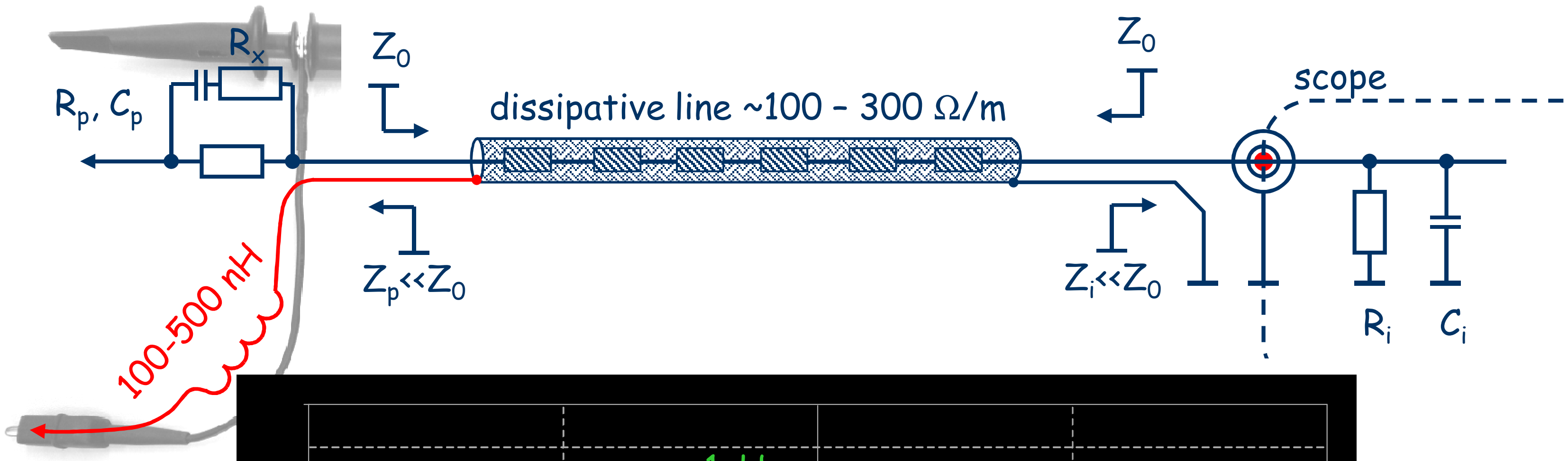


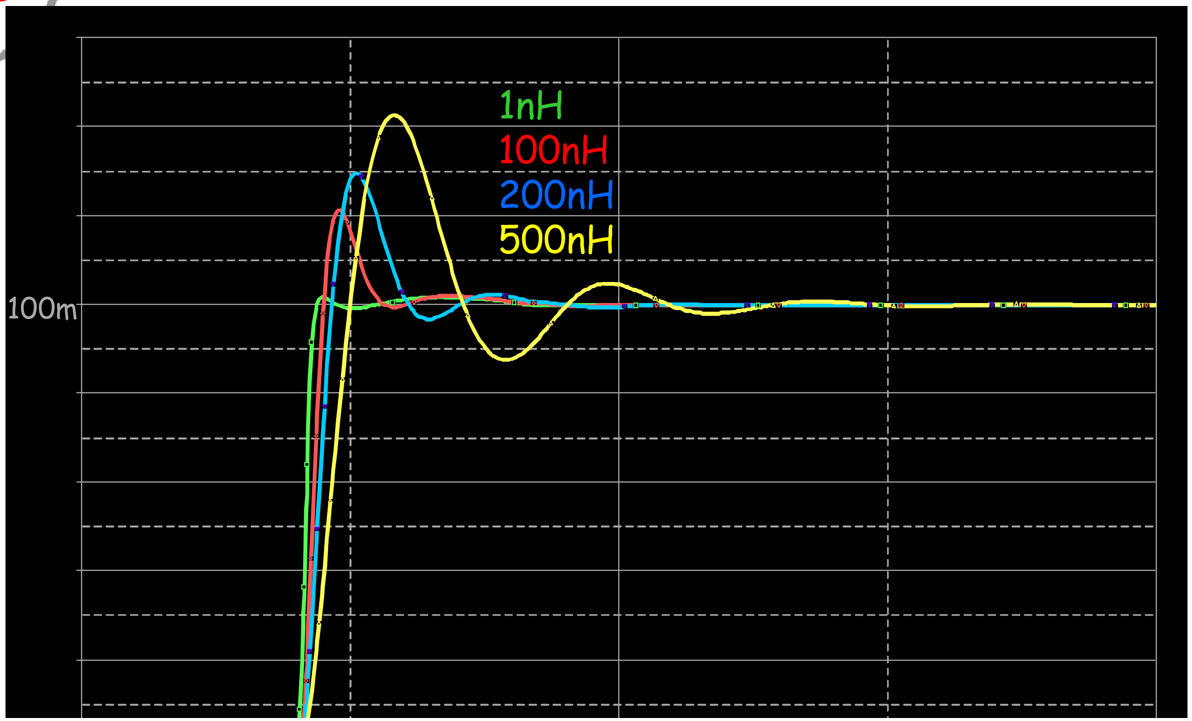


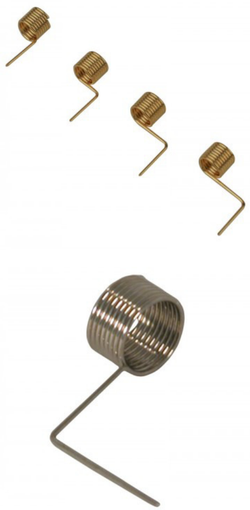
Oscilloscope probe for curious...

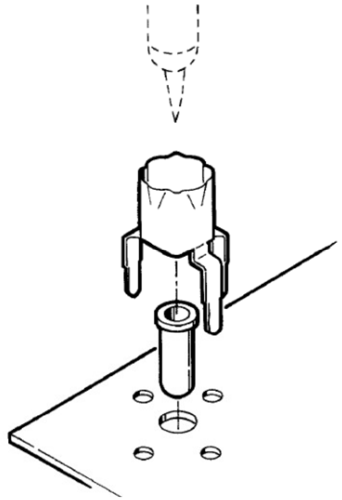


Oscilloscope probe for curious...





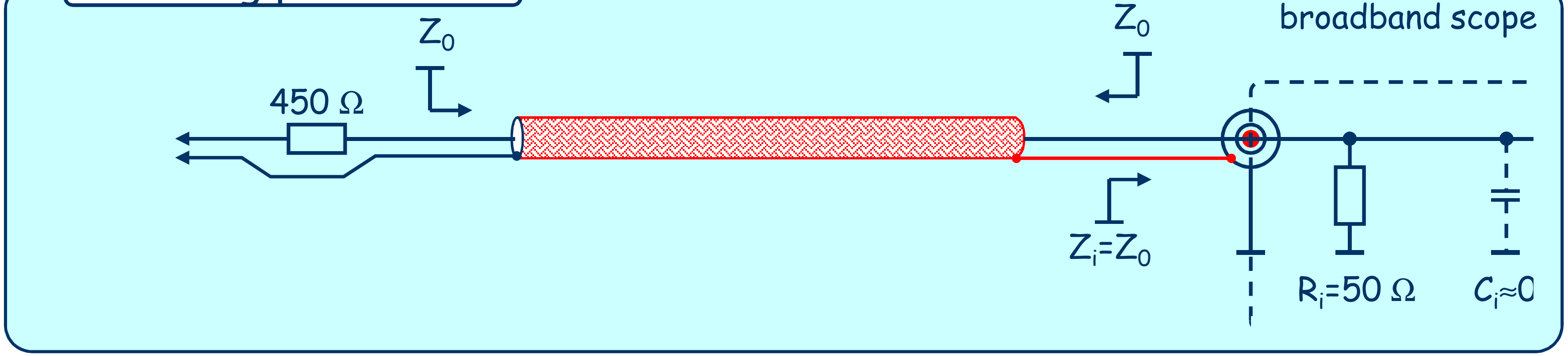




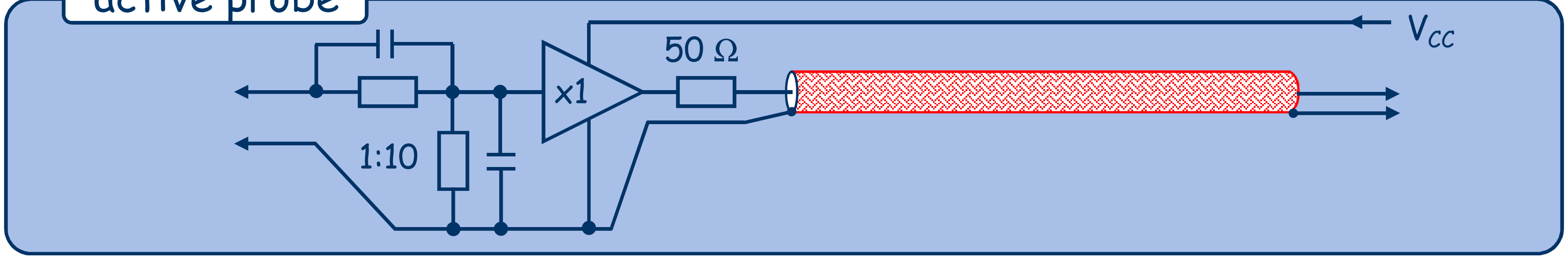
Respect your probe – its a complex piece of equipment!

Probe for really advanced...

dividing probe 1:10



active probe



differential measurements