EE1320: Measurement Science

Lecture 7:
Measurement Instruments II

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Course program 2013

week	date	topic
4.1	Tu 23/4	#1 intro measurements and meas. systems
	Fr 26/4	#2 sensors
4.3	Tu 7/5	#3 sensor readout and signal conditioning
4.4	Tu 14/5	#4 instrumentation amplifiers
	We 15/5	intermediate test
4.5	Tu 21/5	#5 analog-to-digital converters
4.6	We 29/5	#6 measurement instruments I
4.7	Tu 4/6	#7 measurement instruments II
	We 5/6	intermediate test
4.8	Tu 11/6	tutorial
4.11	We 3/7	final exam

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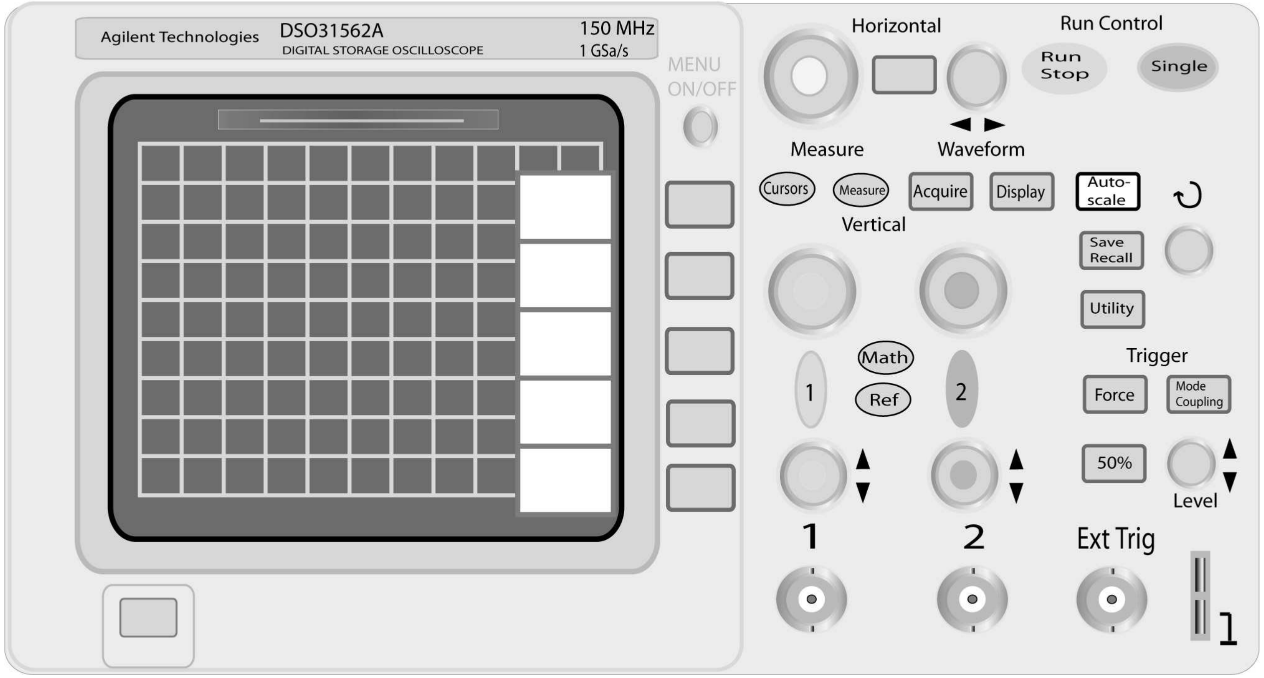
Last time...
Measurement instruments

- Voltage and current measurement
  - input impedance yields gain errors (scale errors)
  - at high frequency, impedance matching is needed for signal transfer without reflections
  - several measures exist for the amplitude of AC signals
- Resistance measurement
  - 2-wire measurement results in errors due to cable resistance
  - solution: 4-wire measurement with Kelvin connections

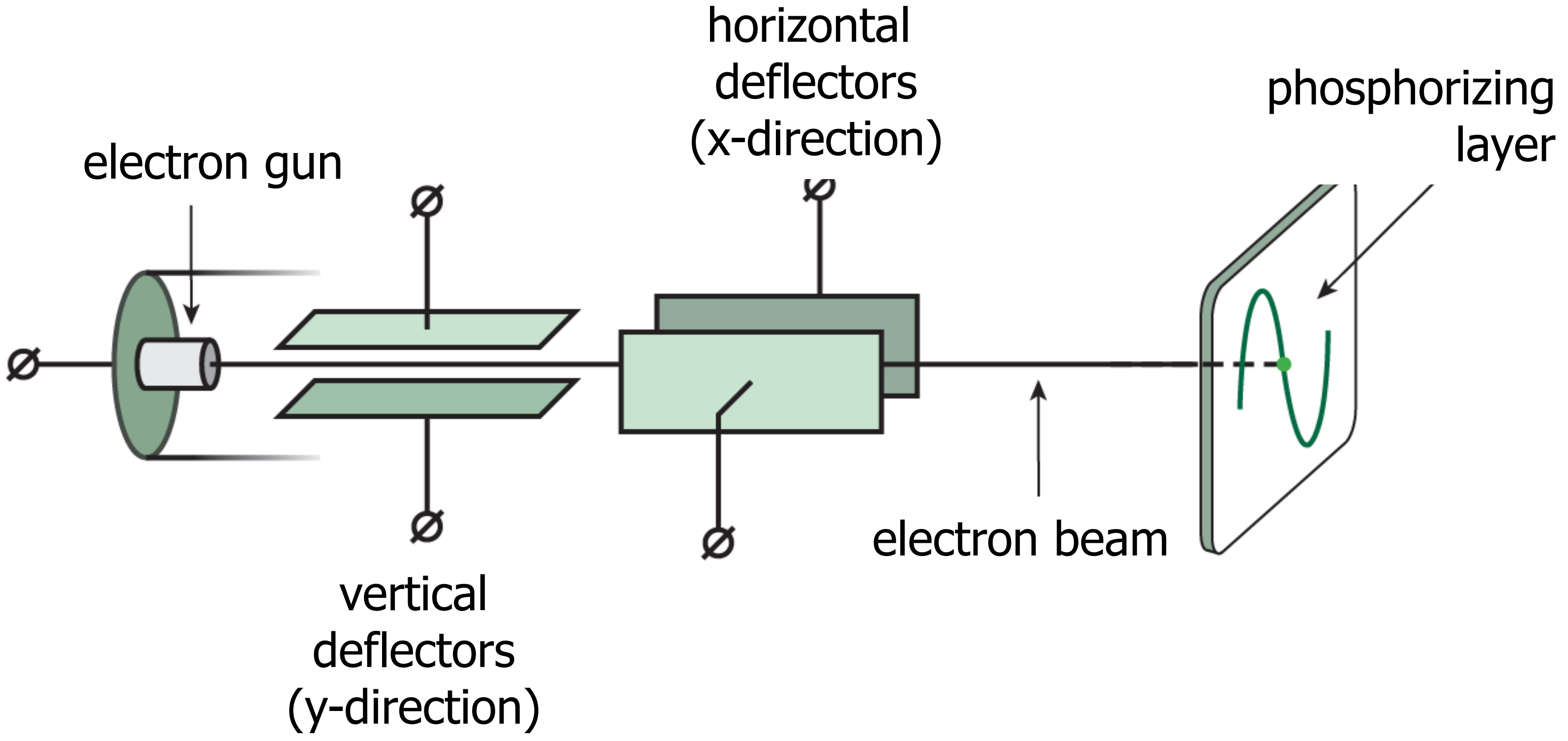
Today: measurement instruments II

- AC waveform measurement: the oscilloscope	Regtien 20.1.2
- Time and frequency measurements	Regtien 20.1.4 **+ slides** Regtien 14.1.1, 14.1.2

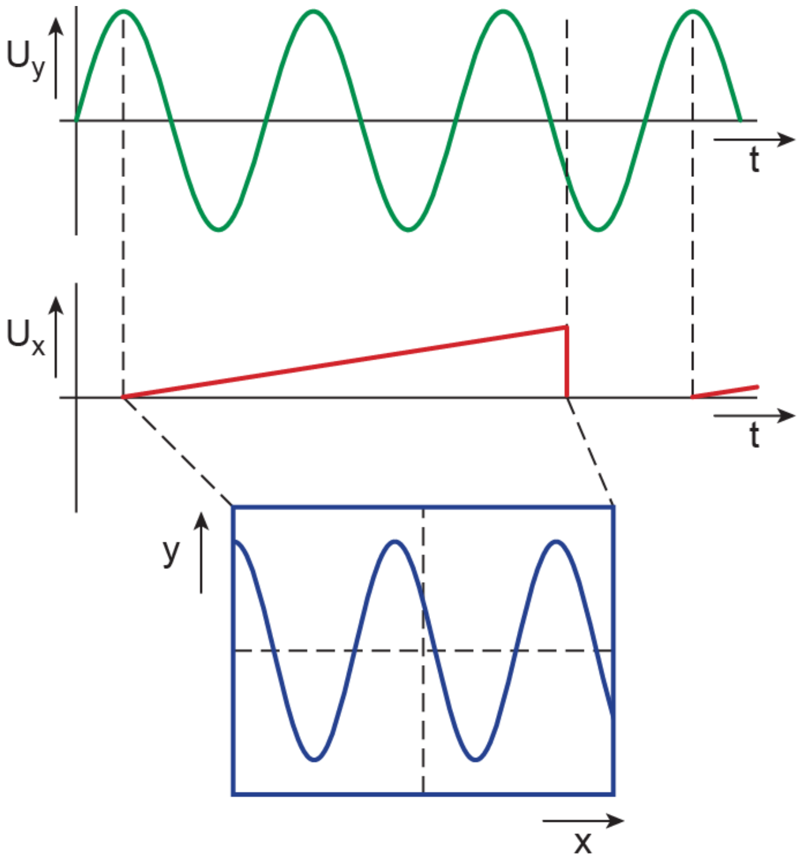
The oscilloscope



Operation principle of an oscilloscope

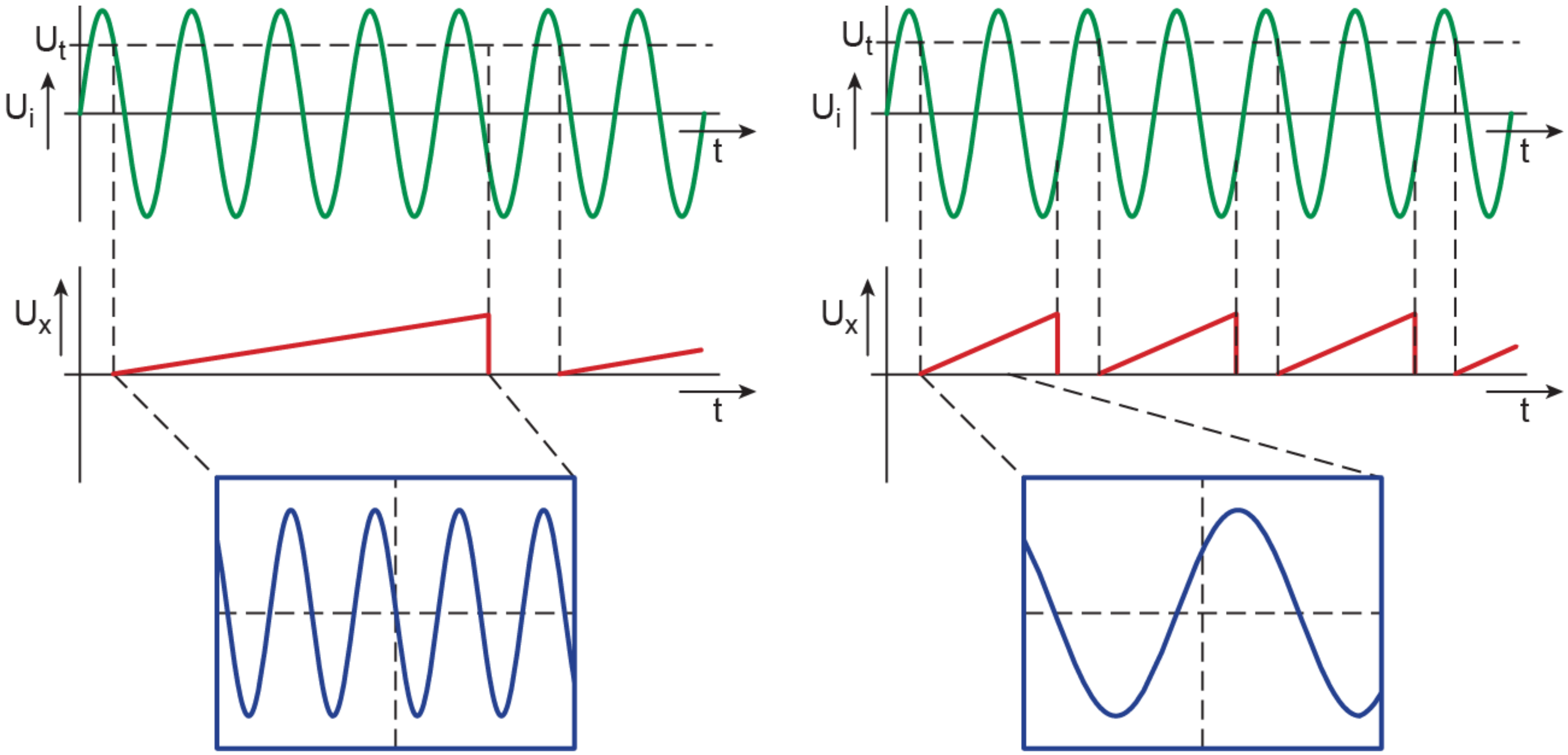


Operation principle of an oscilloscope

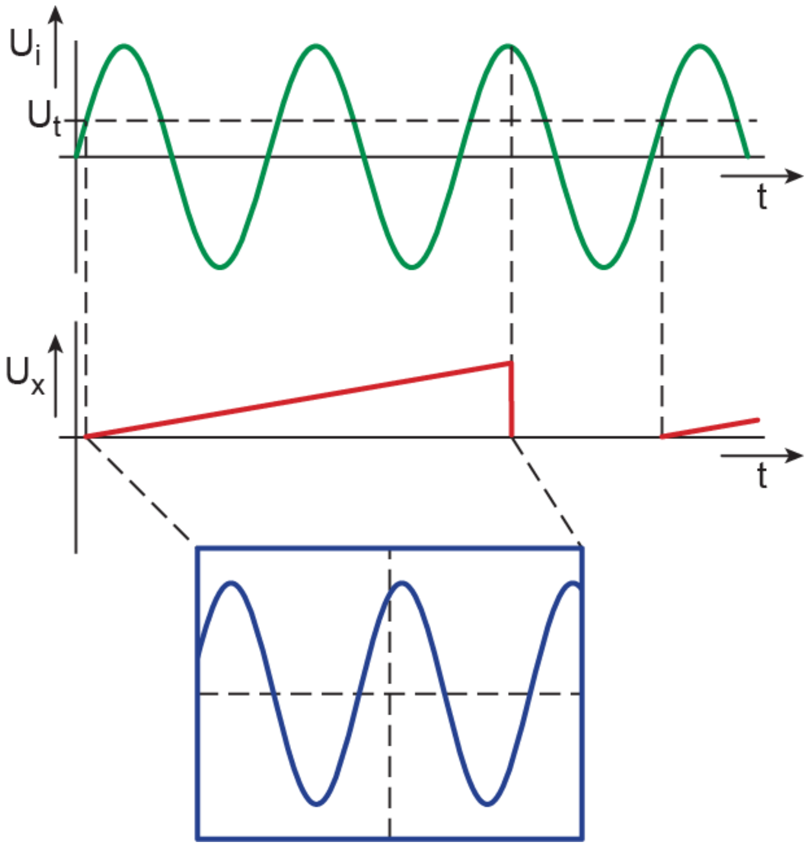


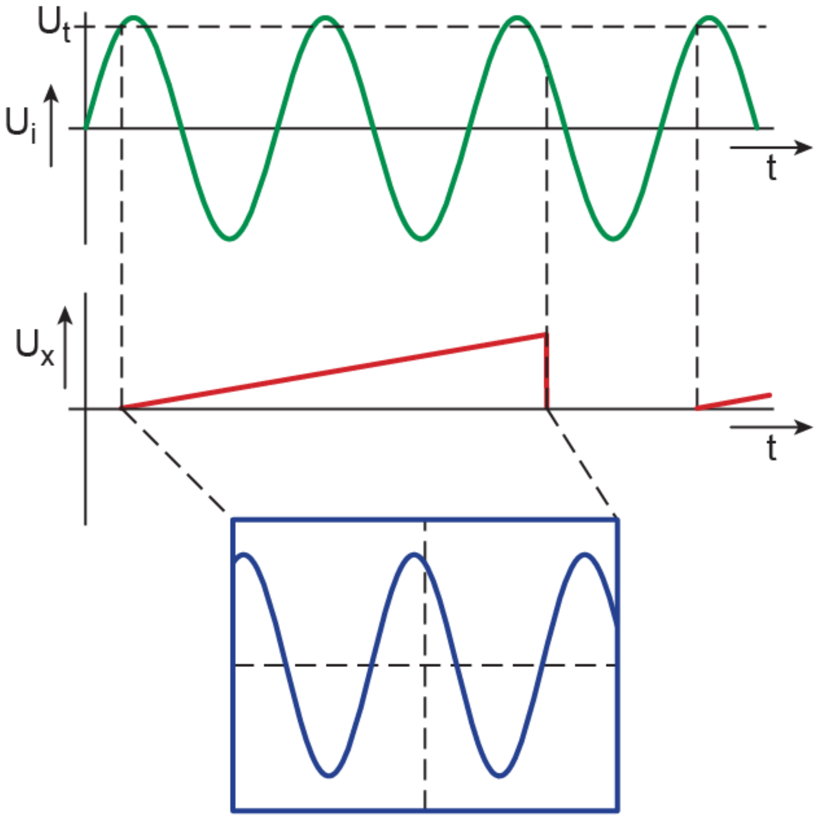
Regtien 20.1.2

Time base



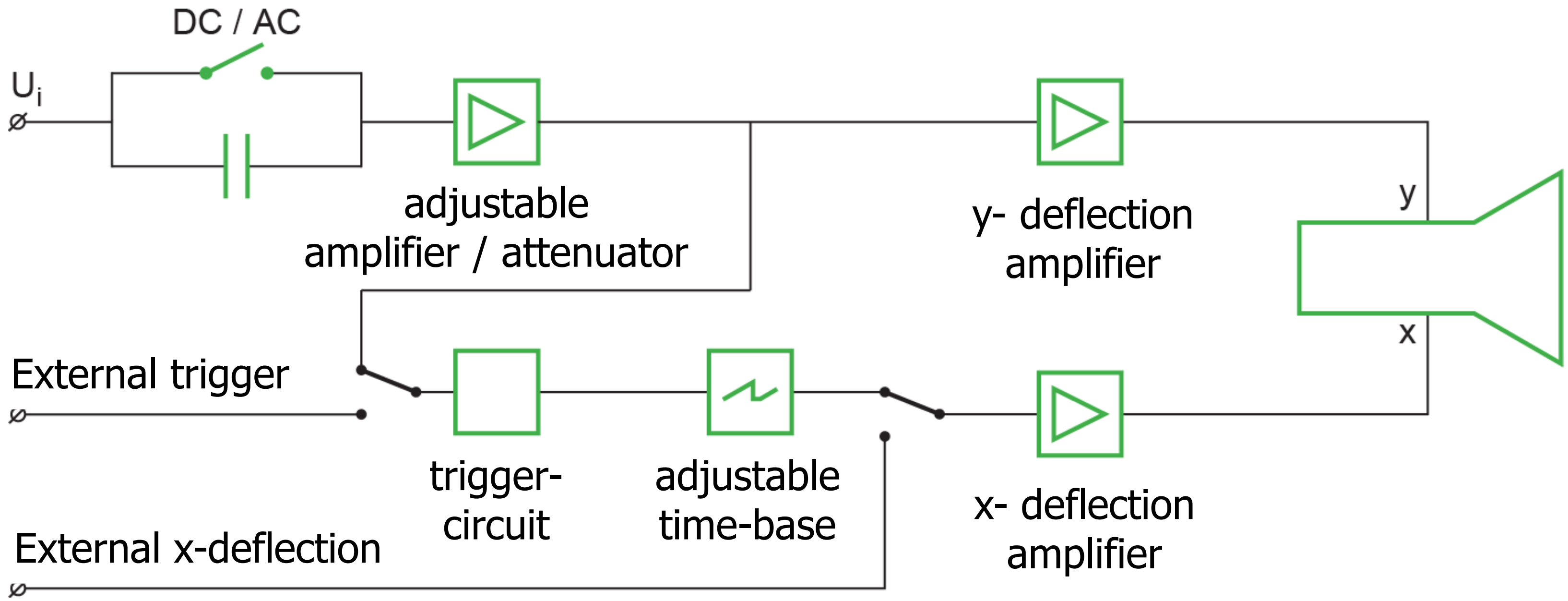
Triggering



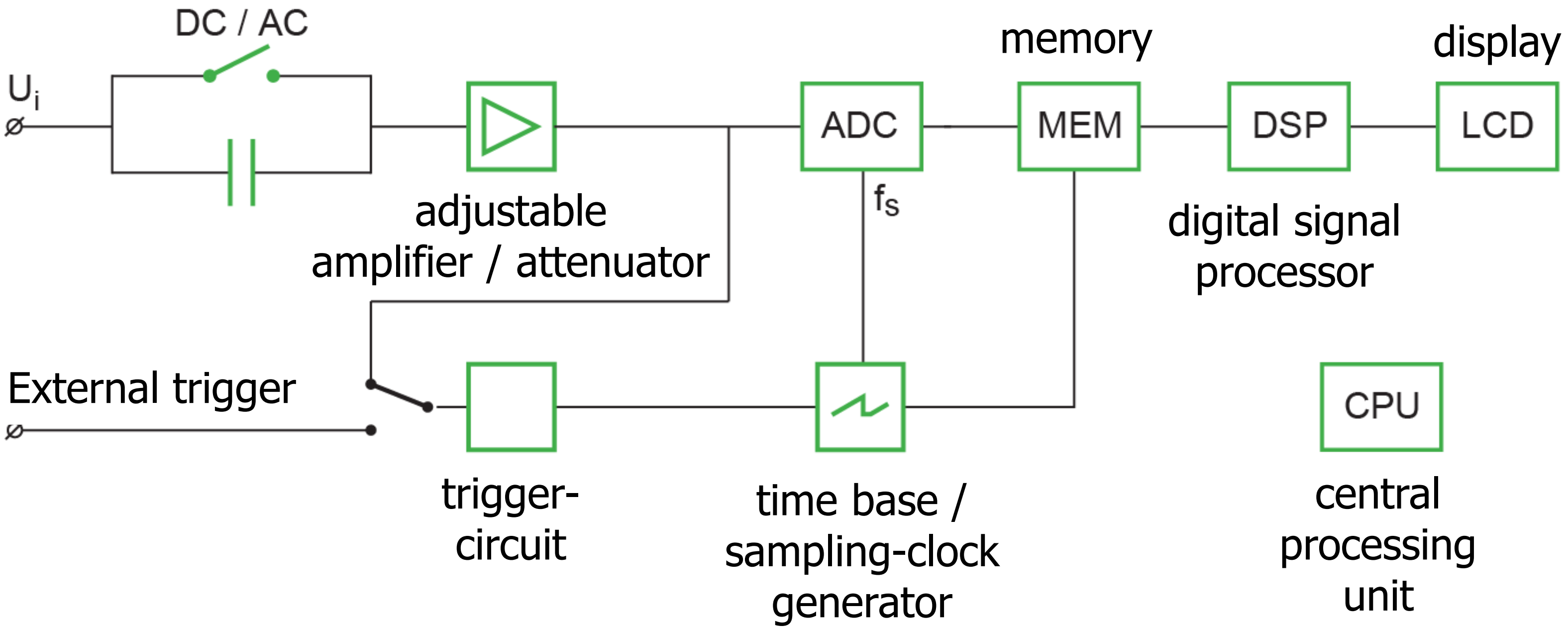


Regtien 20.1.2

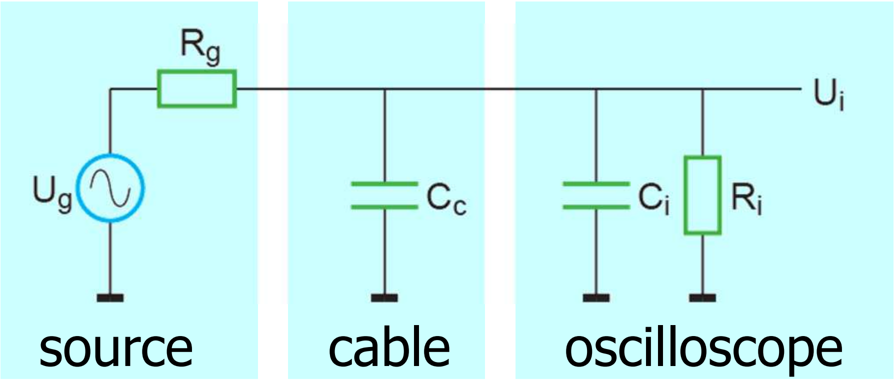
Analog oscilloscope



Digital oscilloscope



Measuring without a probe

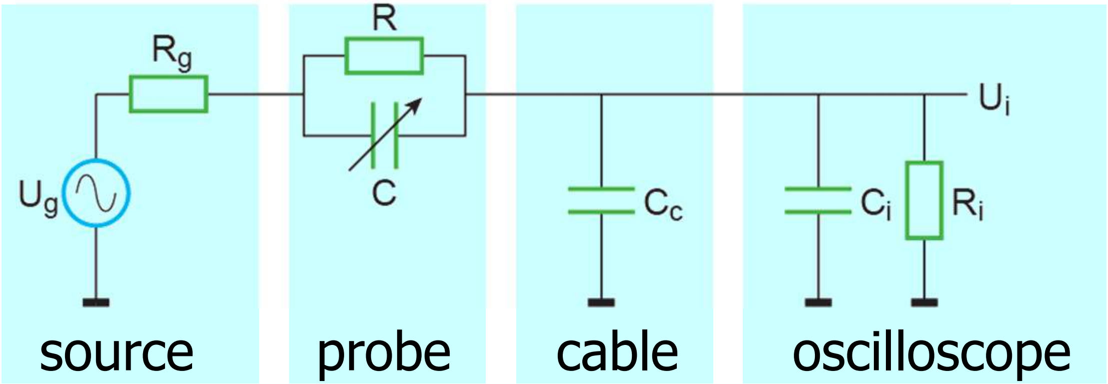


- Oscilloscope: typical C_i = 20 pF, R_i = 1 MΩ
- Coax cable: approximately 100 pF for 1 m cable

- Input impedance: 1 MΩ // 120 pF

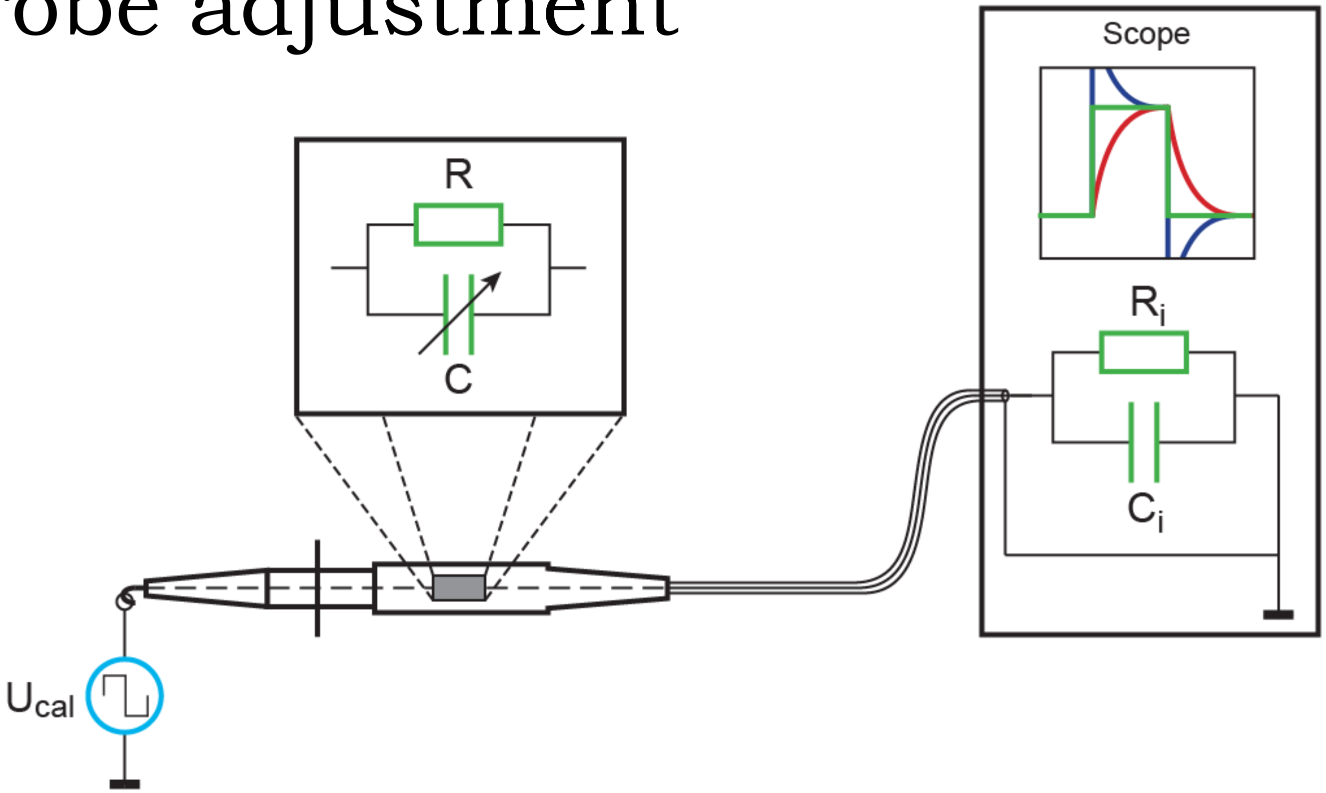
- Say: R_g = 1 kΩ $\Rightarrow f_{-3dB} = \dfrac{1}{2\pi R_g (C_c + C_i)} = 1.3\,\text{MHz}$

Measuring with a probe



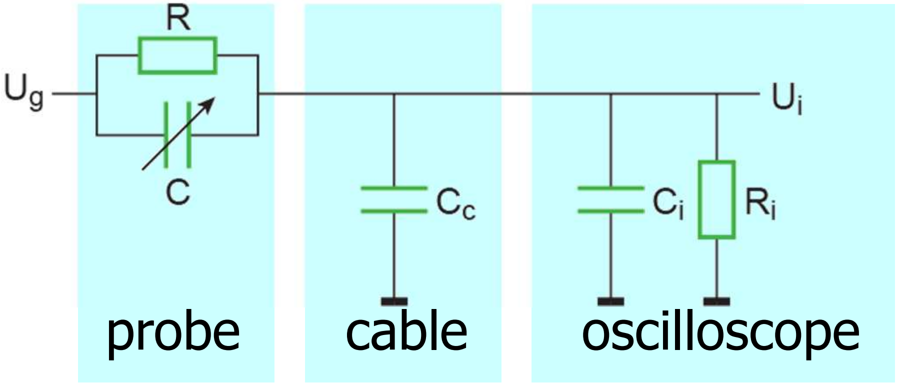
- Oscilloscope: typically C_i = 20 pF, R_i = 1 MΩ
- Coax cable: approximately 100 pF for 1 m cable
- 1:10 probe: $R = 9 \cdot R_i = 9$ MΩ
  frequency-independent attenuation
  $\Rightarrow R / R_i = (C_c + C_i) / C \Rightarrow C = 13.3$ pF
- Input impedance: 10 MΩ // 12 pF **10x** higher impedance
- Say: R_g = 1 kΩ $\Rightarrow f_{-3dB} = \dfrac{C + C_c + C_i}{2\pi R_g C (C_c + C_i)} = 13\,\mathrm{MHz}$ **10x** larger bandwidth

Probe adjustment



- To make sure that $R / R_i = (C_c + C_i) / C$, C is adjusted such that a test square wave is displayed correctly
- R_i and C_i differ from scope to scope
  ⇒ always adjust probes to the scope on which you're using them!!

Exercise

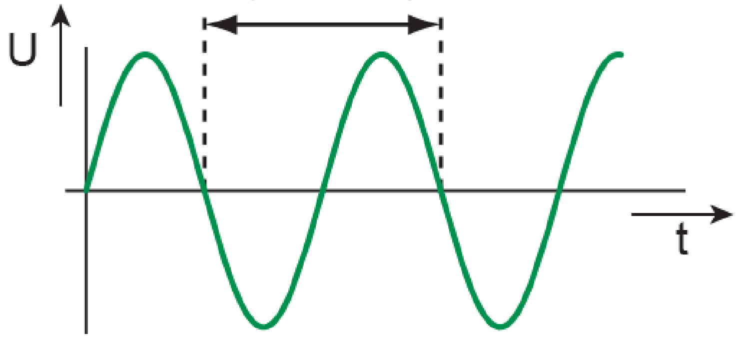


- Given:
  - scope: R_i // C_i = 1 MΩ // 20 pF
  - cable: C_c = 70 pF
- If this is a 1:10 probe, determine R en C…

Time and frequency measurements

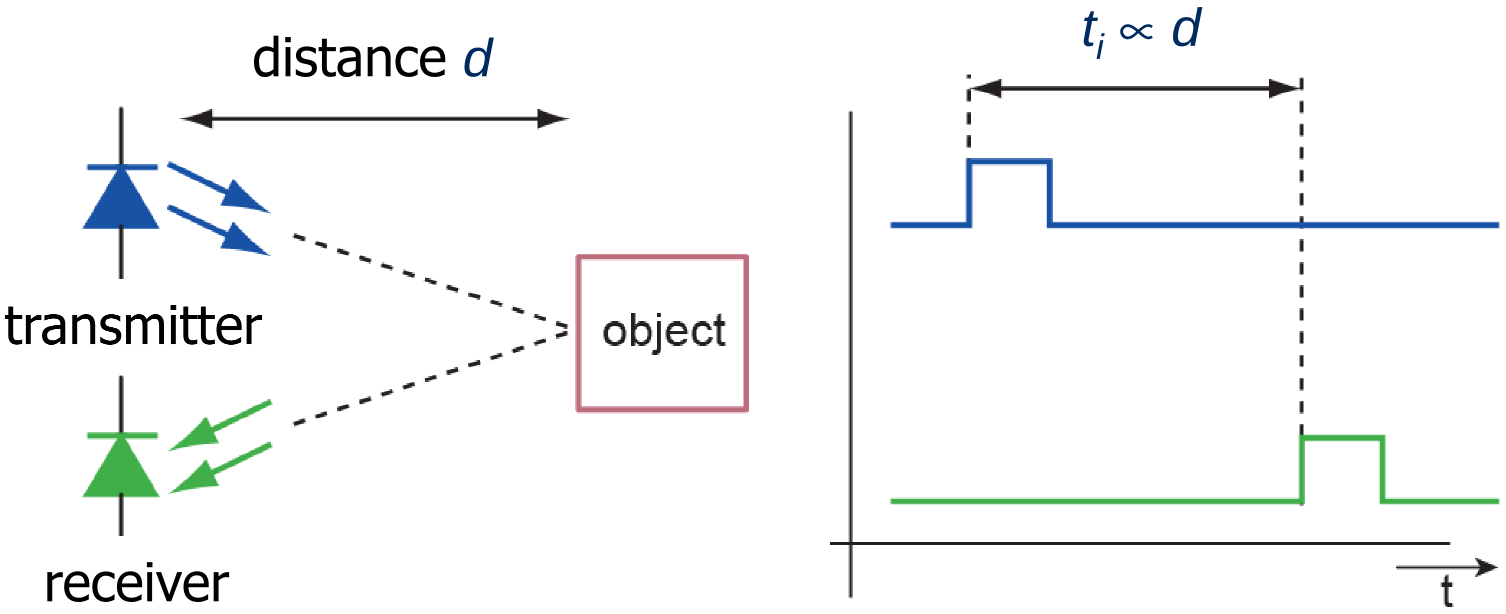
- Periodic signals: period duration and frequency
  - Reciprocal quantities
  - Independent of amplitude

$t_i = 1 / f_i$



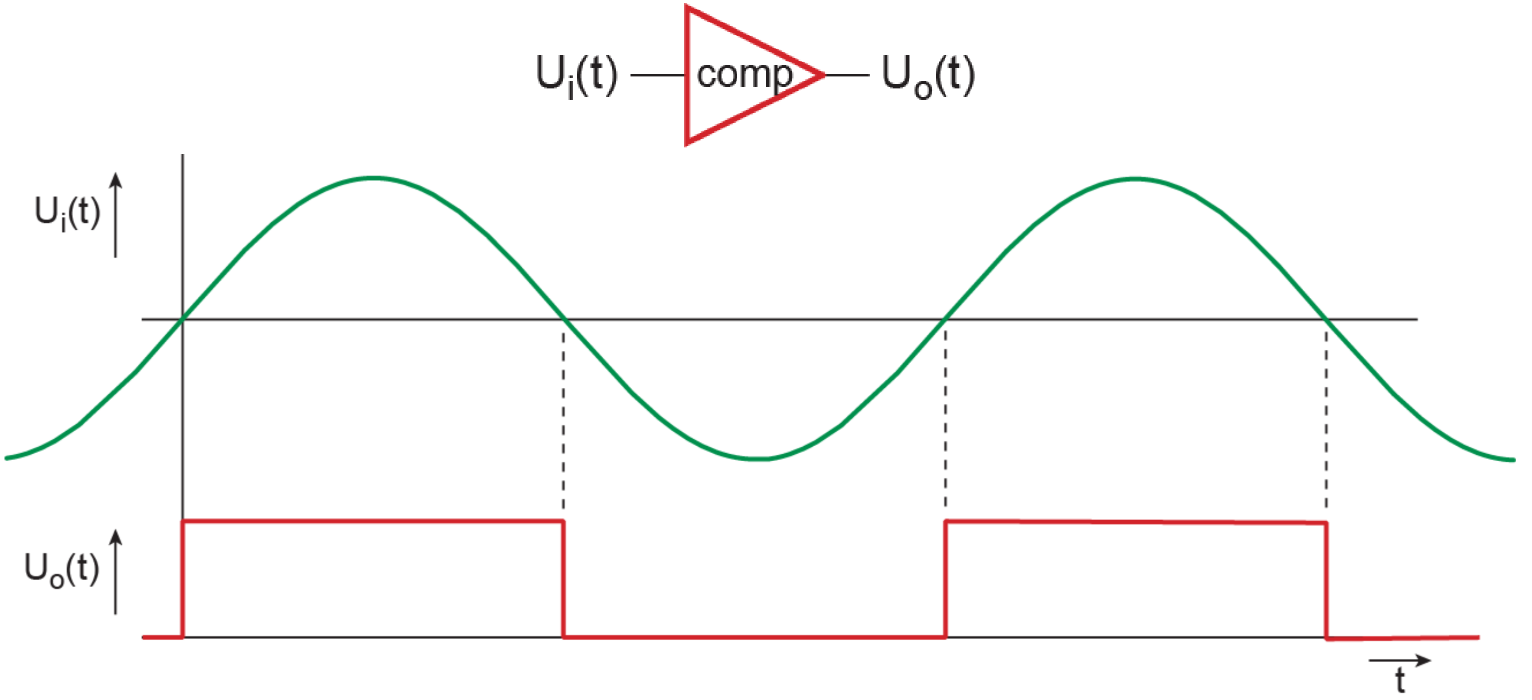
Time measurements

- Also applied for non-periodic signals
- Example: distance measurement based on time-of-flight measurement



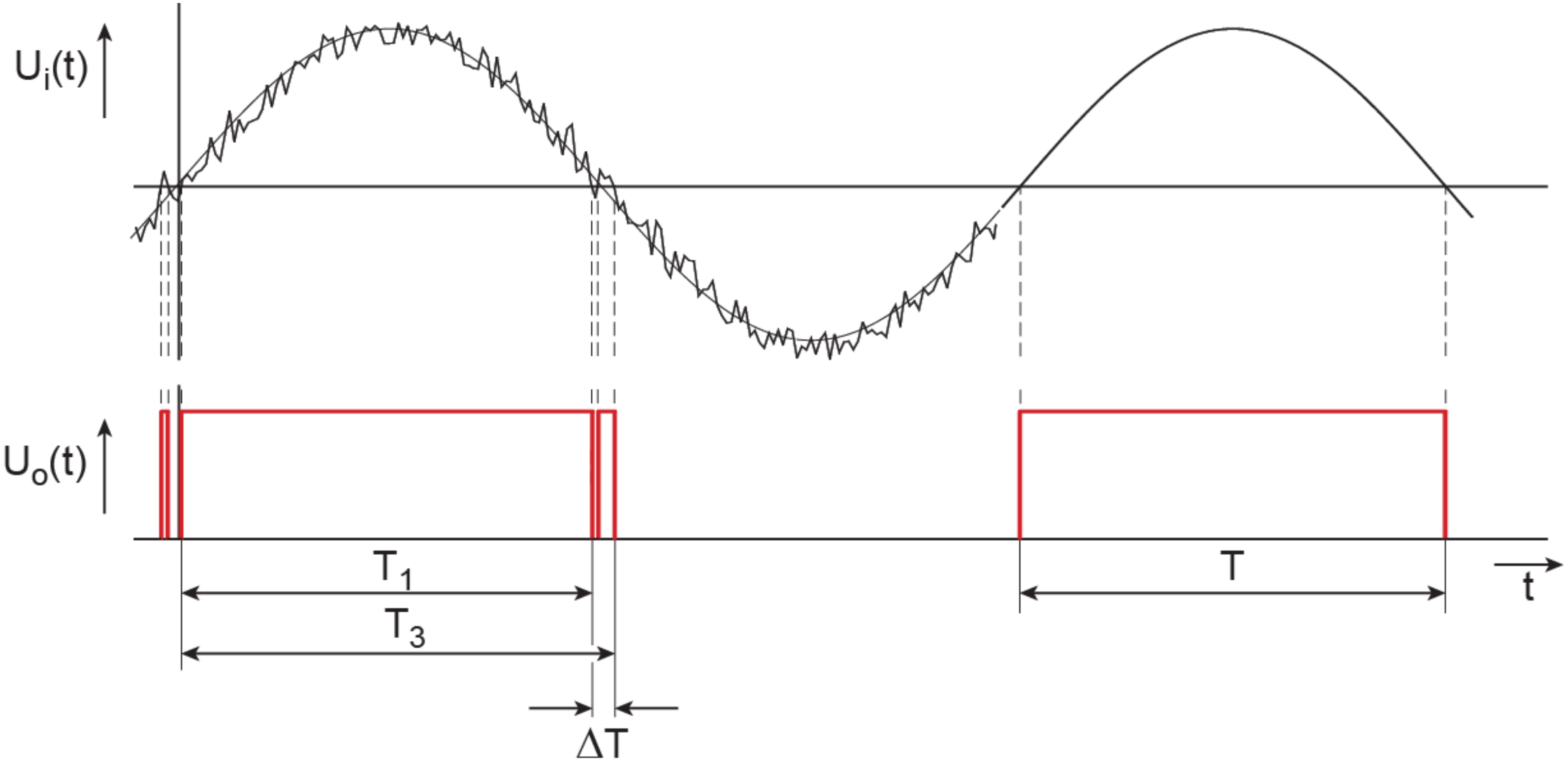
Removing amplitude information using a comparator

- Ideal comparator: detects zero crossings in input signal



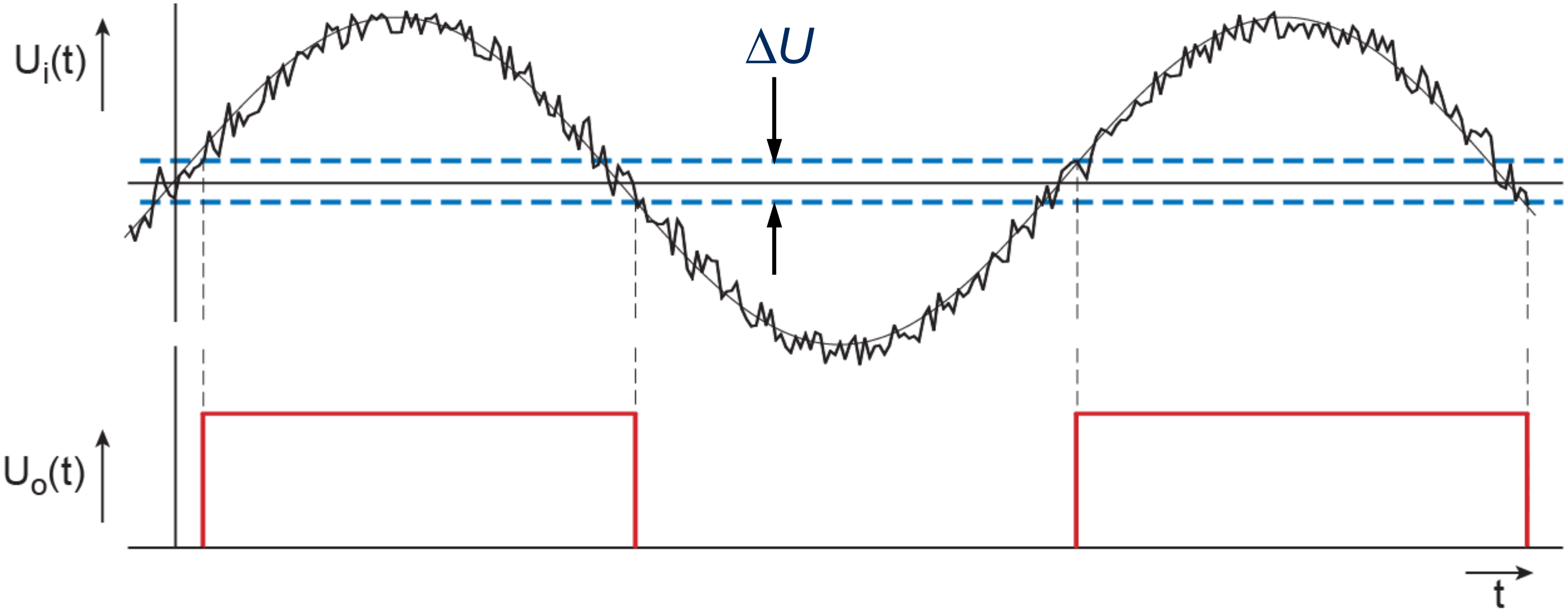
Comparator with noise

- Noise causes uncertainty ΔT and multiple zero crossings



Comparator with hysteresis

- Hysteresis: two detection levels (**trigger window** ΔU)

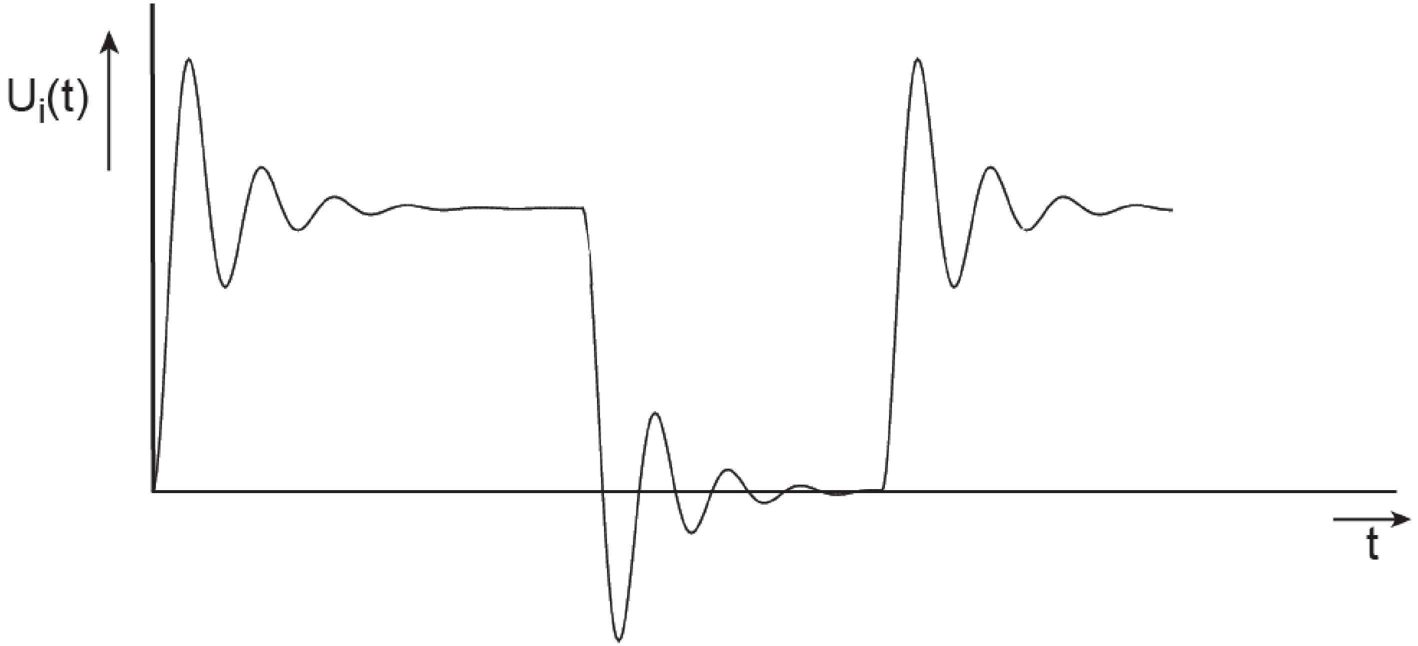


- Noise does not cause false detections unless $\Delta U > U_{noise,pp}$

Exercise

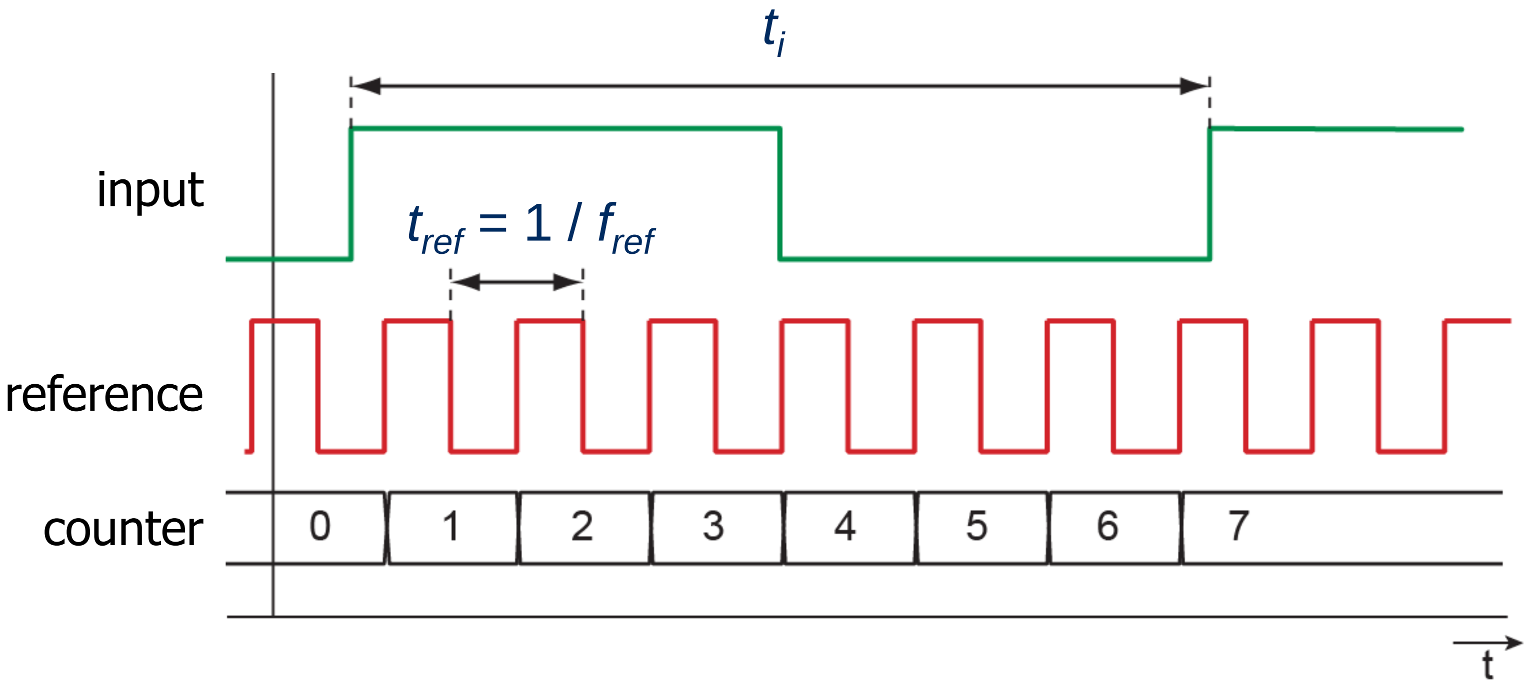
- How to set up the comparator for a proper frequency measurement?

  Trigger level? Trigger window?



Time measurement by counting

- Counting the number of periods of a reference signal within one period of the signal to be measured

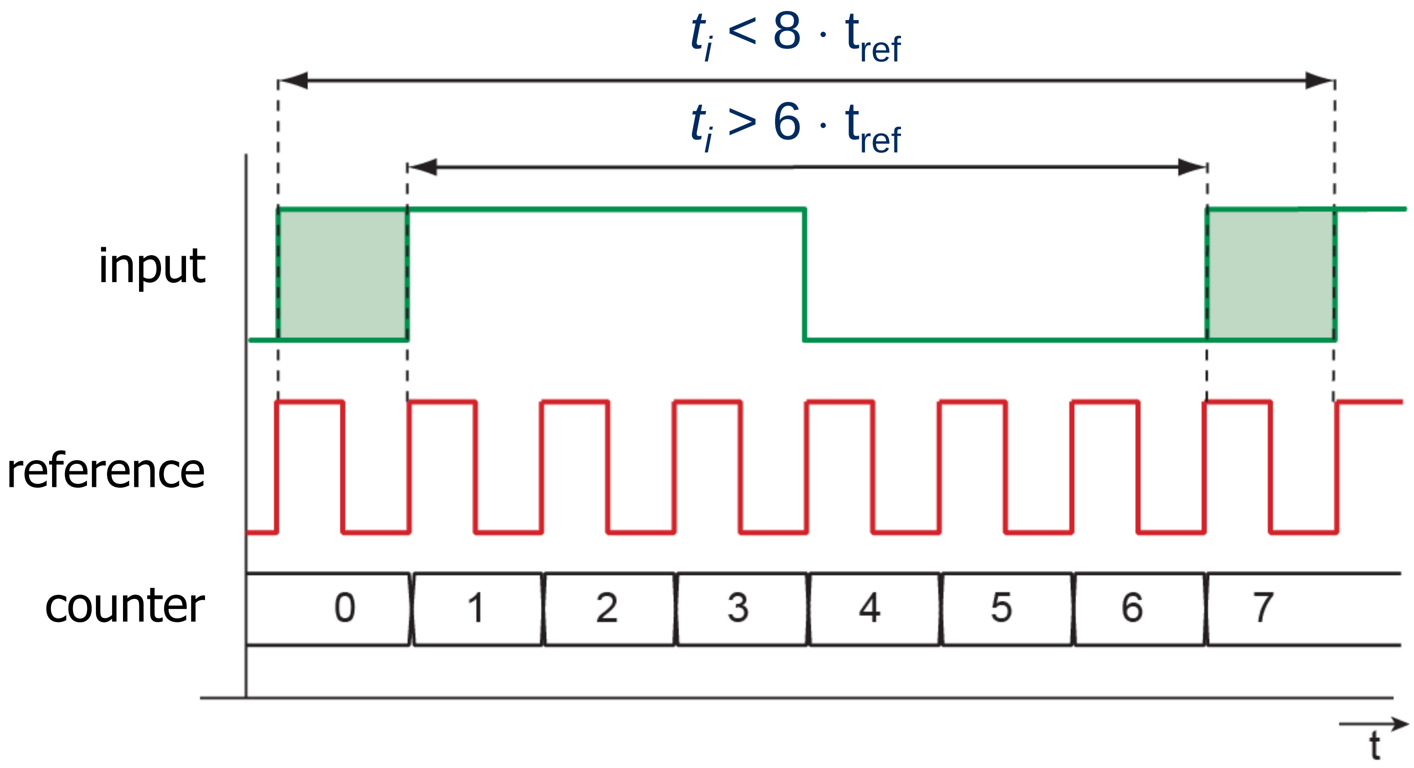


- Counter value = quantization of t_i with t_{ref} as quantization interval
- Resolution (LSB): t_{ref}

Regtien 20.1.4

Quantization errors in time measurement by counting

- Various input signals give the same counter value



counter c

$\Rightarrow$

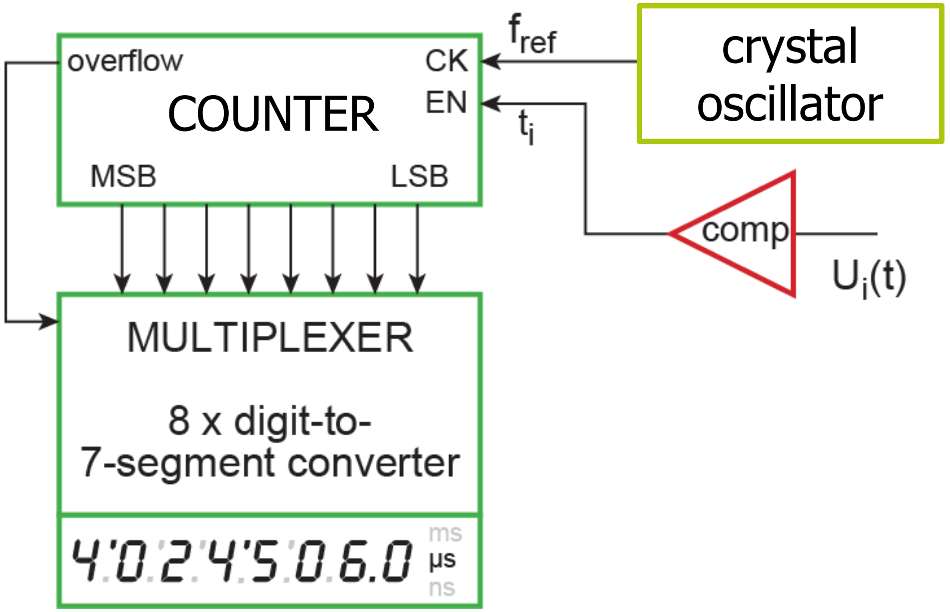
$(c - 1)\, t_{ref}$

$< t_i <$

$(c + 1)\, t_{ref}$

or: quantization error < ± 1 LSB

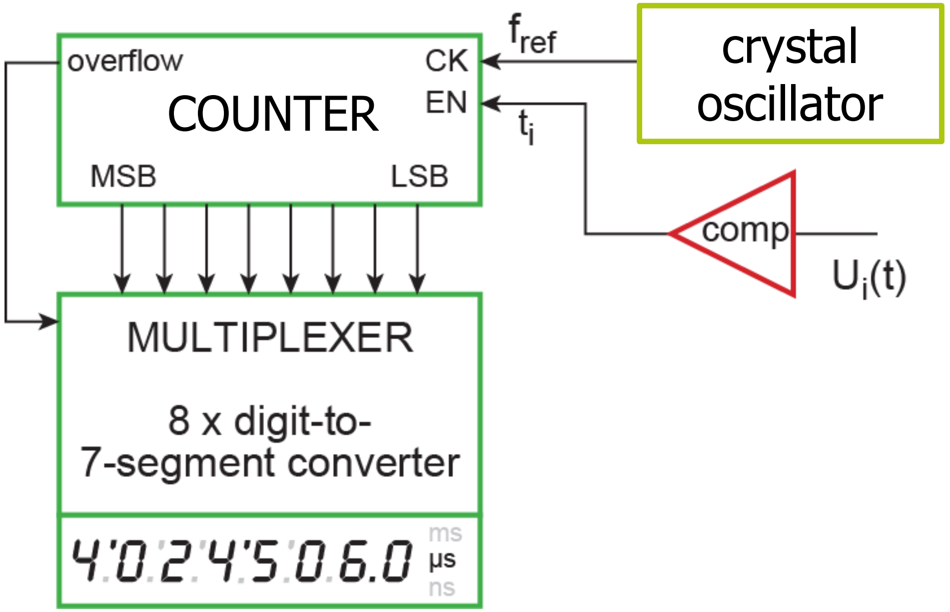
Simple implementation



- Crystal oscillator used as time reference
  - based on quartz
  - stable and relatively insensitive to temperature
- Maximum measurement time

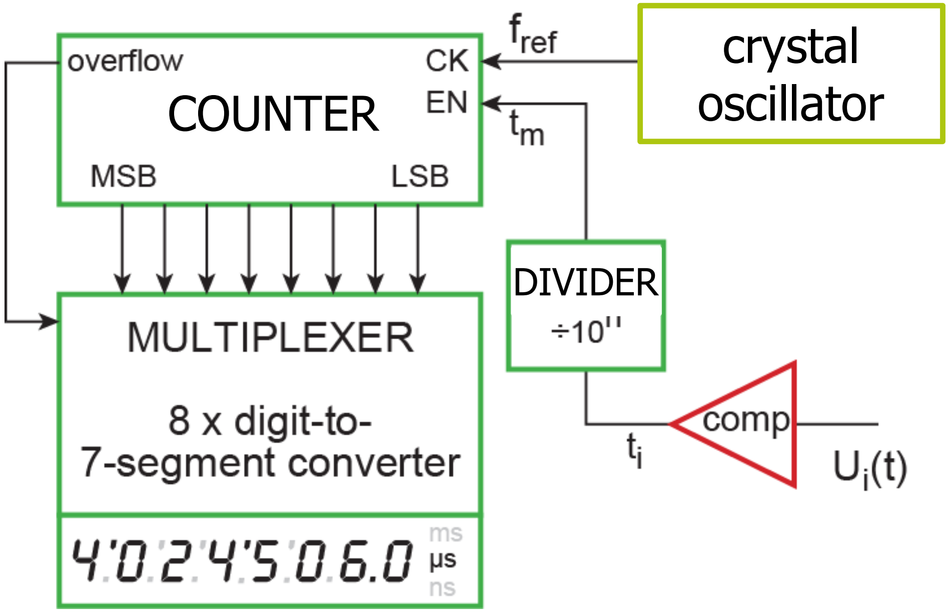
  $t_{i,max} = c_{max} / f_{ref}$
- Resolution $\Delta t = 1 / f_{ref}$

Simple implementation



- Example:
  $f_{ref} = 10\text{ MHz}, c_{max} = 10^8$
  $\Rightarrow \quad t_{i,max} = 10\text{ s}$
  $\Delta t = 0.1\ \mu\text{s}$
- Larger relative errors at shorter measurement times!
- Example:
  $t_i = 10\ \mu\text{s} \Rightarrow \varepsilon_{rel} = 1\%$

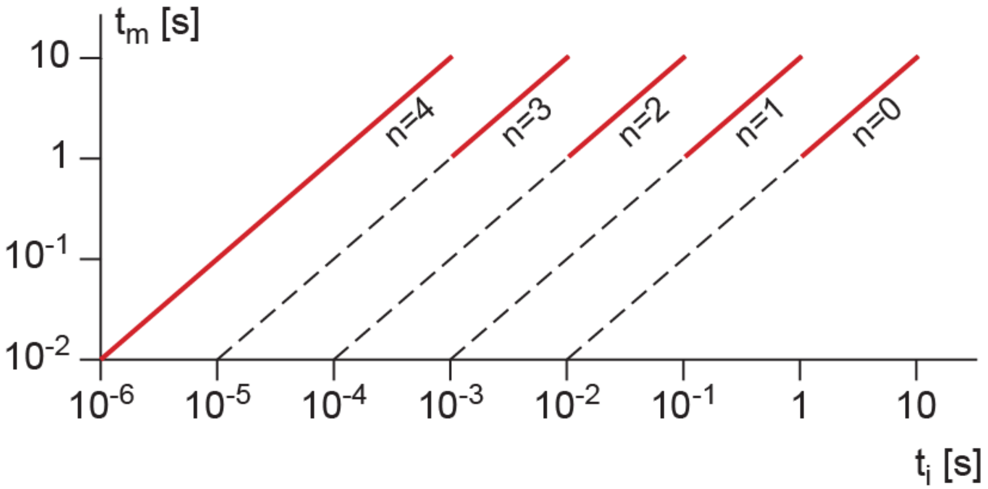
Implementation with period averaging



- Measurement of 10^n periods
  $\Rightarrow$ measurement time $t_m = 10^n \cdot t_i$
  resolution $\Delta t = \dfrac{1}{10^n \cdot f_{res}}$
- Example: $t_i = 10\,\mu s$
  $f_{ref} = 10$ MHz, $c_{max} = 10^8$
  $n = 0 \Rightarrow \Delta t = 0.1\,\mu s$
  $\Rightarrow \varepsilon = 1\%$
  $n = 4 \Rightarrow \Delta t = 10$ ps
  $\Rightarrow \varepsilon = 1$ ppm

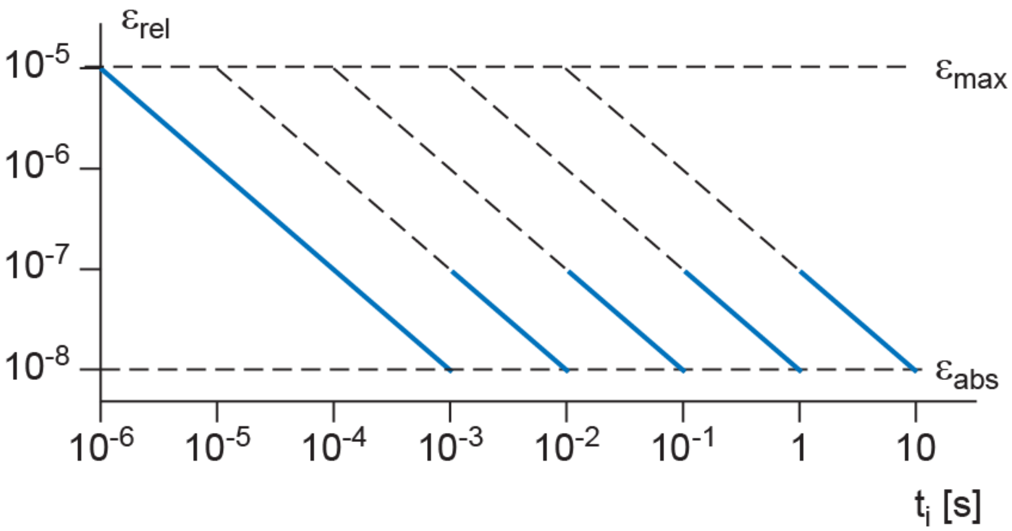
Example period averaging

measurement time



$c_{max} = 10^8$
$f_{ref} = 10\,\text{MHz}$

relative error



Exercise time measurement

- Given: 1 MHz crystal oscillator
  maximal counter reading: 999 999

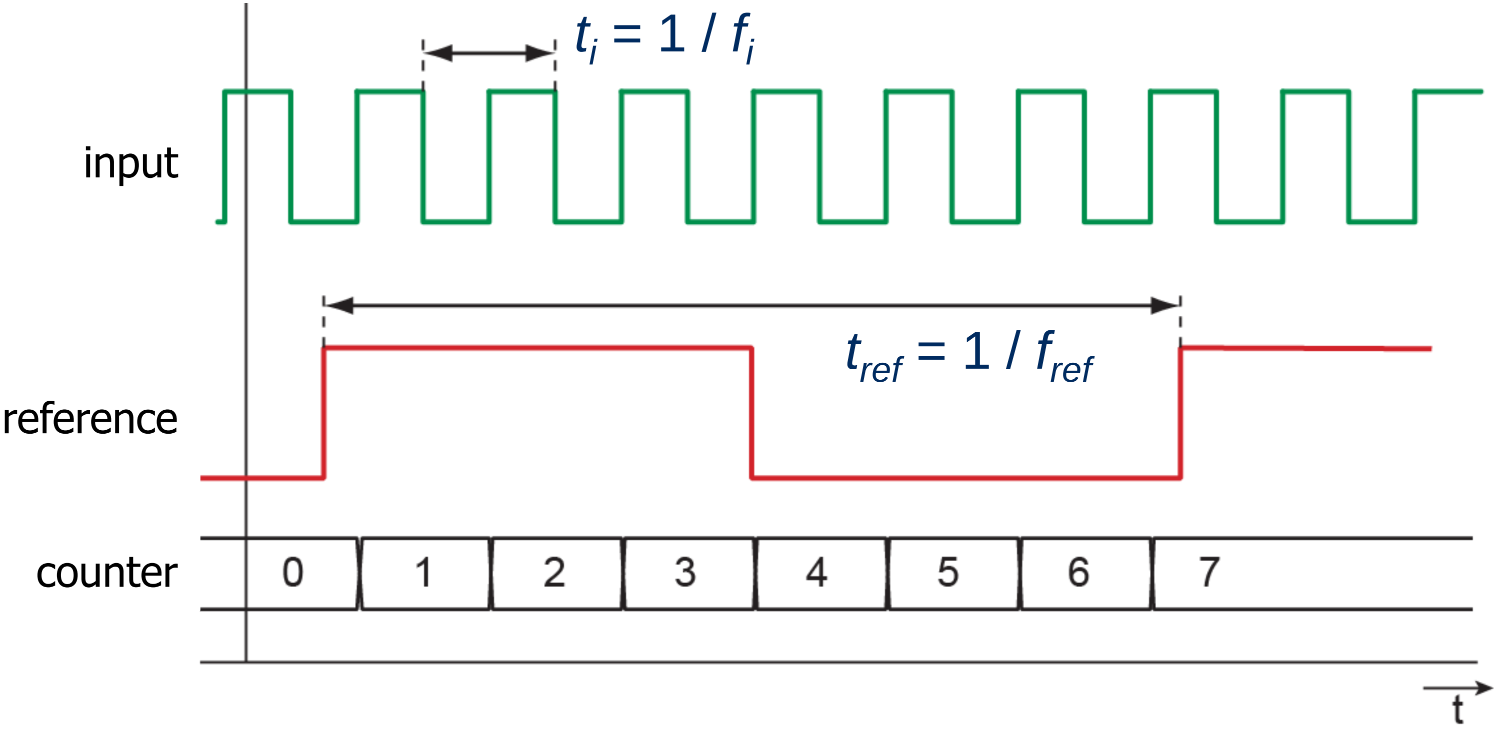
- What is the resolution of the time measurement?

- What is the maximum measurement time?

- When employing period averaging, which division factor (10^n) makes optimal use of the resolution when measuring a 2 kHz signal?

Frequency measurement by counting

- Counting the number of periods of the signal to be measured, within one period of the reference signal



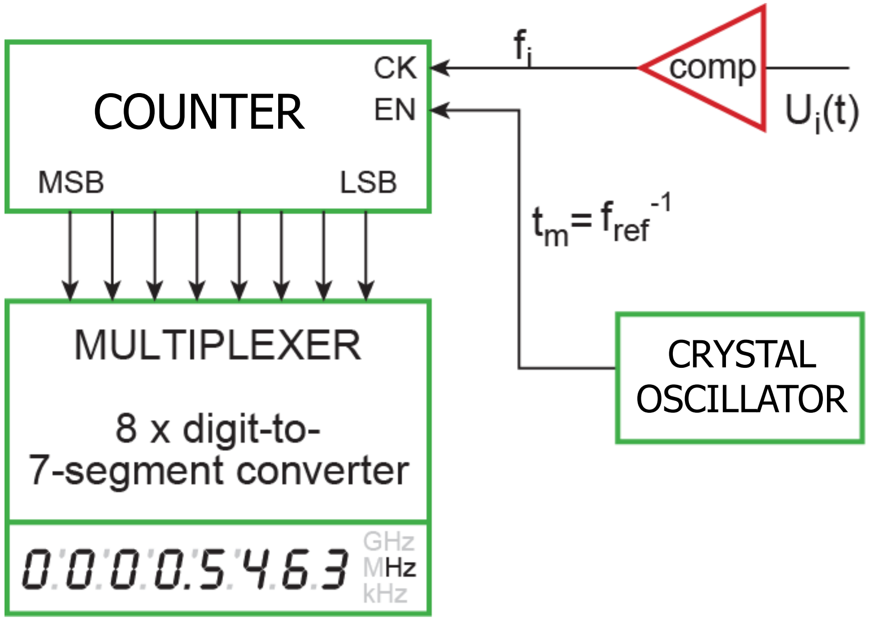
counter value c

$$\Rightarrow \quad (c-1)\, t_i < t_{ref} < (c+1)\, t_i$$

$$\Rightarrow \quad (c-1)\, f_{ref} < f_i < (c+1)\, f_{ref}$$

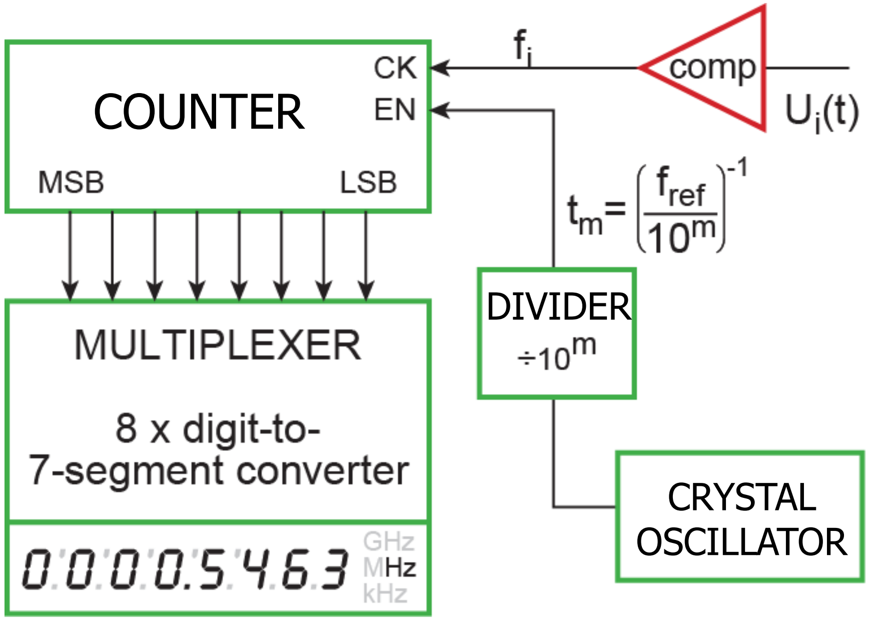
Regtien 20.1.4

Simple implementation



- Fixed measurement time
  $t_m = 1 / f_{ref}$
- Resolution $\Delta f = f_{ref}$
- Example:
  $f_{ref} = 10$ MHz
  $\Rightarrow \quad t_m = 0.1\ \mu s$
  $\Delta f = 10$ MHz
- Large errors for low-frequency signals!

Implementation with frequency division

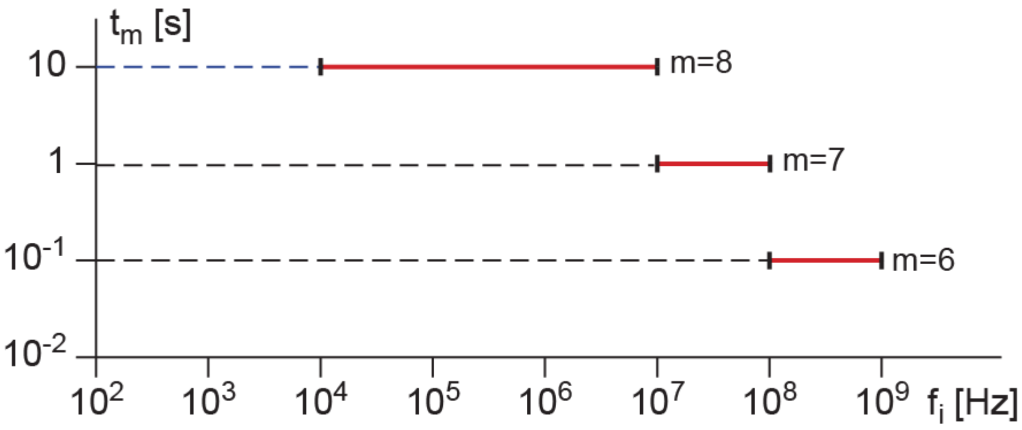


- Reference is divided by 10^m
- Measurement time $t_m = 10^m / f_{ref}$
- Resolution $\Delta f = f_{ref} / 10^m$
- Example:
  $f_{ref} = 10$ MHz, $m = 8$
  $\Rightarrow \quad t_m = 10$ s
  $\Delta f = 0.1$ Hz

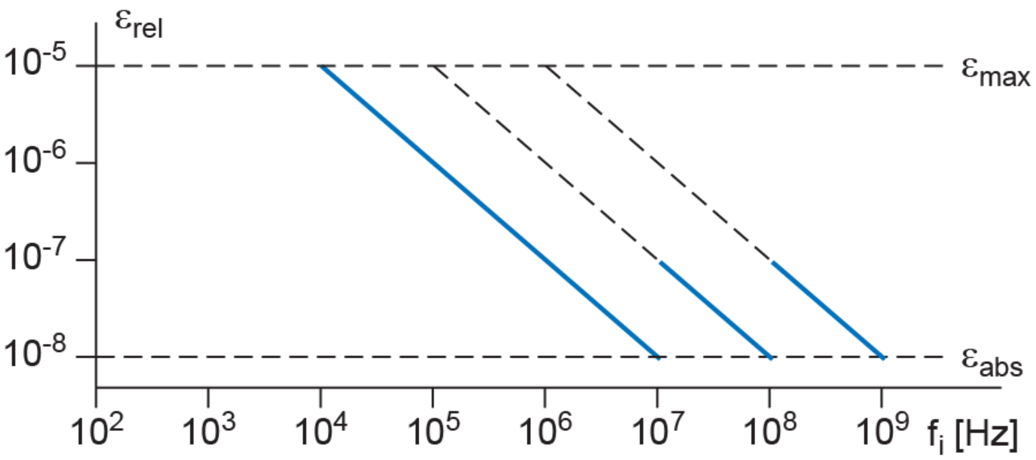
Example frequency division

$c_{max} = 10^8$
$f_{ref} = 10\,\text{MHz}$

measurement
time



relative
error



Summary

- Oscilloscope: qualitative display of signal waveform
  - basic principles: time base, triggering
  - well-adjusted probes enlarge input impedance and bandwidth
- Comparator used in time and frequency measurement to remove amplitude information
  - hysteresis to avoid false detections due to noise
- Time measurement: counting the number of periods of a reference signal within one period of the input signal
  - period averaging to increase resolution (at short periods)
- Frequency measurement: counting the number of periods of the input signal within one period of a reference signal
  - division of reference signal to increase resolution (at low frequencies)

What's next?

- Study:
  - Regtien sections 14.1.1, 14.1.2, 20.1.2, 20.1.4 + slides

- Practice:
  - See Blackboard for exercises!

- Questions, things unclear? Let me know!
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Next time: tutorial