EE1320: Measurement Science

Lecture 6: Measurement Instruments I

Dr. ir. Michiel Pertijs, Electronic Instrumentation Laboratory

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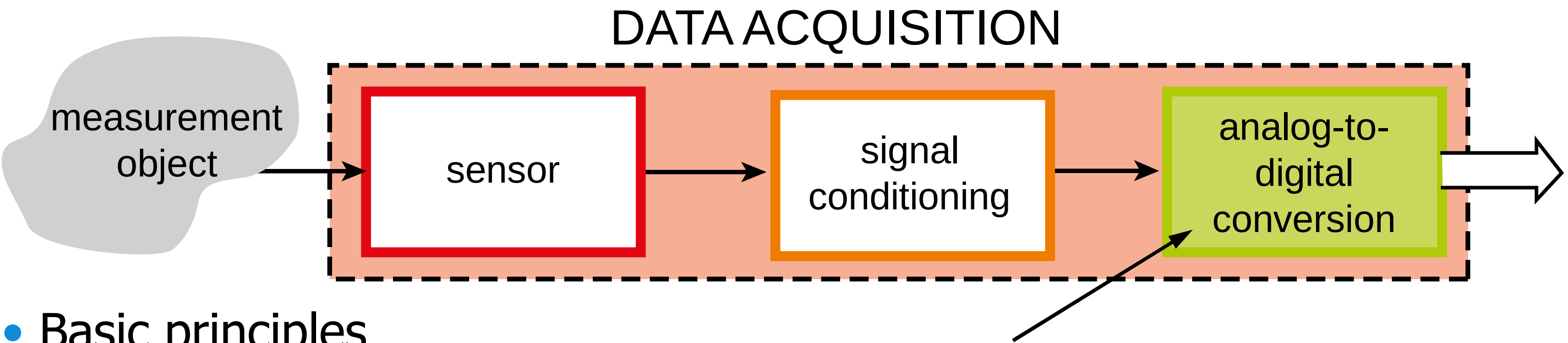
Course program 2013

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

Lecturer: dr. ir. Michiel Pertijs
room HB 15.050, M.A.P.Pertijs@tudelft.nl, 015-2786823

Last time…
analog-to-digital convertors



- Basic principles
  - Sampling
  - Quantization
- Three important ADC types:
  - Flash ADCs
  - Dual-slope ADCs
  - Successive-approximation ADCs

Today: measurement instruments

- Measurement instruments
  - voltage measurement
  - current measurement
  - resistance measurement

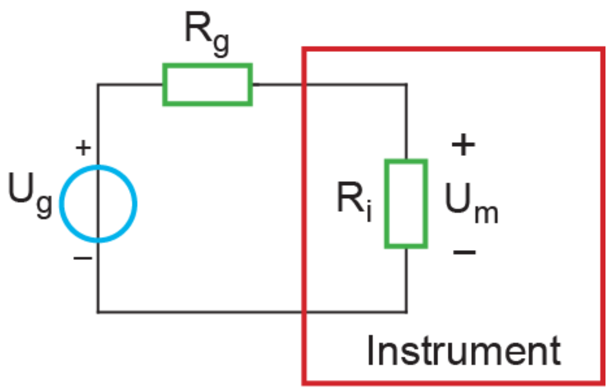
Overview study material

- Regtien 20.1.1: multimeters
- Regtien 5.1.3: loading errors and impedance matching
- Four-wire resistance measurement (slides)
- Regtien 2.1.2: amplitude measures (peak, rms, etc.)

Multimeters

Voltage measurement

- Practical voltage meters impose a load on the source



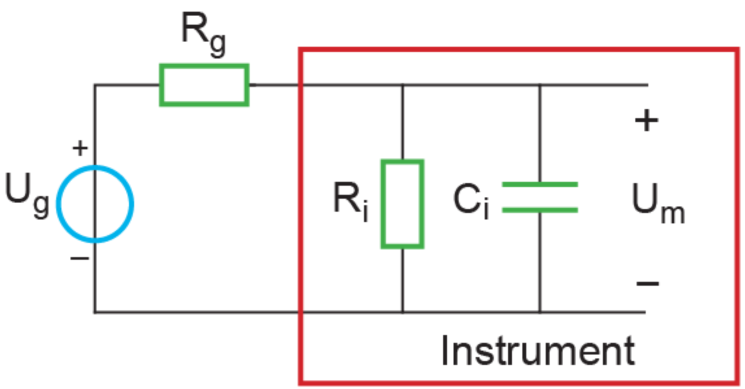
$$U_m = \frac{R_i}{R_g + R_i} U_g = \left(1 - \frac{R_g}{R_g + R_i}\right) \cdot U_g$$

gain error / tracking error

- For a small gain error: $R_i >> R_g$ *(voltage matching)*

Voltage measurement

- At higher frequencies, the capacitive load also comes into play



$$U_m = \frac{Z_i}{R_g + Z_i} U_g = \left(1 - \frac{R_g}{R_g + Z_i}\right) \cdot U_g$$

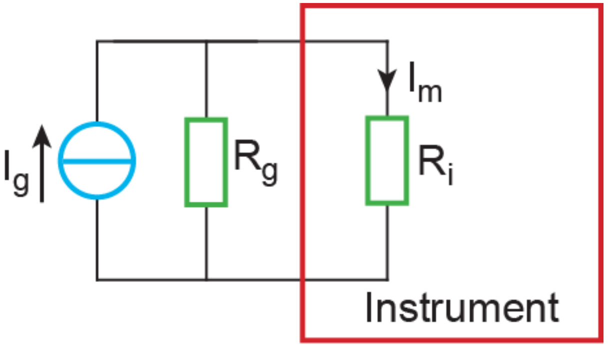
frequency dependent gain error

- Input impedance: $Z_i = R_i // C_i = R_i \dfrac{1}{1 + j\omega R_i C_i}$

$\Rightarrow$ Larger gain errors at higher frequencies

Current measurement

- Current meters also impose a load on the source



$$I_m = \frac{R_g}{R_g + R_i} I_g = \left(1 - \frac{R_i}{R_g + R_i}\right) \cdot I_g$$

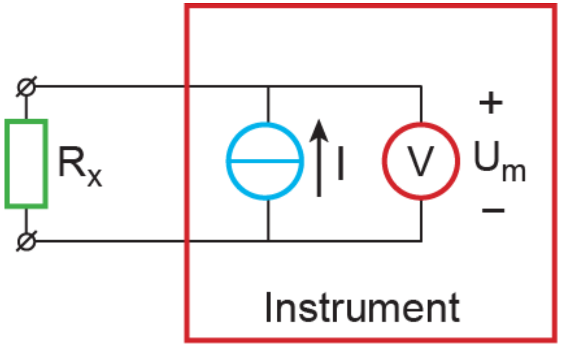
gain error / tracking error

- For a small gain error: $R_i << R_g$ *(current matching)*

- Inductive load leads to gain errors that increase with frequency

Resistance measurement

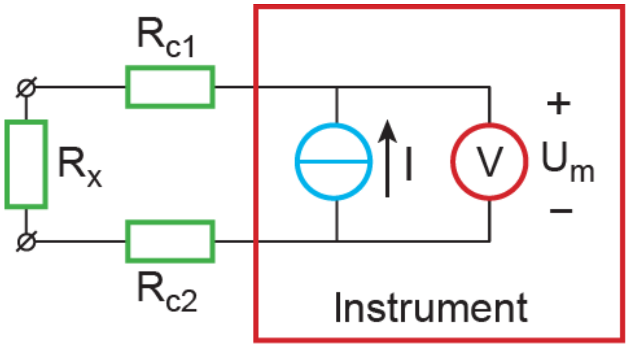
- Basic principle: send a current through the resistor and measure the voltage drop



$$R_m = \frac{U_m}{I} = R_x$$

Resistance measurement

- Wiring induces an offset error



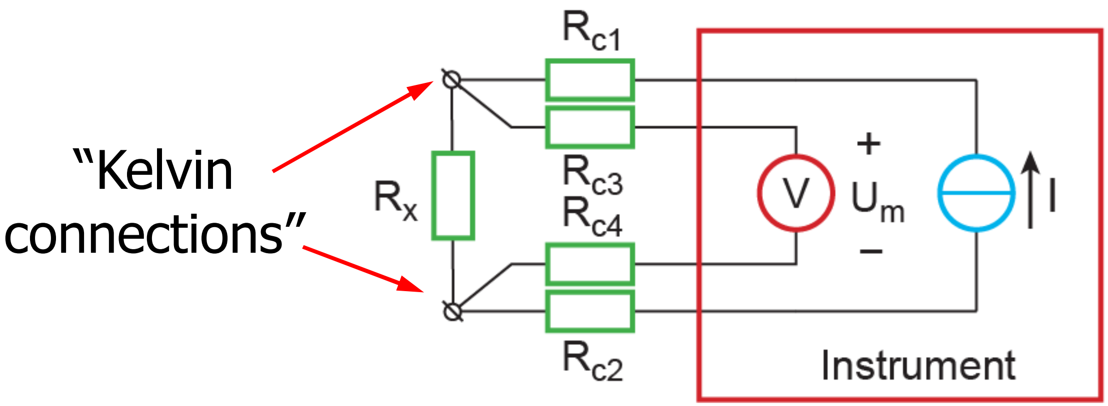
$$R_m = \frac{U_m}{I} = R_x + \underbrace{R_{c1} + R_{c2}}_{\text{offset error}}$$

offset error
due to series resistances

How can you solve this???

Four-wire measurement

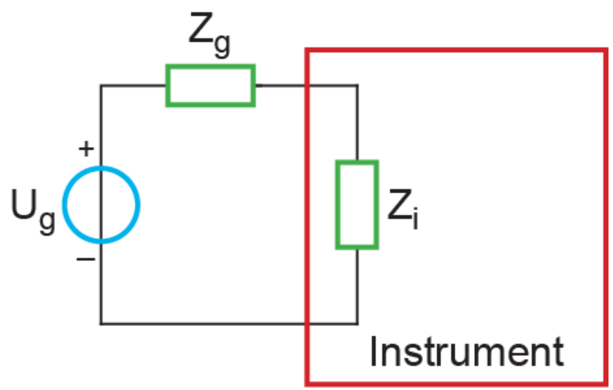
- Four-wire measurement prevents errors due to series resistances:
  - voltage drop across R_{c1} en R_{c2} is not measured
  - voltage drop across R_{c3} en R_{c4} is zero (no current)



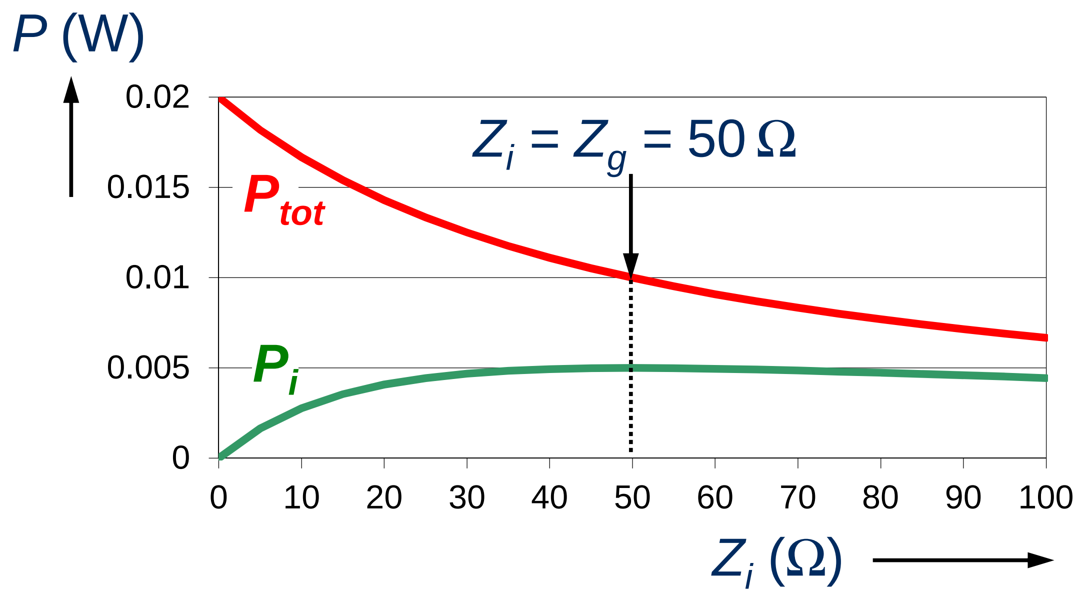
$$R_m = \frac{U_m}{I} = R_x$$

Impedance matching

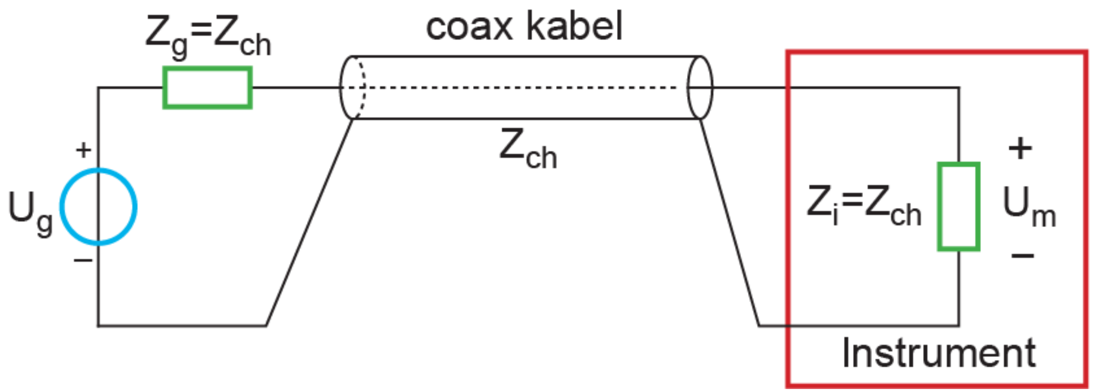
- **Non-energetic** matching: no load imposed on source
  - voltage measurement with $Z_i >> Z_g$
  - current measurement where $Z_i << Z_g$
- **Energetic** matching / impedance matching:
  power transfer is maximized: $Z_i = Z_g$



$U_g = 1\,\text{V}, Z_g = 50\,\Omega$

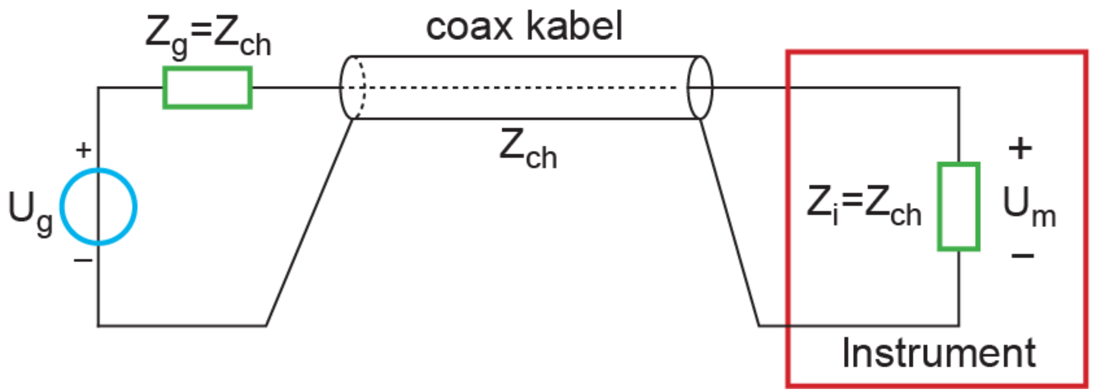


Impedance matching



- Especially important at high frequencies, when the wavelength is comparable to the cable length
- Cable acts as a **transmission line**
- Impedance matching is needed to prevent **reflections**

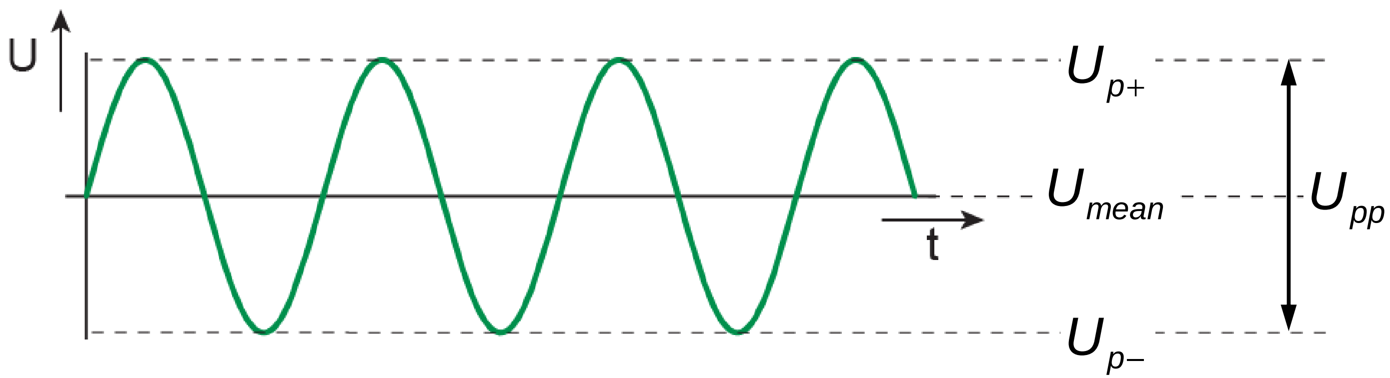
Characteristic impedance



- Impedance matching: source impedance = input impedance = **characteristic impedance** of the cable
- Characteristic impedance is determined by cable geometry: often **50Ω** for coax measuring cables
- Ideal lossless cable $\Rightarrow U_m = U_g / 2$

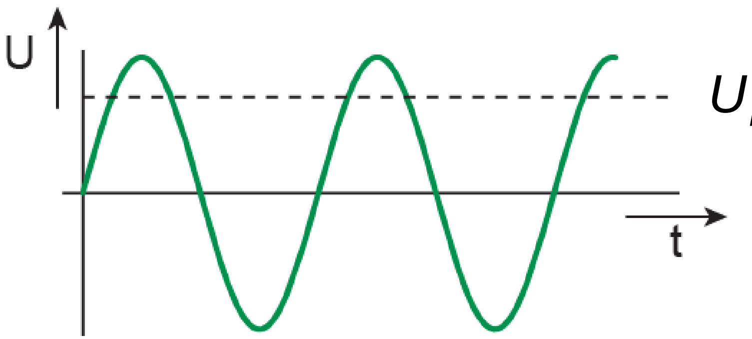
Amplitude measurement of periodic signals

- Average value, peak value, peak-to-peak value



Amplitude measurement of periodic signals

- **Root-mean-square** (rms) value



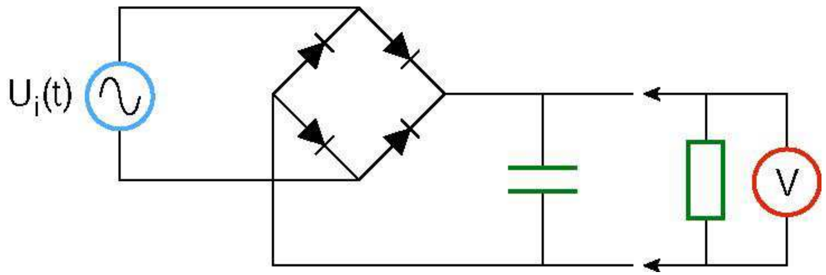
$$U_{rms} = \sqrt{\frac{1}{T}\int_0^T U^2(t)dt}$$

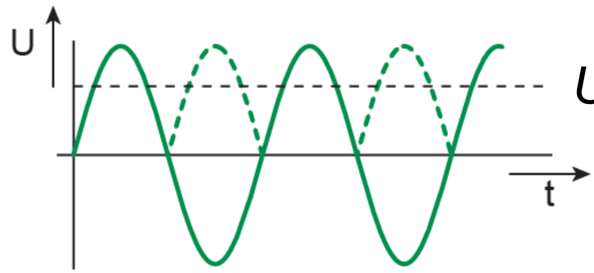
- Measure for the signal power:
  U(t) dissipates the same average power in a resistor as a DC voltage of U_{rms}

- **Crest factor**: $CF = \frac{U_{p+}}{U_{rms}}$ Sine? $CF = \sqrt{2}$

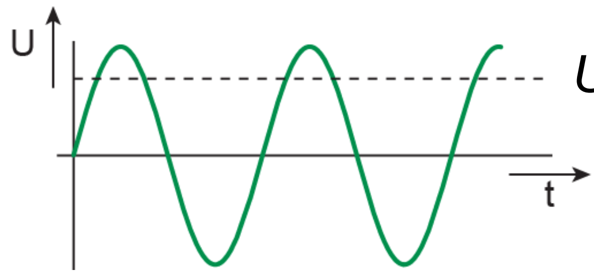
AC measurement with a rectifier

- Some instruments estimate the rms value U_{rms} based on the average of the modulus U_{ma} and a correction factor





$$U_{ma} = \frac{2}{\pi} \cdot U_{p+}$$



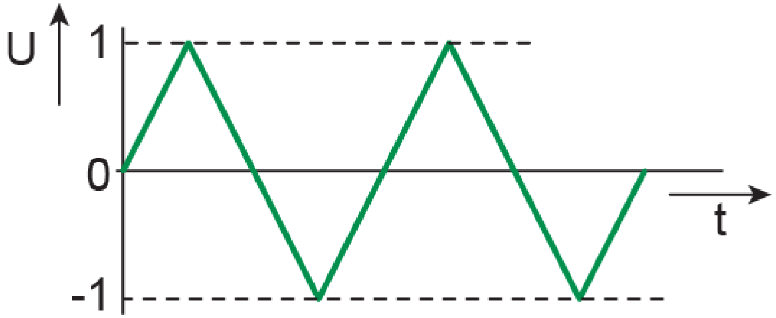
$$U_{rms} = \frac{1}{2}\sqrt{2} \cdot U_{p+}$$

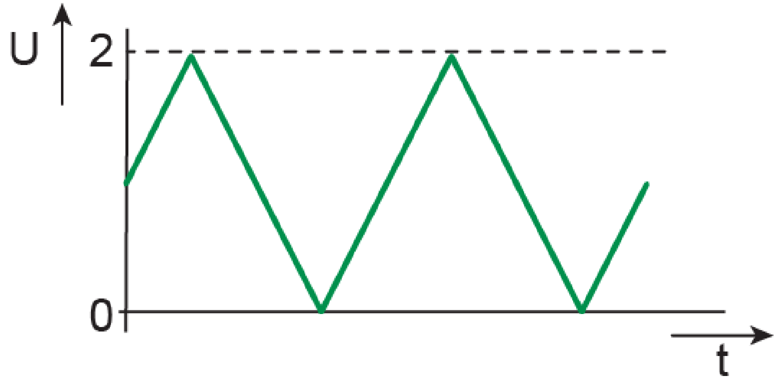
- correction factor for a sine:

$$U_{rms} = \frac{\pi}{2\sqrt{2}} \cdot U_{ma} \cong 1.11 \cdot U_{ma}$$

- Correction factor is strongly dependent on the waveform!

Exercise: triangular waveform





$$U_{p+} = 1$$

$$U_{pp} = 2$$

$$U_{rms} = \frac{1}{3}\sqrt{3}$$

$$U_{ma} = \frac{1}{2}$$

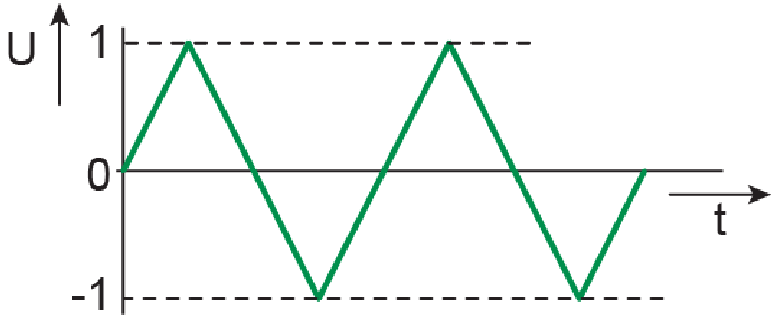
$$U_{p+} =$$

$$U_{pp} =$$

$$U_{rms} =$$

$$U_{ma} =$$

Exercise: triangular waveform

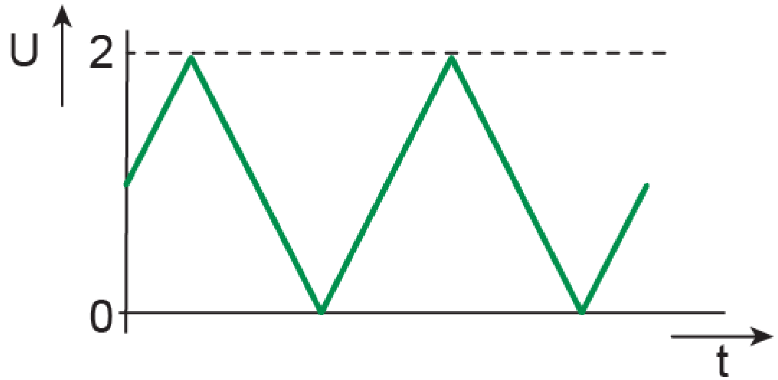


$$U_{p+} = 1$$

$$U_{pp} = 2$$

$$U_{rms} = \frac{1}{3}\sqrt{3}$$

$$U_{ma} = \frac{1}{2}$$



$$U_{p+} = 2$$

$$U_{pp} = 2$$

$$U_{rms} = \sqrt{1^2 + \left(\frac{1}{3}\sqrt{3}\right)^2} = \sqrt{1 + \frac{1}{3}} = \frac{2}{\sqrt{3}}$$

$$U_{ma} = U_{mean} = 1$$

Summary

- 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

What's next?

- Study:
  - Regtien sections 2.1.2, 5.1.3, 20.1.1, slides
- Practice:
  - See Blackboard for exercises!
- Questions, things unclear? Let me know!

M.A.P.Pertijs@tudelft.nl

Next time:
Measurement instruments II