Voltage and current measurement - multimeters

DC voltage measurement

- Typical DC voltage to be measured: 1mV – 100VDC – common multimeters
- Out of our scope:
  - Small DC voltage (µV or nV): difficult (voltage offset and drift of DC amplifiers), special nano and microvoltmeters
  - High voltage (above kV) – question of user safety, isolation materials – special high voltage probes, indirect measurements
- DC voltmeter and DC voltage measurement is the basic function of nearly all modern digital multimeters
  - Al other quantities to be measured are converted to DC voltage inside multimeters

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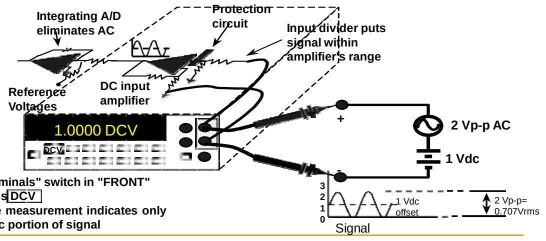
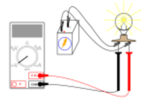
Measuring DCV

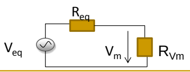


*"Terminals" switch in "FRONT"
*Press DCV
*Note measurement indicates only the dc portion of signal

Connection



- Voltmeter must be connected in parallel
- The input resistance (impedance) must be much higher than internal equivalent resistance (impedance) in measured points to decrease the measurement error ΔV
  - modern digital multimeters $R_{voltmeter}$ ~10 – 100MΩ



$$V_m = V_{eq} \frac{R_{Vm}}{R_{eq} + R_{Vm}}$$

$$\Delta V = V_{eq} - V_m = V_{ekv} \frac{R_{eq}}{R_{eq} + R_{Vm}}$$

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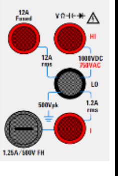
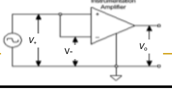
Leads connection

- Hi, Lo/com – voltage is measured between them
- Voltage / current inputs (connectors for leads)
- Be careful of common voltage!
  - CMV – the voltage among inputs and general ground.
  - Overloading the given limit can destroy the instrument
  - Common mode ration (CMR in dB) – rejection of common voltage on result of measurement





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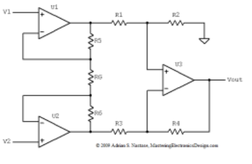
Basic electronic circuits

$$V_{out} = G(V_1 - V_2)$$

- Instrumentation amplifiers
  - High input resistance
  - Easy gain control by one resistor R_G
  - Low f_{max}
- AD conversion
  - High resolution (number of bits)
  - Low rate of measurements
  - Integrating ADC
  - Sigma-delta or successive approximation followed by digital processing



$$V_{DC} = \frac{1}{N} \sum_{i=1}^{N} V(t_i),$$

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AC voltage measurement

- Required parameter of AC voltage to be measured: rms value
  - AC voltage is converted to DC voltage
    - Rectifiers
    - Convertors to rms
- Bandwidth:
  - multimeter: Hz – kHz (see datasheet)
  - Special AC voltmeters – narrowband (out of scope)
- Is DC component included into measurement?

$$V_{rms\,ac+dc} = \sqrt{\frac{1}{T}\int_0^T v_{ac+dc}^2(t)dt} = \sqrt{\frac{1}{T}\int_0^T V_{dc}^2 dt + \frac{1}{T}\int_0^T v_{ac}^2(t)dt} = \sqrt{V_{dc}^2 + V_{rms\,ac}^2}$$

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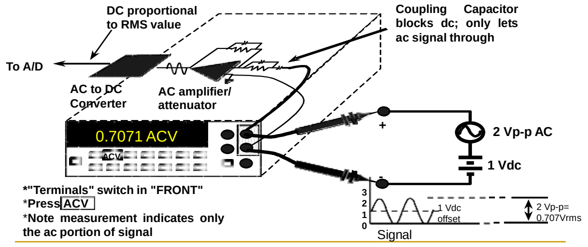
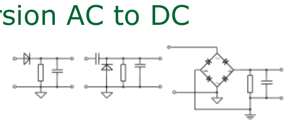
Measuring ACV

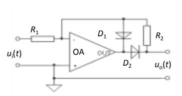


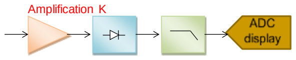
*"Terminals" switch in "FRONT"
*Press ACV
*Note measurement indicates only the ac portion of signal

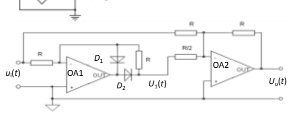
Conversion AC to DC

- Rectifiers
  - Passive
  - Active









$U_o = -k\frac{T_-}{T}\frac{R_2}{R_1}\overline{u_i^-(t)}, \quad U_o = k\overline{|u_i(t)|},$

- Output DC is not rms value of input AC voltage!!!

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Is it possible to recalculate the mean of absolute value to rms value?

- Harmonic

$$U_m = \mathrm{avr}\left|A\sin(2\pi f t)\right| = \frac{1}{\pi}\int_0^{\pi} A\sin(x)dx = \frac{A}{\pi}\left[-\cos x\right]_0^{\pi} = \frac{2A}{\pi}$$

$$U_{rms} = \frac{A}{\sqrt{2}} \Rightarrow K = \frac{U_{rms}}{U_m} = \frac{\pi}{2\sqrt{2}}$$

- Triangular

$$U_m = \mathrm{avr}\left|\frac{A.t}{T/2}\right| = \frac{1}{T/2}\int_0^{T/2}\frac{2A.t}{T}dt = \frac{4A}{T^2}\left[\frac{t^2}{2}\right]_0^{T/2} = \frac{A}{2}$$

$$U_{rms} = \frac{A}{\sqrt{3}} \Rightarrow K = \frac{U_{rms}}{U_m} = \frac{2}{\sqrt{3}}$$

- Square

$$U_m = \mathrm{avr}\left|A\right| = \frac{1}{T/2}\int_0^{T/2} A dt = \frac{2A}{T}\left[t\right]_0^{T/2} = A$$

$$U_{rms} = A \Rightarrow K = \frac{U_{rms}}{U_m} = 1$$

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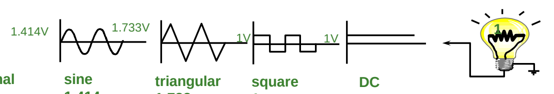
RMS value?



Signal	sine	triangular	square	DC
V_{peak}	1.414	1.733	1	1
V_{rms}	1	1	1	1

- The ratio rms value / mean value or peak value (achieved by rectification) = shape coefficient is not constant (it depends on waveform shape)
- AC voltmeter with rectifier is calibrated for sinewave to indicate rms value; the indicated value is wrong for different shapes

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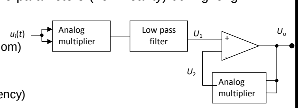
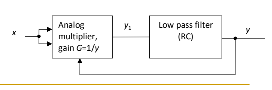
Converters to the TRUE rms

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T v_{AC}^2(t)dt}$$

- Definition contains nonlinear operations
  - Nonlinear circuits – difficult to keep stable parameters (nonlinearity) during long period
- Solutions
  - Analog processing (see e.g. www.analog.com)
    - Explicit principle
    - Implicit principle
    - Conversion on temperature (high frequency)
    - …
  - Digital processing
    - Calculation from digitized signal





$$V_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} v^2(i.T_s)}$$

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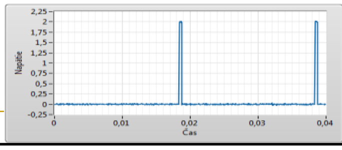
Crest factor

- **Crest factor** of signal is defined as the ratio of peak value to rms value of a waveform
- It describes for AC voltmeter the maximal overloading of instrument without limitation of measured signal
- Example of signal



Current measurement

- Ammeter
- The common need and ranges from µA to tens A
- Difficulties:
  - Small DC current (nA or pA) – input current and its drift
  - Large currents above 100A – indirect methods based on EM field, …
- Multimeter in the mode of ammeter: conversion from current to voltage in multimeter input circuits

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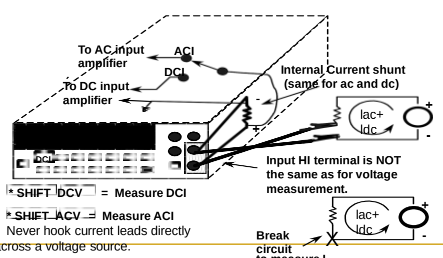
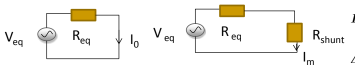
Measuring CURRENT



* Never hook current leads directly across a voltage source.

Connection

- Ammeter must be connected into break of circuit
- Input resistance (shunt) changes conditions in the measured circuit – the results of measurement differs from true current in circuit without meter (systematic error)
- The smaller is the input resistance the smaller is the error – modern digital multimeters $R_{ampermetra}$ ~0,1 – 10Ω



$$I_m = \frac{V_{eq}}{R_{eq} + R_{shunt}};$$

$$\Delta I_m = \frac{V_{eq}}{R_{eq}} - I_m = V_1 \frac{R_{shunt}}{R_{eq}\left(R_{eq} + R_{shunt}\right)}$$

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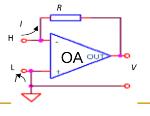
Conversion I to V

- Very small resistance
- Pasive convertors = accurate sensing resistor – shunt
  - Conversion constant is given by resistance of shunt
- Active (electronic) convertors with operational amplifier
  V=-R.I



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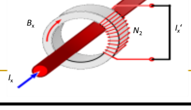
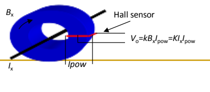
Large current measurement

- Clamp meters
- Two principles:
  - Current transformer:
    - Only AC current, limited bandwidthh
    - Low cost, simple construction
  - Hall sensor – semiconductor sensor of magnetic field:
    - AC and DC current, higher costs





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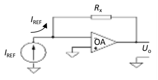
DC resitance measurement

- Test signal: DC current
- Principle based on Ohm law – measuring voltage across the measured resistor at known current

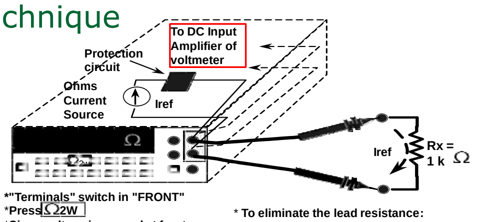
$$R_x = \frac{V_{measured}}{I_{source}}$$

- Modern instrumentations: active convertor resistance to voltage



$$U_o = -I_{REF} \cdot R_x$$

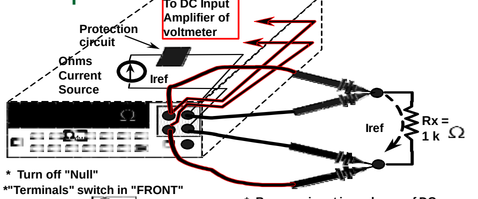
Measuring Resistance, Two-Wire Technique



*"Terminals" switch in "FRONT"
*Press Ω2W
*Since voltage is sensed at front terminals, measurement includes all lead resistance

* To eliminate the lead resistance:
* Short leads together
* Press Null
* Original value will now be subtracted from each reading

Measuring Resistance - Four-Wire Technique



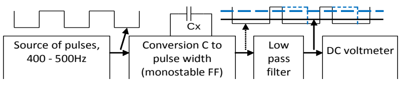
* Turn off "Null"
*"Terminals" switch in "FRONT"
*Press Ω 4W
*Voltage is now sensed directly at the resistor, so lead resistance is not a factor

* Because input impedance of DC Input Amplifier is so high, no current flows through sense leads, hence no lead resistance error

Measuring capacity and inductance

- Conversion C or L to DC voltage

$t_i = kRC_x$



$$U_m = U_H \frac{t_i}{T} + U_L \frac{T - t_i}{T} = (U_H - U_L)\frac{t_i}{T} + U_L = (U_H - U_L)\frac{kRC_x}{T} + U_L$$

$$C_x = \frac{U_m - U_L}{U_H - U_L}\frac{T}{kR} = aU_m + b$$ if $U_L = 0$ $$C_x = \frac{U_m}{U_H}\frac{T}{kR} = KU_m,$$

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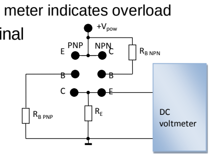
Diode and bipolar transistor test

- Diode:
  - PN junction test by constant DC current
    - If junction is open, the voltage across the junction is indicated
    - If junction is closed (reverse direction), the meter indicates overload
  - Results indicate anode and cathode terminal and status of PN junction (broken)
- Bipolar transistor
  - Test of BC and BE junctions (diodes – status, NPN or PNP)
  - Common-emitter current gain h_{21E} (β_E)



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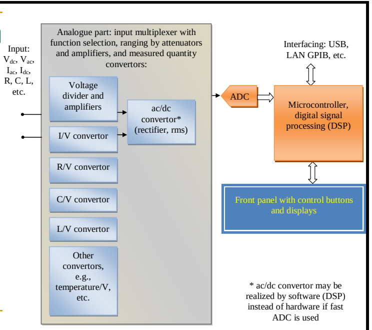
Block diagram

- Many measuring functions
- Conversion of any measured quantity to DC voltage
- Additional functions:
  - Statistical data processing
  - Communication interface
  - Continuity test
  - Triggering
  - Additional displays with numerical and graphical presentation of acquired results
  - …



Examples

- Handheld (batteries)
- Desktop (socket 230V)

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