EM NOISE & INTERFERENCE IN MEASUREMENT SETUPS

Tools for Physicists 2025

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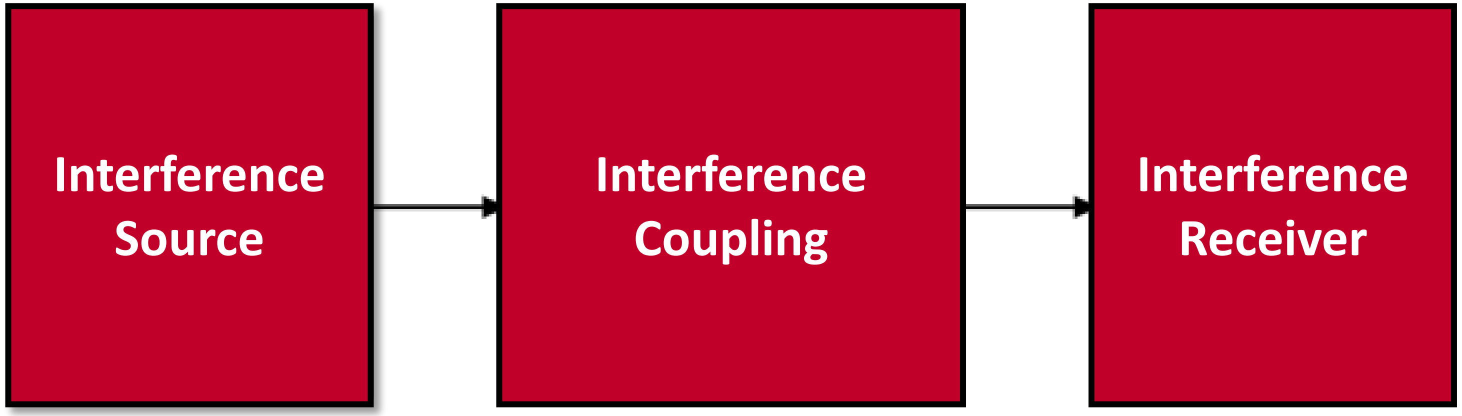
DISCLAIMER

- What this is not…
  - Teaching design principles
  - Silver bullet for your measurement problems
- but rather…
  - Discussing possible reasons
  - Giving hints for solutions
  - Help with checking your setup

MODEL OF INTERFERENCE INFLUENCE



Reason for interference

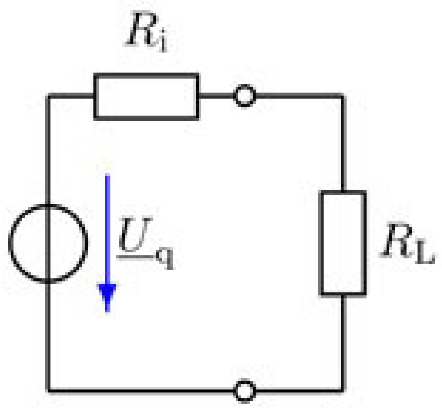
Type of coupling

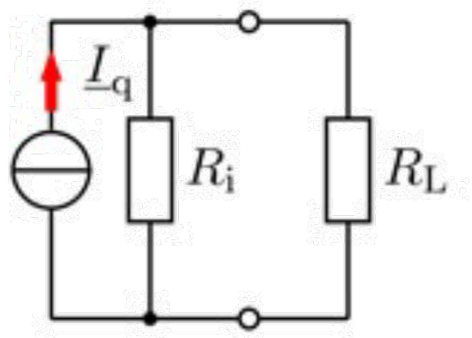
- Capacitive
- Inductive
- Impedance

Device influenced by interference

- Voltage/Current
- Constant/Periodic/…

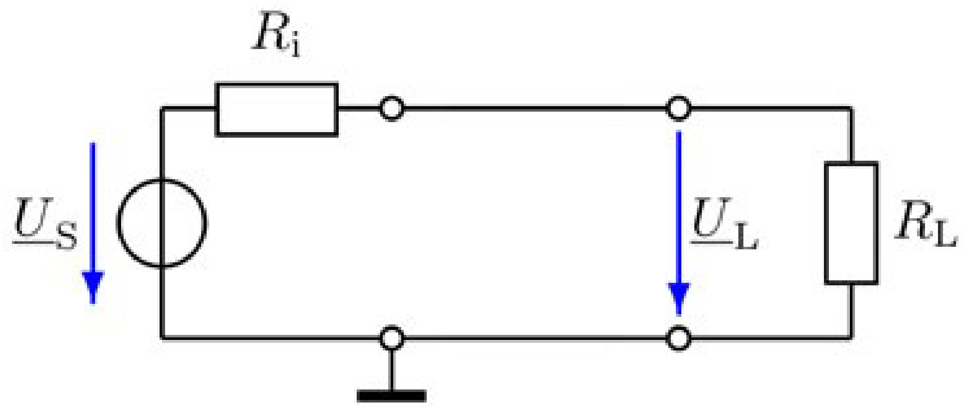
SIGNAL TRANSMISSION

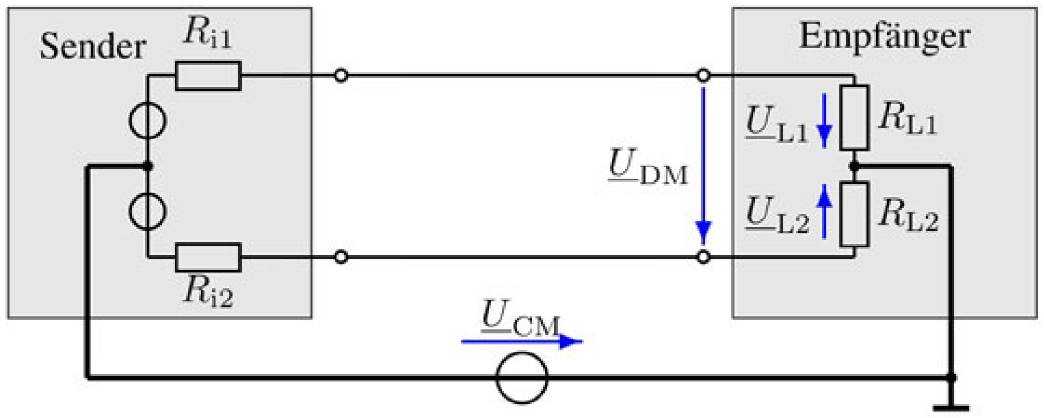




- Voltage
  - In general: $R_L \gg R_i$
  - Current determined by R_L
    - Can be ignored for large R_L
- Current
  - In general: $R_L \ll R_i$
  - Voltage determined by R_L
    - Can be ignored for $R_L \rightarrow 0$
  - Example: PMT

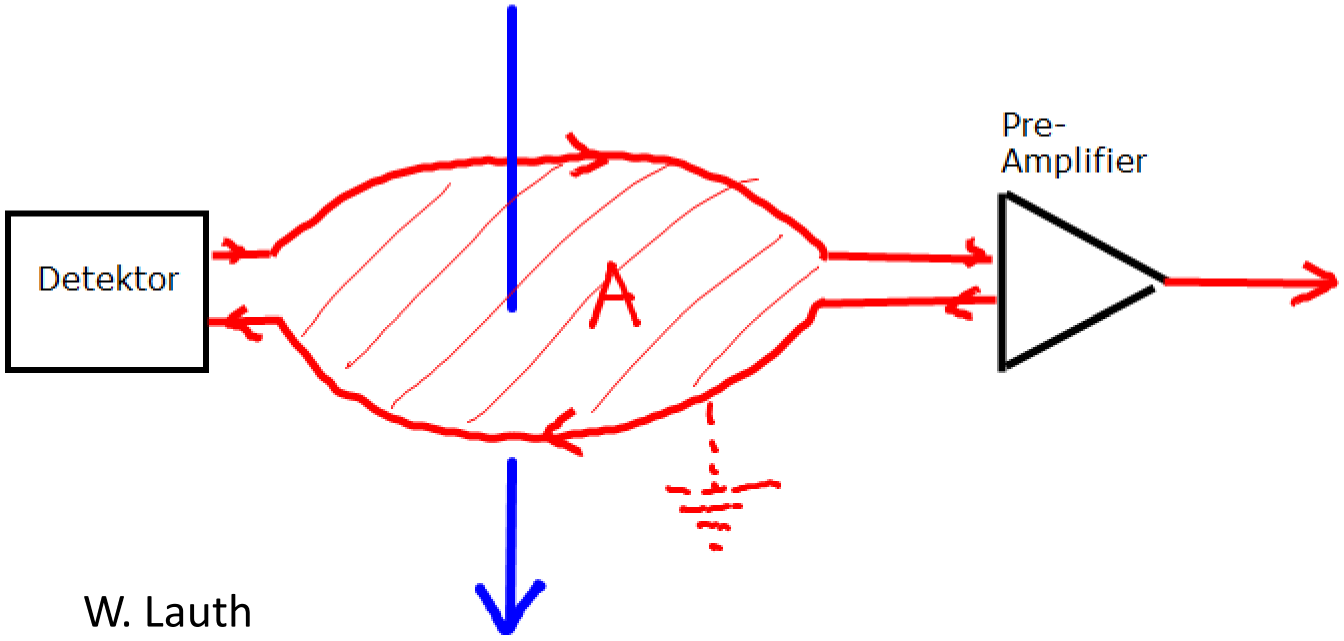
SIGNAL TRANSMISSION





- Loop is always closed
  - Signal current has a return path!
- Asymmetric
  - One conductor connected to ground
- Symmetric
  - Signals symmetric wrt ground
  - Opposite polarity
  - Better in terms of interference

SIGNAL TRANSMISSION – CABLE ROUTING



Keep area between wires as small as possible!

- Example: Radio Transmitter (100MHz)

$$E \cong 100 \frac{\mu V}{m} \Rightarrow B = \frac{E}{c}$$

$$= 3.3 \cdot 10^{-13} \frac{Vs}{m^2}$$

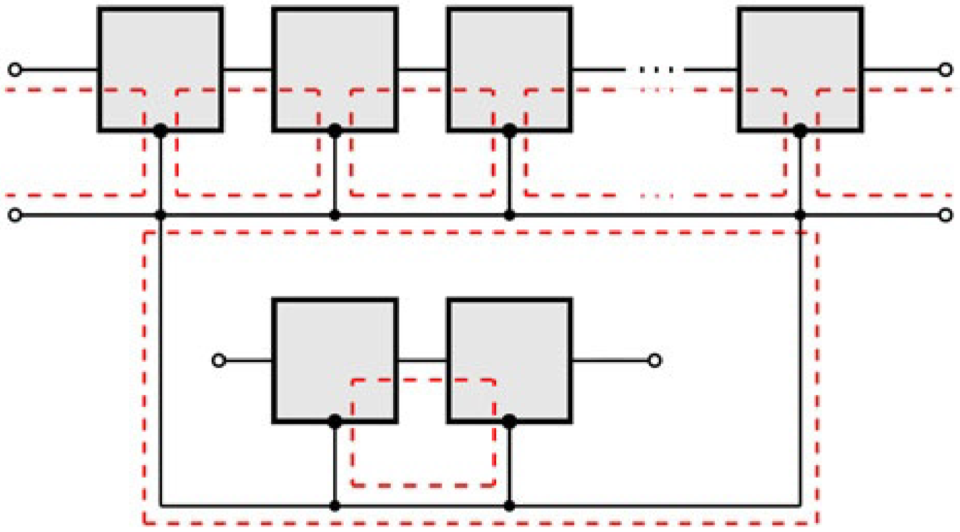
$$|U_{ind}| = \frac{\partial B}{\partial t} \cdot A = 3 \cdot 10^{-5} \frac{V}{m^2} \cdot A$$

With $A = 1m^2$ you get

$$|U_{ind}| = 30\mu V$$

But if transmitter is closer…

GROUND/EARTH

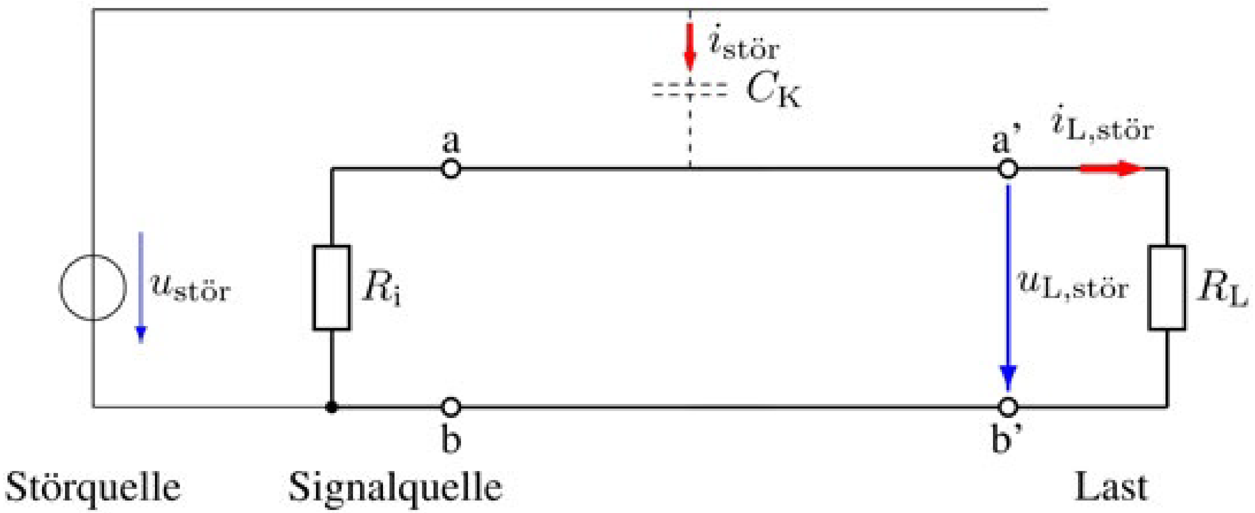


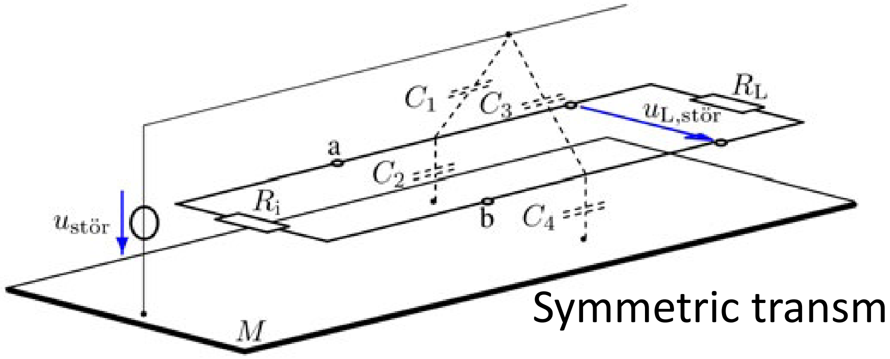
Devices connected in rows (typical lab setup)

- Two main tasks
  1) Reference potential
  2) Equalize potential
- Can lead to substantial currents
  - Bad for task 1)
- (Unwanted) Coupling of different loops

INTERFERENCE COUPLING - CAPACITIVE

Asymmetric transmission

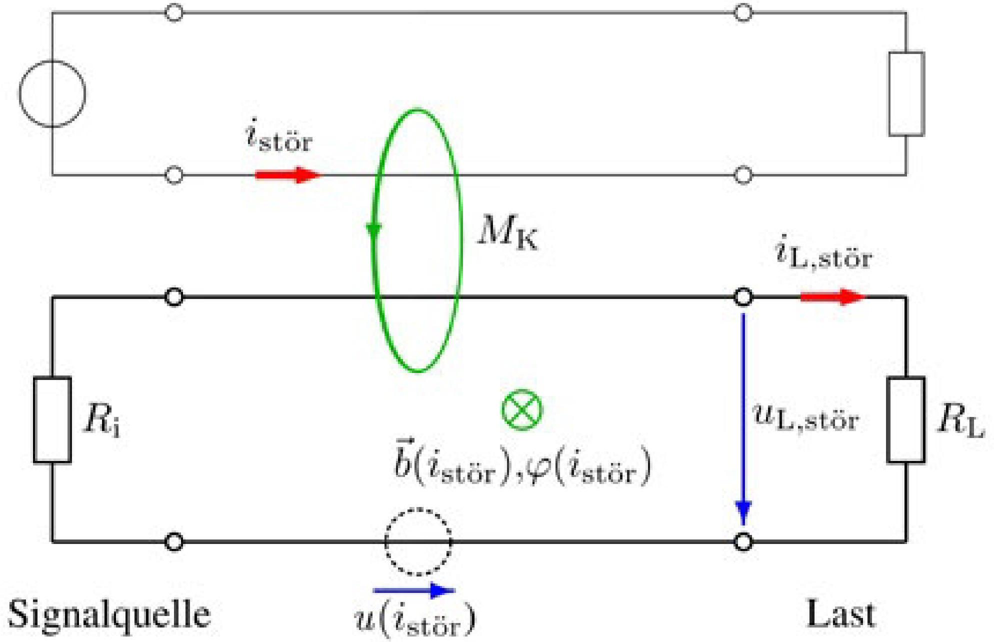




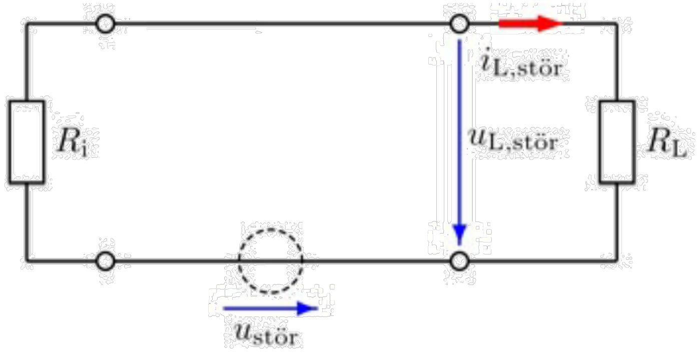
Symmetric transmission

- Coupling via capacitance C_K
  - https://www.emisoftware.com/calculator/wire-over-ground-plane-capacitance/
- $I_{IF} = C_K \frac{\mathrm{d}U_{IF}}{\mathrm{d}t}$
  - Depends on frequency
- $U_{L,IF} = C_K \frac{\mathrm{d}U_{IF}}{\mathrm{d}t} \frac{R_i \cdot R_L}{R_i + R_L}$
- Countermeasures
  - Reduce C_K, $\frac{\mathrm{d}U_{IF}}{\mathrm{d}t}$
  - Use low-pass filter

INTERFERENCE COUPLING - INDUCTIVE

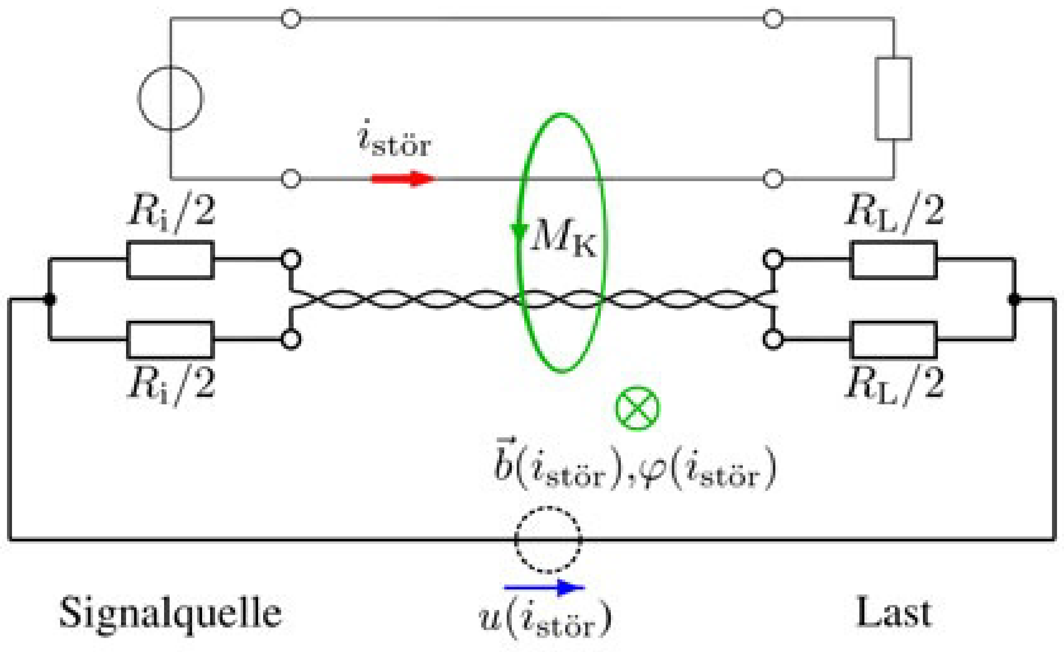


Equivalent circuit diagram



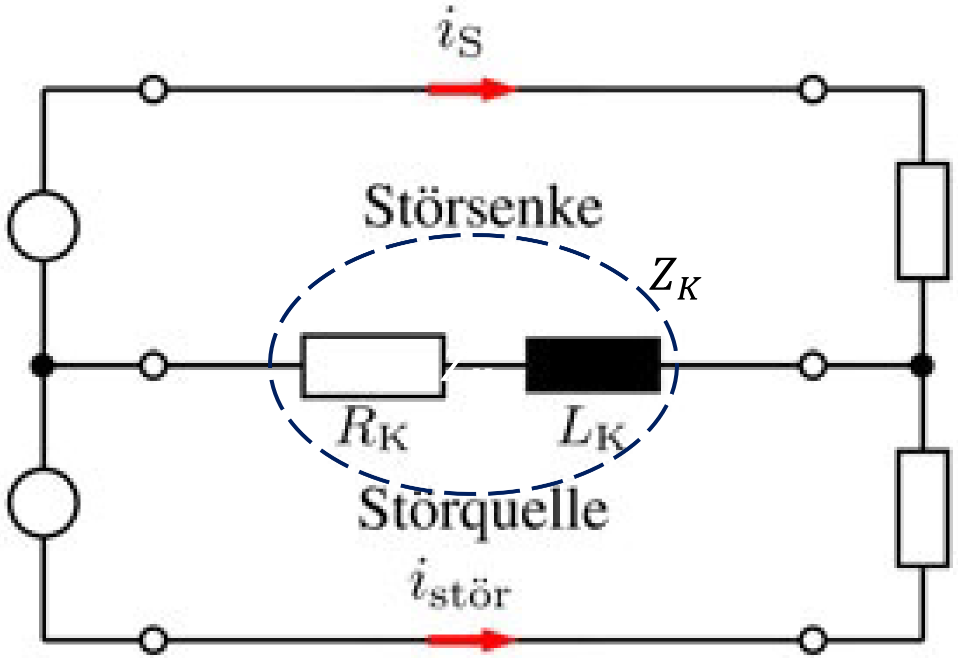
- Mutual inductance M_K reason for coupling
- $U_{IF} = M_K \frac{\mathrm{d}I_{IF}}{\mathrm{d}t} \approx U_{L,IF}$
  - Depends on frequency
- Countermeasures
  - Reduce coupling M_K
  - Use current transmission
  - Reduce $\frac{\mathrm{d}I_{IF}}{\mathrm{d}t}$

INTERFERENCE COUPLING - INDUCTIVE



- Countermeasures cnt'd
  - Twisting transmission lines
    - Causes change of sign for magnetic flux
    - Still influence between neighbouring lines
  - Use low-pass filter

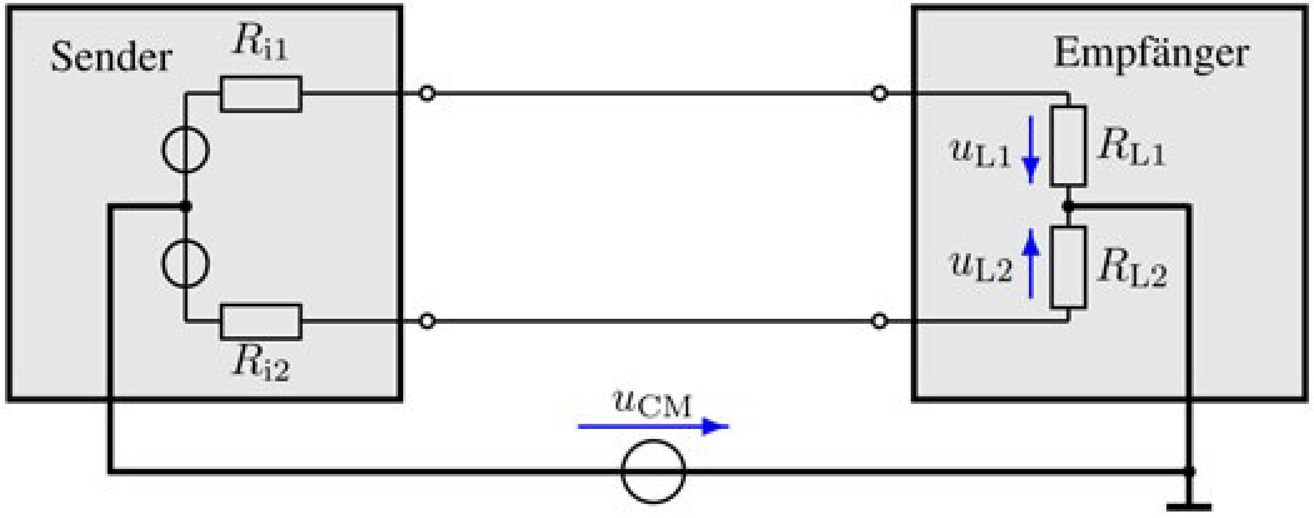
INTERFERENCE COUPLING - IMPEDANCE



Asymmetric transmission

- Coupling through common impedance Z_K
  - Often a common ground connection
- Different reference potentials
  - $U_{IF} = R_K \cdot I_{IF} + L_K \frac{\mathrm{d}I_{IF}}{\mathrm{d}t}$
- Minimize Z_K, I_{IF}, and $\frac{\mathrm{d}I_{IF}}{\mathrm{d}t}$

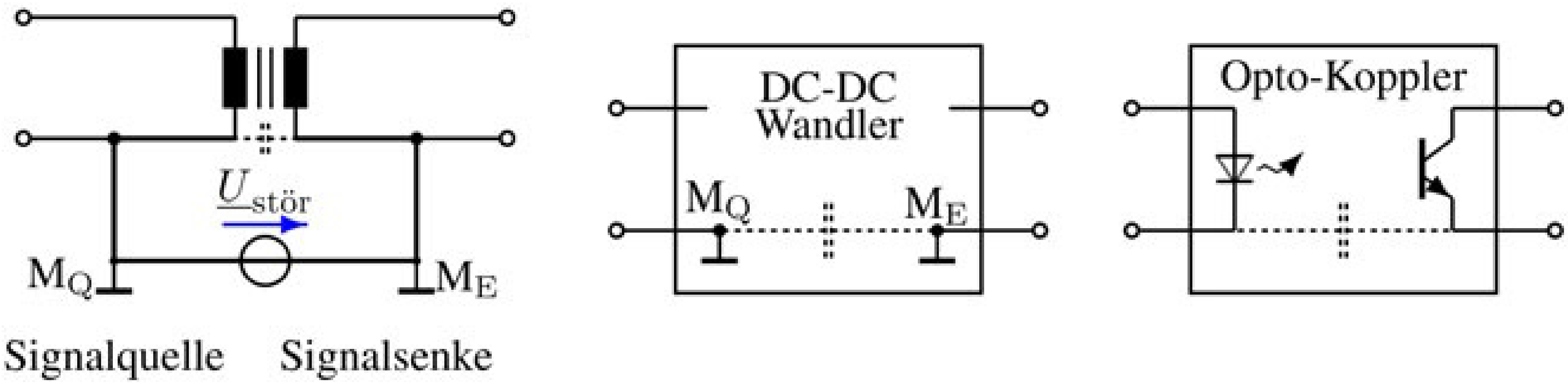
INTERFERENCE COUPLING - IMPEDANCE



Symmetric transmission

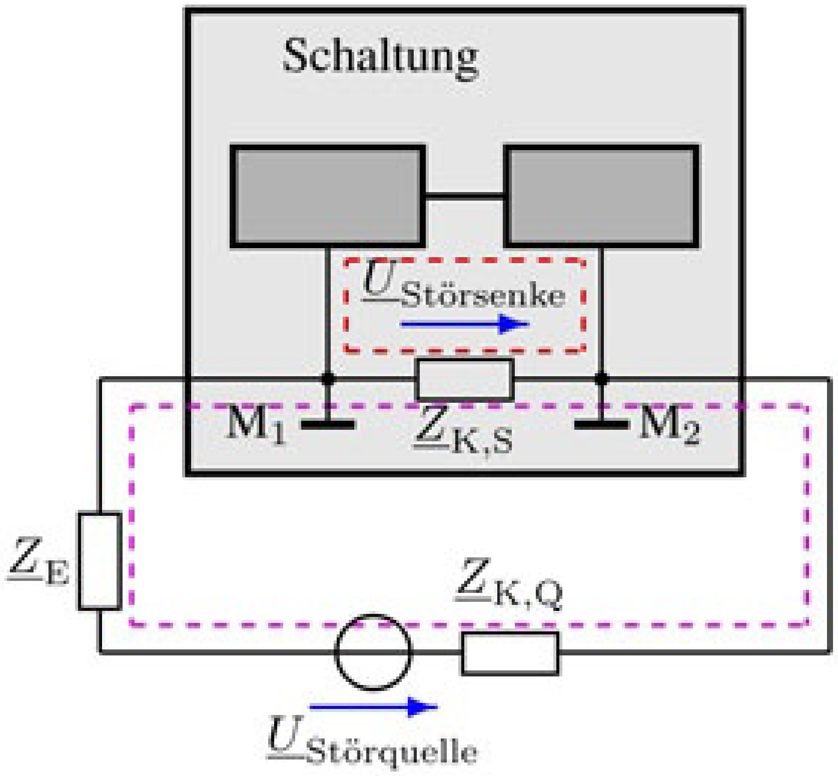
- Only common-mode interference signal
- Reduces coupling to other loops
  - Compensates current on ground line

COUNTER MEASURES IN THE LAB - ISOLATING TRANSFORMER



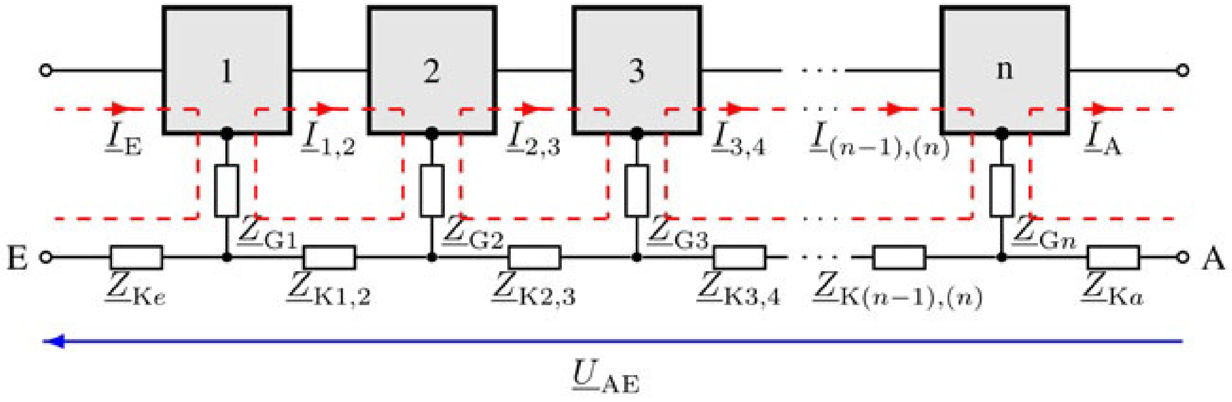
- Insert large resistance between different grounds
  - Decoupling (especially at low frequency)
- Might not be fast enough for some signals

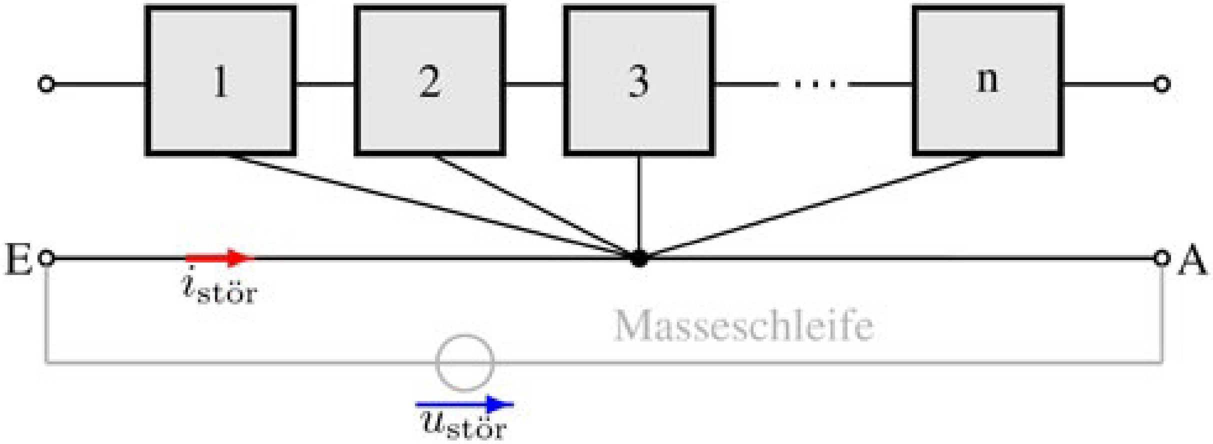
COUNTER MEASURES IN THE LAB – GROUND LOOPS



- Multiple connections to ground in one circuit
  - Can be connected via a capacitance
- Z_K define the coupling of the interference
  - Keep Z_K small
- Z_E decouples interference
  - Make Z_E large
- Improve grounding scheme

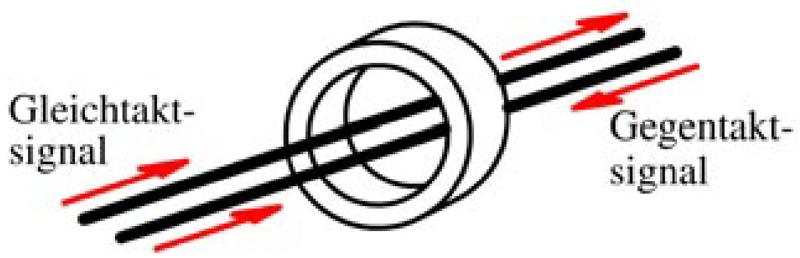
COUNTER MEASURES – GROUND CONNECTIONS





- Use one common connection to ground
  - No coupling from external ground loop
  - Impedance between stages is zero
- Might enhance coupling between different stages
  - Oscillations?

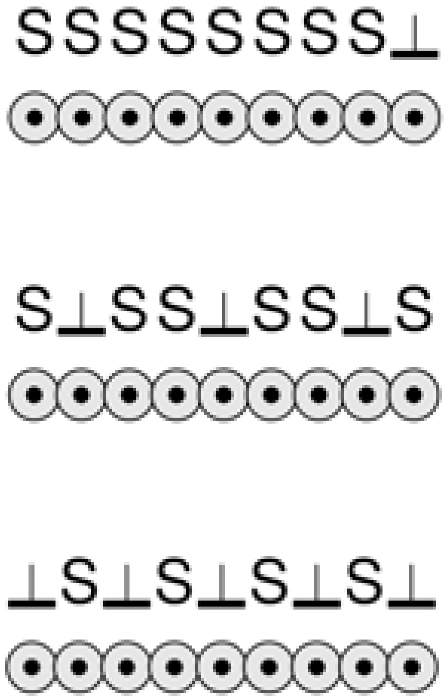
COUNTER MEASURES - COMMON MODE CHOKE (GLEICHTAKTDROSSEL)



https://commons.wikimedia.org/w/index.php?curid=5107944

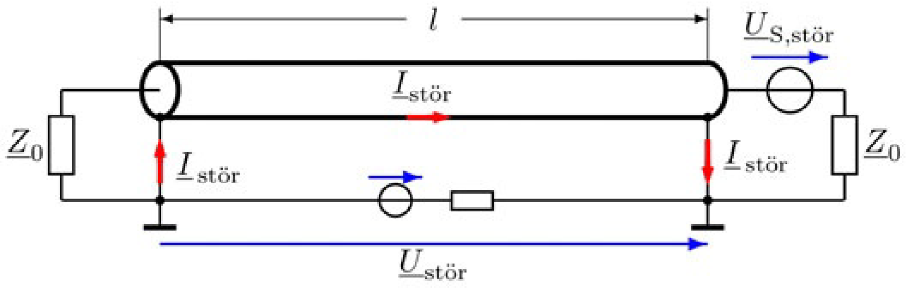
- Only common-mode signal has net current
- Ground loops have low impedance
  - Improvement already with small change of impedance
- Can also be used for multiple wires, e.g. flat-ribbon

COUNTER MEASURES – FLAT RIBBON CABLE



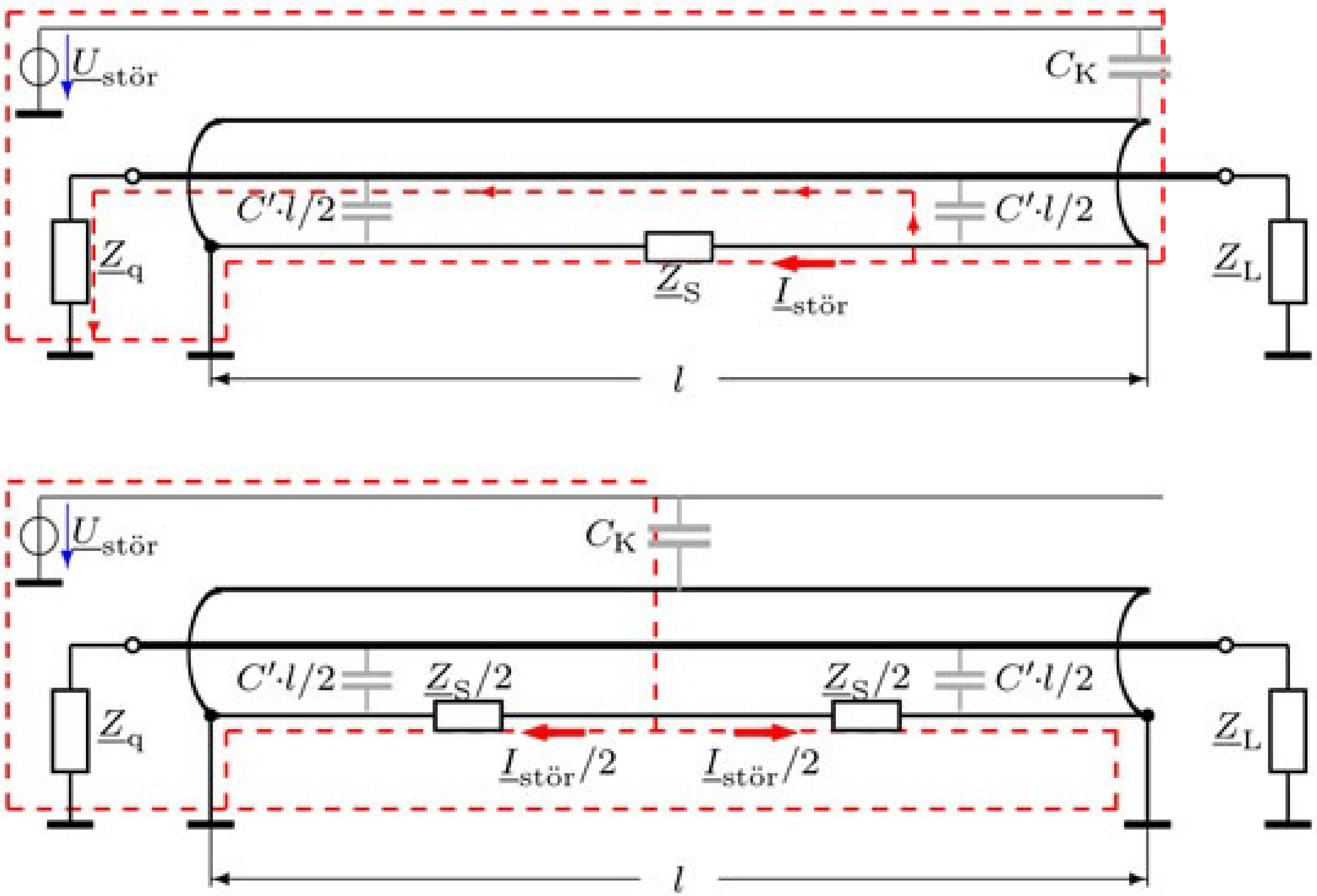
- Keep loop area small
  - Reduce inductance
- More ground connections reduce resistance
  - Less voltage drop
- Twisted line pairs

COUNTER MEASURES – CABLE CONNECTIONS



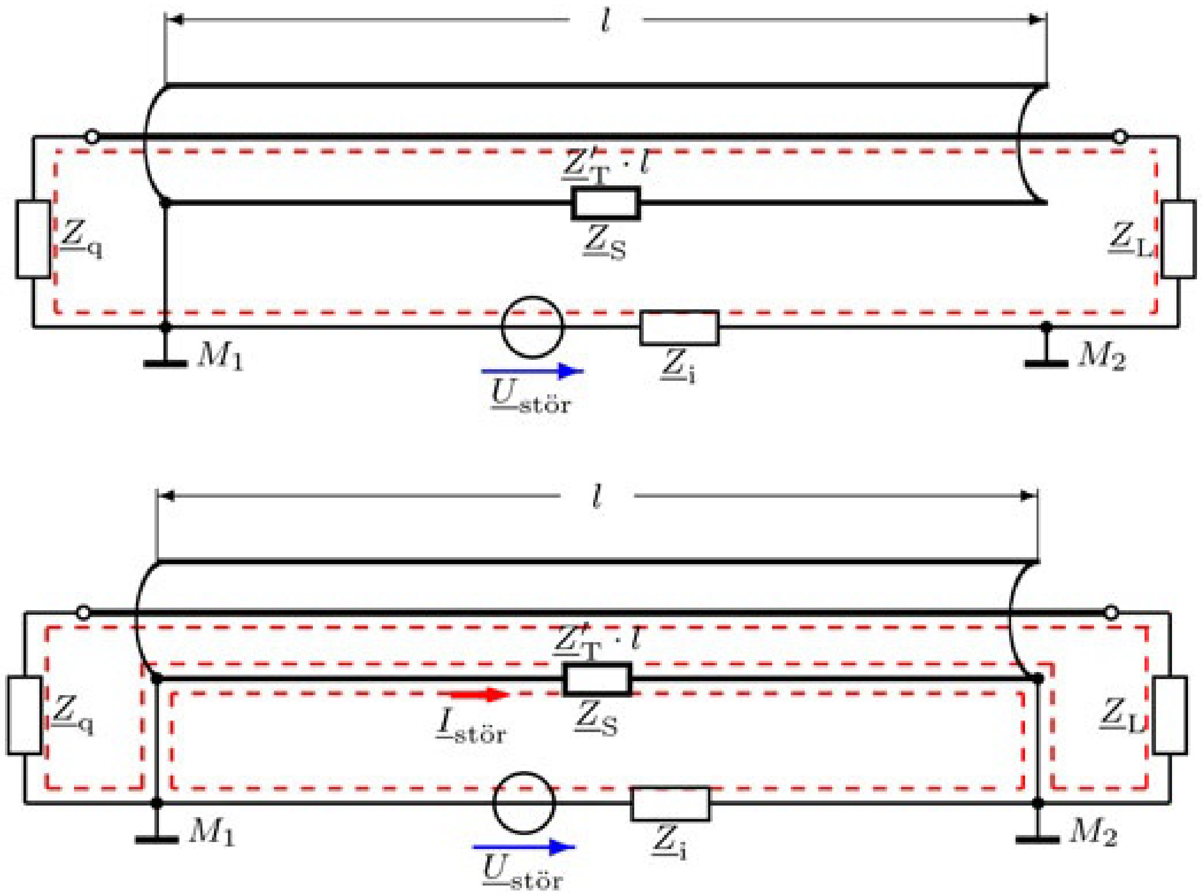
- Capacitive and EM coupling can be suppressed by screen
- Current I_{IF} in screen can cause interference $U_{S,IF}$
- Braided screen
  - Magnetic field inside screen ≠0
  - Inductance
- Keep connection impedance low

COUNTER MEASURES – CABLE CONNECTIONS



- Capacitive coupling
- One-sided ground connection
  - Induced potential causes noise on signal line
- Two-sided ground connection
  - Both branches (partially) compensate

COUNTER MEASURES – CABLE CONNECTIONS



- Inductive or impedance coupling
- One-sided ground connection
  - U_{IF} directly superimposed on signal!
- Two-sided ground connection
  - Only partially superimposed $(\frac{Z'_T \cdot l}{Z_S})$

FINDING THE SOURCES – MAY BE?

- Capacitive Coupling
  - Short signal source ($R_i = 0$)
    - Interference should vanish
- Inductive Coupling
  - Open signal source ($R_i \rightarrow \infty$)
    - Interference should vanish (but gets larger if capacitive)
    - True also for impedance coupling
  - Shielding
    - Do not ground (capacitive coupling)