Topic 4

Bridges for dc and ac measurements of resistance.
Transformer and current-comparator-based capacitance bridges.

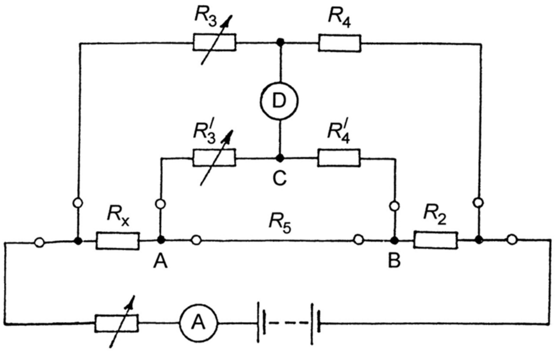
Bridges for dc and ac measurements of resistance

- Need to cover measurement range from 10 μΩ up to 10 PΩ

NIST, Fluke, MINTL, Ceebuild

- Measurement methods – ratio between known and unknown standard:
  - Potentiometric method - apply same *I*, measure ratio of *V* *(for medium and high-ohm resistances)*
  - Comparator method - apply same *U*, measure ratio of *I* *(for low-ohm and medium resistances)*

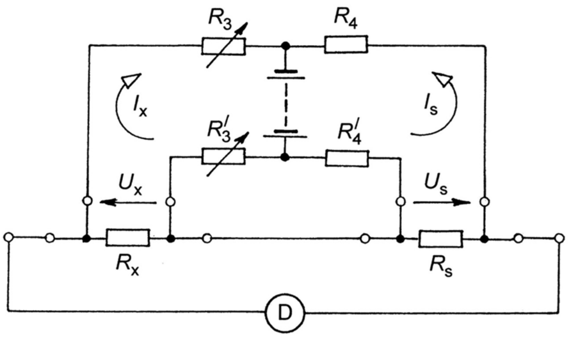
Kelvin double bridge



$$R_x = R_2 \frac{R_3}{R_4} +$$

$$+ R_5 \frac{R_{4a}}{R_{3a} + R_{4a} + R_5} \left(\frac{R_3}{R_4} - \frac{R_{3a}}{R_{4a}} \right)$$

Kelvin double bridge with source and detector interchanged

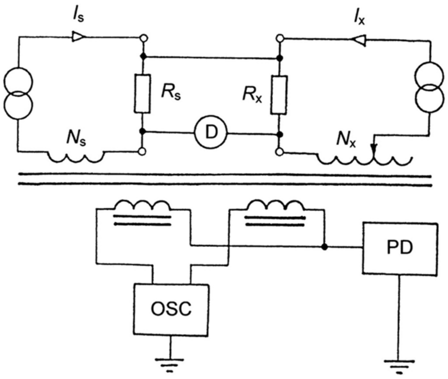


$$U_x = U_s$$

$$R_x I_x = R_s I_s$$

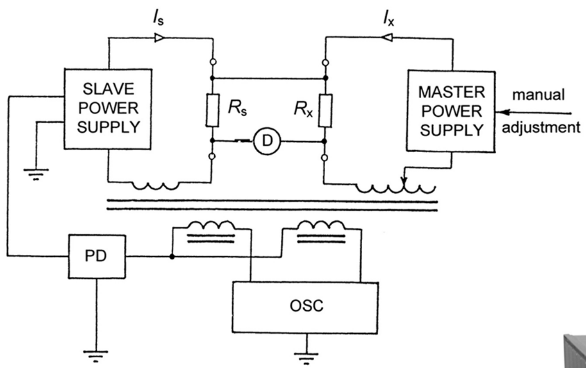
$$\frac{R_x}{R_s} = \frac{I_s}{I_x}$$

DC comparator bridge



$$R_X I_X = R_S I_S$$
$$N_X I_X = N_S I_S$$
$$R_X = \frac{N_X}{N_S} R_S$$

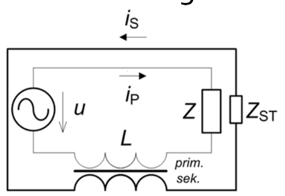
Bridge based on an automatically balanced DC comparator



$$R_X = \frac{N_X}{N_S} R_S$$

Coaxial ac bridges

- All components are surrounded by electrical shields
- All components are connected by coaxial cables
- Goal: currents in the outer shields are equal to opposite of currents in the inner components and conductors
- Coaxial bridge – two superposed networks:



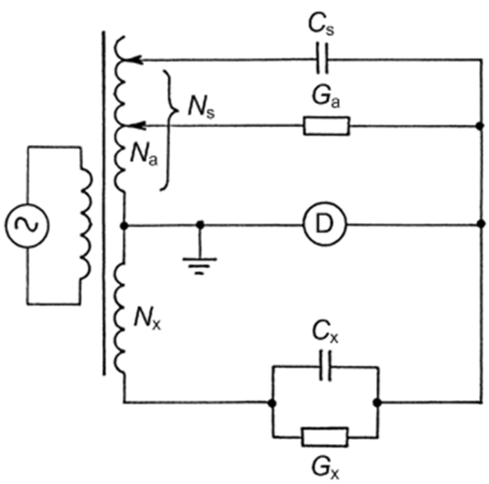
$$\frac{\mathrm{d}(\Phi_P - \Phi_S)}{\mathrm{d}t} = L\frac{\mathrm{d}(\boldsymbol{i}_P - \boldsymbol{i}_S)}{\mathrm{d}t} = \mathrm{j}\omega L(\boldsymbol{i}_P - \boldsymbol{i}_S) = \boldsymbol{i}_S \boldsymbol{Z}_{ST}$$

$$\boldsymbol{i}_S = \frac{\boldsymbol{i}_P}{1 + \dfrac{\boldsymbol{Z}_{ST}}{\mathrm{j}\omega L}}$$

$Z_{ST} << \omega L \rightarrow i_S \sim i_P$

- The ideal coaxial bridge produces no external magnetic field and zero electric field → the bridge is insensitive to external fields

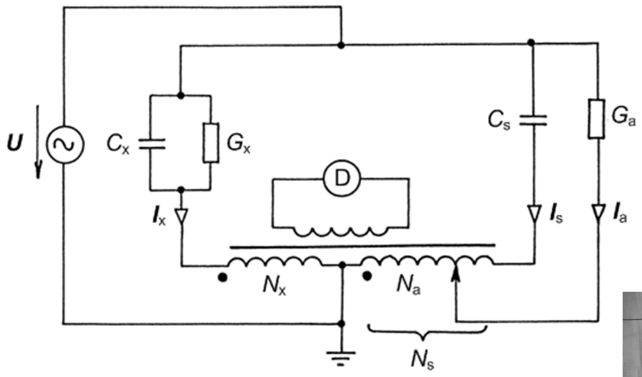
AC transformer C-C bridge



$$C_x = \frac{N_s}{N_x} C_s$$

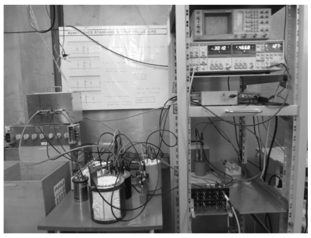
$$G_x = \frac{N_a}{N_x} G_a$$

AC comparator C-C bridge

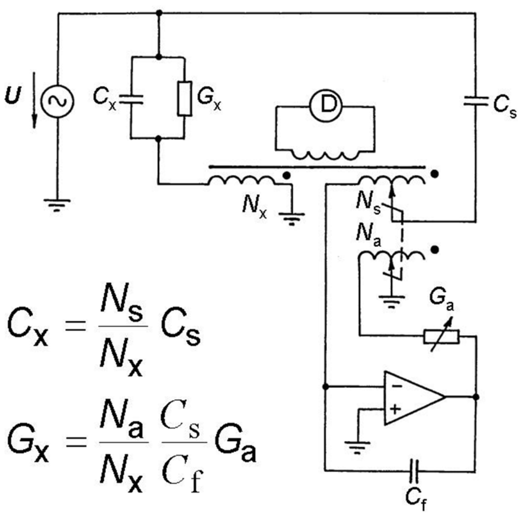


$$C_x = \frac{N_s}{N_x} C_s$$

$$G_x = \frac{N_a}{N_x} G_a$$



High voltage comparator C-C bridge

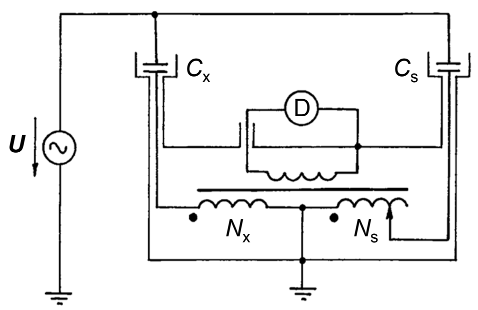


$$C_x = \frac{N_s}{N_x} C_s$$

$$G_x = \frac{N_a}{N_x} \frac{C_s}{C_f} G_a$$

$C_F >> C_S$

Shielding of AC comparator C-C bridge

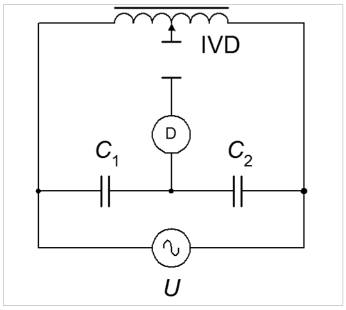


- Omitting effects of parasitic capacitances

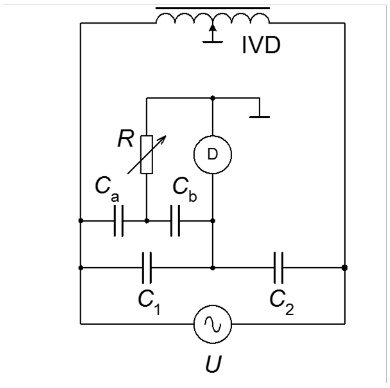
Development of a four-terminal-pair C-C bridge

Development
of a four-terminal-pair
C-C bridge

Simple C-C bridge

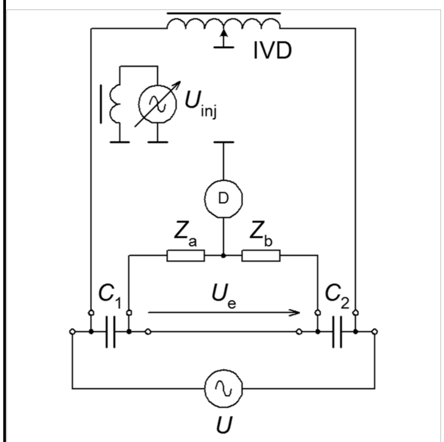


Simple bridge for comparing
2TP lossless capacitors

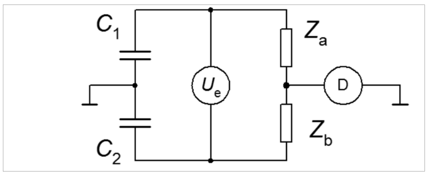


Simple bridge for comparing
2TP capacitors with losses

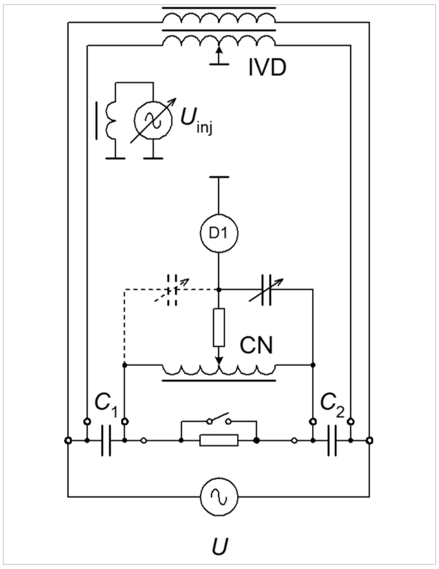
Injection and combining network



Bridge for comparison of 4TP lossless
capacitors



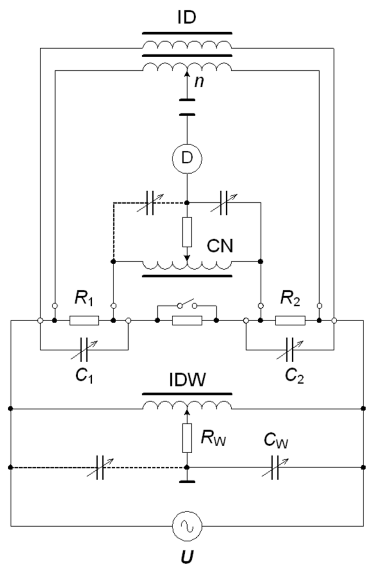
Improved version



Improving accuracy with:
- Two-stage divider
- CN formed with variable IVD

Four-terminal pair R-R bridge

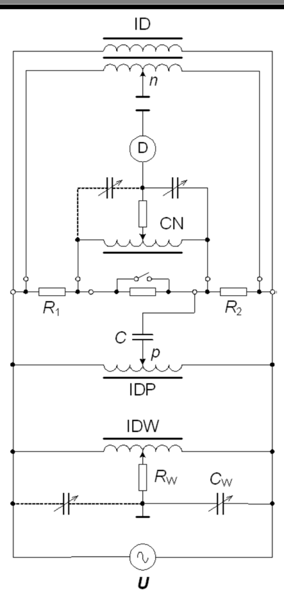
R–R bridge, version 1



- Two stage IVDs
- Compensation networks
- Wagner earth circuit

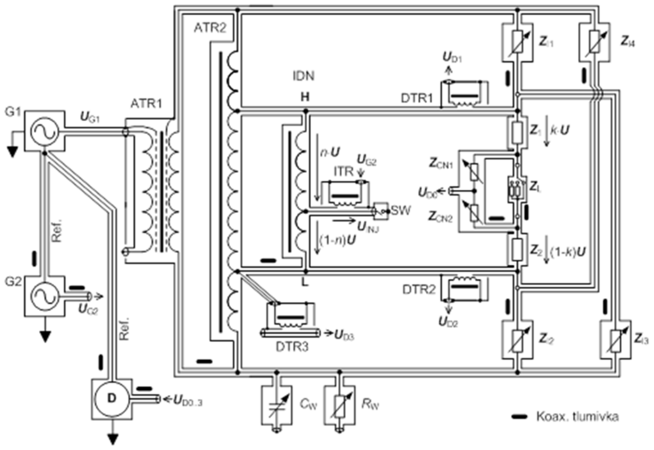
- Measurement of time constant difference between R_1 and R_2: small variable capacitors C_1, C_2

R–R bridge, version 2



- Quadrature balance performed with IDP and C

Example of realization of a fully coaxial R-R bridge



$$k_i = n + \frac{U_{INJi}}{U}$$

$$K_i = \frac{k_i}{1 - k_i}$$

$$K = \sum_{i=1}^{N} K_i$$