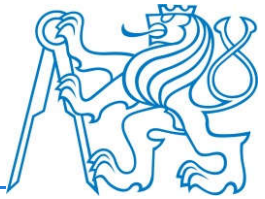
Czech Technical University in Prague
Faculty of Electrical Engineering



Digital coaxial bridges for impedance metrology

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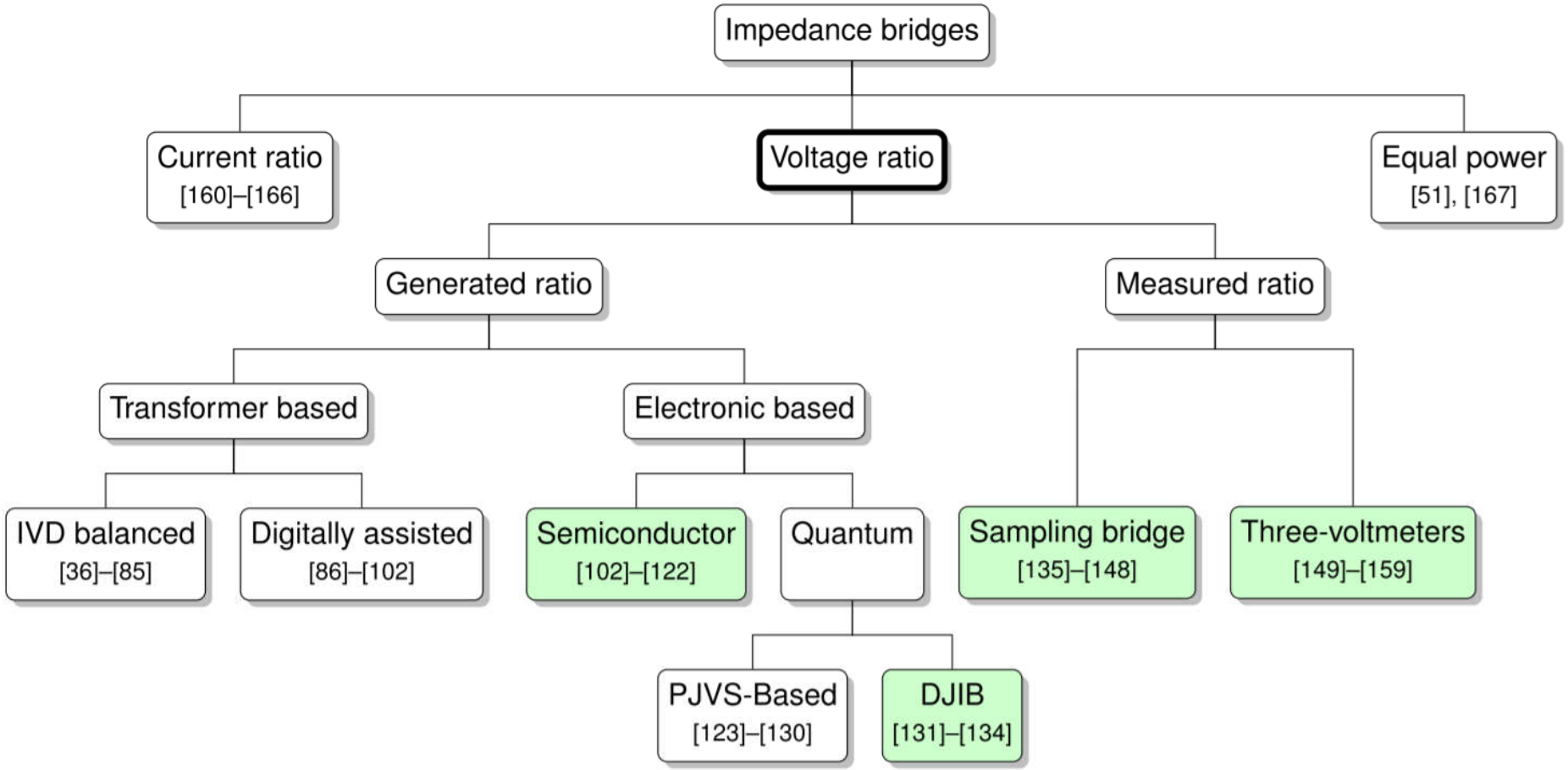
Content

- Impedance definitions and basic troubles in bridges
- Basic concept of AC Wheatstone bridge – first AC bridge used for unknown impedance measurement
- Transformer bridges of Wheatstone type
- 4TP auto-balancing bridge (principle of RLC meter)
- 4TP sampling impedance ratio bridge
- 4TP digitally assisted impedance ratio bridges (realisation of MITAS, CMI Brno, CMI Prague)
- 2TP double Josephson impendence bridge (DJIB)

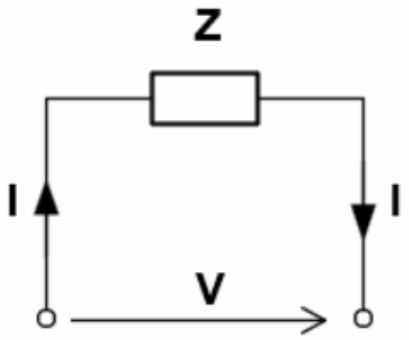
General division of impendence bridges



Taken from [8]

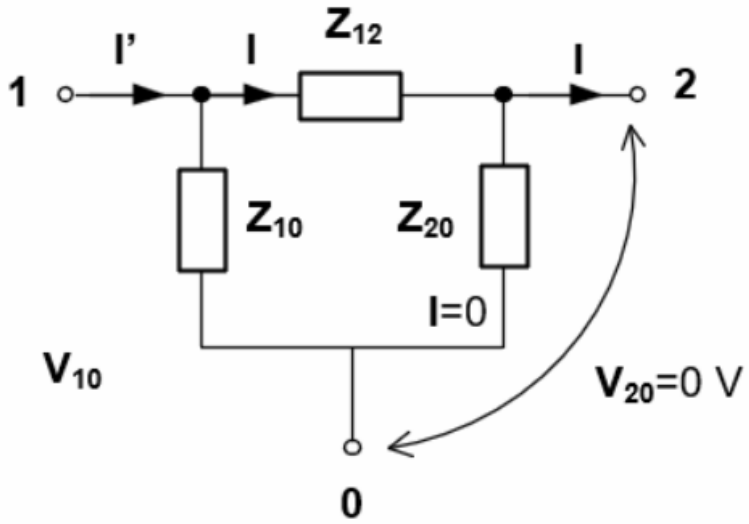
Several impedance definition

1) two terminal definition



$$Z = \frac{\hat{V}e^{j\omega t+\varphi_V}}{\hat{I}e^{j\omega t+\varphi_I}} = |Z|e^{j\varphi}$$

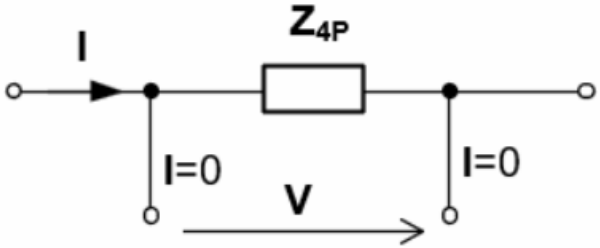
2) three terminal definition



$Z_{12}=V_{10}/I$

Z_{12} …. direct impedance

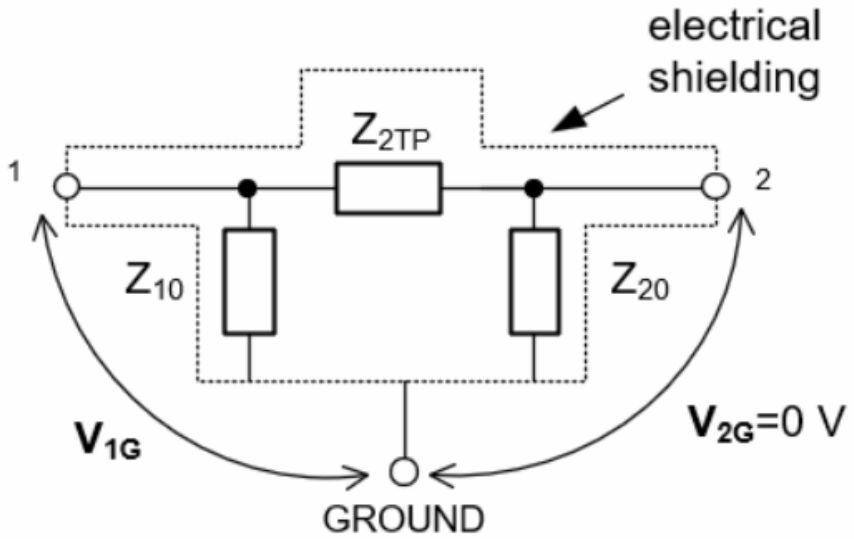
3) four terminal definition



$Z_{4P}=V/I$

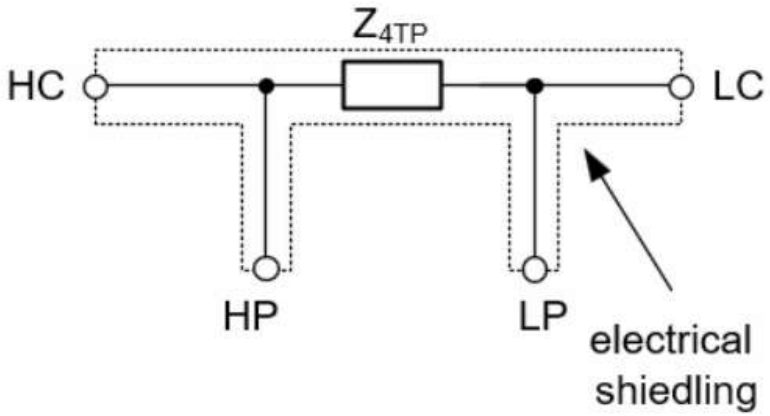
Several impedance definition

4) two terminal-pair terminal definition



$$Z_{2TP} = V_{1G} / I$$

5) four terminal-pair terminal definition



$$Z_{4TP} = V_{HP} / I_{LC}$$

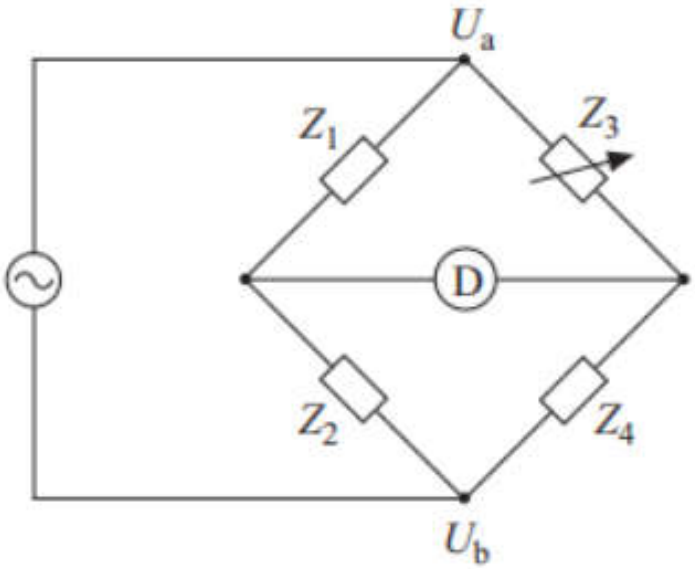
just then $V_{LP} = 0$ V

$I_{HP} = 0$ A

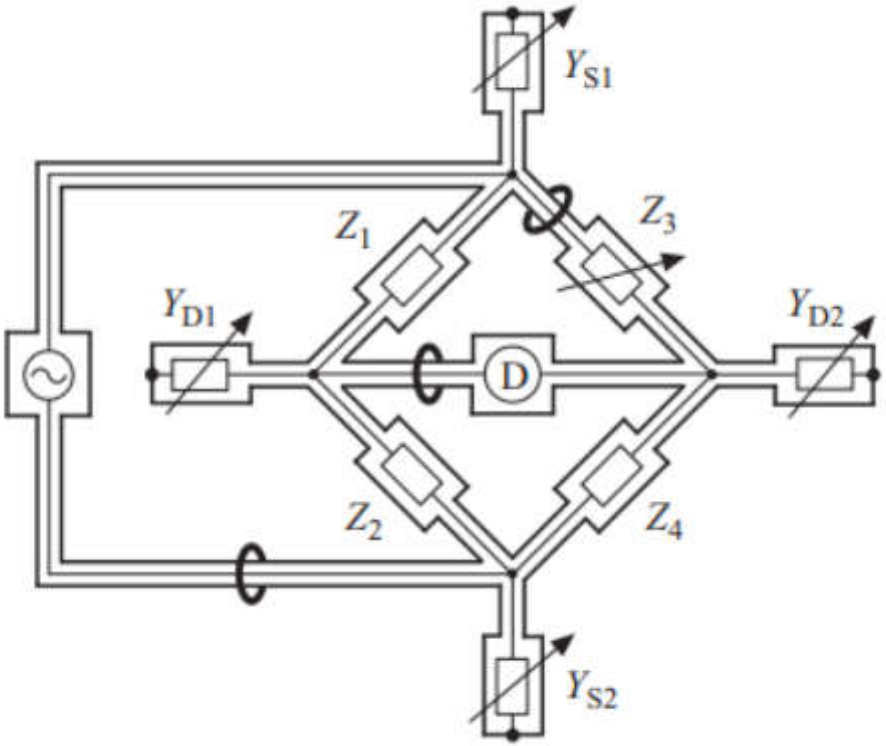
- For achievement of the best accuracy, 2TP or 4TP impendence definition should be used
- If I do not meet the required definition conditions, I measure impedance with error

AC Wheatstone bridge (WB)

Single-conductor AC WB



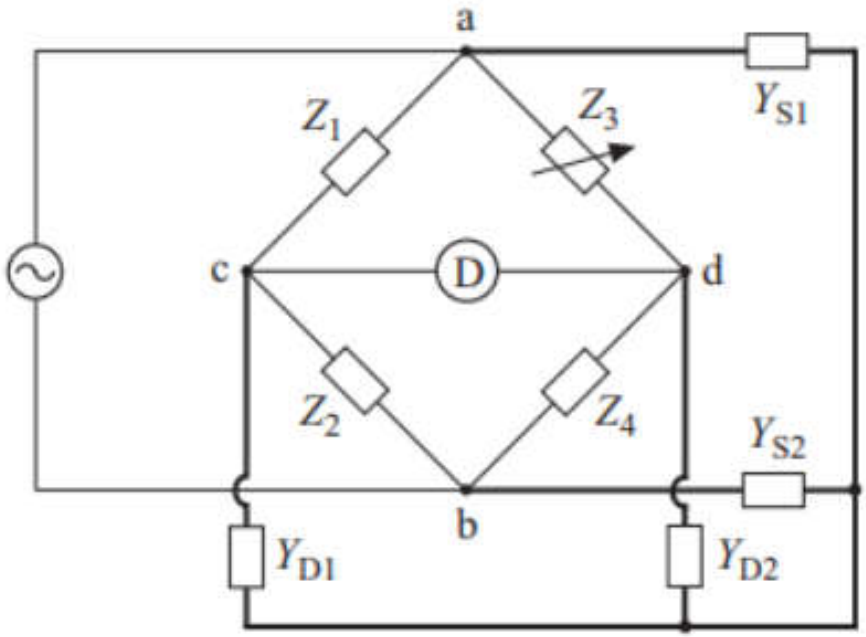
Screened single-conductor AC WB



Taken from [1]

Wagner ground in bridges

- Simplified line drawing of a completed screened AC Wheatstone bridge

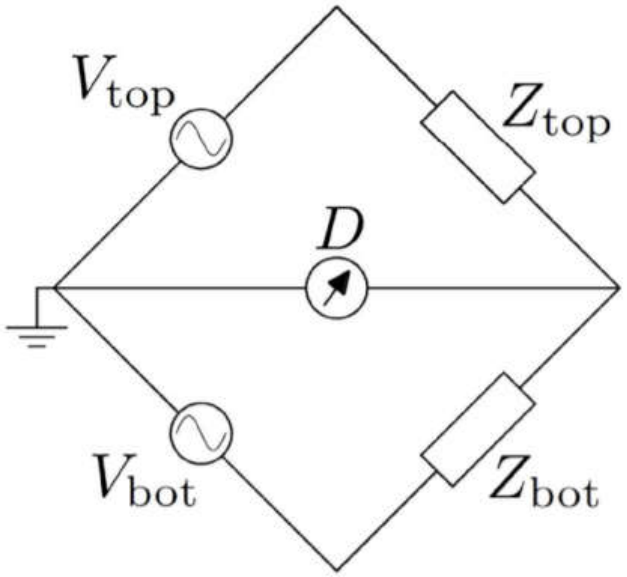


- Wagner ground (balance) circuit formed by Ys1 and Ys2
- Ratio Ys1/Ys2 must equals Z3/Z4 ratio

Taken from[1]

Wheatstone bridge with two voltage sources and realisation

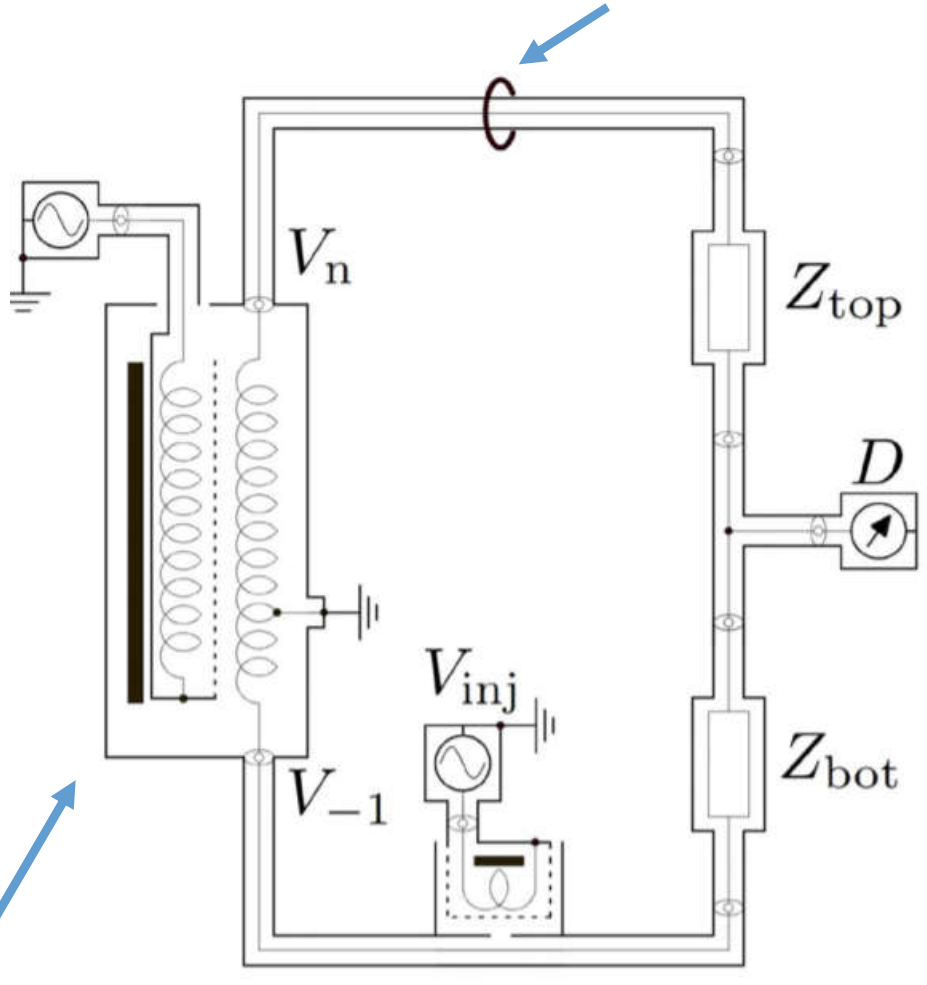
- Can be used for comparison like impedances (R-R, C-C)



$$\frac{Z_{bot}}{Z_{top}} = -\frac{V_{bot}}{V_{top}}$$

Taken from [1]

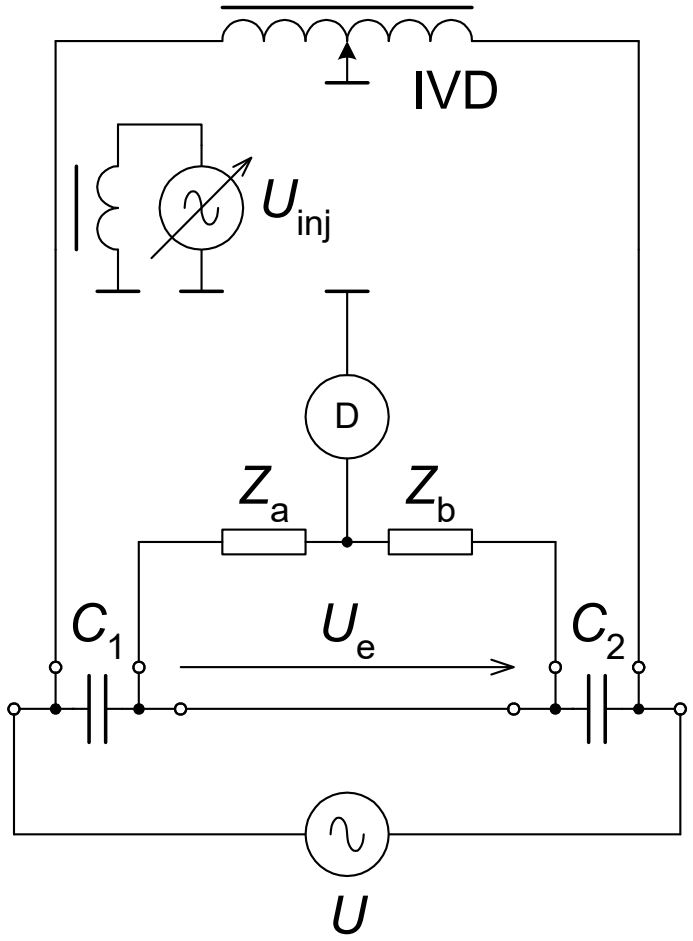
Current equaliser

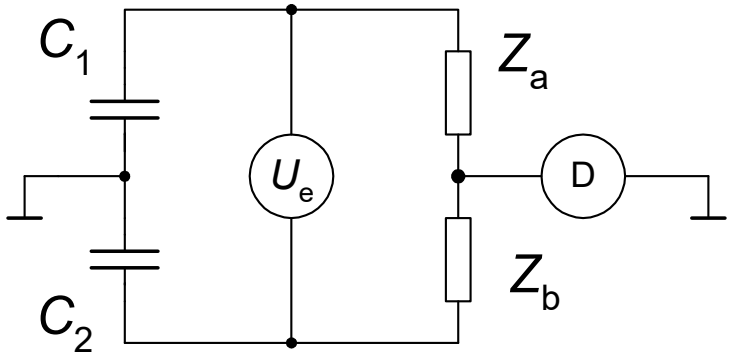


Inductive voltage divider with excitation winding used as voltage ratio definition

Combining network – elimination of voltage drops over link between compared impedances

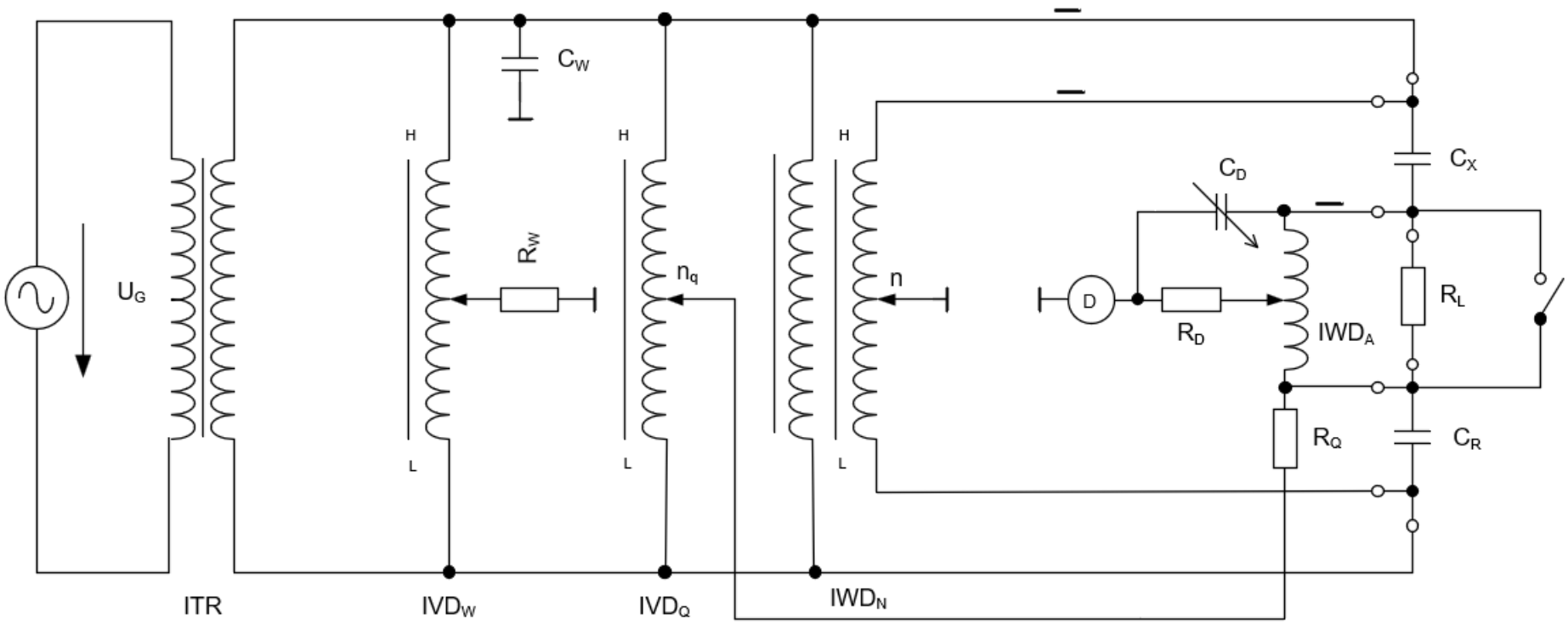
- Principle of Kelvin bridge





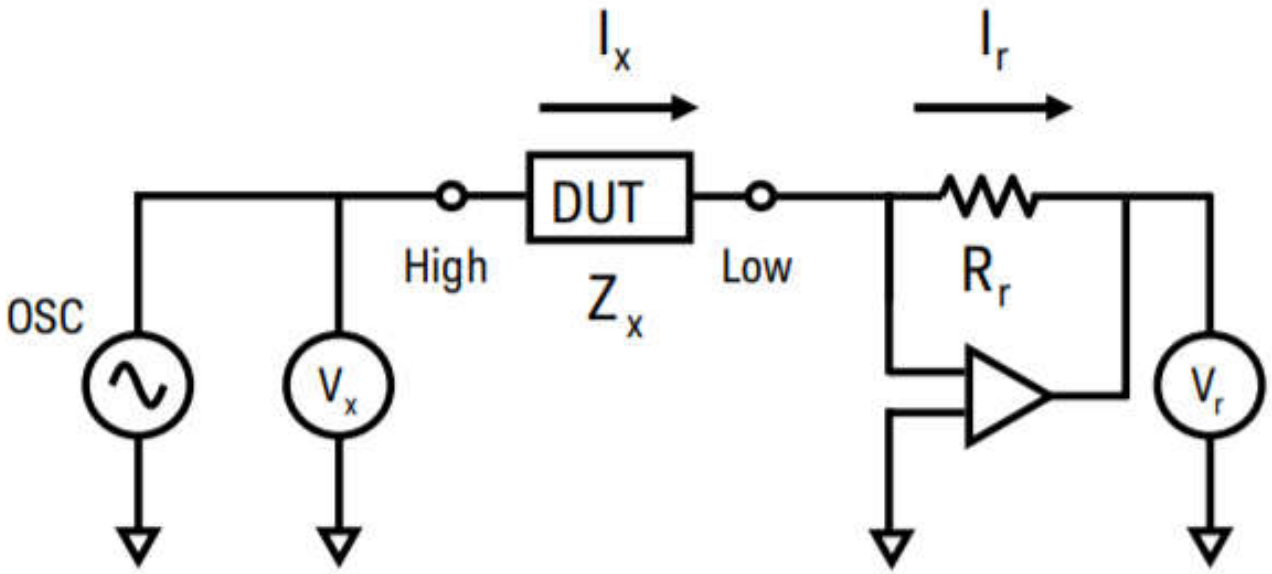
Transformer bridge for linking like impedances (R-R, C-C)

- - can be achieved uncertainty measurement < 1 x 10^{-7}



Auto-balancing bridge method

- Principle of the most RLC meters



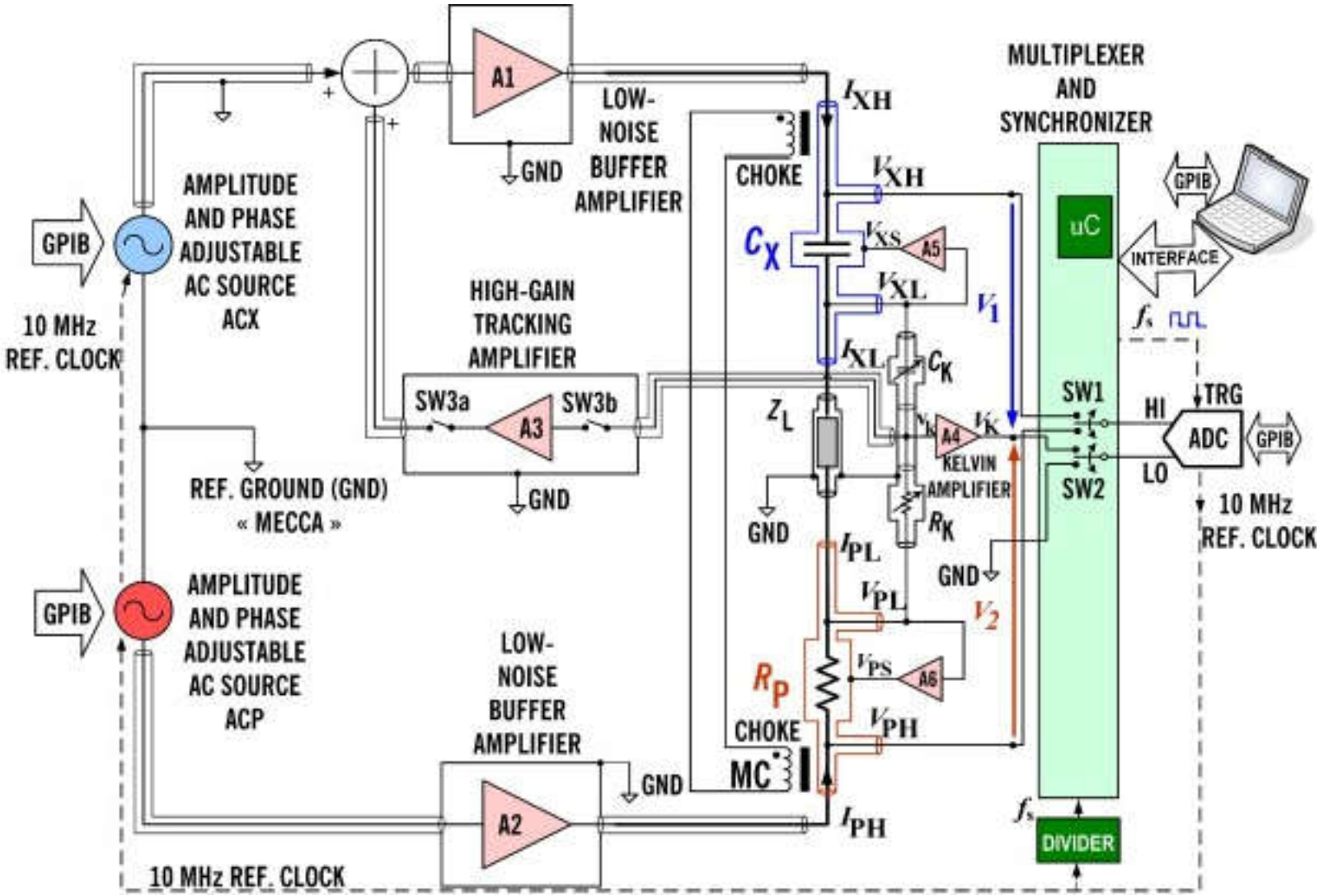
$$\frac{V_x}{Z_x} = I_x = I_r = \frac{V_r}{R_r}$$

$$\longrightarrow Z_x = \frac{V_x}{I_x} = R_r \frac{V_x}{V_r}$$

Taken form [2]

Digital sampling AC impedance ratio bridge (INMETRO)

- Uncertainty of measurement a few parts in 10^6

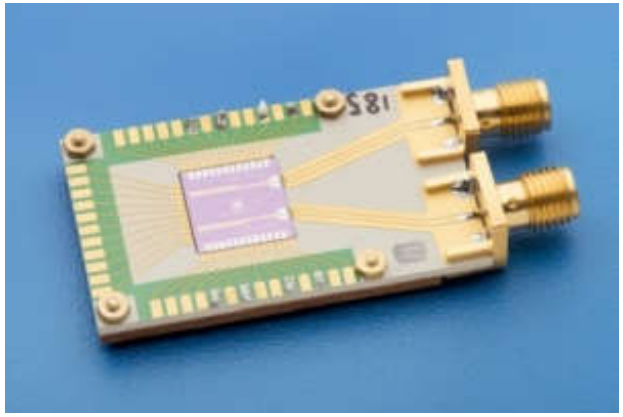


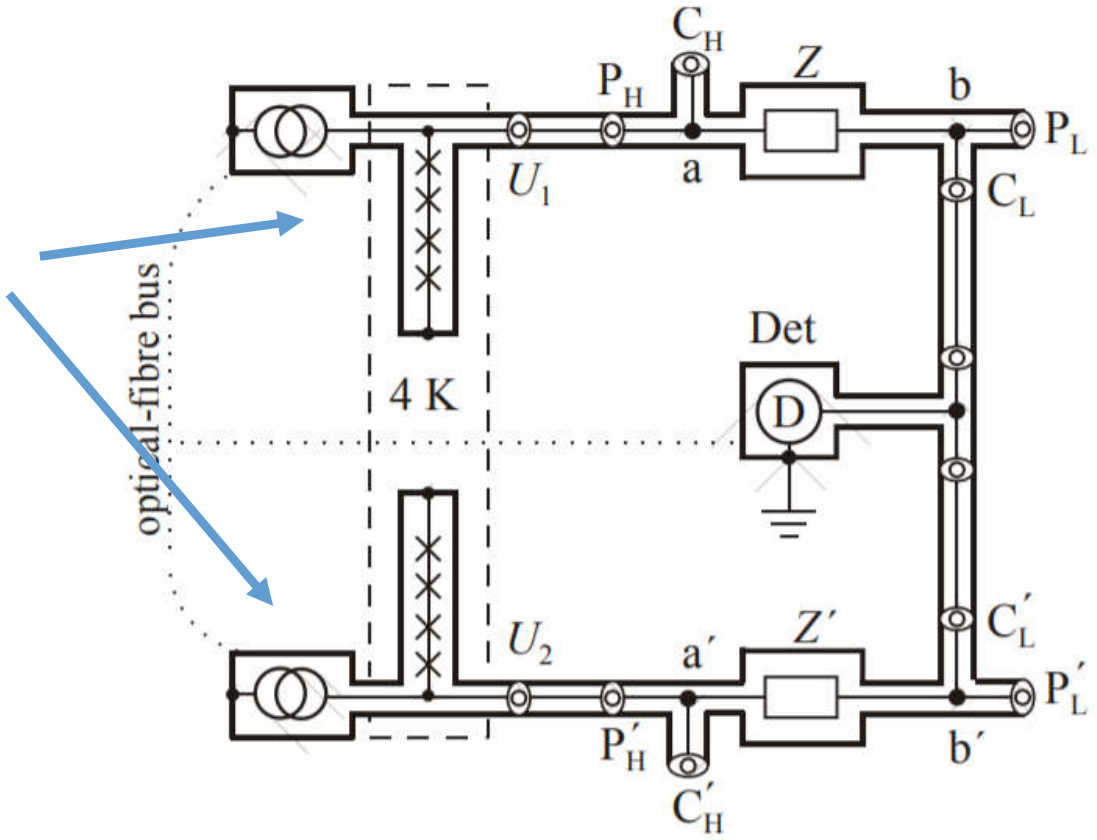
Taken form [3]

2TP Josephson impedance bridge (PTB)

- Accuracy of R-R comparison (2x10 kOhm) 2×10^{-8} @ f< 10 kHz
- Accuracy of C-C comparison (2x100 pF) 2×10^{-8} @ f< 10 kHz
- Accuracy of R-C comparison (12k9, 10 nF - quadrature bridge) 1.6×10^{-6} (K=1) @ f < 10 kHz

Josephson waveform synthesizers: typical voltage amplitude 10 V (70 000 JC)

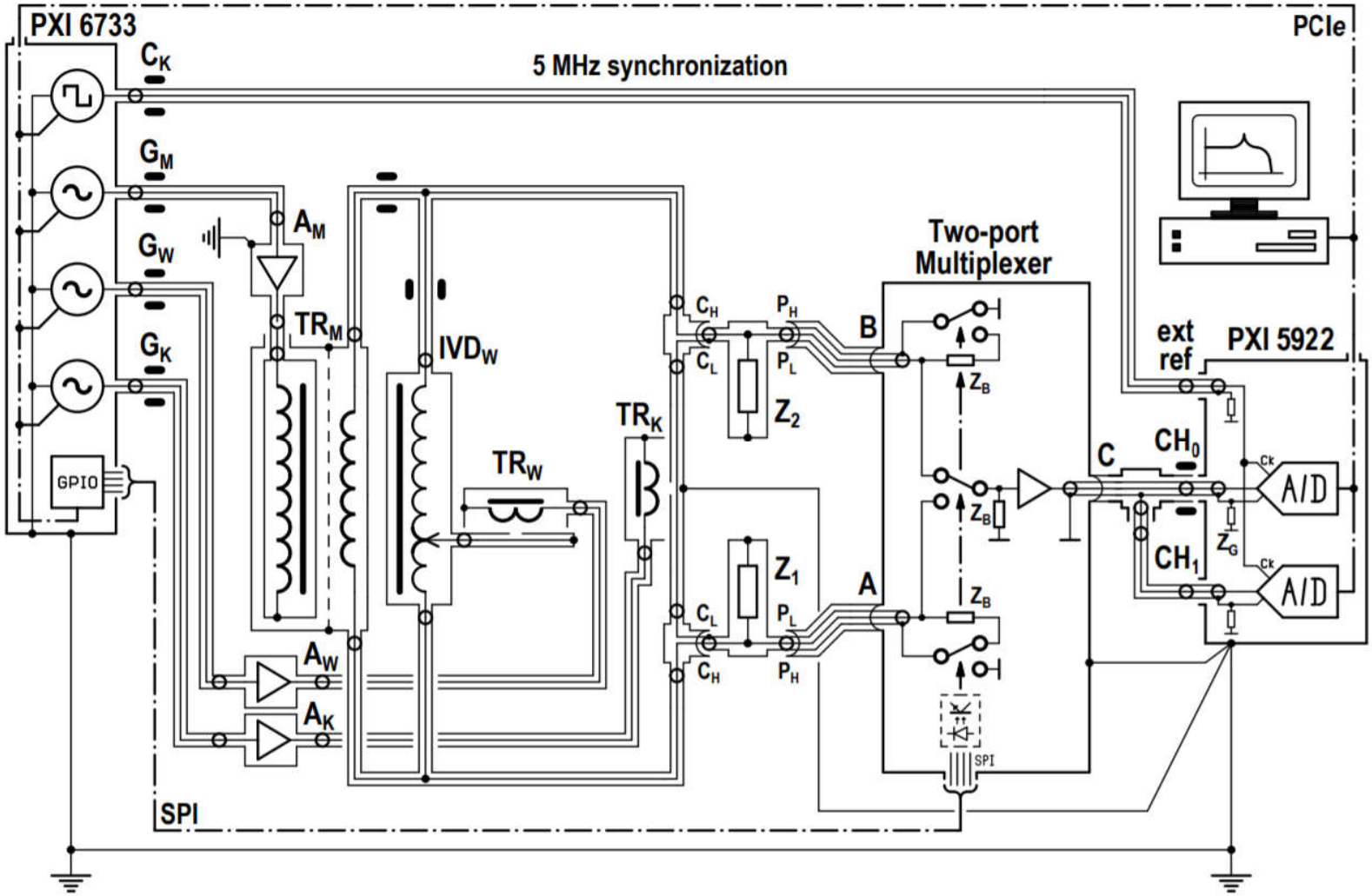




Taken from website of PTB and [4]

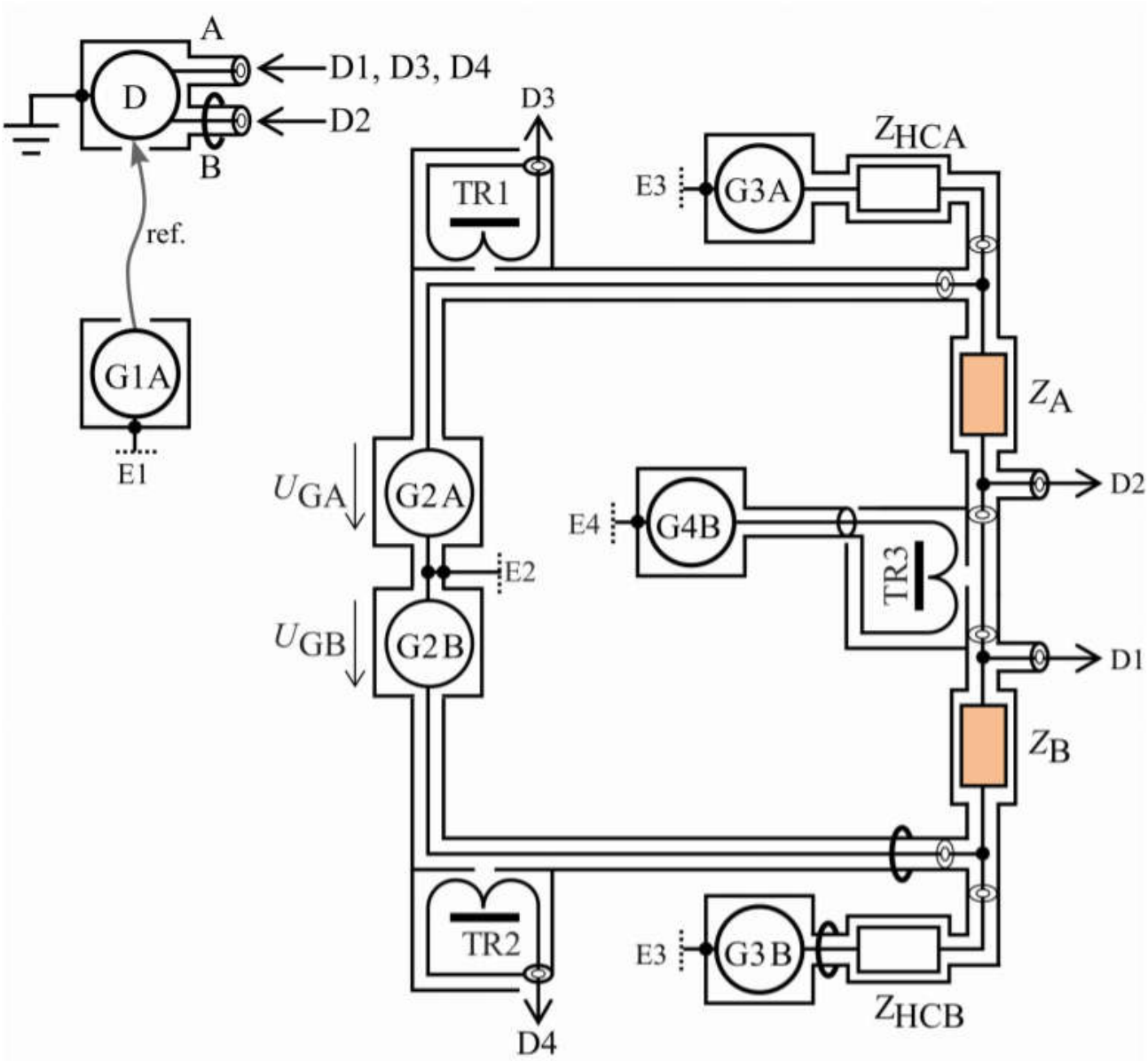
Digital sampling impedance ration bridge (CMI Brno)

- Frequency range up to 40 kHz
- Magnitude uncertainty in order of uV/V, phase uncertainty in order 1 μrad @ 1 kHz



Taken from [5]

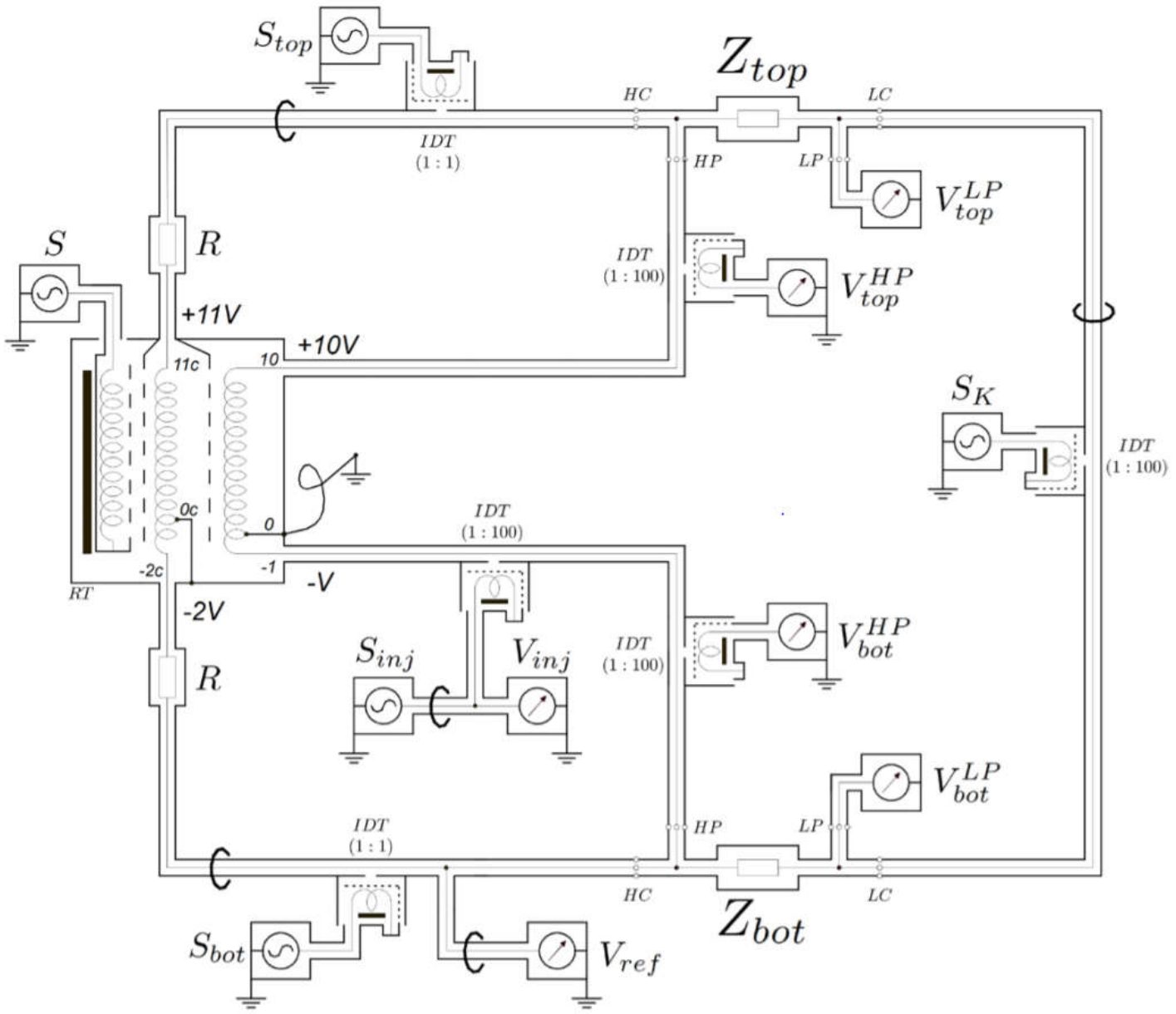
General scheme of fully digitally assisted impedance ration bridge



Taken from [6]

4TP digitally assisted impedance ration bridge (METAS)

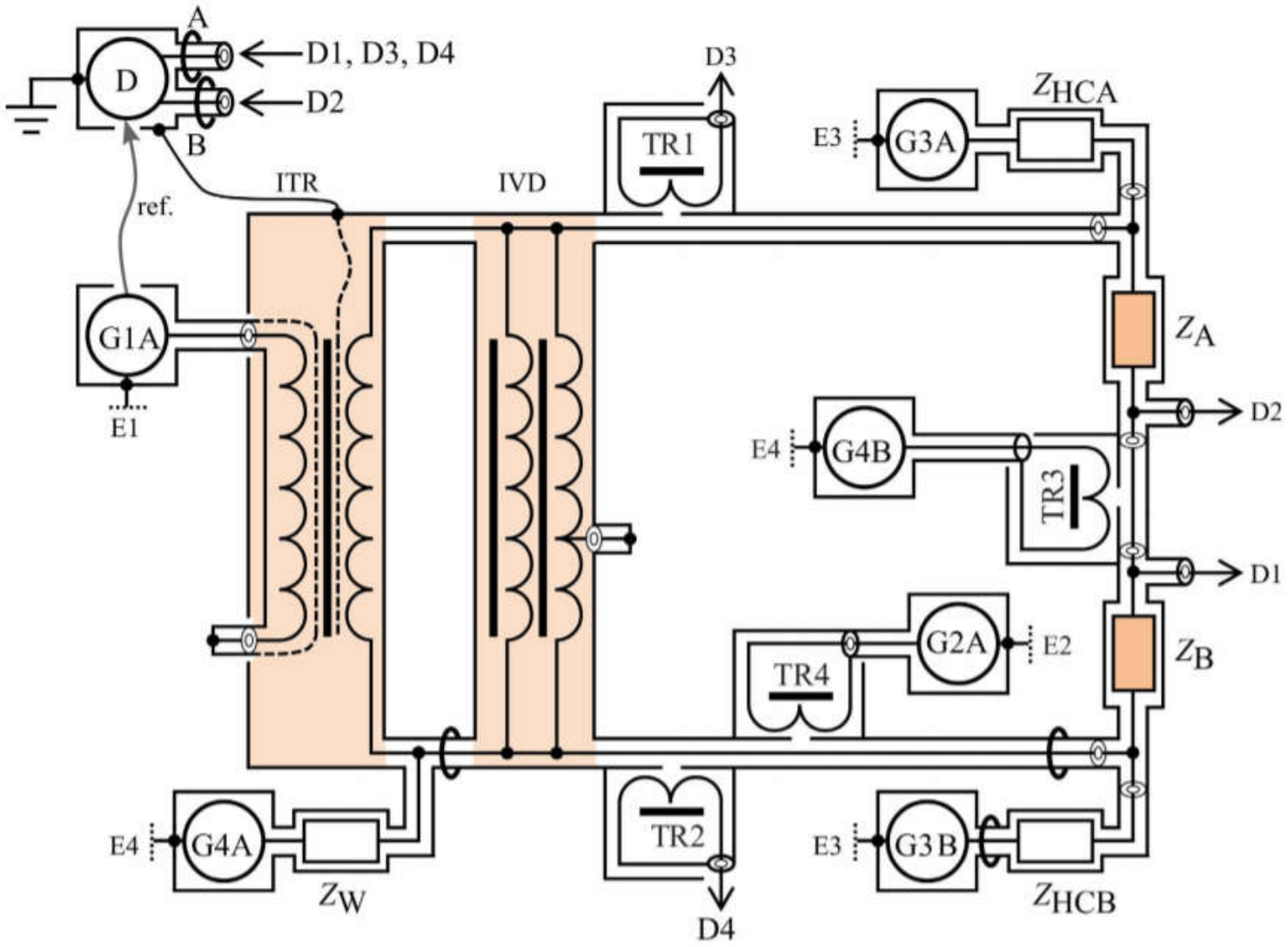
- Frequency range
  60 Hz up to 50 kHz
- Used 3x NI PXI 4461
  (2xDACx 2xADC,
  fsam max 204,8kSa/s)
- Uncertainty ration ~ 5 x 10^{-8} @ 5 kHz , 1 x 10^{-7} @ 20 kHz, 0.8 x 10^{-6} @ 50 kHz



Taken from [7]

4TP digitally assisted impedance ration bridge (CMI Prague)

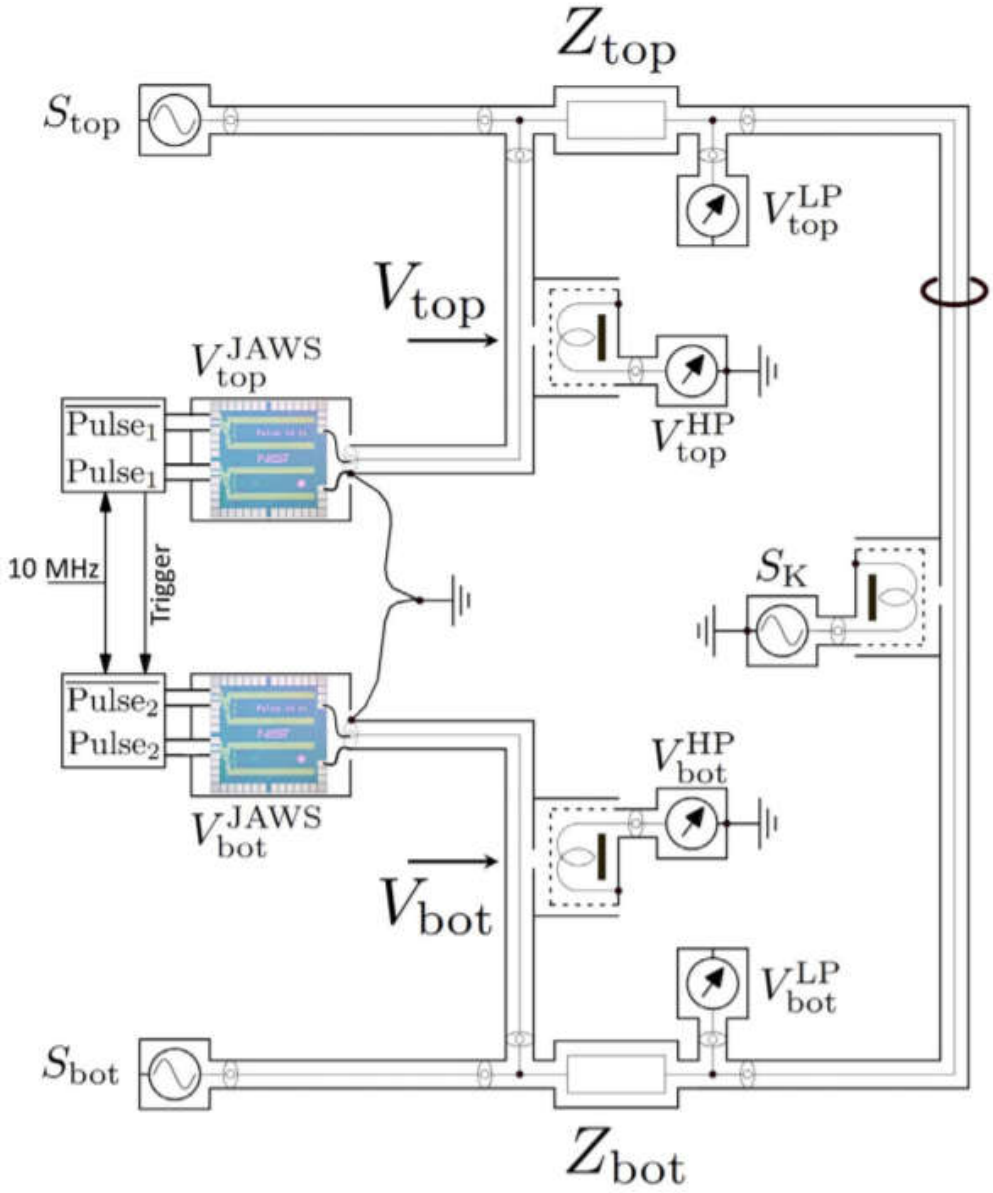
- Uncertainty ration measurement < a few parts in 10^{-8} @ 1 kHz



Taken from [6]

Dual Josephson impendence bridge (DJIB)(METAS)

- Similar accuracy in comparison with the best transformer bridges
- In the near future DJIB will be used for linking impedances after replacement JAWS form liquid helium to cryocooler

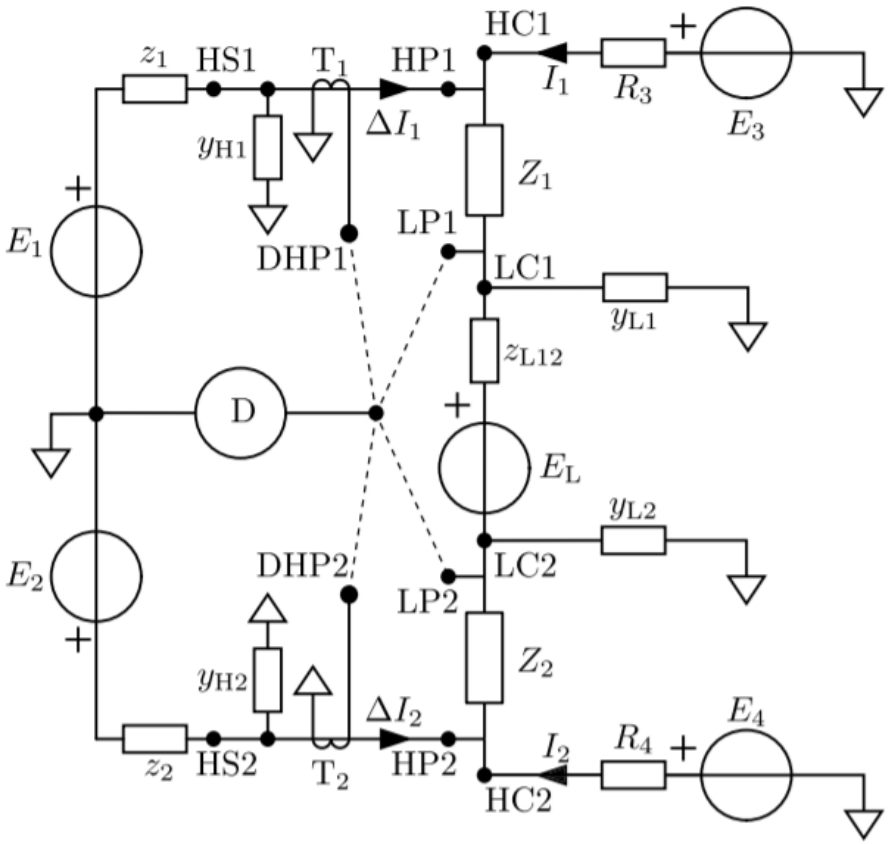


- Taken from [9]

Error analysis of fully digital (FD) impedance bridges

Errors in generating bridges

- Generator nonlinearity
- Generator crosstalk
- Generator loading (effect of y_{H1}, y_{H2})
- Low unbalance ($V_{LP1} \neq 0, V_{LP2} \neq 0$)
- High unbalance ($\Delta I_1 \neq 0, \Delta I_2 \neq 0$)



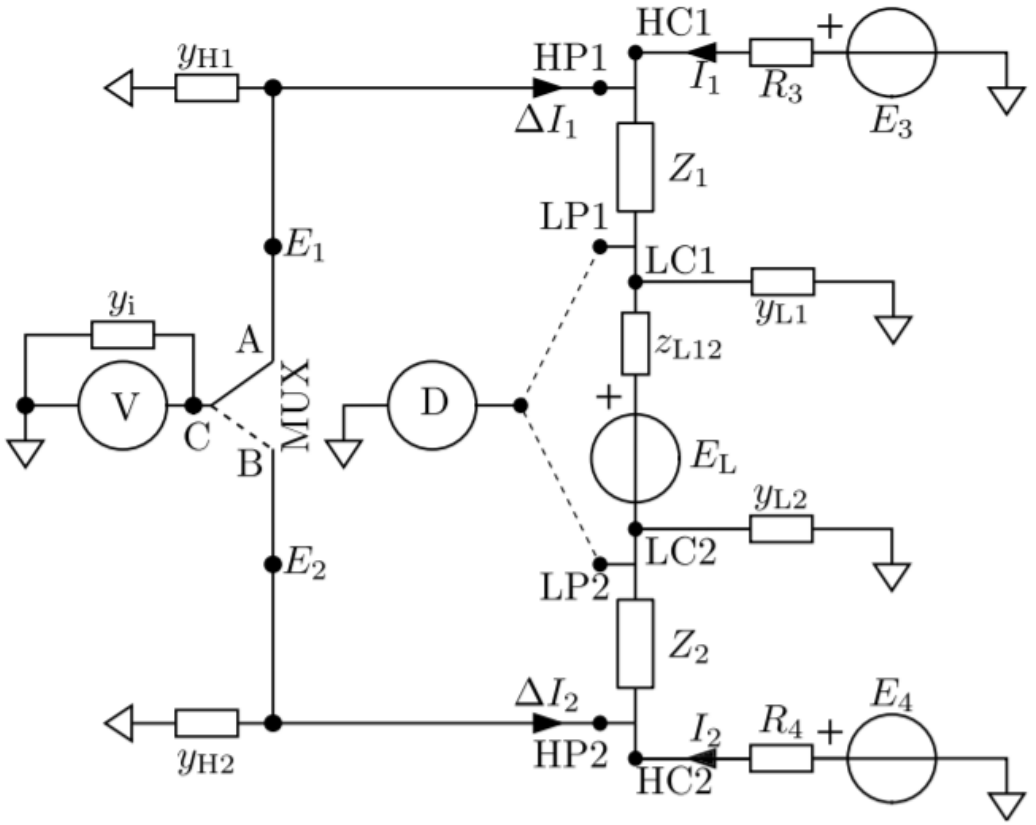
Taken from [10]

Error analysis of fully digital (FD) impedance

Errors in digitising bridges

- Digitizer nonlinearity
- Multiplex switching
- Low unbalanced

High precision, high accuracy digitizer (e.i. Keysight 3458)



Taken from [10]

Thank you

For Your Attention and Time

Resources & references

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