Structured Electronic Design

Accurate amplification

Right choice

Orthogonalization

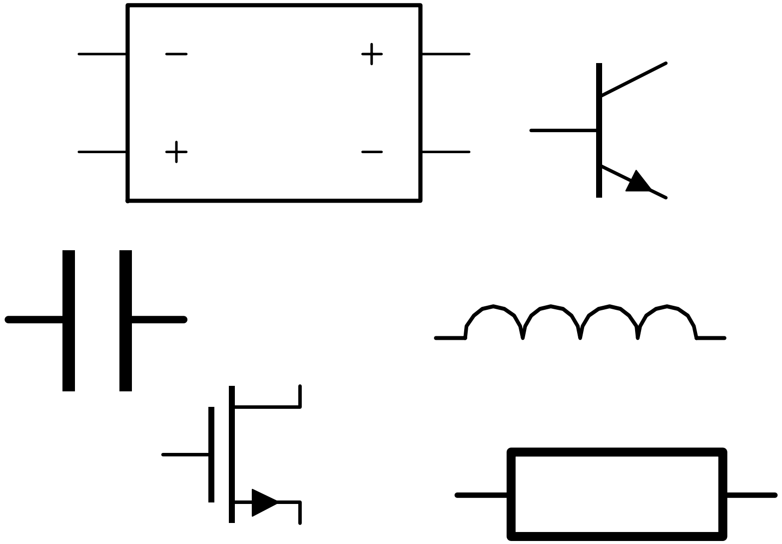
Optimization

The criteria

- Clear definition of the function
- *The* criteria

$$C = B\ {}^{2}\log\frac{S+N}{N}$$

Design procedure?



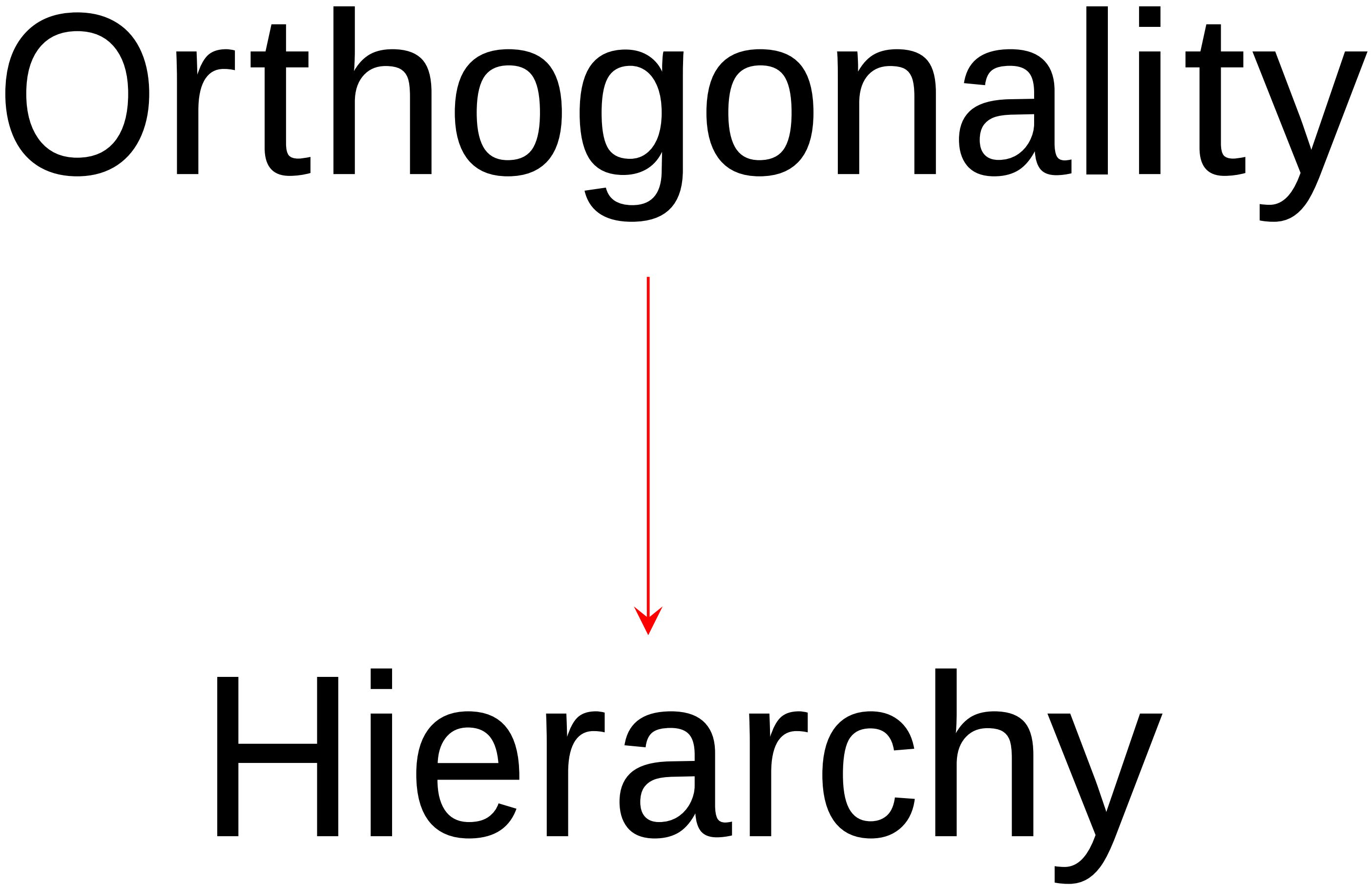
bandwidth – noise – distortion
bandwidth – distortion - noise
noise - bandwidth – distortion
noise – distortion - bandwidth
distortion - noise – bandwidth
distortion – bandwidth - noise

Specs

Design?

verification

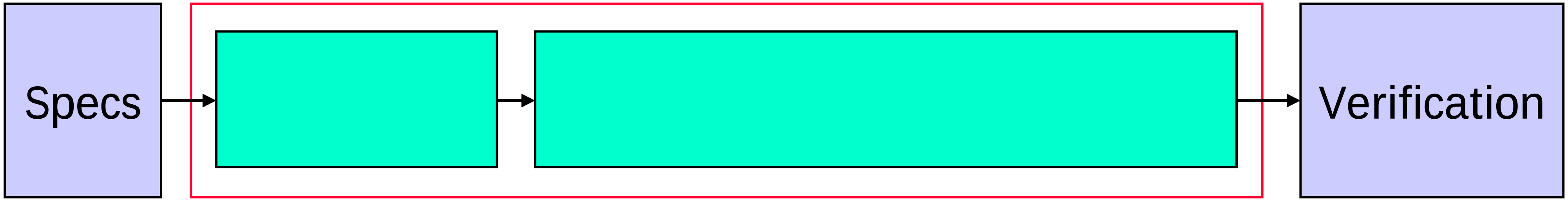
Structured design method



Orthogonality

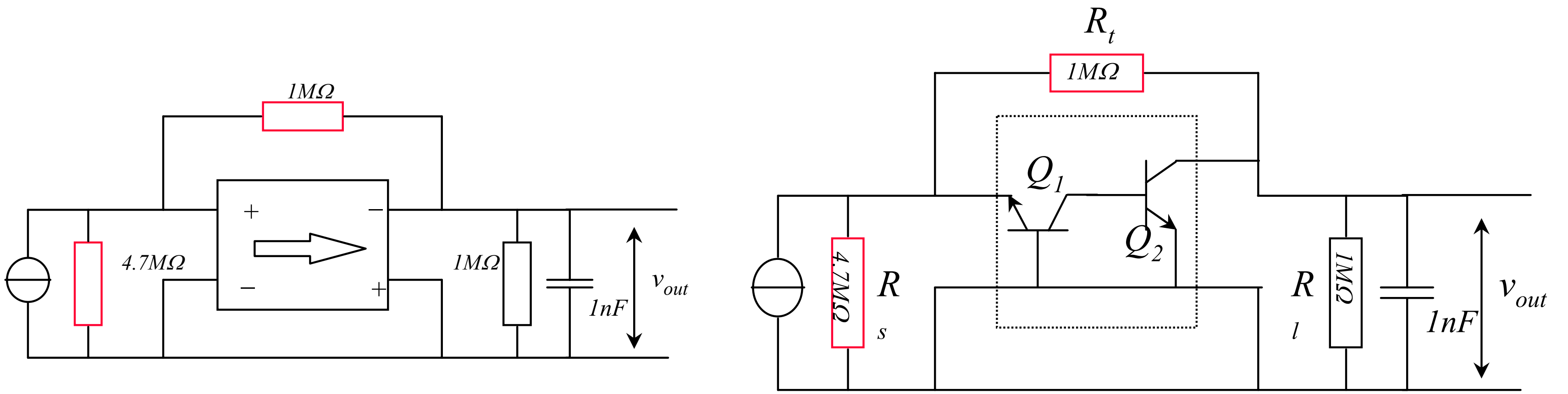
Hierarchy

Hierarchy



Specs

Verification

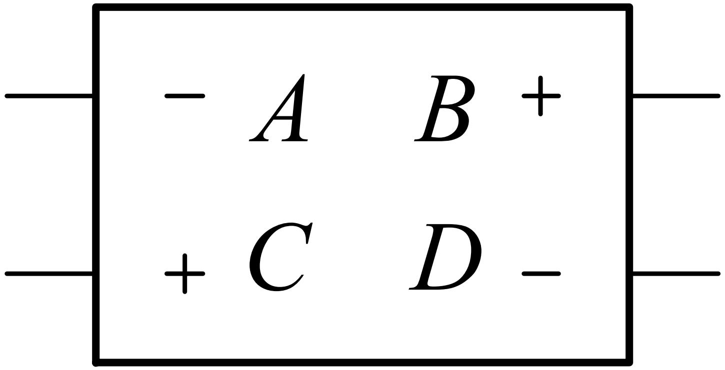


What is an amplifier?

Accurate amplification

Information from source to load

- Signal power is enlarged
- Information stays unaltered



A,B,C,D indicate gain

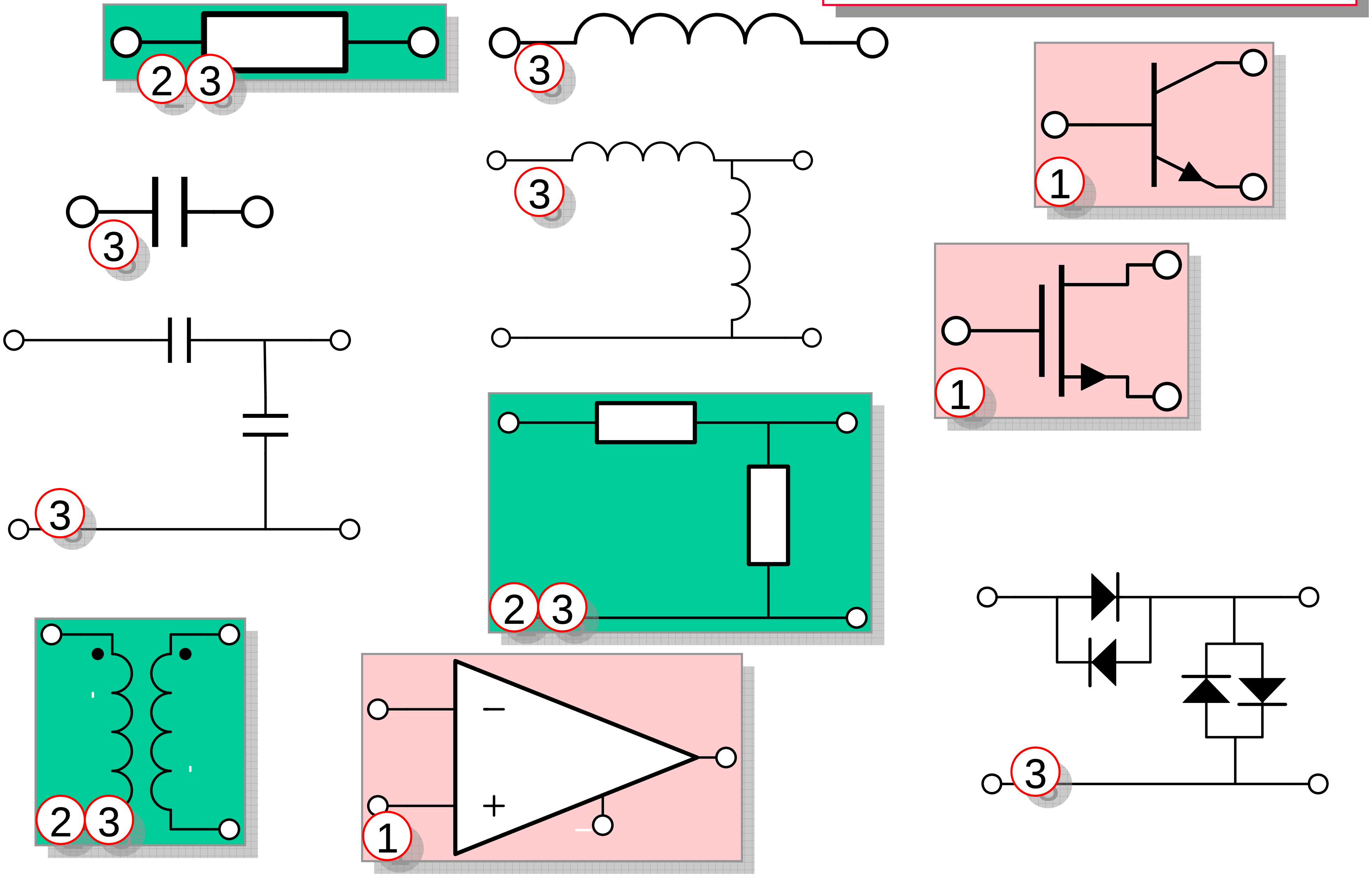
A,B,C,D constant

A,B,C,D accurately known

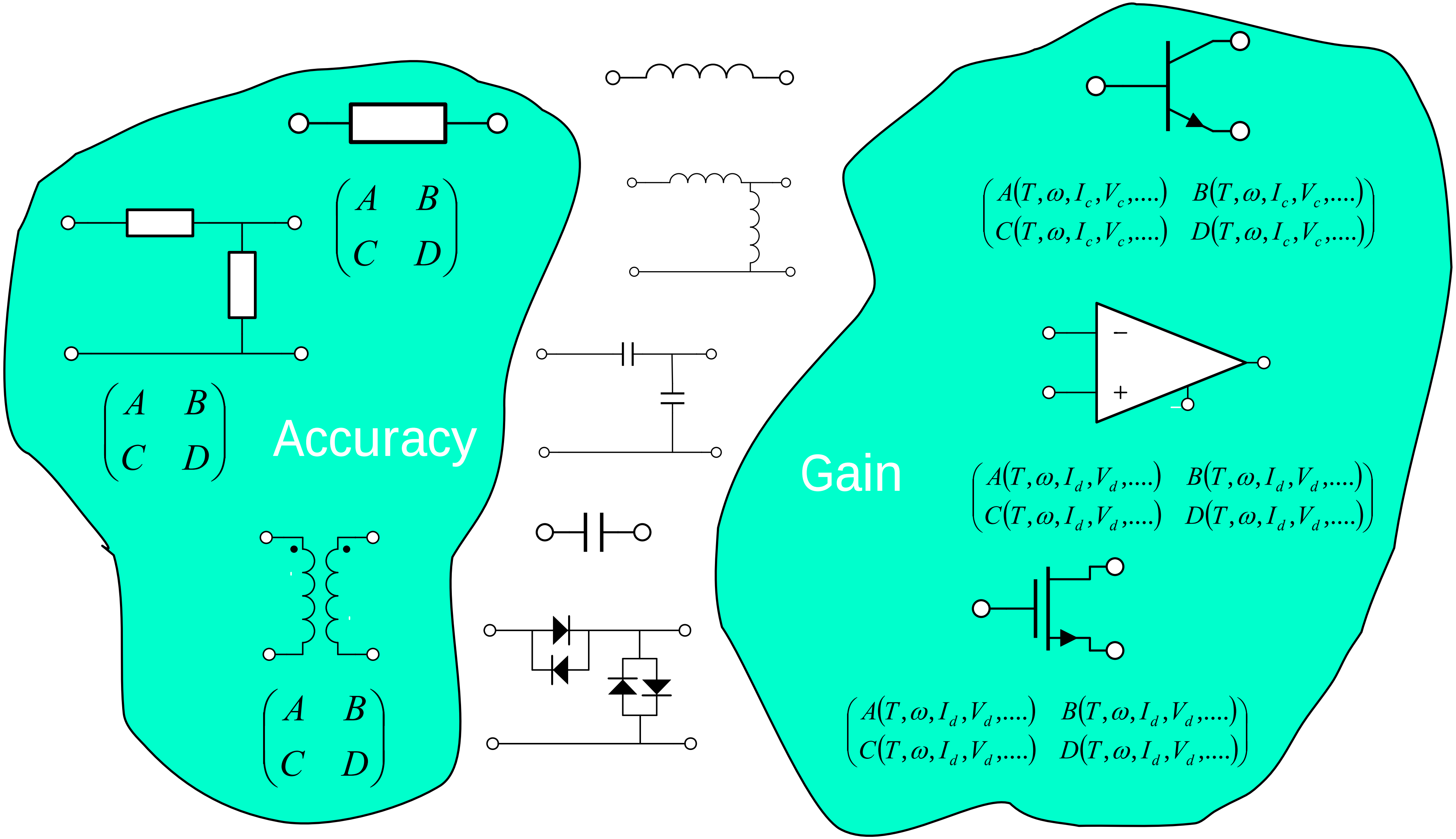
$$\begin{pmatrix} v_{in} \\ i_{in} \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} v_{out} \\ i_{out} \end{pmatrix}$$

Classificatio

1. *A,B,C,D* indicate gain
2. *A,B,C,D* constant
3. *A,B,C,D* accurately known



Classification of available components



$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}$$

$$\begin{pmatrix} A(T,\omega,I_c,V_c,....) & B(T,\omega,I_c,V_c,....) \\ C(T,\omega,I_c,V_c,....) & D(T,\omega,I_c,V_c,....) \end{pmatrix}$$

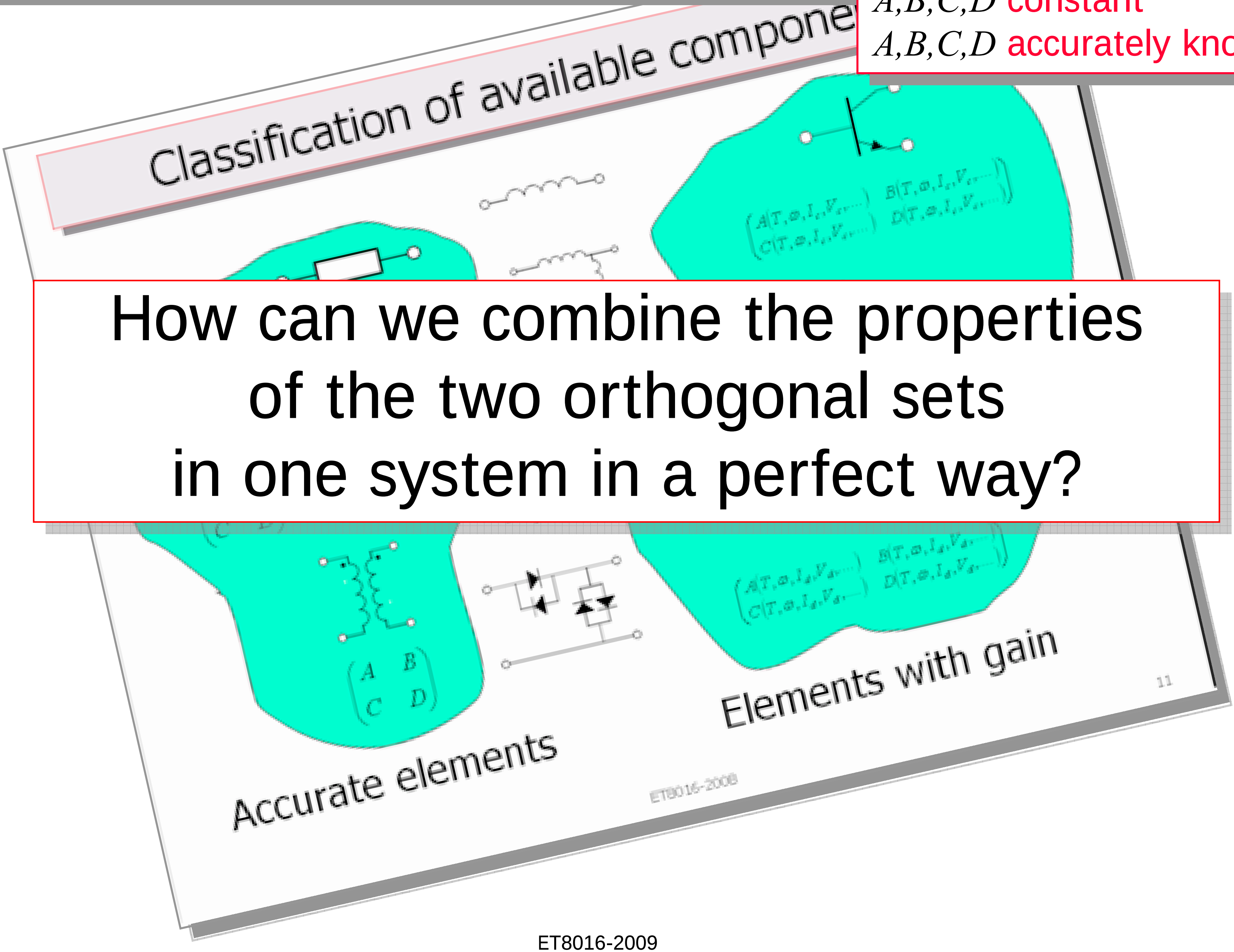
$$\begin{pmatrix} A(T,\omega,I_d,V_d,....) & B(T,\omega,I_d,V_d,....) \\ C(T,\omega,I_d,V_d,....) & D(T,\omega,I_d,V_d,....) \end{pmatrix}$$

Accurate elements

Elements with gain

The big question.

A,B,C,D indicate gain
A,B,C,D constant
A,B,C,D accurately known



Classification of available compone

$\begin{pmatrix}A(T,\omega,I_c,V_{ce},\ldots) & B(T,\omega,I_c,V_{ce},\ldots)\\ C(T,\omega,I_c,V_{ce},\ldots) & D(T,\omega,I_c,V_{ce},\ldots)\end{pmatrix}$

$\begin{pmatrix}A & B\\ C & D\end{pmatrix}$

$\begin{pmatrix}A(T,\omega,I_d,V_{ds},\ldots) & B(T,\omega,I_d,V_{ds},\ldots)\\ C(T,\omega,I_d,V_{ds},\ldots) & D(T,\omega,I_d,V_{ds},\ldots)\end{pmatrix}$

Accurate elements

Elements with gain

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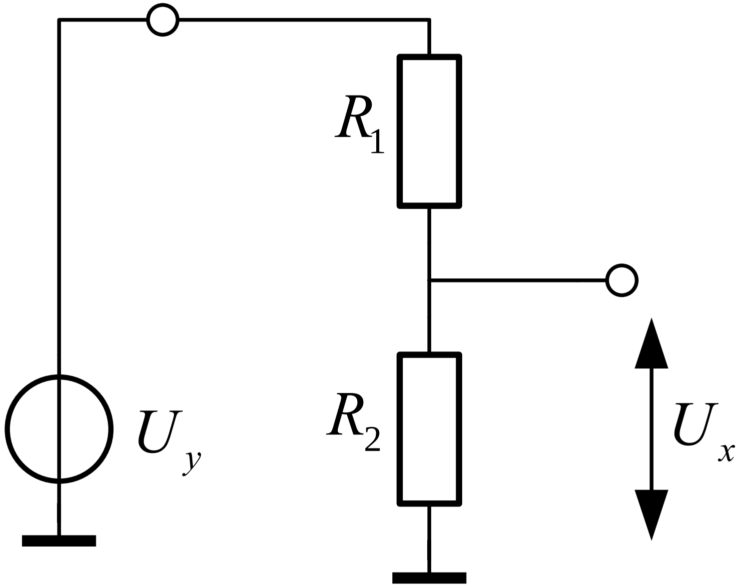
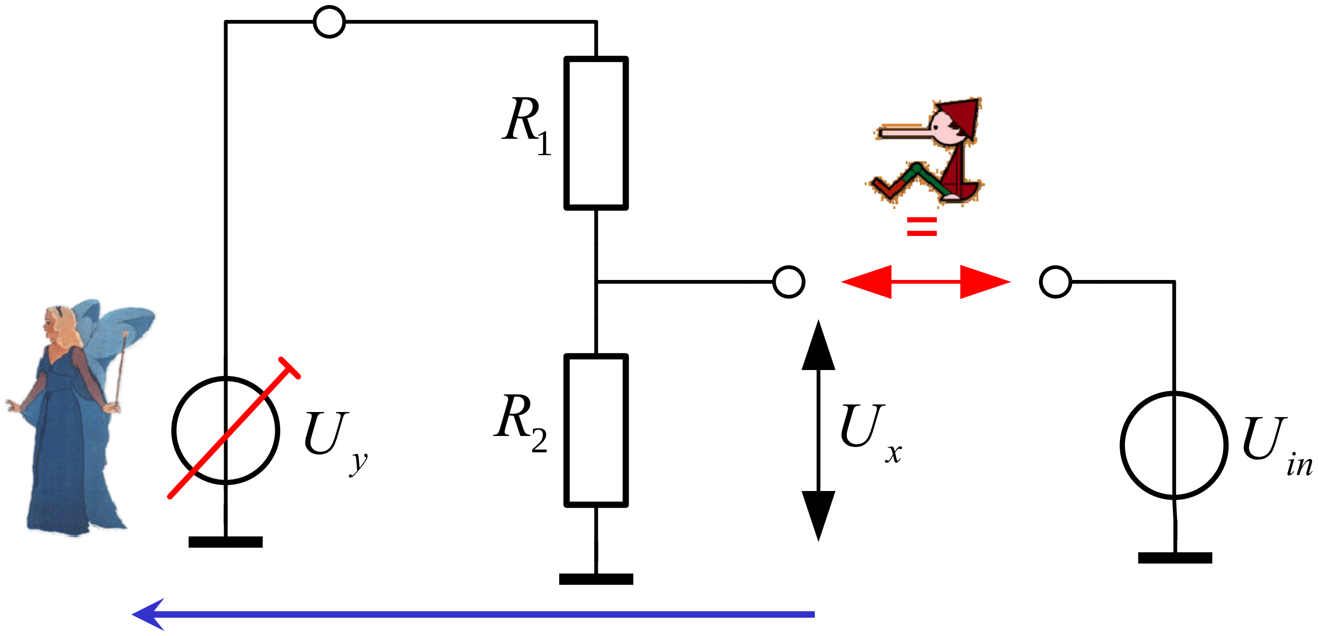
How can we combine the properties
of the two orthogonal sets
in one system in a perfect way?



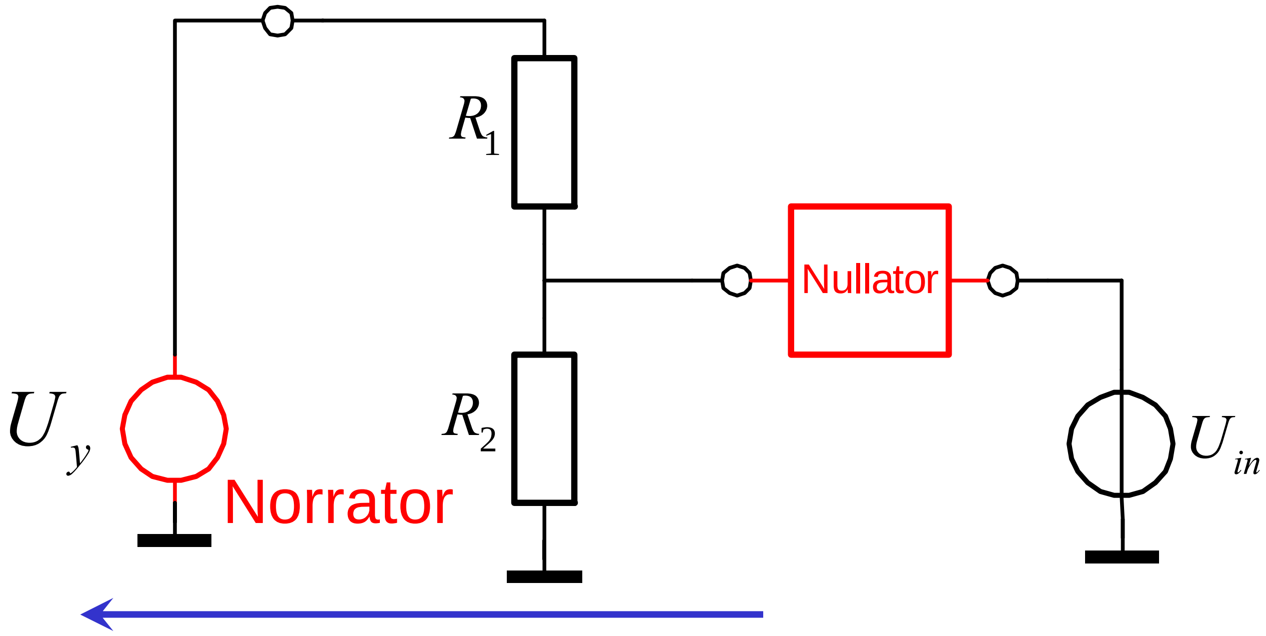
Accurate reduction

$$U_x = \frac{R_2}{R_1 + R_2} U_y$$



Accurate amplification

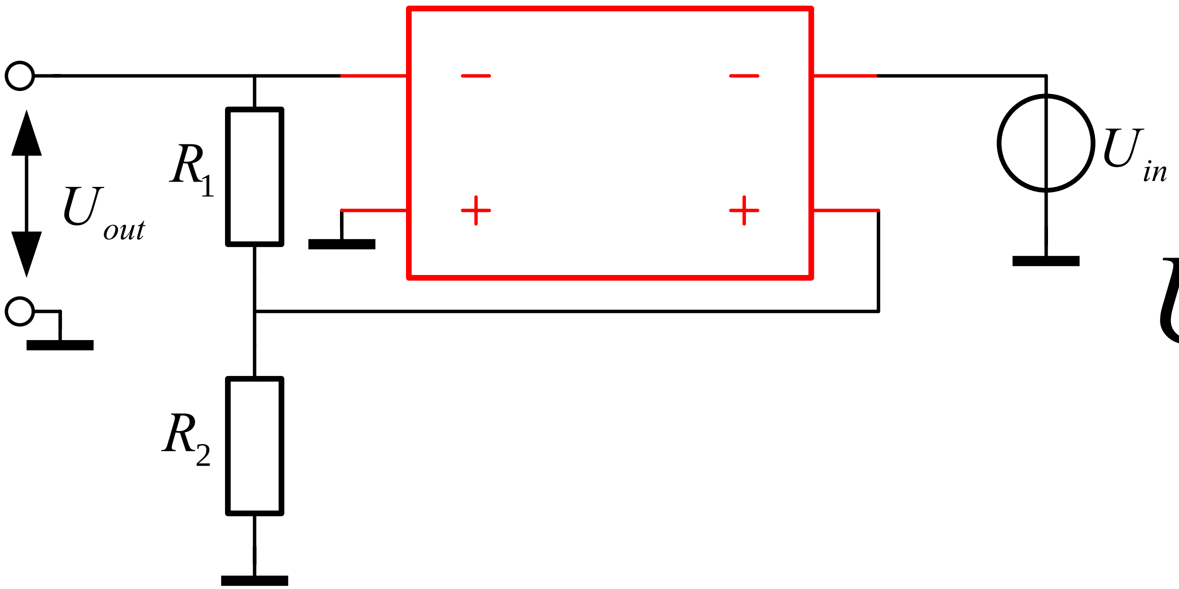
$$U_x = \frac{R_2}{R_1 + R_2} U_y$$



Accurate amplification

$$U_y = \frac{R_1 + R_2}{R_2} U_{in}$$

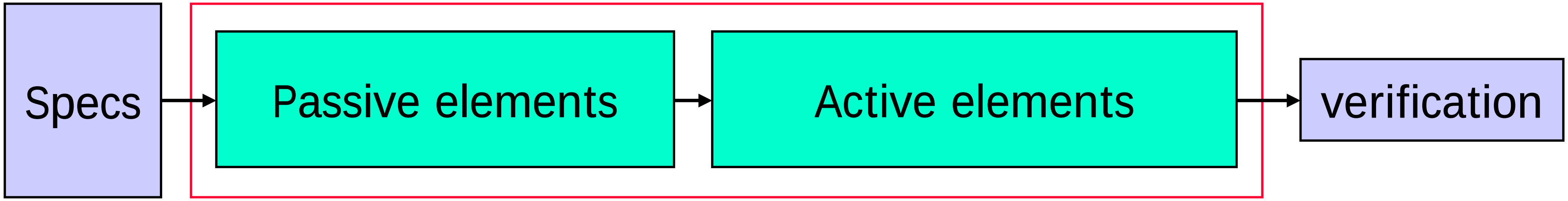
Negative feedback



$$U_{out} = \frac{R_1 + R_2}{R_2} U_{in}$$

- Nullor + *passive* components ⇒ accurate amplifier
- The ***perfect*** method
- Nullor = simplest model for active circuit

Hierarchy



- Accurate reduction
- ONLY passive elements

- Gain
- ONLY active elements

Only!!

Amplifier design in **two orthogonal steps**

1) design of feedback network with nullor in the loop

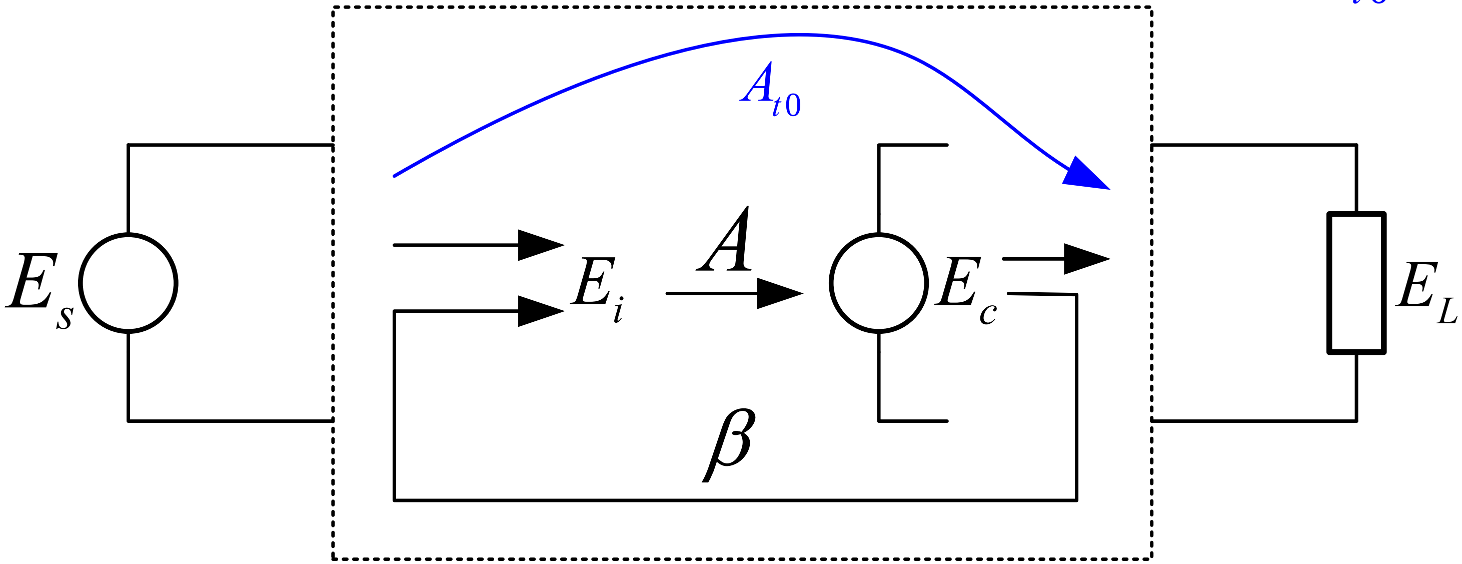
Nullor: absolute design freedom

- No noise
- No distortion
- No bandwidth limitations

2) design of the active circuit

The general negative feedback system

A_{t0}: The direct transfer



$$E_L = A_{t0}E_s + E_c$$

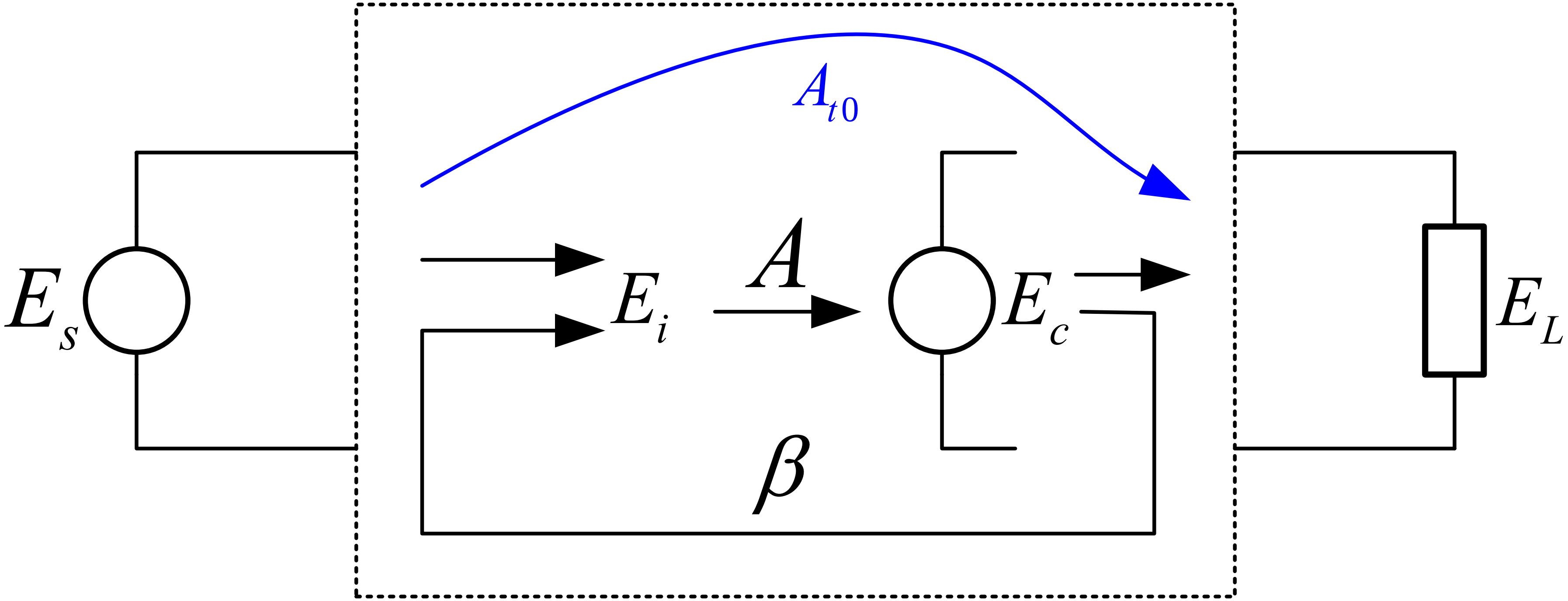
$$E_i = E_s + \beta E_c$$

$$E_c = AE_i$$

$$A_{t0} = \left.\frac{E_L}{E_s}\right|_{E_c=0}$$

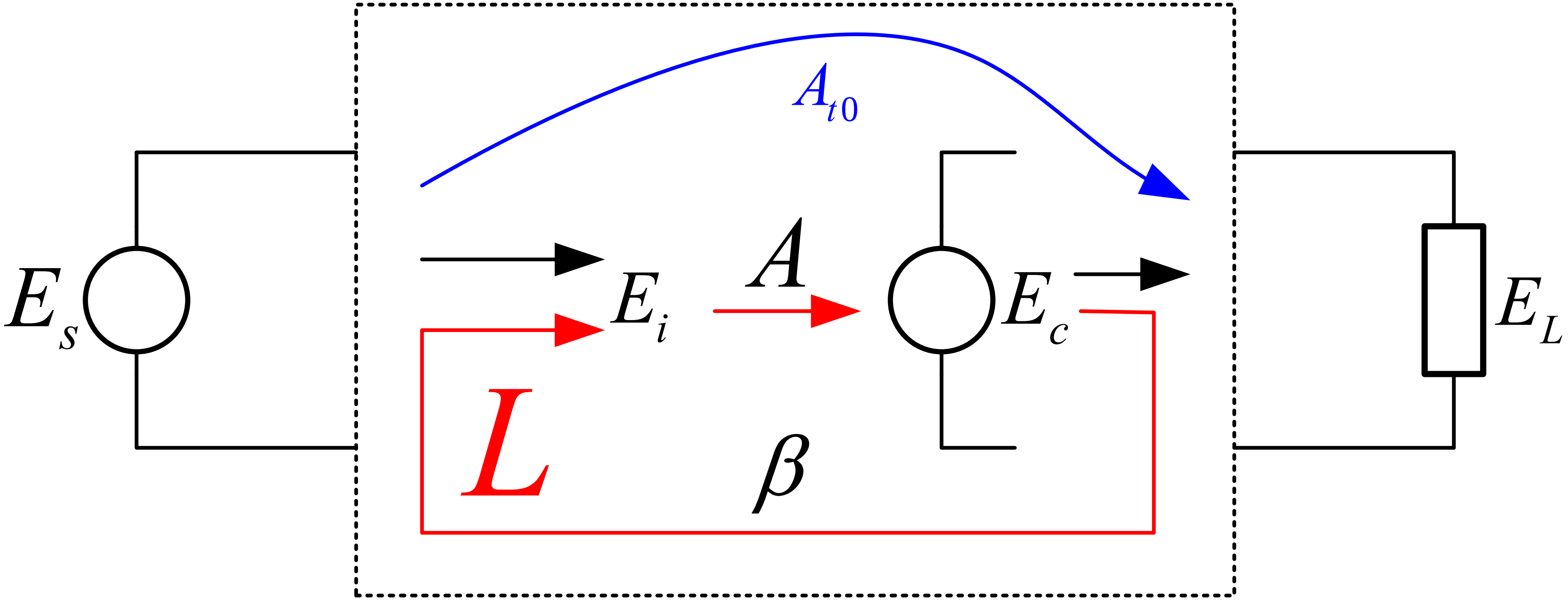
$$\beta = \left.\frac{E_i}{E_c}\right|_{E_s=0}$$

The overall gain A_t



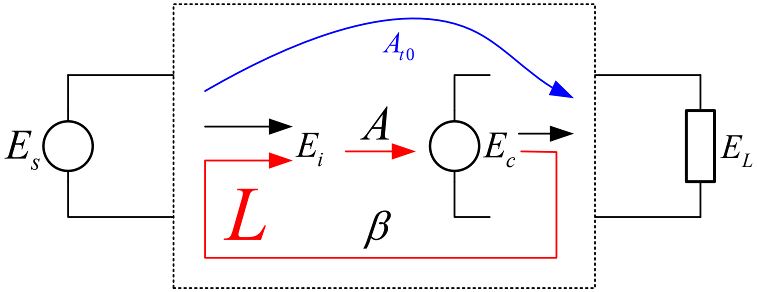
$$A_t = \frac{E_L}{E_s} = A_{t0} + \frac{1}{\beta}\left(\frac{A\beta}{1-A\beta}\right)$$

The loopgain L



$$A_t = \frac{E_L}{E_s} = A_{t0} + \frac{1}{\beta}\left(\frac{L}{1-L}\right)$$

The asymptotic gain $A_{t\infty}$

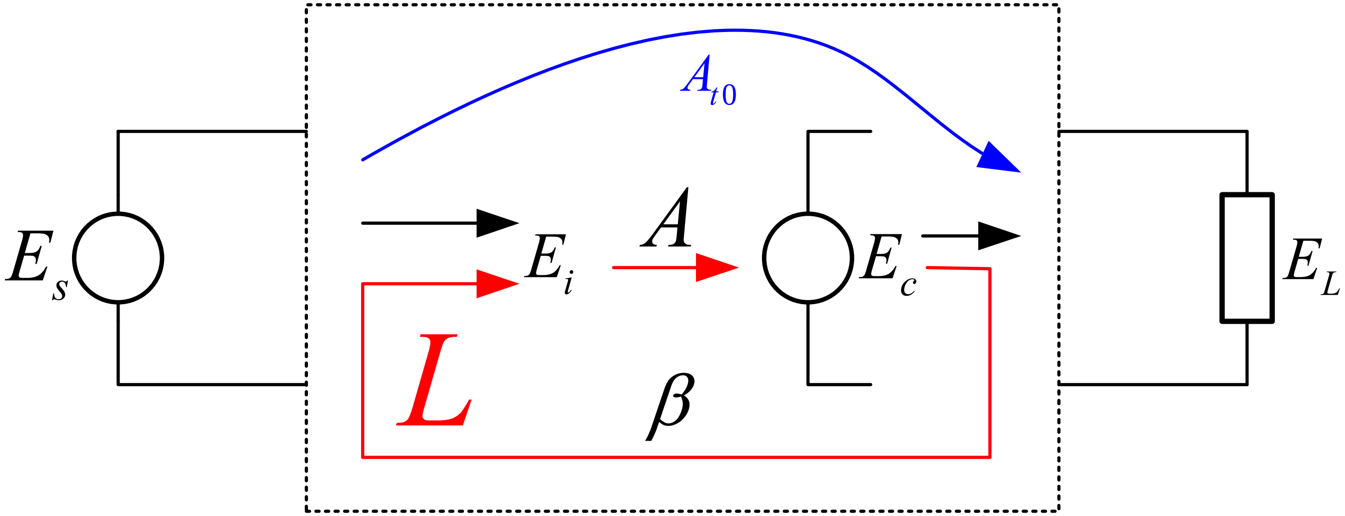


$$A_t = \frac{E_L}{E_s} = A_{t0} + \frac{1}{\beta}\left(\frac{L}{1-L}\right)$$

$$\lim_{L\to\infty} A_t = A_{t0} - \frac{1}{\beta} = A_{t\infty}$$

The asymptotic gain model

$$A_{t\infty} = A_{t0} - \frac{1}{\beta}$$



$$A_t = \cancel{\frac{A_{t0}}{1-L}} + A_{t\infty}\frac{-L}{1-L}$$

$A_{t0} - \frac{1}{\beta}$ (!)

Hierarchy, Orthogonality

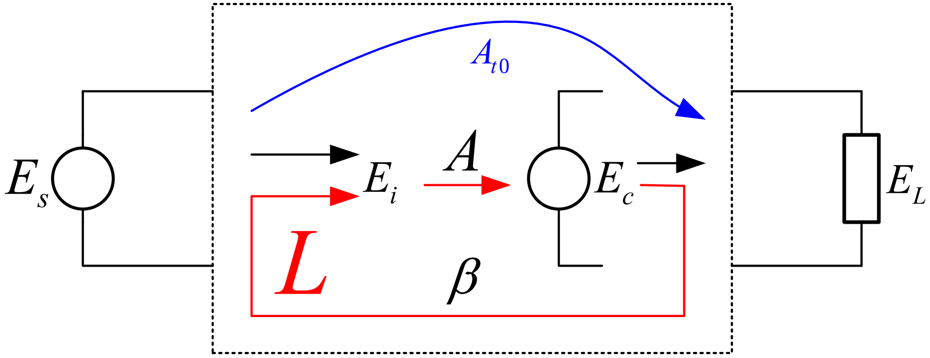
$$A_t = A_{t\infty}\frac{-L}{1-L}$$

1

Passive elements

Ac nts

Nullor



$$A_{t\infty} = A_{t0} - \frac{1}{\beta}$$

$$A_t = A_{t\infty}\frac{-L}{1-L}$$

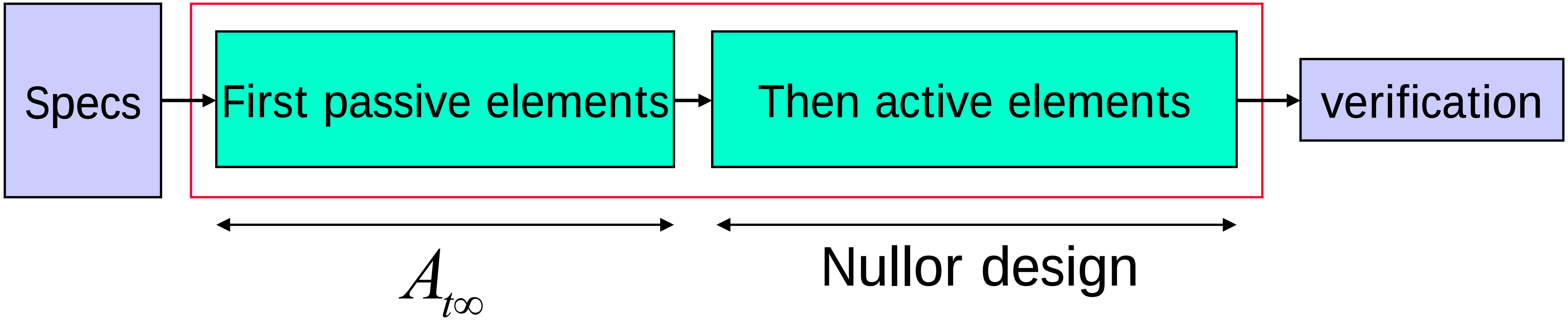
Amplifier design in two steps

1) design of $A_{t\infty}$ with nullor in the loop

Nullor: absolute design freedom
- No noise
- No distortion
- No bandwidth limitations

2) design of the nullor *approximation*

Hierarchical design



Specs

First passive elements

Then active elements

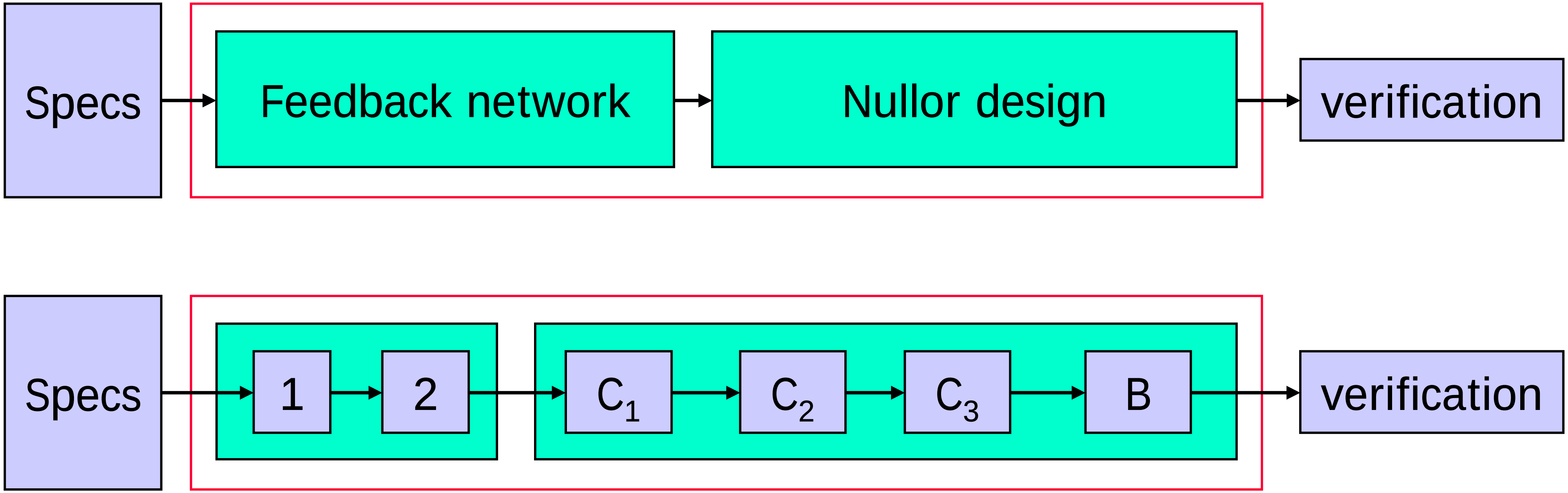
verification

$A_{t\infty}$

Nullor design

$$A_t = \boxed{A_{t\infty}}\boxed{\frac{-L}{1-L}}$$

More detailed hierarchy..



Specs → Feedback network → Nullor design → verification

Specs → 1 → 2 → C_1 → C_2 → C_3 → B → verification

$$C = B\ {}^{2}\log\frac{S+N}{N}$$

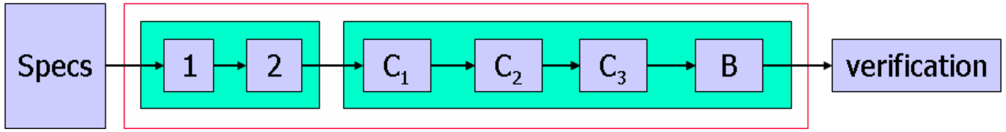
bandwidth – noise – distortion
bandwidth – distortion - noise
noise - bandwidth – distortion
noise – distortion - bandwidth
distortion - noise – bandwidth
distortion – bandwidth - noise

Step 1

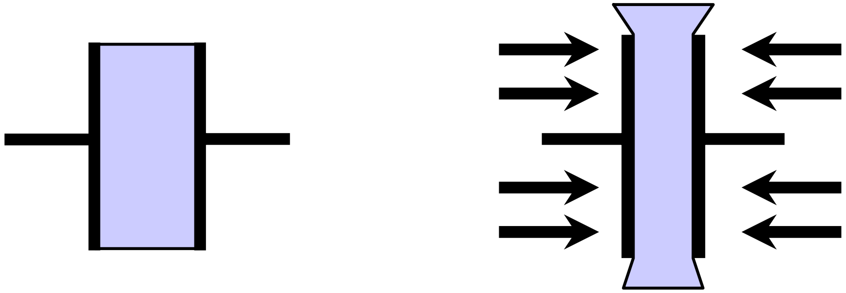
Determination amplifier type:

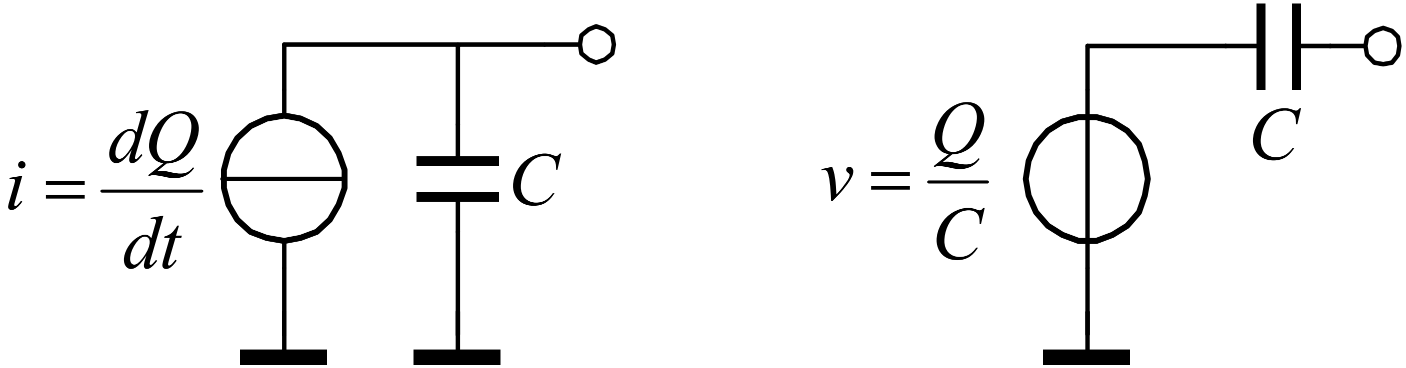
- Specification input and output quantities
- Specification of the transfer

What may have influence and what not?



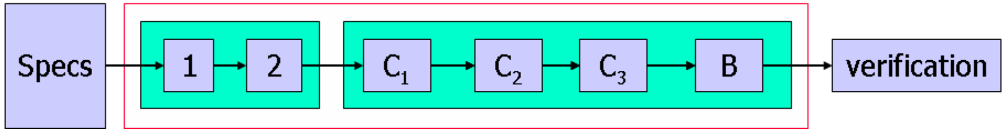
Specification input and output quantities





$$i = \frac{dQ}{dt}$$

$$v = \frac{Q}{C}$$



Specs → 1 → 2 → C_1 → C_2 → C_3 → B → verification

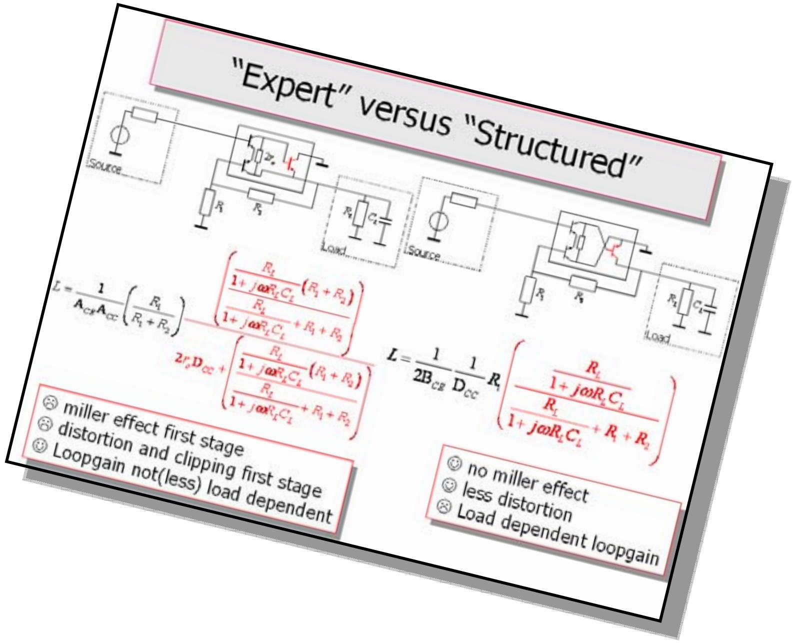
Specification of the transfer

V → V
A

V → I
B

I → V
C

I → I
D



"Expert" versus "Structured"

$$L=\frac{1}{\mathbf{A}_{CE}\mathbf{A}_{CC}}\left(\frac{R_1}{R_1+R_2}\right)\frac{\left(\dfrac{\dfrac{R_L}{1+j\omega R_L C_L}(R_1+R_2)}{\dfrac{R_L}{1+j\omega R_L C_L}+R_1+R_2}\right)}{2r_e\mathbf{D}_{CC}+\left(\dfrac{\dfrac{R_L}{1+j\omega R_L C_L}(R_1+R_2)}{\dfrac{R_L}{1+j\omega R_L C_L}+R_1+R_2}\right)}$$

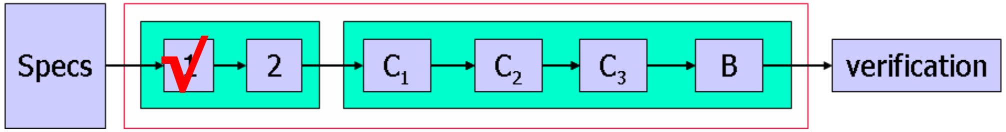
$$L=\frac{1}{2\mathbf{B}_{CE}}\frac{1}{\mathbf{D}_{CC}}R_1\left(\frac{\dfrac{R_L}{1+j\omega R_L C_L}}{\dfrac{R_L}{1+j\omega R_L C_L}+R_1+R_2}\right)$$

- ☹ miller effect first stage
- ☹ distortion and clipping first stage
- ☺ Loopgain not(less) load dependent

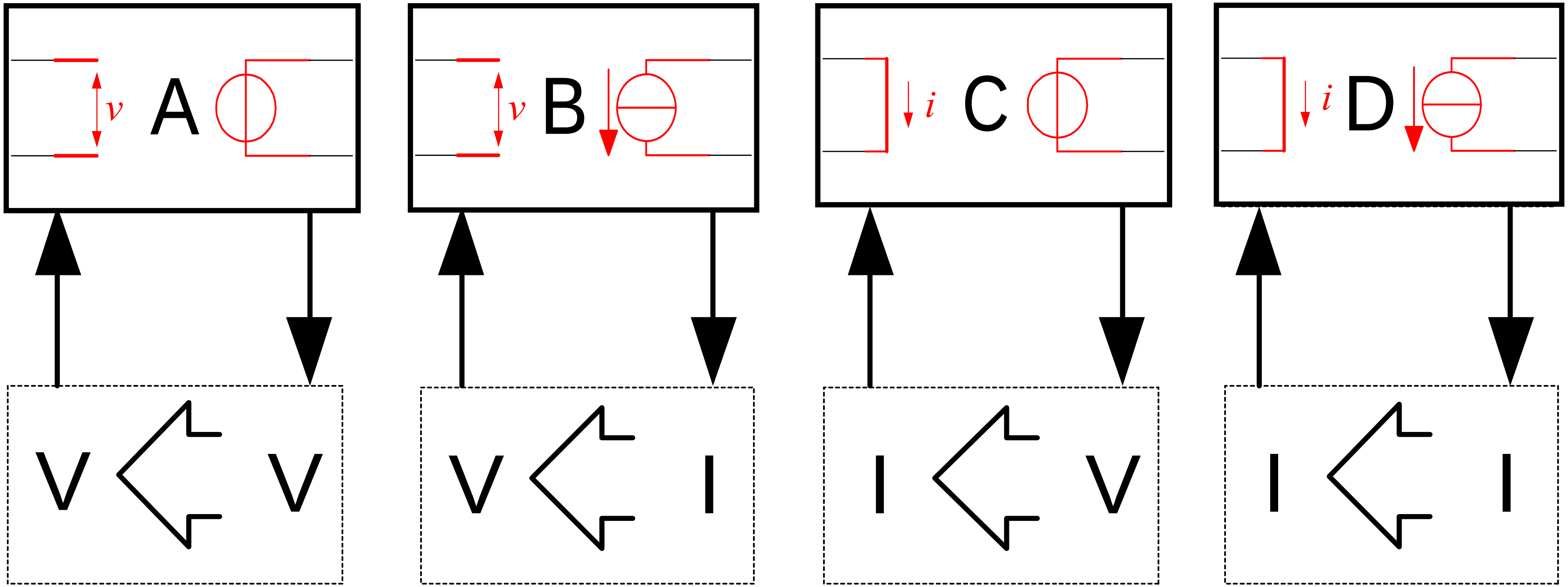
- ☺ no miller effect
- ☺ less distortion
- ☹ Load dependent loopgain

Step 1: the right choice

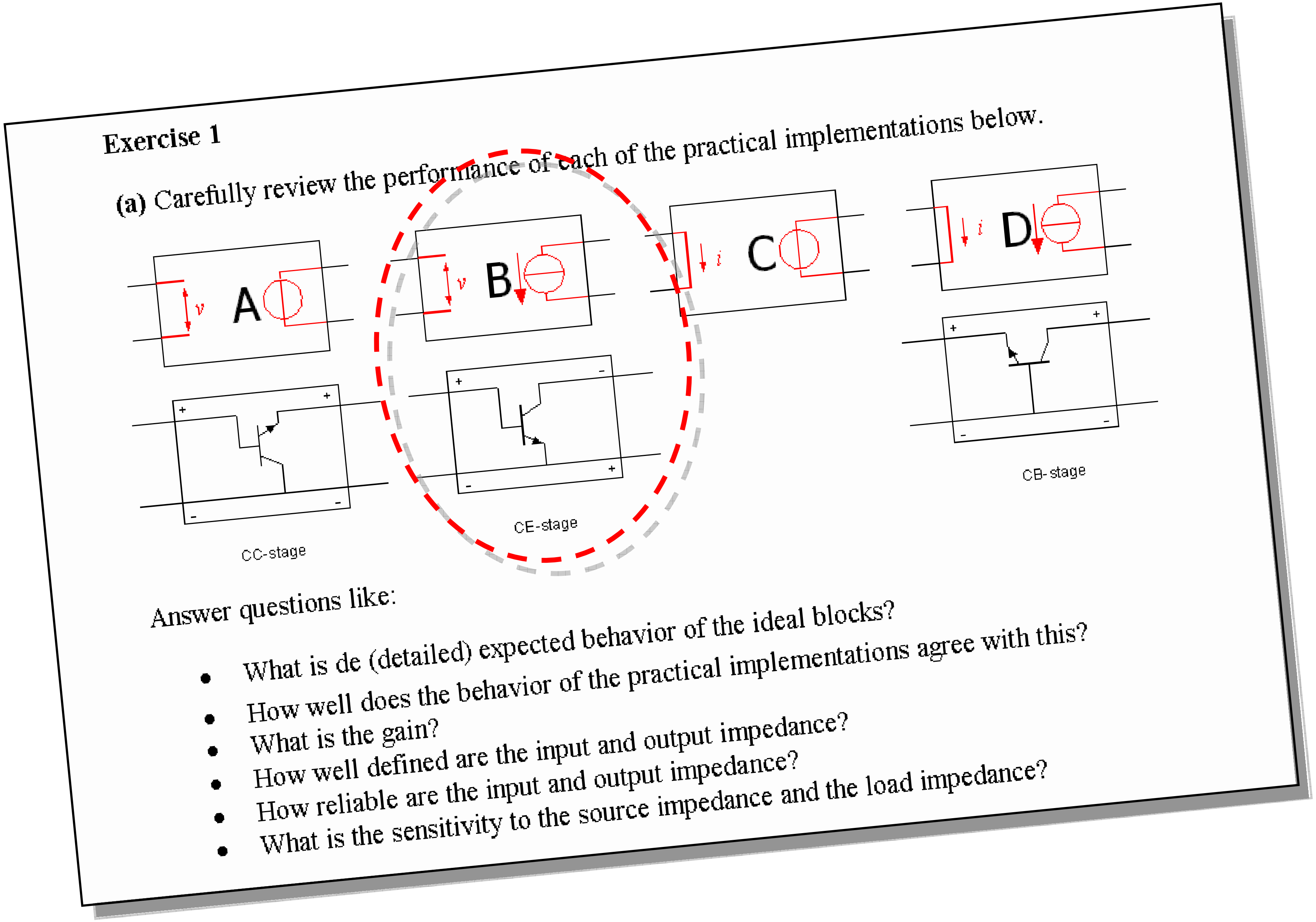
- Feed back network determines transfer
- Source impedance *no influence*
- Load impedance *no influence*
- Best nullor implementation
  - No A_{t0} and no influence on L by source and load impedance



Best nullor implementation



Technological limits



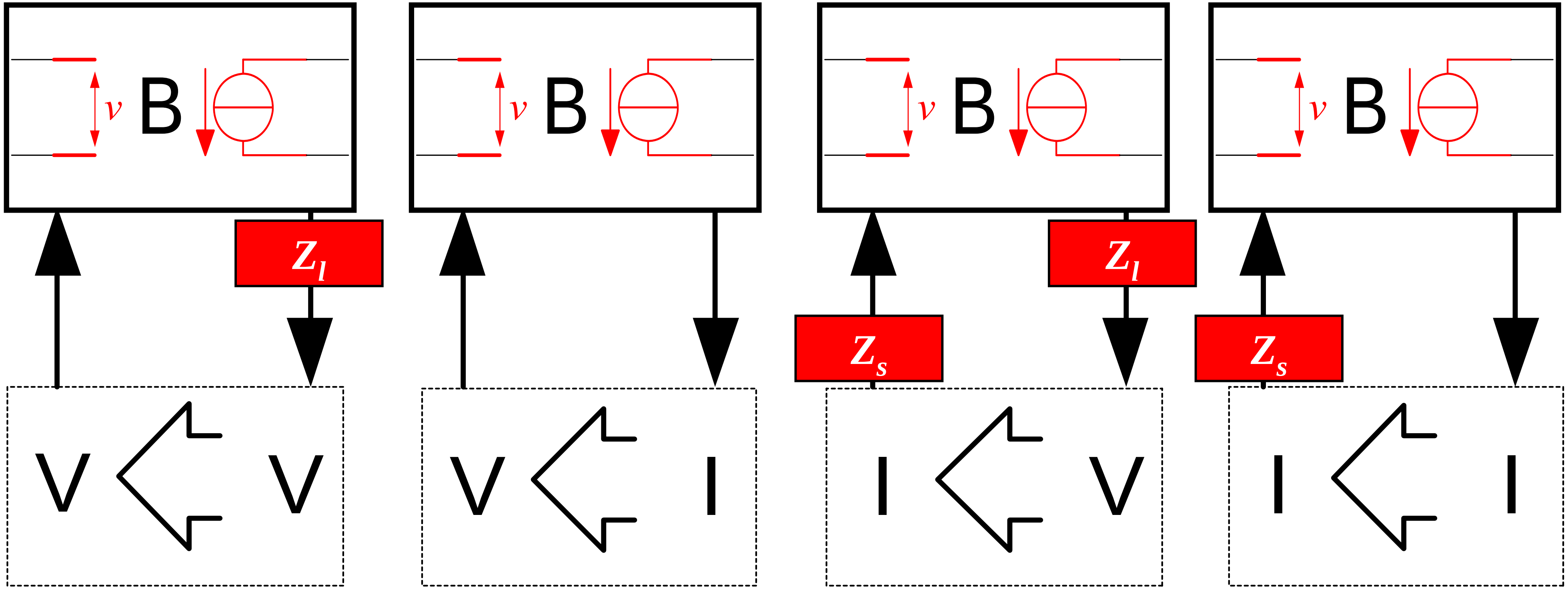
Exercise 1

(a) Carefully review the performance of each of the practical implementations below.

Answer questions like:

- What is de (detailed) expected behavior of the ideal blocks?
- How well does the behavior of the practical implementations agree with this?
- What is the gain?
- How well defined are the input and output impedance?
- How reliable are the input and output impedance?
- What is the sensitivity to the source impedance and the load impedance?

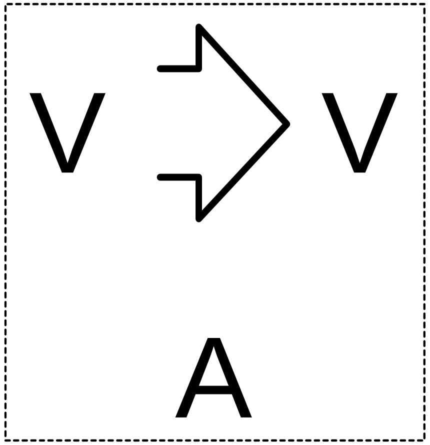
Nullor implementation close to technology



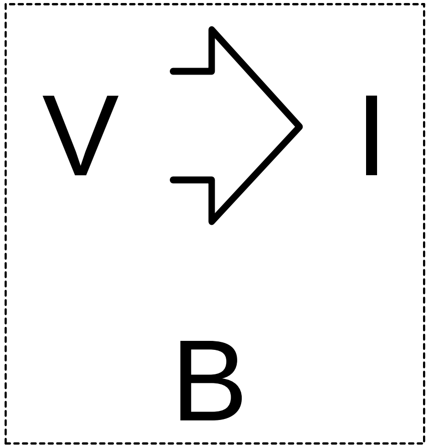
- **Remember the best choice**
- **Know the penalty for the others!**

Step 2, the feed back network

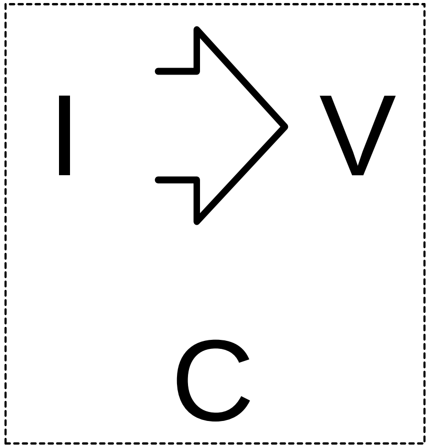
The active part *is* a nullor



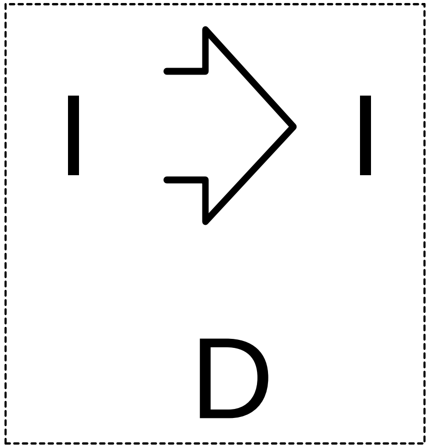
A



B



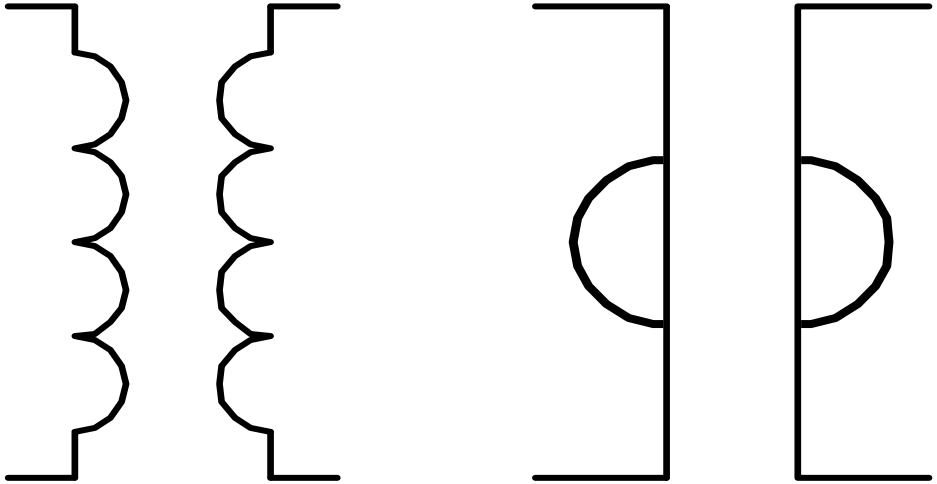
C



D

Ideal feedback components

$$\begin{pmatrix} n & 0 \\ 0 & \frac{1}{n} \end{pmatrix}$$



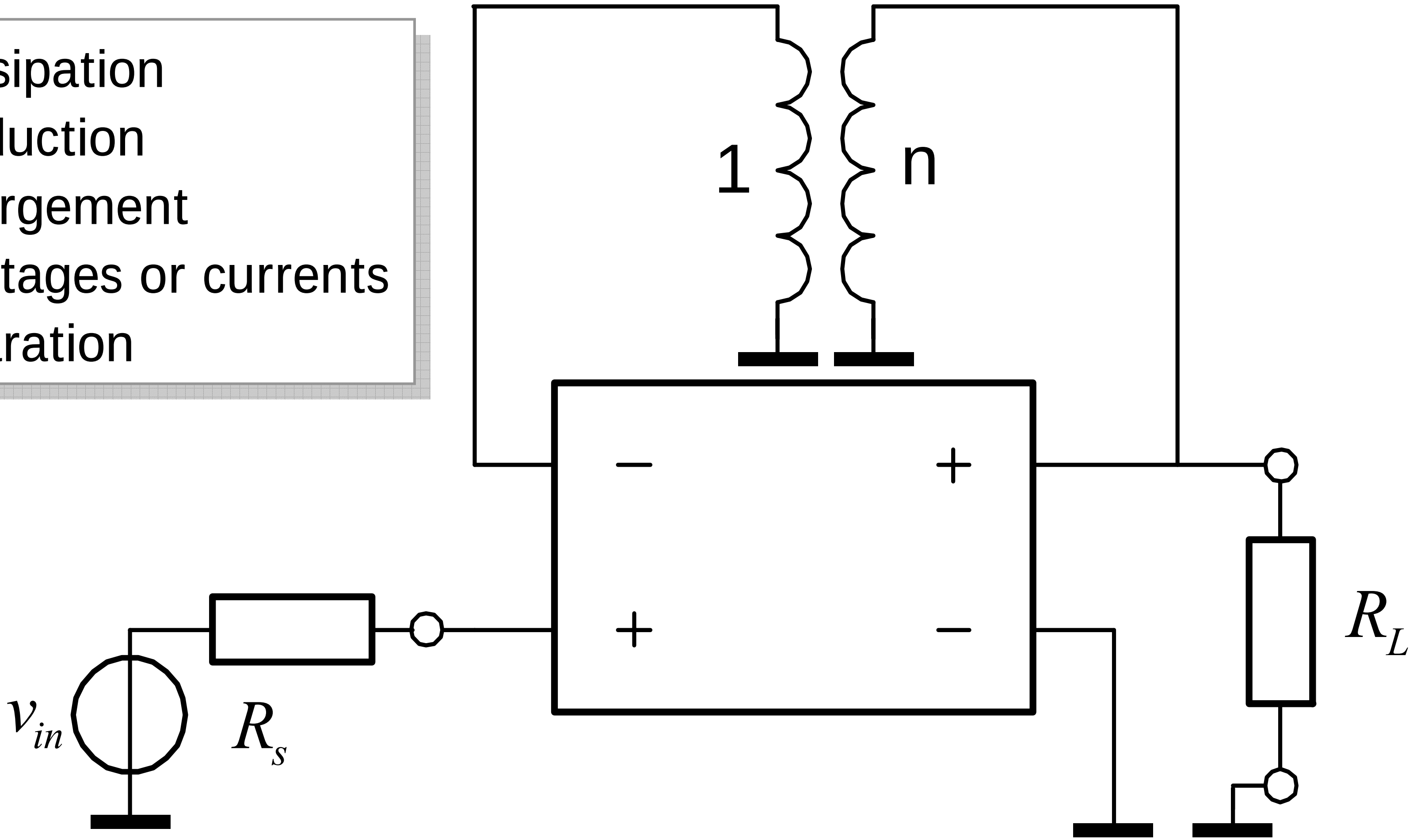
$$\begin{pmatrix} 0 & R \\ \frac{1}{R} & 0 \end{pmatrix}$$

Transformer *Gyrator*

- No power dissipation
- No noise production
- No noise enlargement
- No excess voltages or currents
- Galvanic separation

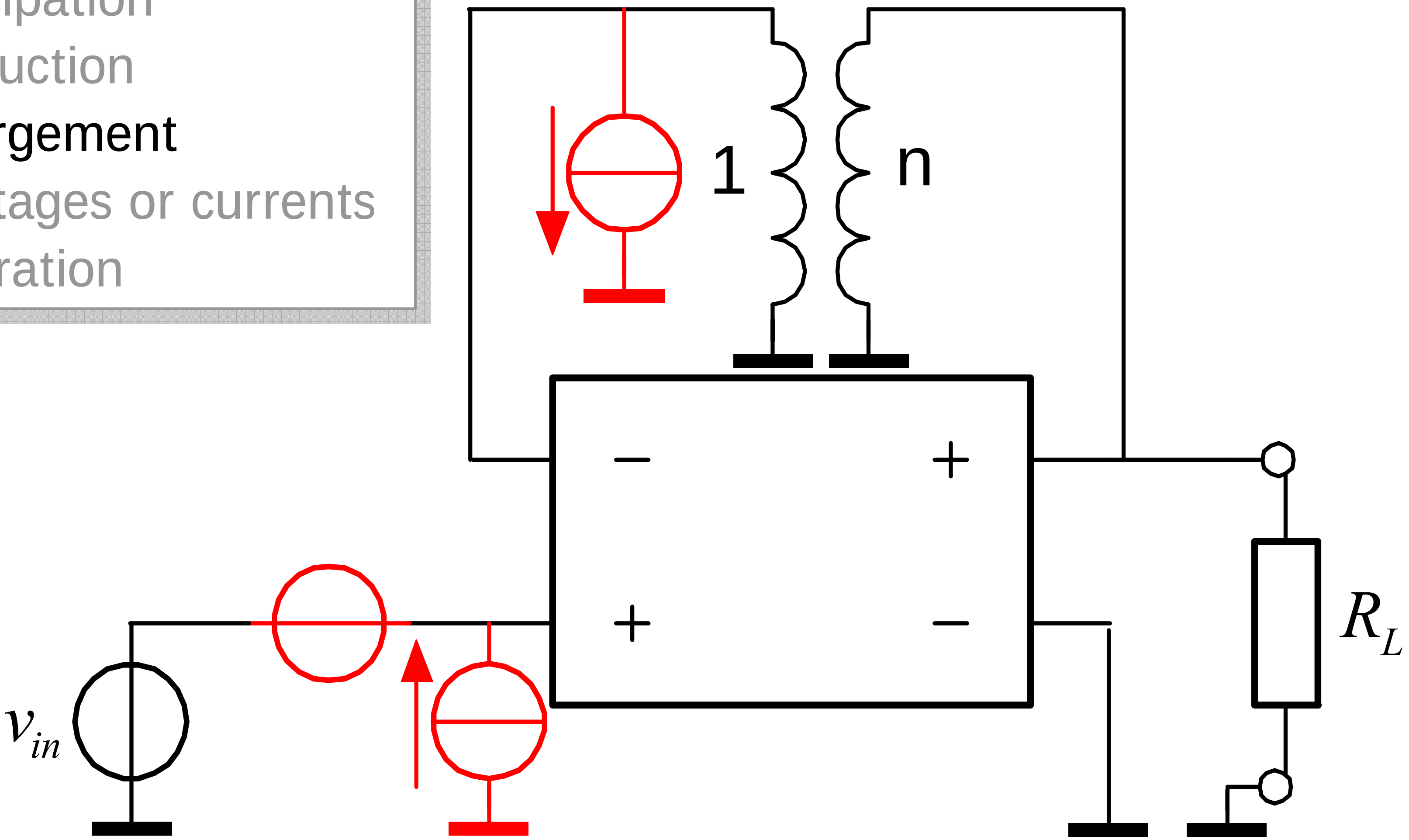
Voltage amplifier

- No power dissipation
- No noise production
- No noise enlargement
- No excess voltages or currents
- Galvanic separation



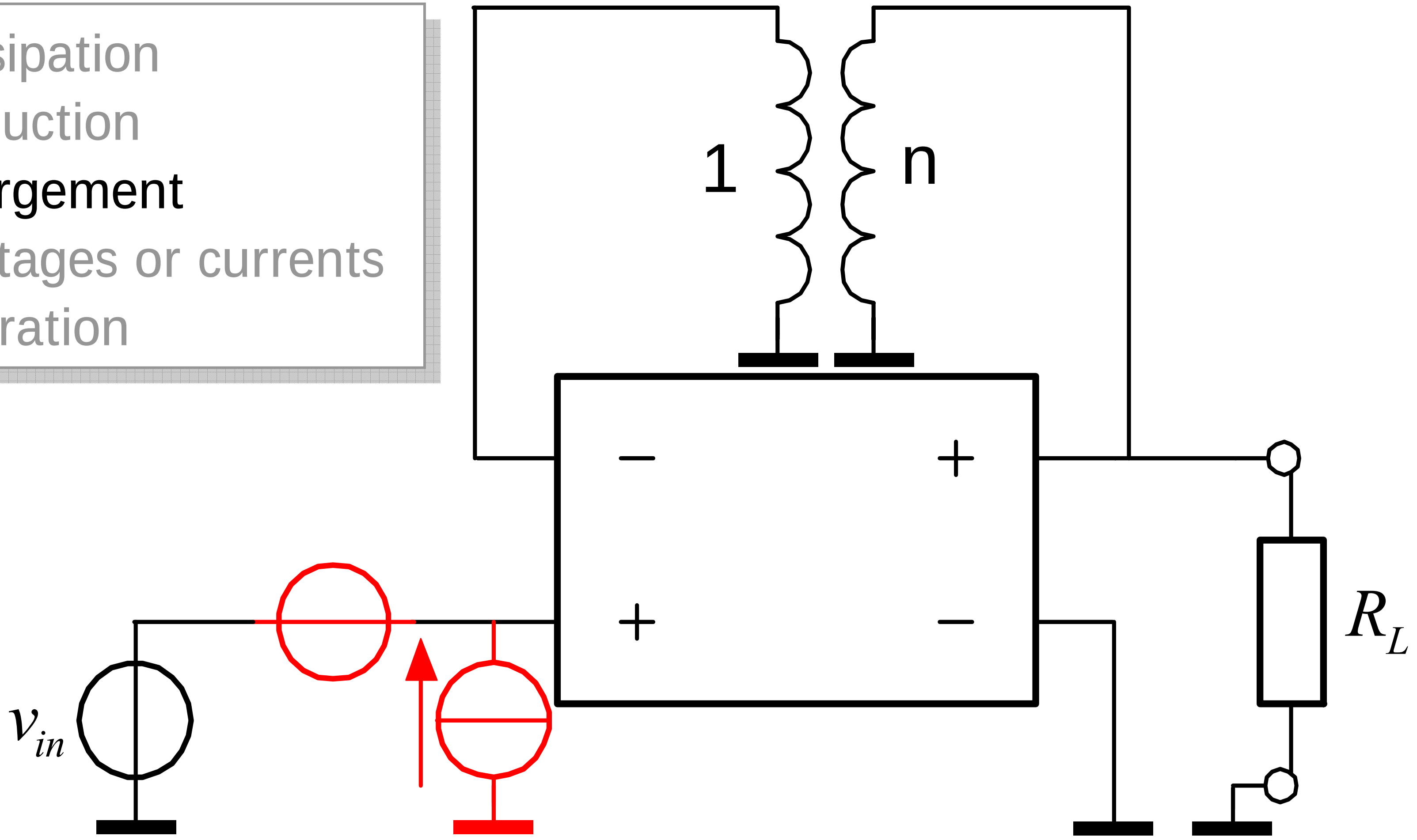
Noise influence

- No power dissipation
- No noise production
- No noise enlargement
- No excess voltages or currents
- Galvanic separation

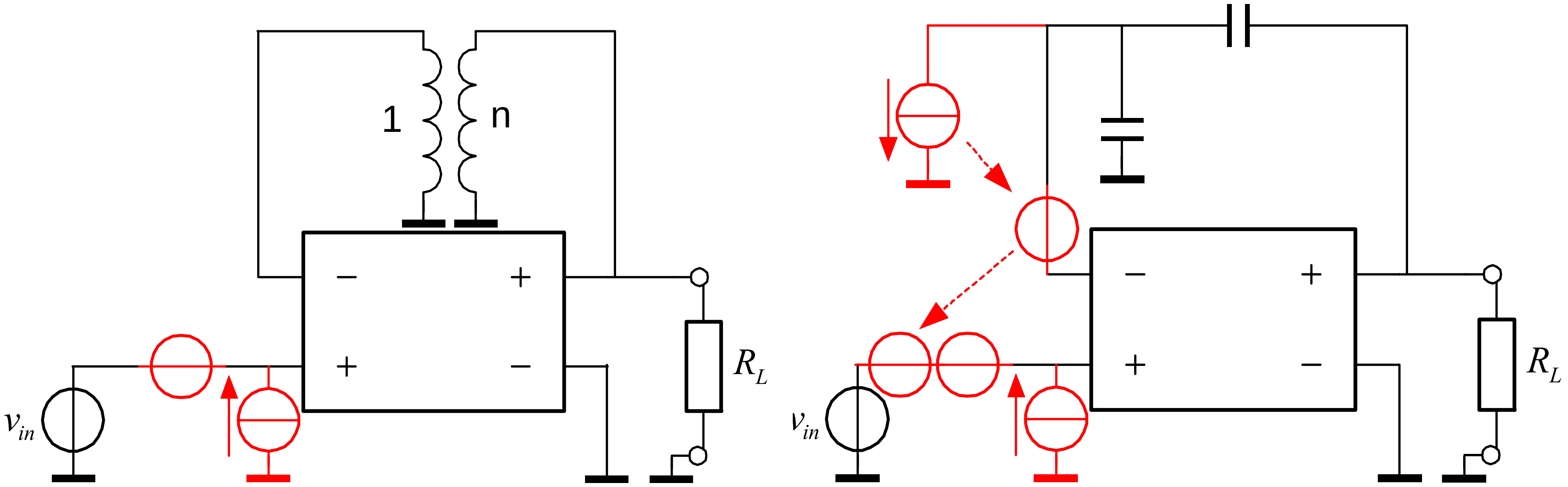


Noise influence

- No power dissipation
- No noise production
- **No noise enlargement**
- No excess voltages or currents
- Galvanic separation

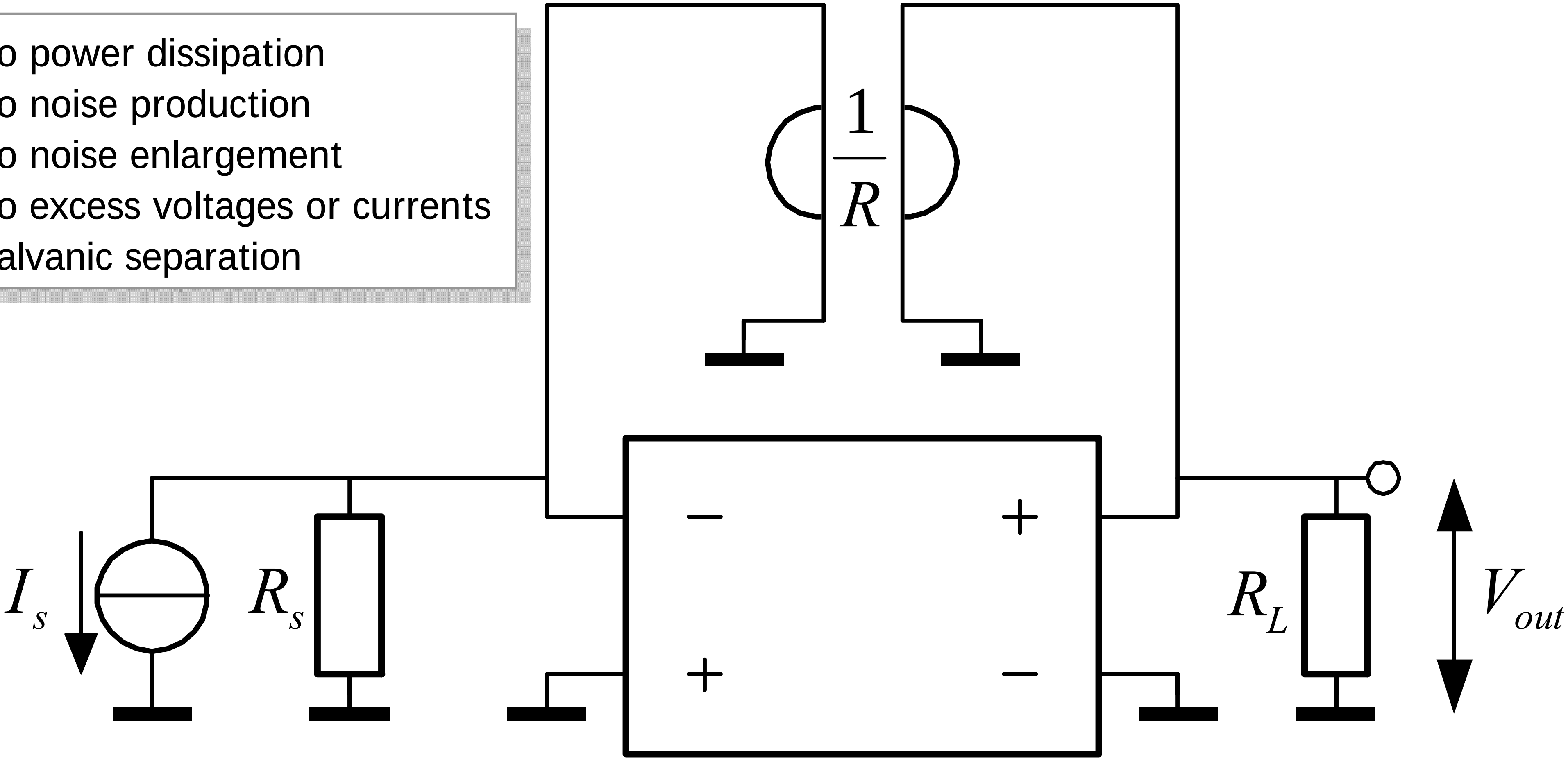


Noise influence impedance network

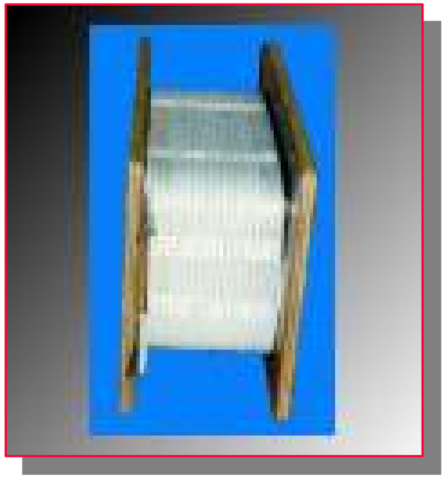


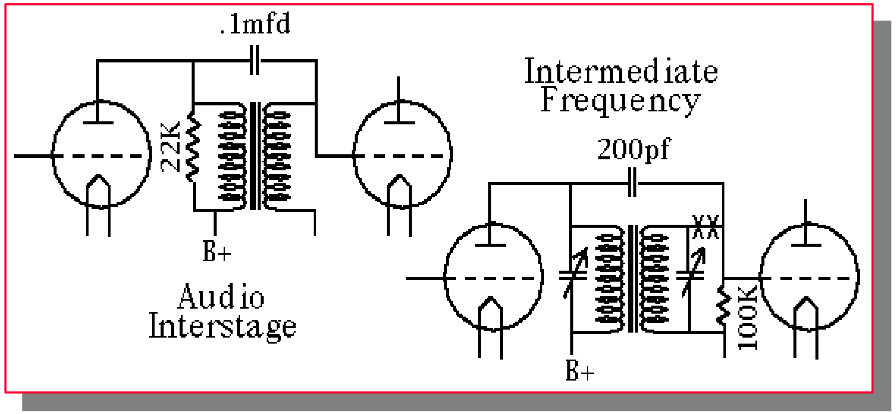
Trans-impedance amplifier

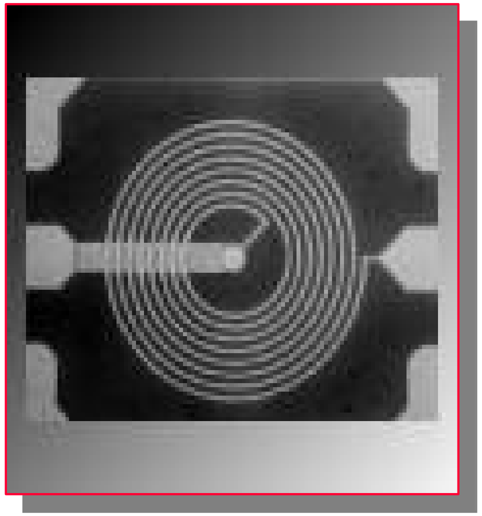
- No power dissipation
- No noise production
- No noise enlargement
- No excess voltages or currents
- Galvanic separation



Ideal versus reality: transformer



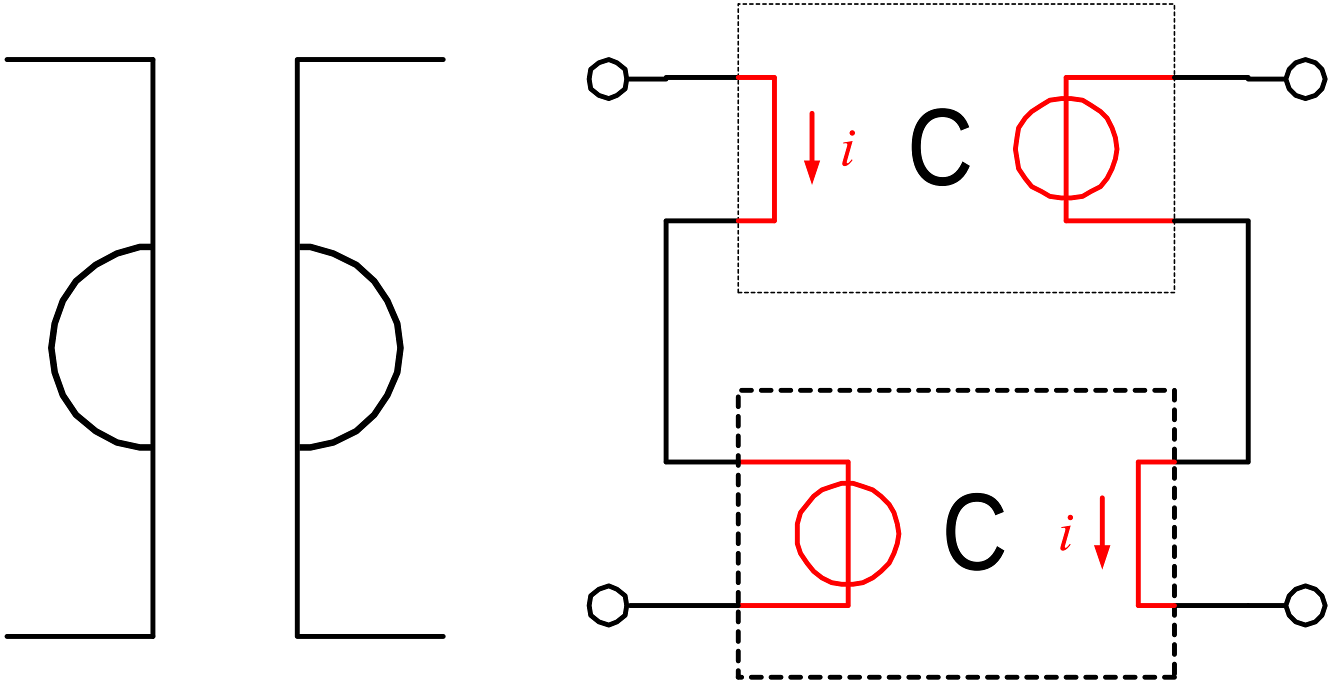




Not always feasible

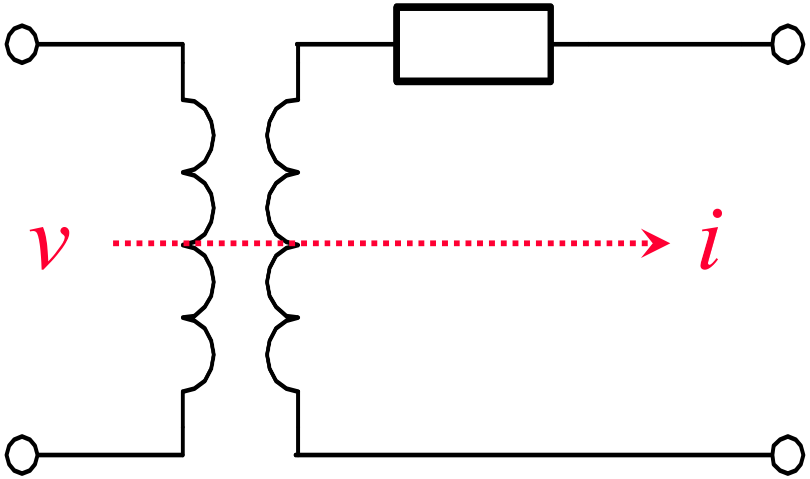
- Parasitic impedances
- Limited frequency range
- Non-linearity (saturation)
- Technological problems

Ideal versus reality: gyrator



- Needs controlled sources (active elements)
- Practical implementation produces noise
- Non-linearity
- Bandwidth restrictions

“Poor mans” gyrator



☹ Feature lost : No power dissipation

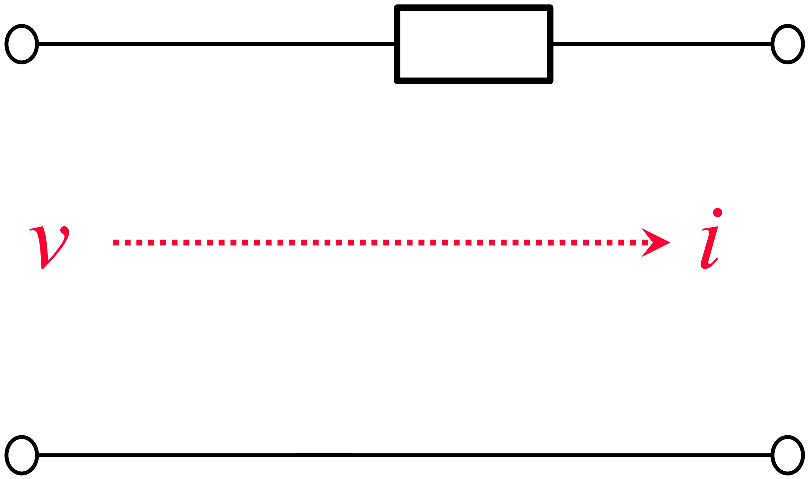
☹ Feature lost : No noise production

☹ Feature lost : No noise enlargement

☹ Feature lost : No excess voltages or currents

☺ Galvanic separation

“Very poor mans” gyrator



- ☹ Feature lost: No power dissipation
- ☹ Feature lost : No noise production
- ☹ Feature lost : No noise enlargement
- ☹ Feature lost : No excess voltages or currents
- ☹ Feature lost : Galvanic separation
- ☹ Direct connection between input and output node

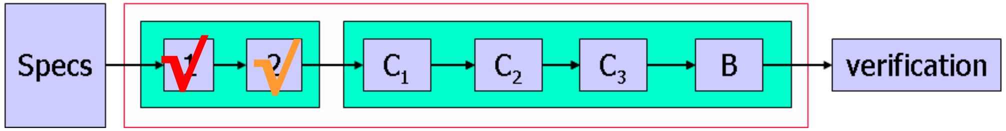
Why use the ideal transformers and gyrator?

Absolute minimum of:

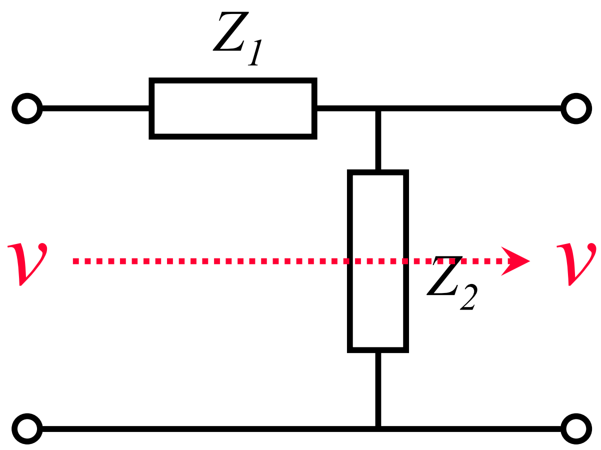
- Power consumption
- Current swing
- Voltage swing
- Noise

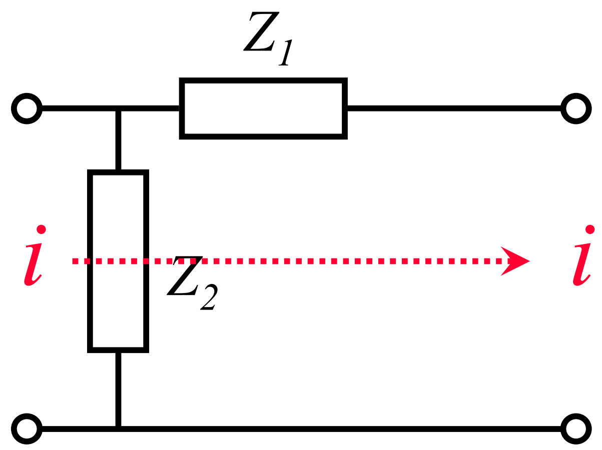
(The specifications)

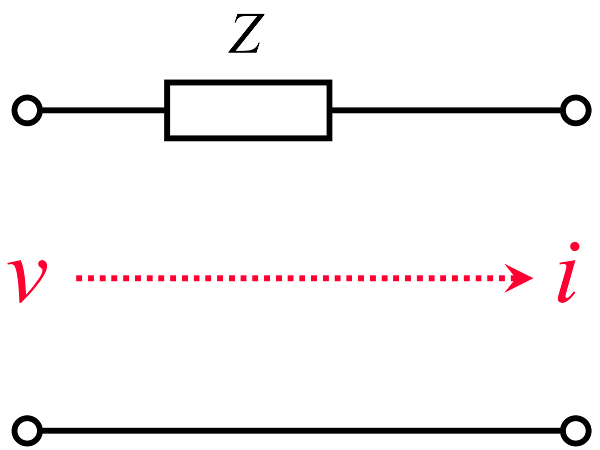
If already this it not enough.....

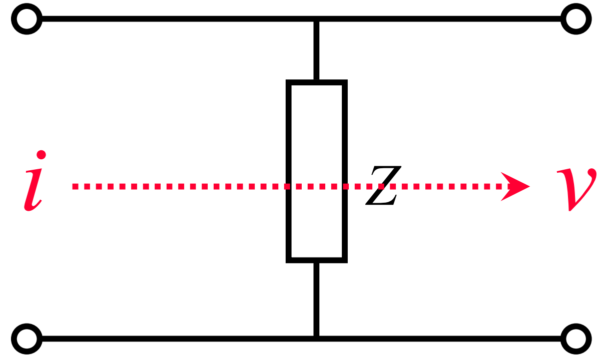


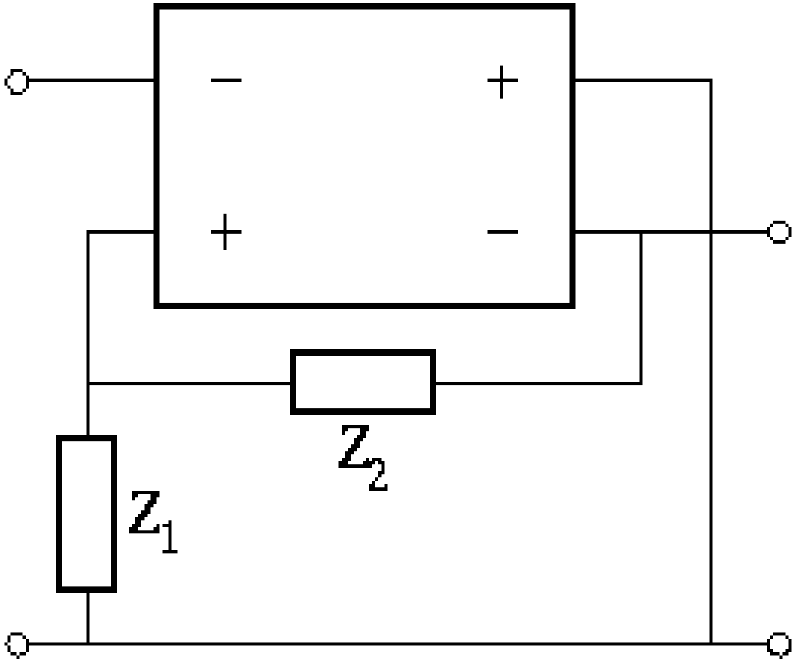
Common feed back networks

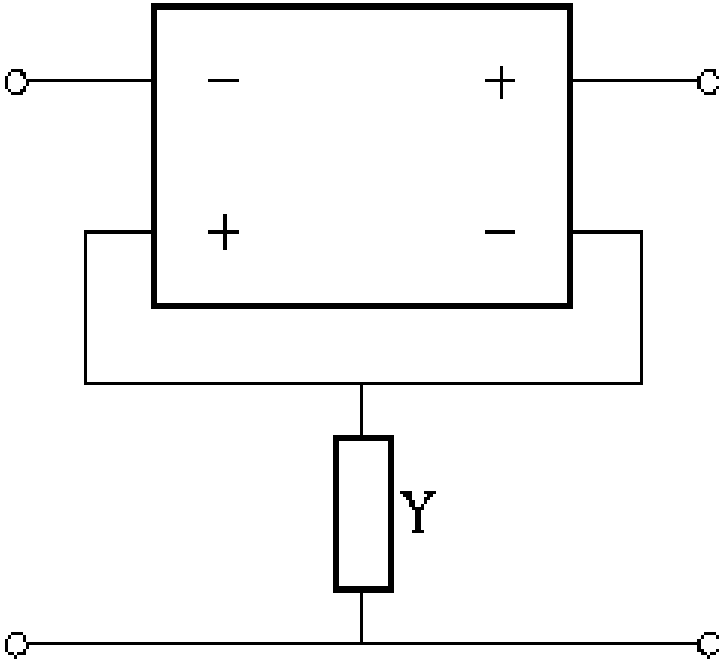


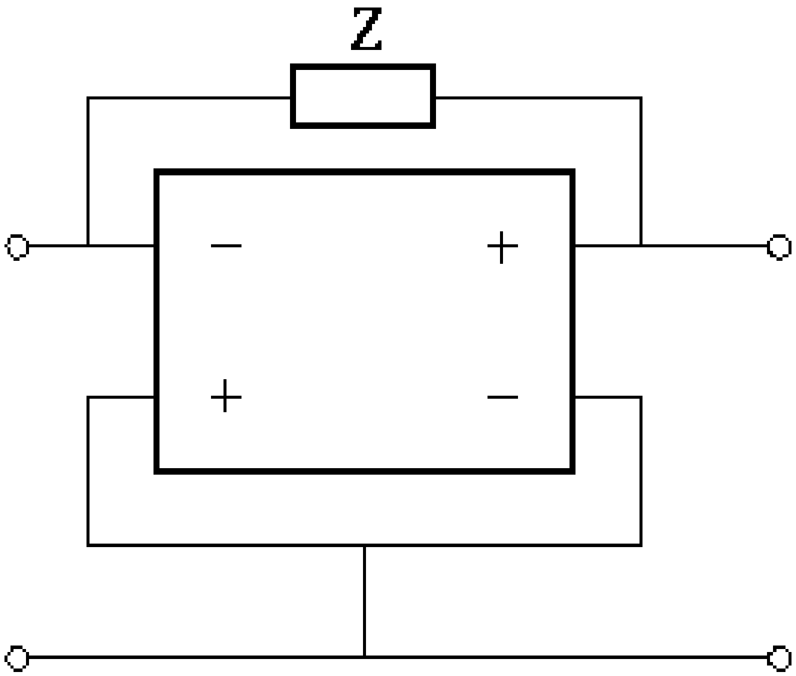


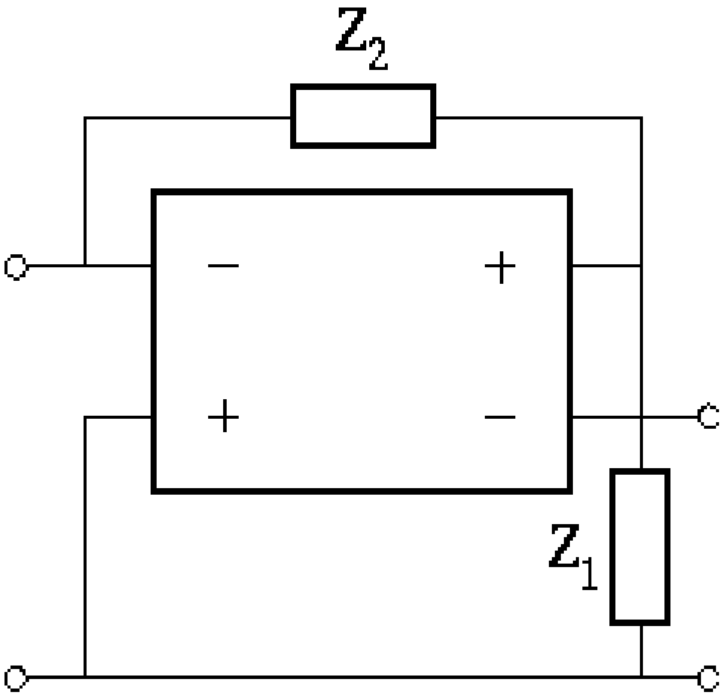




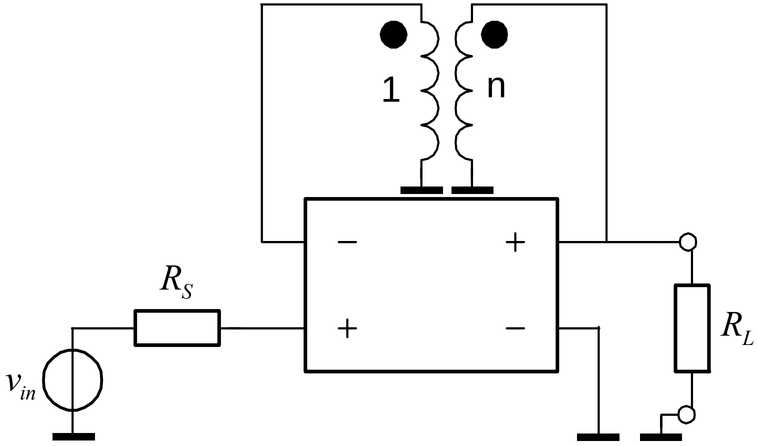

−
+
+
−
Z2
Z1


−
+
+
−
Y


Z
−
+
+
−

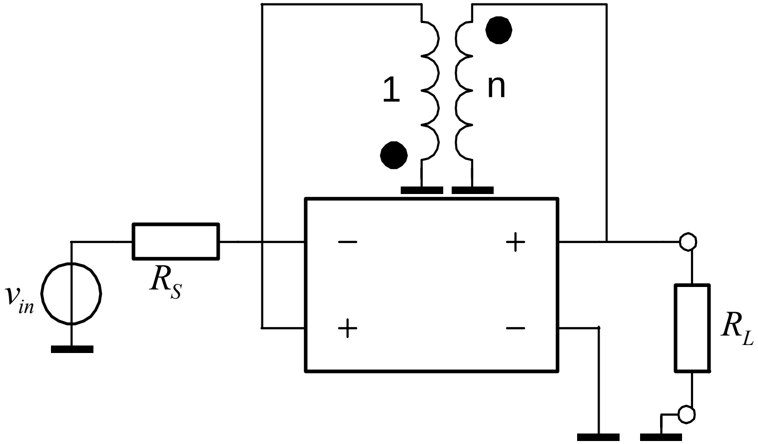

Z2
−
+
+
−
Z1

Common feed back networks : Reduced `flexibility

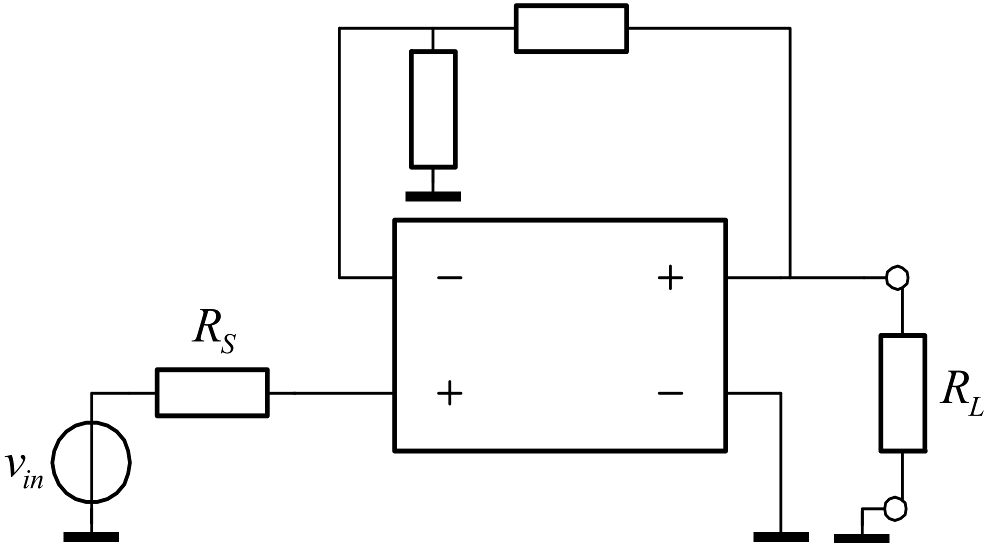


Non-inverting voltage amplifier

$$C = B\,{}^{2}\log\frac{S+N}{N}$$

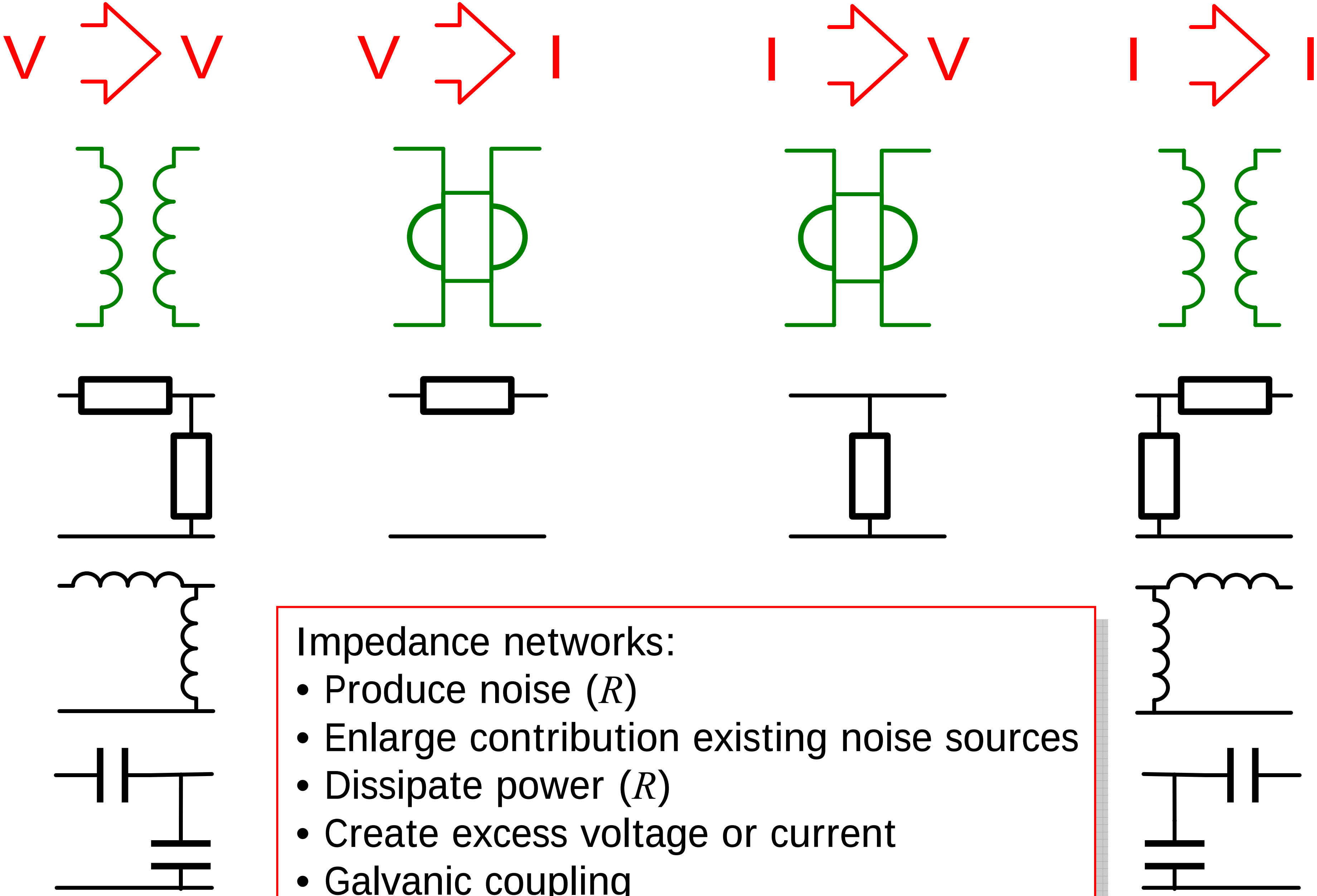


Inverting voltage amplifier



Non-inverting voltage amplifier

Negative feedback networks



Impedance networks:

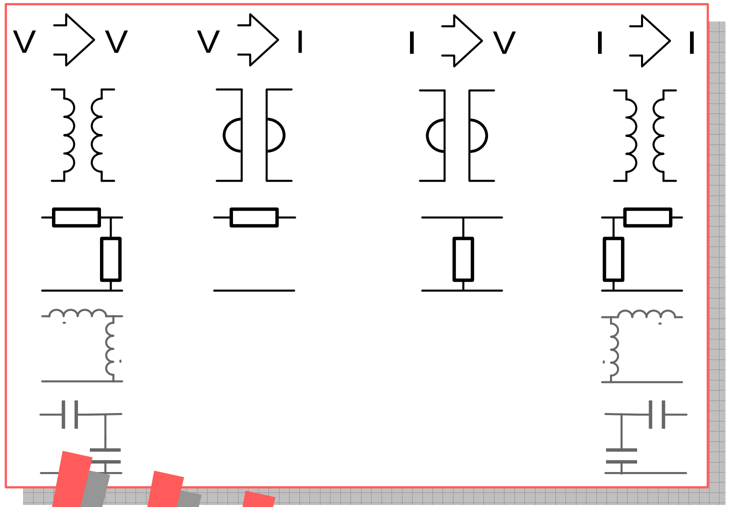
- Produce noise (R)
- Enlarge contribution existing noise sources
- Dissipate power (R)
- Create excess voltage or current
- Galvanic coupling

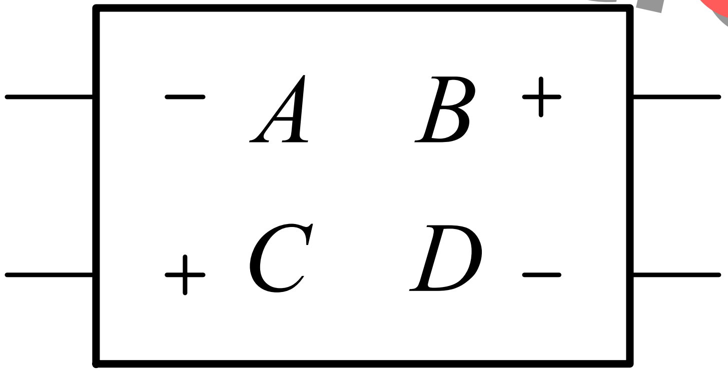
Accurate Amplification

Information from source to load

- Signal power is enlarged
- Information stays unaltered

Definition !!!!!!



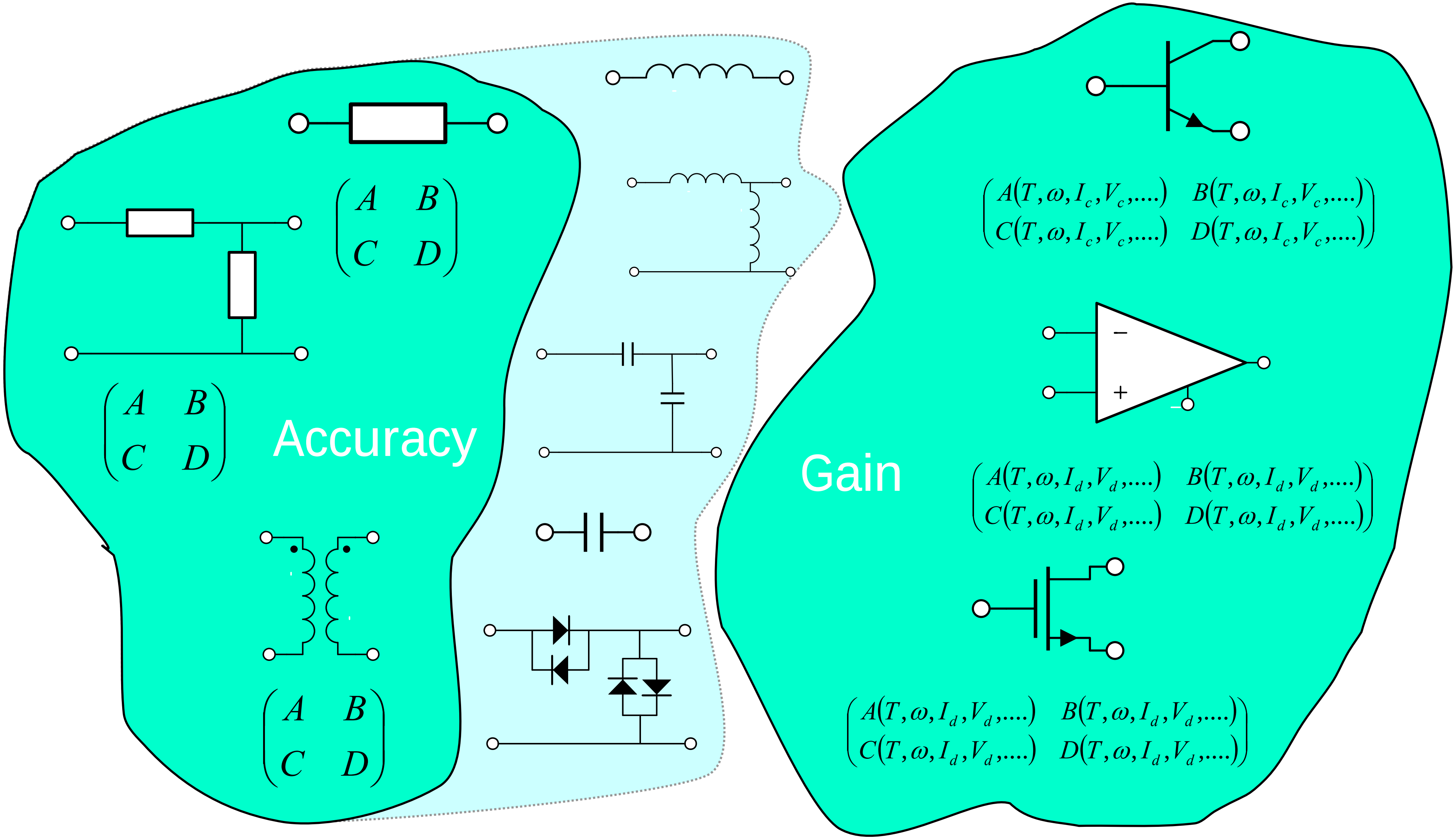


A,B,C,D <<1

A,B,C,D constant

A,B,C,D accurately known

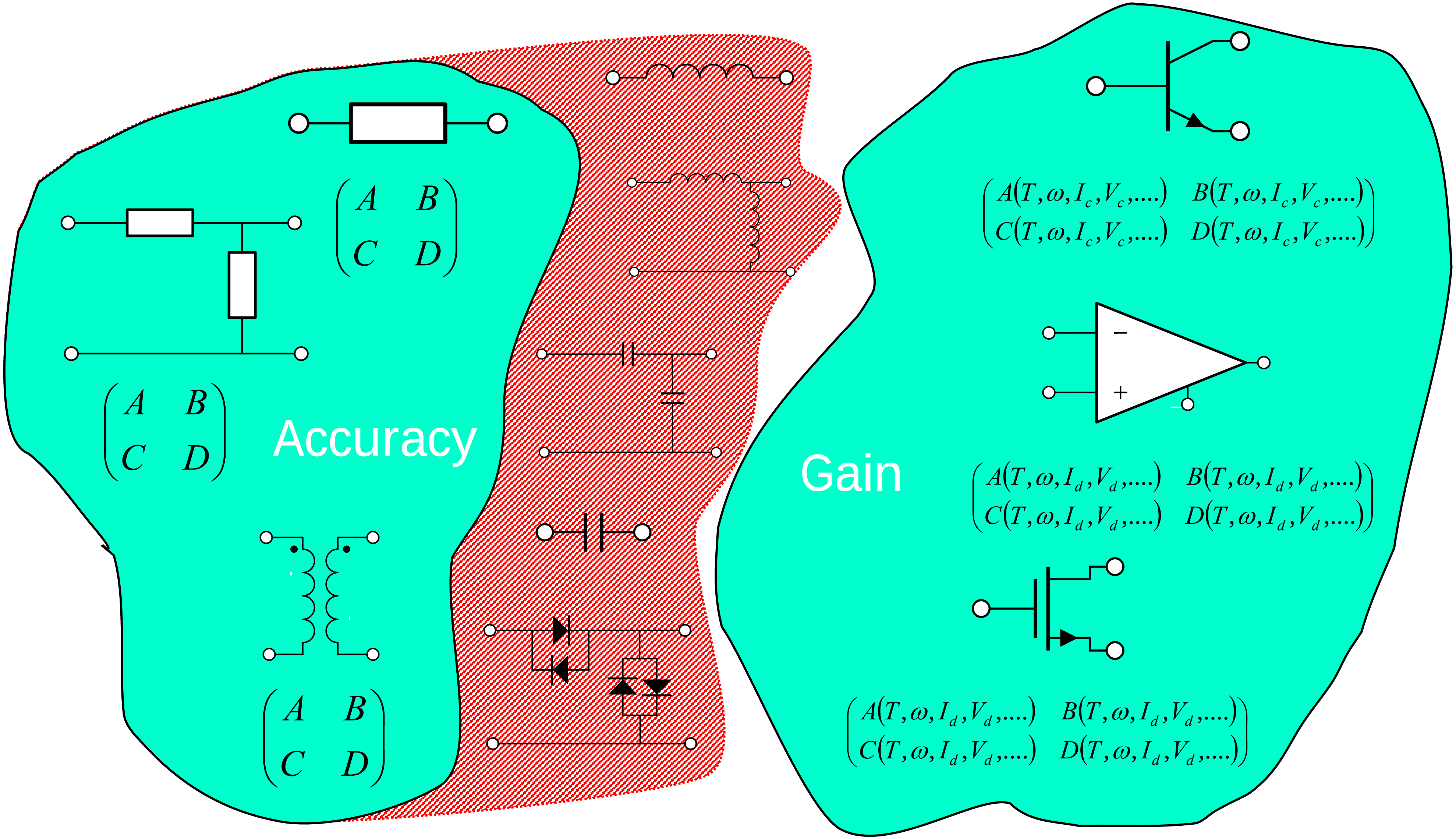
Common classification of available components



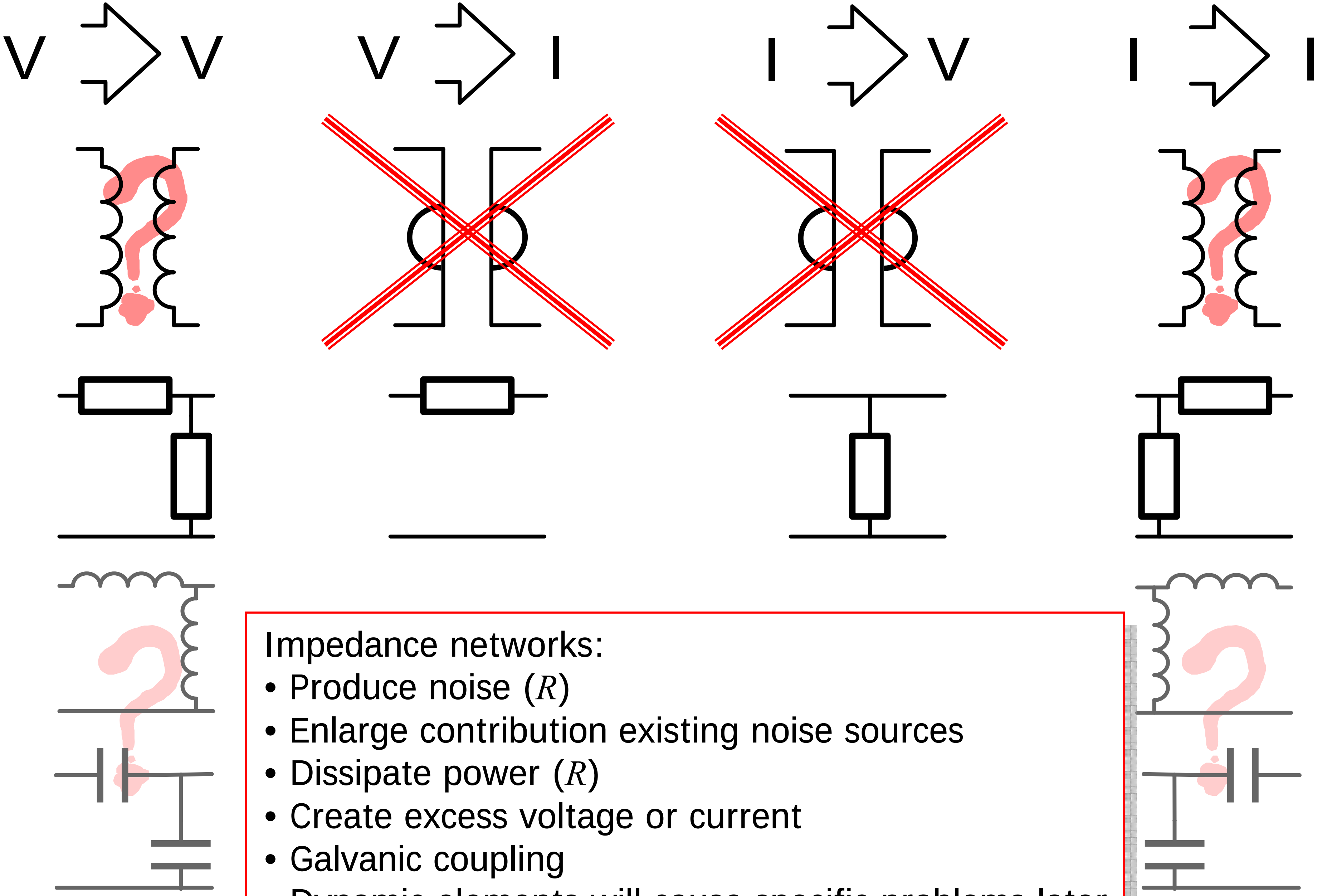
Accurate elements

Elements with gain

Exactly according to the definition



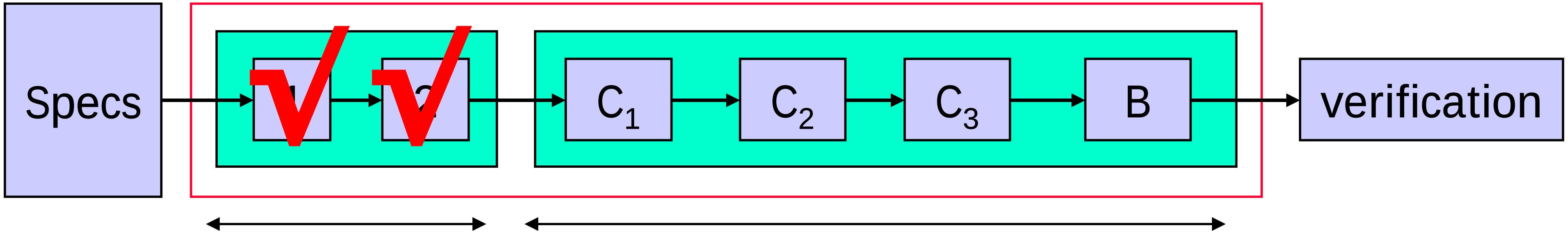
An amplifier is a non-dynamic circuit.
Why would there be dynamic elements in the feedback network?



Impedance networks:

- Produce noise (R)
- Enlarge contribution existing noise sources
- Dissipate power (R)
- Create excess voltage or current
- Galvanic coupling
- Dynamic elements will cause specific problems later

Conclusion



Known:

- Topology
- Best nullor implementation
- Voltage and current swing
- Power consumption
- Minimal noise level
- Penalties for “second-best” choices