Structured Electronic Design

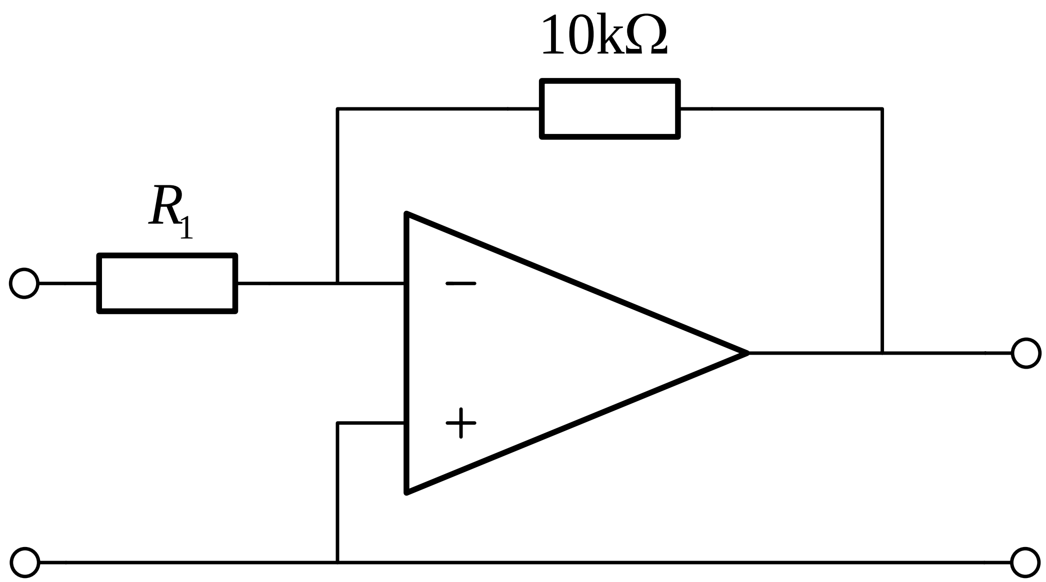
- ET 8016
- 5 ECTS credits

Structured Electronic Design

Some keywords:

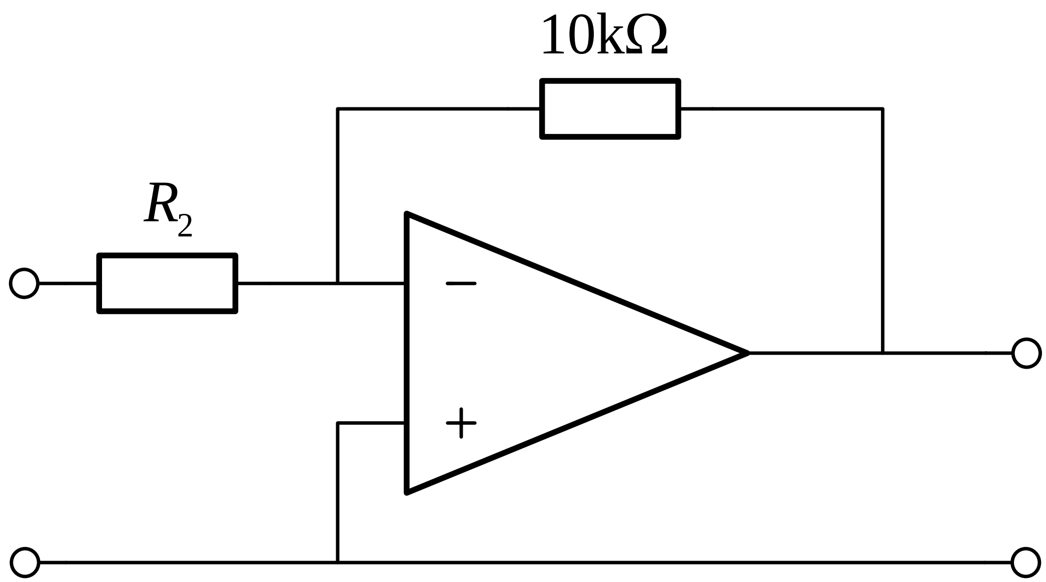
- Design methodology
- Analysis and **Synthesis**
- Applied network theory
- Fundamental research
- Free-swinging intellect

An amplifier



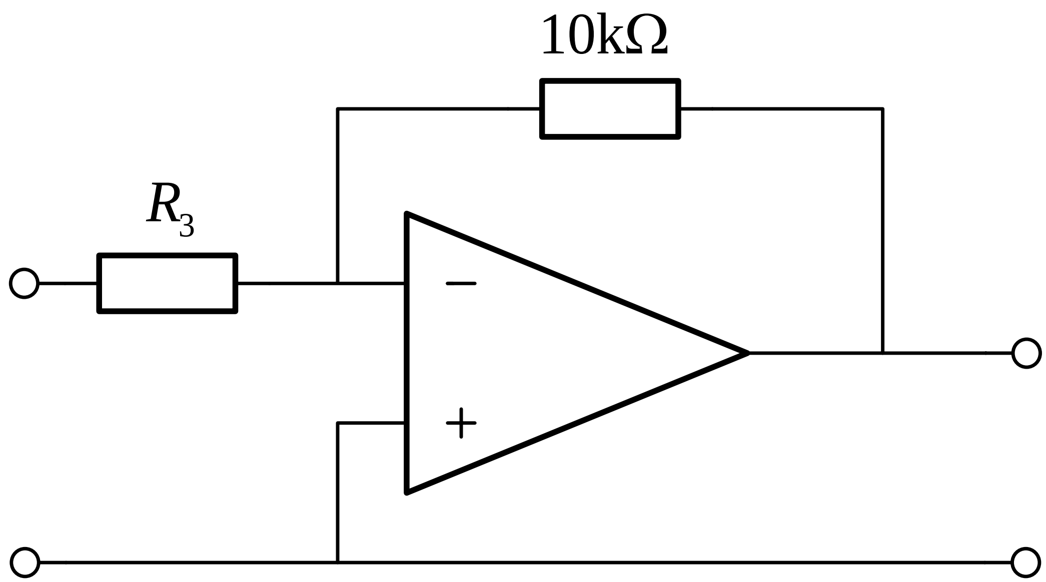
1. What type of amplifier is this?
2. When the gain is 10, what is the value of R_1?

Another amplifier



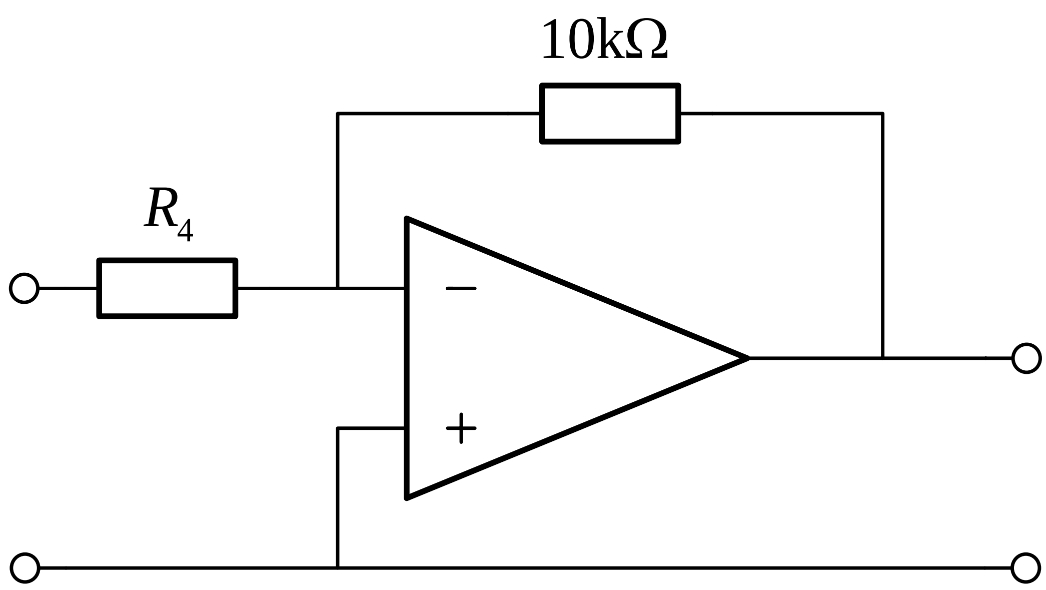
3. When the gain is 100, what is the value of R_2?

And another amplifier

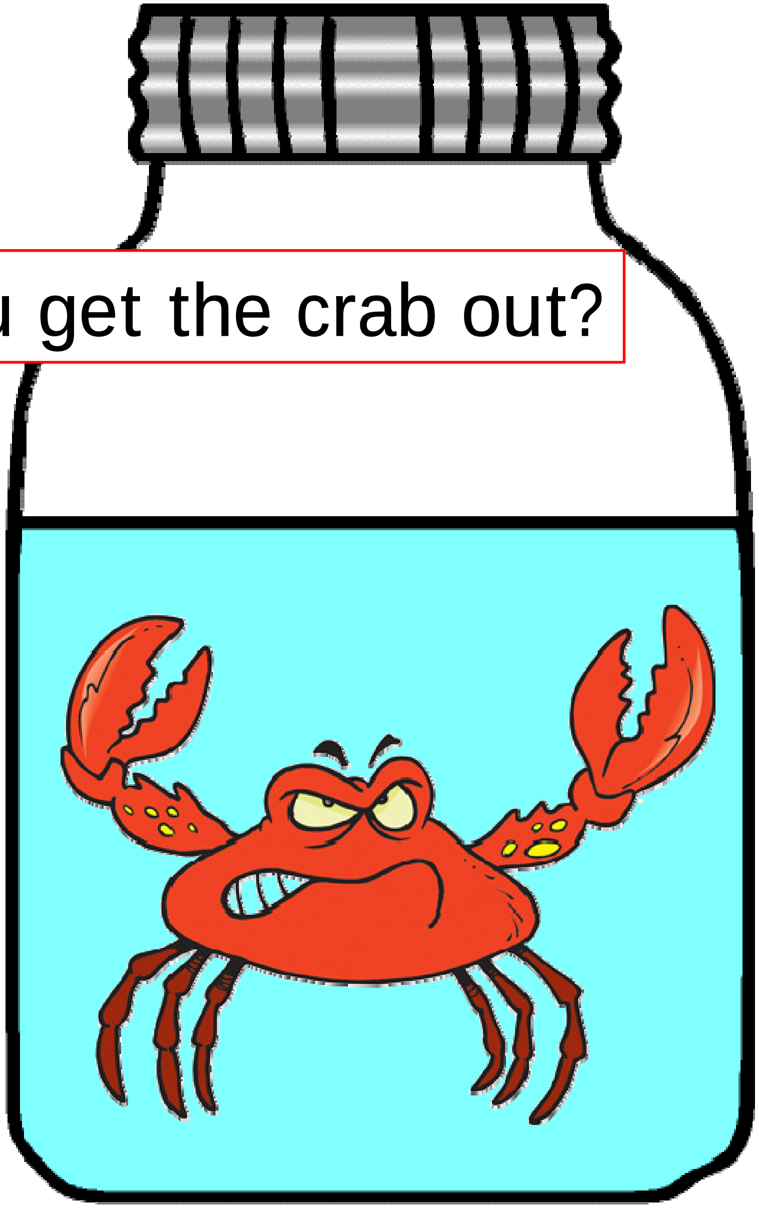


4. When the gain is 2, what is the value of R_3?

And another...



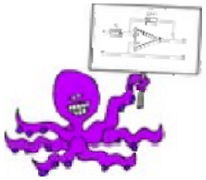
5. When the gain is 20, what is the value of R_4?



6. How do you get the crab out?


First try the lid is on very loose

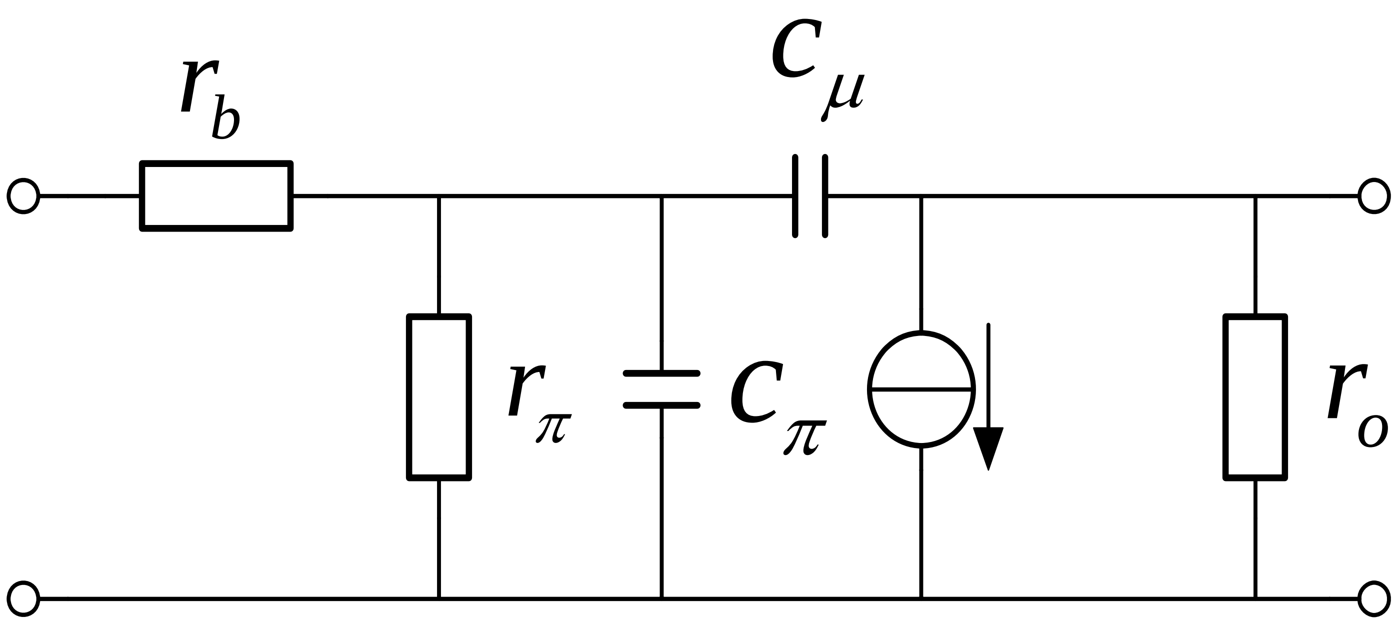
Fundamental research



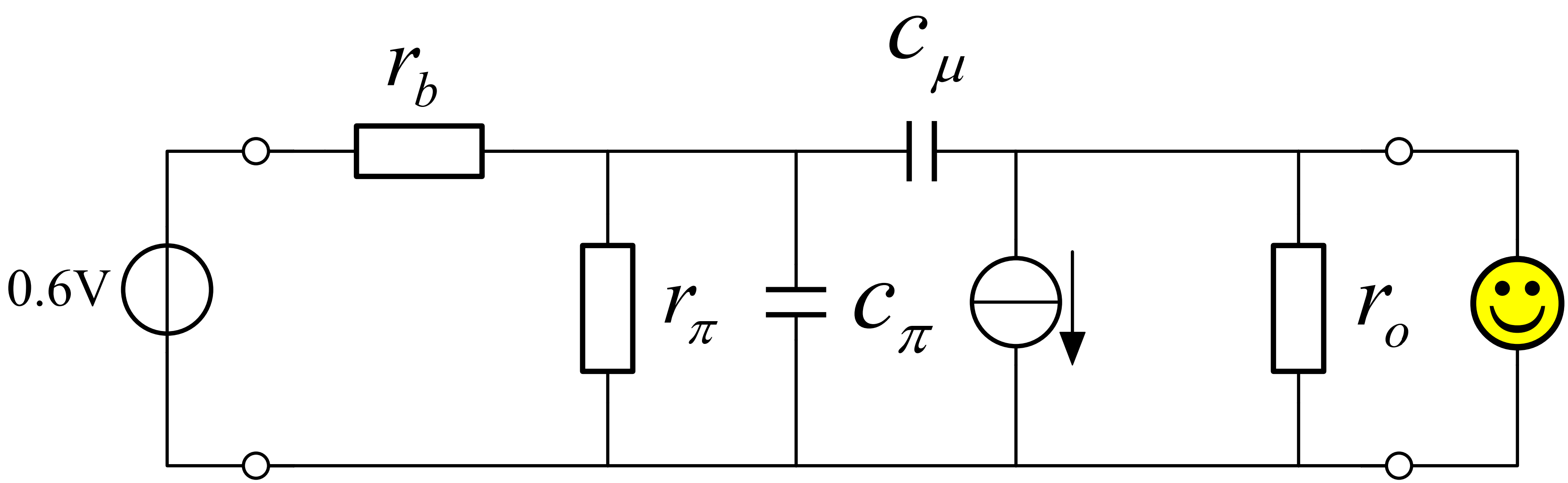
- How to design an amplifier? (techniques)

- ***Why*** do it this way? (philosophy)

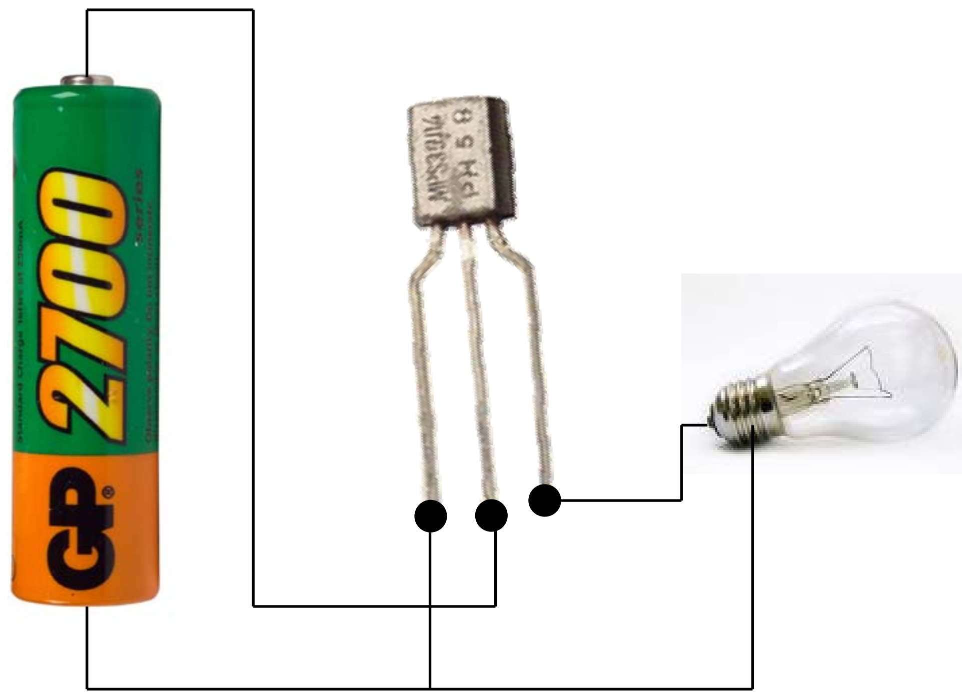

Why?



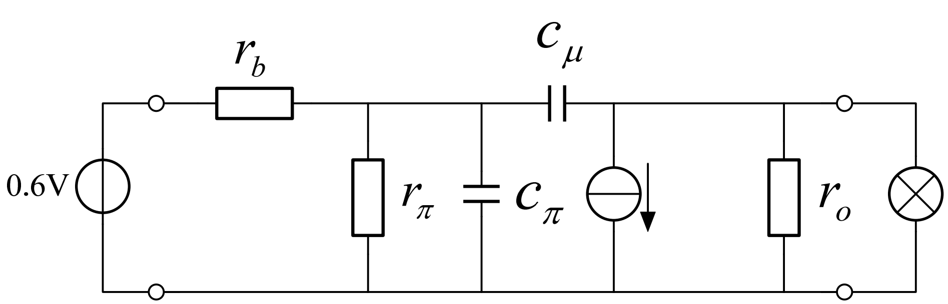
7. What is this?

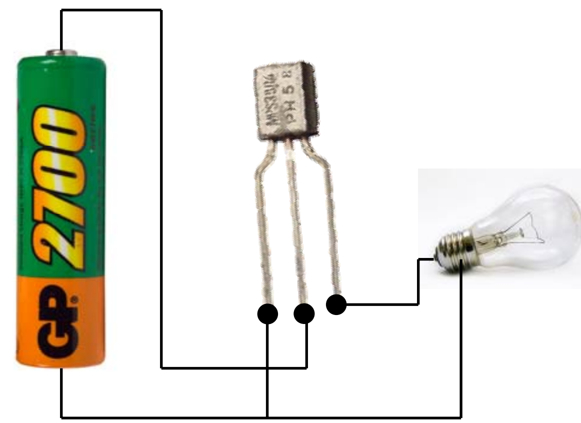


8. Will the lamp light up?



9. Will the lamp light up?

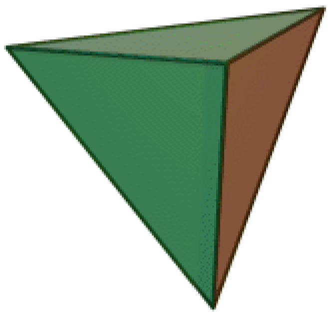




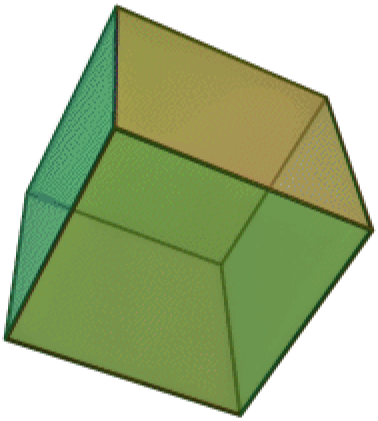
YES

NO

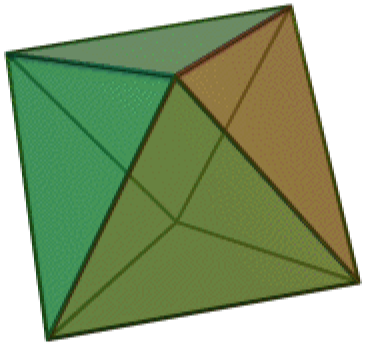
Platonic solids



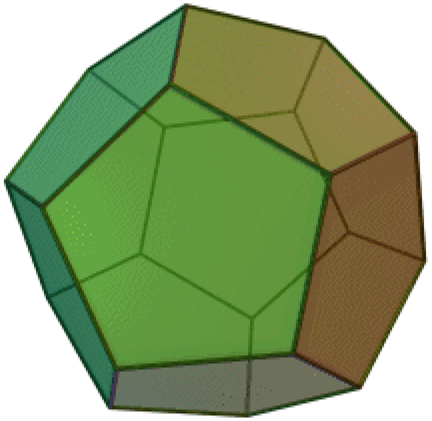
Tetrahedron



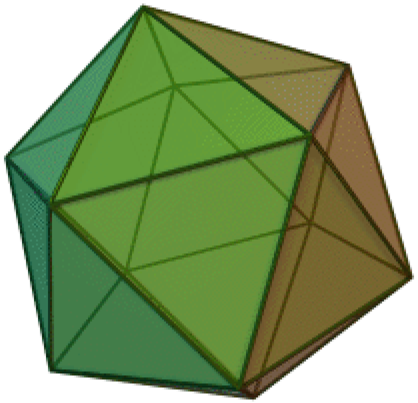
Hexahedron



Octahedron

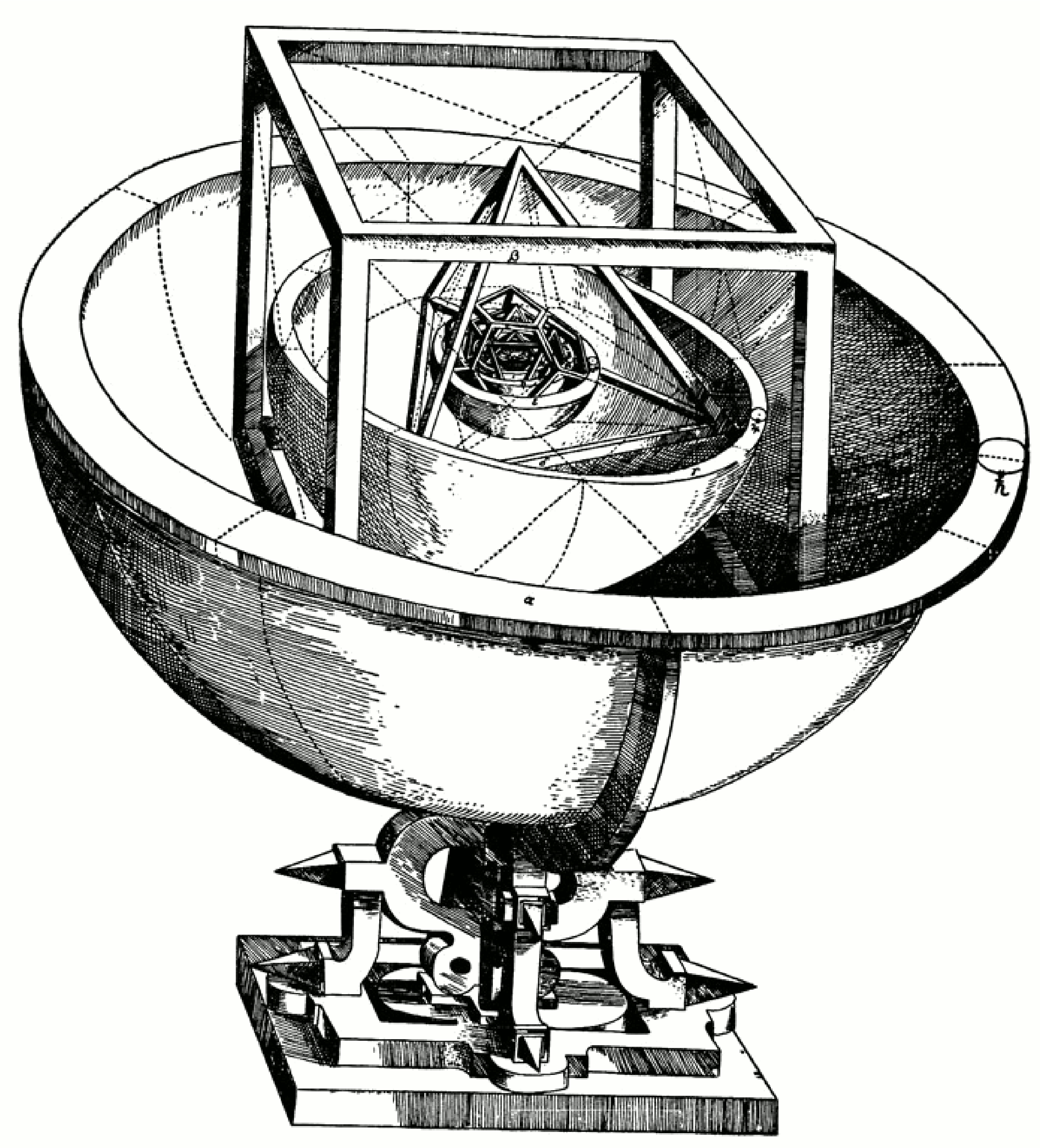


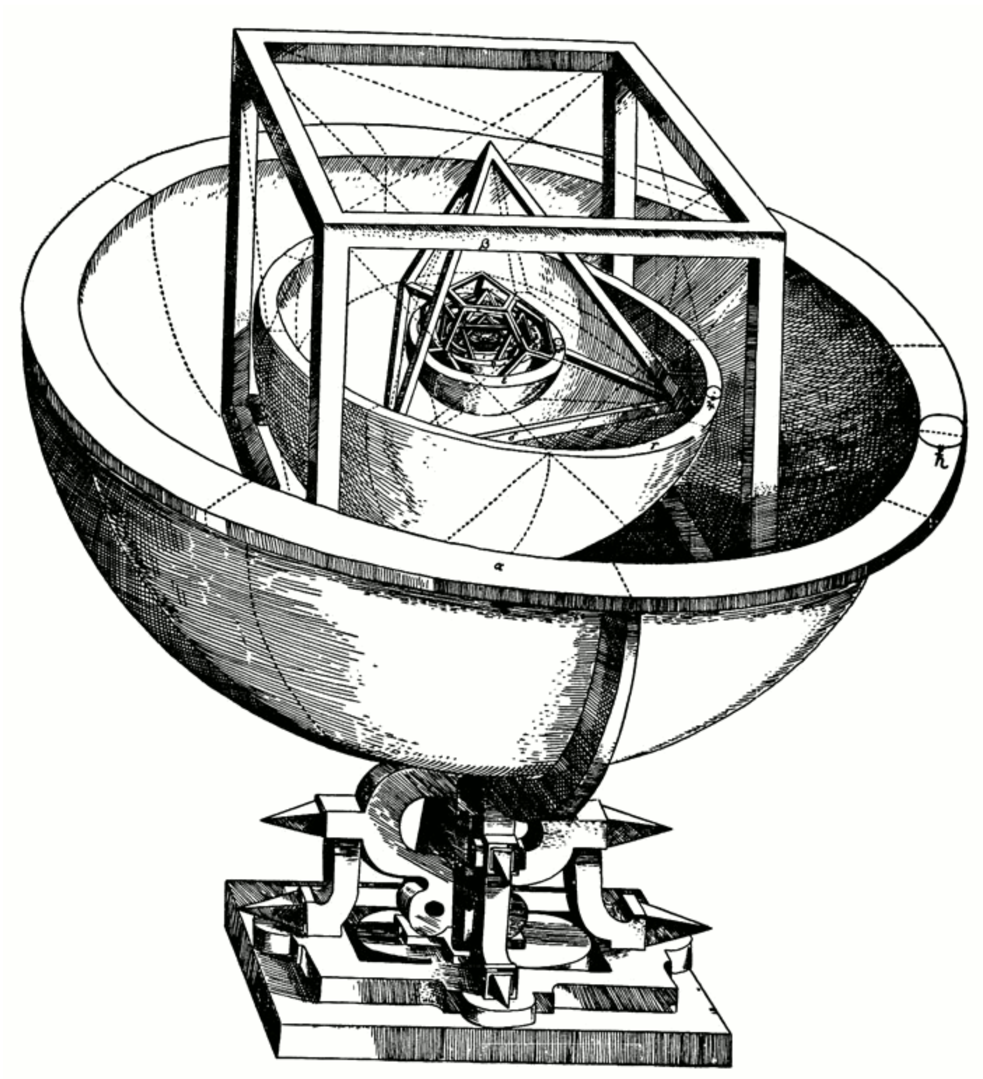
Dodecahedron

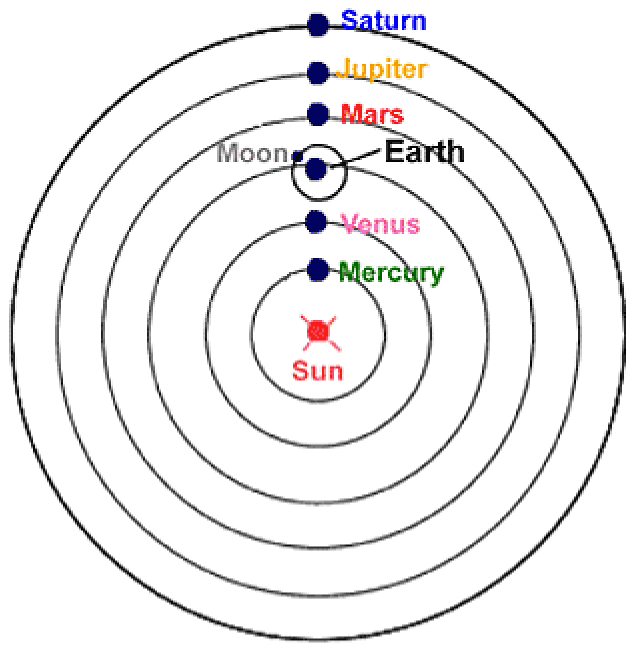


Icosahedron

Edges and angles are all congruent







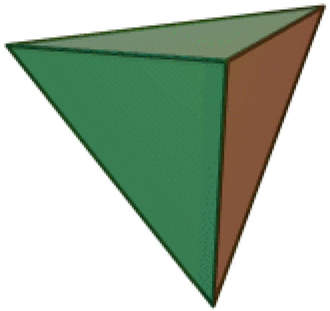
It correctly predicts the orbit of all planets you can see with the naked eye.

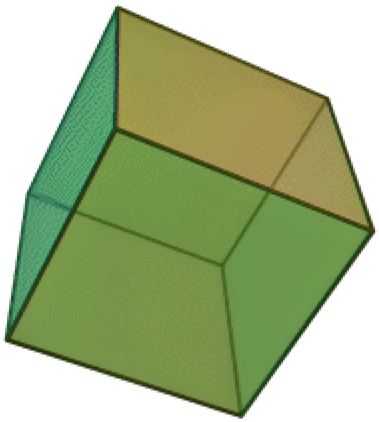
10. Is this a good model?

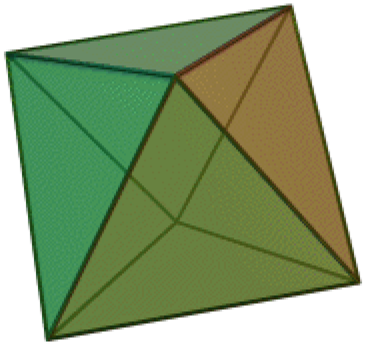
Modeling

A correct model gives a correct prediction

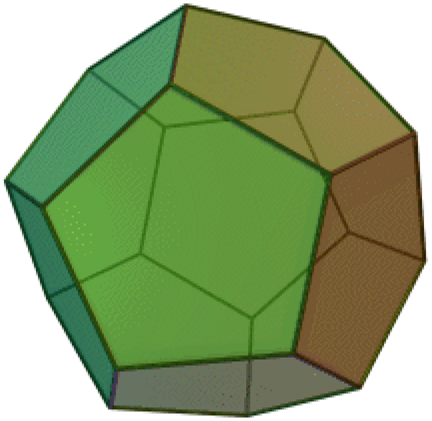
Platonic solids



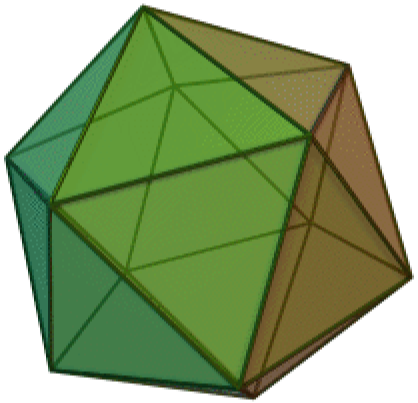




“The five Pythagorean regular polyhedra dictate the structure of the universe and reflect God's plan through geometry”; June19, 1595, Johannes Kepler



Dodecahedron



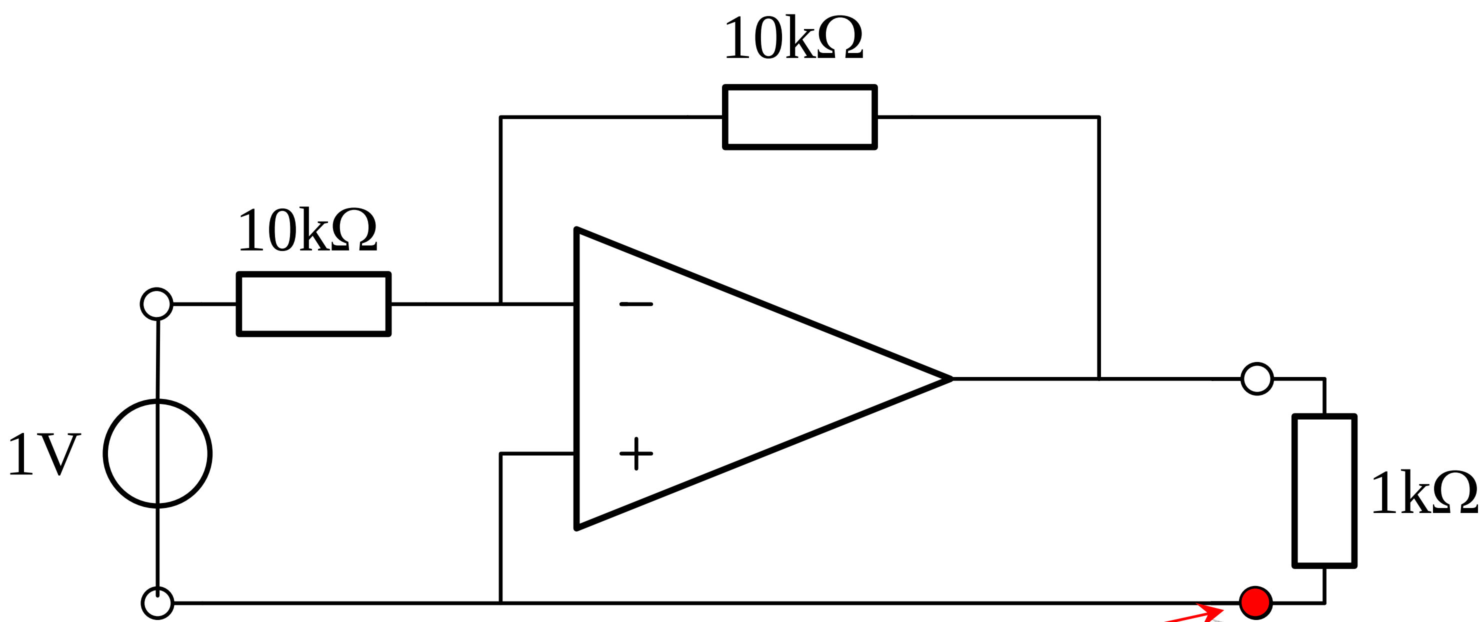
Icosahedron

Modeling

A correct model gives a correct prediction

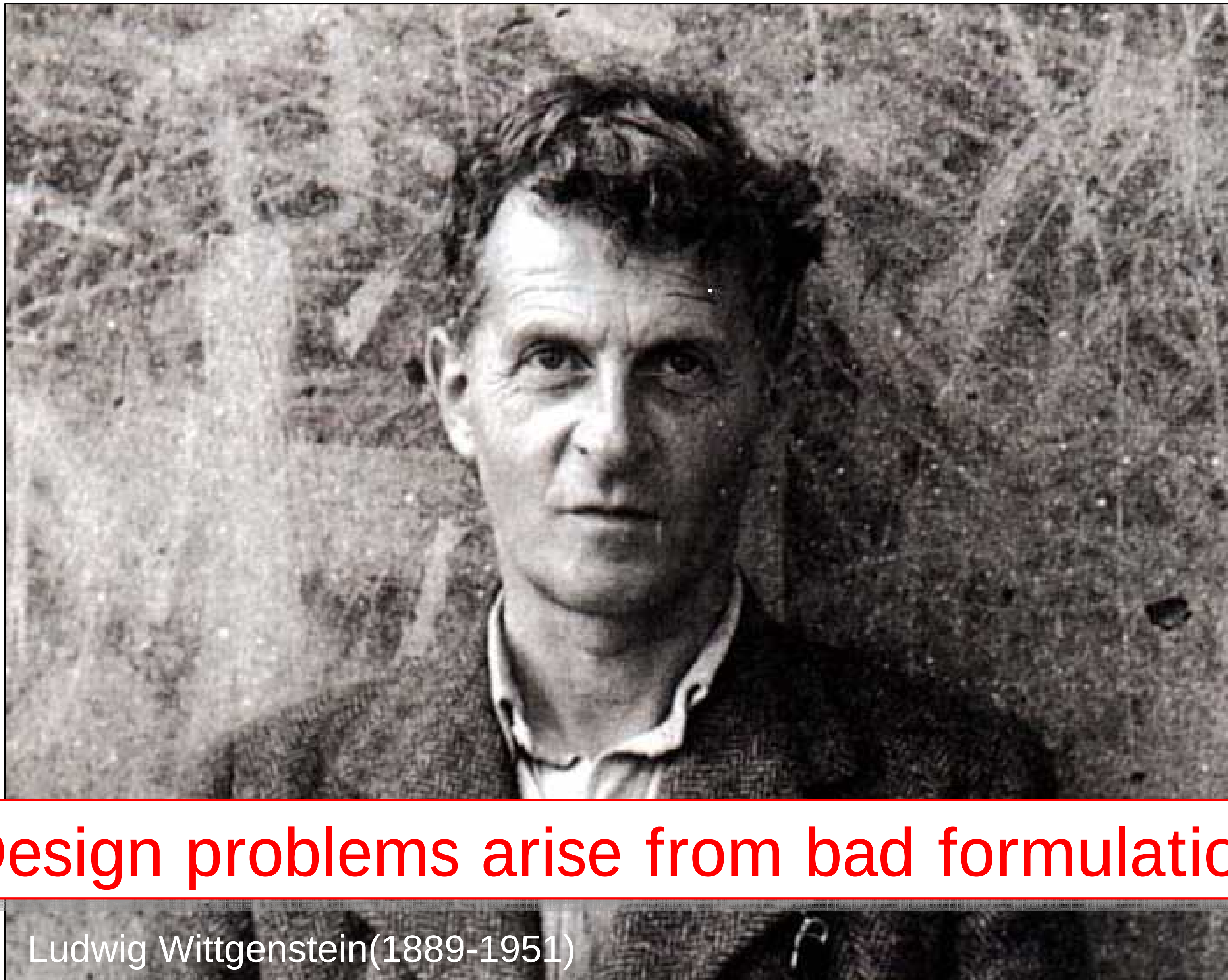
Never confuse models with “the truth”

Back to the amplifier...



Kirchoffs first law is not obeyed!

6. What is the current through the load?

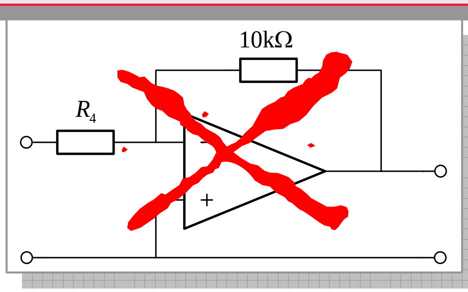


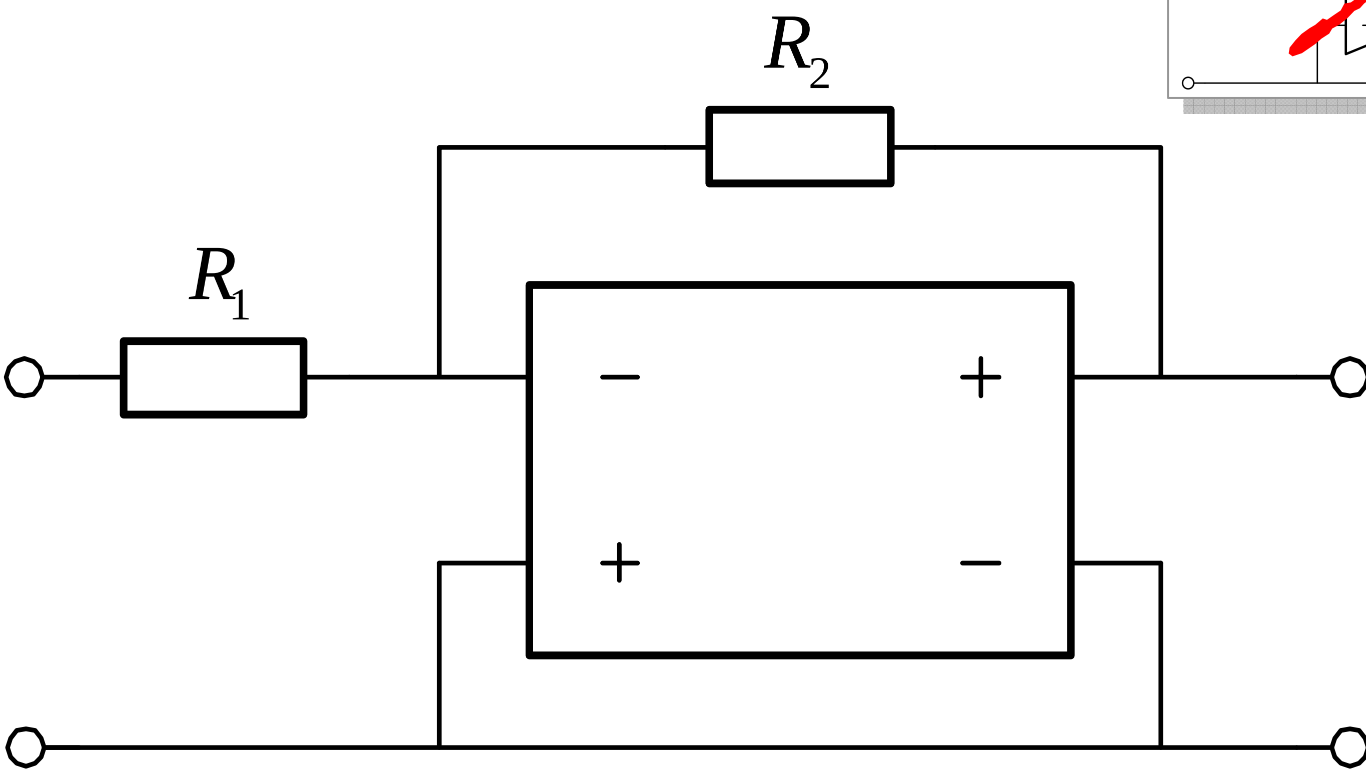
Design problems arise from bad formulations

Ludwig Wittgenstein(1889-1951)

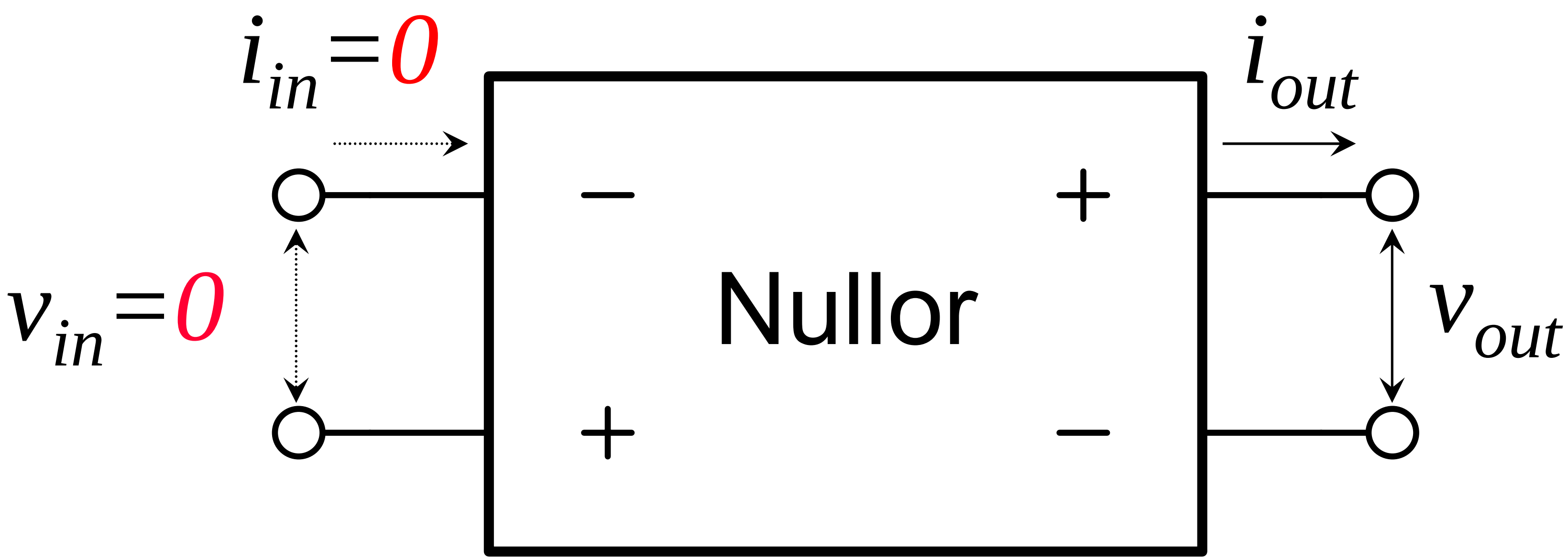
Amplifier design

An amplifier with a nullor



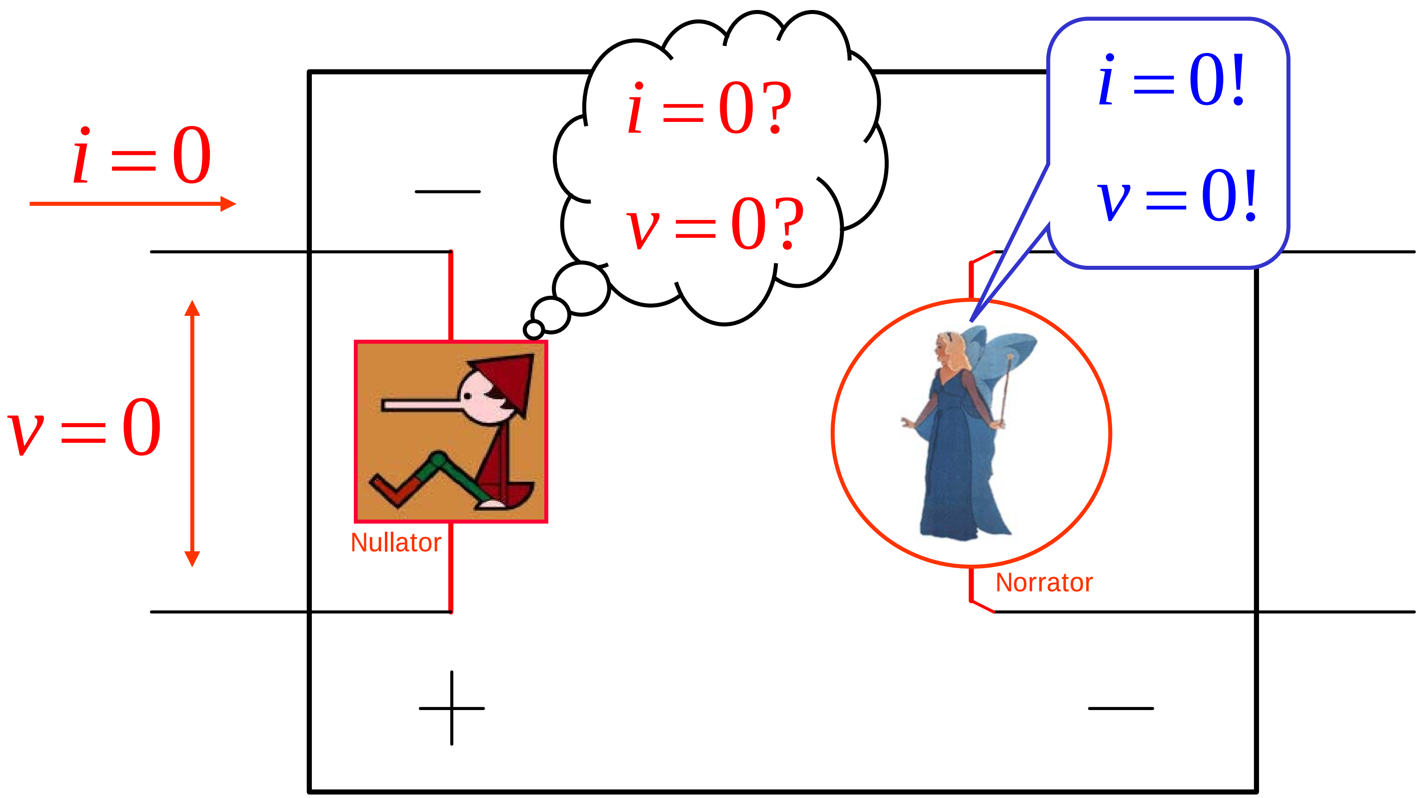


Nullor



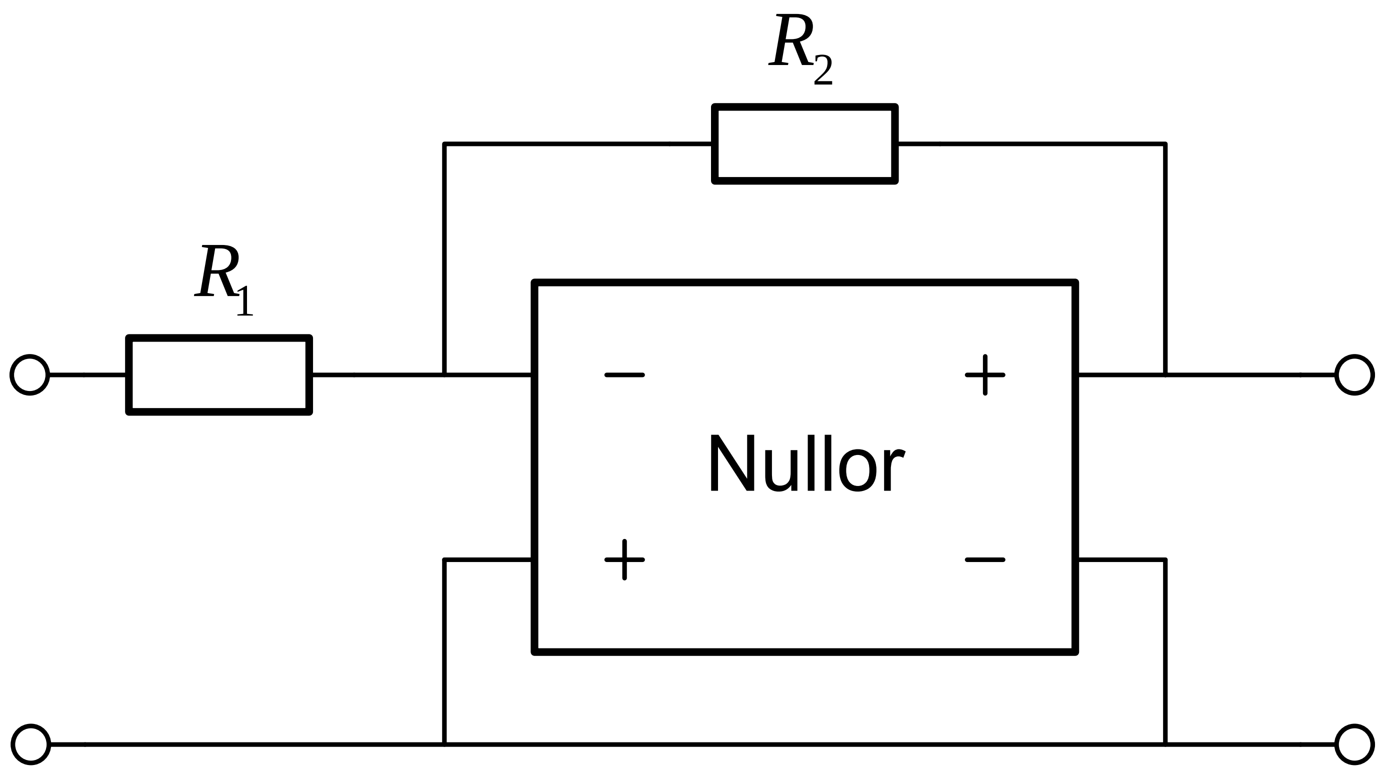
Input current and input voltage of the nullor **are made zero** by the output signals of the nullor

Inside the Nullor



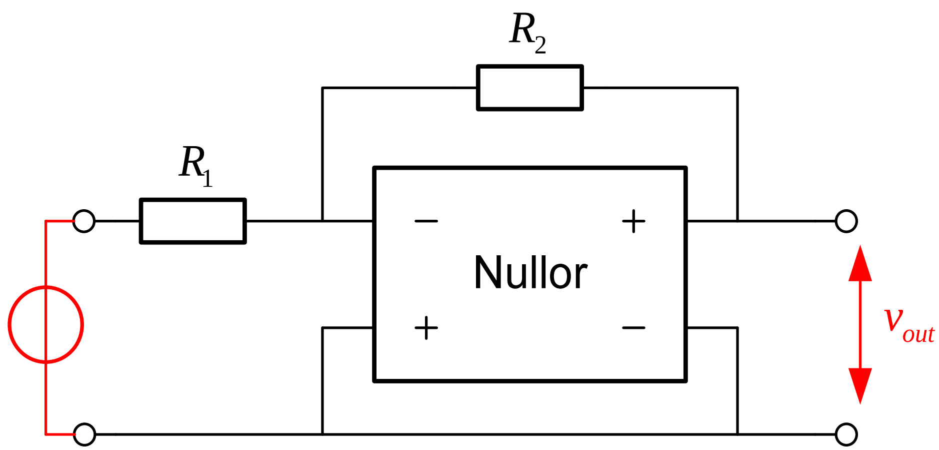
Input current and input voltage of the nullor **are made zero** by the output signals of the nullor

What is the transfer T of this amplifier?



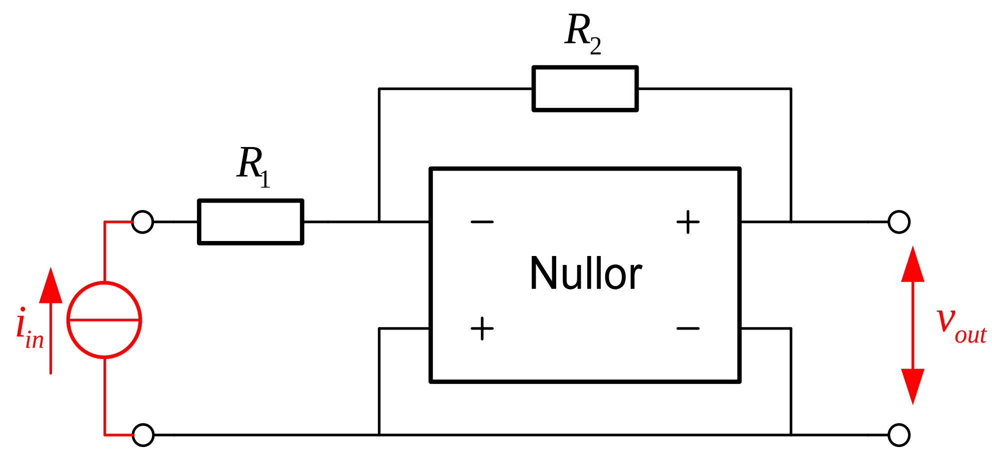
The transfer T of this amplifier

$$T = -\frac{R_2}{R_1}$$



Another transfer T of this amplifier

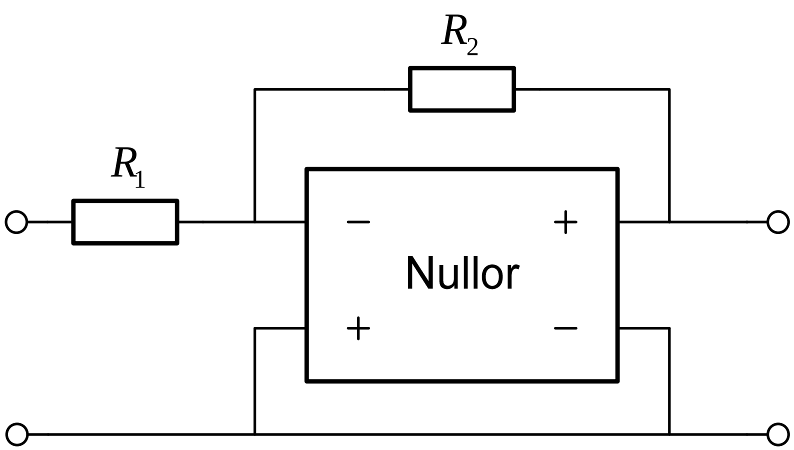
$$T_{another} = -R_2$$



Joseph Henry

The seeds of great discovery are constantly floating around us, but they only take root in minds well prepared to receive them

The chain matrix of this amplifier



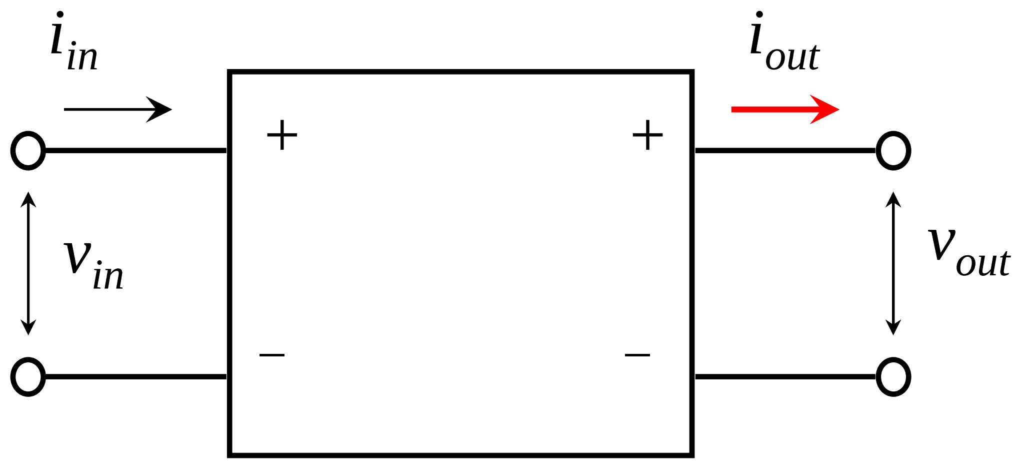
$$\begin{pmatrix} v_{in} \\ i_{in} \end{pmatrix} = \begin{pmatrix} -\dfrac{R_1}{R_2} & 0 \\ -\dfrac{1}{R_2} & 0 \end{pmatrix} \begin{pmatrix} v_{out} \\ i_{out} \end{pmatrix}$$

$$T = -\frac{R_2}{R_1}$$

$$T_{another} = -R_2$$

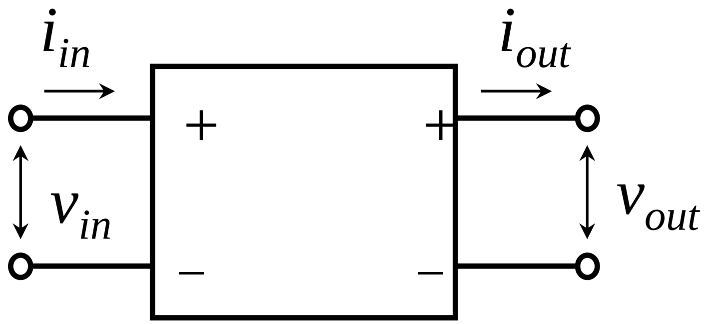
$$T_{again\ another} = ??$$

The two-port and its chain matrix



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

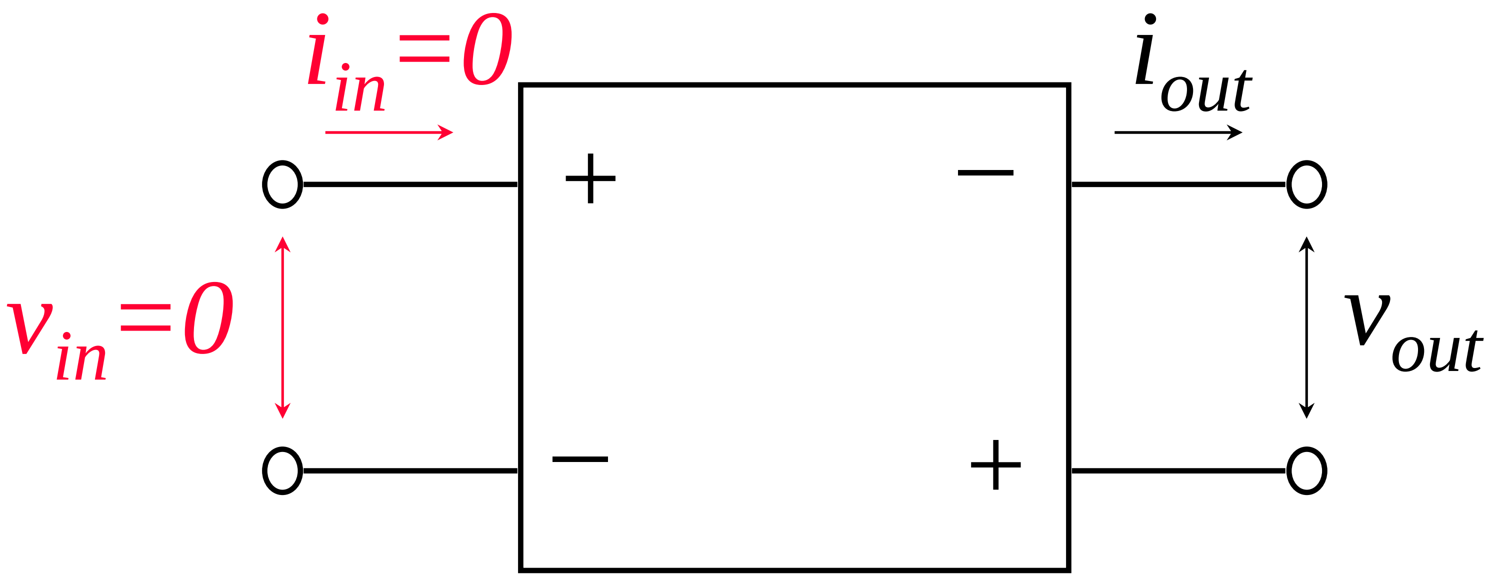
The two-port and its chain matrix



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

$$A = \left.\frac{v_{in}}{v_{out}}\right|_{i_{out}=0} \qquad B = \left.\frac{v_{in}}{i_{out}}\right|_{v_{out}=0} \qquad C = \left.\frac{i_{in}}{v_{out}}\right|_{i_{out}=0} \qquad D = \left.\frac{i_{in}}{i_{out}}\right|_{v_{out}=0}$$

Nullor



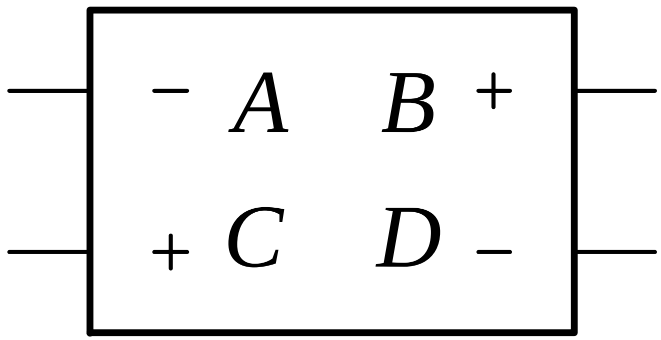
Input current and input voltage of the nullor **are made zero** via the output signals of the nullor

$$\begin{pmatrix} v_{in} \\ i_{in} \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} v_{out} \\ i_{out} \end{pmatrix}$$

Accurate amplification

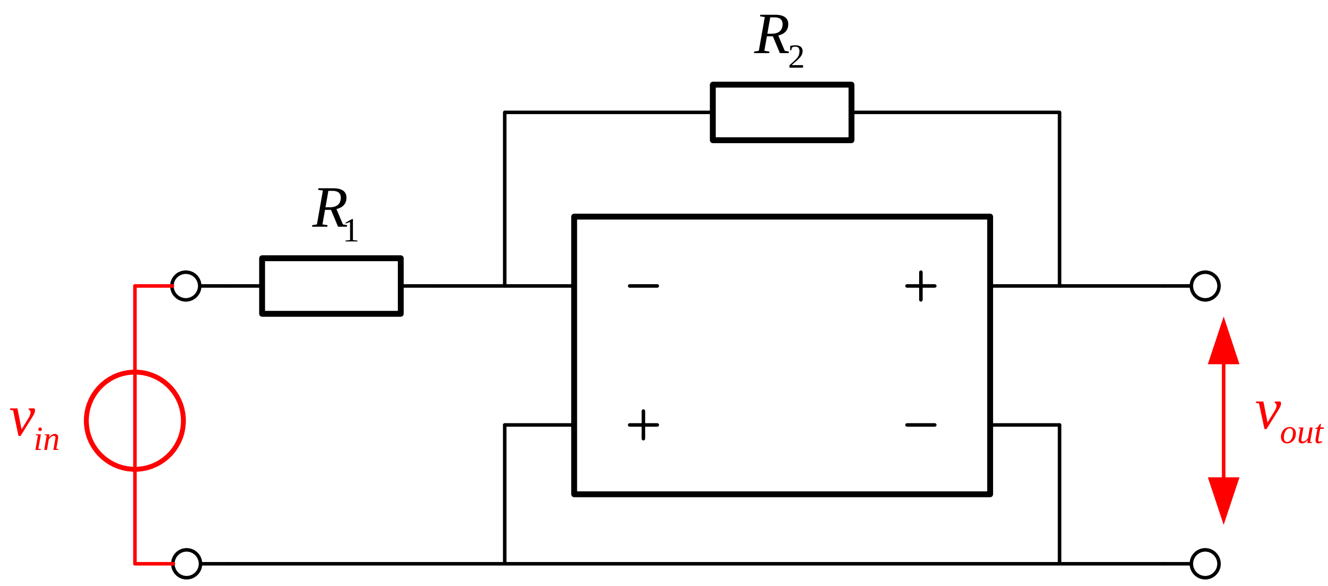
Information from source to load

- Signal power is enlarged
- Information stays unaltered



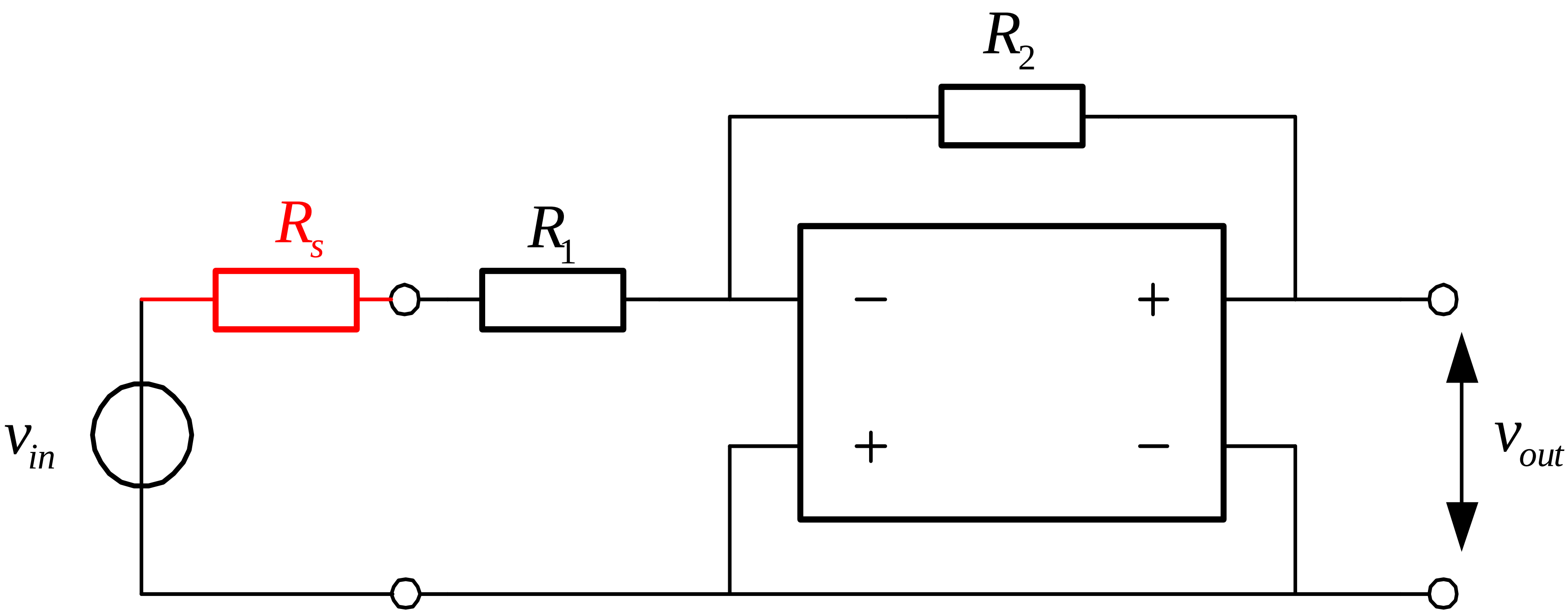
A,B,C,D constant
A,B,C,D accurately known

A voltage-to-voltage amplifier



$$\begin{pmatrix} -\dfrac{R_1}{R_2} & 0 \\ -\dfrac{1}{R_2} & 0 \end{pmatrix}$$

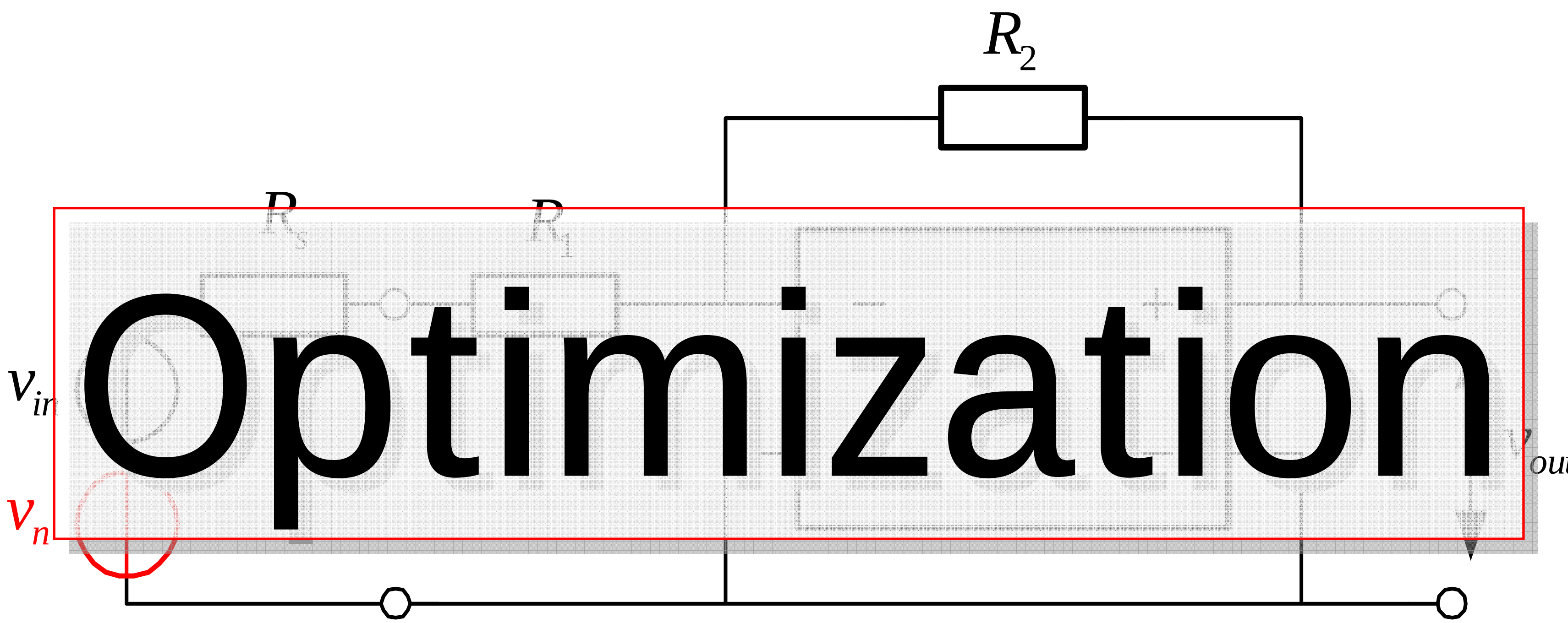
$$\boxed{A_v = -\frac{R_2}{R_1}}$$



$$A_v = -\frac{R_2}{R_1 + R_s}$$

Amplification factor becomes inaccurate.

Optimization



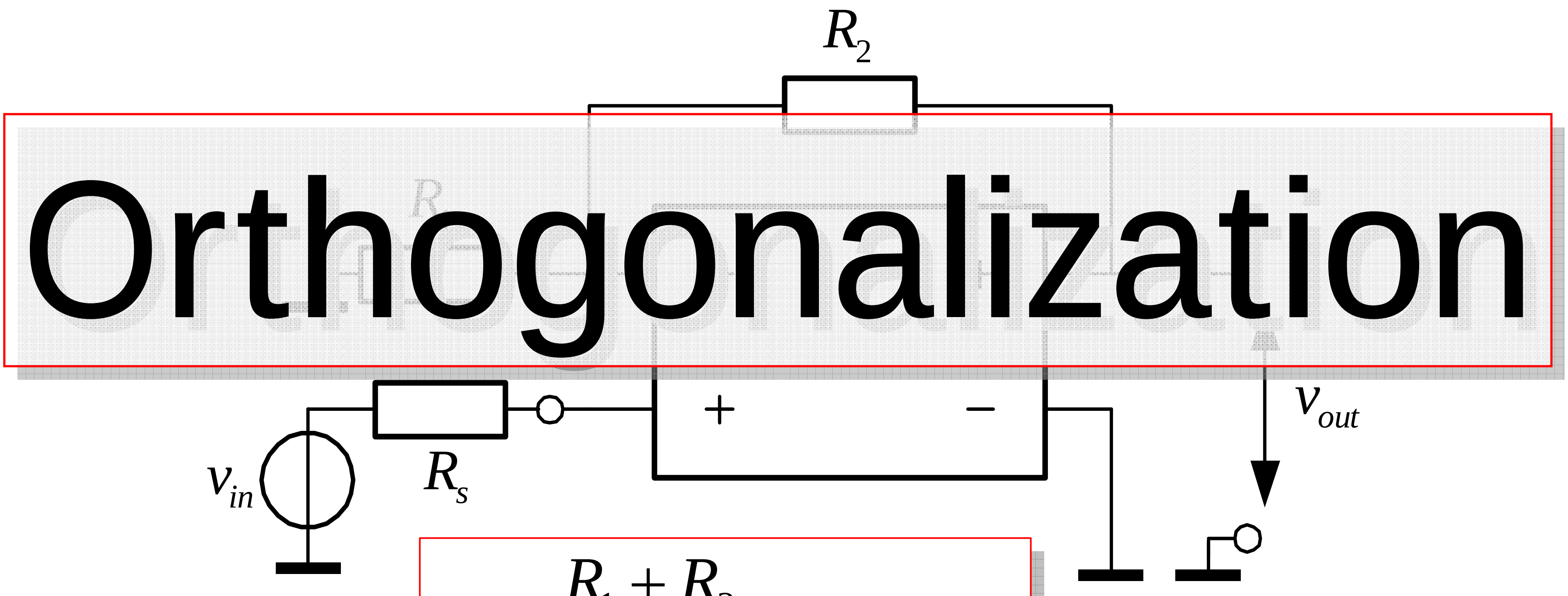
$$A_v = -\frac{R_2}{R_1 + R_s}$$

$$S_{v_n} = 4kT\left(R_1 + R_s\right) // R_2$$

☹ Information is disturbed

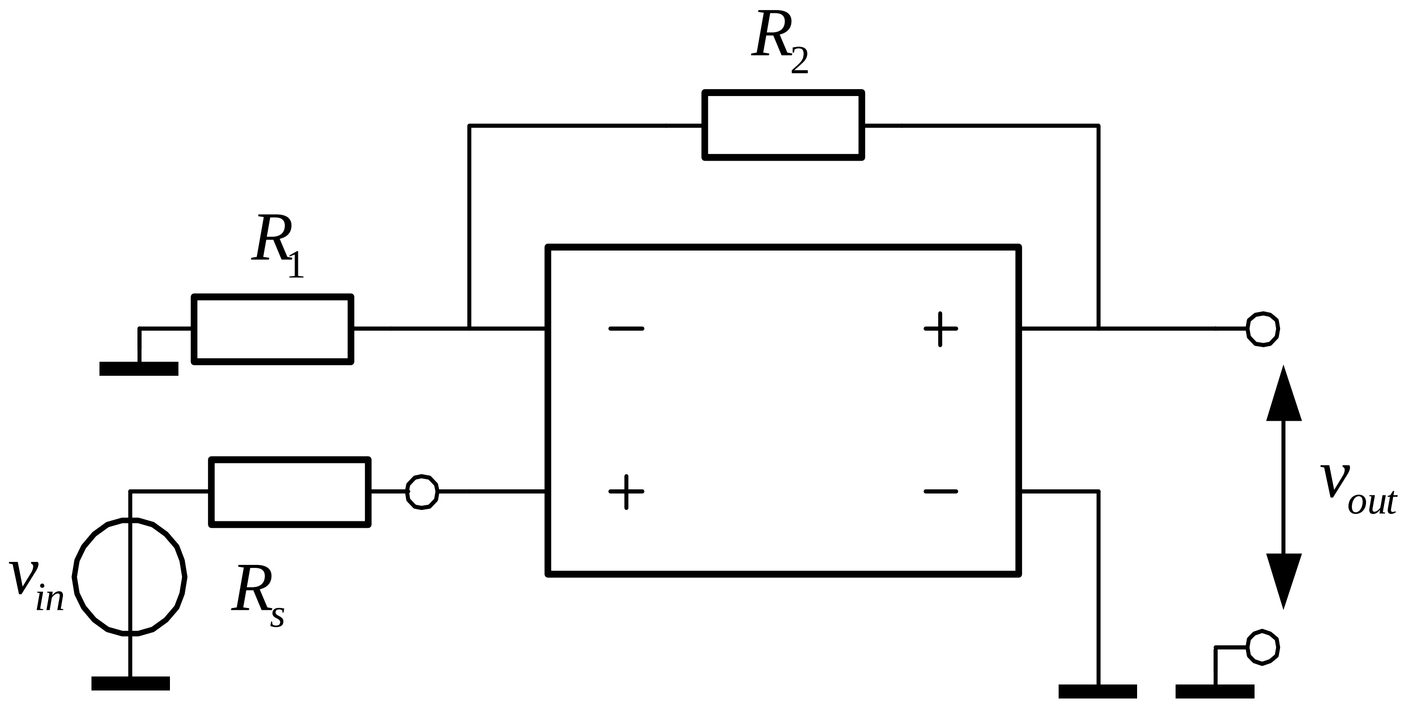
☹ Amplification factor still inaccurate.

Change topology



$$A_v = \frac{R_1 + R_2}{R_1}$$

$$S_{v_n} = 4kT(R_s + R_1 // R_2)$$

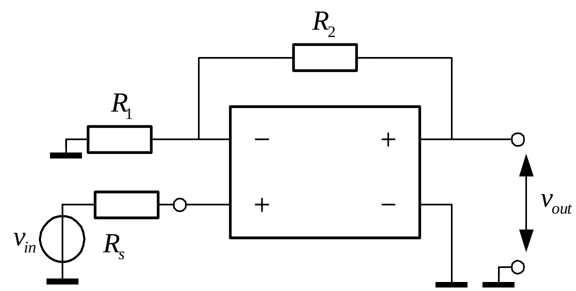


$$A_v = \frac{R_1 + R_2}{R_1}$$

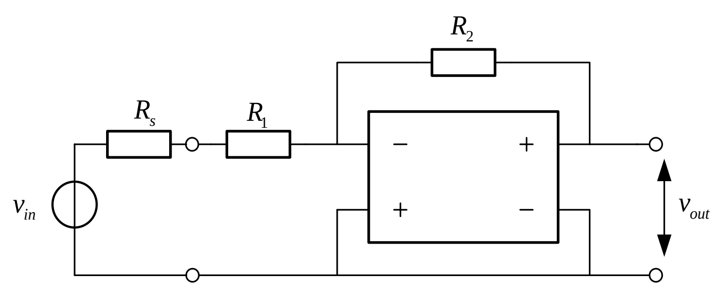
$$S_{v_n} = 4kT(R_s + R_1 // R_2)$$

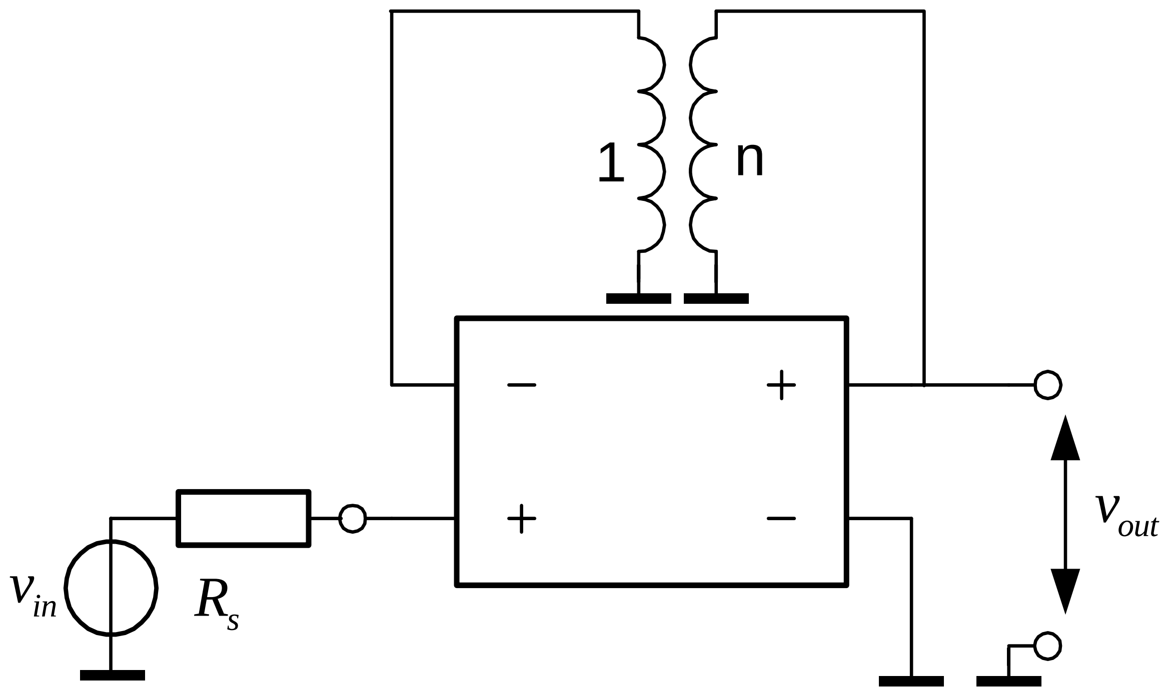
$$i_{fb} = \frac{v_{out}}{R_1 + R_2}$$

Orthogonalization



Optimization





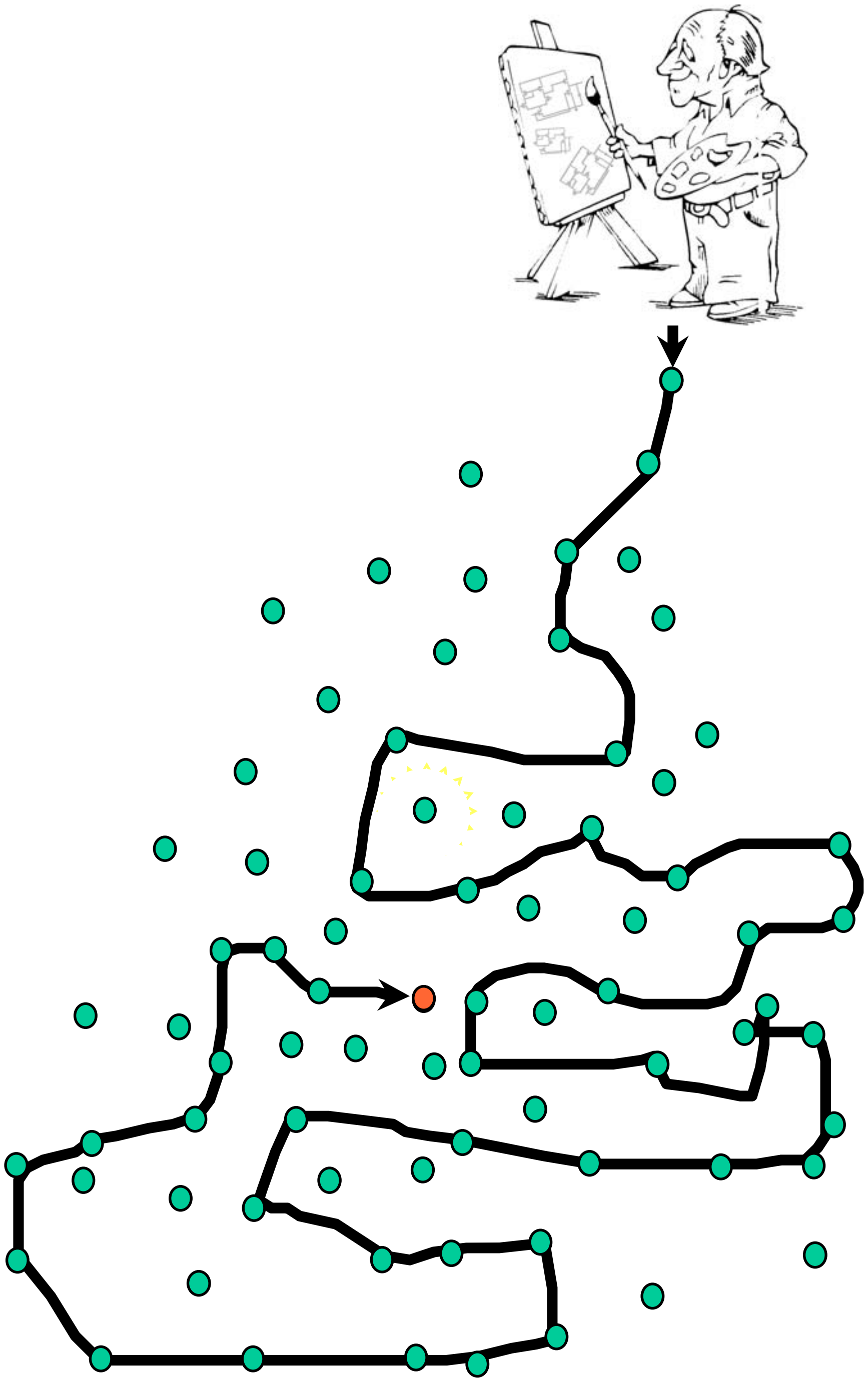
$$A_v = n$$
$$S_{v_n} = 4kTR_s$$
$$i_{fb} = 0$$

$$A_v = \frac{R_1 + R_2}{R_1}$$
$$S_{v_n} = 4kT(R_s + R_1 // R_2)$$
$$i_{fb} = \frac{v_{out}}{R_1 + R_2}$$

Right choice

Orthogonalization

Optimization



The “right” choice:

- Start? (as usual?)
- Analyze?
- Optimize?
- Orthogonality?
- Specifications?
- Criteria?

The criteria

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

1. Noise
2. Signal power (distortion)
3. Bandwidth

And what about supply voltage, current, power consumption, technology etc.?

Correlated properties

1. Noise
2. Signal power (distortion)
3. Bandwidth

- Optimization

- Orthogonalization

Orthogonal properties (2)

- Properties are generally not orthogonal
- But design as if
- **Make it right**

As if...

When optimizing bandwidth:

- Small-signal models (no non-linearity)
- No noise

When optimizing noise behavior:

- Small-signal models (no non-linearity)
- No bandwidth details

When optimizing non-linear behavior (distortion):

- No dynamic effects
- No noise

The most orthogonal sequence?

bandwidth – noise – distortion

bandwidth – distortion - noise

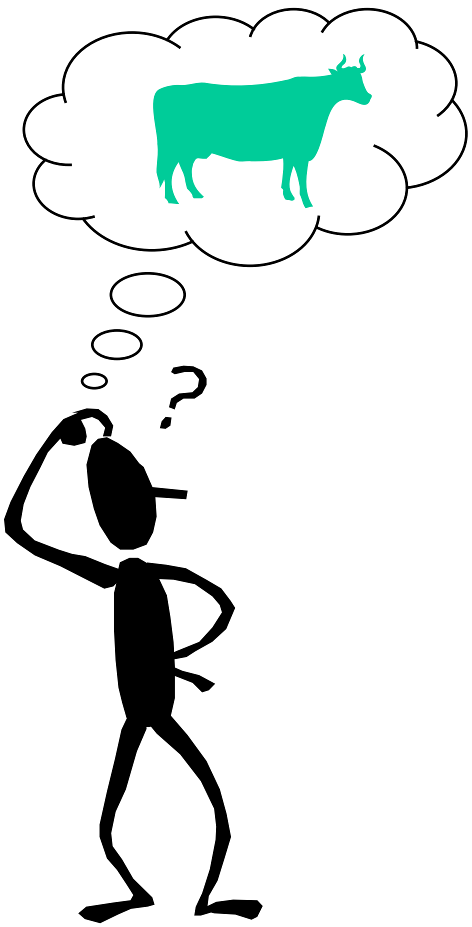
noise - bandwidth – distortion

noise – distortion - bandwidth

distortion - noise – bandwidth

distortion – bandwidth - noise

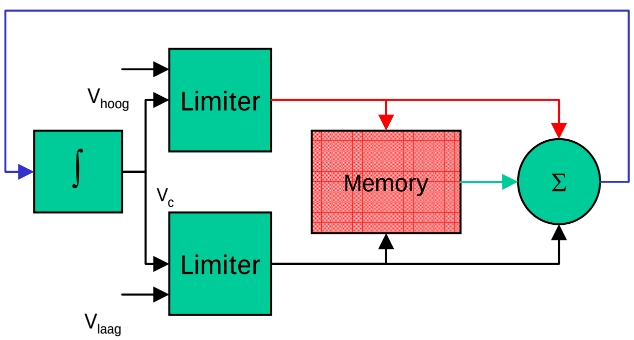
Know which problem to solve first

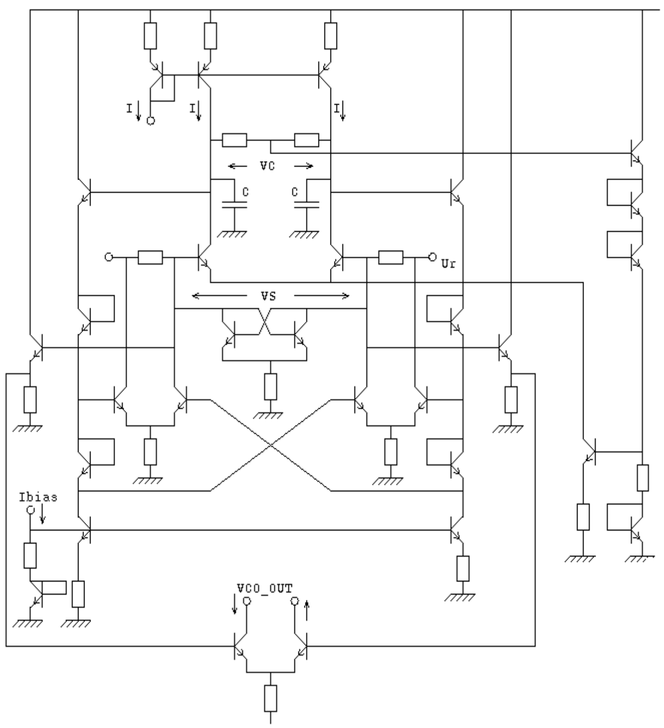


- Is it a cow?
- Is it green?
- Is it an animal?

See the structure: Create Hierarchy!

Global → Detail





Efficient design

- The right design step at the right time
- A design step occurs only once

Orthogonality, hierarchy, classification

Efficient design (2)

Reduce the search space as fast as possible.

Look for “fast” criteria:

- Necessary but not sufficient (e.g. *LP* -product)

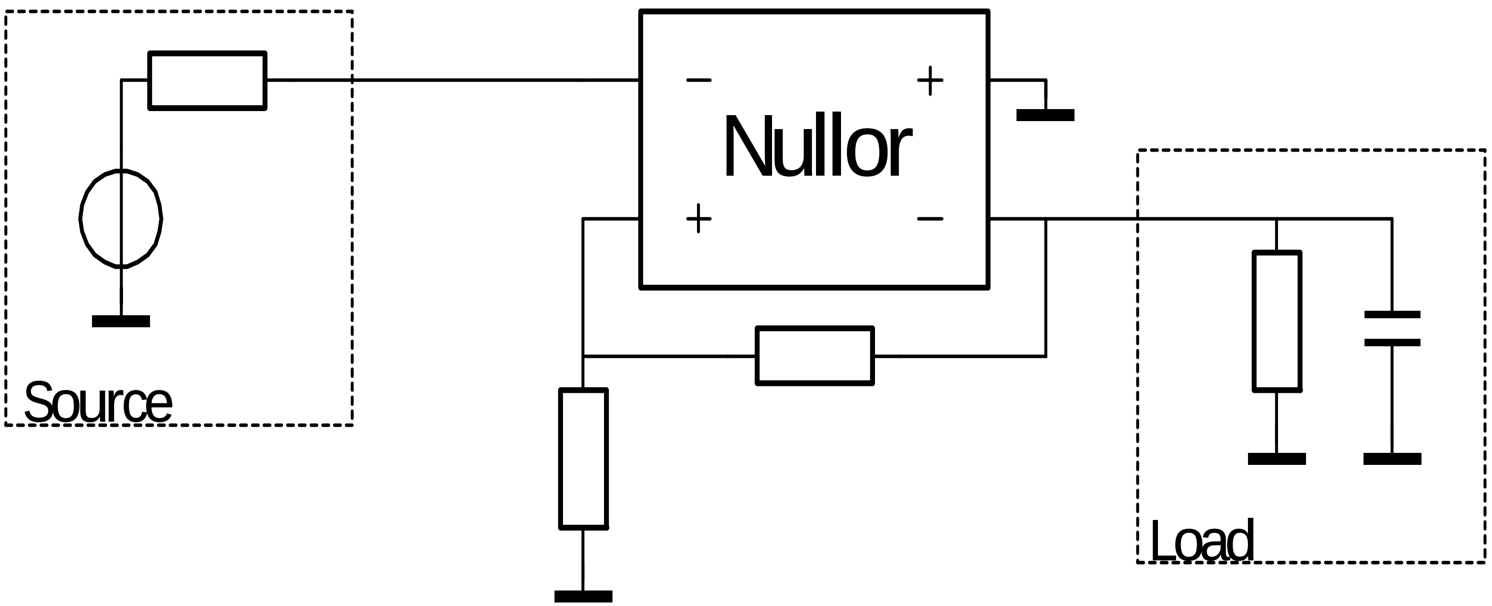
Extensive calculations only when it “makes sense”

- Simplest model that suffices

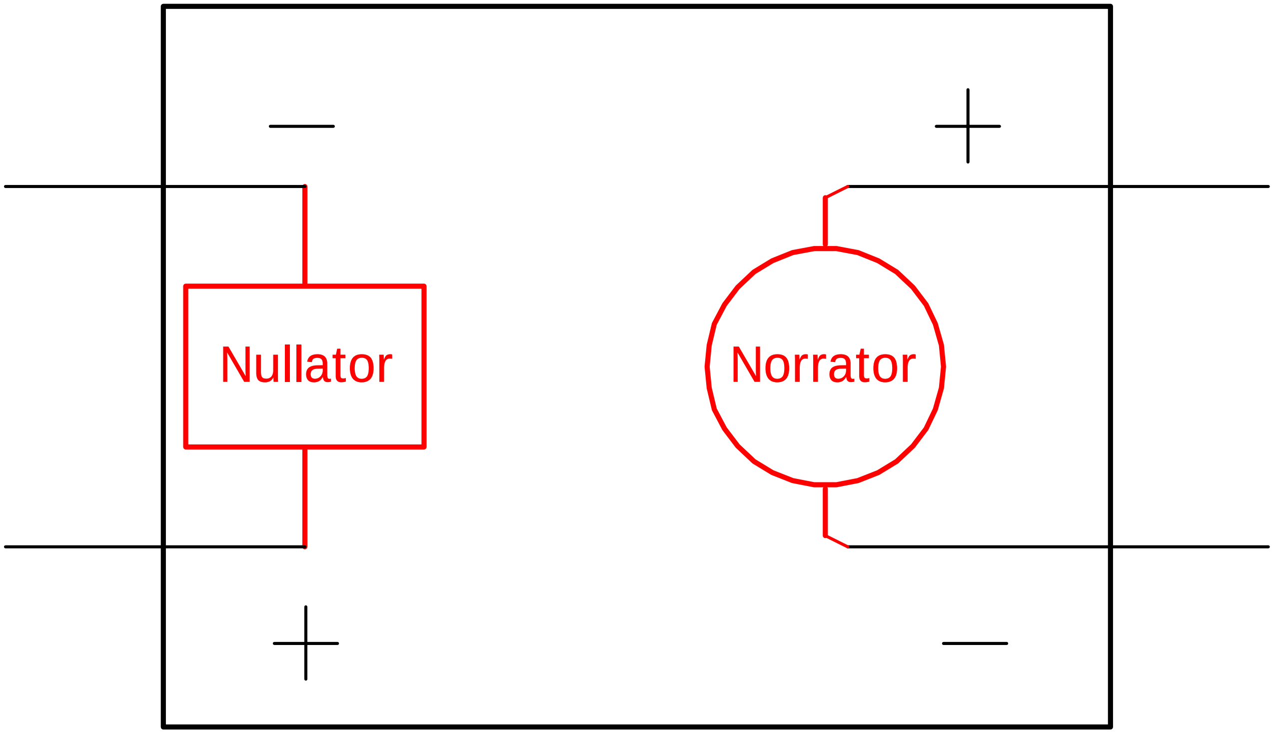
Attitude

- Know exactly what you want
- Use second best, if you can’t have it
- *Know* the penalty

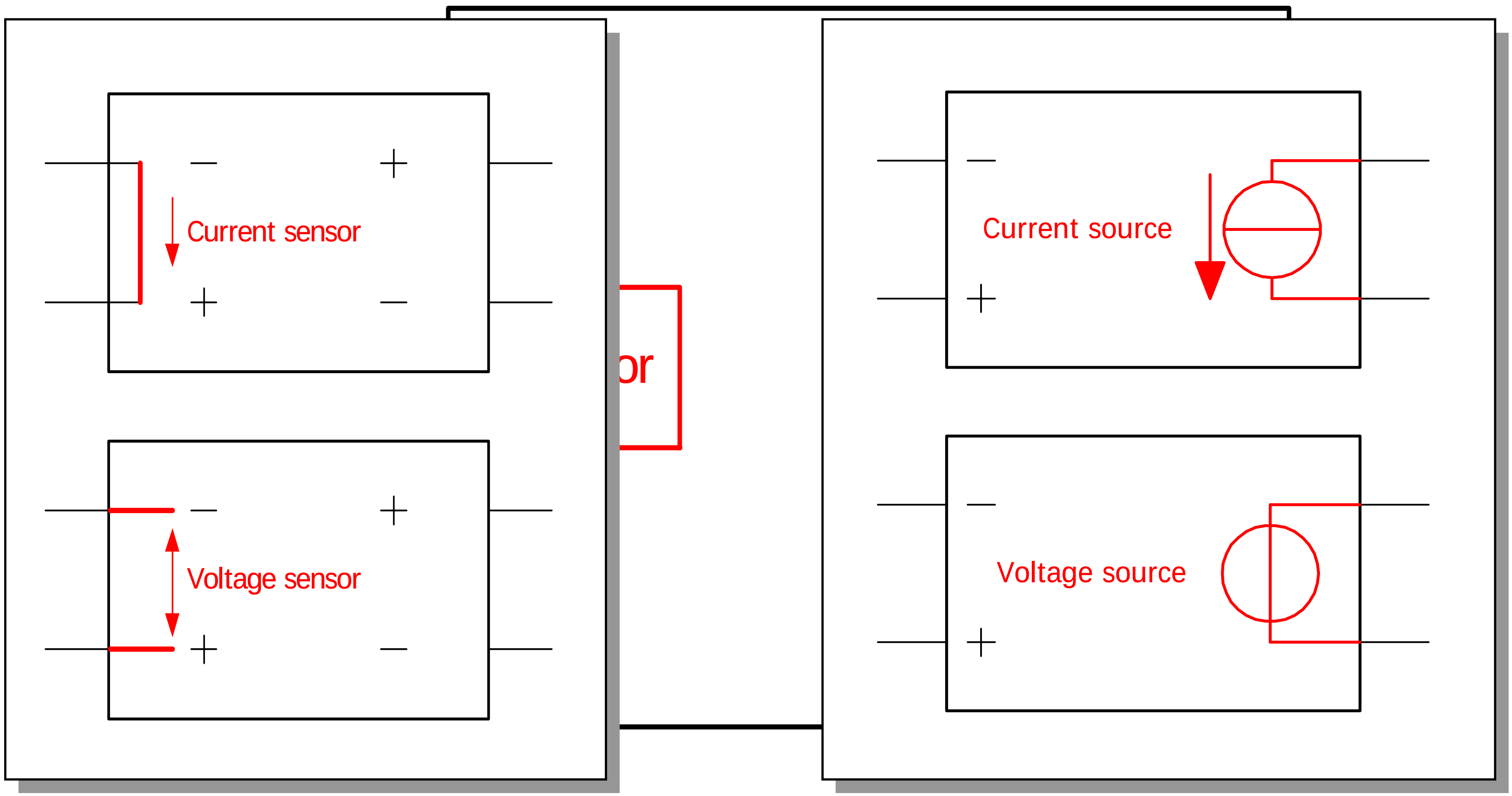
Voltage amplifier, what’s in the nullor?



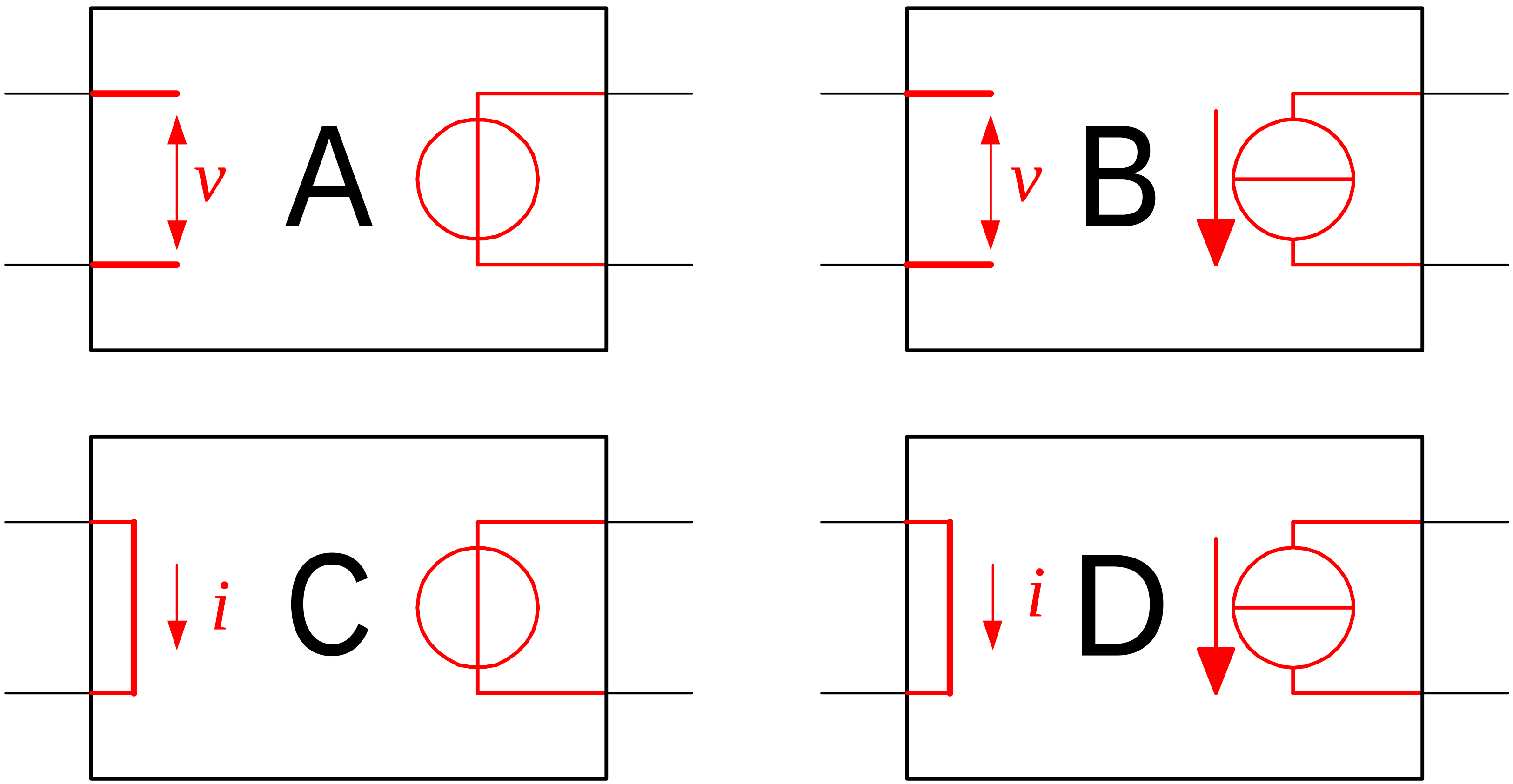
Inside the Nullor



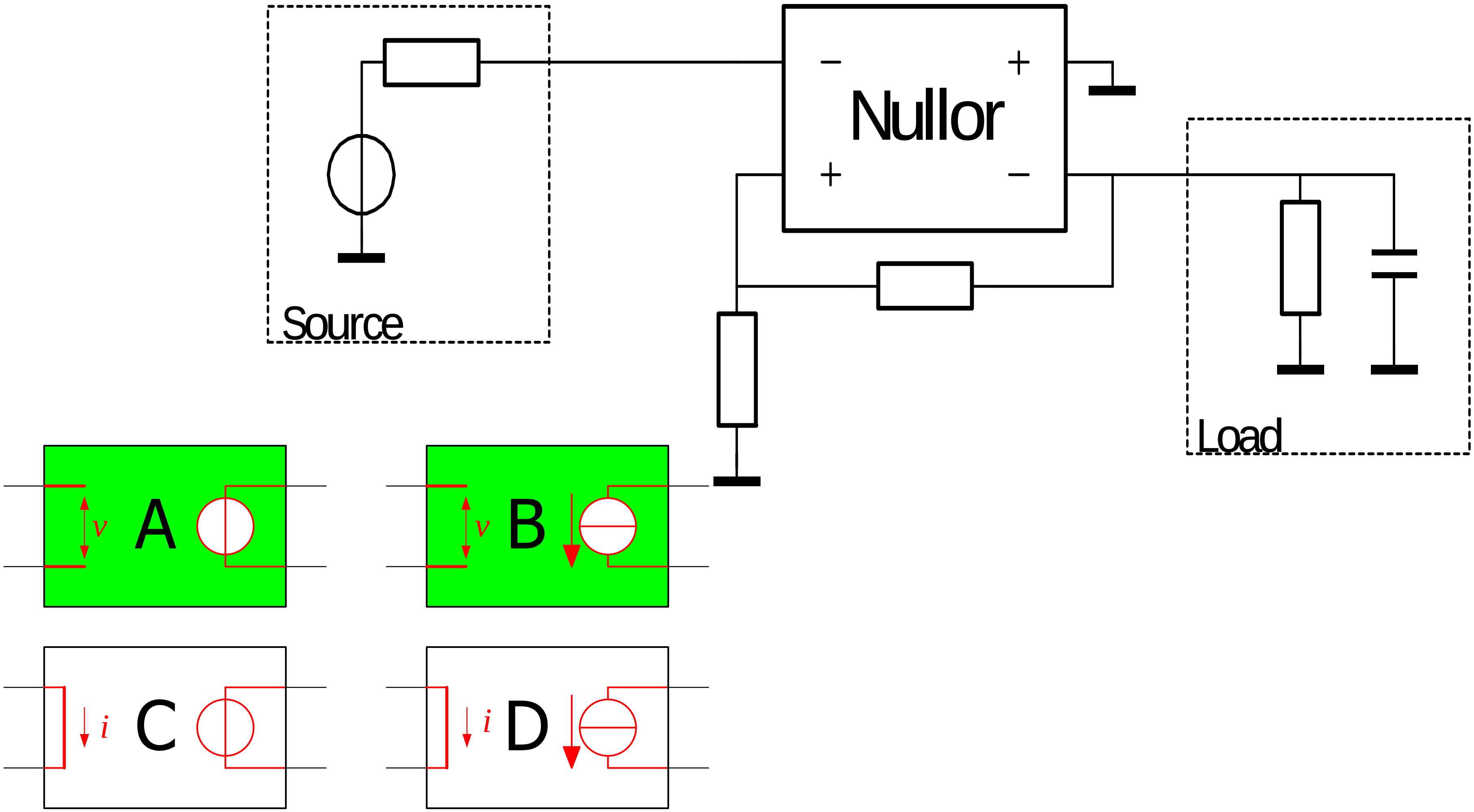
Nullator? Norrator?



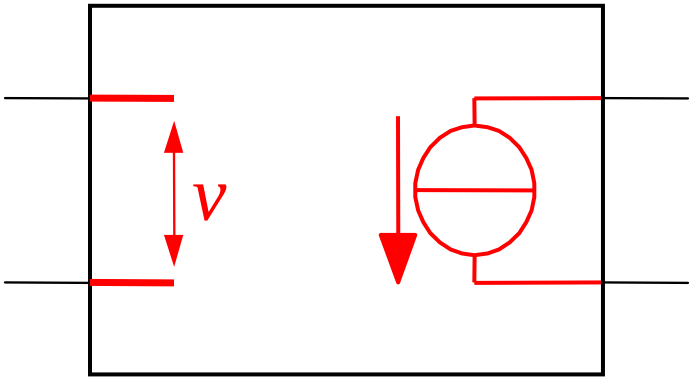
practical nullor implementations



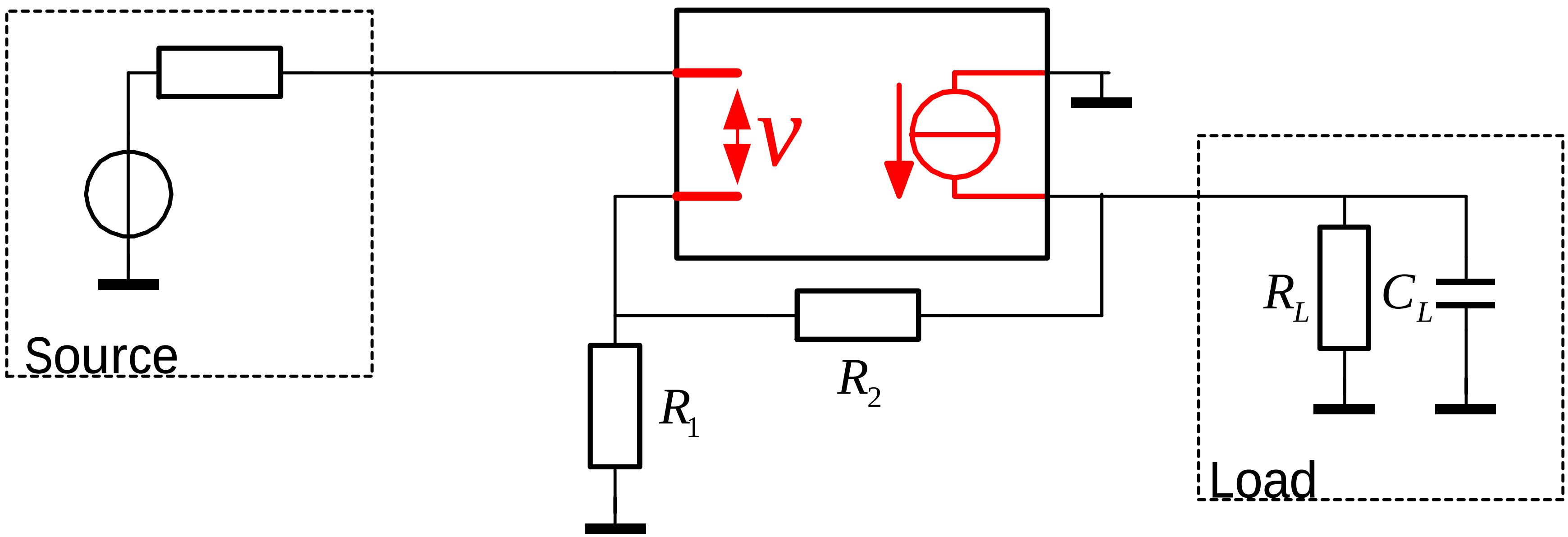
Choose



The experts with practical experience...

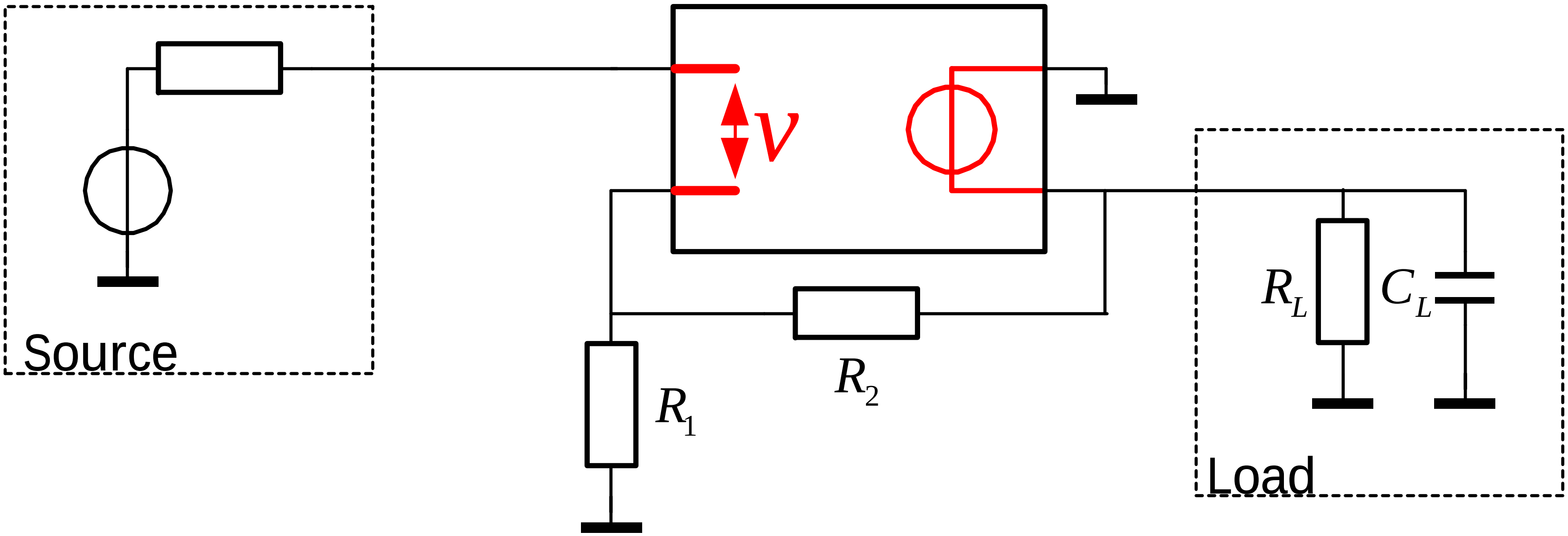


Loopgain with B-type block



$$L = \frac{1}{B} R_1 \left(\frac{\dfrac{R_L}{1 + j\omega R_L C_L}}{\dfrac{R_L}{1 + j\omega R_L C_L} + R_1 + R_2} \right)$$

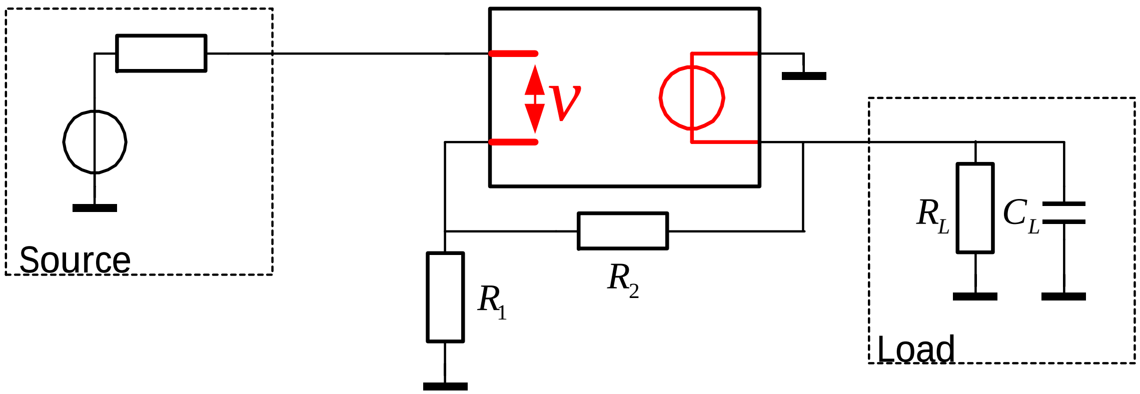
Loopgain with A-type block

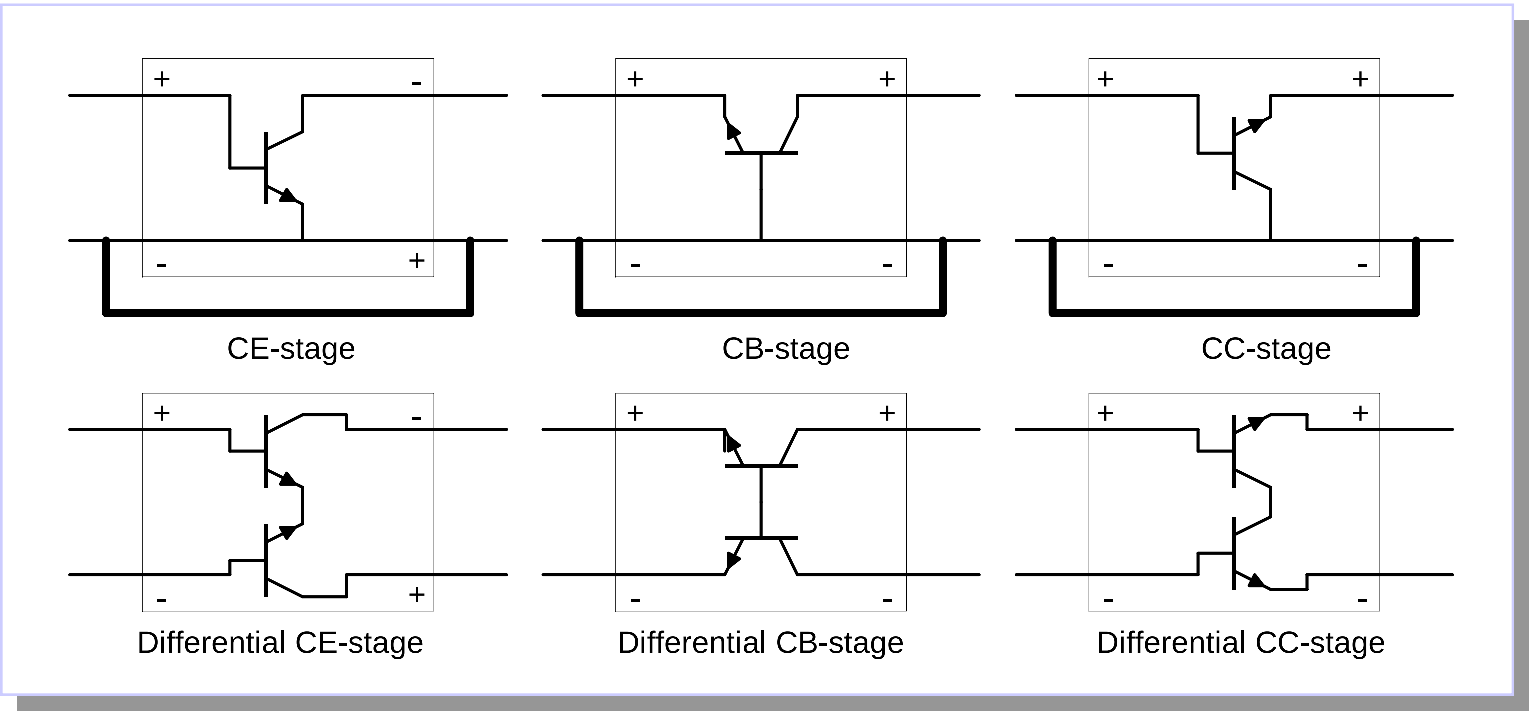


$$L = \frac{1}{A}\left(\frac{R_1}{R_1 + R_2}\right)$$

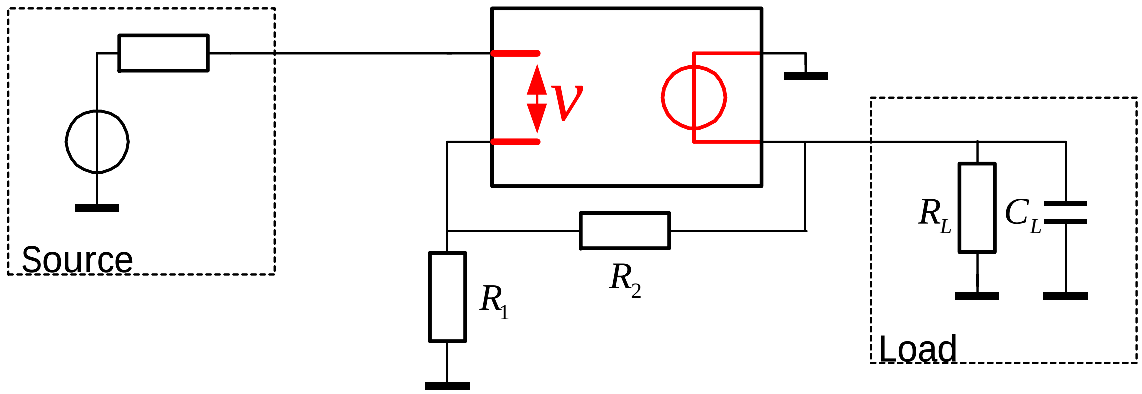
$$L = \frac{1}{B} R_1 \left(\frac{\dfrac{R_L}{1 + j\omega R_L C_L}}{\dfrac{R_L}{1 + j\omega R_L C_L} + R_1 + R_2} \right)$$

Which transistor stage?

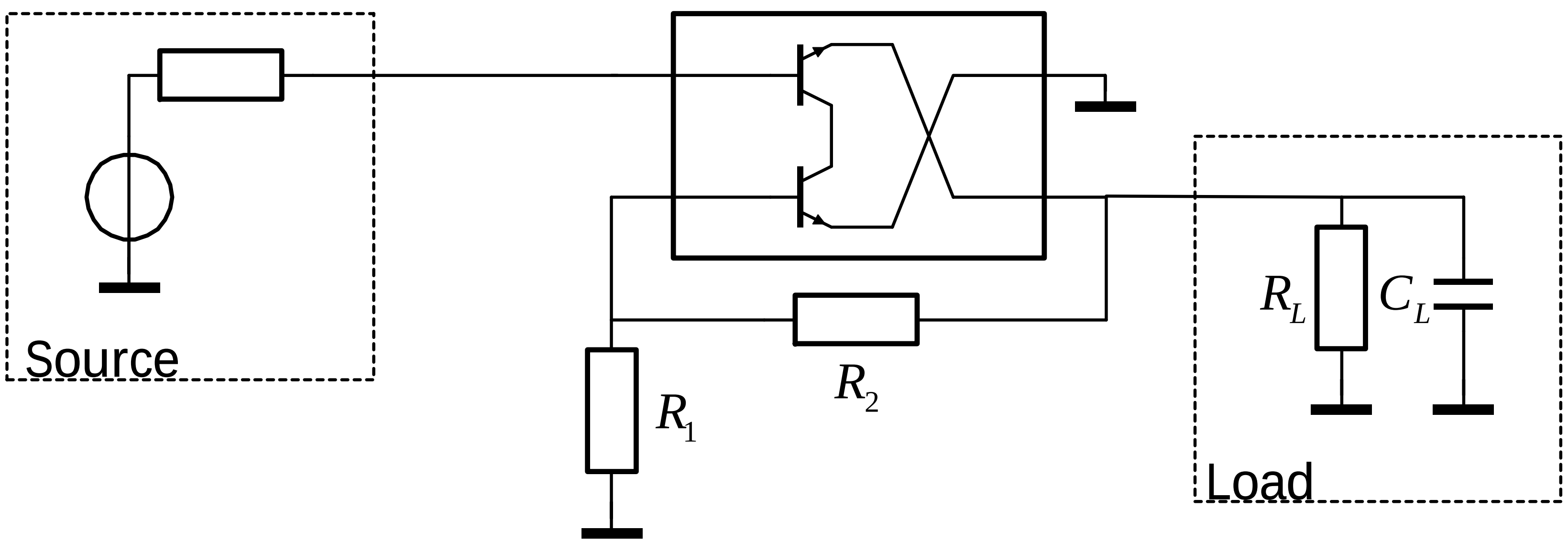




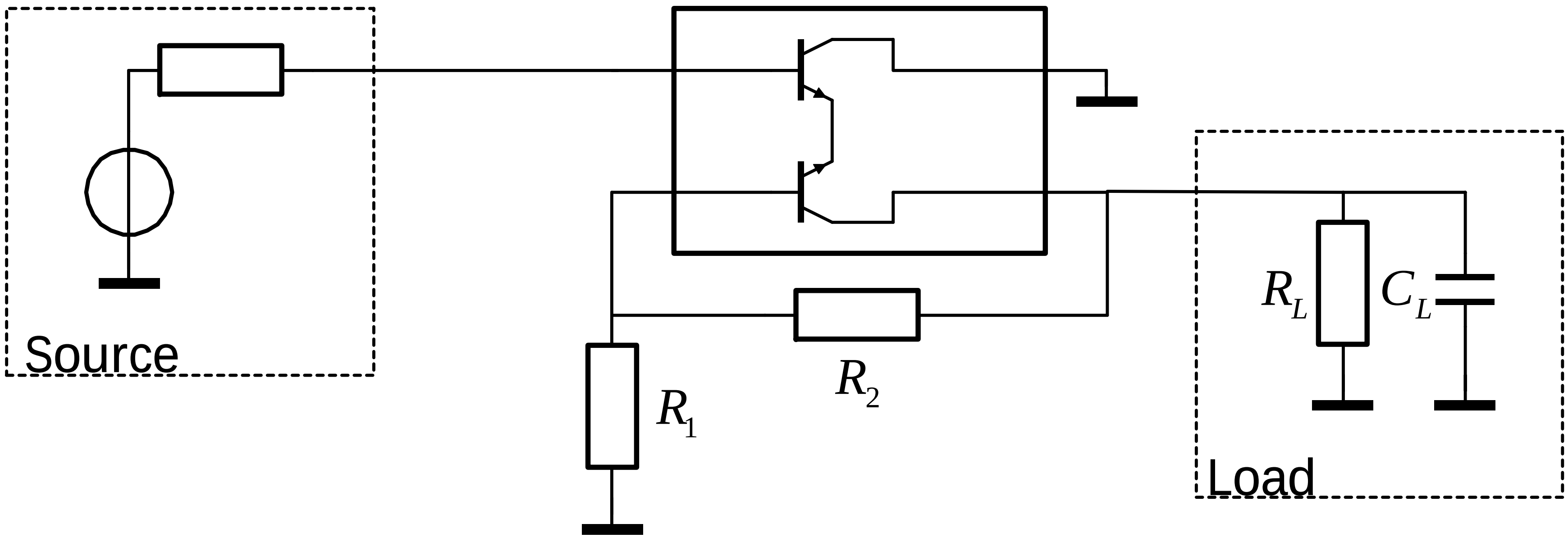
Voltage amplifier with A-type block



$$L<1$$

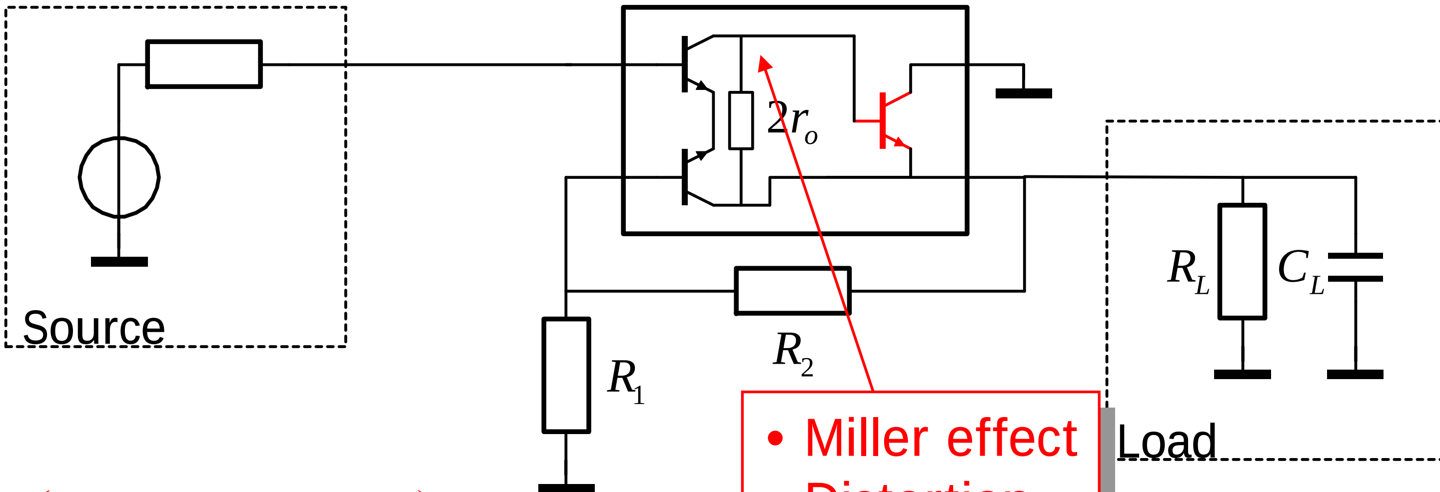


Back to the B-type solution (told you so....)



$$L = \frac{1}{2B_{CE}} R_1 \left(\frac{\dfrac{R_L}{1 + j\omega R_L C_L}}{\dfrac{R_L}{1 + j\omega R_L C_L} + R_1 + R_2} \right) > 1$$

The “expert” solution



- Miller effect
- Distortion

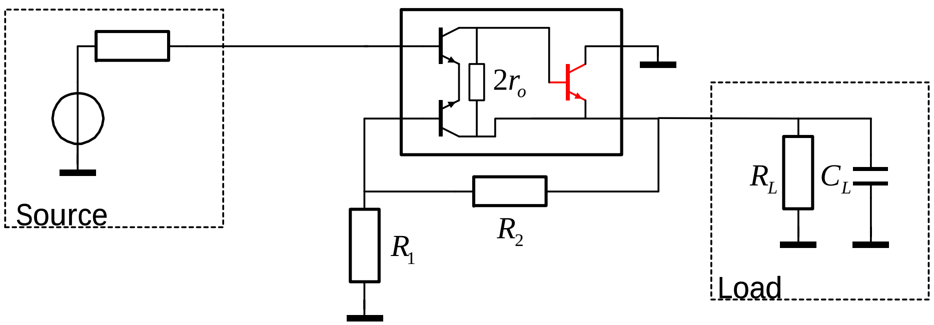
$$L = \frac{1}{A_{CE}A_{CC}}\left(\frac{R_1}{R_1+R_2}\right)\frac{\left(\dfrac{\dfrac{R_L}{1+j\omega R_L C_L}\left(R_1+R_2\right)}{\dfrac{R_L}{1+j\omega R_L C_L}+R_1+R_2}\right)}{2r_o D_{CC}+\left(\dfrac{\dfrac{R_L}{1+j\omega R_L C_L}\left(R_1+R_2\right)}{\dfrac{R_L}{1+j\omega R_L C_L}+R_1+R_2}\right)}$$

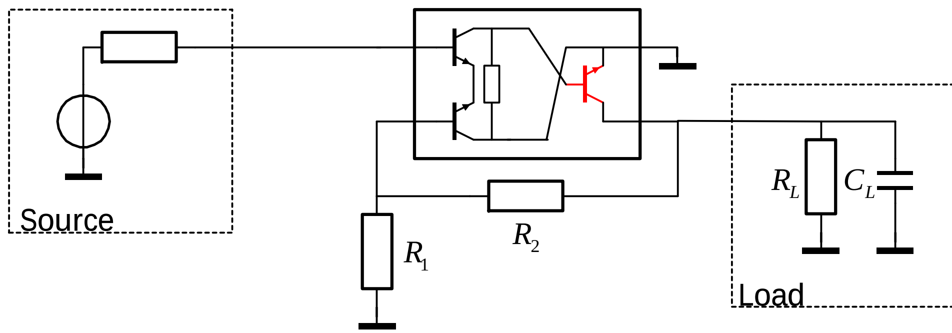
$$\lim_{r_o\to\infty} L = \frac{1}{2B_{CE}}\frac{1}{D_{CC}}R_1\left(\frac{\dfrac{R_L}{1+j\omega R_L C_L}}{\dfrac{R_L}{1+j\omega R_L C_L}+R_1+R_2}\right)$$

$$A_{CE} = \frac{B_{CE}}{r_o}$$

r_o should be ***low***???

“Expert” versus “logic”





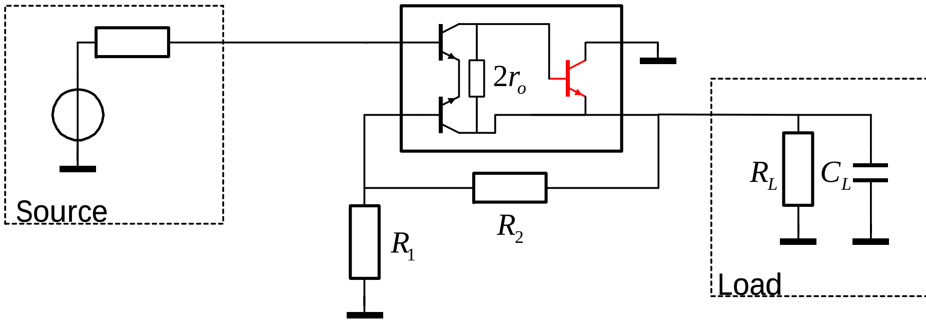
$$L = \frac{1}{A_{CE}A_{CC}}\left(\frac{R_1}{R_1+R_2}\right)\frac{\left(\dfrac{\dfrac{R_L}{1+j\omega R_L C_L}\left(R_1+R_2\right)}{\dfrac{R_L}{1+j\omega R_L C_L}+R_1+R_2}\right)}{2r_o D_{CC}+\left(\dfrac{\dfrac{R_L}{1+j\omega R_L C_L}\left(R_1+R_2\right)}{\dfrac{R_L}{1+j\omega R_L C_L}+R_1+R_2}\right)}$$

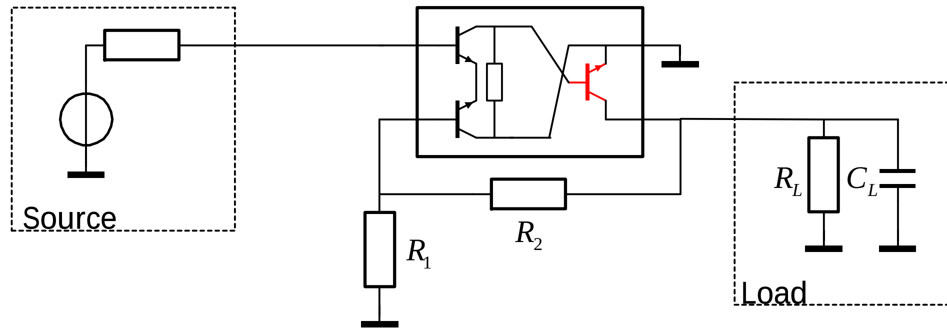
$$L = \frac{1}{2B_{CE}}\frac{1}{D_{CC}}R_1\left(\frac{\dfrac{R_L}{1+j\omega R_L C_L}}{\dfrac{R_L}{1+j\omega R_L C_L}+R_1+R_2}\right)$$

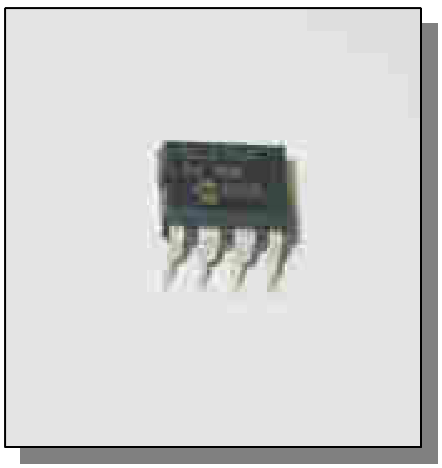
☹ miller effect first stage
☹ distortion and clipping first stage
☺ Loopgain not(less) load dependent

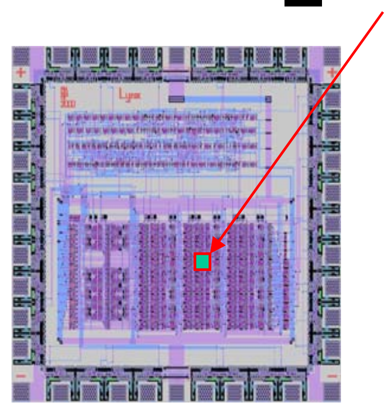
☺ no miller effect
☺ less distortion
☹ Load dependent loopgain

Which solution when?









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

☺ no miller effect
☺ less distortion
😐 Load dependent loopgain

Alternatives

TEXAS INSTRUMENTS
www.ti.com

TPA2013D1

SLOS520–AUGUST 2007

2.7-W CONSTANT OUTPUT POWER CLASS-D AUDIO AMPLIFIER WITH INTEGRATED BOOST CONVERTER

FEATURES

- High Efficiency Integrated Boost Converter (Over 90% Efficiency)
- 2.2-W into an 8-Ω Load from a 3.6-V Supply
- 2.7-W into an 4-Ω Load from a 3.6-V Supply
- Operates from 1.8 V to 5.5 V
- Efficient Class-D Prolongs Battery Life
- Independent Shutdown for Boost Converter and Class-D Amplifier
- Differential Inputs Reduce RF Common Noise
- Built-in INPUT Low Pass Filter Decreases RF and Out of Band Noise Sensitivity
- Synchronized Boost and Class-D Eliminates Beat Frequencies
- Thermal and Short-Circuit Protection
- Available in 2.275 mm x 2.275 mm 16-ball WCSP and 4 mm x 4 mm 20-Lead QFN Packages
- 3 Selectable Gain Settings of 2 V/V, 6 V/V, and 10 V/V

APPLICATIONS

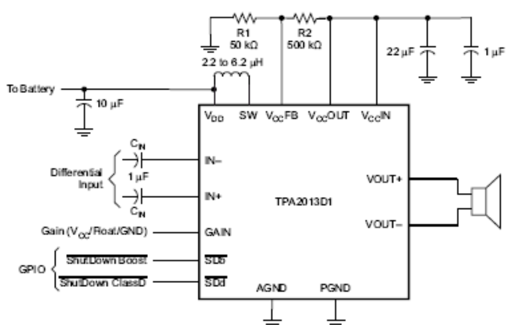
- Cell Phones
- PDA
- GPS
- Portable Electronics

DESCRIPTION

The TPA2013D1 is a high efficiency Class-D audio power amplifier with an integrated boost converter. It drives up to 2.7 W (10% THD+N) into a 4 Ω speaker. With 85% typical efficiency, the TPA2013D1 helps extend battery life when playing audio.

The built-in boost converter generates the voltage rail for the Class-D amplifier. This provides a louder audio output than a stand-alone amplifier connected directly to the battery. It also maintains a consistent loudness, regardless of battery voltage. Additionally, the boost converter can be used to supply external devices.

The TPA2013D1 has an integrated low pass filter to improve RF rejection and reduce out-of-band noise, increasing the signal to noise ratio (SNR). A built-in PLL synchronizes the boost converter and Class-D switching frequencies, thus eliminating beat frequencies and improving audio quality. All outputs are fully protected against shorts to ground, power supply, and output-to-output shorts.

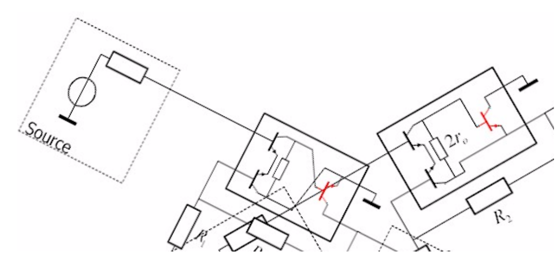


Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

CLASS D AMPLIFIER DC CHARACTERISTICS

T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
CMR	Input common mode range	V_{in} = ±100 mV, V_{DD} = 1.8 V, V_{CC} = 3 V, R_L = 8 Ω	0.5		2.2	V
		V_{in} = ±100 mV, V_{DD} = 2.5 V, V_{CC} = 3.6 V, R_L = 8 Ω	0.5		2.8	
		V_{in} = ±100 mV, V_{DD} = 3.6 V, V_{CC} = 5.5 V, R_L = 8 Ω	0.5		4.7	
CMRR	Input common mode rejection	R_L = 8 Ω, V_{icm} = 0.5 and V_{icm} = V_{CC} – 0.8, differential inputs shorted		–75		dB
V_{OO}	Output offset voltage Class-D	V_{CC} = 3.6 V, Av = 2 V/V, IN+ = IN– = V_{ref}, R_L = 8 Ω		1	6	mV
		V_{CC}= 3.6 V, Av = 6 V/V, IN+ = IN– = V_{ref}, R_L = 8 Ω		1	6	
		V_{CC}= 3.6 V, Av = 10 V/V, IN+ = IN– = V_{ref}, R_L = 8 Ω		1	6	
		V_{CC} = 5.5 V, Av = 2 V/V, IN+ = IN– = V_{ref}, R_L = 8 Ω		1	6	
R_{in}	Input Impedance	Gain = 2 V/V (6 dB)		32		kΩ
		Gain = 6 V/V (15.5 dB)		15		
		Gain = 10 V/V (20 dB)		9.5		
$R_{DS(on)}$	OUTP High-side FET On-state series resistance	I_{OUTx} = –300 mA; V_{CC} = 3.6 V		0.36		Ω
	OUTP Low-side FET On-state series resistance			0.36		
$R_{DS(on)}$	OUTN High-side FET On-state series resistance			0.36		
	OUTN Low-side FET On-state series resistance			0.36		
A_V	Low Gain	GAIN ≤ 0.35 V	1.8	2	2.2	V/V
	Mid Gain	GAIN = 0.8 V	5.7	6	6.3	V/V
	High Gain	GAIN ≥ 1.35 V	9.5	10	10.5	V/V



Conclusions

- Know ideal case
- Know the penalty for choosing second best
- Beware of experts !
- **Always remember the ideal case!**

The seeds of great discovery are constantly floating around us, but they only take root in minds well prepared to receive them