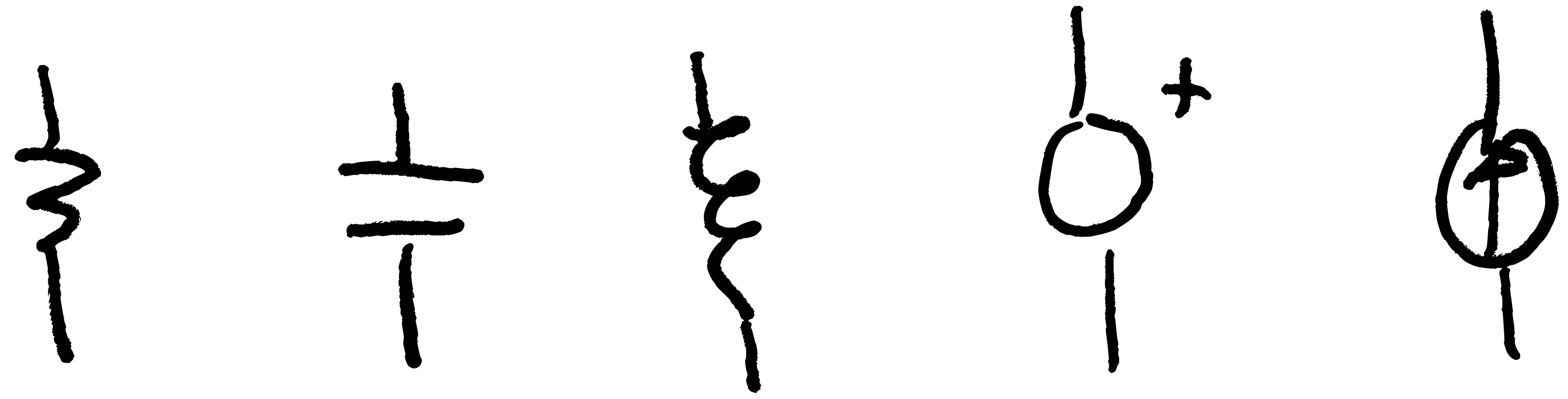
ME133 Lecture 3

1/17/23
~~1/12/23~~

Last time:

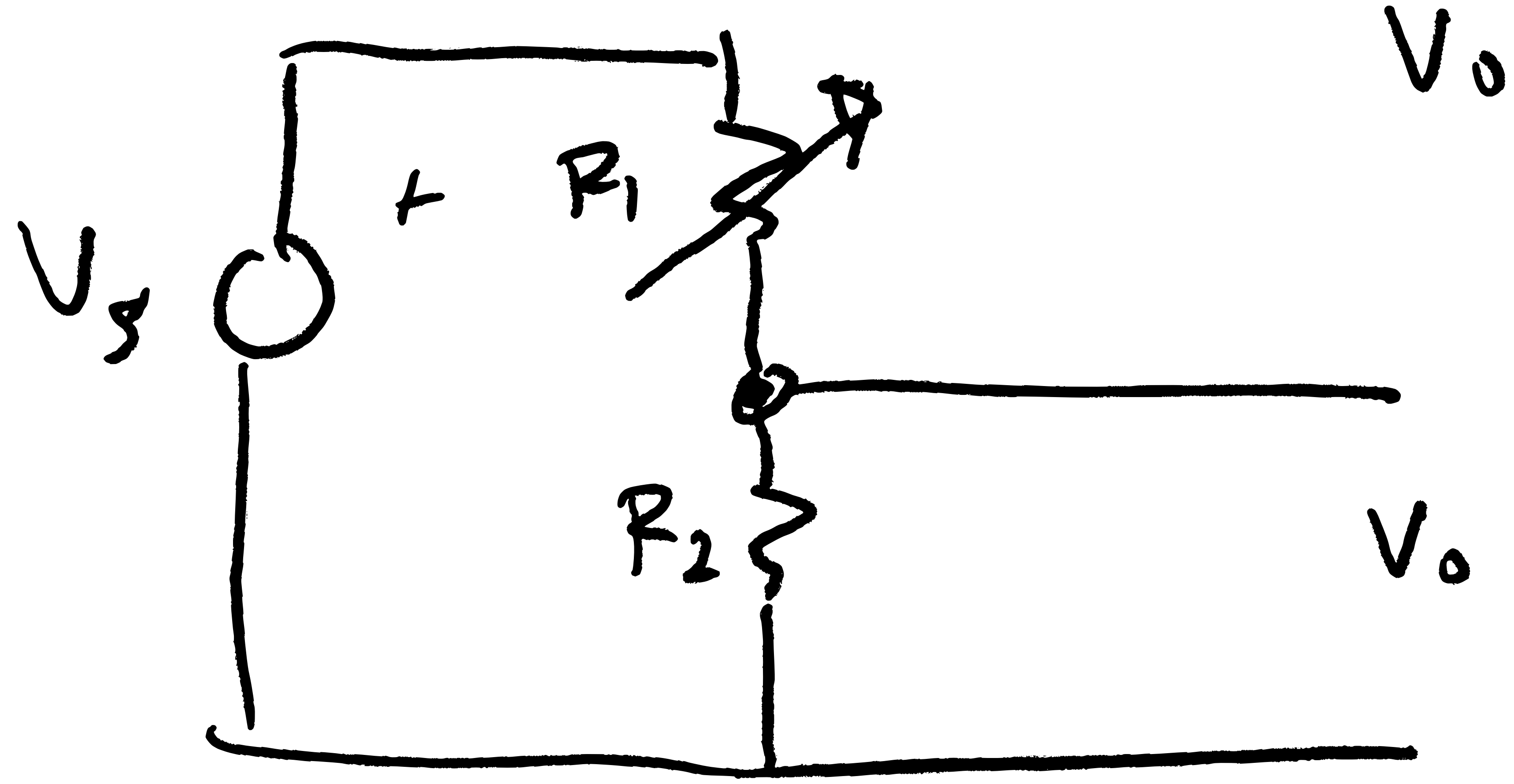
→ passive electrical elements



→ Ohms Law $V = IR$

Kirchoffs Laws

→ Voltage Divider



$$V_o = \left(\frac{R_2}{R_1 + R_2} \right) V_s$$

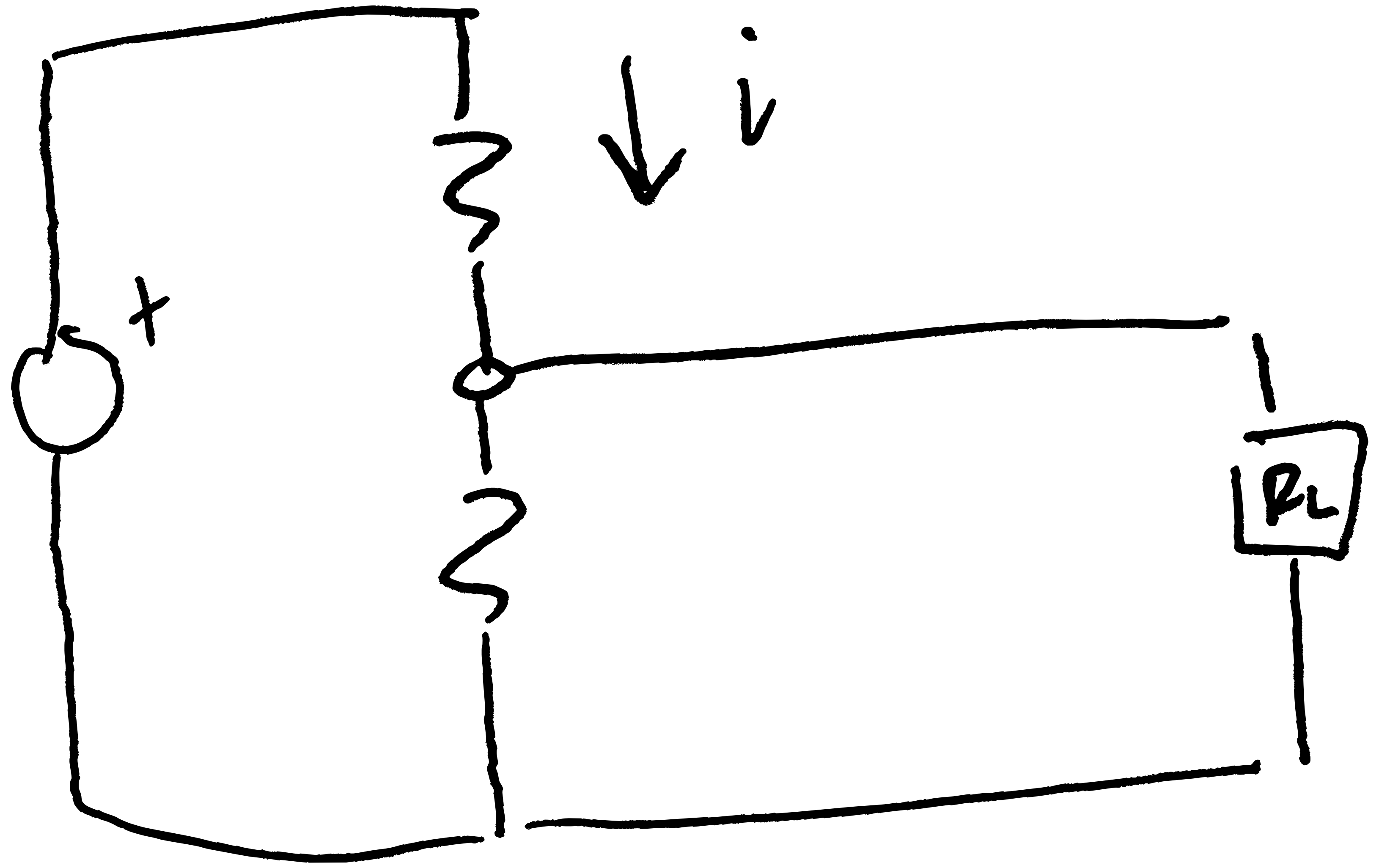
Today:

- Equivalent Series + Parallel circuits
- Sources & meters
- Thevenin & Norton Equivalent circuits
- Power
- Impedance

■ CLASS DISCUSSION ITEM 2.6

Improper Application of a Voltage Divider

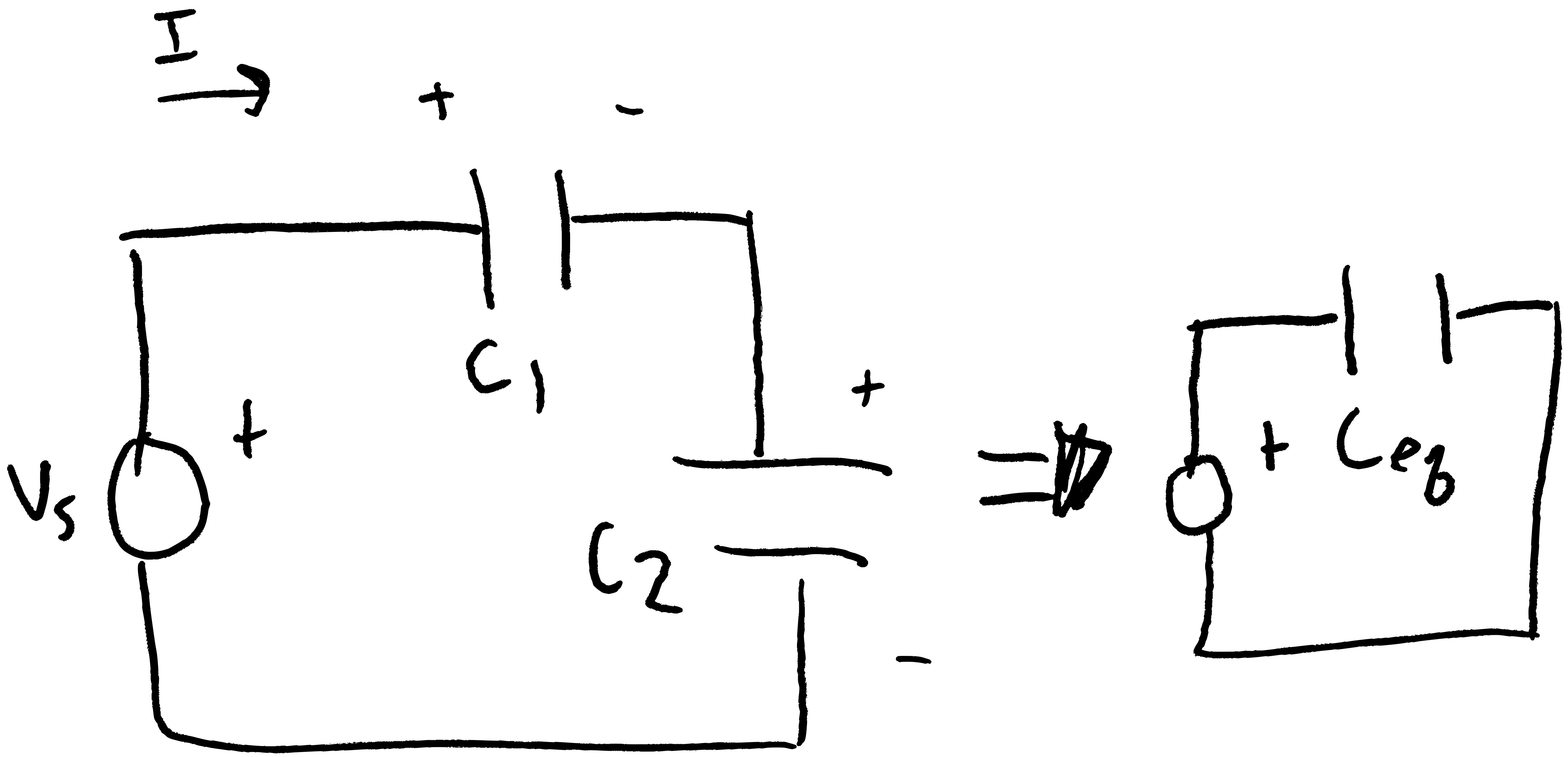
Your car has a 12 V battery that powers some circuits in the car at lower voltage levels. Why is it inappropriate to use a simple voltage divider to create a lower voltage level for circuits that might draw variable current?



→ load will mess up the voltage divider

"Load effect"

Series capacitance: Find the equivalent capacitance



Find C_{eq}?

KVL: $V_s = V_1 + V_2$

$$I = C\dot{V}$$

$$\dot{V}_s = \dot{V}_1 + \dot{V}_2$$

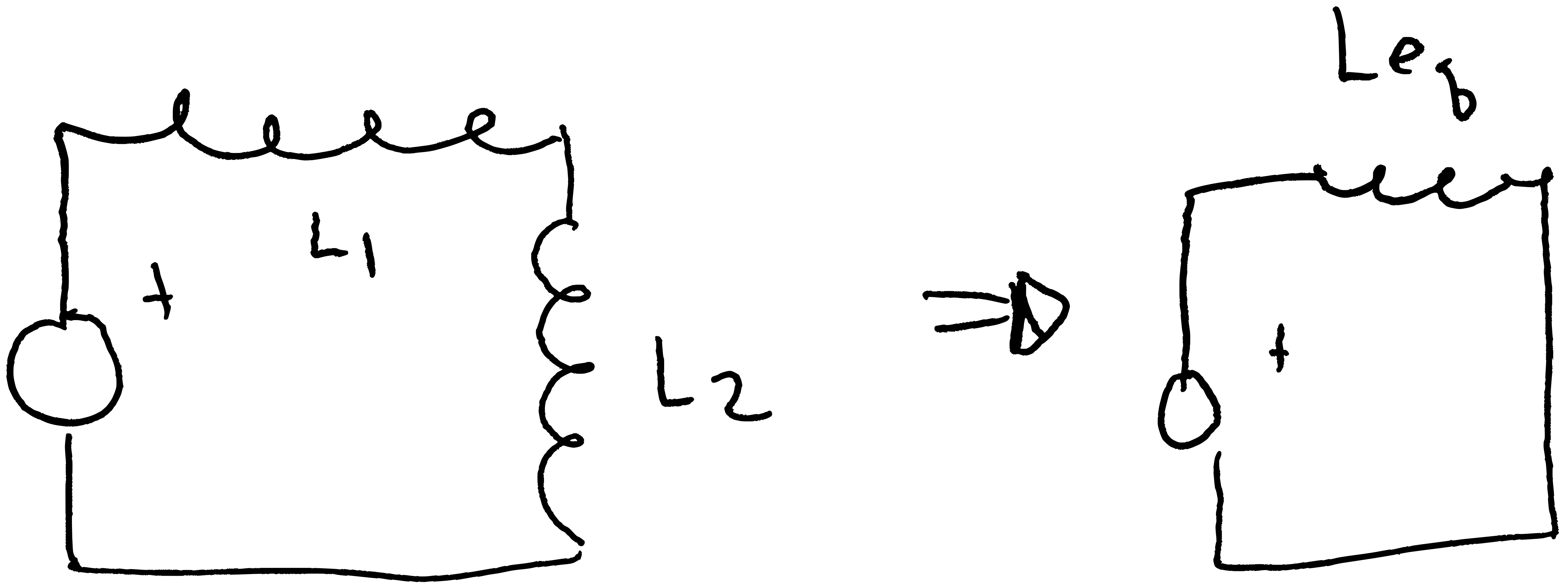
$$\dot{V}_s = \frac{I_1}{C_1} + \frac{I_2}{C_2}$$

KCL: $I = I_1 = I_2$

$$\dot{V}_s = \underbrace{\left(\frac{1}{C_1} + \frac{1}{C_2}\right)}_{\frac{1}{C_{eq}}} I$$

$$\therefore \boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}}$$

Series inductance: Find the equivalent inductance



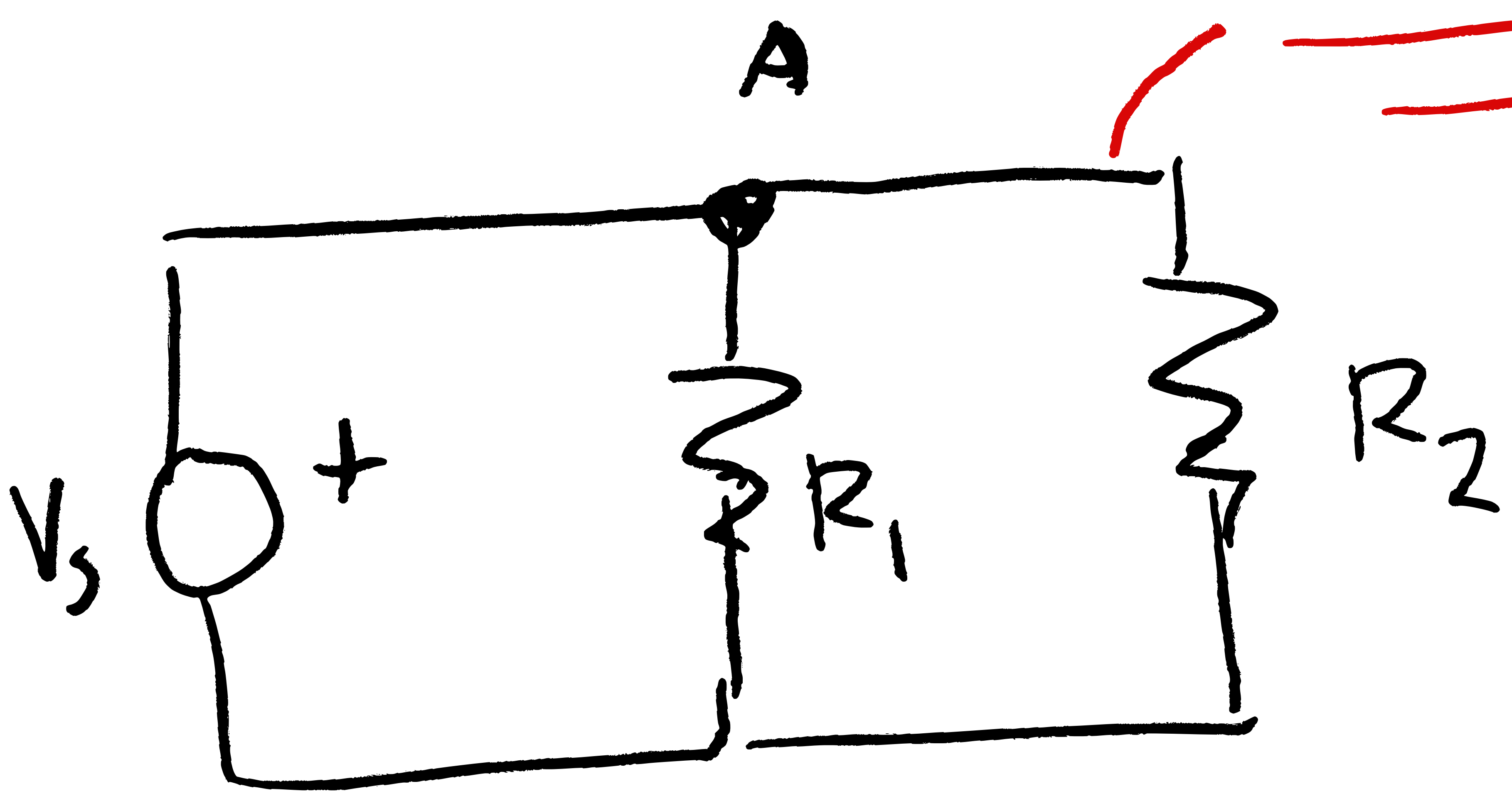
KVL: $V_s = V_1 + V_2$

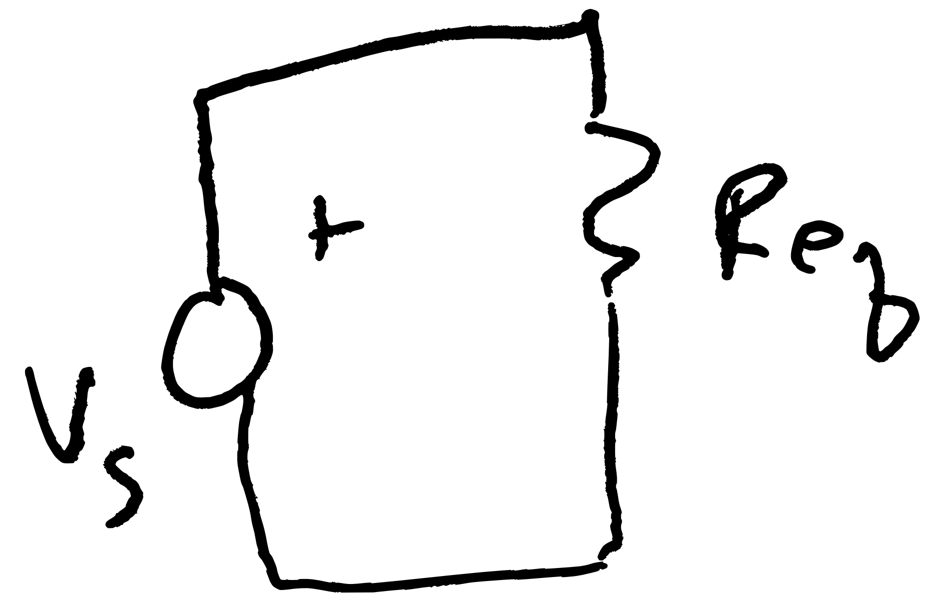
KCL: $I = I_1 = I_2$

$$V = L\dot{I}$$

$$V = \underbrace{(L_1 + L_2)}_{L_{eq}}\dot{I}$$

Parallel resistance: Find the equivalent resistance





KVL: $V_s = V_{R_1} = V_{R_2}$

KCL: $I = I_{R_1} + I_{R_2}$

$V = IR$

$I = I_{R_1} + I_{R_2}$

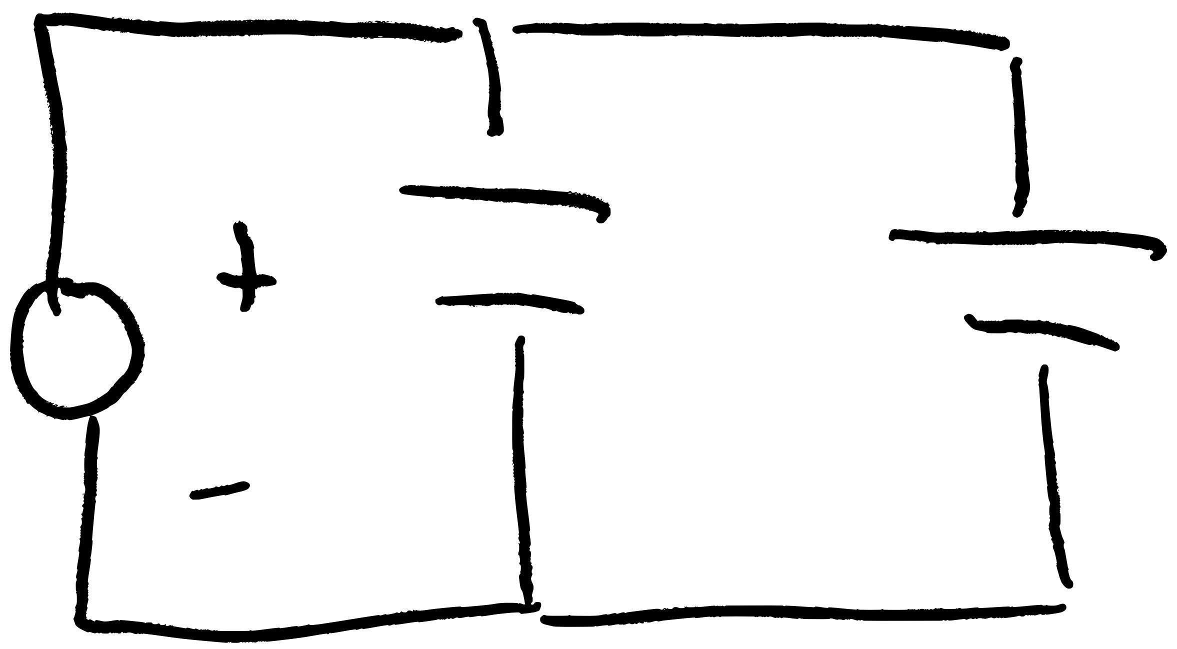
→ Ohms Law

$$I = \frac{V_{R_1}}{R_1} + \frac{V_{R_2}}{R_2}$$

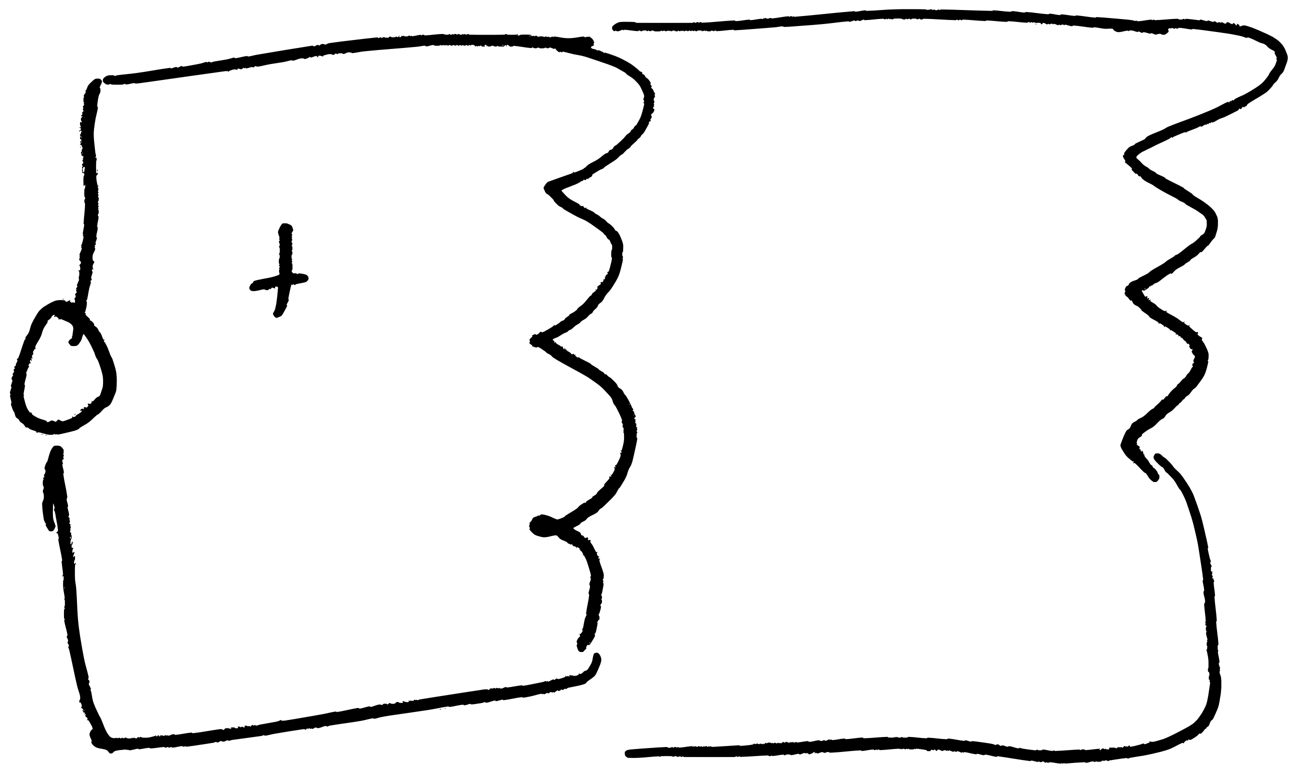
$$I = \left(\frac{1}{R_1} + \frac{1}{R_2}\right) V_s$$

$$\frac{1}{R_{eq}} = \frac{R_1 + R_2}{R_1 R_2}$$

Capacitors and Inductors in parallel

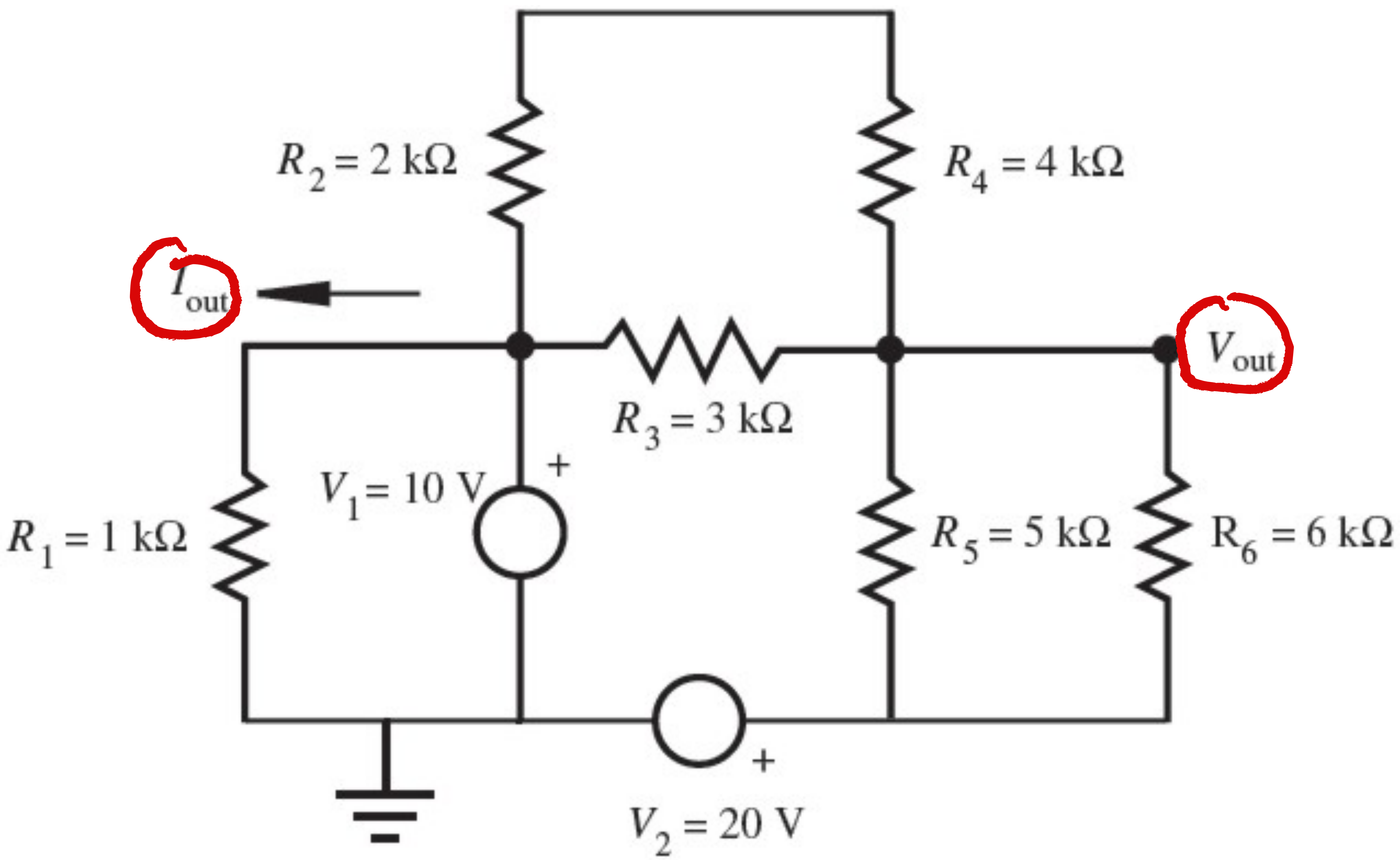


$$C_{eq} = C_1 + C_2$$



$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2}$$

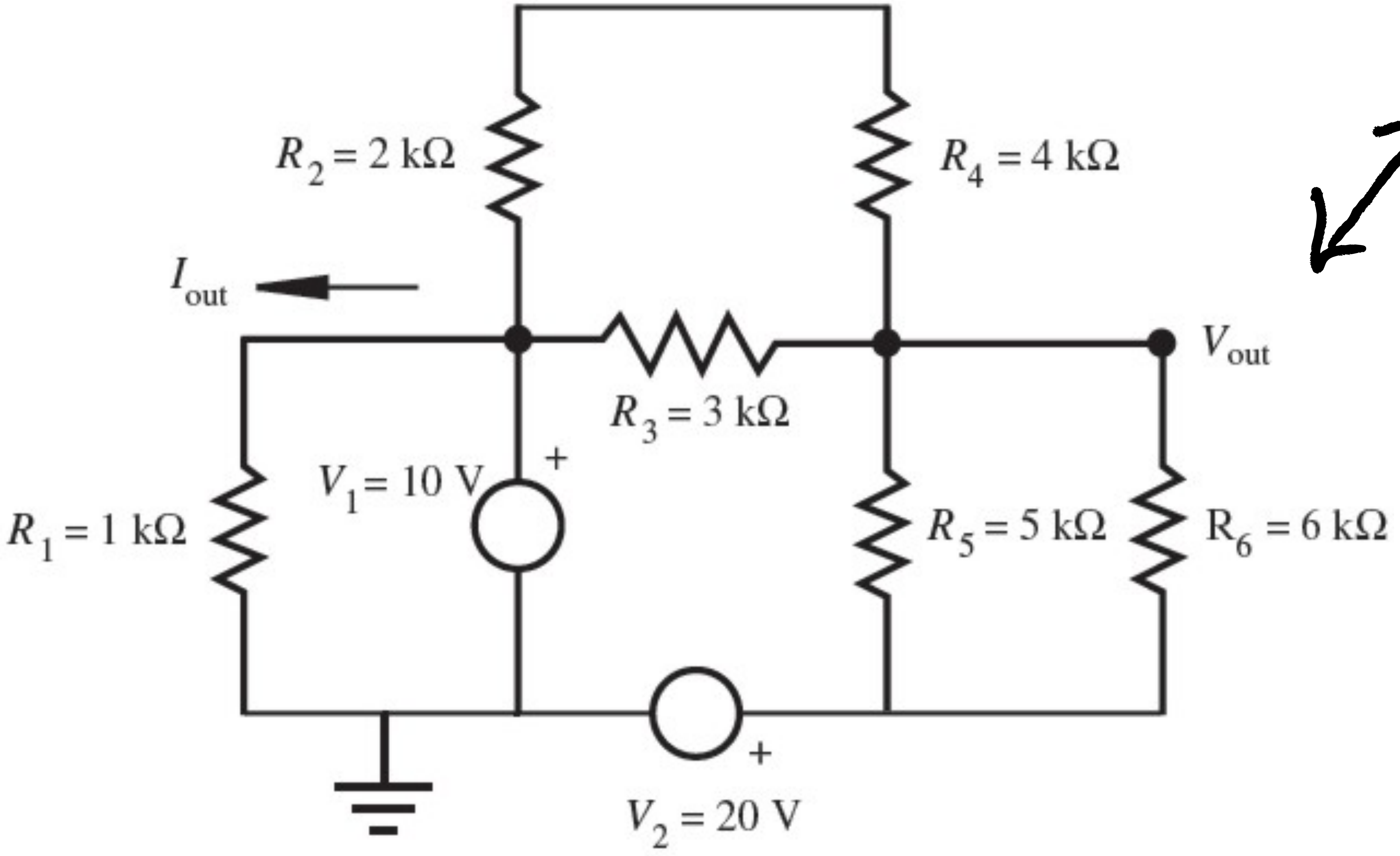
Example 2.4: Find Iout and Vout

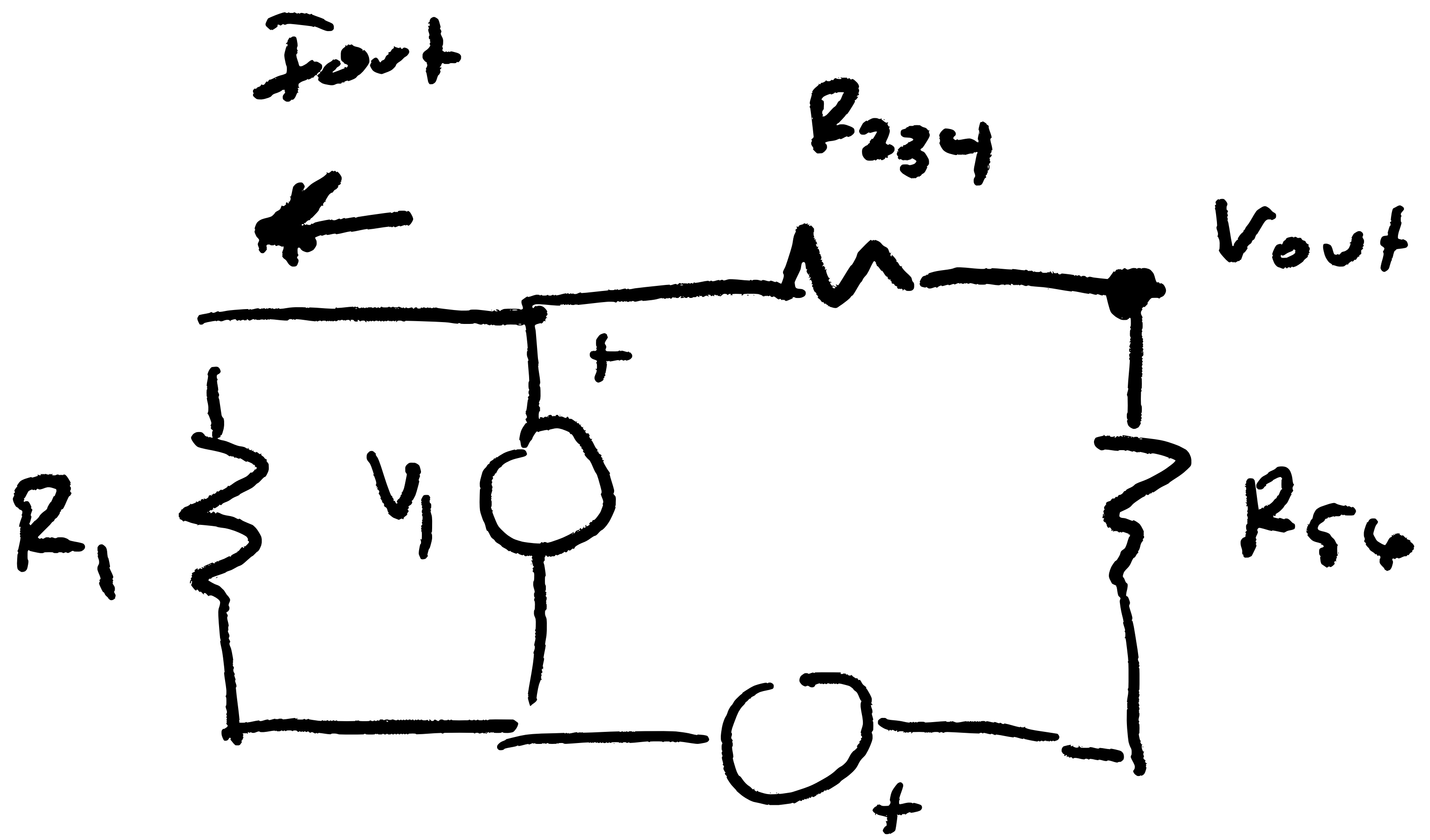


What's our plan to solve?

1. Combine R_2 & R_3 & R_4
2. Combine R_5 & R_6

Example 2.4: Find Iout and Vout





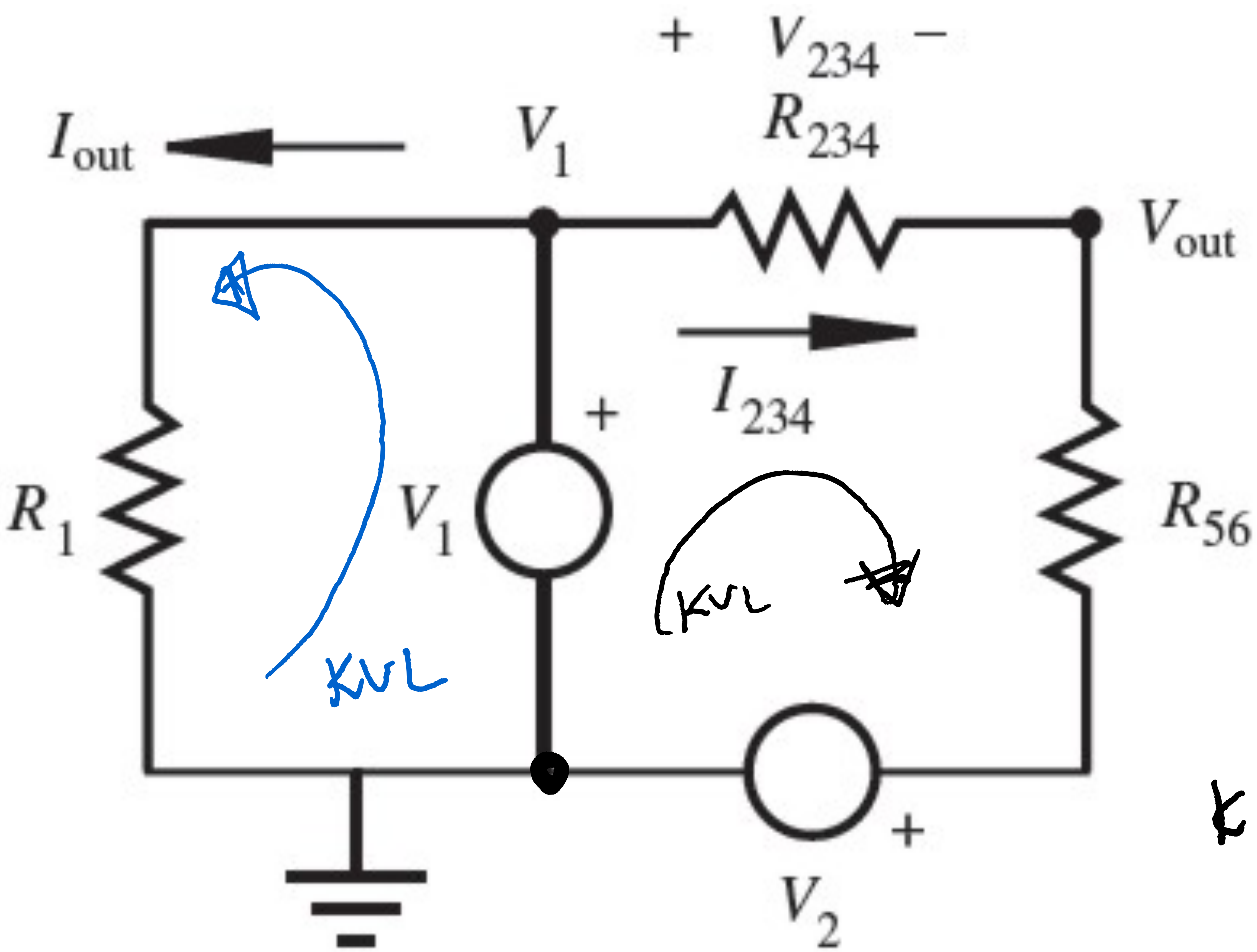
$$(R_2 - R_4) \,//\, R$$

$$R_{234} = \frac{(R_2 + R_4) \cdot R_3}{R_2 + R_3 + R_4}$$

$$R_5 \,//\, R_6$$

$$R_{56} = \frac{R_5 R_6}{R_5 + R_6}$$

Example 2.4: Find Iout and Vout



KVL: $V_1 = V_{R_1}$

Ohms Law: $V_{R_1} = I_{out} R_1$

$$\boxed{I_{out} = \frac{V_1}{R_1}}$$

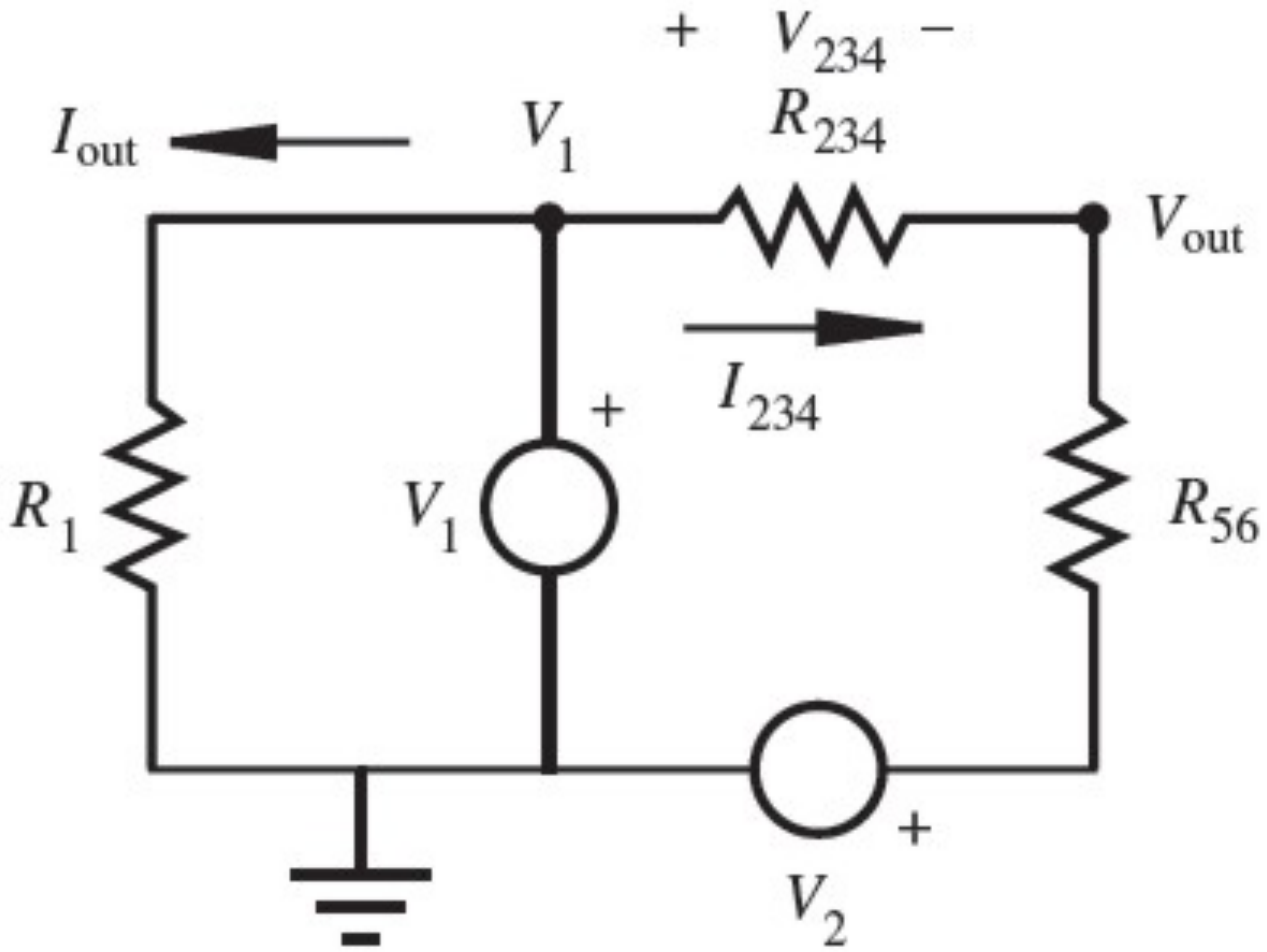
KVL: $-V_1 + \overbrace{V_{234} + V_{56}}^{V_{23456}} + V_2 = 0$

$$V_{23456} = V_1 - V_2$$

$$V_{234} = \left(\frac{R_{234}}{R_{234} + R_{56}}\right)(V_1 - V_2)$$

$$\boxed{V_o = V_1 - V_{234}}$$

Example 2.4: Find Iout and Vout



Sources and Meters

Voltage Source

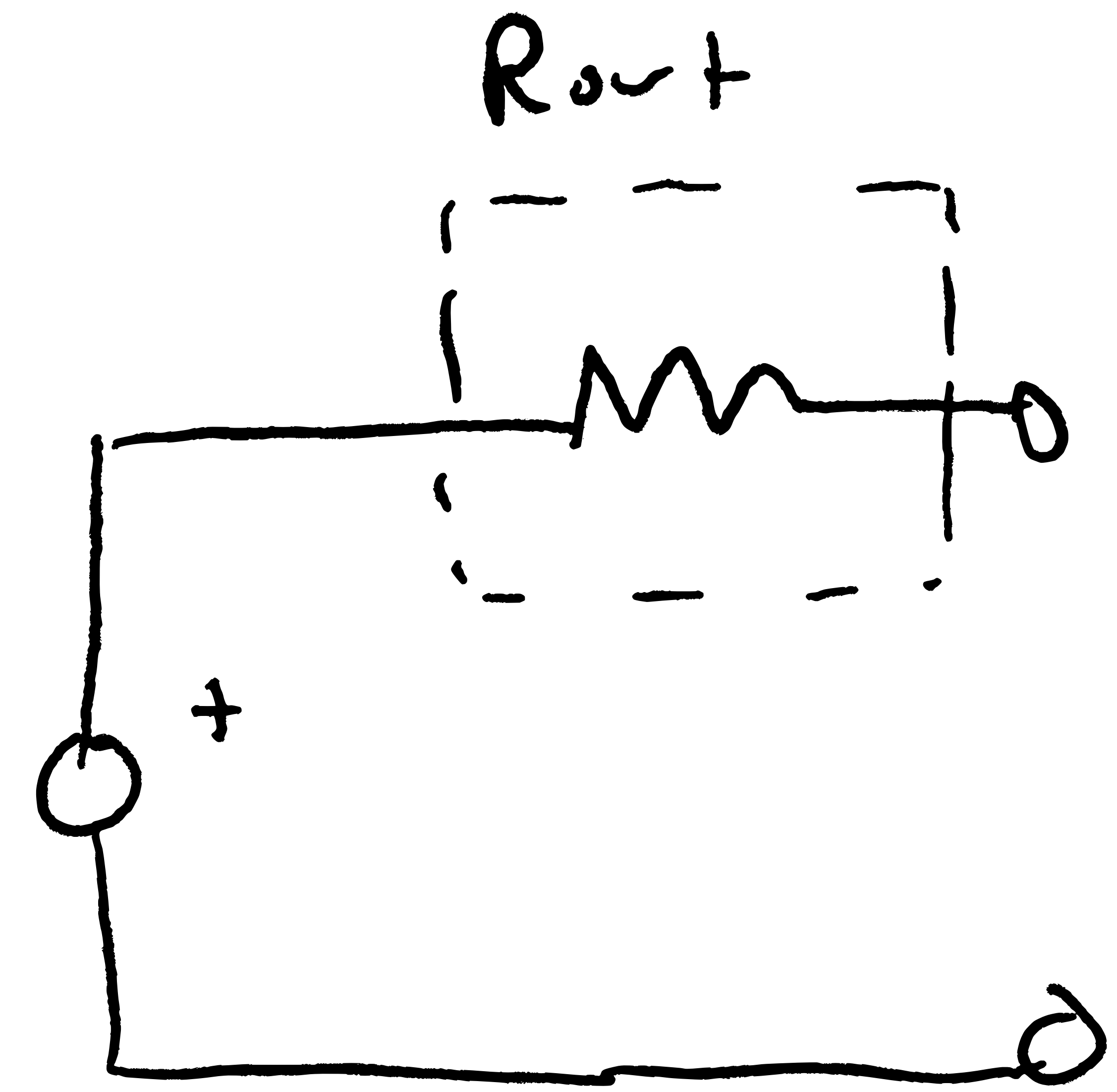
Power supply!

• ideal source

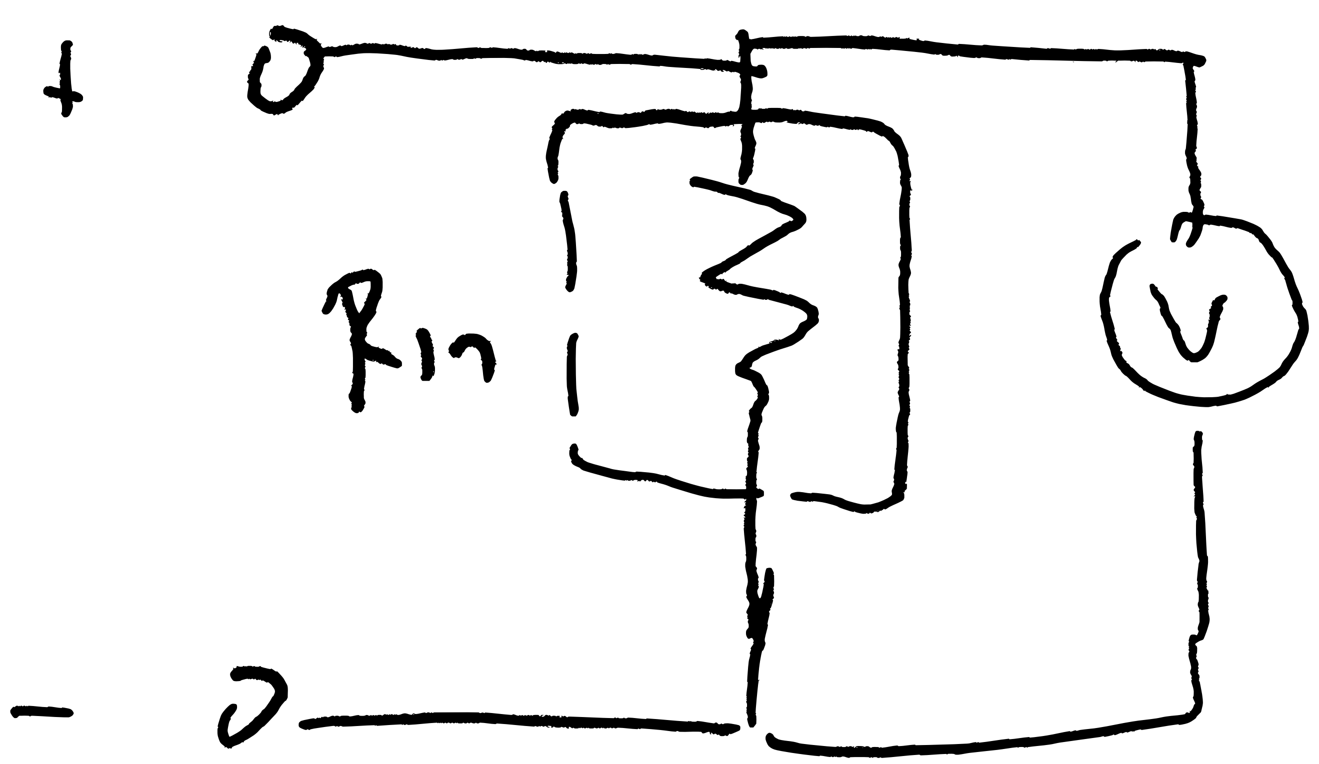
→ zero output impedance (generalized resistance Z)

→ sustain voltage @ ∞ current.

real voltage



Voltmeter

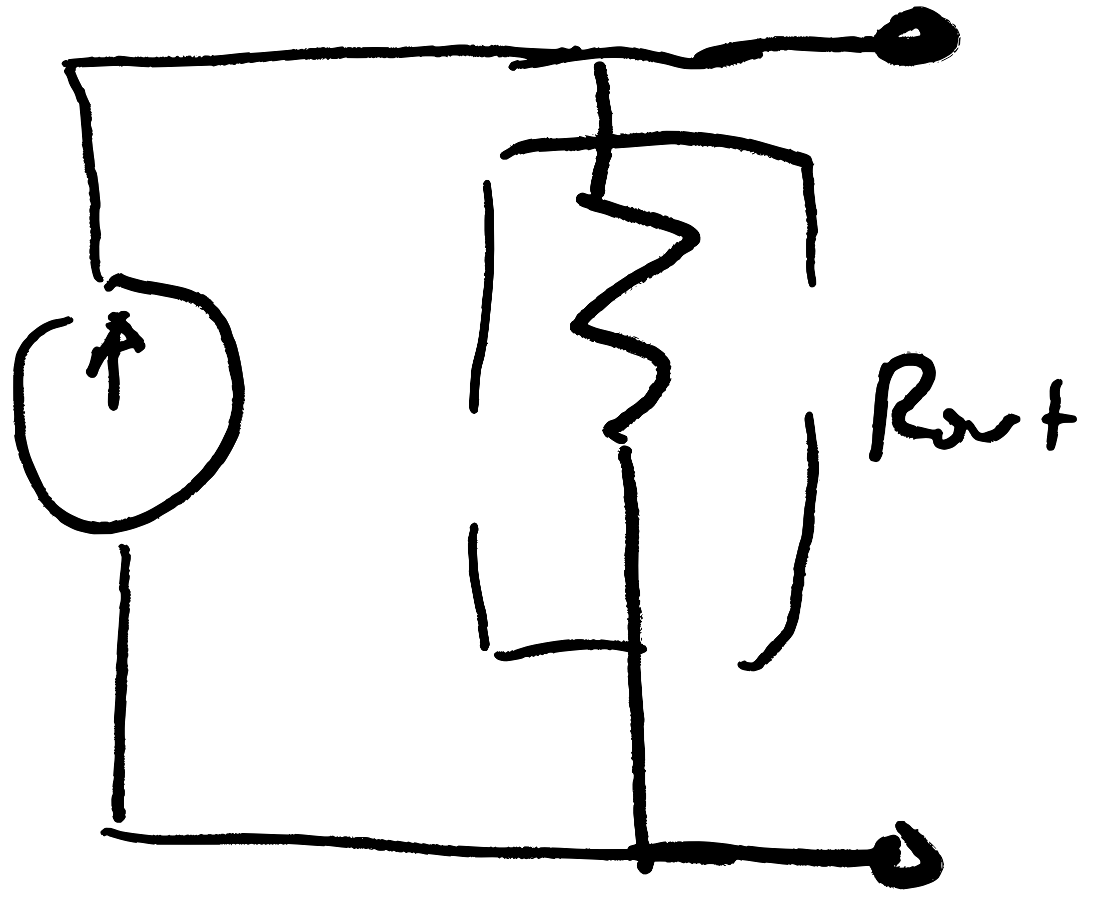


Sources and Meters

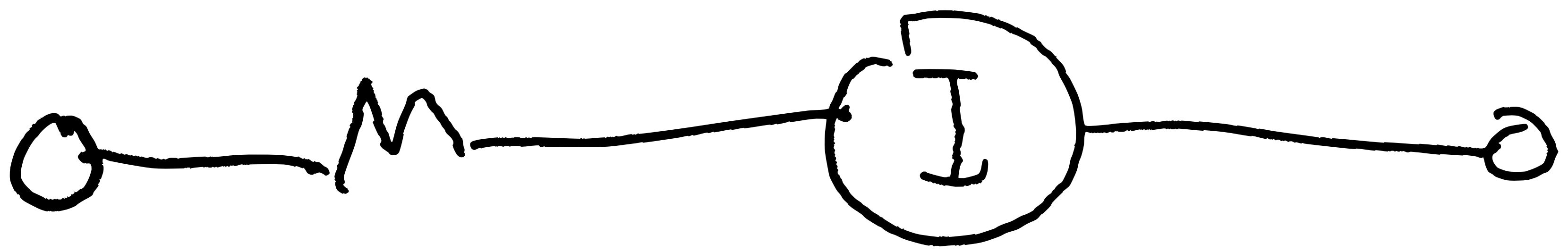
Current Source

- ideal current source
  - → ∞ output impedance
  - → ∞ voltage

Real Current Source



Ammeter



How to use a multimeter?

Switch Position Or Symbols	Measurement Functions
$\tilde{V}$	AC Voltage
$\overline{V}$	DC Voltage
A⎓	DC Current
Ω	Resistance (Ohms)
·)))	Continuity Beeper
➔⊢	Diode Test
OFF	ON/OFF Switch

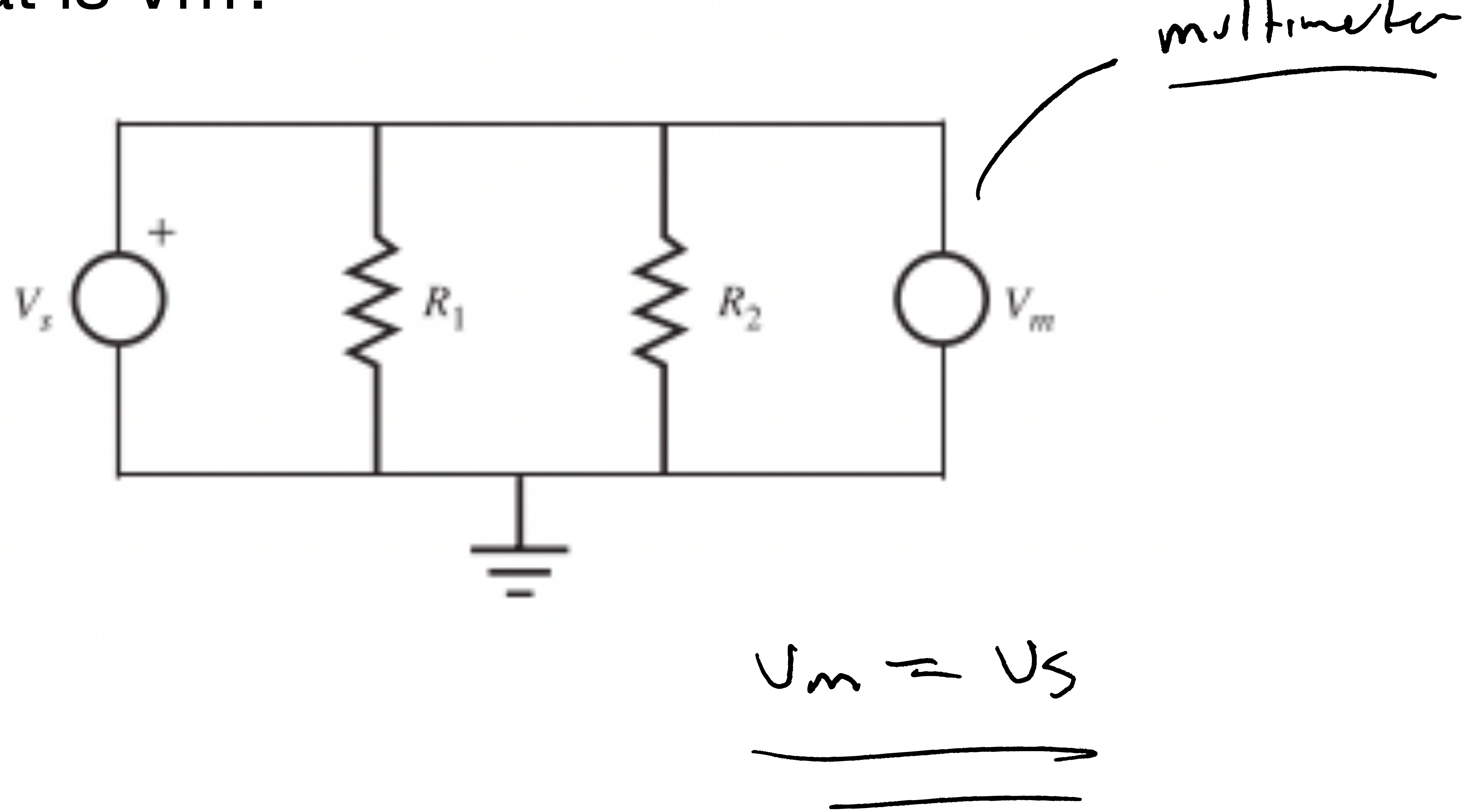
Why should we care about input/output impedance?

<u>Loading effect matters!</u>

the effect on a measurement system → can load rest of system?

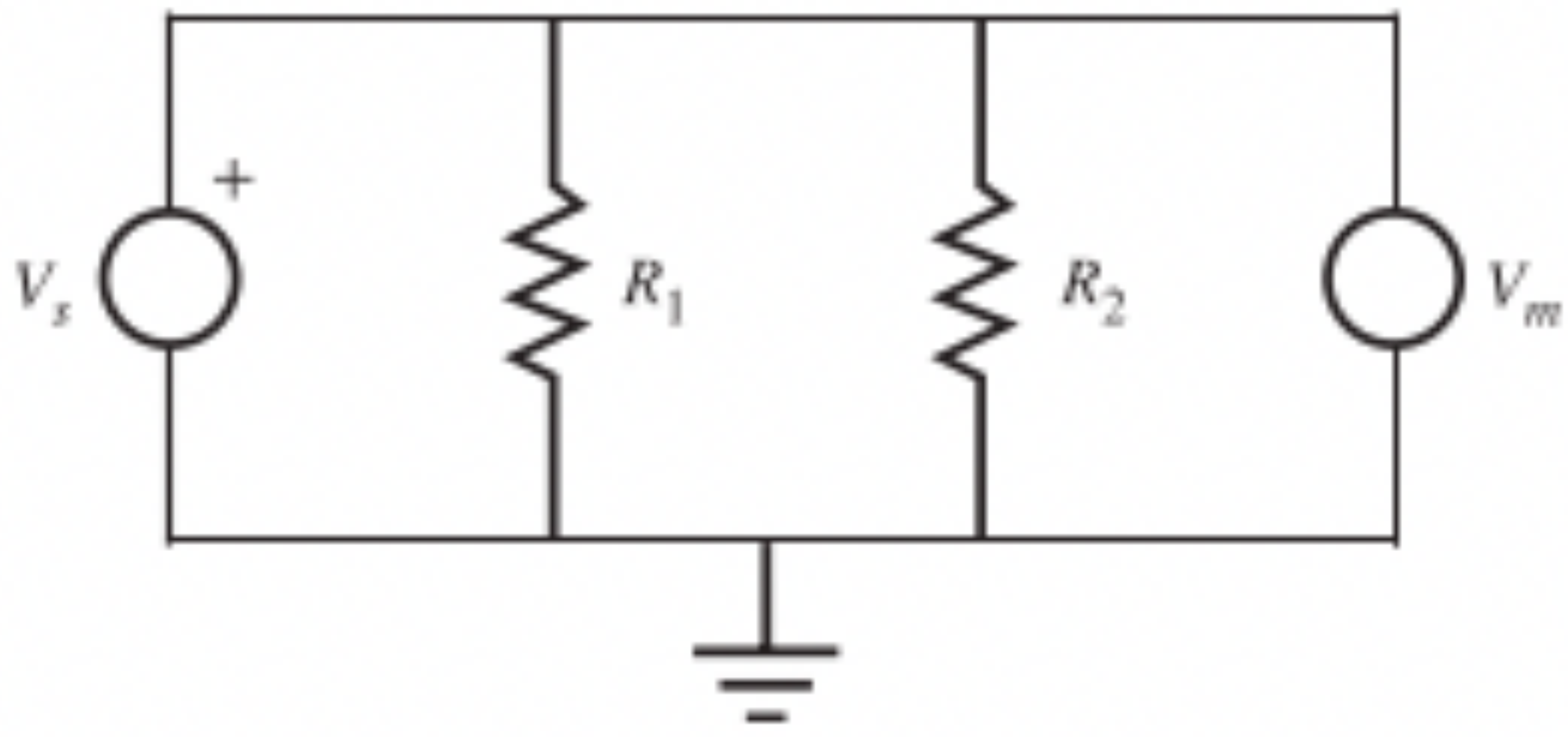
Why should we care about input/output impedance?

Ideal case, what is Vm?



Why should we care about input/output impedance?

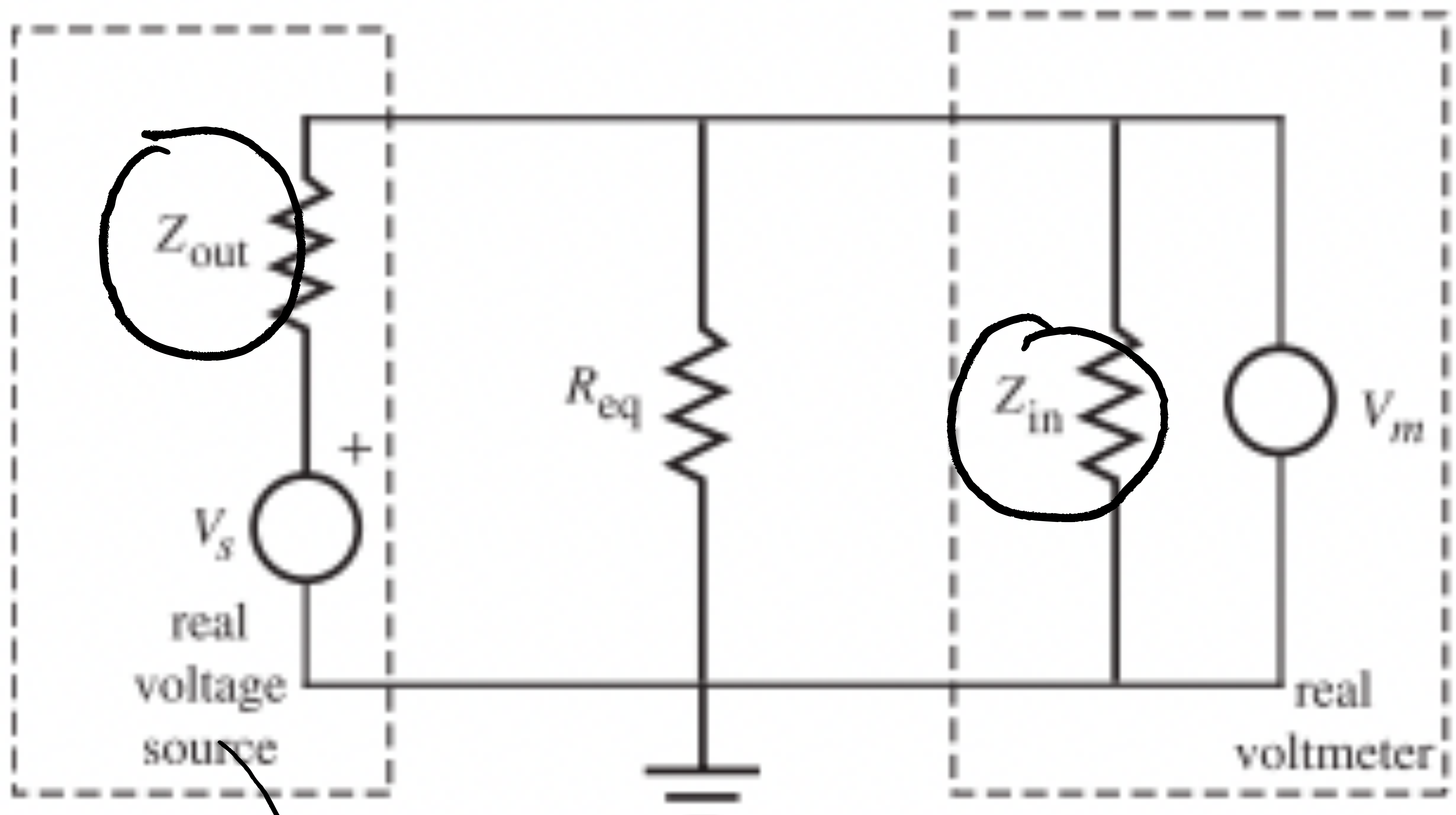
Actual case, with output/input impedance, what is Vm?



Why should we care about input/output impedance?

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

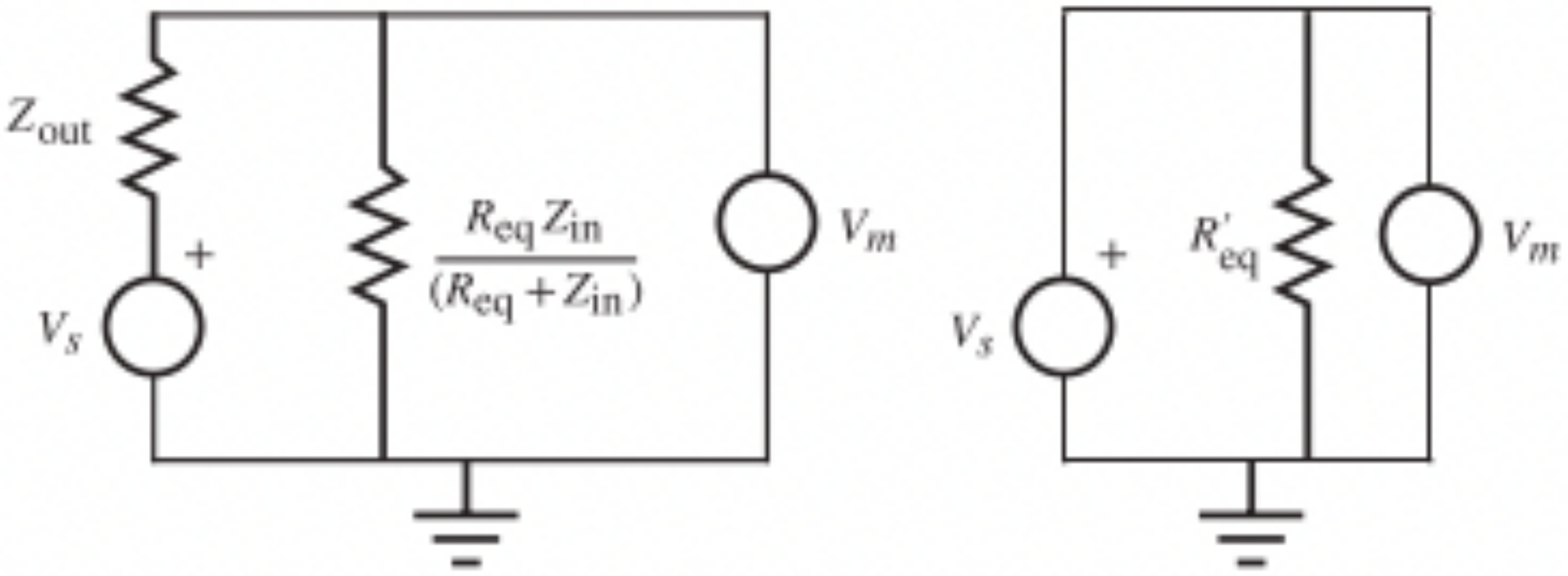
Actual case, with output/input impedance, what is Vm?



$$V_m = \left(\frac{\frac{R_{eq} Z_{in}}{(R_{eq} + Z_{in})}}{\frac{R_{eq} Z_{in}}{(R_{eq} + Z_{in})} + Z_{out}} \right) V_s$$

$$V_s \neq V_m$$

Why should we care about input/output impedance?



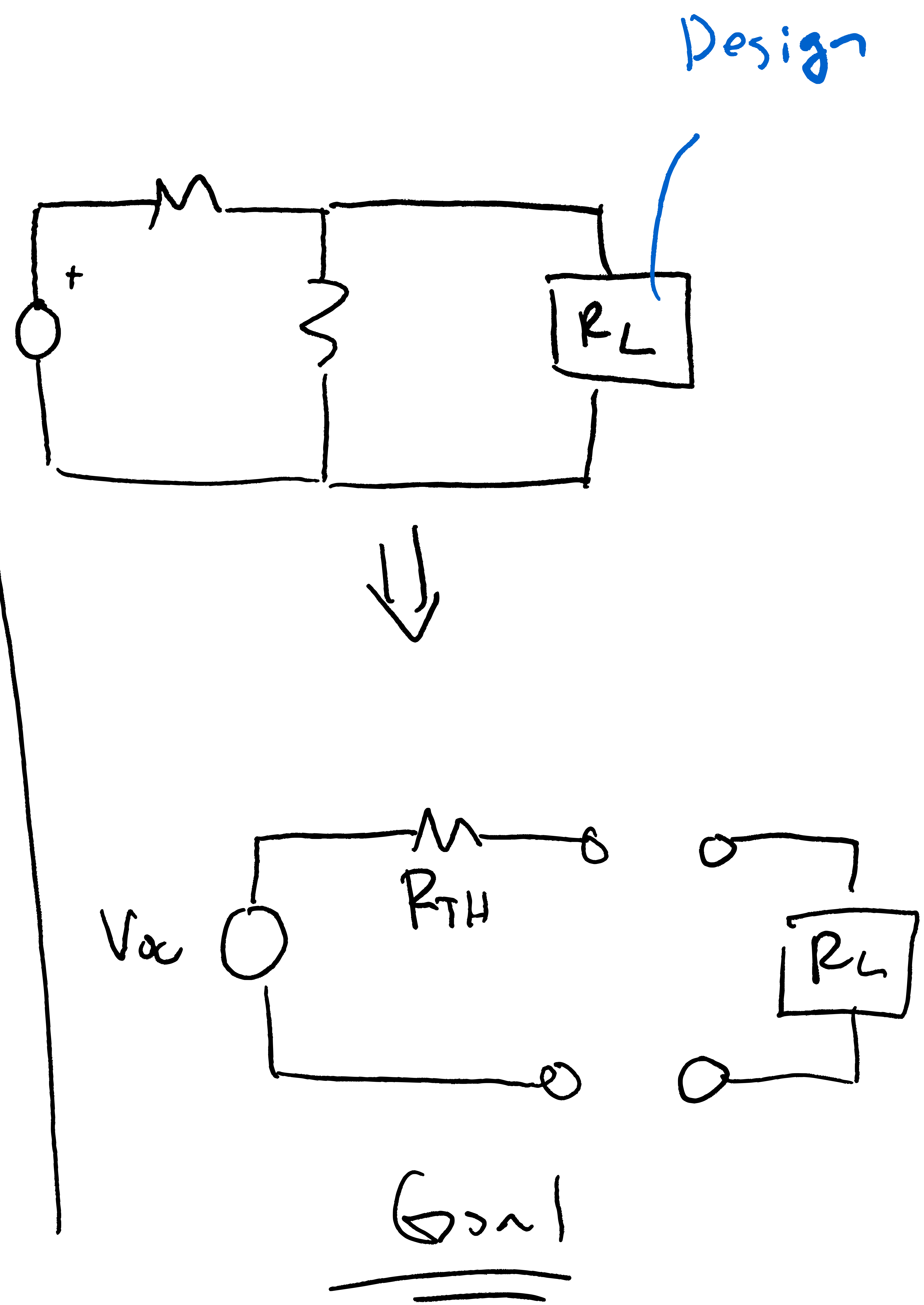
Thevenin Equivalent Circuits

What:

to simplify complex circuits by replacing w/ Eq. Source and Series Resistance

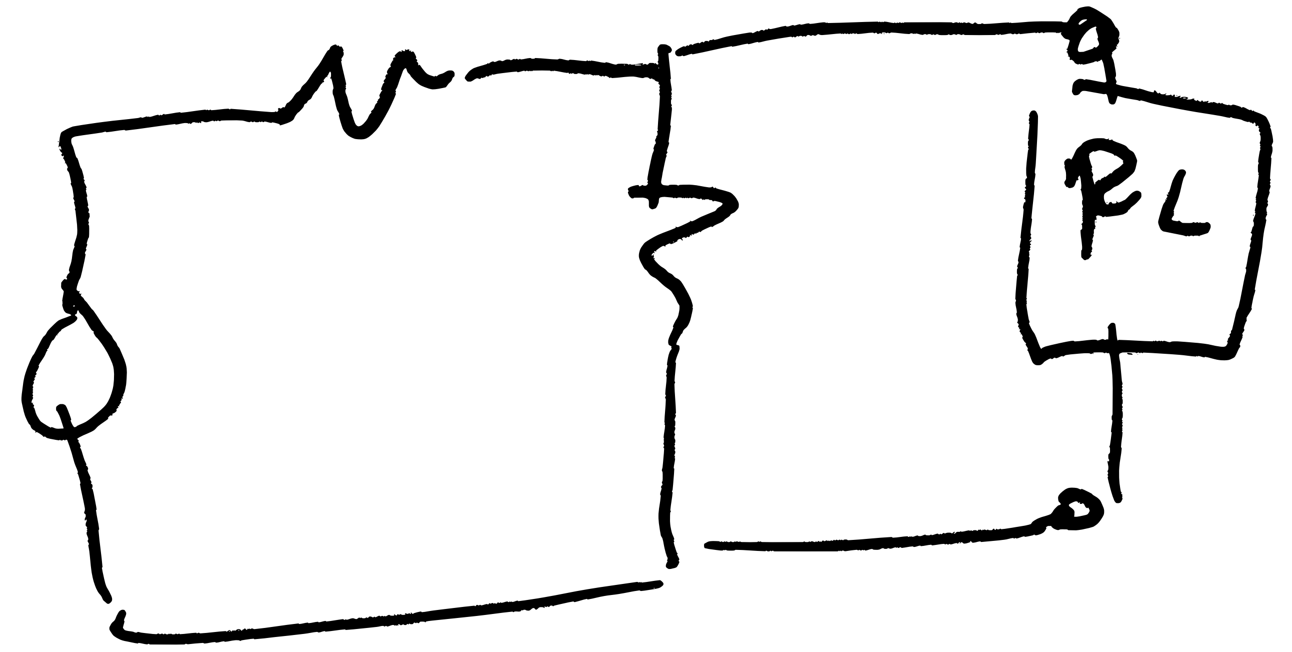
Why:

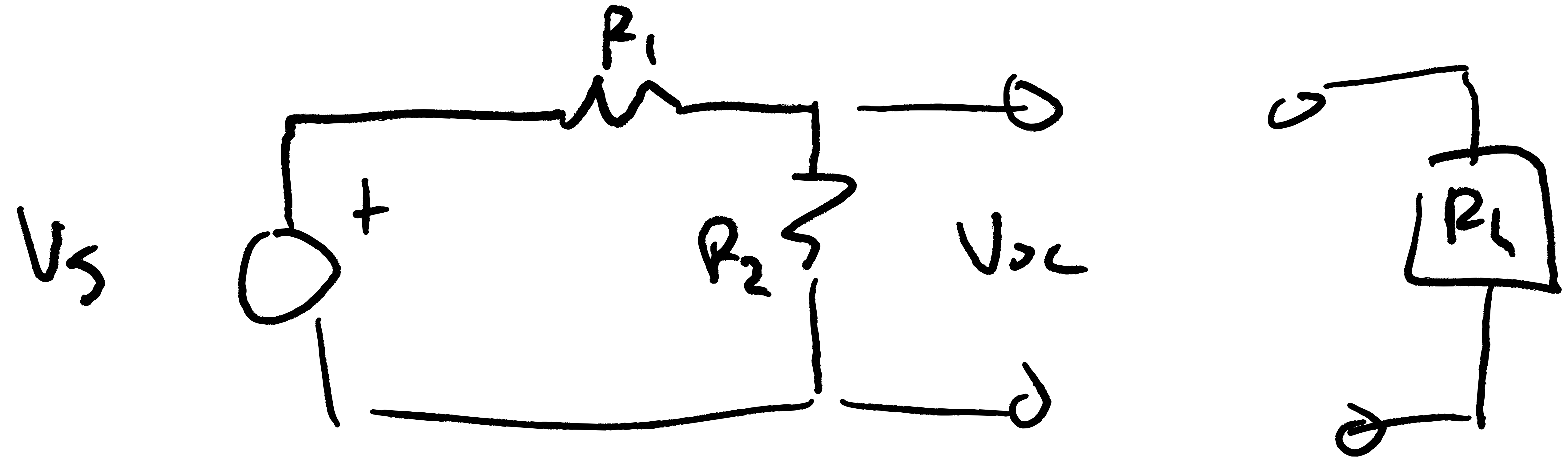
→ can help w/ designing circuits



Thevenin Equivalent Circuits: Step by Step

1. Find open circuit voltage Voc
   - disconnect the load
   - find voltage across



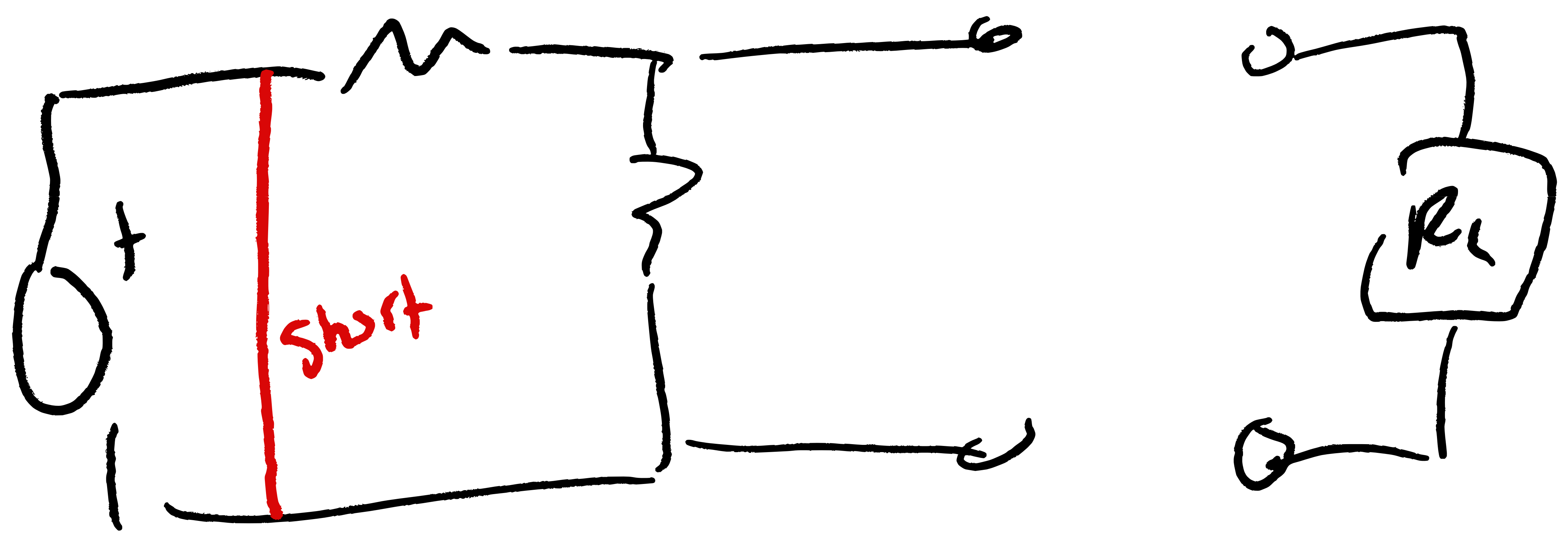


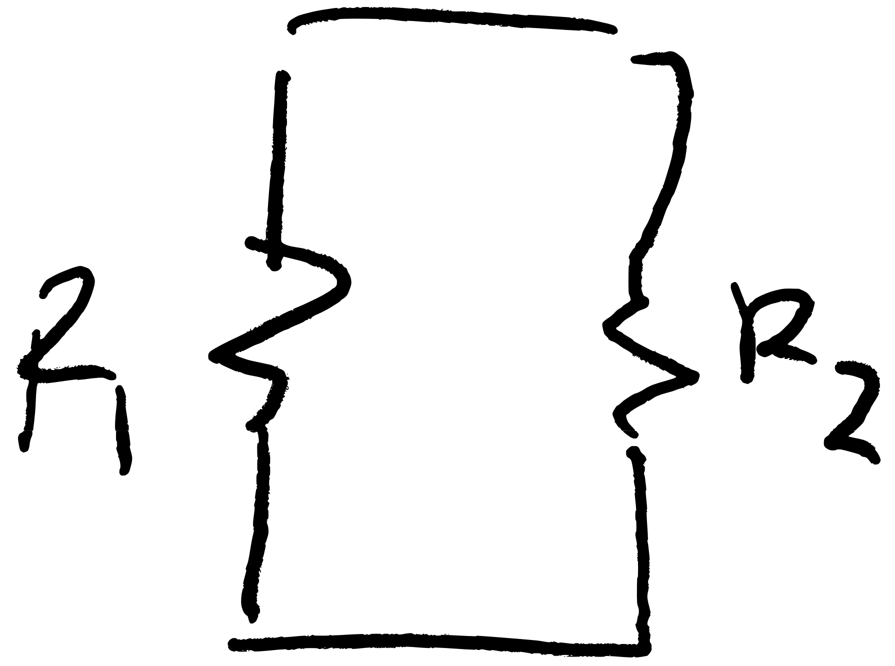
$$V_{oc} = \left(\frac{R_2}{R_1 + R_2}\right) V_s$$

Thevenin Equivalent Circuits: Step by Step

2. Find the Thevenin Eq. resistance

- short V_s.

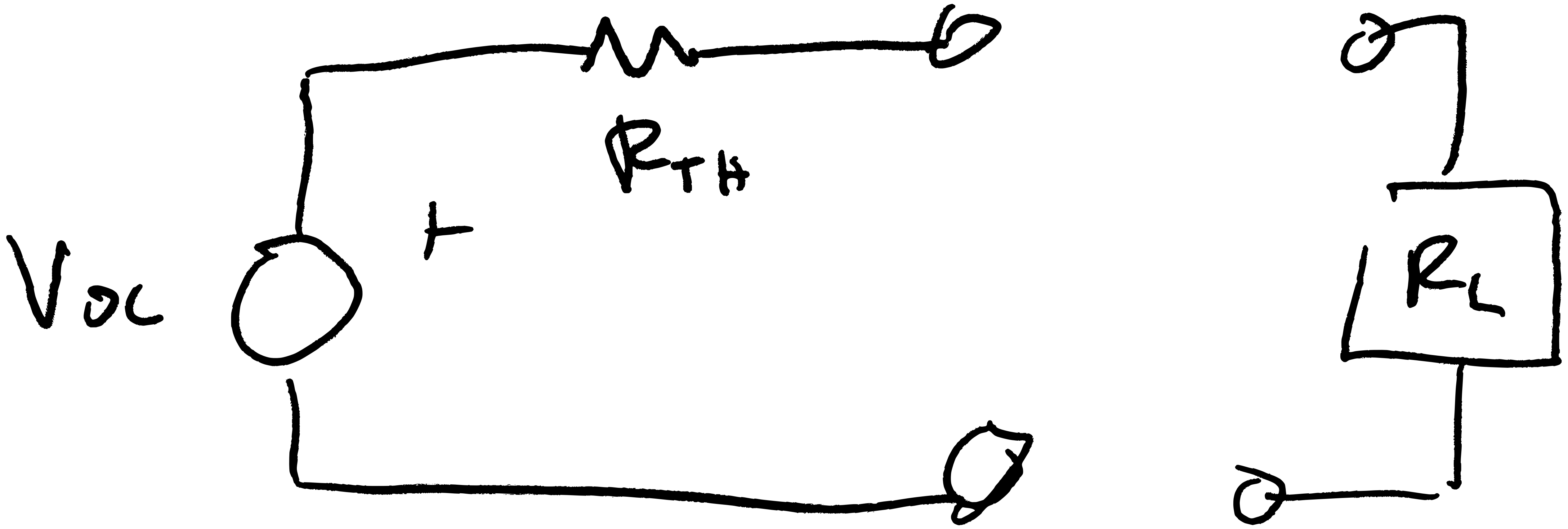




$$R_{Th} = \frac{R_1 R_2}{R_1 + R_2}$$

Thevenin Equivalent Circuits: Step by Step

3. Analyze

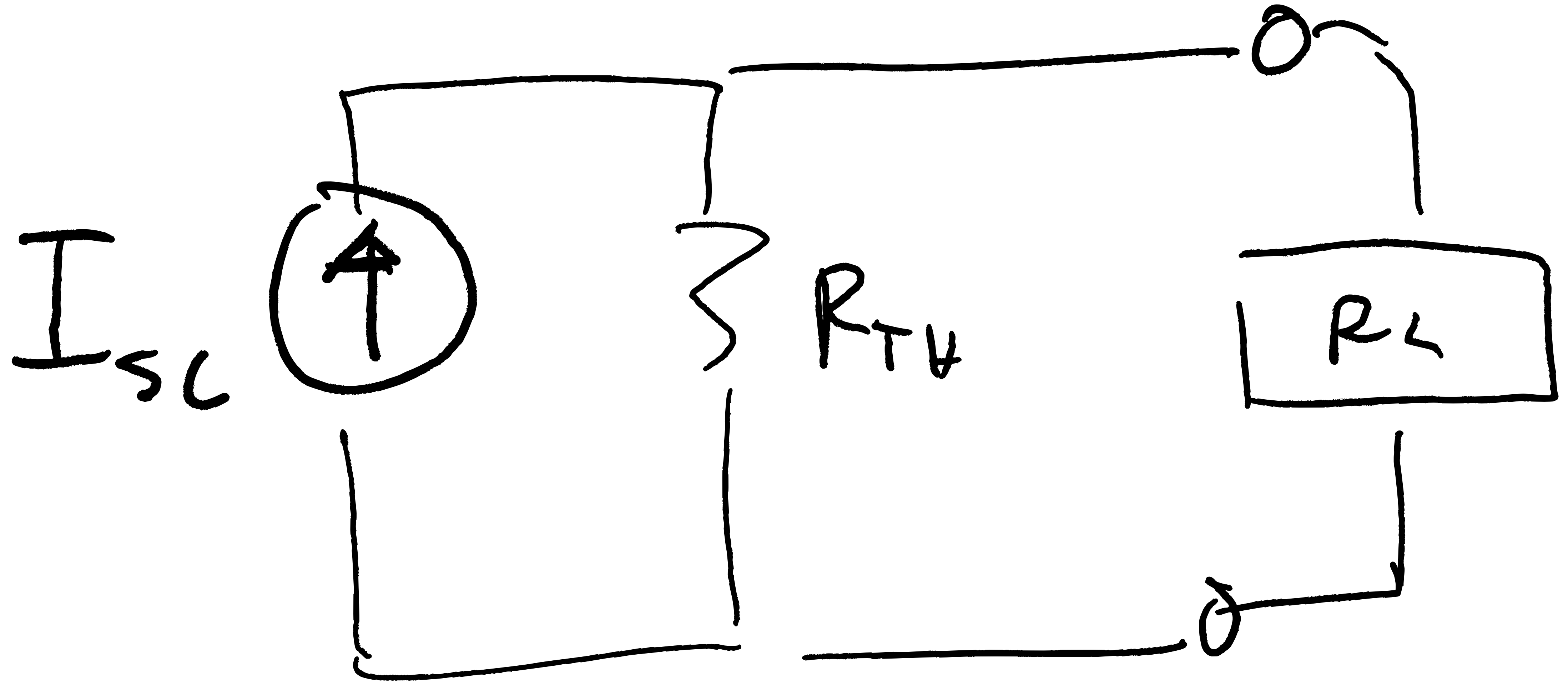


$$V_L = \left(\frac{R_L}{R_L + R_{TH}} \right) V_{oc}$$

Norton Equivalent Circuits

What:

same reason



Why:

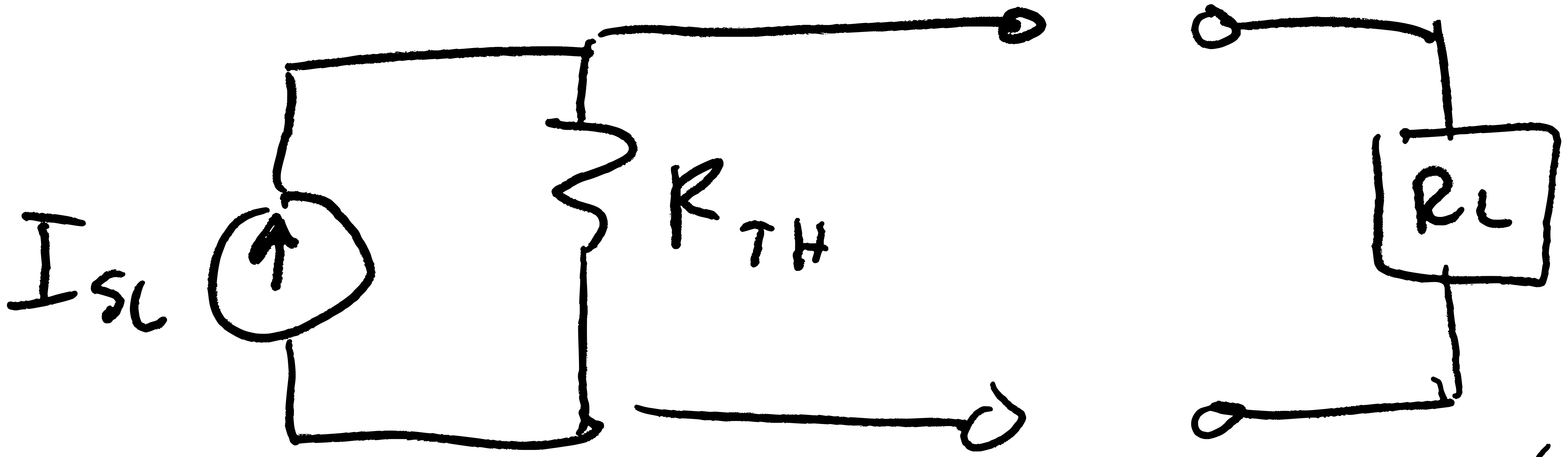
same reason

Norton Equivalent Circuits: Step by Step

1. Find short circuit
   - short the load

2. Find R_{TH} → same as Thevenin

3. Analyze



$$I_L = \left(\frac{R_{TH}}{R_{TH} + R_L} \right) I_{SC}$$

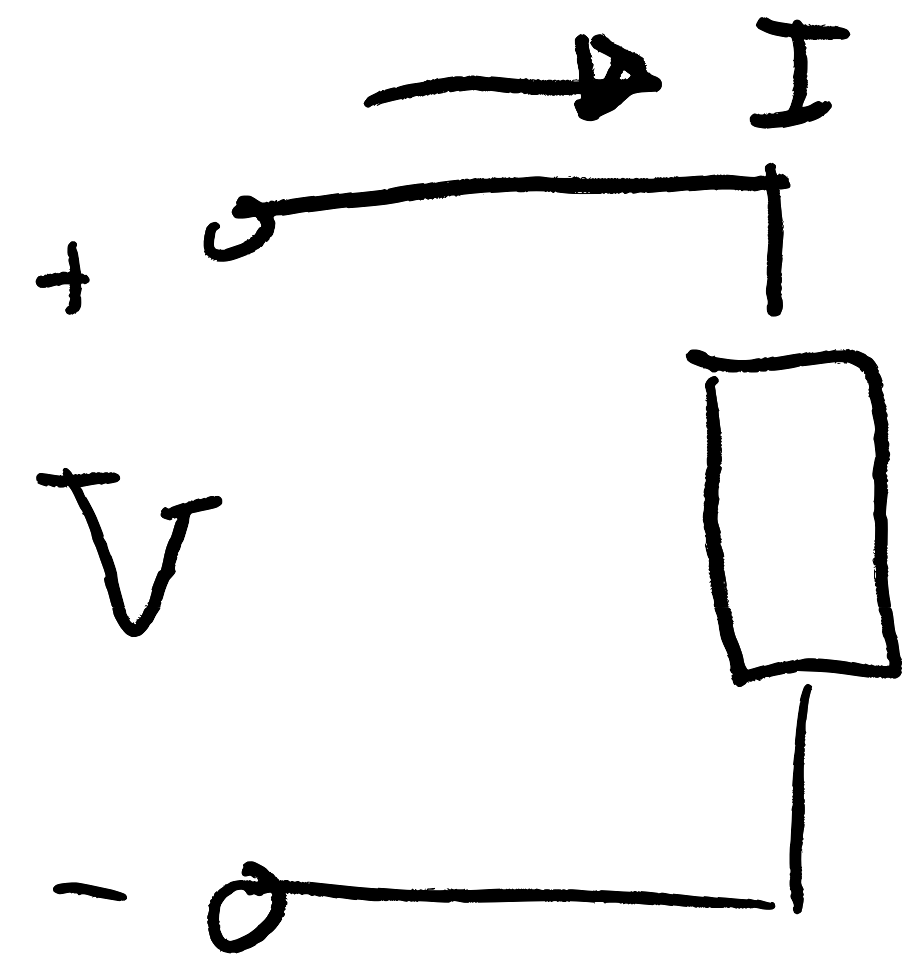
Thevenin and Norton Equivalent Circuits: Why all the trouble?

- Thevenin / Norton are independent of the load
- we can make changes without re analyzing whole circuit

Electrical Power

All circuit elements either dissipate, store, or deliver power

→ physical interaction between charge & electromagnetic fields.



$$dW = V\,dq$$

Power is the rate of work:

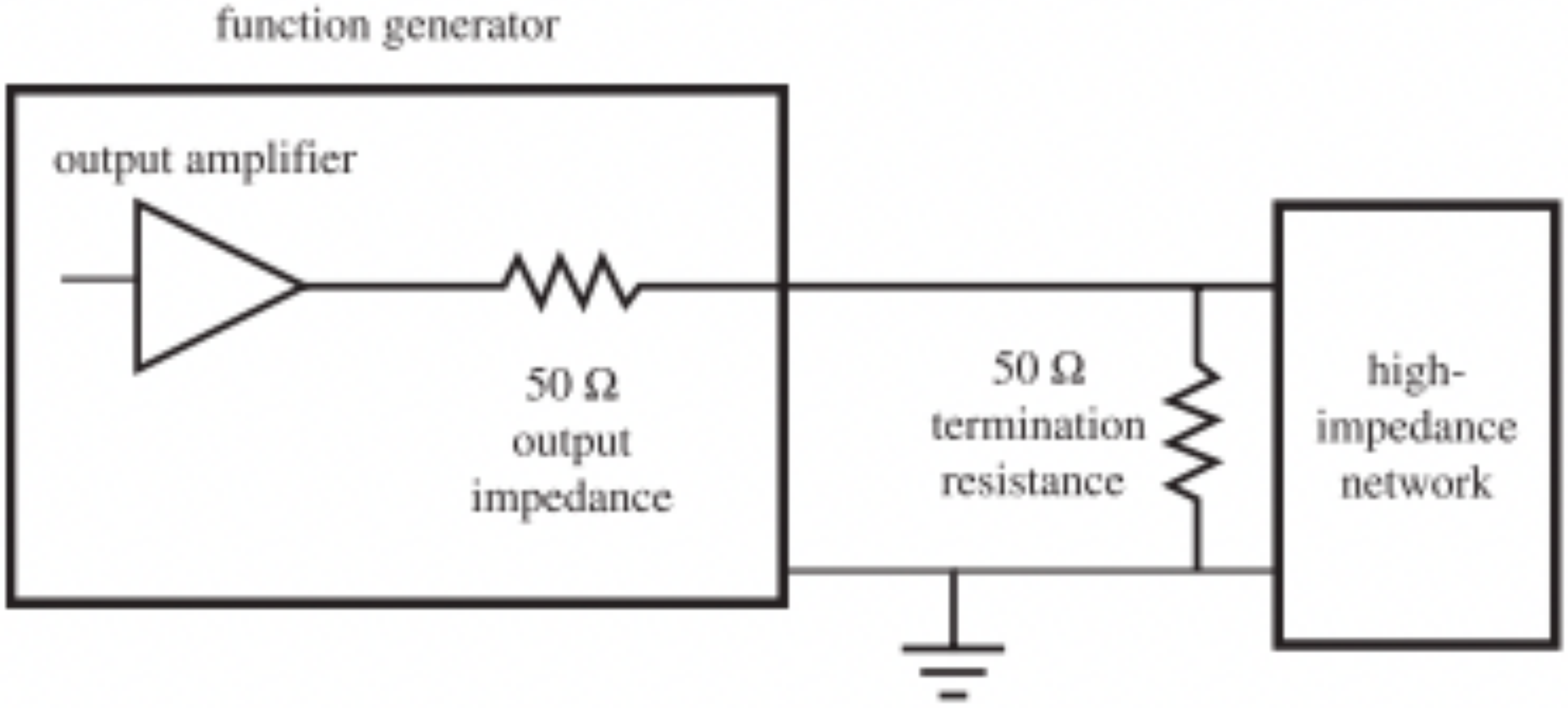
$$P = \frac{dW}{dt} = V\frac{dq}{dt}$$

~~$= VI^2 = \frac{V^2}{R}$ check~~

$$= VI = \frac{V^2}{R} = I^2 R$$

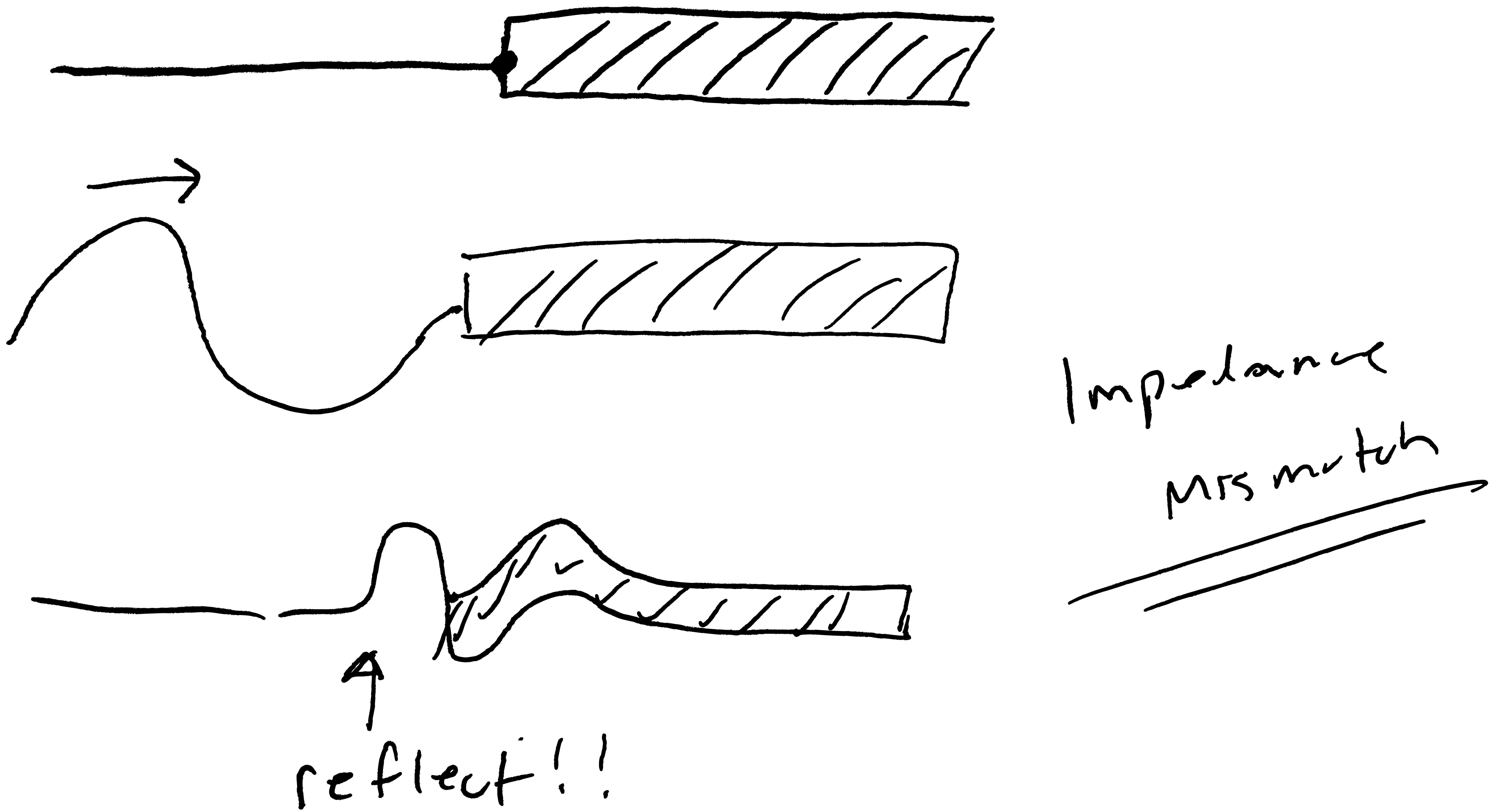
Electrical Power

Impedance Matching



What does the termination resistant do?

More on Impedance: String Analogy



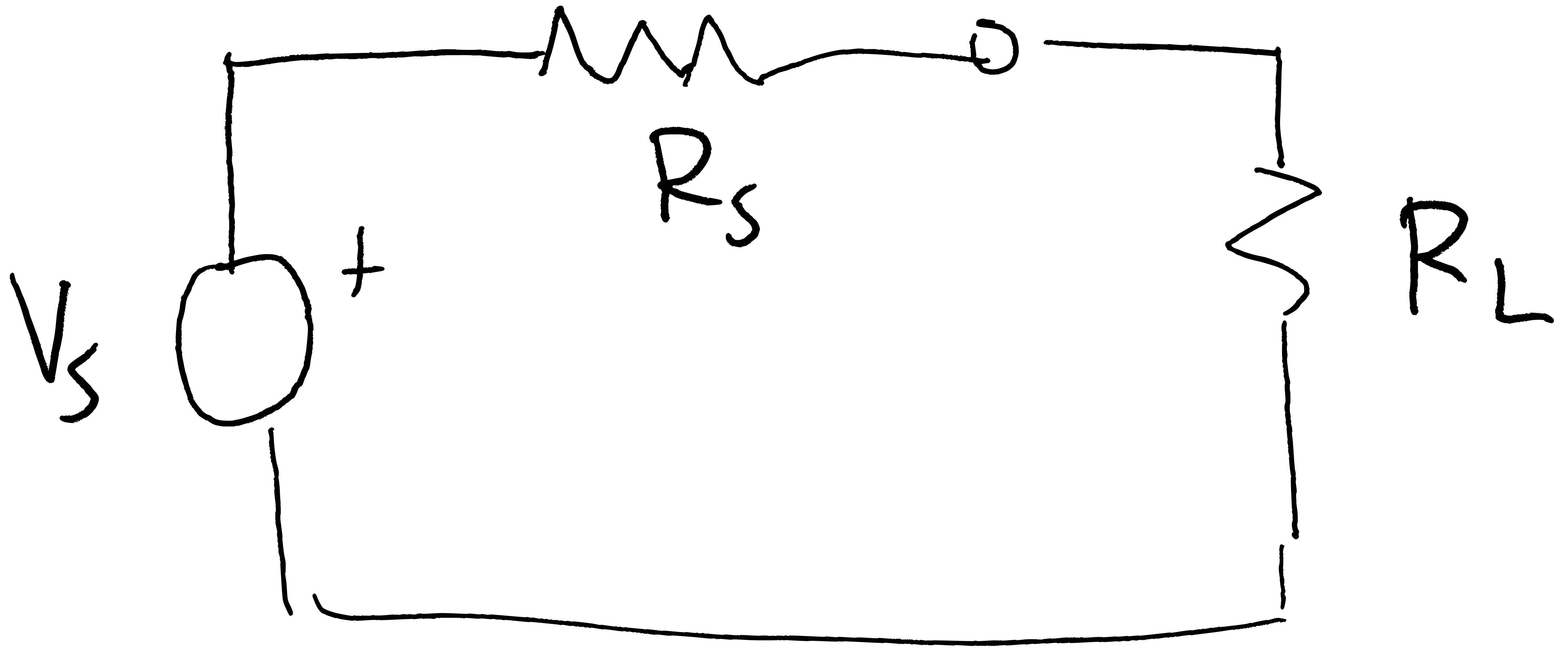
Discussion

■ CLASS DISCUSSION ITEM 2.12

Audio Stereo Amplifier Impedances

Why are audio stereo amplifier output impedances important specifications when selecting speakers?

Consider simple circuit. Find RL to maximize power transfer



How to approach?

$P_L(R_L)$

$$\frac{dP_L}{dR_L} = 0$$

solve for R_L

Consider simple circuit. Find RL to maximize power transfer