Structured Electronic Design
Estimation of poles and zeros
in networks without feedback

Time-constant matrix

Time-constant matrix

Basis for intuitive determination of poles in networks without feedback

Time-constant matrix

Basis for intuitive determination of poles in networks without feedback

MNA matrix in first-order differential form:

Time-constant matrix

Basis for intuitive determination of poles in networks without feedback

MNA matrix in first-order differential form: $\mathbf{M} = \mathbf{G} + s\mathbf{C}$

Time-constant matrix

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Characteristic equation:

Time-constant matrix

Basis for intuitive determination of poles in networks without feedback

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Time-constant matrix

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Generalized eigenvalue problem:

Time-constant matrix

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If τ_i is an eigenvalue of $\mathbf{T}$ then $p_i = -\frac{1}{\tau_i}$ is a pole of the network.

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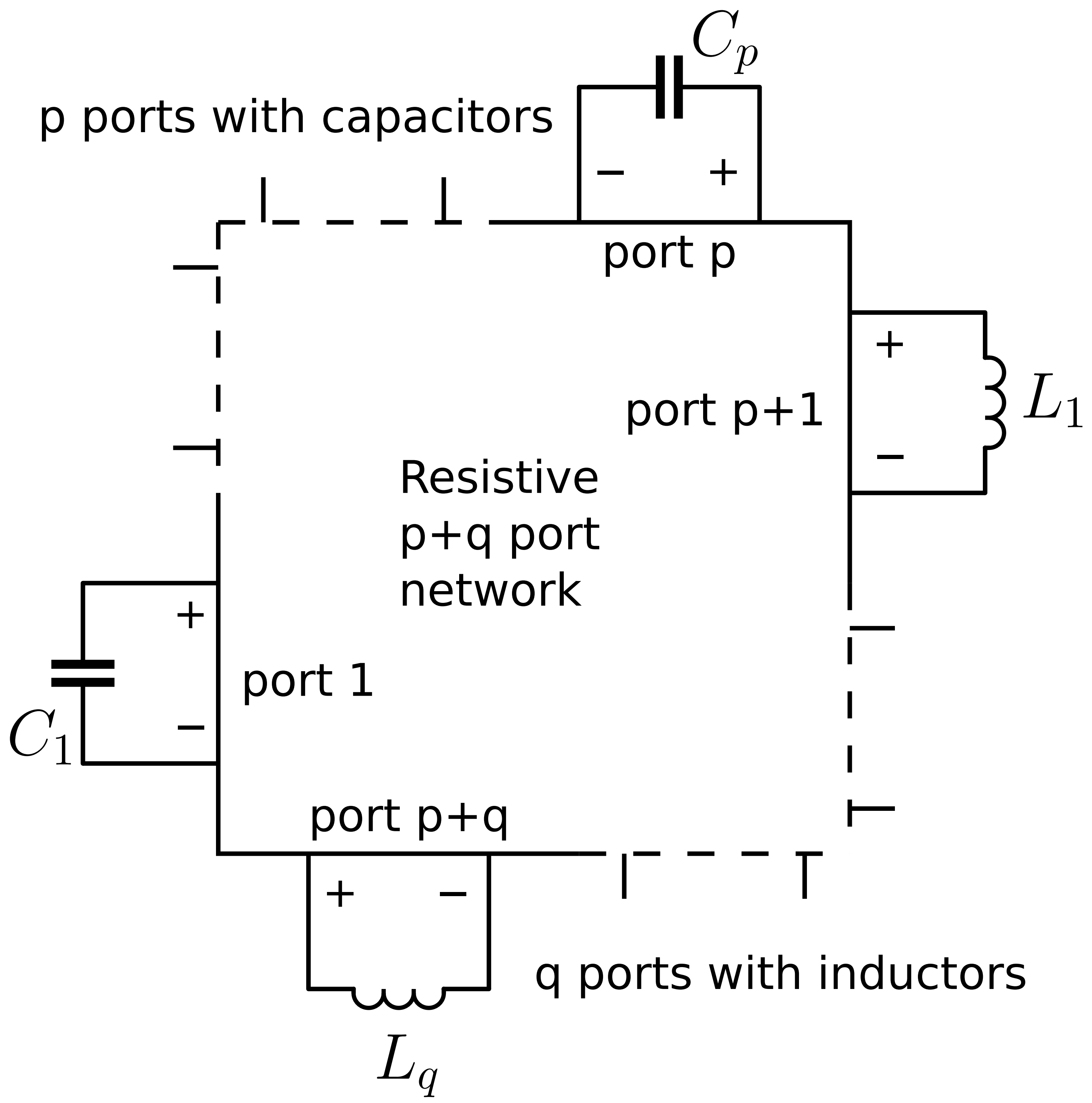
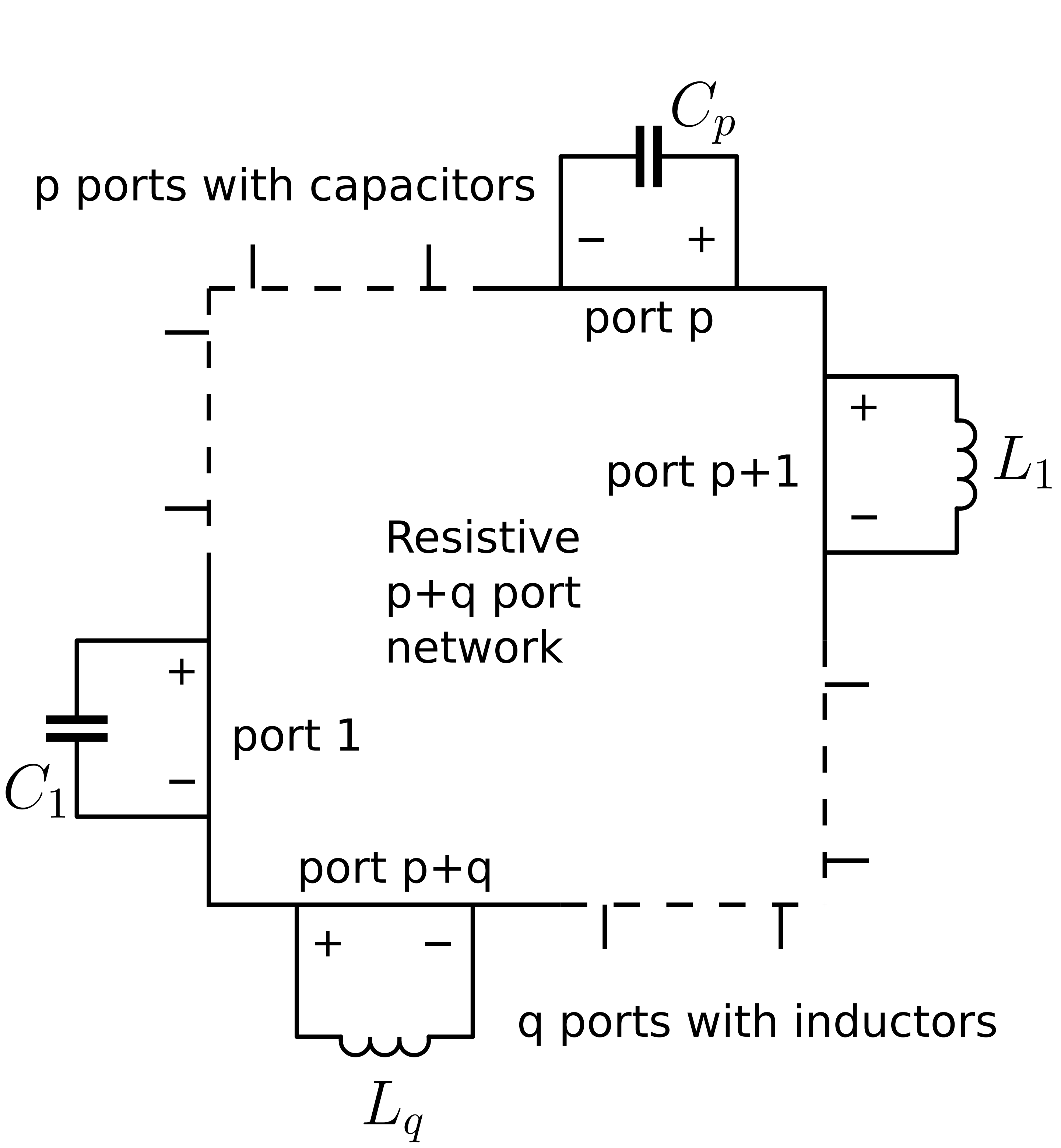
If τ_i is an eigenvalue of $\mathbf{T}$ then $p_i = -\frac{1}{\tau_i}$ is a pole of the network.

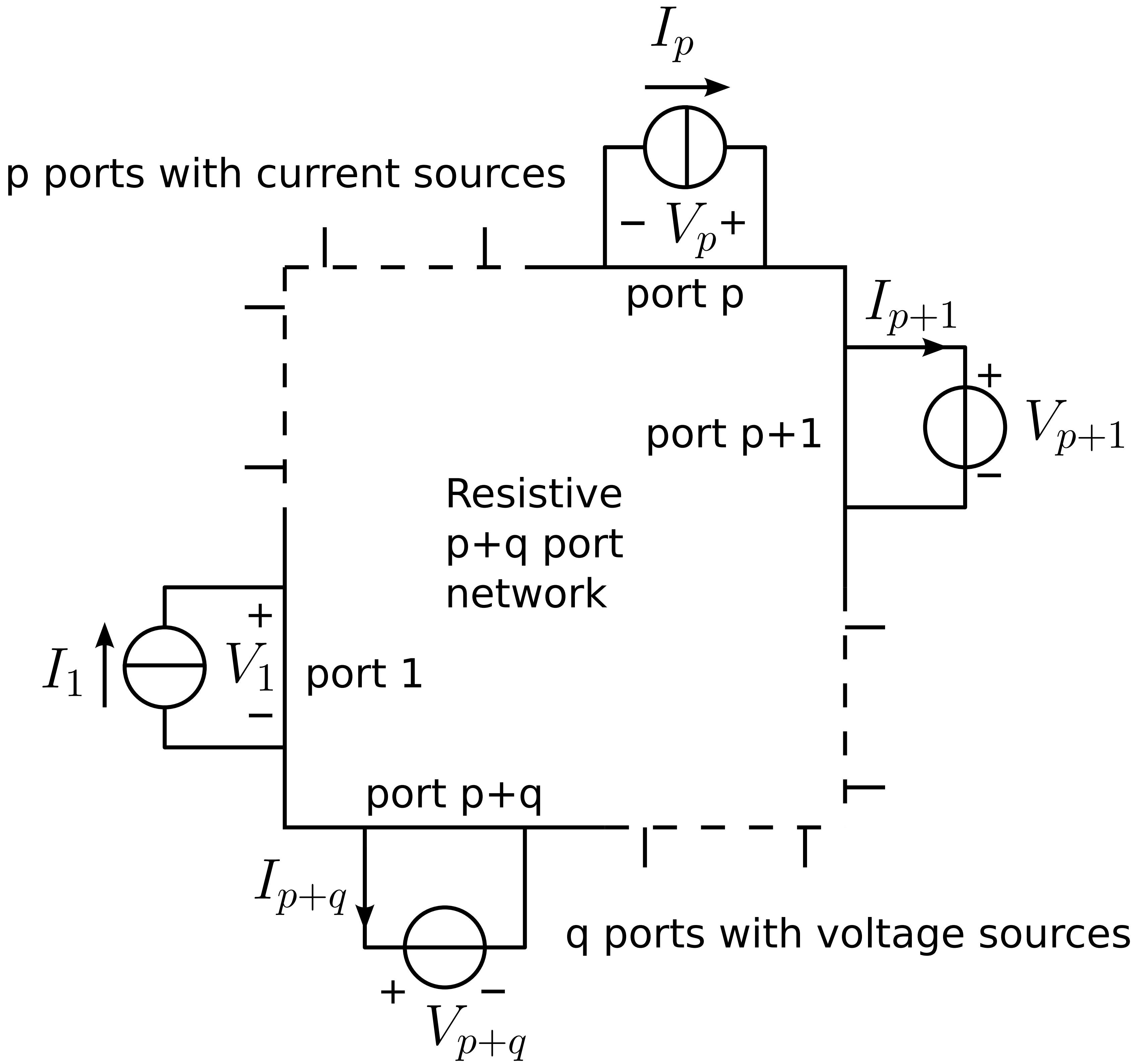
Resistance matrix

Resistance matrix



Resistance matrix





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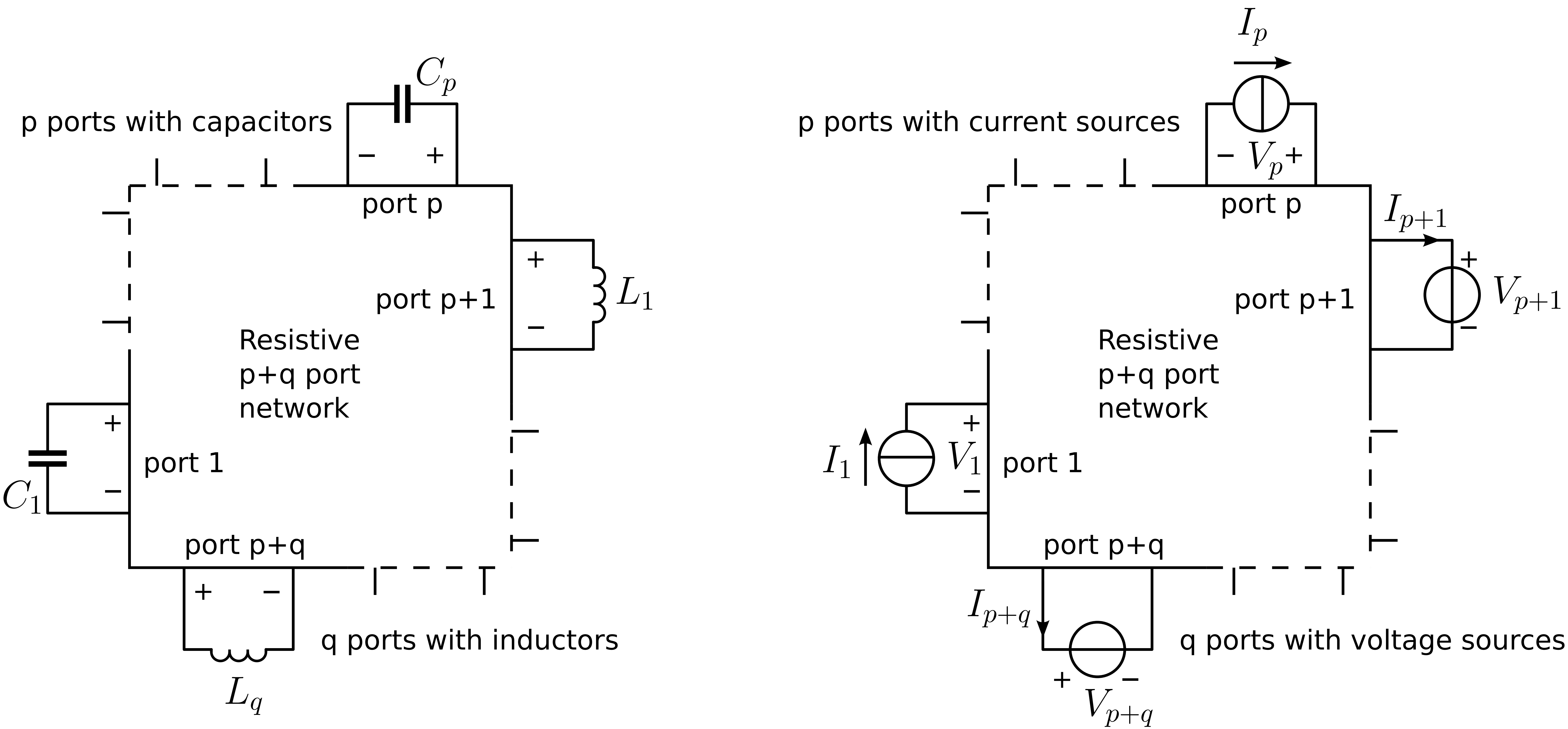
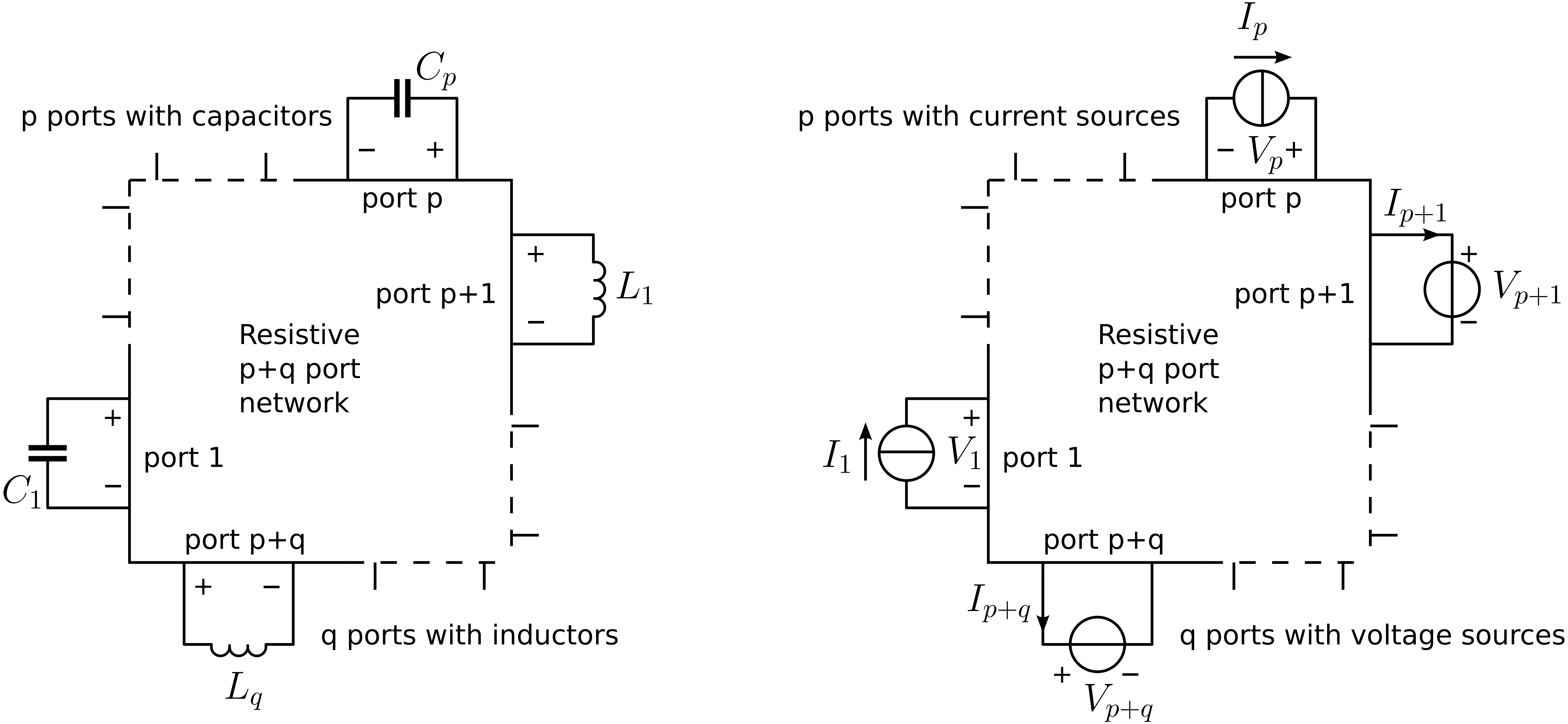


Resistance matrix relates dependent port variables to independent port variables

Resistance matrix



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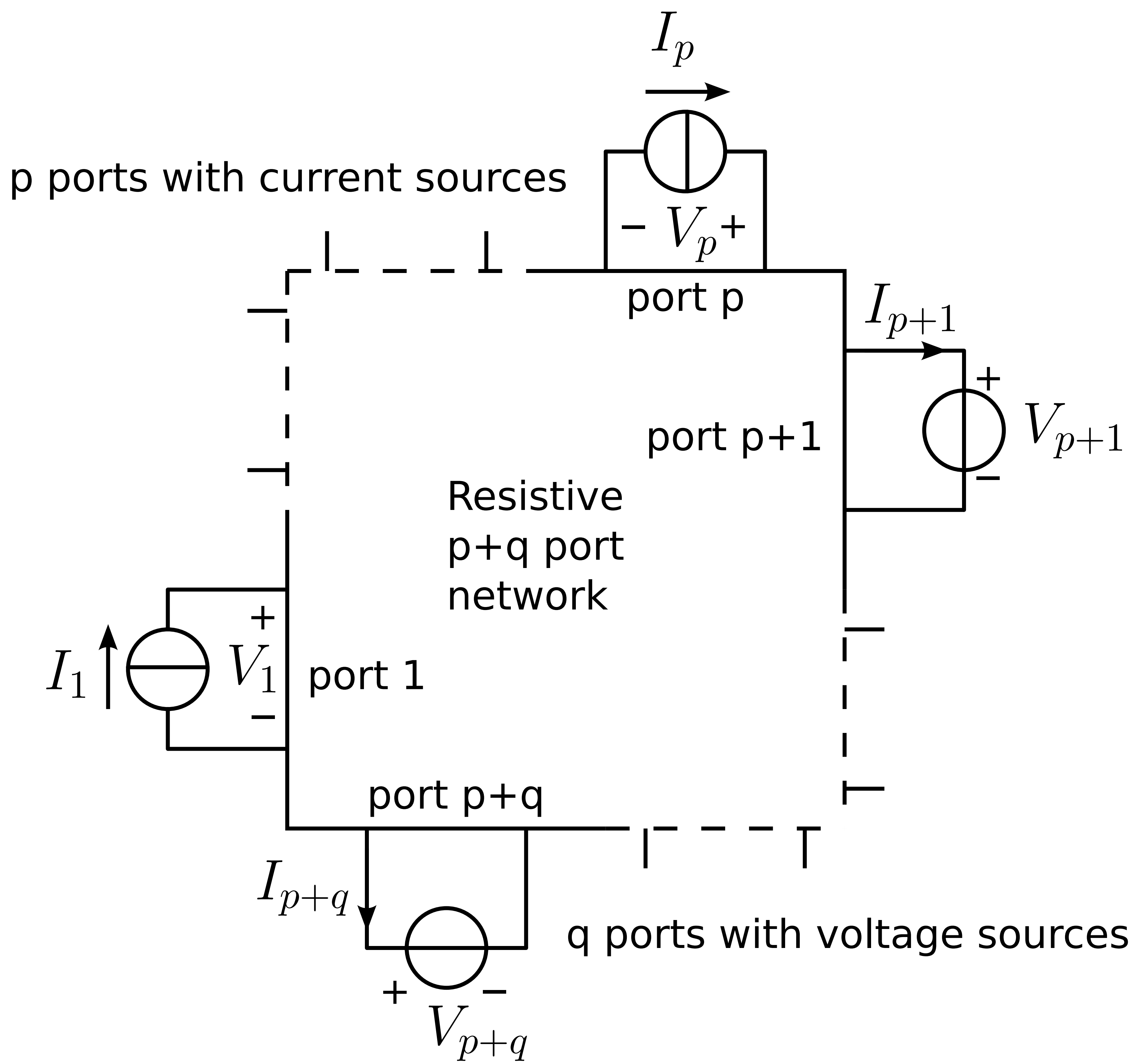

$$\begin{pmatrix} V_1 \\ \vdots \\ V_p \\ I_{p+1} \\ \vdots \\ I_{p+q} \end{pmatrix} = \begin{pmatrix} r_{11} & \cdots & r_{1p} & \mu_{11} & \cdots & \mu_{1q} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ r_{p1} & \cdots & r_{pp} & \mu_{p1} & \cdots & \mu_{pq} \\ \alpha_{11} & \cdots & \alpha_{1p} & g_{11} & \cdots & g_{q1} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \alpha_{q1} & \cdots & \alpha_{qp} & g_{1q} & \cdots & g_{qq} \end{pmatrix} \begin{pmatrix} I_1 \\ \vdots \\ I_p \\ V_{p+1} \\ \vdots \\ V_{p+q} \end{pmatrix}$$

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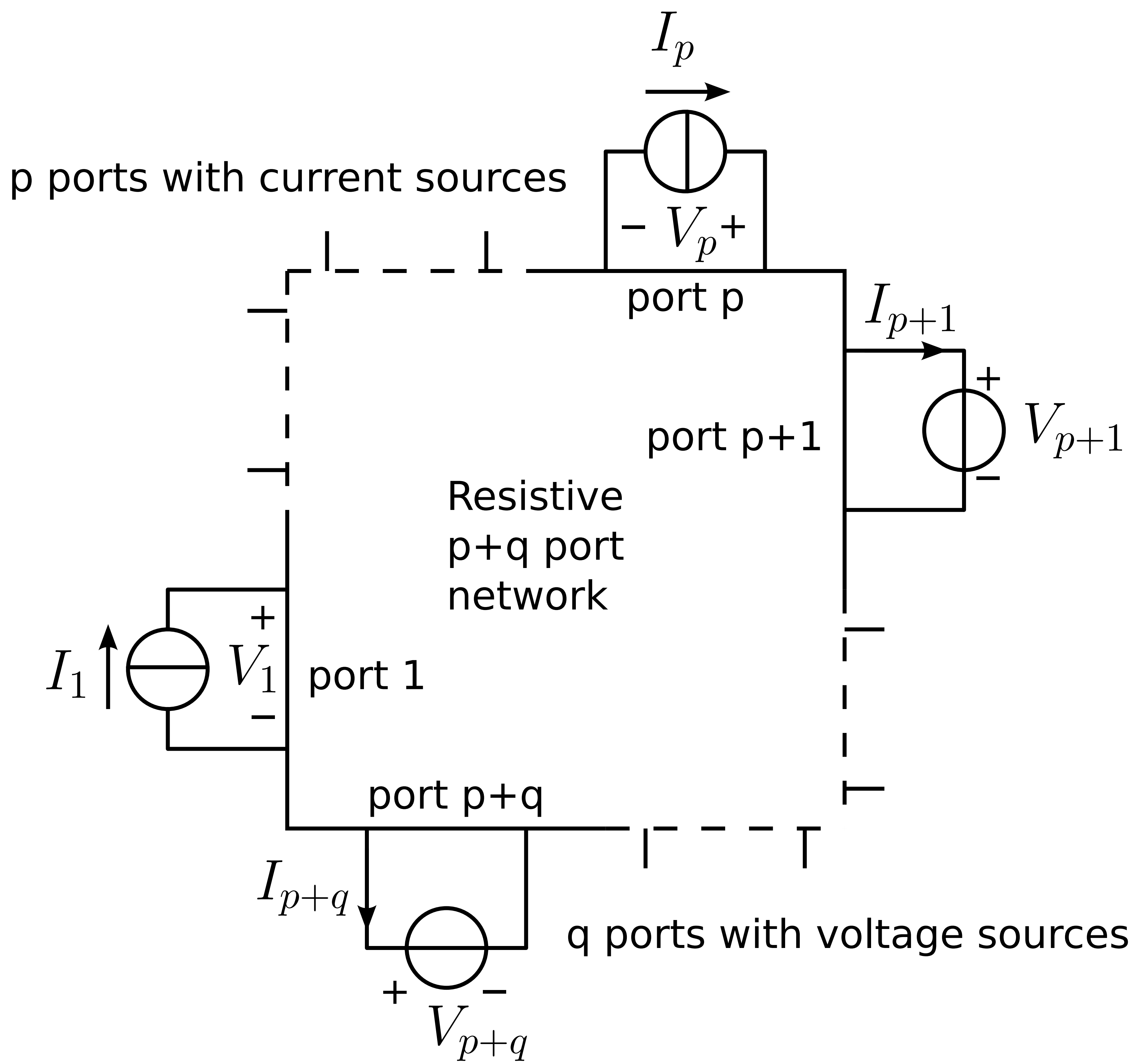

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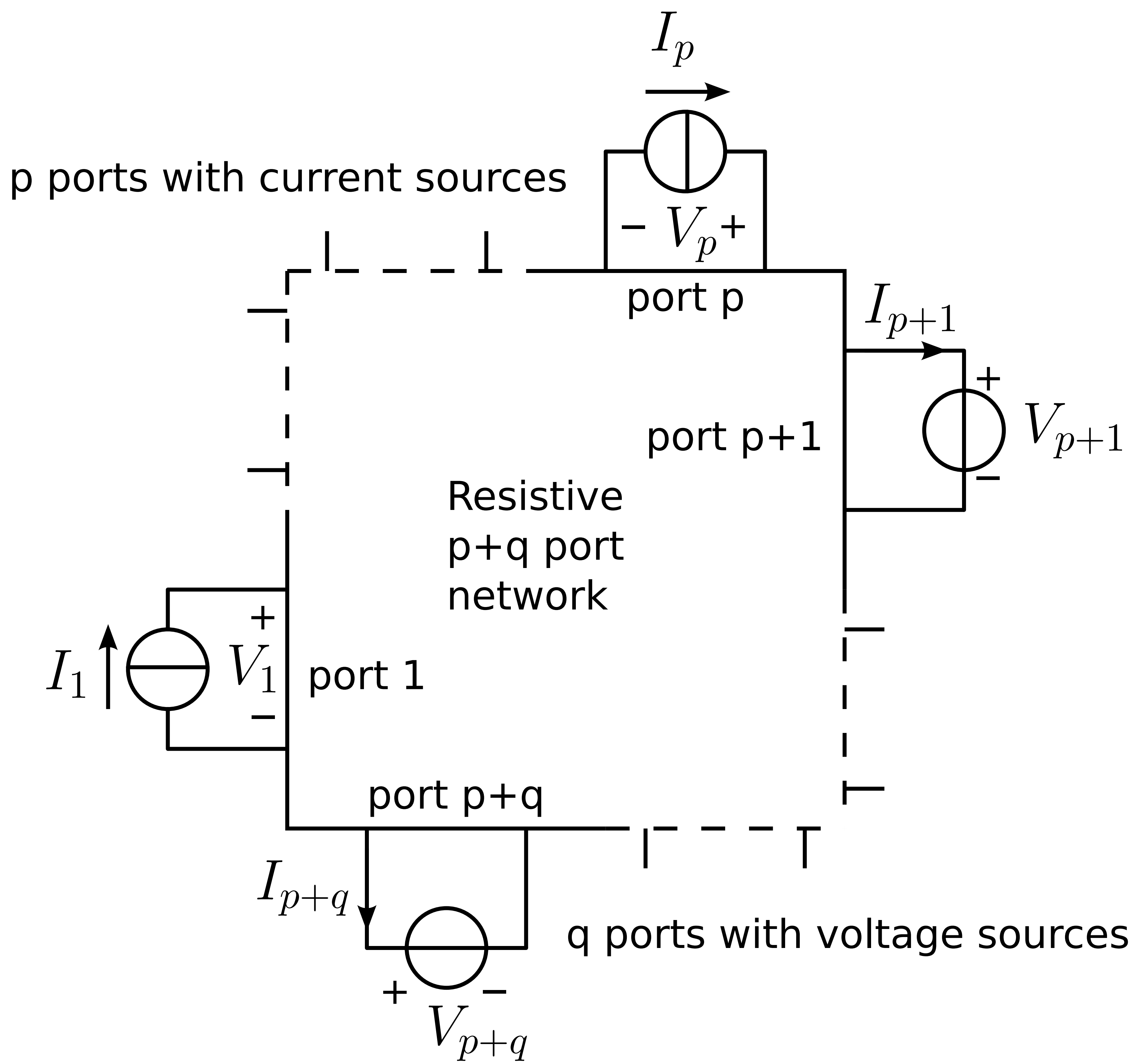
Diagonal elements: $\mathcal{R}_{i,i}$

Resistance matrix



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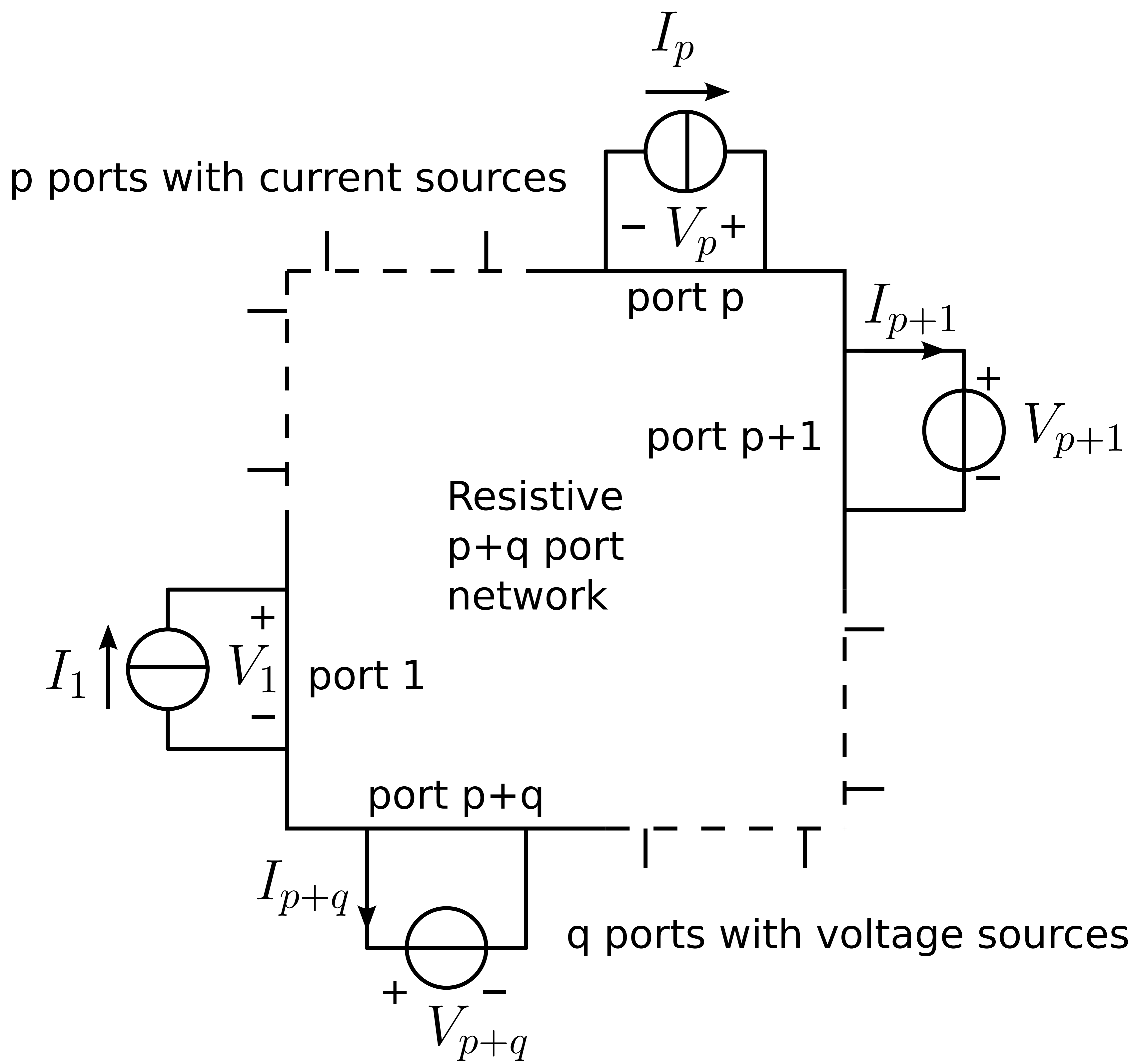
Resistance, conductance at port i

Resistance matrix



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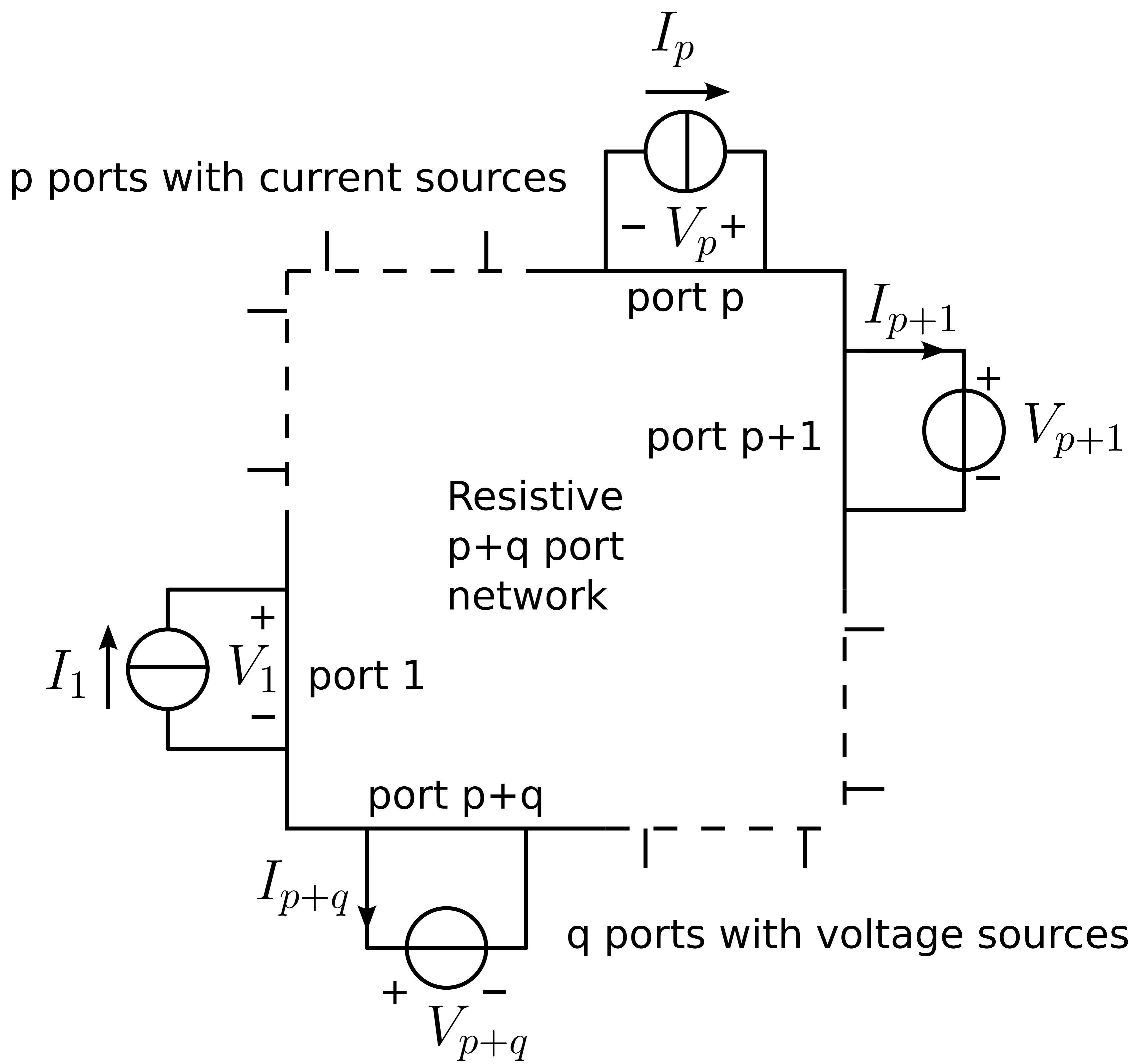
Resistance, conductance at port i

Off-diagonal elements: $\mathcal{R}_{i,j}$

Resistance matrix



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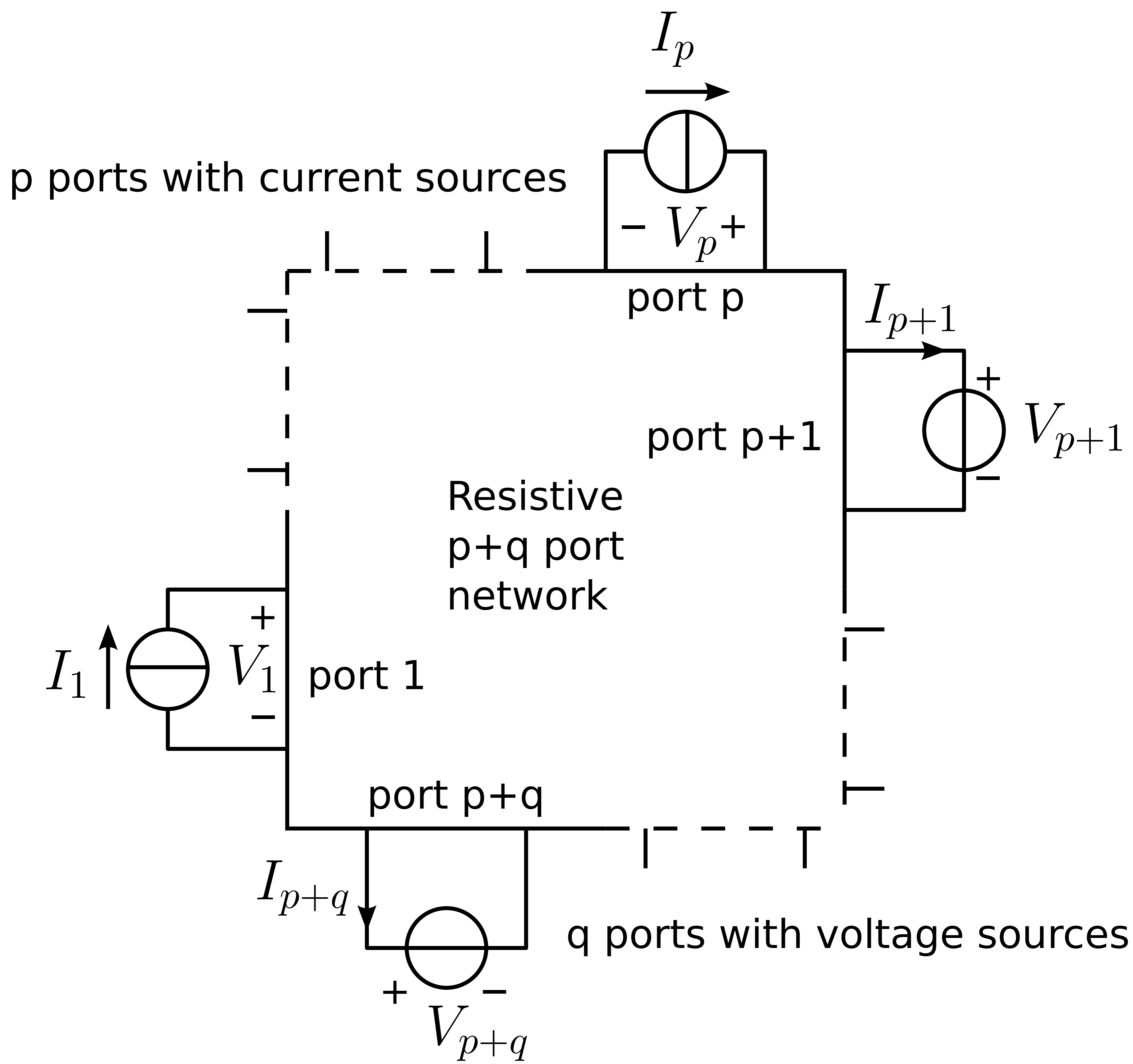
Resistance, conductance at port i

Off-diagonal elements: $\mathcal{R}_{i,j}$

transresistance

Resistance matrix



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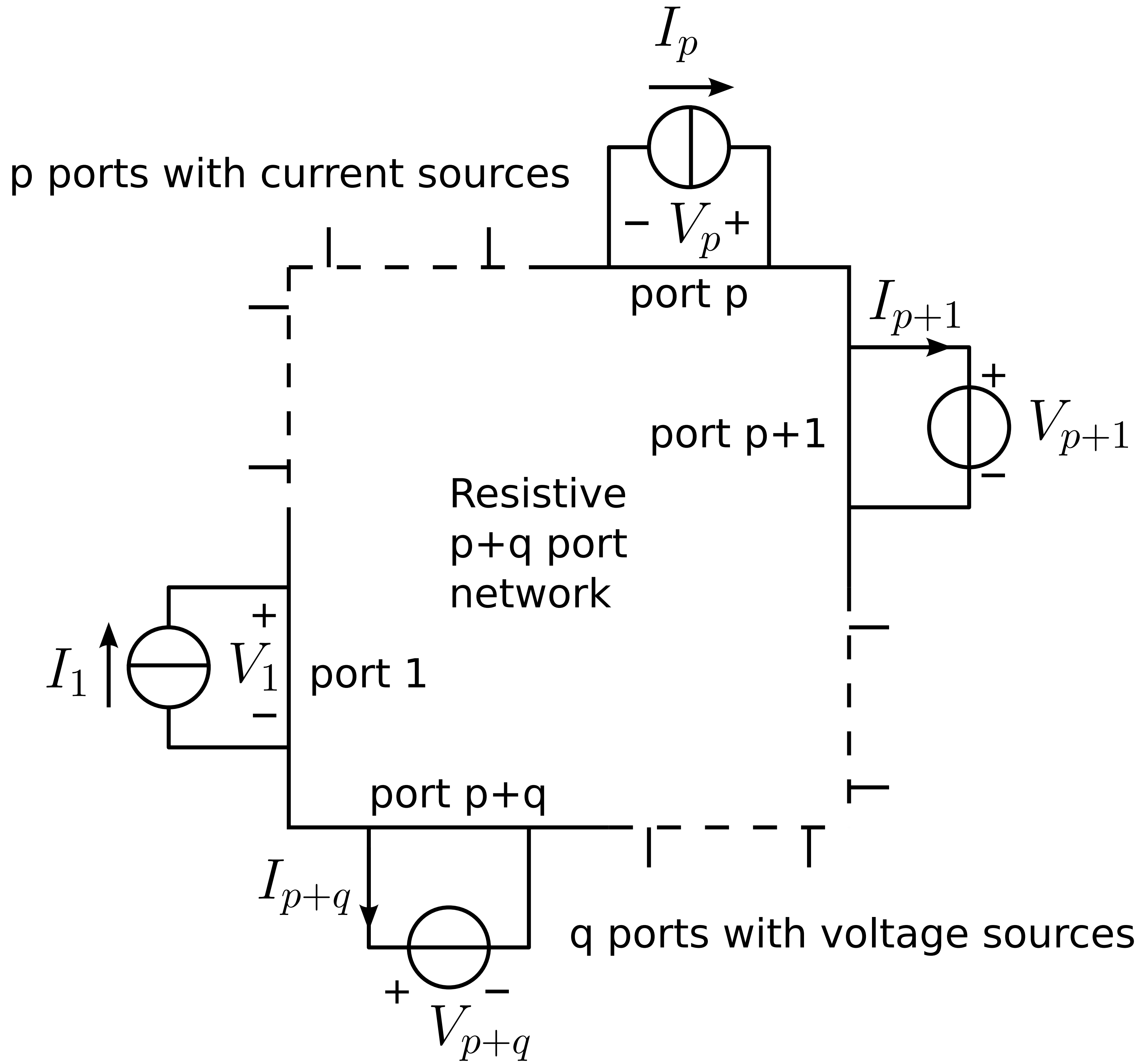
Resistance, conductance at port i

Off-diagonal elements: $\mathcal{R}_{i,j}$

transresistance
transconductancer

Resistance matrix



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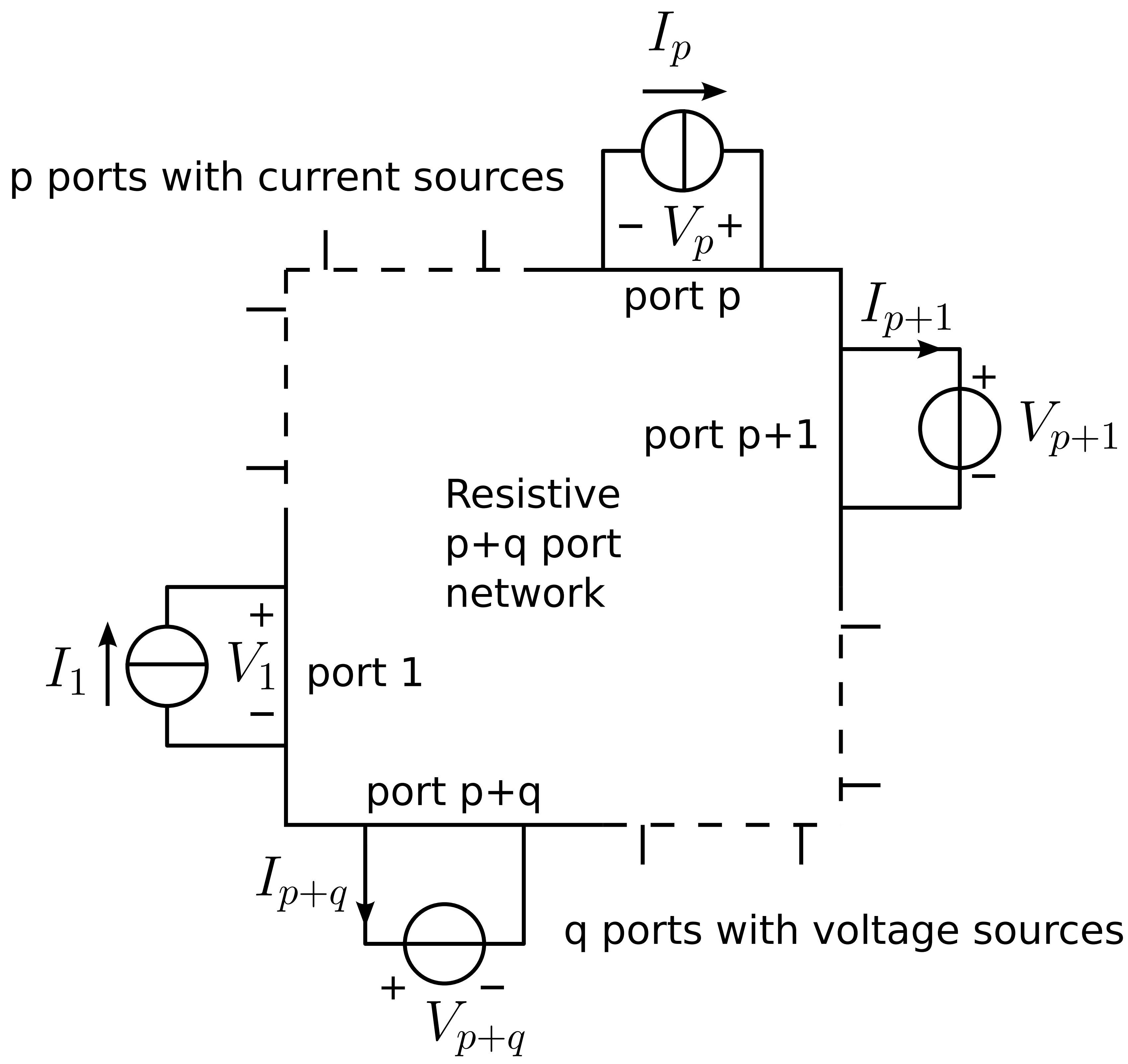
Resistance, conductance at port i

Off-diagonal elements: $\mathcal{R}_{i,j}$

transresistance
transconductance
voltage gain factor

Resistance matrix



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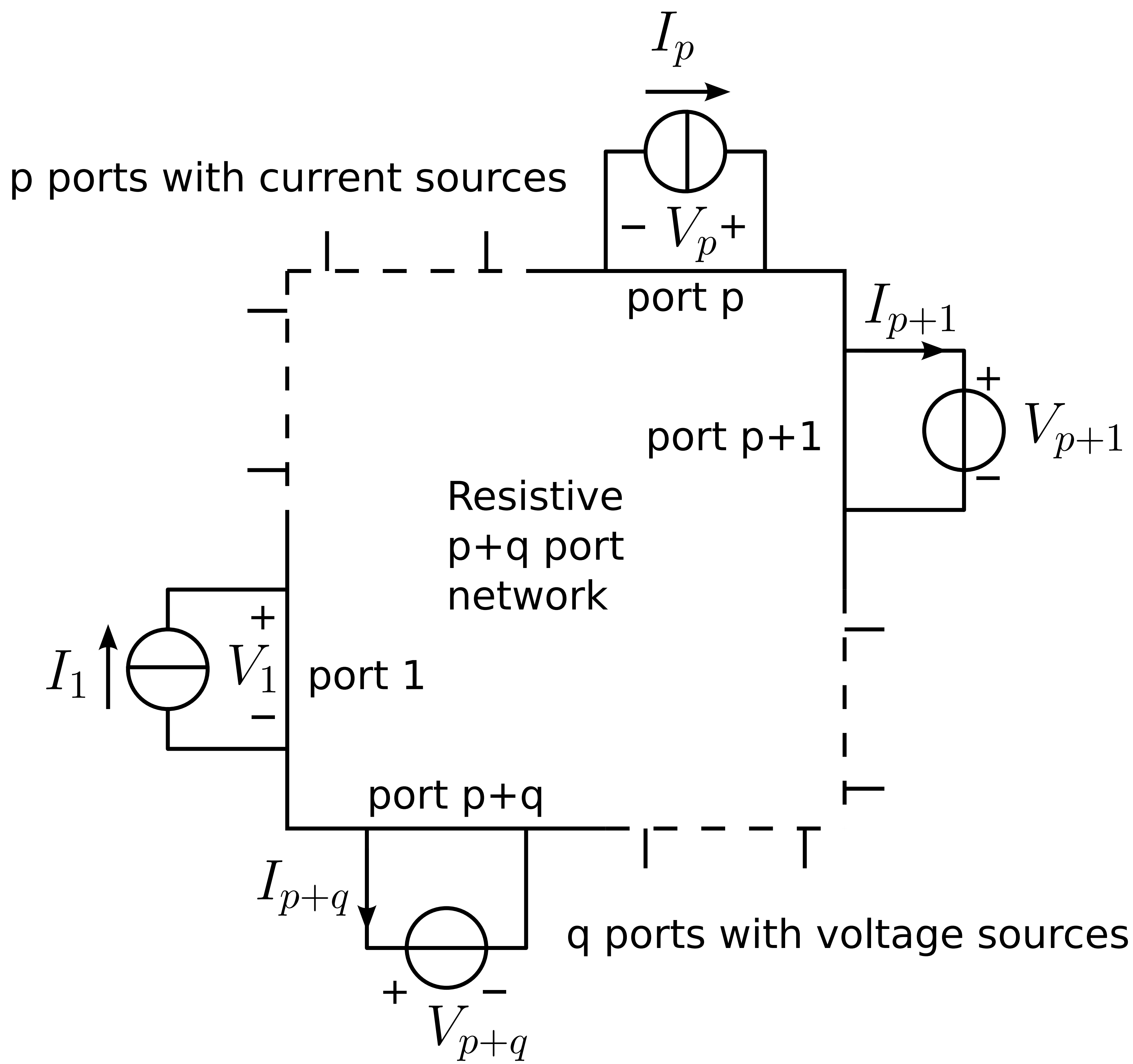
Resistance, conductance at port i

Off-diagonal elements: $\mathcal{R}_{i,j}$

transresistance
transconductance
voltage gain factor
current gain factor

Resistance matrix



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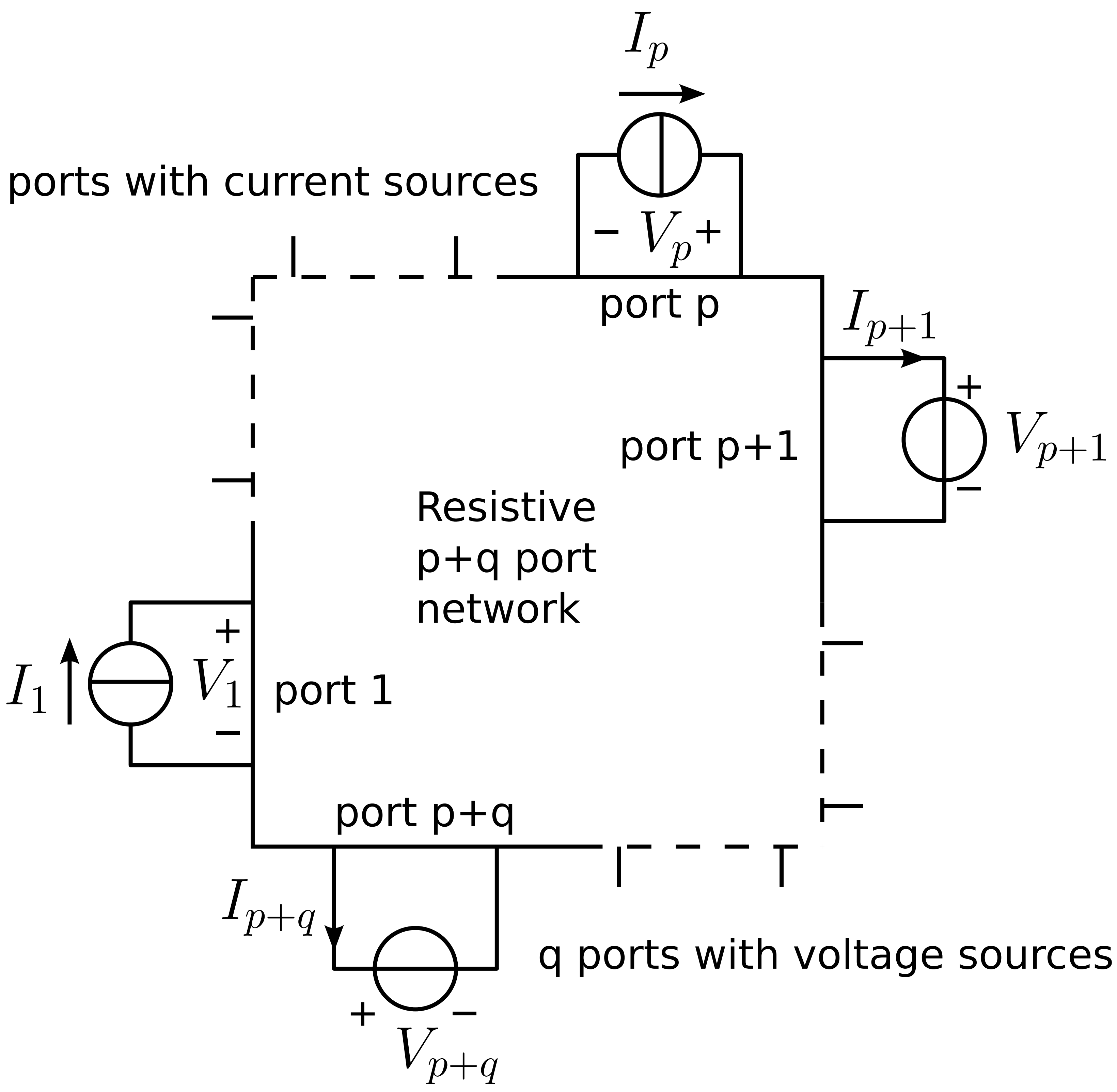
Resistance, conductance at port i

Off-diagonal elements: $\mathcal{R}_{i,j}$

transresistance
transconductance
voltage cain factor
current gain factor

from port i to port j

Resistance matrix



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transresistance
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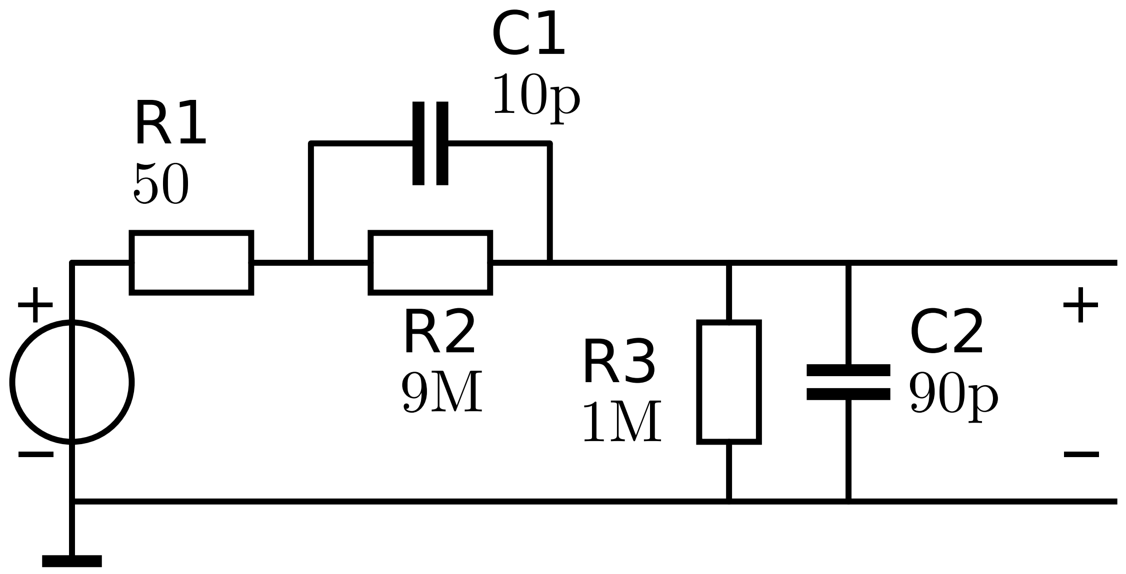
current gain factor

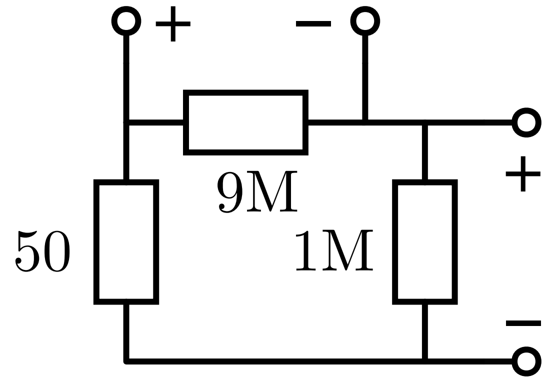
from port i to port j

RC matrix example

Oscilloscope probe circuit



R-port



R-matrix

$$\begin{pmatrix} \frac{9\cdot10^6\left(50+10^6\right)}{50+10\cdot10^6} & -\frac{9\cdot10^6\times10^6}{50+10\cdot10^6} \\ -\frac{9\cdot10^6\times10^6}{50+10\cdot10^6} & \frac{10^6\left(50+9\cdot10^6\right)}{50+10\cdot10^6} \end{pmatrix}$$

C-matrix

$$\begin{pmatrix} 10^{-11} & 0 \\ 0 & 90\cdot10^{-12} \end{pmatrix}$$

Poles from eigenvalues of RC:

$p_1 = -1768\text{Hz}$

$p_2 = -0.3537\text{GHz}$

RC matrix example

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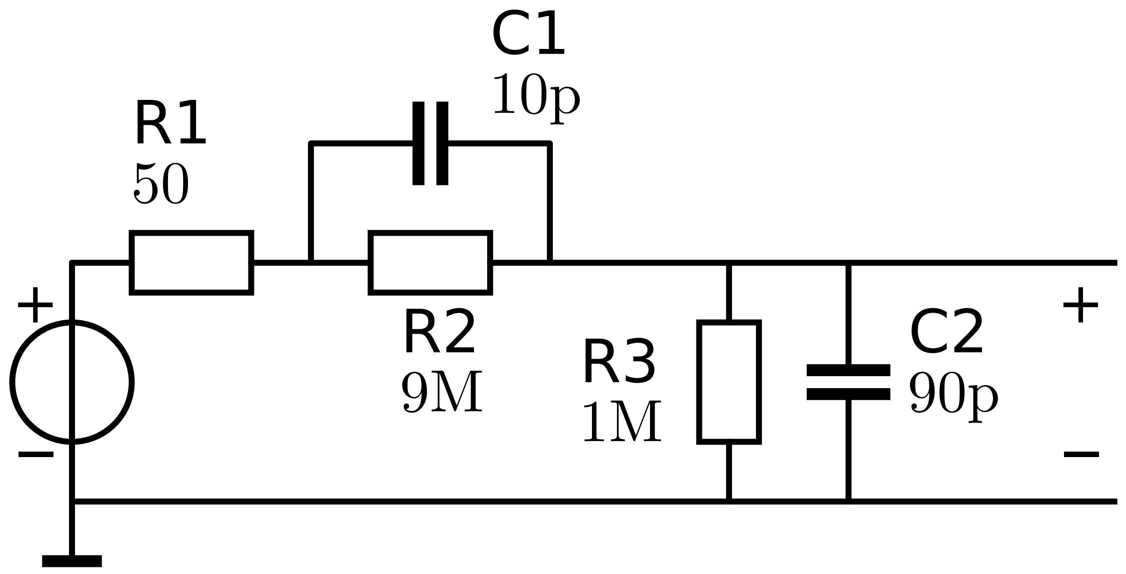

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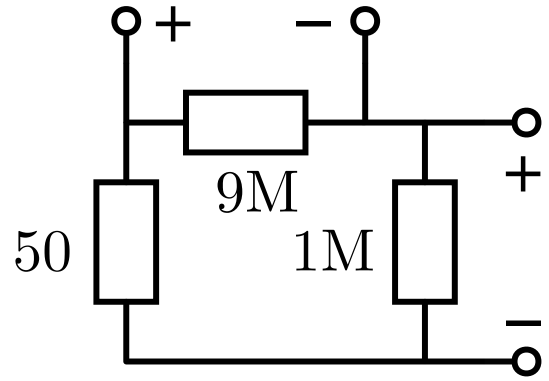

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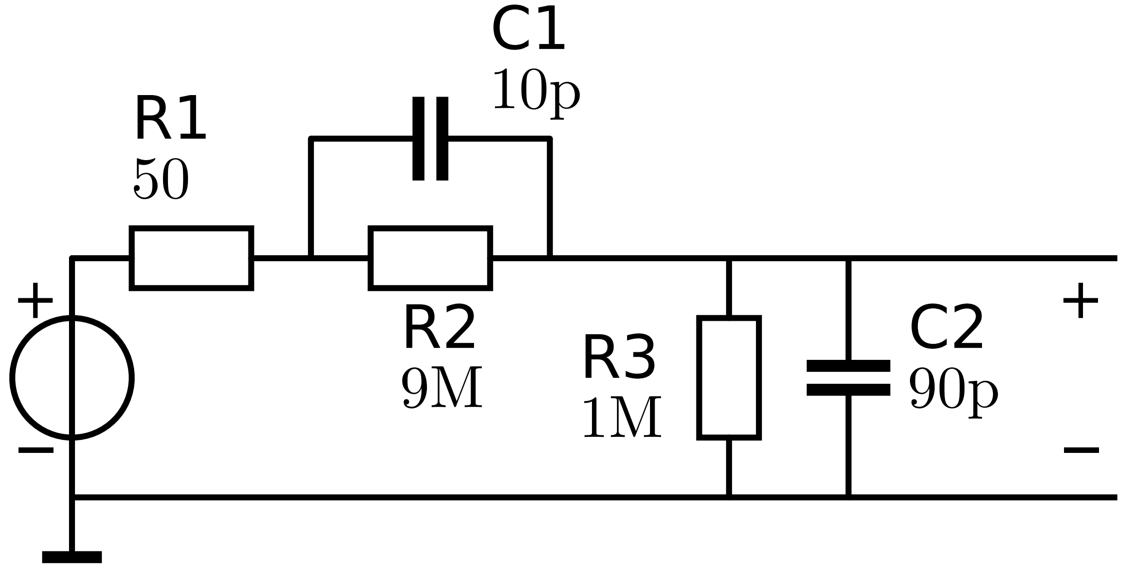

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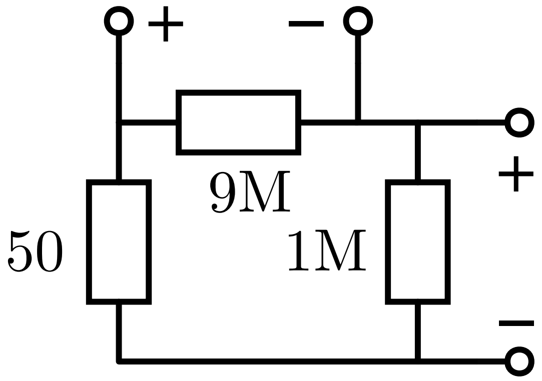

R-matrix

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RC matrix example

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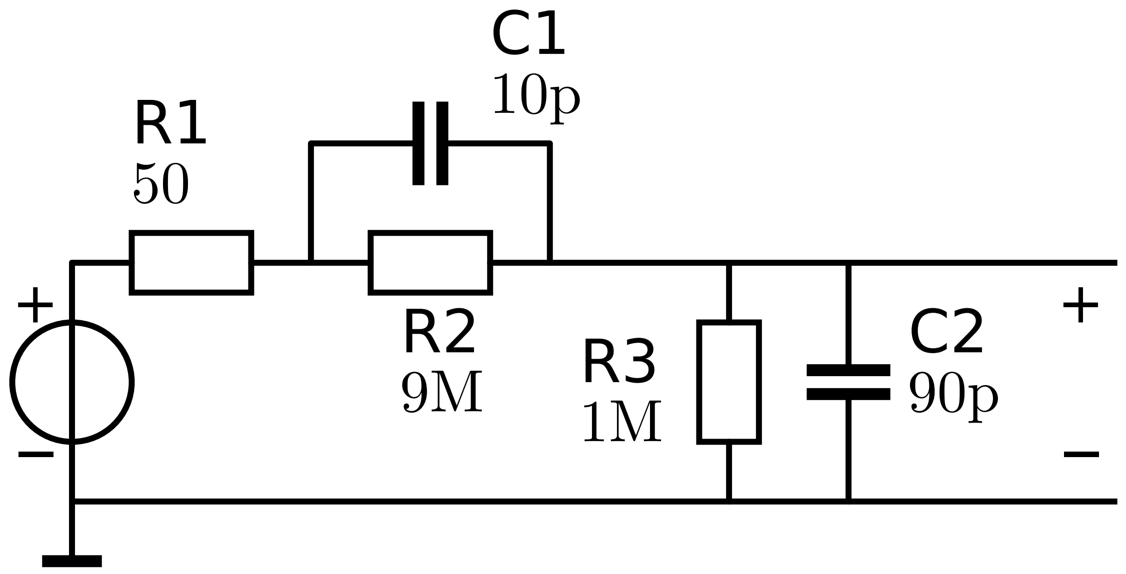

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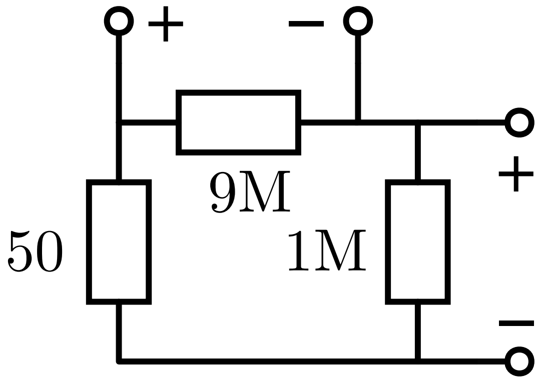

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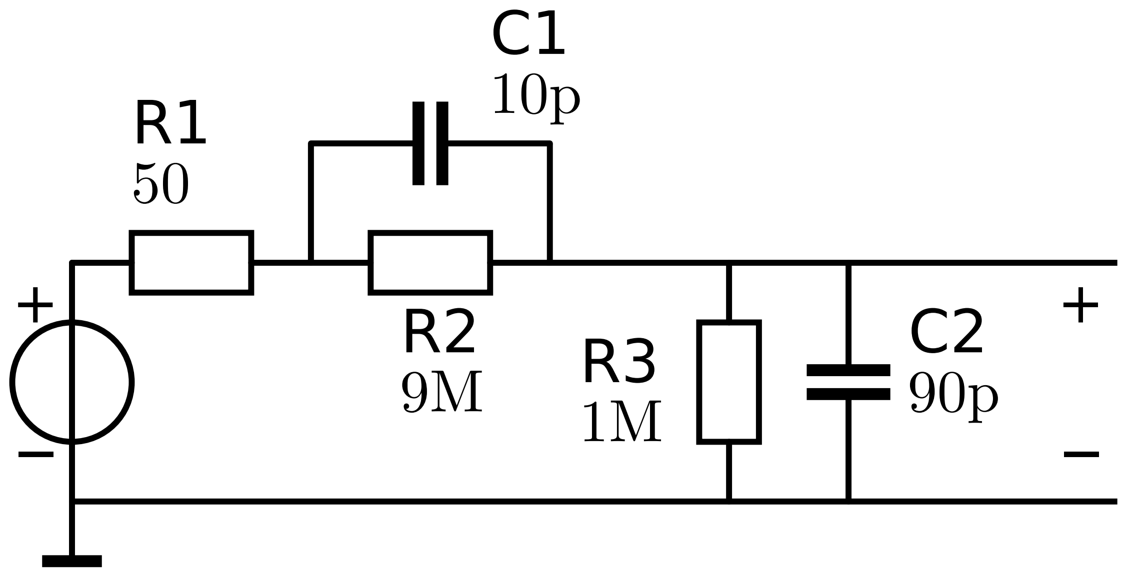

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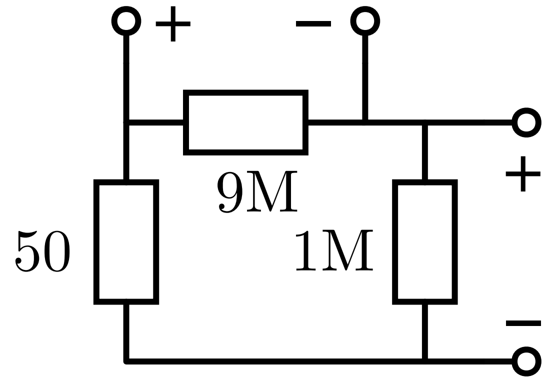

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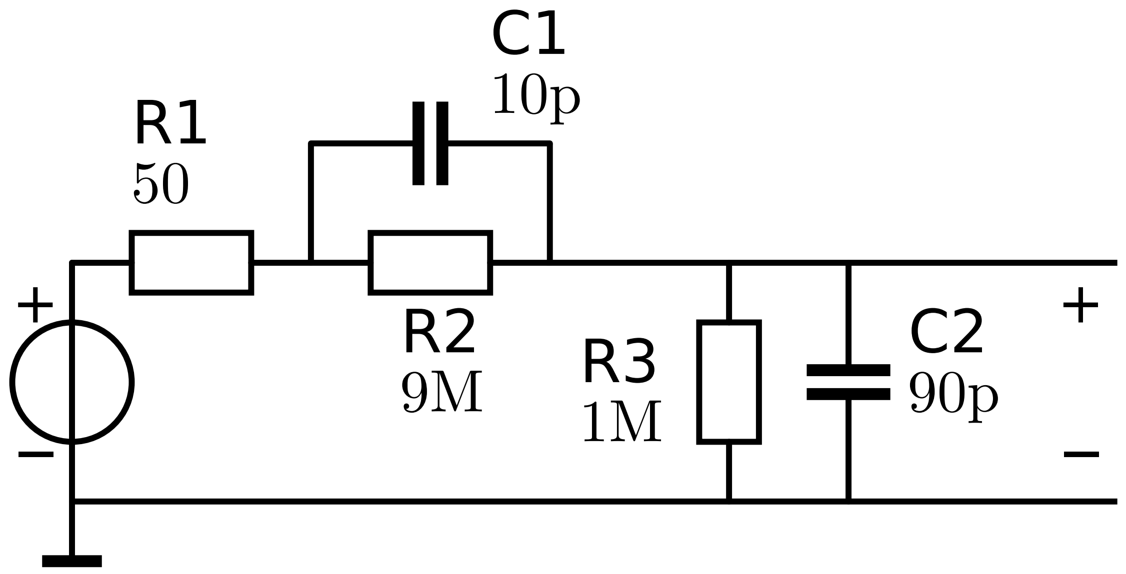

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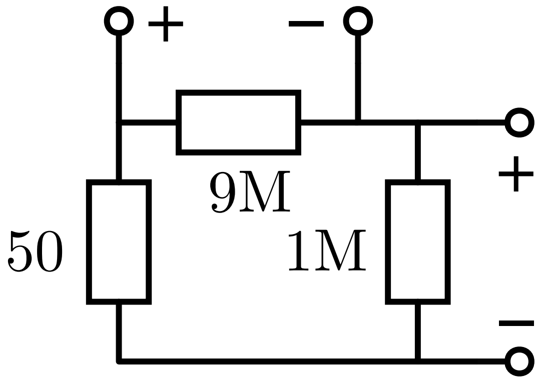

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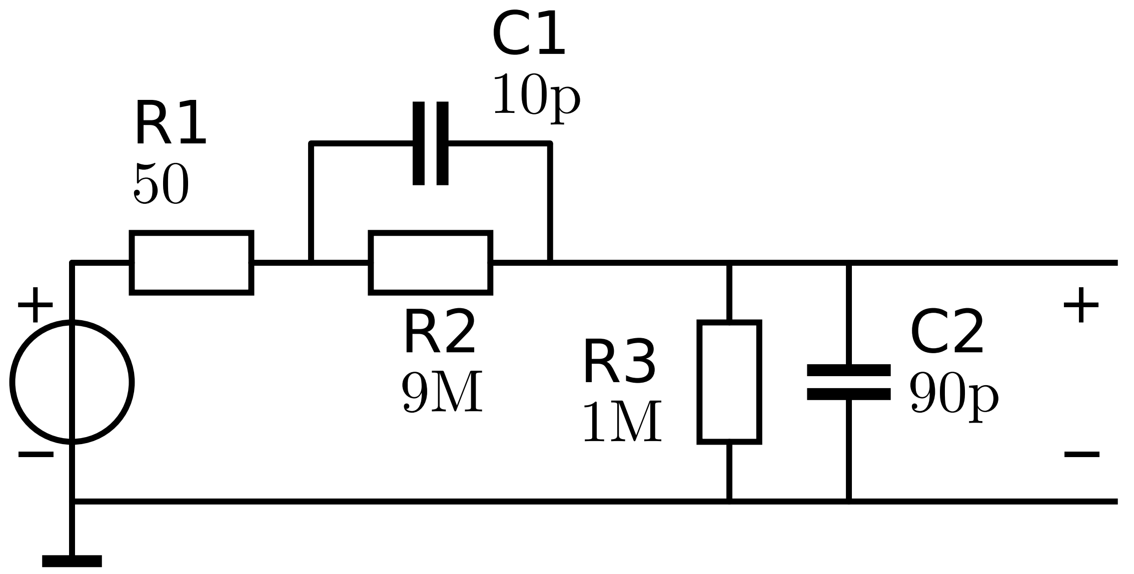
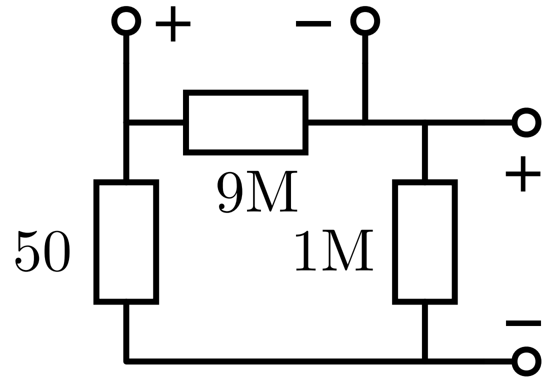
RC matrix example

Oscilloscope probe circuit



R-port



R-matrix

$$\begin{pmatrix} \frac{9\cdot 10^6\left(50+10^6\right)}{50+10\cdot 10^6} & -\frac{9\cdot 10^6\times 10^6}{50+10\cdot 10^6} \\ -\frac{9\cdot 10^6\times 10^6}{50+10\cdot 10^6} & \frac{10^6\left(50+9\cdot 10^6\right)}{50+10\cdot 10^6} \end{pmatrix}$$

C-matrix

$$\begin{pmatrix} 10^{-11} & 0 \\ 0 & 90\cdot 10^{-12} \end{pmatrix}$$

Poles from eigenvalues of RC:

$p_1 = -1768\text{Hz}$ $\qquad$ $p_2 = -0.3537\text{GHz}$

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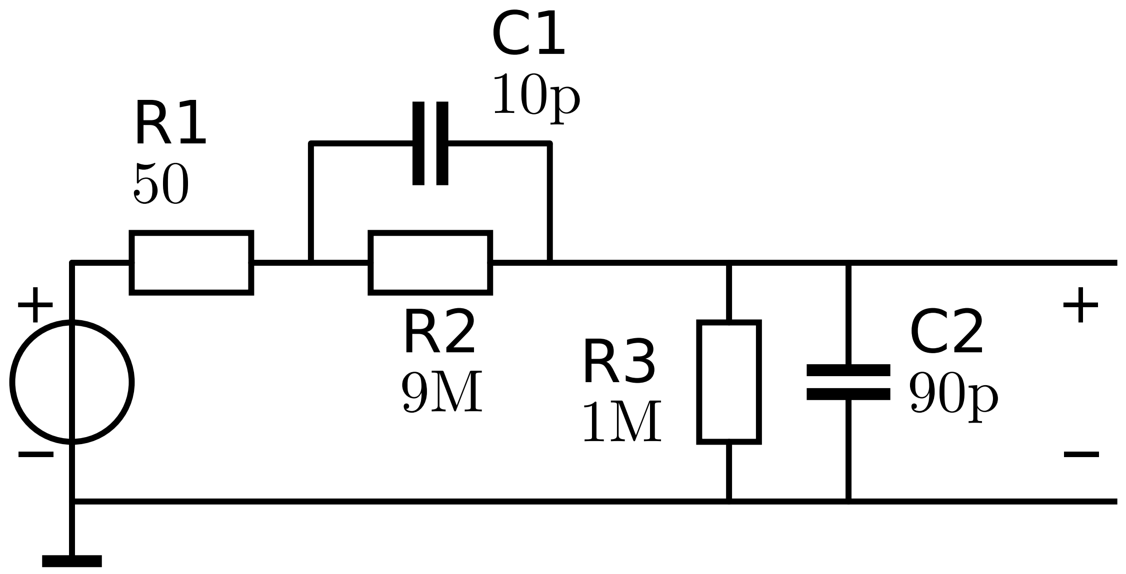
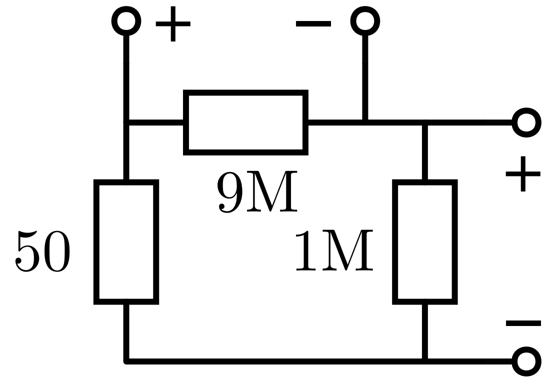


R-port



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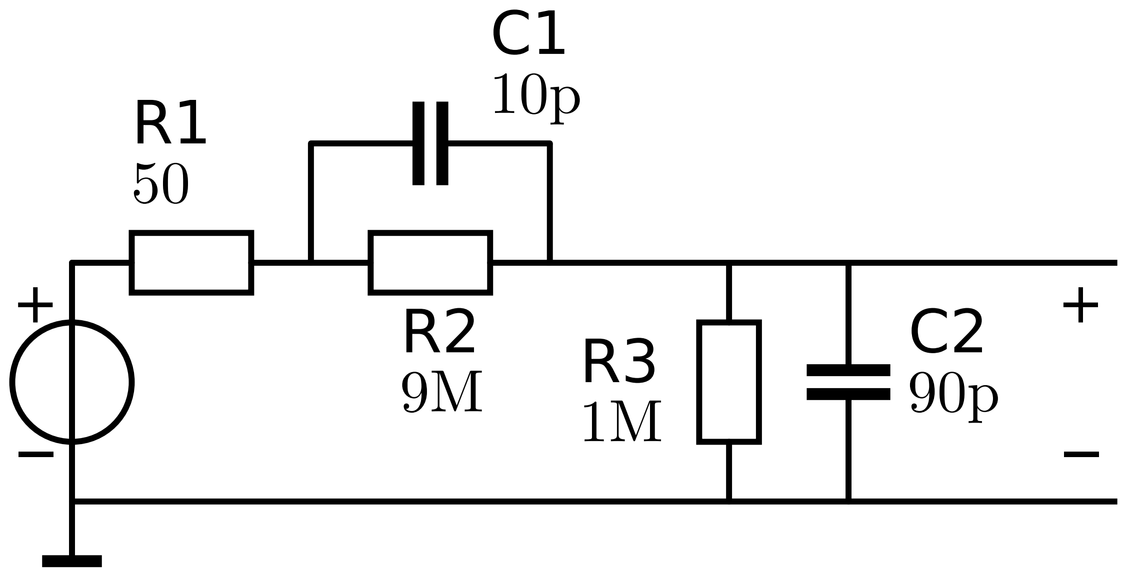

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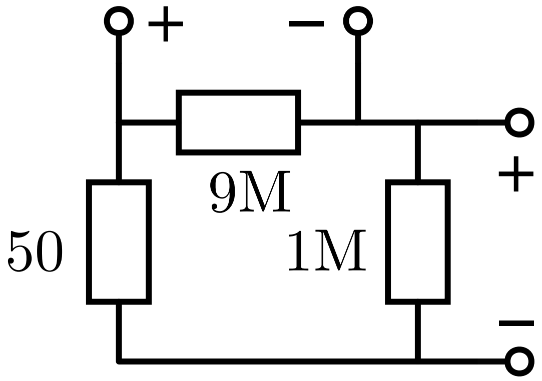

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Estimation of the poles from the diagonal elements of the RC matrix

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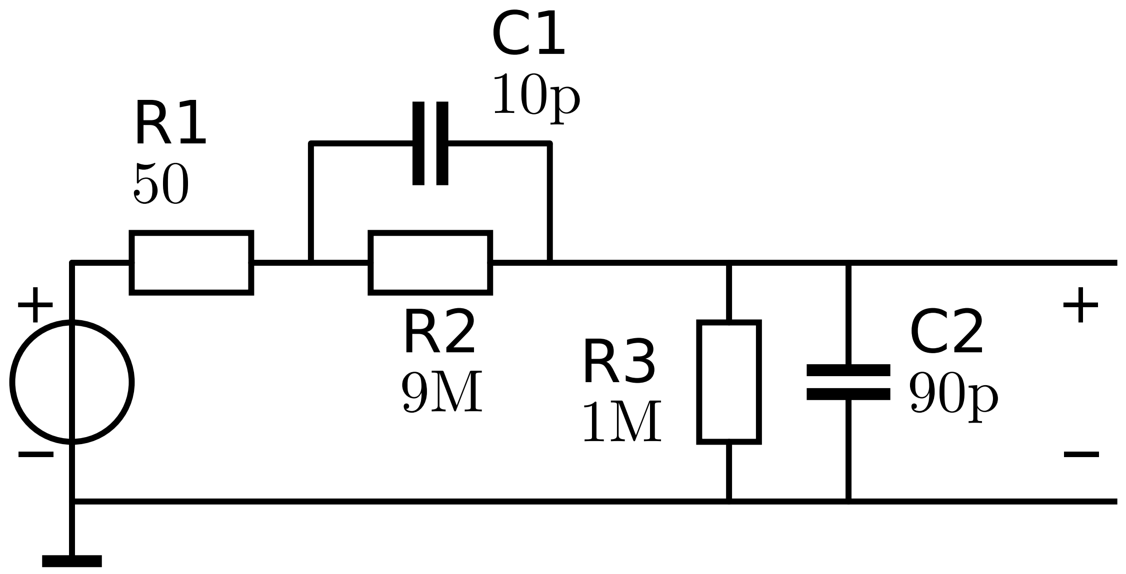
Oscilloscope probe circuit



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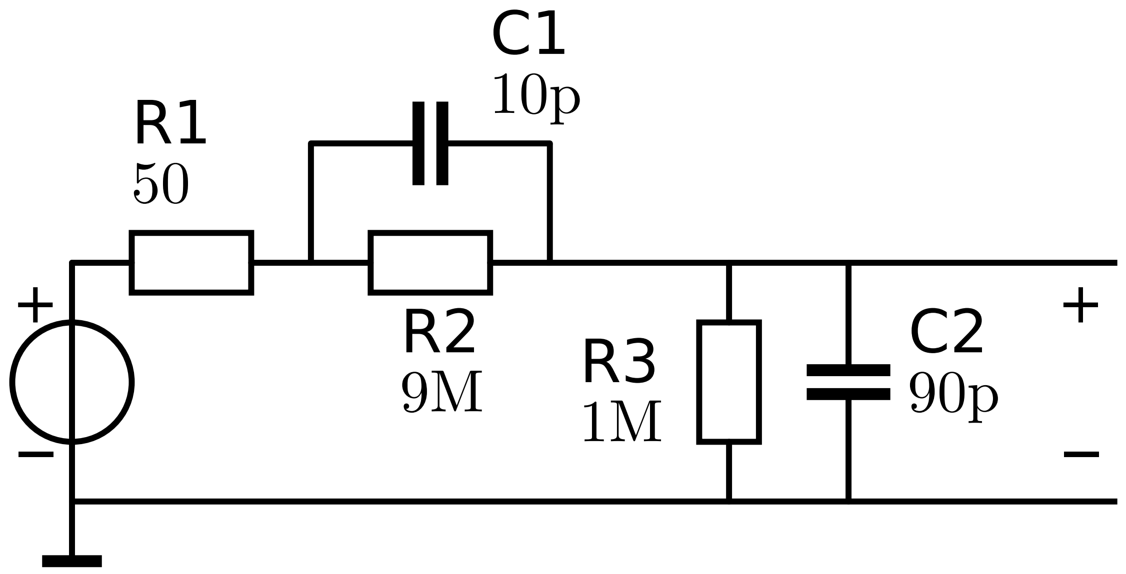

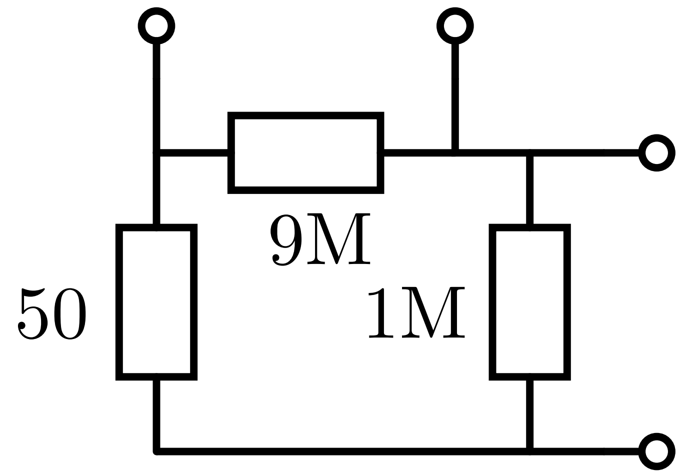

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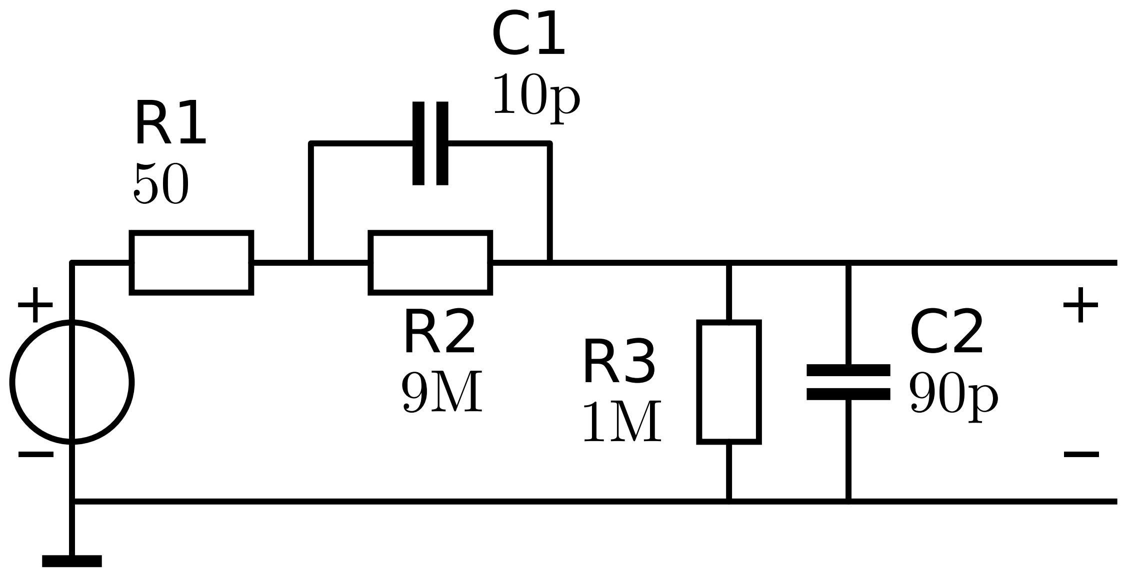

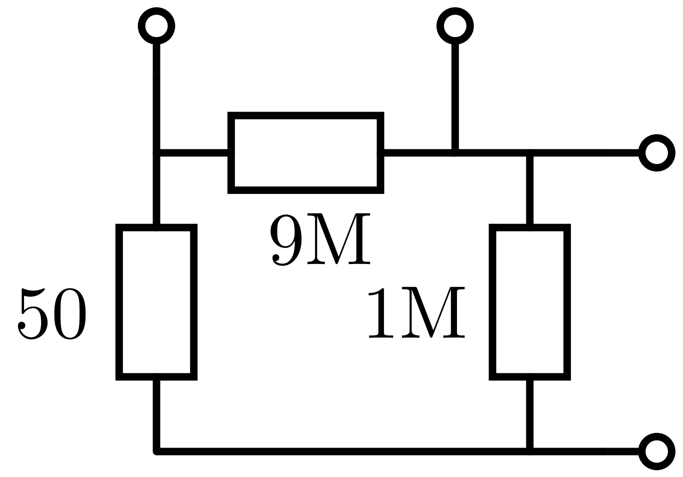

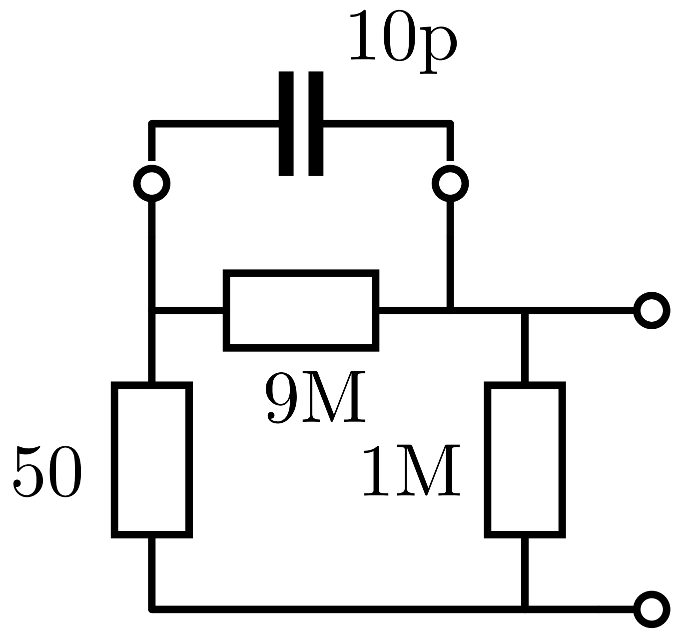

$\tau = 9\mu s$

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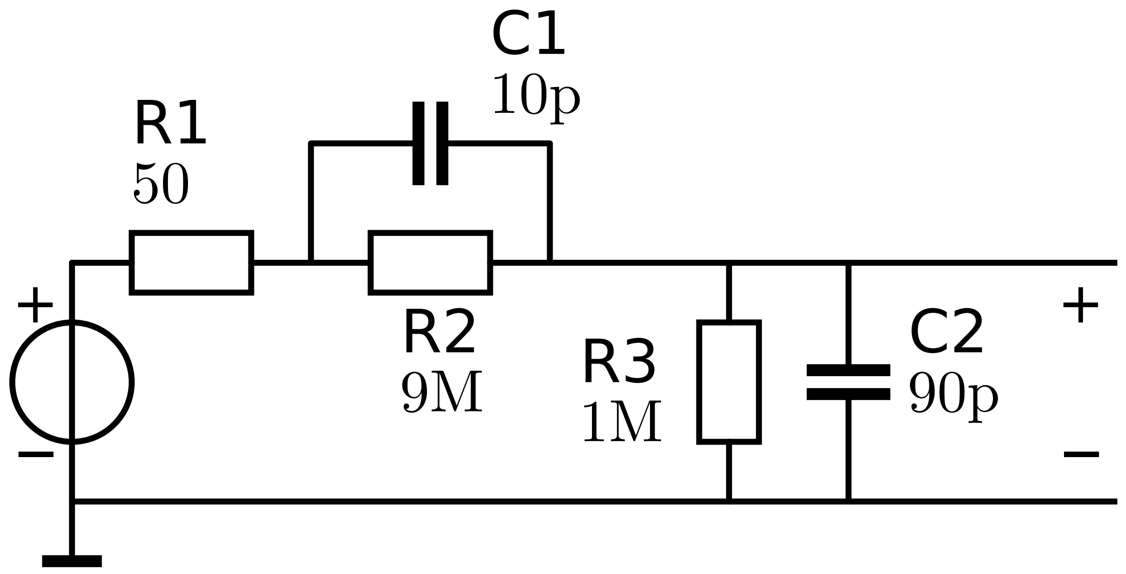

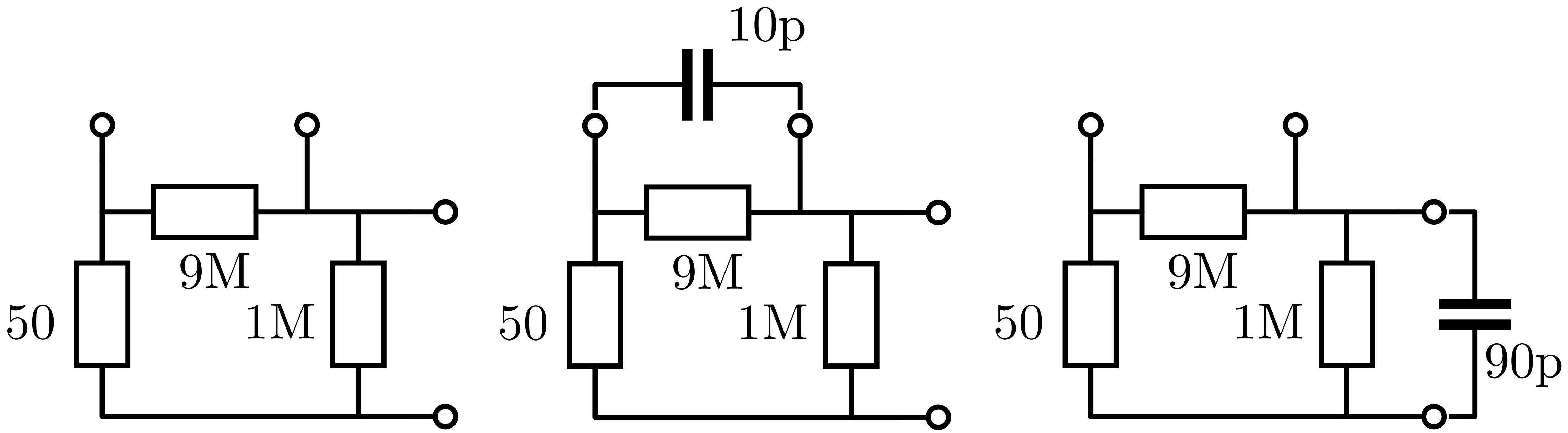

$\tau = 9\mu\mathrm{s}$

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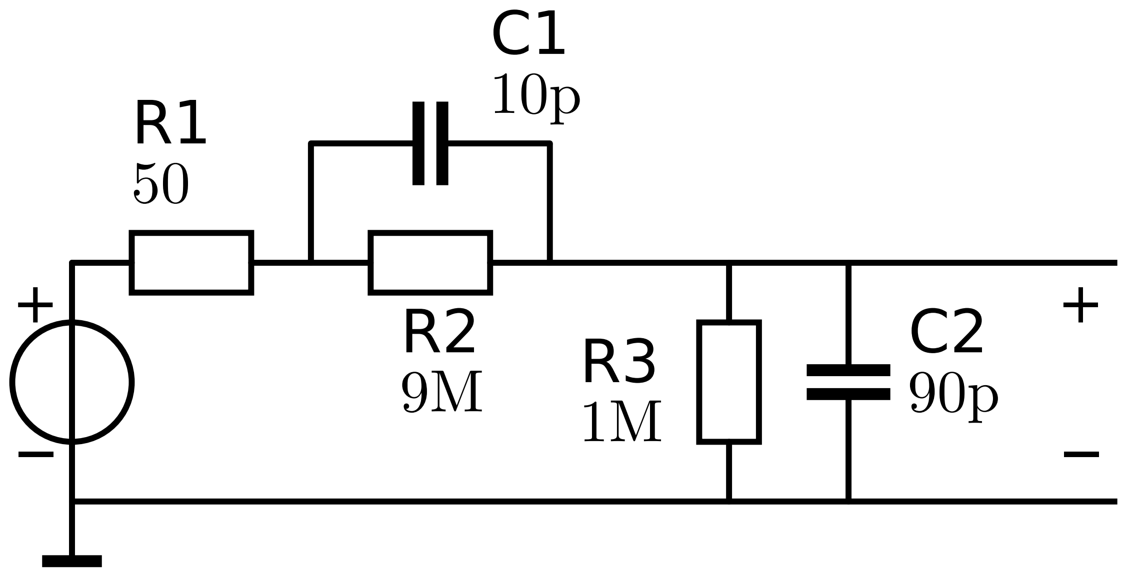
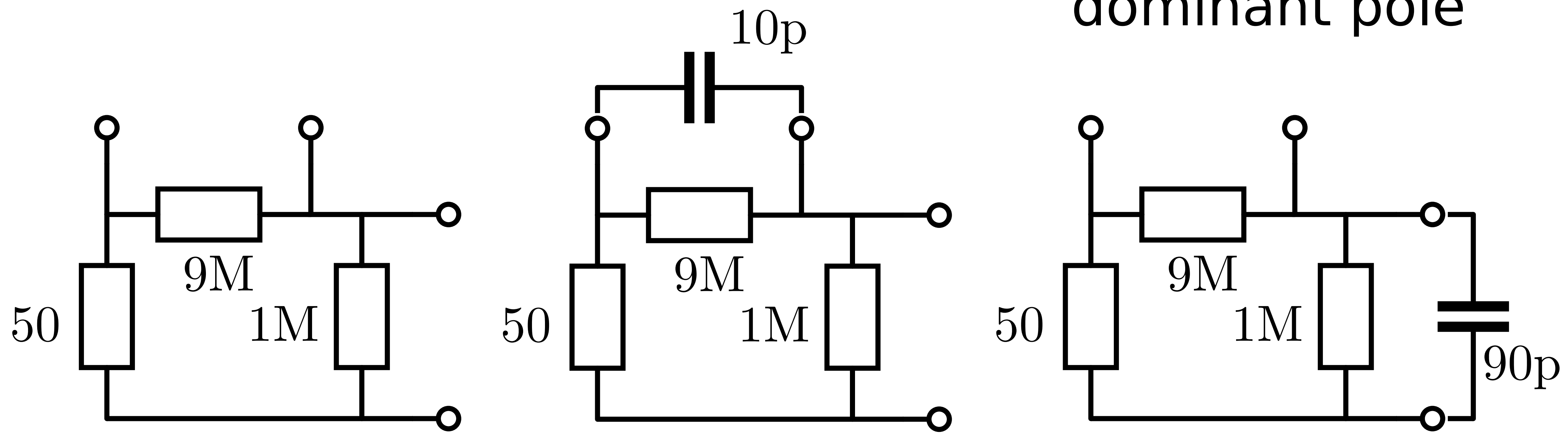
$p_1 = -1965\mathrm{Hz}$

Estimation of the poles from the diagonal elements of the RC matrix

Oscilloscope probe circuit



dominant pole



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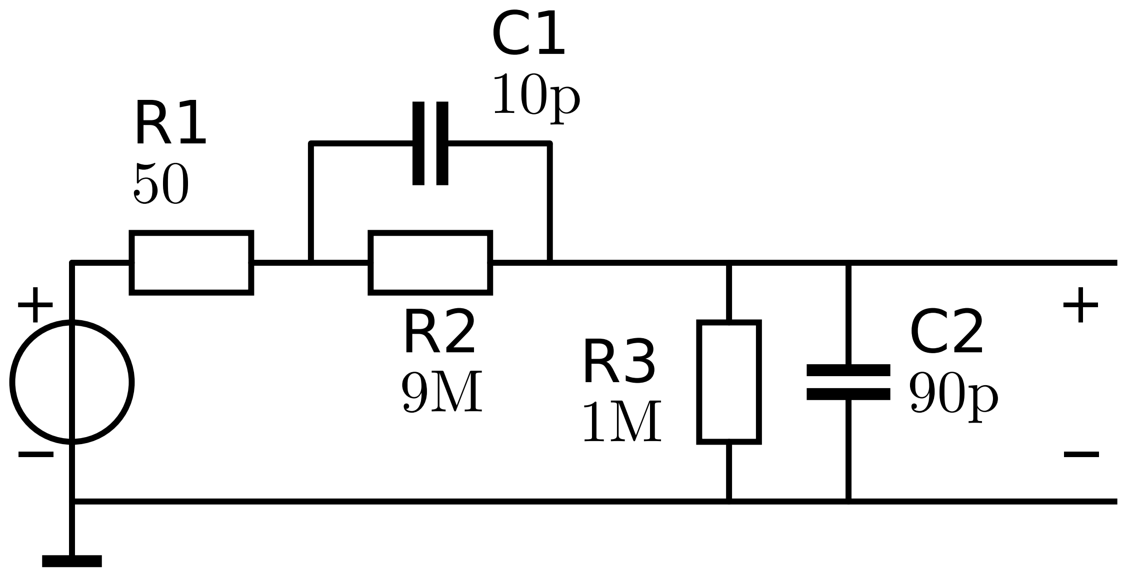

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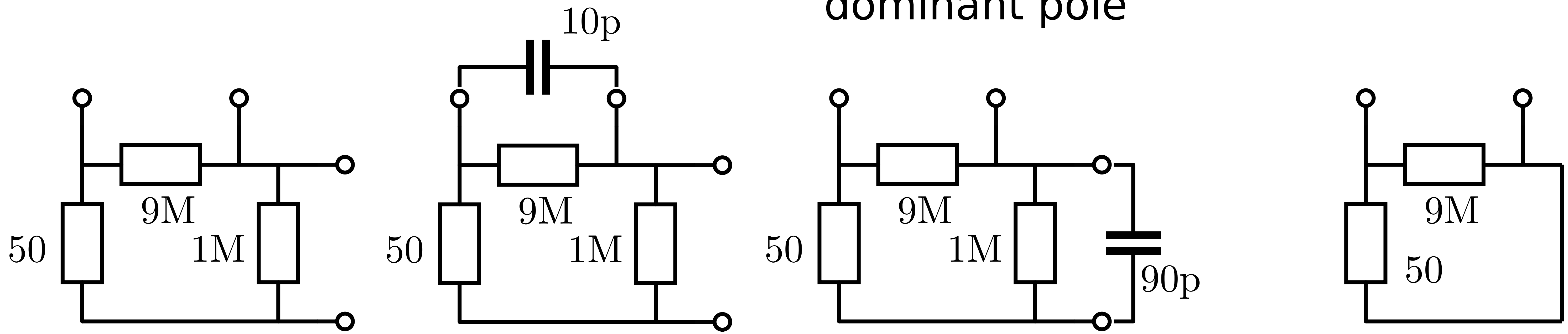

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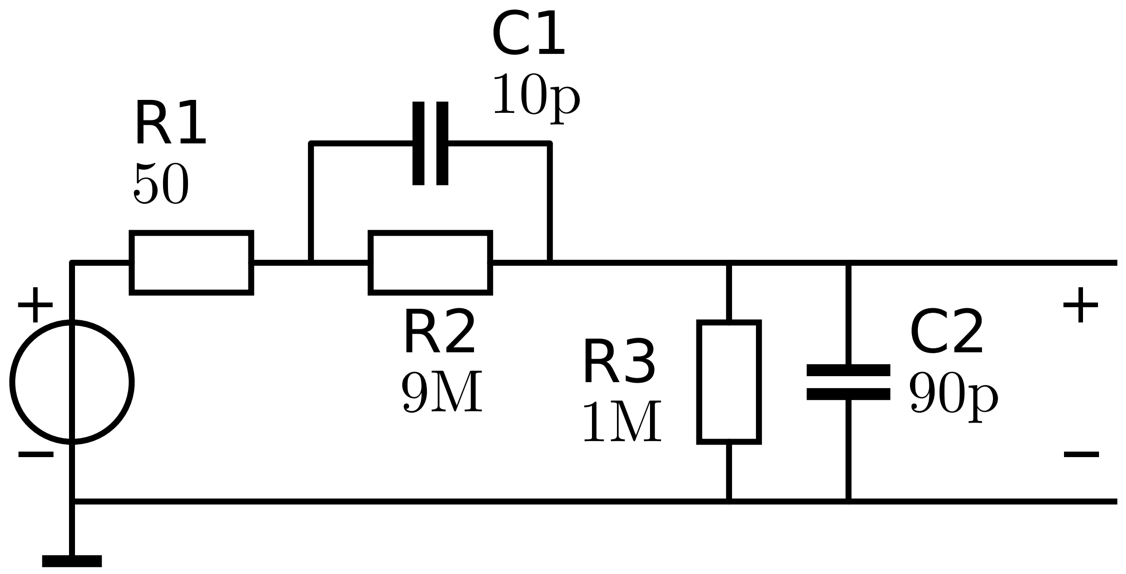

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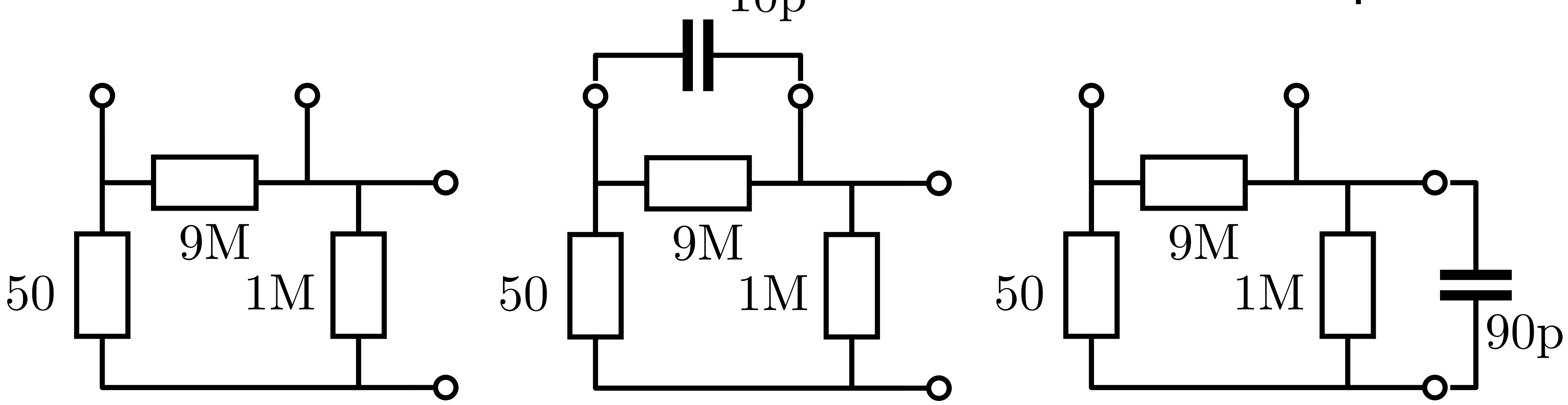

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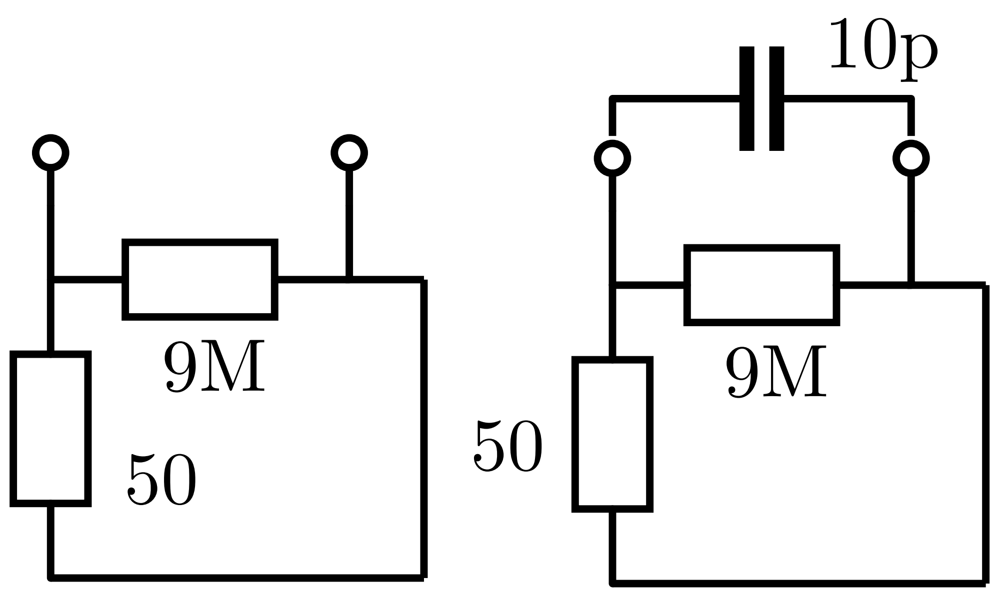
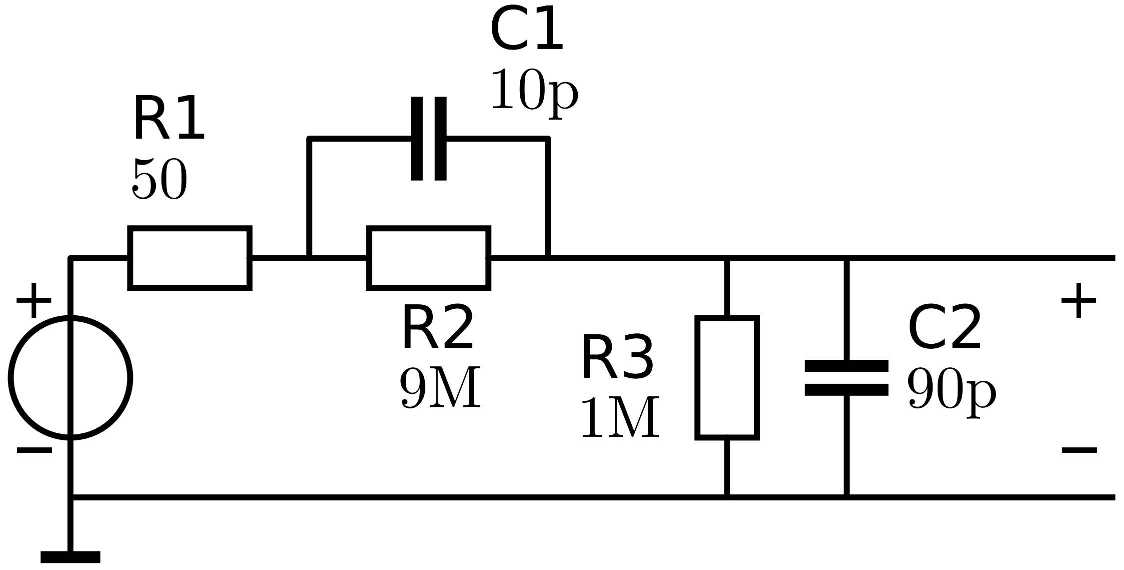


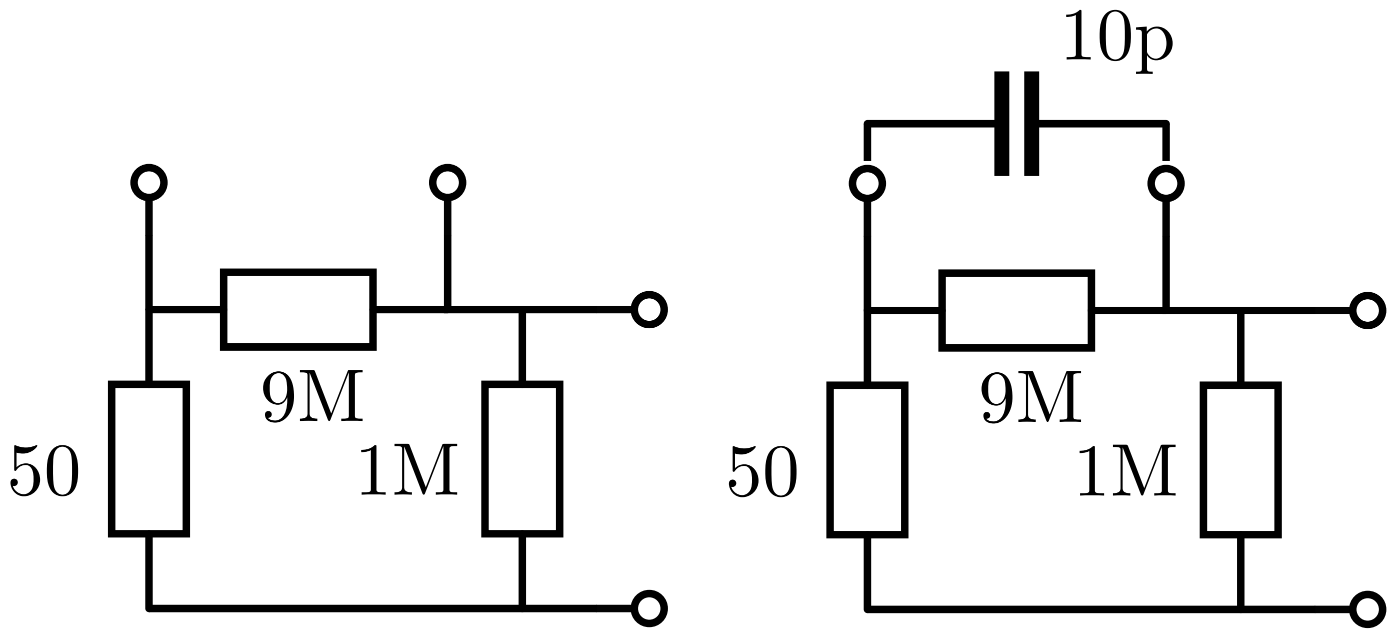
$\tau = 500\text{ps}$

$p_2 = -0.3183\text{GHz}$

Estimation of the poles from the diagonal elements of the RC matrix

Oscilloscope probe circuit





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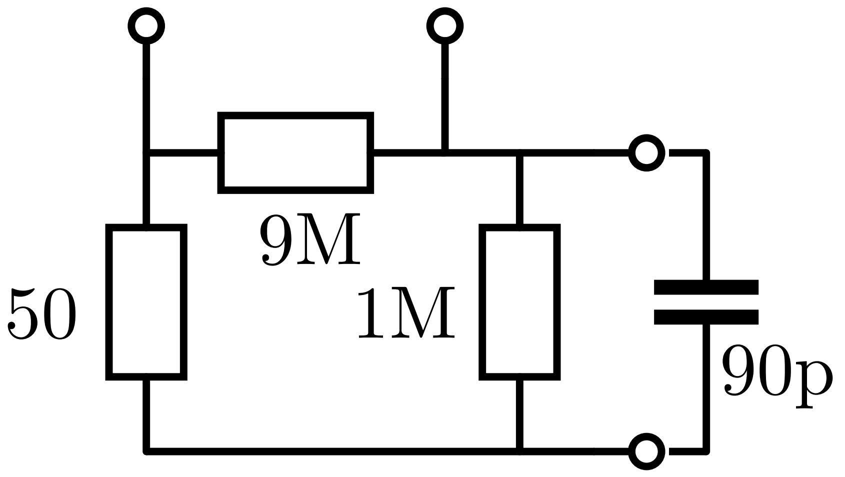

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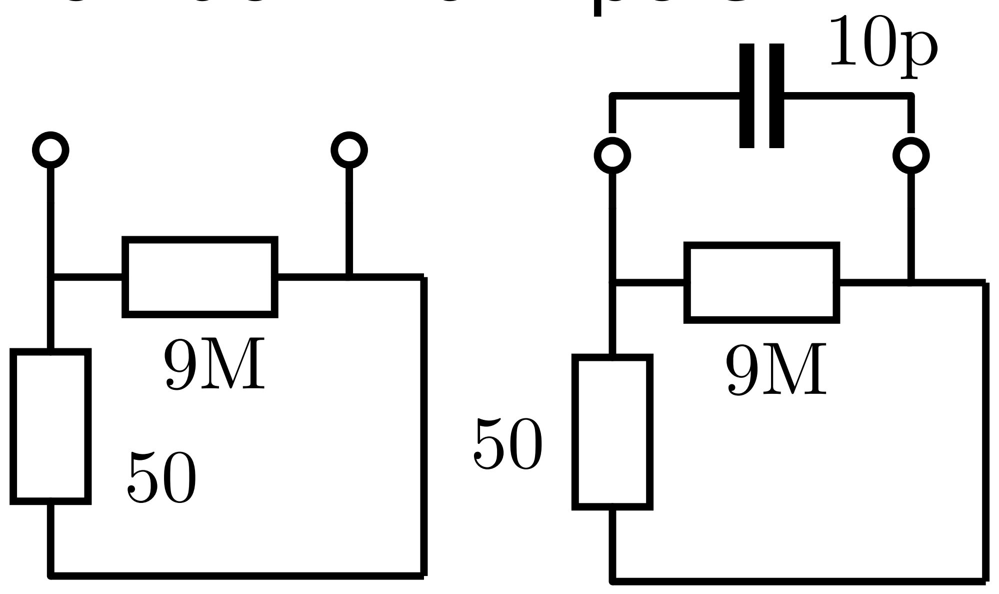
non-dominant pole



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Rules

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The number of poles equals the sum of the number of independent capacitor voltages plus the number of independent inductor currents.

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The number of independent cut sets of inductors and inductors and current sources equals the number of inductors and/or current sources that need to be replaced in the network to obtain a connected graph, after all inductors and current sources that are part of such a cut set have been removed; this yields a tree of the network.

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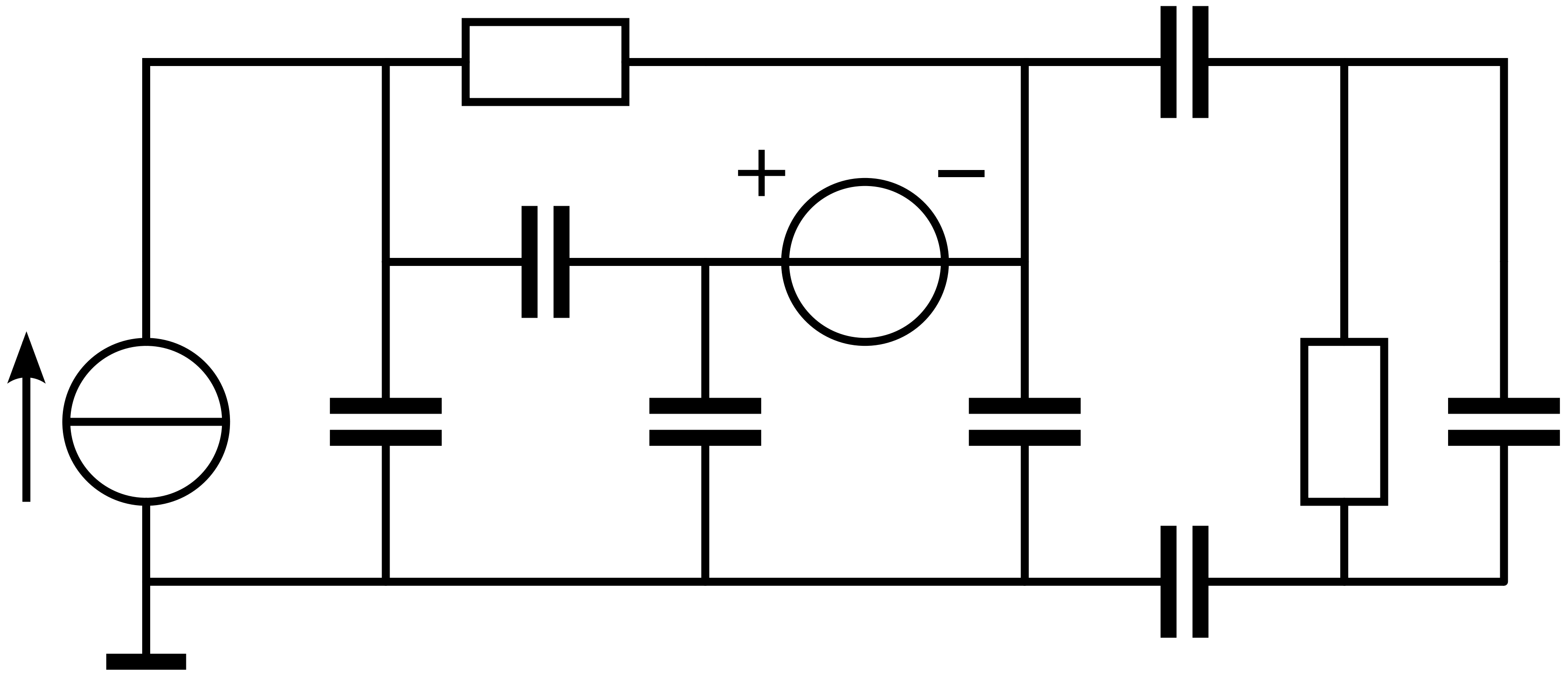
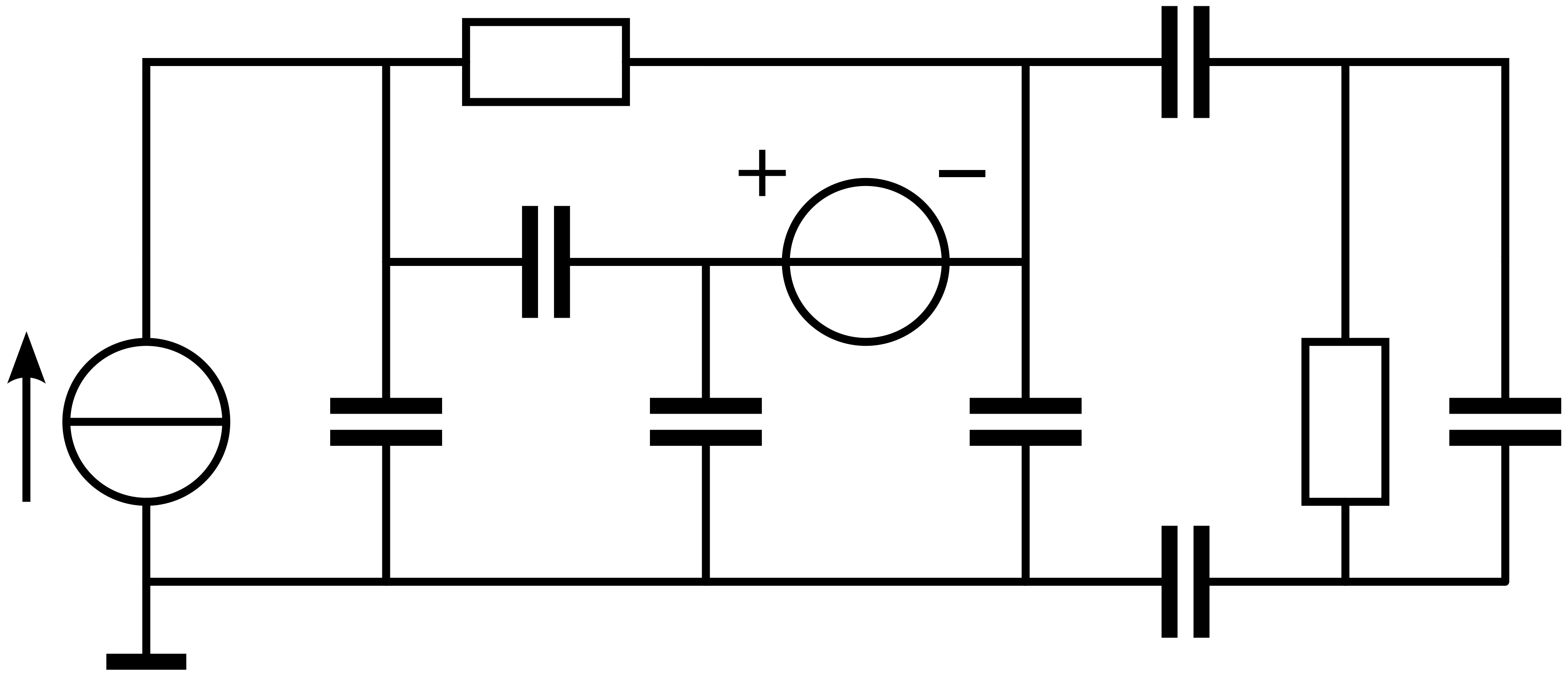
Example



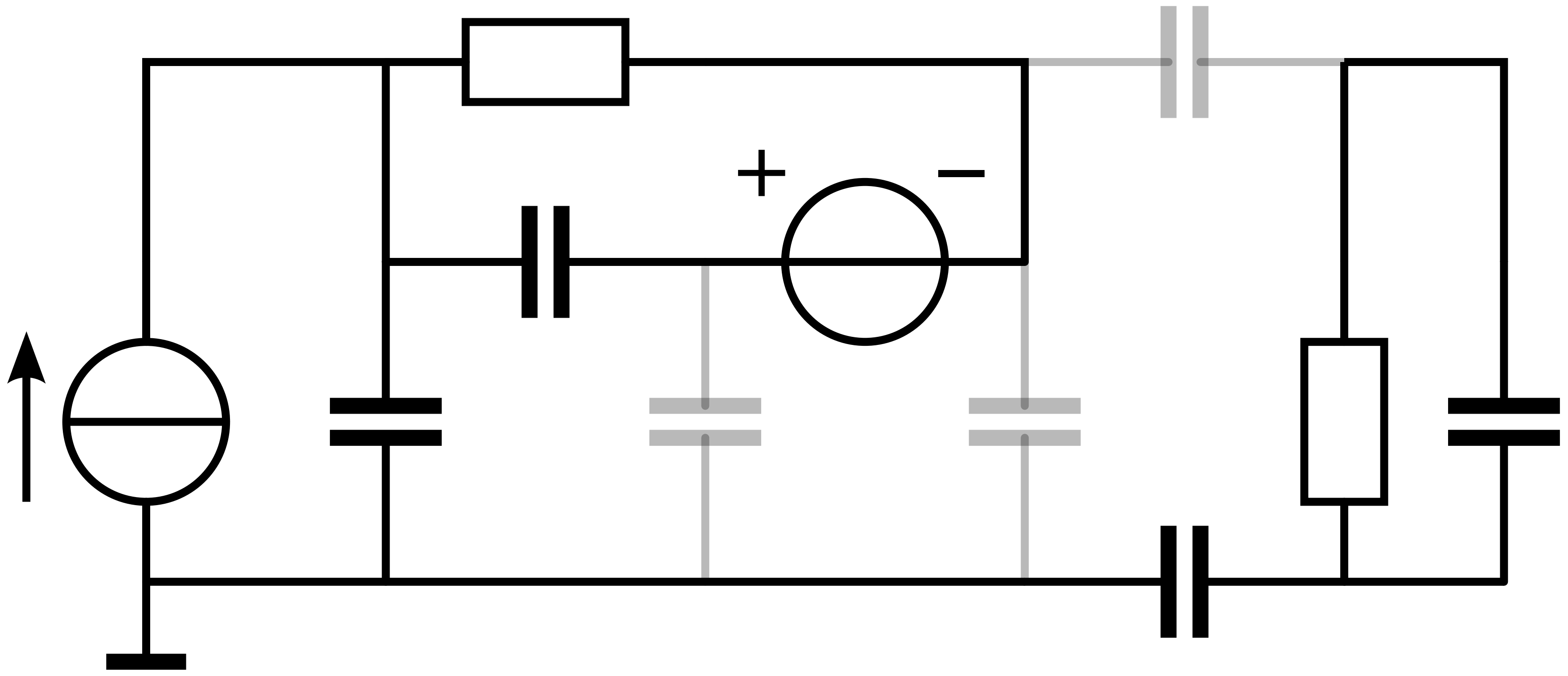
1. How many capacitors?
2. How many independent loops of capacitors and voltage sources?
3. How many poles?
4. How many independent cut sets of capacitors or of capacitors and current sources?
5. How many poles at s=0?

Example



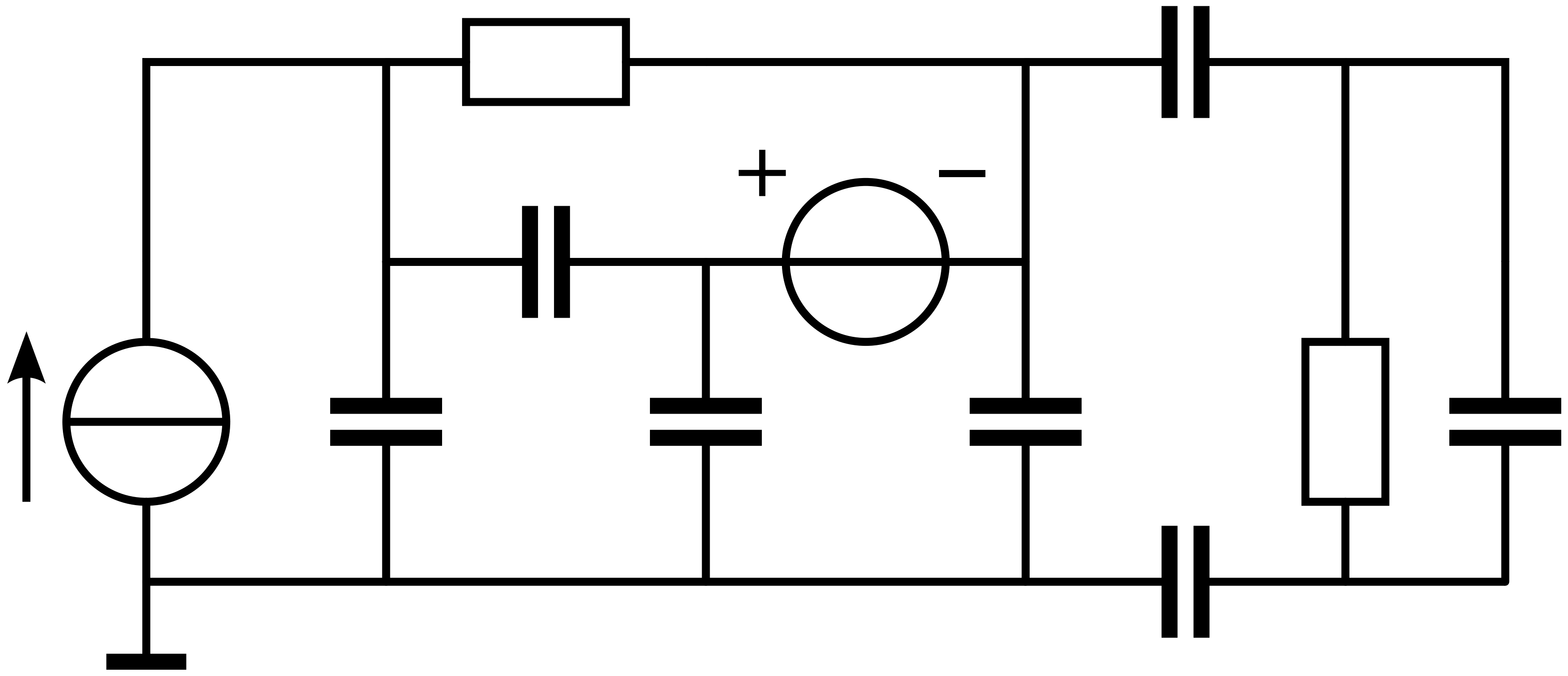
1. How many capacitors? 7

Example



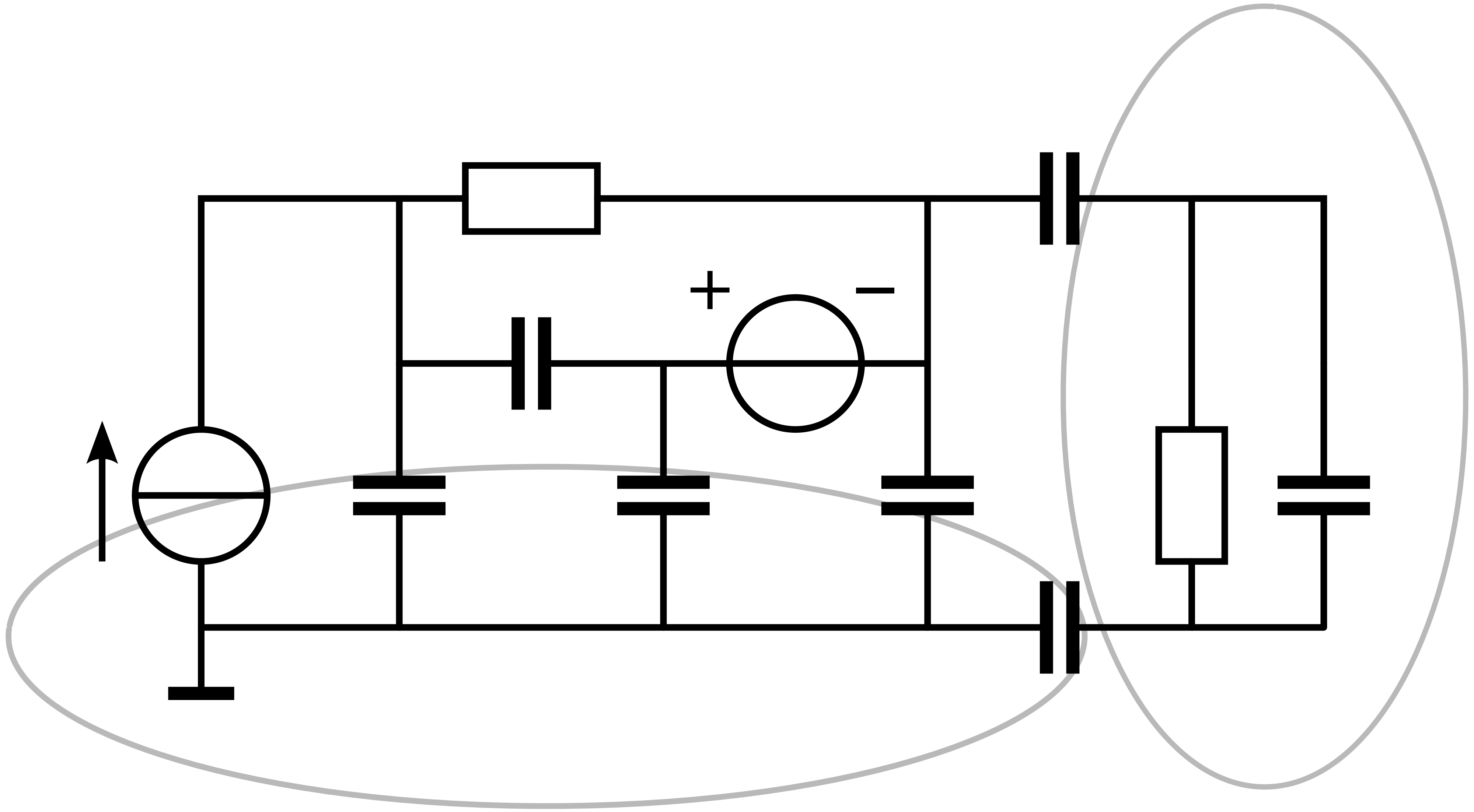
1. How many capacitors?
2. How many independent loops of capacitors and voltage sources? 3

Example



1. How many capacitors?
2. How many independent loops of capacitors and voltage sources?
3. How many poles? 7 - 3 = 4

Example



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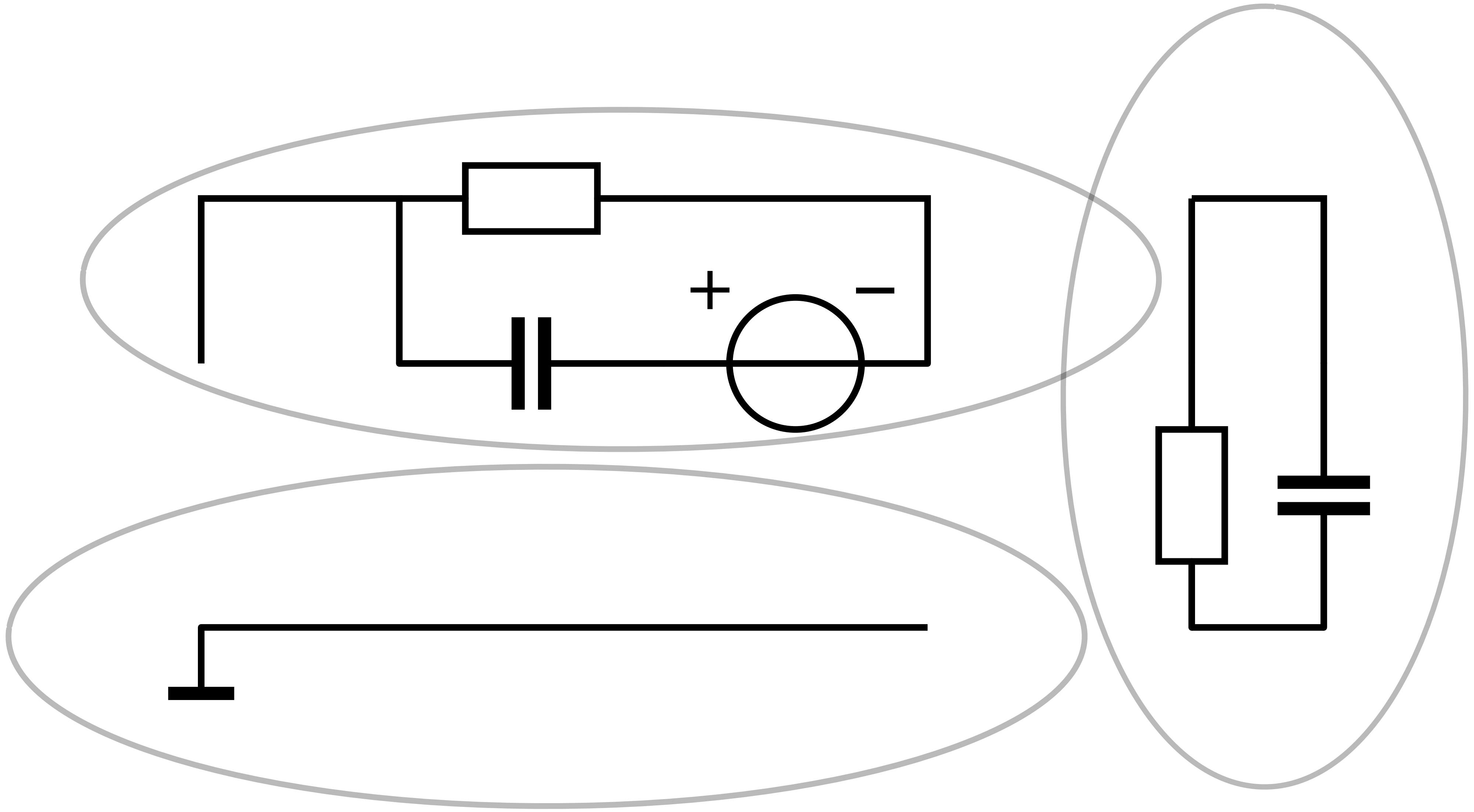

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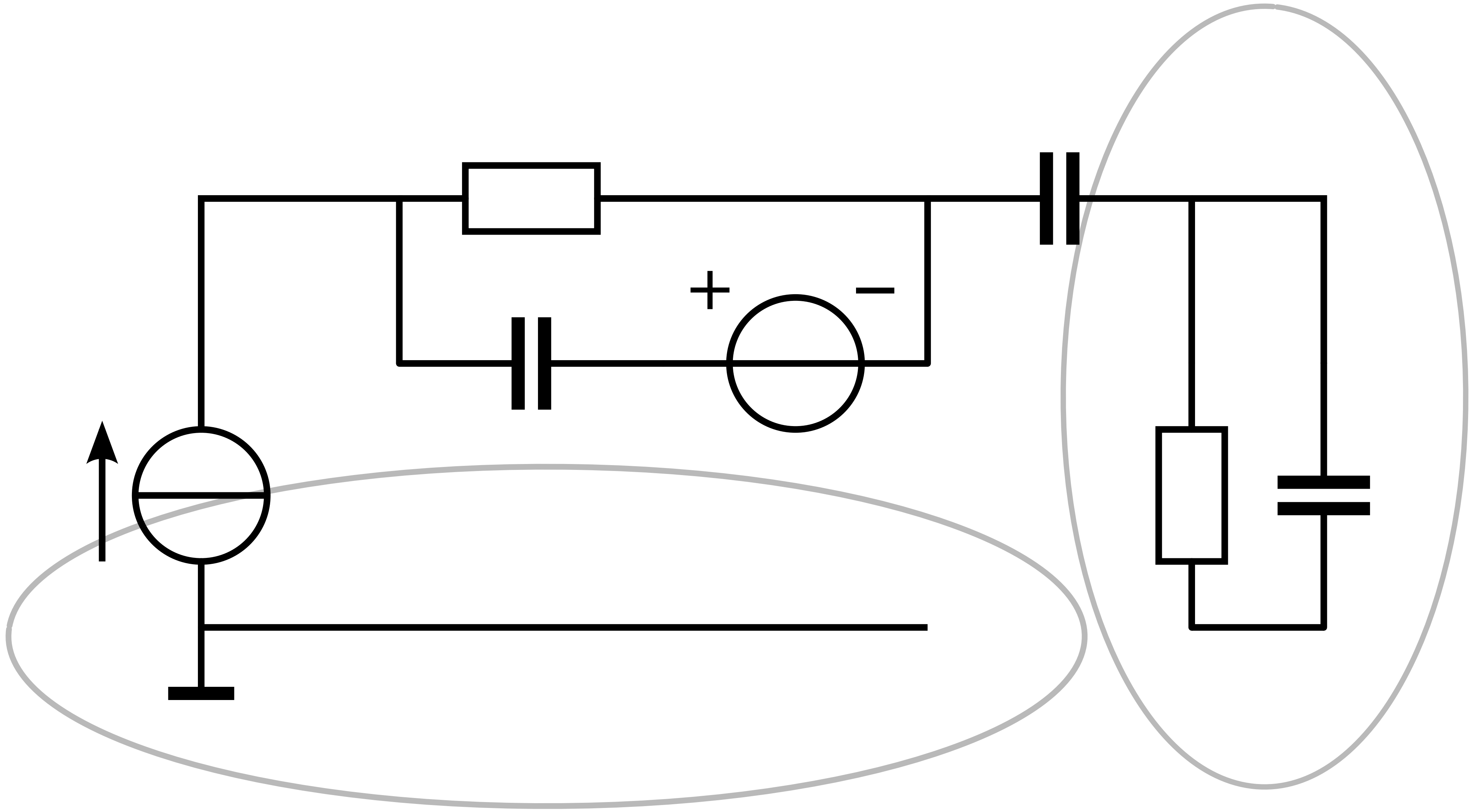

1. How many capacitors? 7
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3. How many poles? 7 - 3 = 4
4. How many independent cut sets of capacitors or of capacitors and current sources? 2

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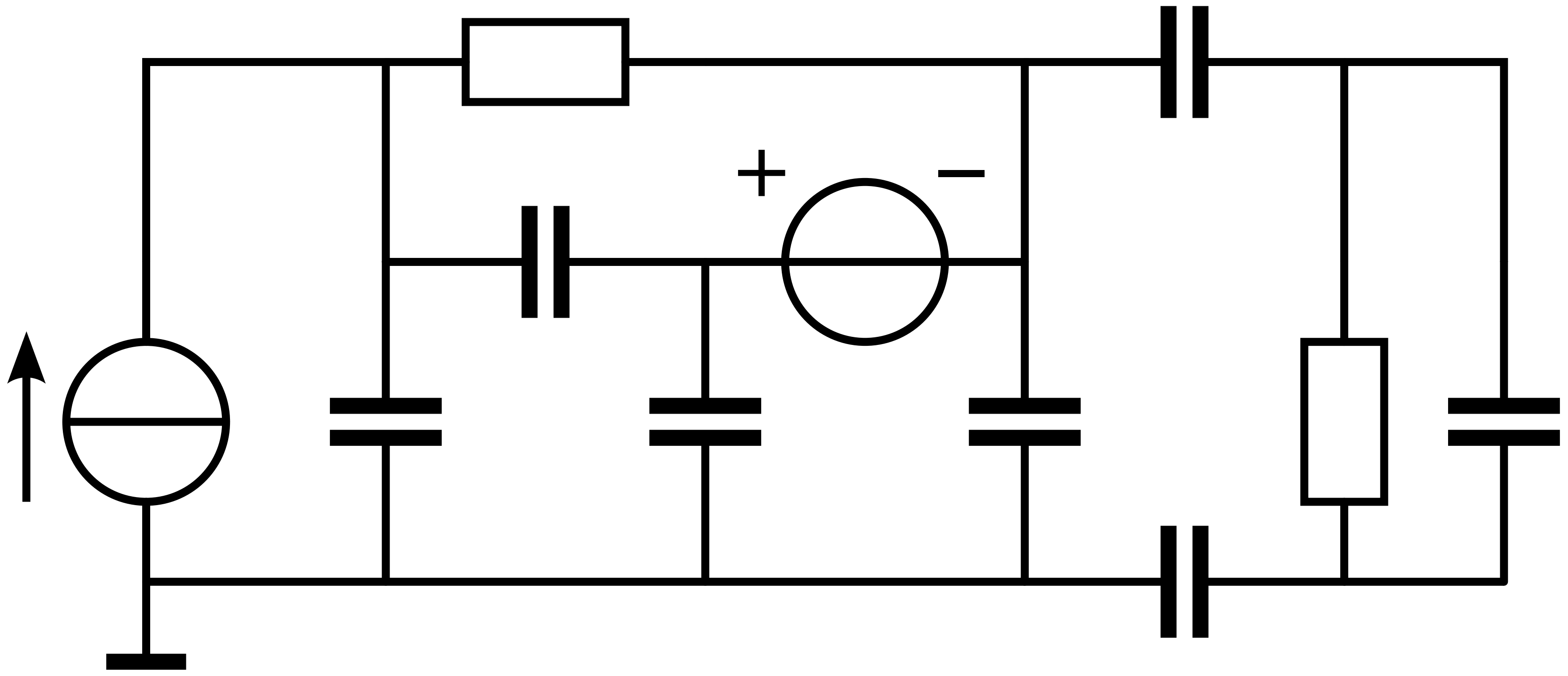

1. How many capacitors? 7
2. How many independent loops of capacitors and voltage sources? 3
3. How many poles? 4
4. How many independent cut sets of capacitors or of capacitors and current sources? 2
5. How many poles at s=0? 2

Zeros

Zeros

Zero transfer at the (complex) frequency of the zero

Zeros

Zero transfer at the (complex) frequency of the zero

Procedure for finding zeros

Short circuit in parallel with the signal path at complex frequency

Zeros

Zero transfer at the (complex) frequency of the zero

Procedure for finding zeros

Short circuit in parallel with the signal path at complex frequency

Open circuit in series with the signal path at complex frequency

Zeros

Zero transfer at the (complex) frequency of the zero

Procedure for finding zeros

- Short circuit in parallel with the signal path at complex frequency
- Open circuit in series with the signal path at complex frequency
- Transfer through multiple paths that cancel each other at complex frequency

Zeros

Short circuit in parallel with the signal path at complex frequency

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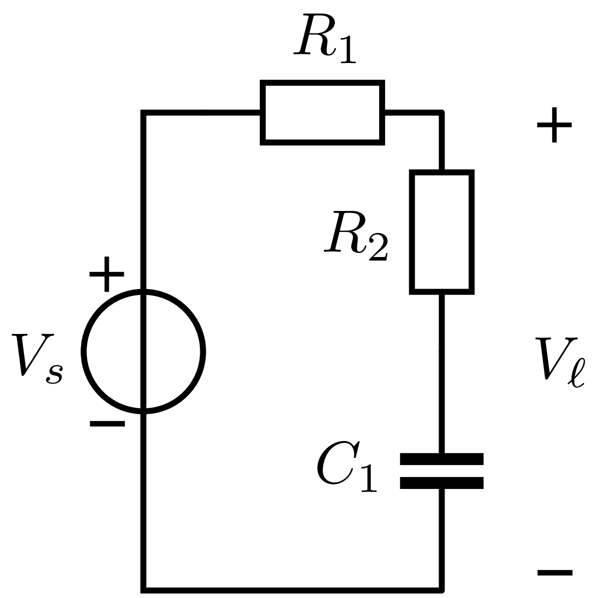
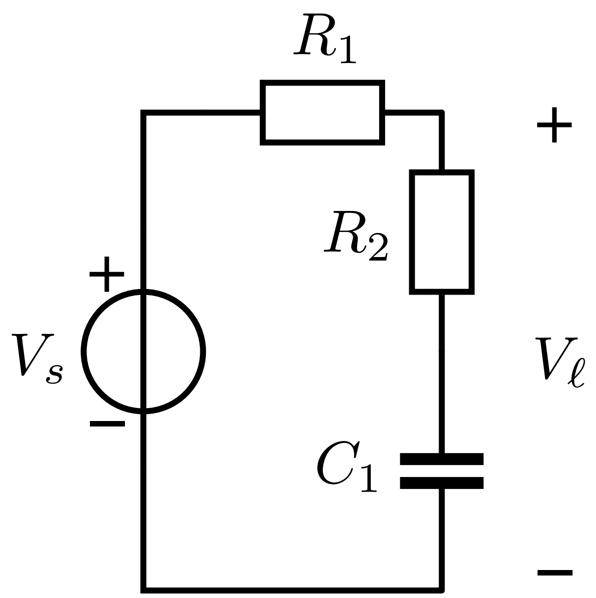
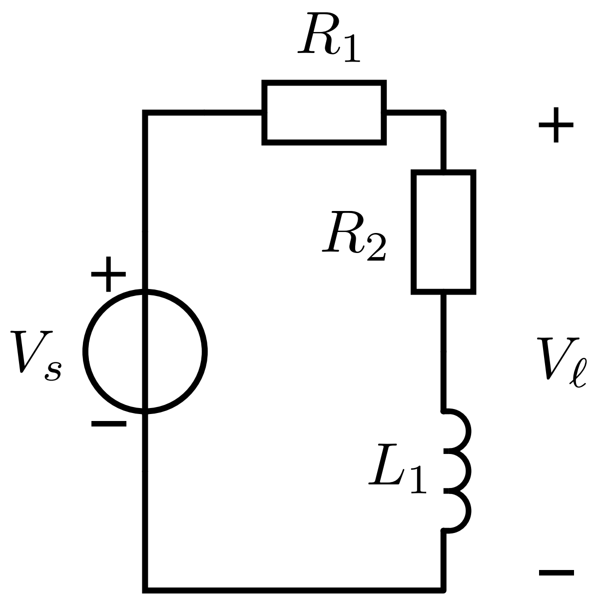


$$R_2 + \frac{1}{sC_1} = 0$$

Zeros

Short circuit in parallel with the signal path at complex frequency

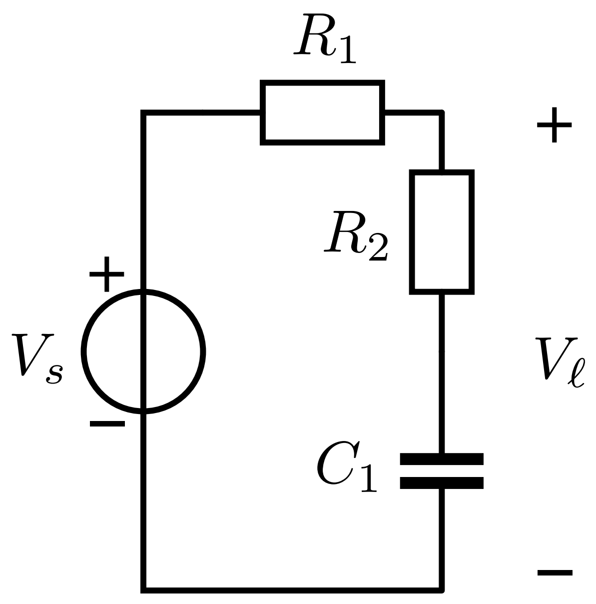


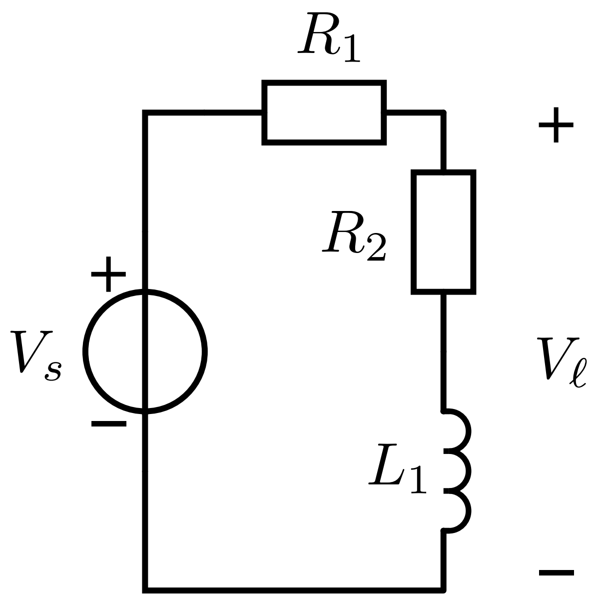


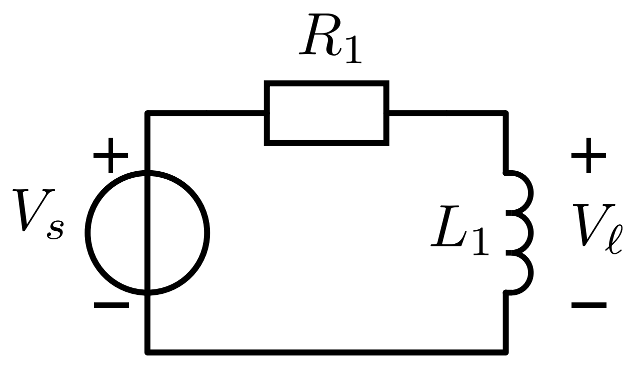
$$R_2 + \frac{1}{sC_1} = 0 \qquad R_2 + sL_1 = 0$$

Zeros

Short circuit in parallel with the signal path at complex frequency







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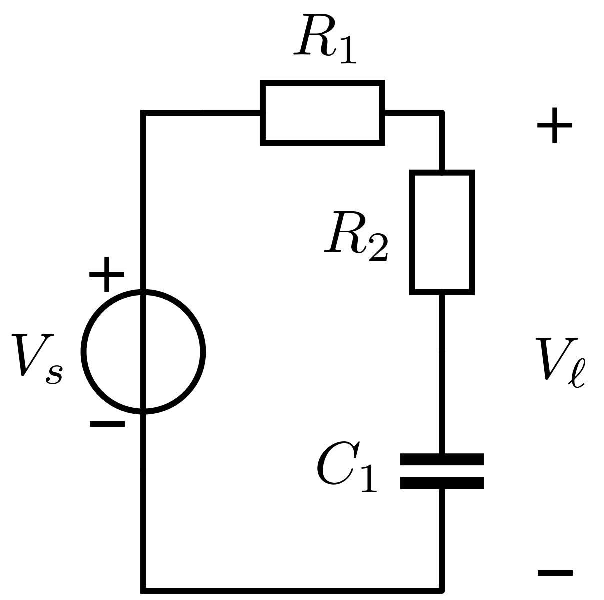

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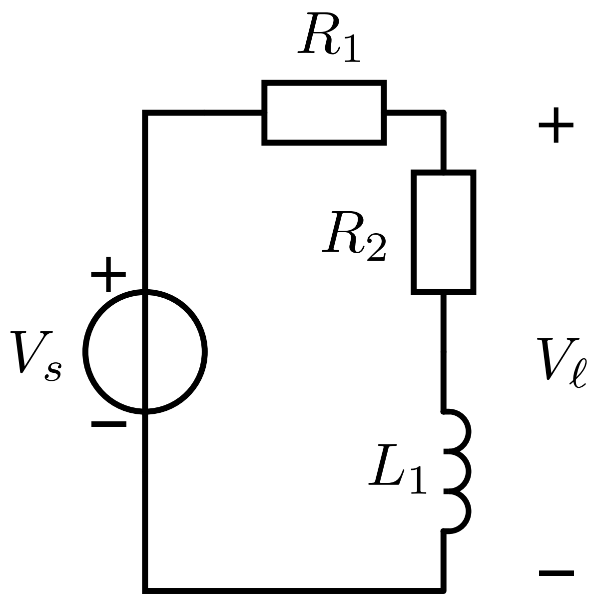

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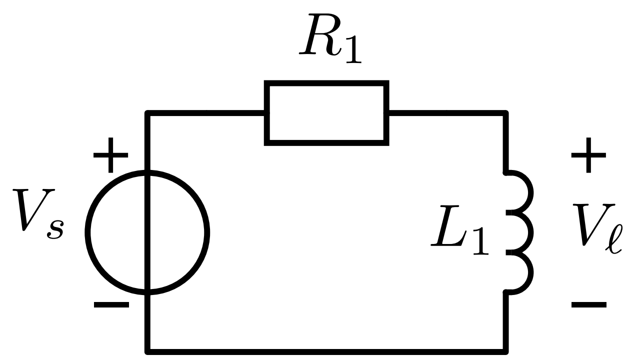
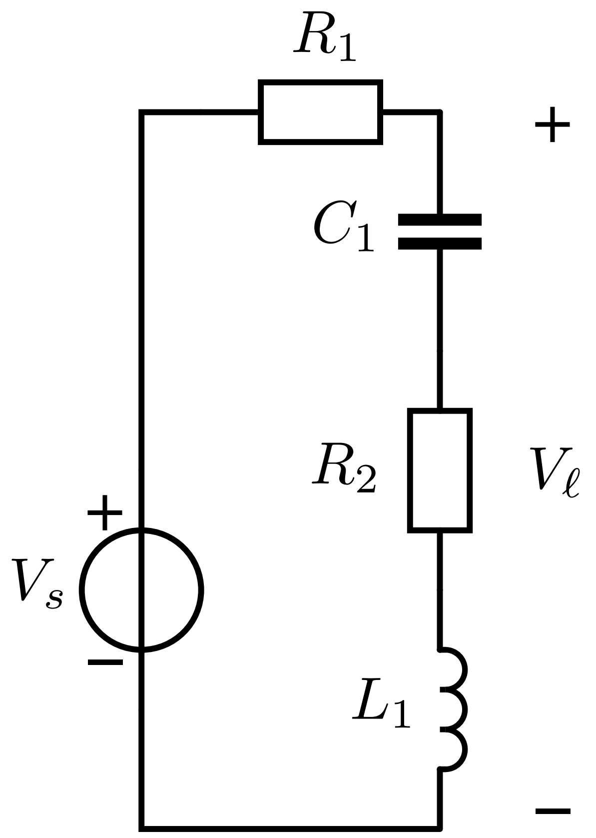


$$sL_1 = 0$$



$$R_2 + \frac{1}{sC_1} + sL_1 = 0$$

Zeros

Open circuit in series with the signal path at complex frequency

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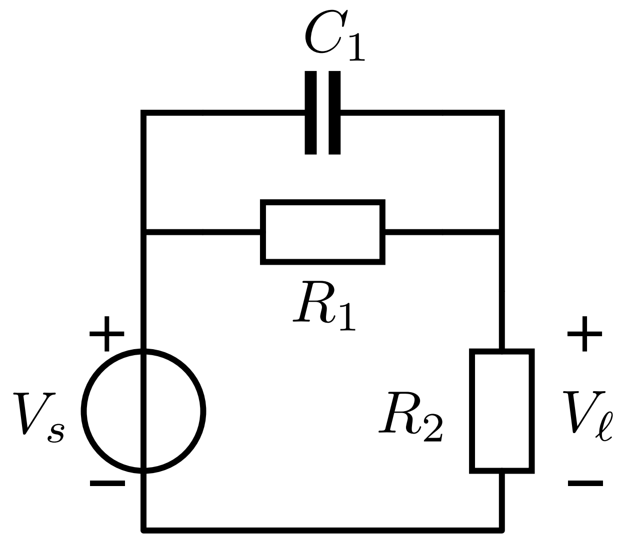
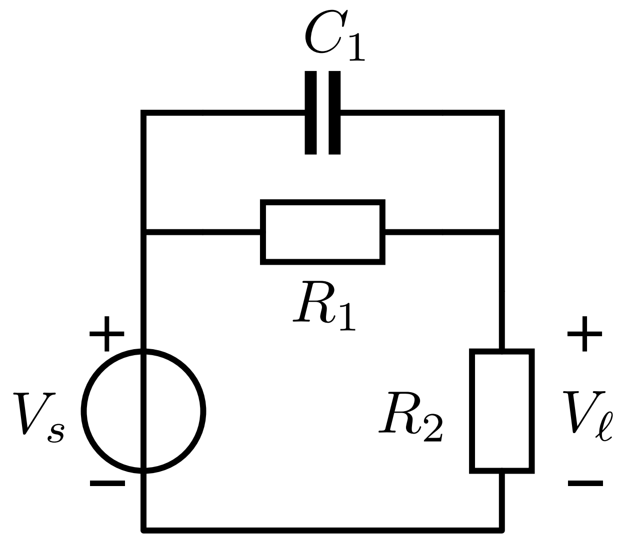
Open circuit in series with the signal path at complex frequency

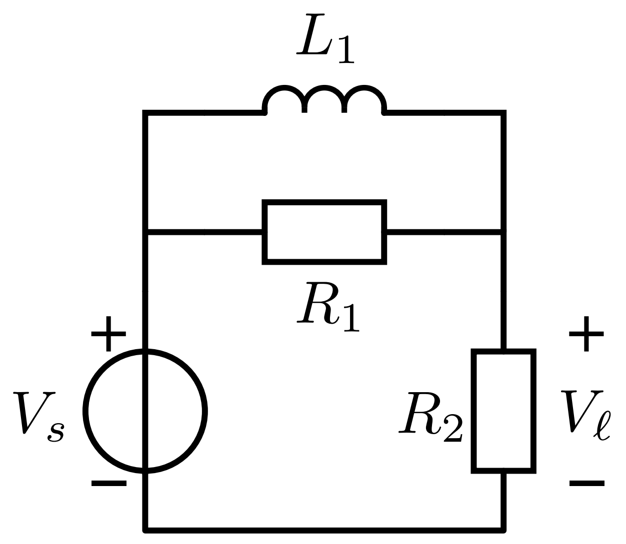


$$sC_1 + \frac{1}{R_1} = 0$$

Zeros

Open circuit in series with the signal path at complex frequency

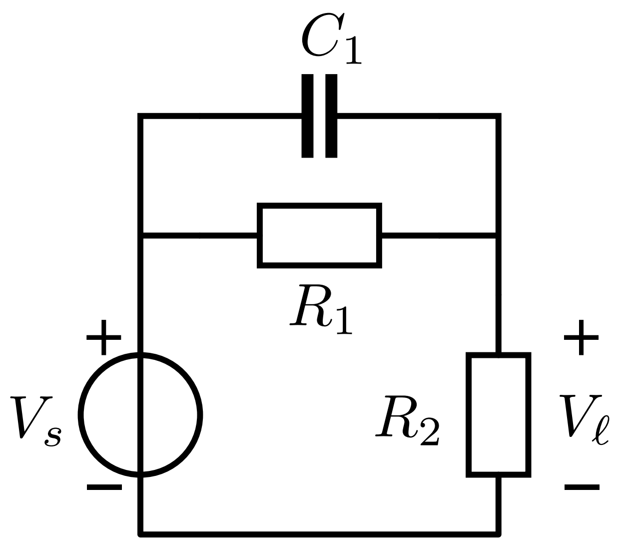


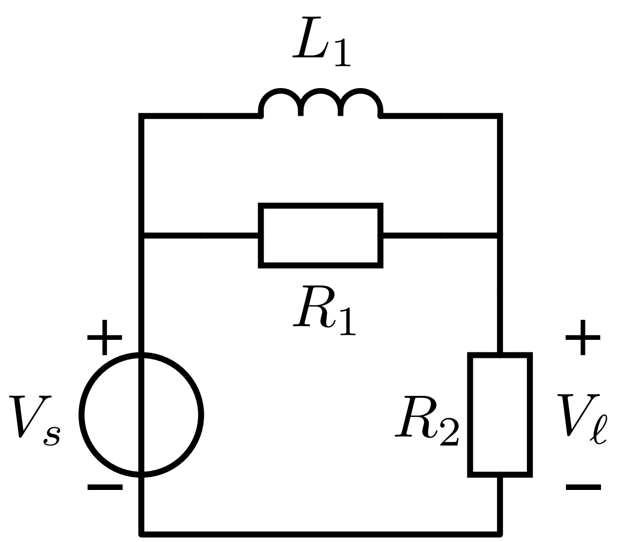


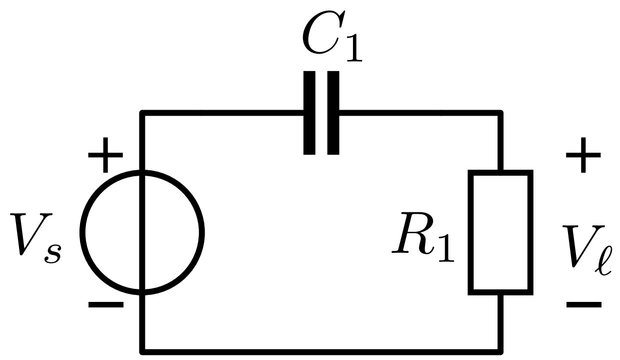
$$sC_1 + \frac{1}{R_1} = 0 \qquad R_1 + \frac{1}{sL_1} = 0$$

Zeros

Open circuit in series with the signal path at complex frequency







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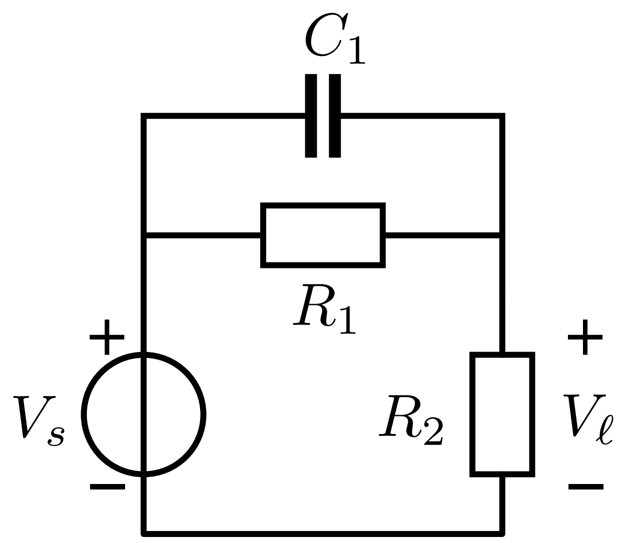
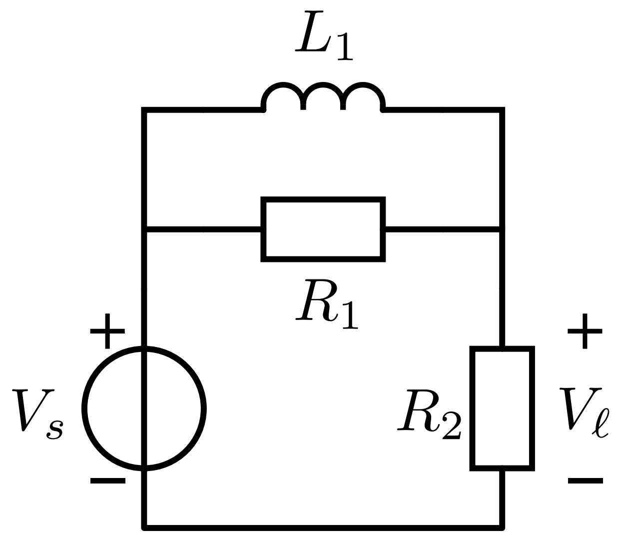
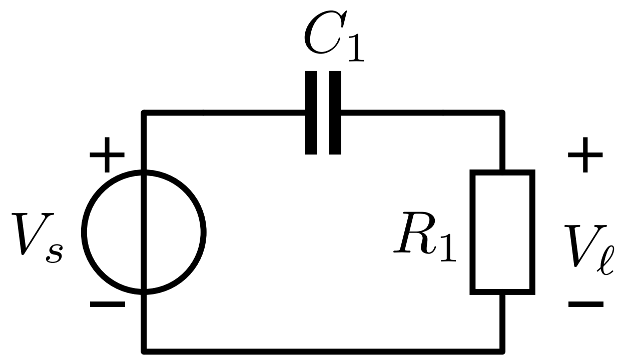
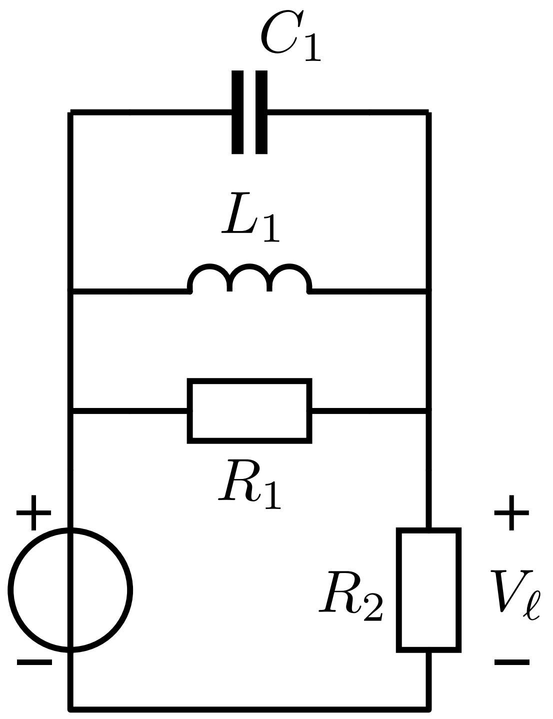
Zeros

Open circuit in series with the signal path at complex frequency









$$sC_1 + \frac{1}{R_1} = 0$$

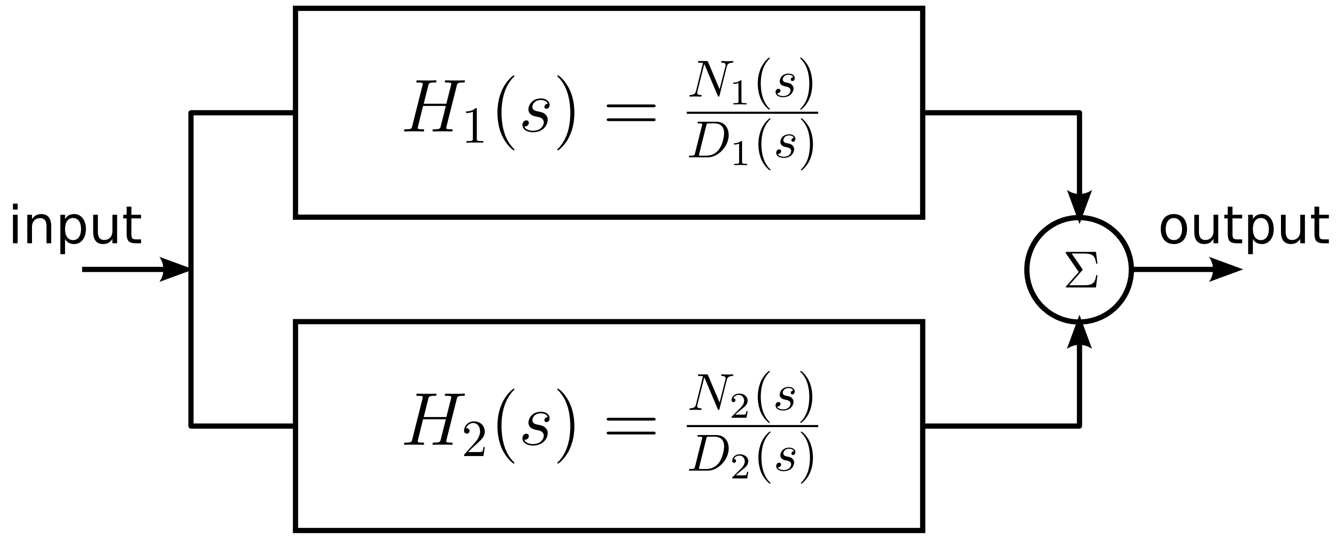
$$R_1 + \frac{1}{sL_1} = 0$$

$$sC_1 = 0$$

$$sC_1 + \frac{1}{R_1} + \frac{1}{sL_1} = 0$$

Zeros

Transfer through multiple paths that cancel each other at complex frequency



$$H_1(s) + H_2(s) = \frac{N_1(s)D_2(s)+N_2(s)D_1(s)}{D_1(s)D_2(s)}$$