Structured Electronic Design
Topics from network theory

Network Analysis

Symbolic Analysis

SLiCAP

Symbolic Linear Circuit Analysis Program

Purpose: find design equations

Stationary linear instantaneous behavior including small random variations

Stationary linear dynamic behavior

Stationary noise behavior

Additional verification techniques

Pole-zero analysis

Routh Hurwitz stability analysis

Root locus analysis

Numeric Analysis

SPICE

Simulation Program with Integrated Circuit Emphasis

Purpose: design verification

OP: initial operating point analysis

DC: stationary nonlinear instantaneous behavior

AC: stationary linear (small-signal) dynamic behavior

NOISE: stationary linear (small-signal) noise behavior

TRAN: time-variant nonlinear dynamic behavior

AC, NOISE and TRAN always preceeded by OP

Parameter stepping, Monte Carlo and sensitivity analysis depend on SPICE version

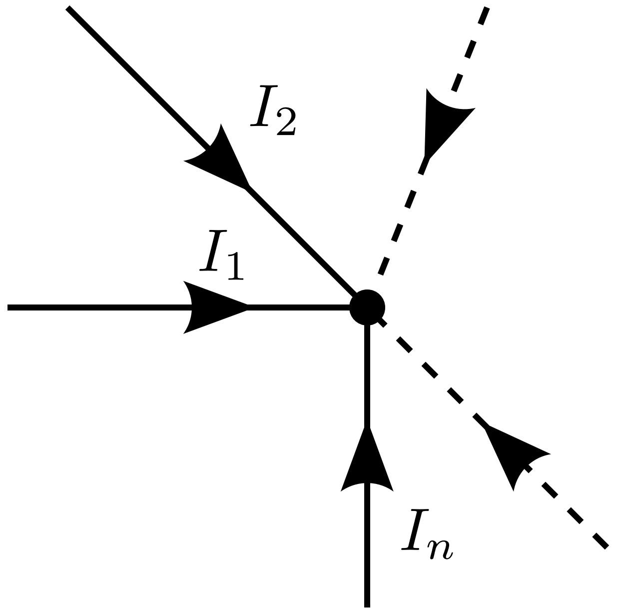
LTSpice in this course

Nodal Analysis

An electrical network consists of interconnected network elements

Node: interconnection point

Branch: element between two nodes



Kirchhoff's current law

The sum of the branch currents that flow into a node, equals zero:

$$\sum_{i=1}^{i=n} I_i = 0$$

Network with n nodes

1 node selected as reference node
n-1 nodal voltages w.r.t. voltage of ref. node
n-1 independent nodal equations

Only voltage-controlled elements:
Branch current can be written as a function of the branch voltage

$$\mathbf{I} = \mathbf{Y} \cdot \mathbf{V}$$

- $\mathbf{I}$: Vector with sum of independent currents flowing into a node
- $\mathbf{Y}$: Admittance matrix
- $\mathbf{V}$: Vector with nodal voltages

Admittance Matrix

General form of nodal equation:

Sum of independent currents flowing into node k

Diagonal element: sum of admittances connected to node k

$$\sum i_k = -\sum \mathbf{Y}_{k,1} v_1 - \sum \mathbf{Y}_{k,2} v_2 \quad ... + \sum \mathbf{Y}_{k,k} v_k \quad ... - \sum \mathbf{Y}_{k,n-1} v_{n-1}$$

Off-diagonal element: $\sum \mathbf{Y}_{k,j} =$ Sum of admittances connected between node k and node j

Modified Nodal Analysis

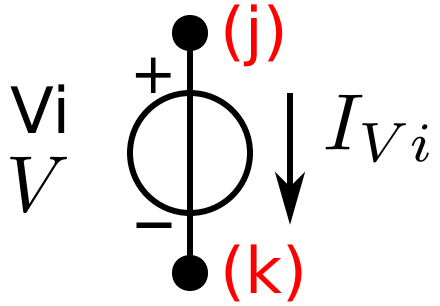
Voltage-controlled notation

Nodal Analysis only suited for networks with elements of which the(ir) branch current(s) can be expressed in terms of branch voltage(s)

Voltage source (example)

Current cannot be written as a function of the voltage

Voltage can be written as a functon of the current:



$$V_j - V_k = V, \forall I_{Vi}$$

Branch voltage equation
in current-controlled notation.

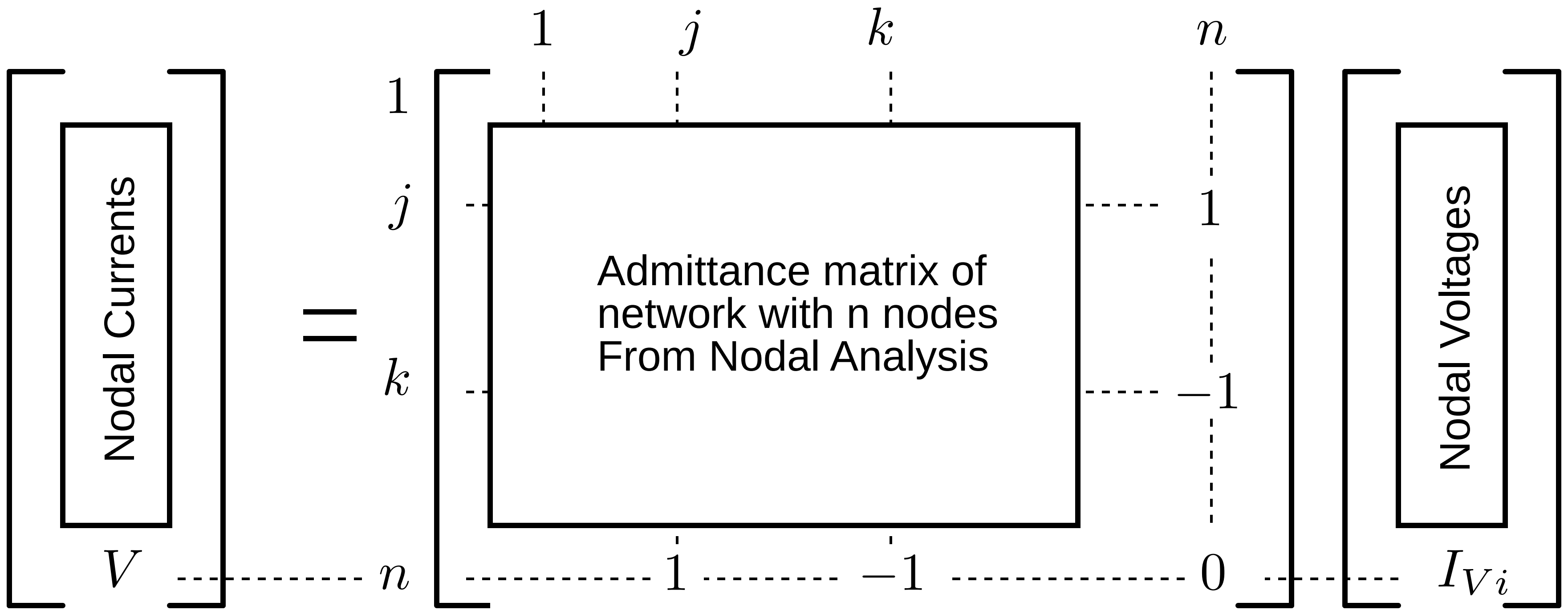
Procedure

Add the branch relation in current-controlled notation to the set of matrix equations:

Unknown current is added to vector with nodal voltages. It flows from node j to node k

Known voltage is added to vector with nodal currents

Branch voltage equation →



← Unknown branch current

Transfer function

Transfer from independent variable k to dependent variable j

$$\frac{\mathbf{V}_j}{\mathbf{I}_k} = \mathbf{M}_{j,k}^{-1} = \frac{(-1)^{j+k}\det(\mathcal{M}_{k,j})}{\det\left(\mathbf{M}\right)}$$

Minor matrix: $\mathcal{M}_{k,j}$ equals M after leaving out row k and column j.

Poles: $\det\left(\mathbf{M}\right) = 0$

Zeros: $\det(\mathcal{M}_{k,j}) = 0$

Time-constant matrix

Basis for intuitive determination of poles in networks without feedback

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

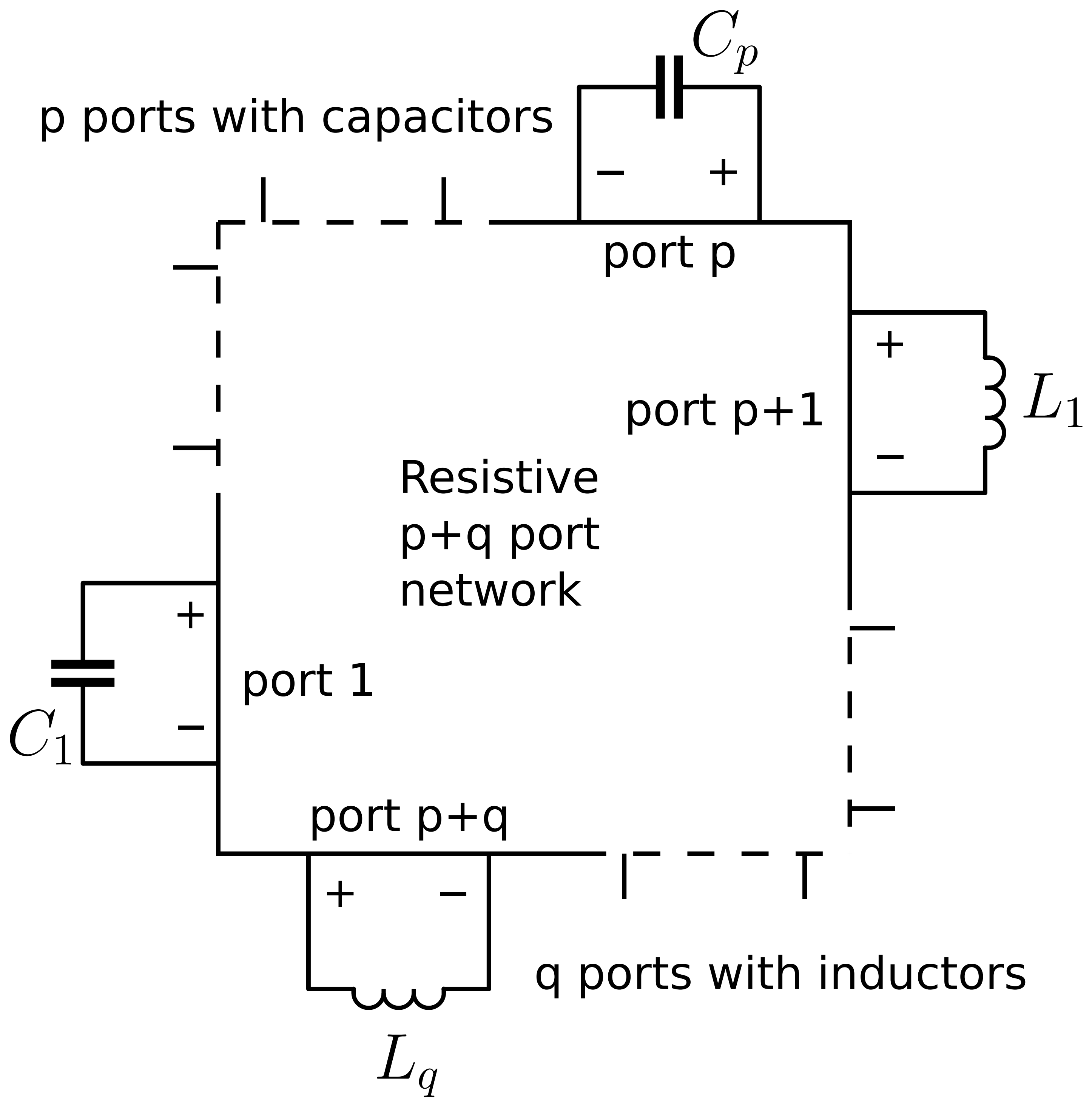
Characteristic equation: $\det\left(\mathbf{G} + s\mathbf{C}\right) = 0$

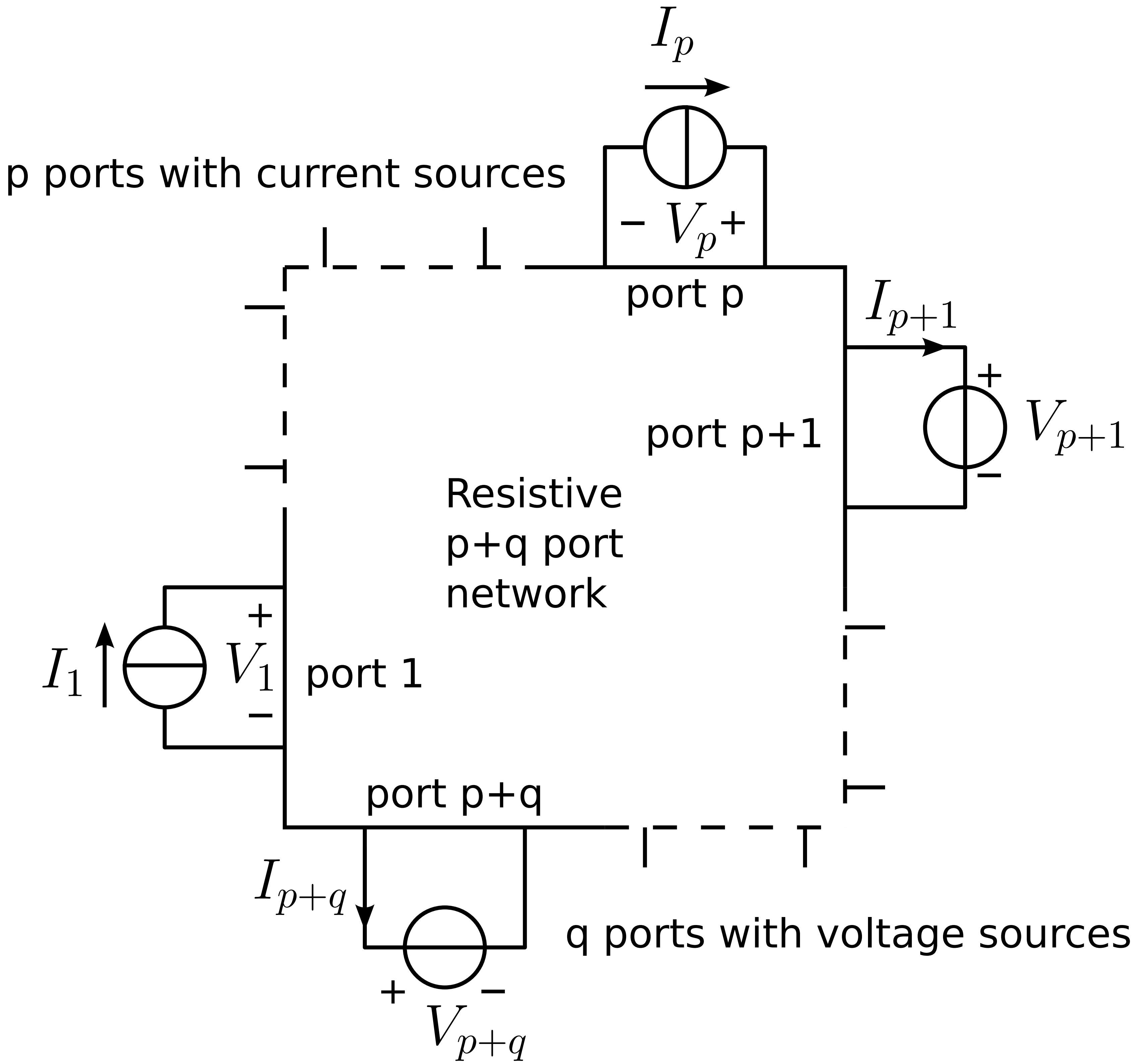
Generalized eigenvalue problem: $\det\left(\mathbf{I} + \lambda\mathbf{T}\right) = 0$

Time-constant matrix: $\mathbf{T} = \mathbf{G}^{-1} \cdot \mathbf{C} = \mathbf{R} \cdot \mathbf{C}$

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

Resistance matrix

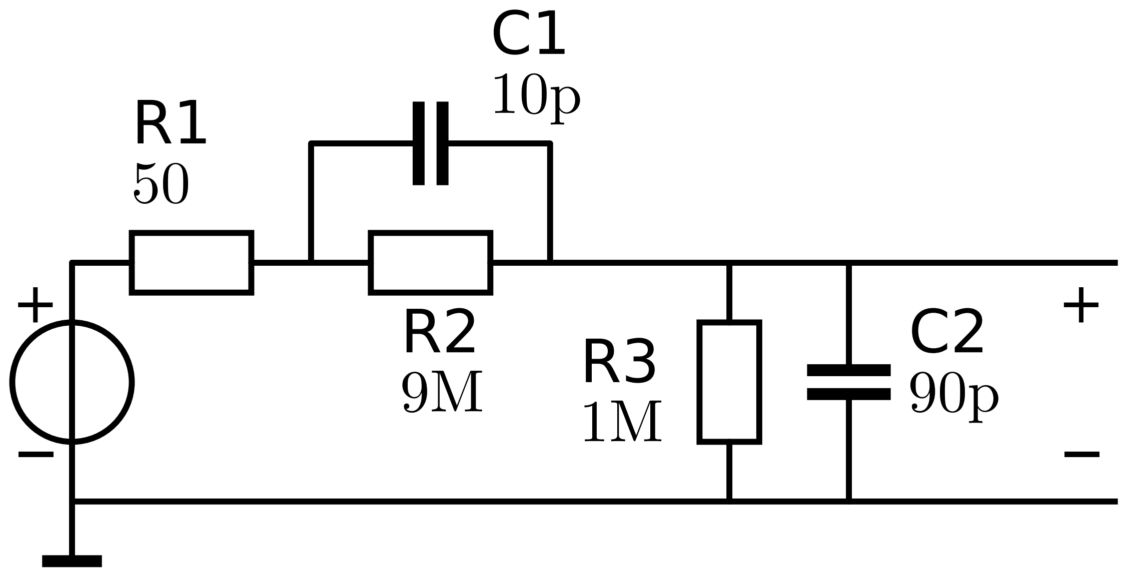




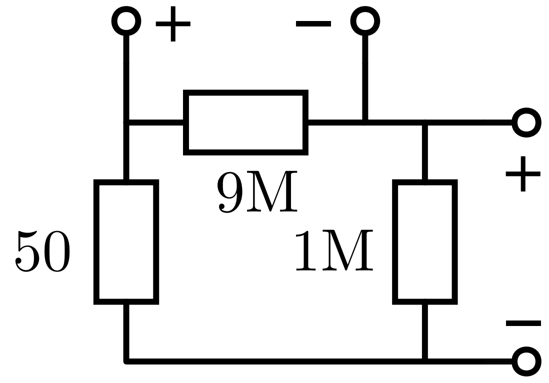
Resistance matrix relates dependent port variables to independent port variables

RC matrix example

Oscilloscope probe circuit



R-port



R-matrix

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

C-matrix

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

Poles from eigenvalues of RC:

$p_1 = -1768\text{Hz}$

$p_2 = -0.3537\text{GHz}$