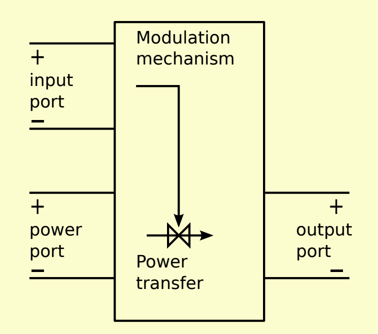
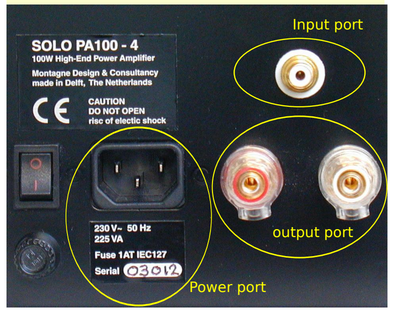
Amplifiers, concept, types and ideal behavioral models





Definition

Amplifier object

Three electrical ports
- input port: connection to signal source
- output port: connection to load
- power port: connection to power supply

Amplification function
- provide load with accurate copy of source signal

Characteristic property
- Available power gain exceeds unity

Functional model

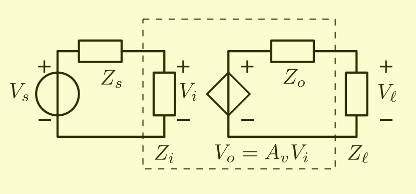
- Two-port input and output port only
- Active (delivers power)
- Linear, instantaneous, and time-invariant:

$$y(t) = A\,x(t)$$
$$A = \text{constant}$$

Example voltage amplifier

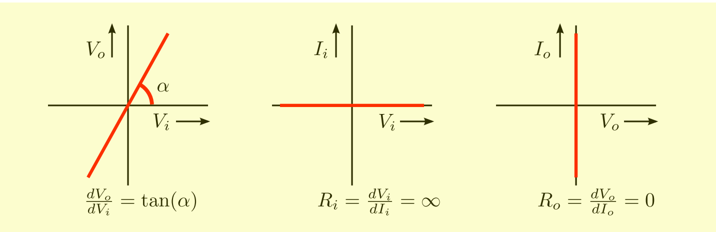
Source
- Information accurately related to open-circuit voltage
- Source impedance inaccurately known

Load
- Information accurately related to driving voltage
- Load impedance inaccurately known

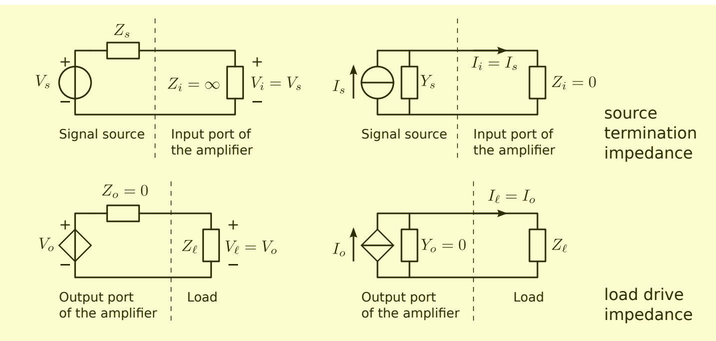


$$\frac{V_\ell}{V_s} = \frac{Z_i}{Z_i+Z_s} A_v \frac{Z_\ell}{Z_\ell+Z_o}$$

Ideal characteristics



Source termination impedance and load drive impedance



Amplifier types

Follow from best source termination and load drive conditions for accurate signal transfer

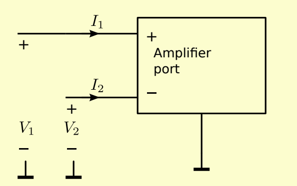
Type	Zi	Zo	A	B	C	D
voltage amplifier	infinite	0	A	0	0	0
transadmittance	infinite	infinite	0	B	0	0
transimpedance	0	0	0	0	C	0
current amplifier	0	infinite	0	0	0	D
voltage to voltage / current	infinite	Ro	A	B	0	0
current to voltage / current	0	Ro	0	0	C	D
voltage / current to voltage	Ri	0	A	0	C	0
voltage / current to current	Ri	infinite	0	B	0	D
voltage / current to voltage /current	Ri	Ro	A	B	C	D

Port isolation properties

input-output	input-power	output-power	configuration
non-isolated	non-isolated	non-isolated	common-ground
non-isolated	non-isolated	isolated	x
non-isolated	isolated	non-isolated	differential receiver
non-isolated	isolated	isolated	floating supply
isolated	non-isolated	non-isolated	x
isolated	non-isolated	isolated	differential driver
isolated	isolted	non-isolated	x
isolated	isolated	isolated	differential receiver / driver

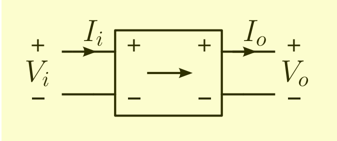
Floating port modeling and characterization

$$V_{cm} = \frac{V_1+V_2}{2}$$
$$V_{dm} = V_1 - V_2 \qquad Z_{cm} = \frac{V_{cm}}{I_{cm}}$$
$$I_{cm} = I_1 + I_2 \qquad Z_{dm} = \frac{V_{dm}}{I_{dm}}$$
$$I_{dm} = \frac{I_1-I_2}{2}$$



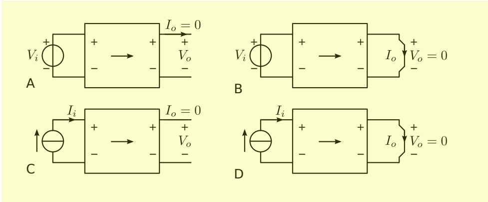
Modeling of ideal behavior (natural two-port)

Transmision-1 matrix representation



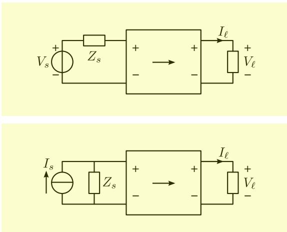
Anti-causal notation:

$$\begin{pmatrix} V_i \\ I_i \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} V_o \\ I_o \end{pmatrix}$$



$$A = \frac{1}{\mu} = \left.\frac{V_i}{V_o}\right|_{I_o=0},$$
$$B = \frac{1}{\gamma} = \left.\frac{V_i}{I_o}\right|_{V_o=0},$$
$$C = \frac{1}{\zeta} = \left.\frac{I_i}{V_o}\right|_{I_o=0},$$
$$D = \frac{1}{\alpha} = \left.\frac{I_i}{I_o}\right|_{V_o=0}.$$

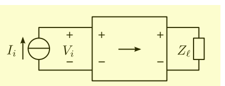
Source-to-load transfer

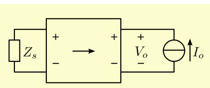


$$A_v = \frac{V_\ell}{V_s} = \frac{1}{A+B\frac{1}{Z_\ell}+CZ_s+D\frac{Z_s}{Z_\ell}}$$
$$A_y = \frac{I_\ell}{V_s} = \frac{1}{AZ_\ell+B+CZ_\ell Z_s+DZ_s}$$
$$A_z = \frac{V_\ell}{I_s} = \frac{1}{A\frac{1}{Z_s}+B\frac{1}{Z_s Z_\ell}+C+D\frac{1}{Z_\ell}}$$
$$A_i = \frac{I_\ell}{I_s} = \frac{1}{A\frac{Z_\ell}{Z_s}+B\frac{1}{Z_s}+CZ_\ell+D}$$

Port impedances

$$Z_i = \frac{V_i}{I_i} = \frac{AZ_\ell+B}{CZ_\ell+D}$$





$$Z_o = \frac{V_i}{I_i} = \frac{DZ_s+B}{CZ_s+A}$$

For design purposes: source-to-load transfers and port impedances can be expressed in terms of the T1 matrix parameters (A,B,C,D) and the source and the load impedance.

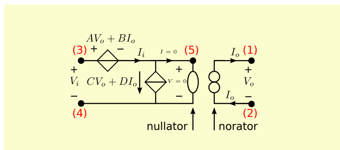
Unilateral amplifier types

Zero reverse transfer

$$AC = BD$$

Nullor and six non-unilateral types not listed in the table

Network model



MNA matrix stamp

$$\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ C & -C & 0 & 0 & 0 & D & 1 \\ -C & C & 0 & 0 & 0 & -D & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ -A & A & 1 & 0 & -1 & -B & 0 \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ I_o \\ I_i \end{pmatrix}$$

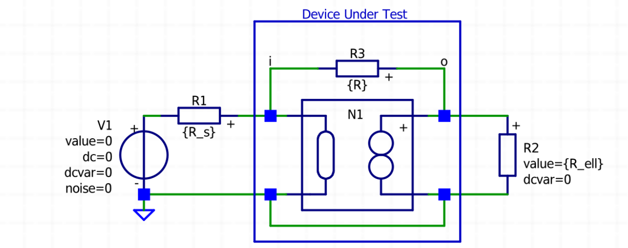
SLiCAP test bench for determination of the T1 matrix parameters

—	Variable	—	SLiCAP or Python keyword
—	Comment	—	String variable

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Python test bench for determination of the T1 parameters
- Use source identifier 'V1'
- Use load resistor value 'R_ell'
- Use the same file name for the .asc, .cir, .PNG, and .SVG
  files associated with a circuit.
"""
from SLiCAP import *

prj = initProject('ABCD-test')

# Create a list with circuit file names if you want to run multiple circuits.
fileNames = ['ABCD-test']

for fileName in fileNames:

    #makeNetlist(fileName + '.asc', fileName)

    # Define an instruction
    i1 = instruction()
    i1.setCircuit(fileName + '.cir')

    i1.setSimType('symbolic')
    i1.setGainType('gain')
    i1.setDataType('laplace')

    # Use the same identifier for the source in all files
    i1.setSource('V1')

    # Define the detector for determination of the input voltage
    i1.setDetector('V_i')
    result = i1.execute()
    # V_i is the transfer from V1 to the voltage V_i at node i
    V_i = result.laplace

    # Define the detector for determination of the input current
    i1.setDetector('I_V1')
    result = i1.execute()
    # I_i is the transfer from V1 to the current through V1
    I_i = -result.laplace

    # Define the detector for determination of the output voltage
    i1.setDetector('V_o')
    result = i1.execute()
    # V_o is the transfer from V1 to the output voltage
    V_o = result.laplace

    # Define the detector for determination of the output current
    i1.setDetector('I_R2')
    result = i1.execute()
    # I_o is the transfer from V1 to the current through R2
    I_o = result.laplace

    # Calculate the T1 parameters
    # Use the same name for the load resistance in all files
    R_ell = sp.Symbol('R_ell')
    A     = sp.simplify(sp.limit(V_i/V_o, R_ell, 'oo'))
    B     = sp.simplify(sp.limit(V_i/I_o, R_ell, 0))
    C     = sp.simplify(sp.limit(I_i/V_o, R_ell, 'oo'))
    D     = sp.simplify(sp.limit(I_i/I_o, R_ell, 0))

    htmlPage('Determination of T1 matrix parameters')
    head2html('Test circuit')
    img2html(fileName + '.svg', 400)
    head2html('T1 matrix of the device under test')
    text2html('The T1 matrix of the device under test is found as:')
    T1 = sp.Matrix([[A,B], [C,D]])
    eqn2html('T_1', T1)
    Vili = sp.Matrix([[sp.Symbol('V_i')], [sp.Symbol('I_i')]])
    Volo = sp.Matrix([[sp.Symbol('V_o')], [sp.Symbol('I_o')]])
    # Display the matrix equation without execution of the multiplication
    text2html('The matrix equation for the two-port (DUT) is found as:')
    text2html('$$' + sp.latex(Vili) + "=" + sp.latex(T1) + '\\cdot' +
              sp.latex(Volo) + '$$')
    # Display the matrix equation with execution of the multiplication
    text2html('This can be written as:')
    eqn2html(Vili, T1*Volo)
```

Determination of T1 matrix parameters

Test circuit



T1 matrix of the device under test

The T1 matrix of the device under test is found as:

$$T_1 = \begin{bmatrix} 0 & 0 \\ -\frac{1}{R} & 0 \end{bmatrix} \tag{1}$$

The matrix equation for the two-port (DUT) is found as:

$$\begin{bmatrix} V_i \\ I_i \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ -\frac{1}{R} & 0 \end{bmatrix} \cdot \begin{bmatrix} V_o \\ I_o \end{bmatrix}$$

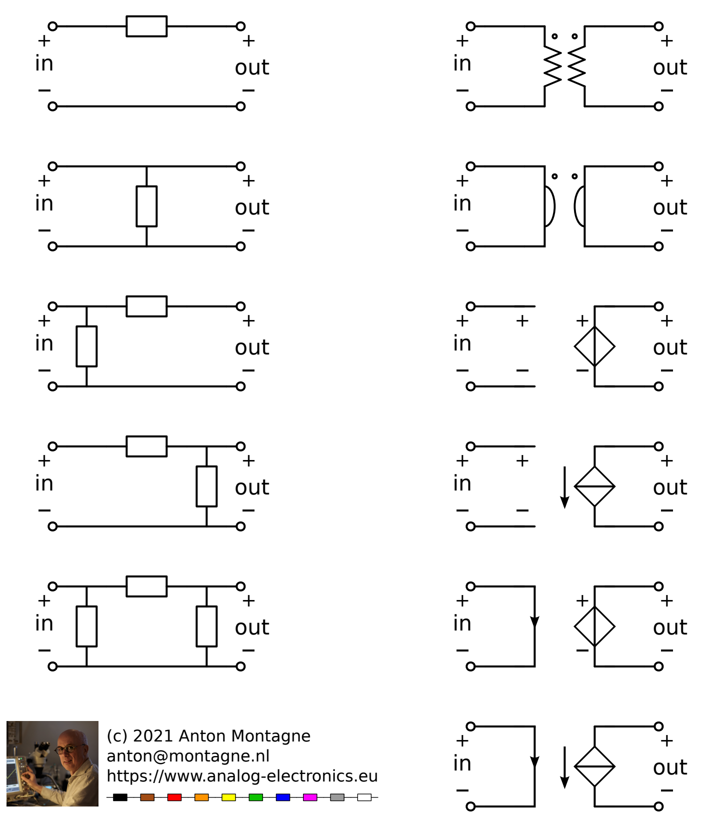
This can be written as:

$$\begin{bmatrix} V_i \\ I_i \end{bmatrix} = \begin{bmatrix} 0 \\ -\frac{V_o}{R} \end{bmatrix} \tag{2}$$

Go to ABCD-test_index

Try yourself and verify the answer with SLiCAP

Assign symbolic values to the elements and determine the T1 transmission parameters by hand. Verify the obtained results with SLiCAP



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