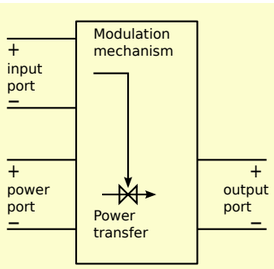
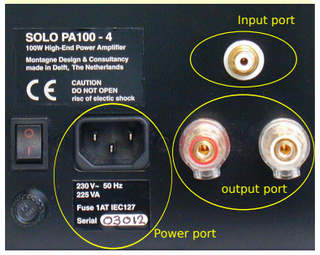
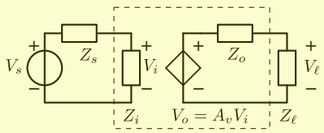




Example voltage amplifier

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

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



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

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

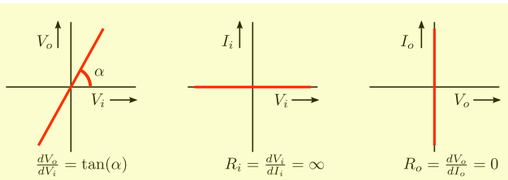
Characteristic property
- Available power gain exceeds unity

Functional model

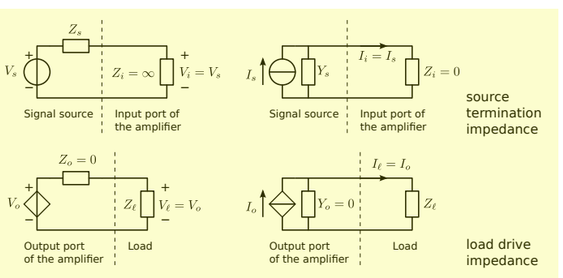
- Two-port
  input and output port only
- Active (delivers power)
- Linear, instantaneous, and time-invariant:

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

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 / curent 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

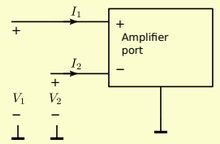
Amplifiers, concept, types and ideal behavioral models

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

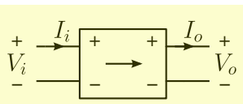
Floating port modeling and characterization

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



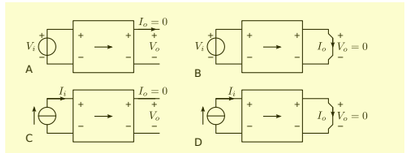
Modeling of ideal behavior (natural two-port)

Transmision-1 matrix representation



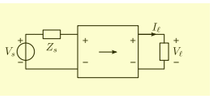
Anti-causal notation:

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



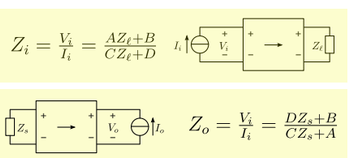
$$A = \frac{1}{\mu} = \left.\frac{V_i}{V_o}\right|_{I_o=0}, \quad B = \frac{1}{\gamma} = \left.\frac{V_i}{I_o}\right|_{V_o=0},$$
$$C = \frac{1}{\zeta} = \left.\frac{I_i}{V_o}\right|_{I_o=0}, \quad D = \frac{1}{\alpha} = \left.\frac{I_i}{I_o}\right|_{V_o=0}.$$

Source-to-load transfer



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

Port impedances



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.

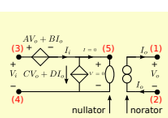
Unilateral amplifier types

Zero reverse transfer

$$AC = BD$$

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

Network model



MNA matrix stamp

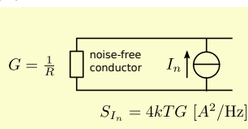
$$\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ C & -C & 0 & 0 & 0 & D & 1 \\ -C & C & 0 & 0 & 0 & -D & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ -A & A & 1 & 0 & -1 & -B & 0 \end{pmatrix}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

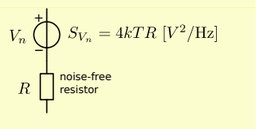
Amplifiers, modeling / characterization of non-ideal behavior

Noise

Thermal noise

Noise in conductors caused by thermal (Brownian) motion (Brown 1828). Experimetally detected by Johnson (1928) and explained by Nyquist (1928).





Shot noise

Noise current associated with a DC current through a junction.

$$S_{I_n} = 2qI_J$$

Excess noise

Noise current resulting from fluctuations in conduction mechanism.

In junctions

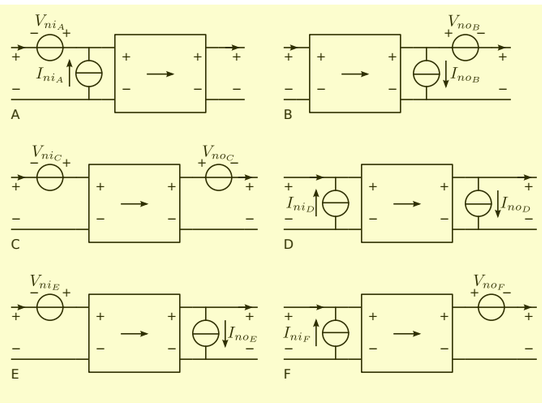
$$S_{I_n} = K\frac{I_J^a}{f}$$

In resistors

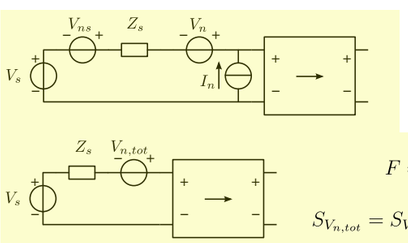
$$S_{V_n} = K\frac{V_R^2}{f}$$

Noisy two-ports

4 port variables: 2 independent, 2 dependent: 6 representations:



Equivalent input representation (A) convenient at an early stage of the design. Represent total noise in source type with Thevenin / Norton equivalent networks:

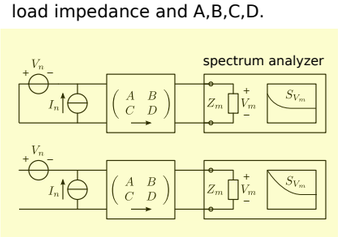


Noise figure

$$F = \frac{\int_0^\infty S_{V_{n,tot}}|W(f)|^2 df}{\int_0^\infty S_{V_{ns}}|W(f)|^2 df}$$
$$S_{V_{n,tot}} = S_{V_{ns}} + S_{V_n} + S_{I_n}|Z_s|^2$$

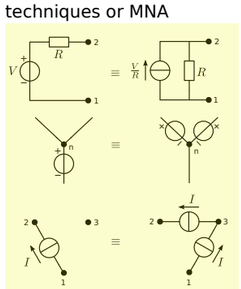
Determination of equivalent input noise sources

By measurements
- Measure spectrum of the output noise for open and shorted input
- Calculate input noise sources from load impedance and A,B,C,D.



By analysis

Source transformation techniques or MNA

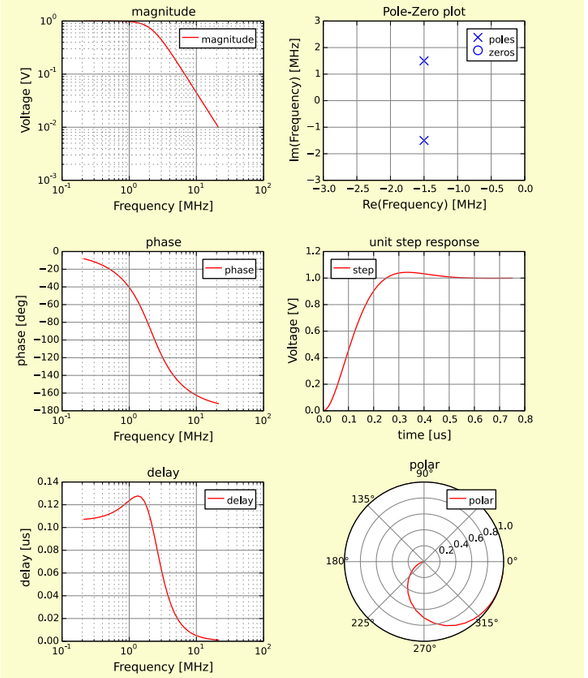


Dynamic behavior

$$H(s) = \frac{b_0+b_1 s+b_2 s^2+\cdots+b_m s^m}{a_0+a_1 s+a_2 s^2+\cdots+a_n s^n}$$

Small-signal dynamic behavior

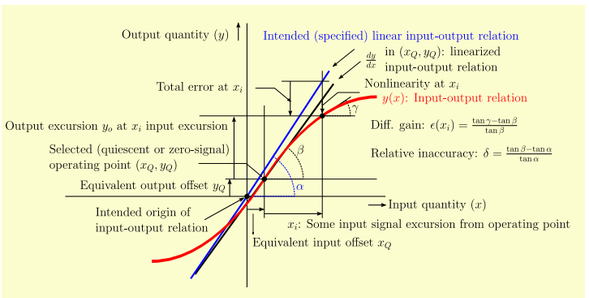
Time domain: unit impulse or unit step response
Frequency domain: Bode plots (frequency characteristics)
Complex frequency domain: poles and zeros



Nonlinear behavior

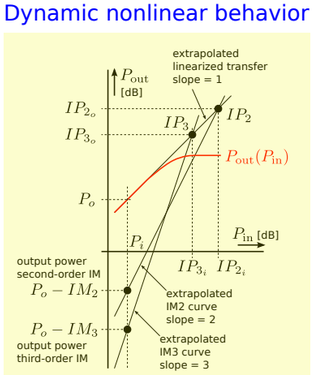
$$y = a_0 + a_1 x + a_2 x^2 + \cdots + a_n x^n$$

Static nonlinear behavior



Rate-independent / frequency-independent distortion
- offset, nonlinearity, differential gain, dead zone, saturation, rate-independent hysteresis
- THD, IMD, gain compression

Dynamic nonlinear behavior



Rate-dependent / frequency-dependent distortion
- THD, IMD
- gain compression
- differential-gain
- differential-phase
- rate-dependent hysteresis
- slew rate
- full-power bandwidth
- overdrive recovery