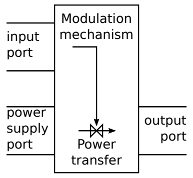
Design of the amplifier's source-load transfer

Amplification

Information processing task

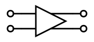
Accurately copy the source information, while increasing the available signal power



Operating principle

The source signal modulates the power transfer from the power supply to the load

Selection of electrical input and output quantity



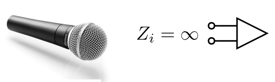
Sensor and actuator interfacing

The electrical input quantity of an amplifier should show the best possible correspondence with the source information

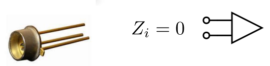
The electrical output quantity of an amplifier should show the best possible correspondence with the load information

Source and load, and input and output impedances can only be part of the transfer if accurately known

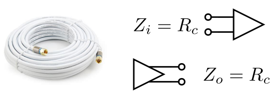
The voltage generated by a microphone is accurately related to the sound pressure



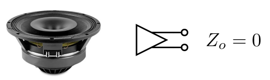
The current generated by a PIN diode is accurately related to the optical power



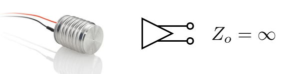
A transmission line shows no reflections iwhen driven from and terminated with its characteristic impedance



The sound pressure generated by a loudspeaker is accurately related to the applied voltage

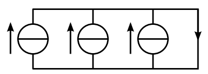


The force generated by a piezo actuator is accurately related to the electrical charge

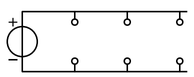


Signal addition, distribution, testability

Addition of currents



Distribution of voltages



Amplifier types

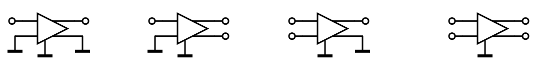
Port impedances

amplifier type	source quantity	load quantity	Z_i	Z_o
Voltage amplifier	voltage	voltage	∞	0
Transadmittance	voltage	current	∞	∞
Voltage to V/I	voltage	voltage or current	∞	Z_o
Transimpedance	current	voltage	0	0
Current amplifier	current	current	0	∞
Current to V/I	current	voltage or current	0	Z_o
V/I to voltage	voltage or current	voltage	Z_i	0
V/I to current	voltage or current	current	Z_i	∞
V/I to V/I	voltage or current	voltage or current	Z_i	Z_o

9 unilateral types:
input impedance independent of load impedance
output impedance independent of source impedance

Amplifier types

Port configuration and common-mode port impedances

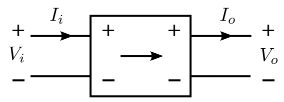


	grounded ports	differential driver	differential receiver	differential receiver/driver
Z_{icm}			0 ∞ R_c	0 ∞ R_c
Z_{ocm}		0 ∞ R_c		0 ∞ R_c
Number of types	9	27	27	81

Total 144 (unilateral) amplifier types

Amplifier functional model

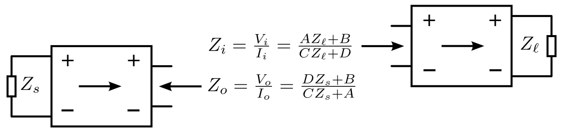
Modeling of the ideal behavor



Anti-causal T1 matrix two-port representation

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

Model for differential-mode and for common-mode behavior



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

$$Z_o = \frac{V_o}{I_o} = \frac{DZ_s + B}{CZ_s + A}$$

Unilateral: $AD = BC$

Design of amplifier types

amplifier type	Z_i	Z_o	A	B	C	D
Voltage amplifier	∞	0	A	0	0	0
Transadmittance amplifier	∞	∞	0	B	0	0
Voltage input, finite nonzero output impedance	∞	Z_o	A	B	0	0
Transimpedance amplifier	0	0	0	0	C	0
Current amplifier	0	∞	0	0	0	D
Current input, finite nonzero output impedance	0	Z_o	0	0	C	D
Finite nonzero input impedance, voltage output	Z_i	0	A	0	C	0
Finite nonzero input impedance, current output	Z_i	∞	0	B	0	D
Finite nonzero input and output impedance	Z_i	Z_o	A	B	C	D

Design of port impedances

The input impedance should be designed such that the electrical input quantity accurately represents the source information

The output impedance should be designed such that the electrical output quantity accurately represents the load information

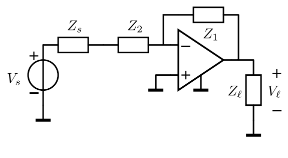
Brute-force techniques

Tune the port impedance to its desired value through insertion of an impedance in series or in parallel with the port

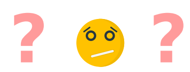
Pros	Cons
Simple	At input port: Reduction of SNR
	At output port: Reduction of power efficiency

Design of high-performance amplifiers

Thou shalt not insert impedances in series or in parallel with the signal path!



This is **not** an inverting voltage amplifier



Feedback techniques

Cons	Pros
Less simple	Allows orthogonal design of performance aspects
	Performance primarily set by feedback network that does not need an available power gain larger than unity.

Design of amplifier types using negative feedback

1. Sense the load quantity of interest

   Sensing of a voltage: in parallel with the load (output parallel feedback)
   Sensing of a current: in series with the load (output series feedback)

2. Convert it into a copy of the source quantity

   The feedback network converts the load signal of the amplifier into a copy of the source signal

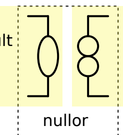
3. Nullify the difference between the source quantity and its copy by controlling the load quantity

   Comparison of voltages: anti-series connection of source voltage and feedback voltage (input series feedback)

   Comparison of currents: anti-parallel connection of source current and feedback current (input parallel feedback)

   The nullor is the ideal controller $\begin{pmatrix} V_i \\ I_i \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} V_o \\ I_o \end{pmatrix}$ **Tellegen 1954**

The input comparison result is connected to a nullator



The load quantity and its sense element are connected to a norator

Synthesis of Feedback Amplifiers

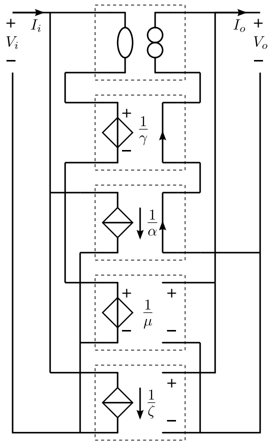
Each T1 matrix parameter fixed with one feedback loop.

A. parallel sensing series comparison

B. series sensing series comparison

C. parallel sensing parallel comparison

D. series sensing parallel comparison



16 combinations:
- 9 unilateral
- 6 non-unilateral
- nullor

Type	A	B	C	D
Nullor	0	0	0	0
Voltage amplifier (unilateral)	$\frac{1}{\mu}$	0	0	0
Transadmittance amplifier (unilateral)	0	$\frac{1}{\gamma}$	0	0
Transimpedance amplifier (unilateral)	0	0	$\frac{1}{\zeta}$	0
Current amplifier (unilateral)	0	0	0	$\frac{1}{\alpha}$
$Z_i = \frac{\alpha}{\gamma}$, $Z_o = \infty$ (unilateral)	0	$\frac{1}{\gamma}$	0	$\frac{1}{\alpha}$
$Z_i = \frac{\zeta}{\mu}$, $Z_o = 0$ (unilateral)	$\frac{1}{\mu}$	0	$\frac{1}{\zeta}$	0
$Z_i = 0$, $Z_o = \frac{\zeta}{\alpha}$ (unilateral)	0	0	$\frac{1}{\zeta}$	$\frac{1}{\alpha}$
$Z_i = \infty$, $Z_o = \frac{\mu}{\gamma}$ (unilateral)	$\frac{1}{\mu}$	$\frac{1}{\gamma}$	0	0
Transformer-like amplifier (non-unilateral)	$\frac{1}{\mu}$	0	0	$\frac{1}{\alpha}$
Gyrator-like amplifier (non-unilateral)	0	$\frac{1}{\gamma}$	$\frac{1}{\zeta}$	0
Triple loop 1 (non-unilateral)	$\frac{1}{\mu}$	$\frac{1}{\gamma}$	$\frac{1}{\zeta}$	0
Triple loop 2 (non-unilateral)	$\frac{1}{\mu}$	$\frac{1}{\gamma}$	0	$\frac{1}{\alpha}$
Triple loop 3 (non-unilateral)	$\frac{1}{\mu}$	0	$\frac{1}{\zeta}$	$\frac{1}{\alpha}$
Triple loop 4 (non-unilateral)	0	$\frac{1}{\gamma}$	$\frac{1}{\zeta}$	$\frac{1}{\alpha}$
Quadruple loop	$\frac{1}{\mu}$	$\frac{1}{\gamma}$	$\frac{1}{\zeta}$	$\frac{1}{\alpha}$

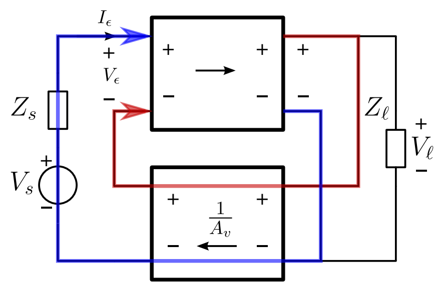
Ideal gain

Source-load transfer of a feedback amplifier in which all controllers are replaced with nullors

Negative feedback

Corrective feedback

- Controller = high-gain error amplifier
- Odd number of minus signs in the loop transfer



Synthesis of Common-mode impedances

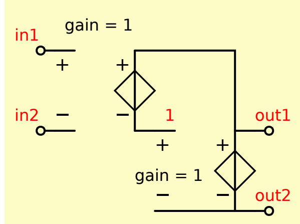
In the case of zero common-mode source-load transfer

- Transformer coupling
- Brute-force technique
- Common-mode feedback on a port

Else also:

- Over-all common-mode feedback

SPICE nullor subcircuit




```
.subckt nullor out1 out2 in1 in2
E1 out1 1 in1 in2 1
E2 out1 out2 1 out2 1
.ends
```

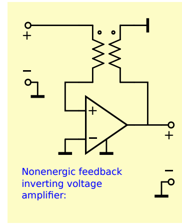
Nonenergic feedback

Feedback networks are nonenergic:

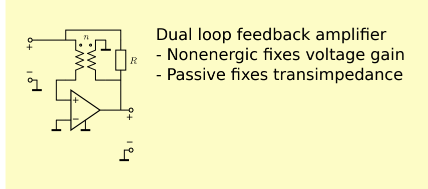
- no energy storage
- no losses

Nonenergic network elements:

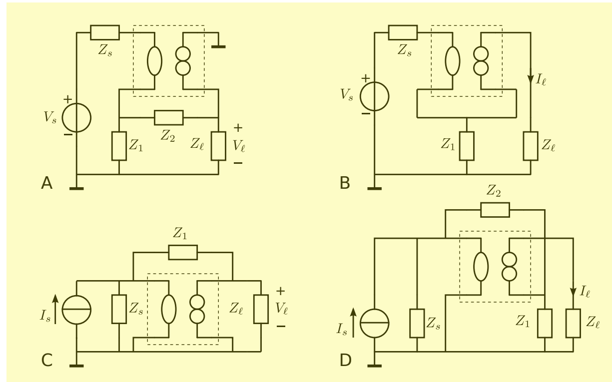
- Transformer
- Gyrator
- Open circuit
- Short circuit



Properties of nonenergic feedback amplifiers:
No noise performance degradation due to feedback network
No power efficiency degradation due to feedback network



Passive feedback



Single-loop passive feedback amplifiers with grounded source and load:

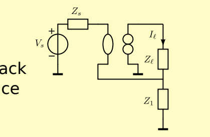
A: Voltage amplifier $\frac{V_\ell}{V_s} = \frac{Z_1 + Z_2}{Z_1}$

B: Transadmittance amplifier $\frac{I_\ell}{V_s} = -\frac{1}{Z_1}$

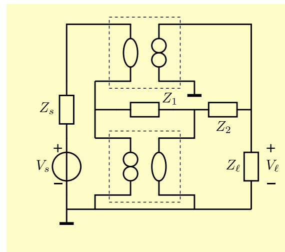
C: Transimpedance amplifier $\frac{V_\ell}{I_s} = -Z_1$

D: Current amplifier $\frac{I_\ell}{I_s} = \frac{Z_1 + Z_2}{Z_1}$

Single-loop noninverting passive feedback transadmittance amplifier:



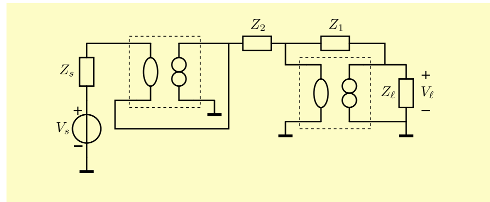
Active feedback



Active feedback Inverting voltage amplifier

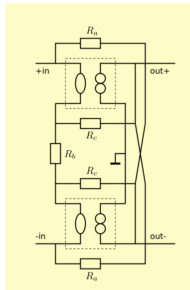
Nullators and norators can be paired differently

There exists no relation between nullators and norators:
- Nullator sets network condition
- Norator introduces a free variable to satisfy this condition



Balanced feedback

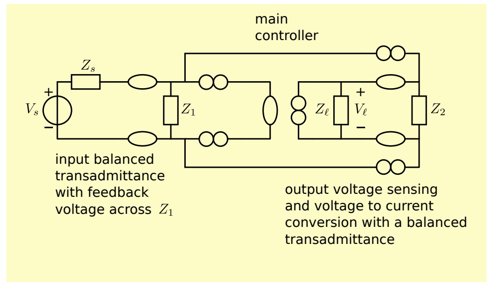
Balanced amplifiers can be obtained through anti-series connection of unbalanced amplifiers Cross coupling can be used for sign inversion of a differential-mode transmission coefficien

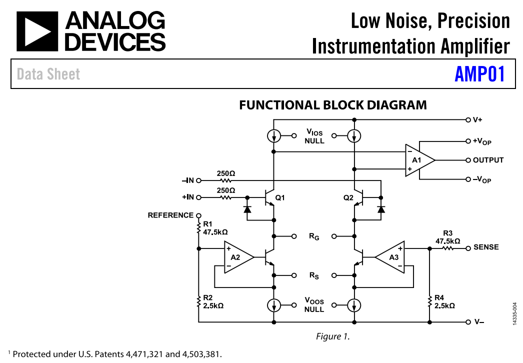


Differential-mode cross coupling does not affect the common-mode feedback.

Extra measures need to be taken to prevent positive common-mode feedback

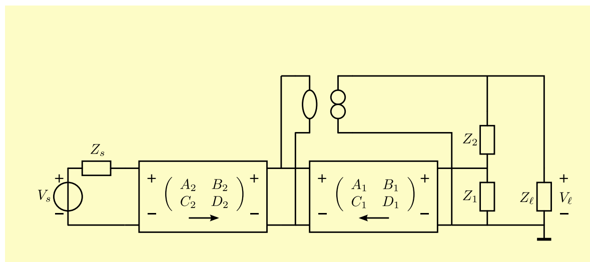
Balanced feedback with improved port isolation





Indirect (model-based) feedback

Instrumentation amplifier with indirect voltage comparison



Inverting current amplifier with indirect current sensing