Structured Design

TU Delft
Anton J. M. Montagne
Chris J. M. Verhoeven

Analog Electronic Signal Processing Systems

Basic Analog Signal Processing & Reference functions

Analog electronic information processing systems can be constructed from a limited number of Basic Analog Information Processing and Reference functions:

Concept (function)	Implementation (object)
Impedance transformation	(impedance) transformer
Amplification	Amplifier
Distribution	Distributer
Combination	Combiner
Selection in amplitude (v, i) domain	Comparator / limiter
Selection in time domain	Switch
Selection in frequency domain	Filter
Amplitude reference (v, i)	Voltage / current reference
Time reference	Time reference (timer)
Frequency reference	Oscillator
Memorization	Memory
Nonlinear function	Multiplier, ...

Limitations to Signal Processing

The amount of information that can be processed by a real-world system is limited due to:

1. Addition of noise: signal processing is about how to deal with noise (of any kind)!

2. Limitation of resources (cost factors):
   A. Physical resources, such as, power, space and matter
      Limitation of electrical power results in:
      i. Speed (bandwidth) limitation
      ii. Limitation of the signal to noise ratio

$$C = B \log_2 \frac{P_{\text{signal}} + P_{\text{noise}}}{P_{\text{noise}}} \text{ [bit/s]}$$

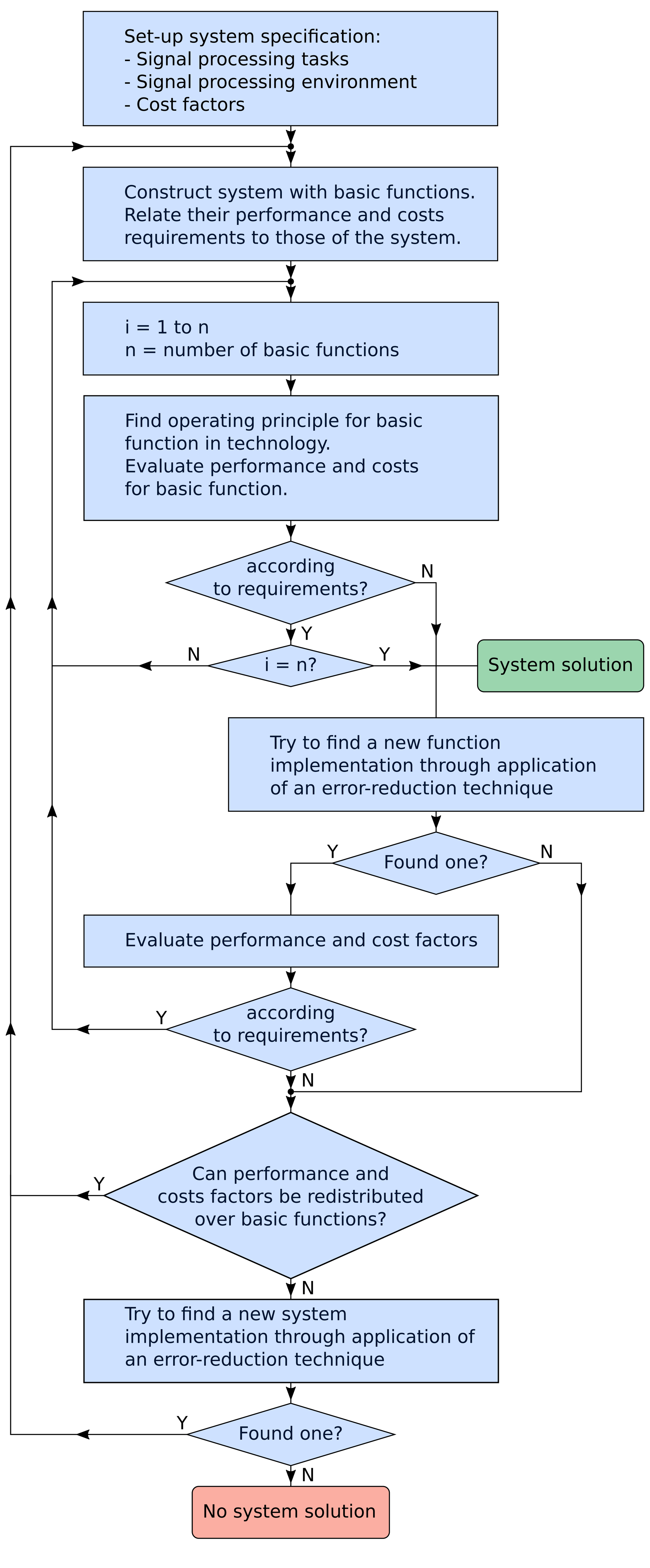
   B. Technological resources:
      i. Imperfect embodiment of a function concept in the operating principle of devices
      ii. Incomplete embodiment of function concepts in operating principles of devices (gyrator, memristor, ...)
   C. Economical resources

Error-reduction techniques (design measures)

The performance and/or the performance versus cost ratio can be improved through application of a limited number of error-reduction techniques:
1. Selection
2. Compensation
3. Error-feedforward
4. Feedback (negative and positive)
5. Sampling
6. Quantization
7. Modulation
8. Coding
9. Parallel processing

Application may change the system breakdown in basic functions.

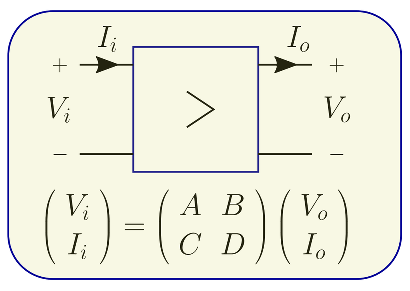
Design flow (simplified)



Amplifier design

Amplification Concept

1. Load information is copy of source information
2. Availabe load power exceeds source power
3. Modeled as two-port:

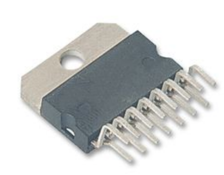


* Linear
* Instantaneous
* Time invariant

All characteristics:
Straight lines through the origin.

Amplifier Object

1. Input port
2. Output port
3. Power supply port

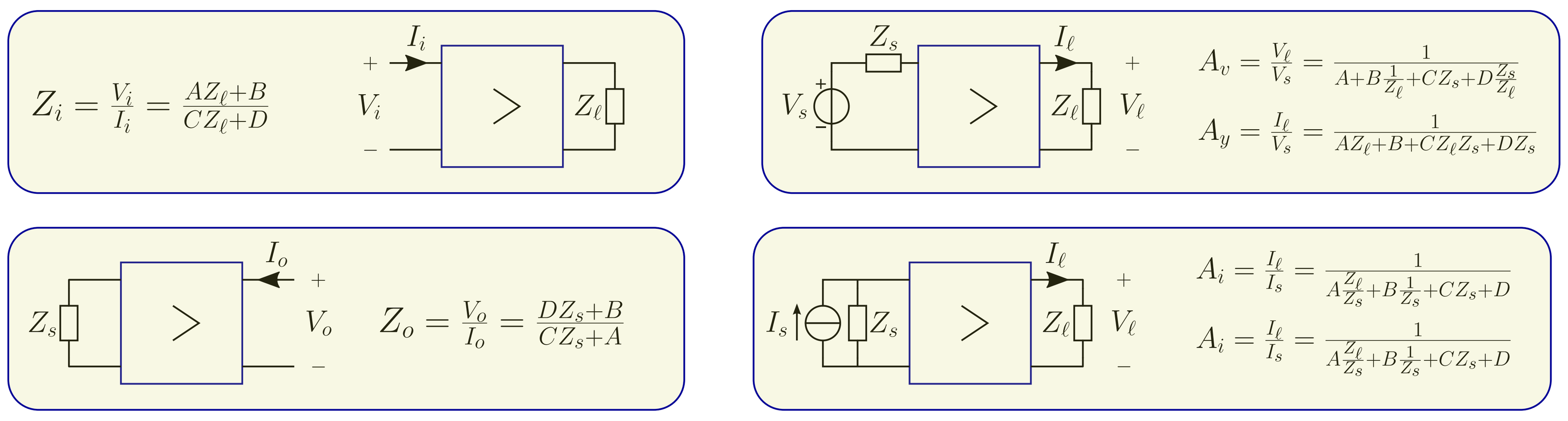


Load power mainly provided by power supply

Amplifier Types

Design of amplifier type => A, B, C, D

Source quantity and load quantity (voltage or current):
Best reproducing relation to **information**



Performance aspects

* Port configurations / impedances
* Source to load transfer
* Noise addition / immunity
* Signal / noise handling capability
* Bandwidth
* ...

Cost factors

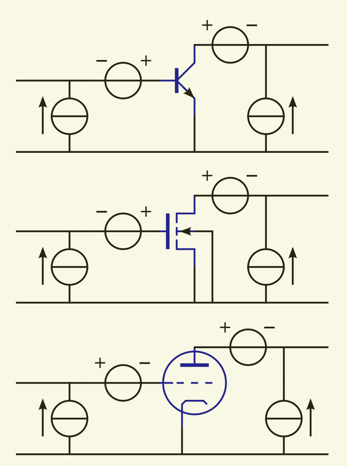
* Power dissipation
* Emission
* Dimensions
* Weight
* Costs
* ...

Environmental conditions

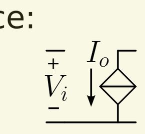
* Temperature range
* Humidity
* Shock and vibration
* EMI
* ...

Operating principle

Properly biased nonlinear devices may provide an available power gain that exceeds unity



Idealized model of physical operation of amplifying devices corresponds to voltage-controlled current source:



$I_o = \frac{1}{B} V_i$
$A, C, D = 0$

Imperfections

1. Nonlinear behavior
2. Dynamic behavior
3. Noise addition
4. Inaccurate
5. Temperature sensitivity
6. ...

Biasing

Biasing is a technique for fixing the electrical operating conditions of electronic devices with the aid of voltage and current sources and deriving the required sources from the power supply voltage(s).

Bias error reduction
1. Compensation and auto-zero
2. AC coupling (selection)
3. Negative feedback
4. Modulation

Minimization of noise addition and minimization of power losses

1. Optimization of device geometry
2. Optimization of device operating conditions
3. No impedances in series or in parallel with the signal path
   Except noise and / or power matching networks in narrow-band applications

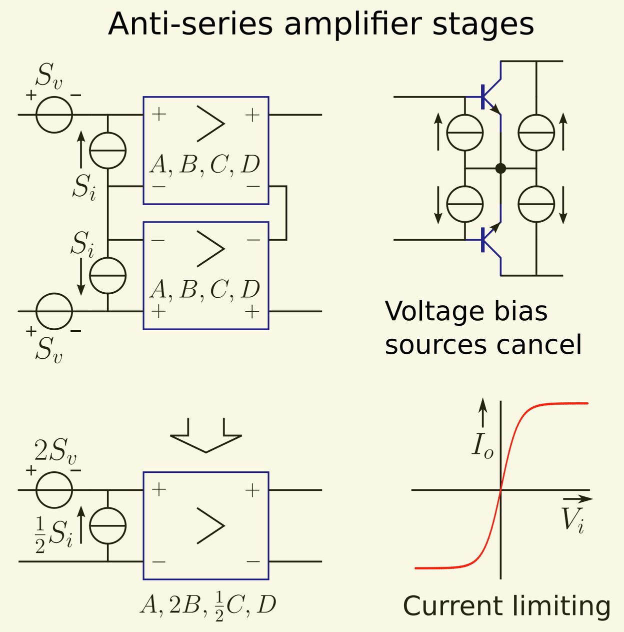
Noise and power performance optimization:
Similar techniques but different goals!

Error reduction

Additive compensation:
balanced amplifier stages
1. Error reproduction with anti-series or complementary parallel connection
2. Even terms in nonlinear transfer cancel
3. Current limiting characteristic with anti-series stage
4. Current expanding characteristic with complementary parallel stage
5. Noise behavior and small-signal dynamic behavior can be similar to basic stage
6. Input-output port isolation with anti-series stage

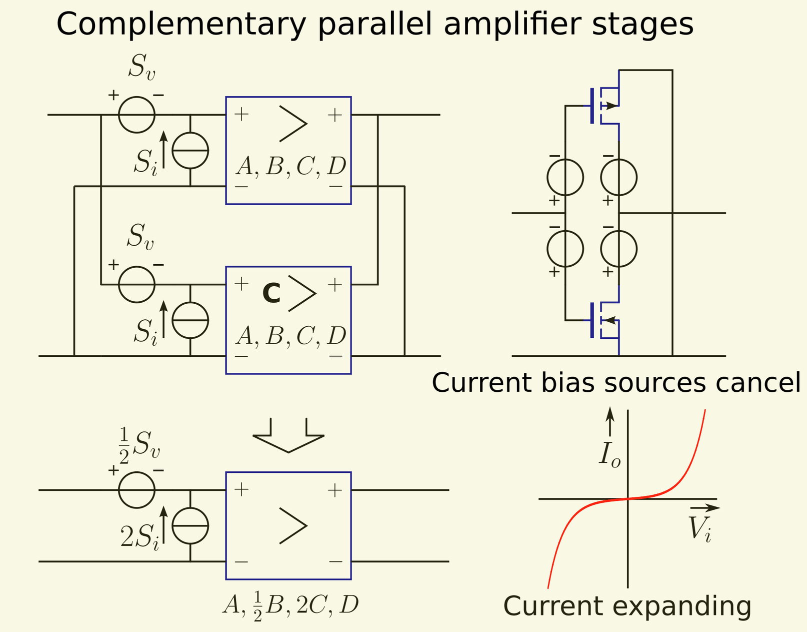
Properties of interconnected two-ports are inherited by their circuit implementations!

Anti-series amplifier stages



Low-offset 4-terminal amplifier stage

Complementary parallel amplifier stages



Amplifier stage with high current-drive capability

Negative feedback

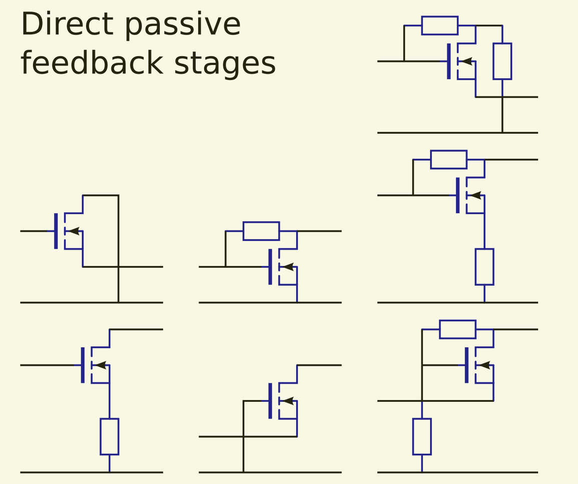
Design of amplifier type
For each T1 matrix parameter that needs to have a nonzero value:
1. Sense its corresponding load quantity
2. Convert it into a copy of its corresponding source quantity
3. Nullify the difference between the source quantity and its copy with the aid of a nullor

Conversion can be implemented with
1. Nonenergic elements (short, open, transformer gyrator)
2. Linear non dissipative passive elements (L, C)
3. Linear dissipative elements (R)
4. Nonlinear elements (diode, transistor, ...)
5. Active elements (amplifiers)

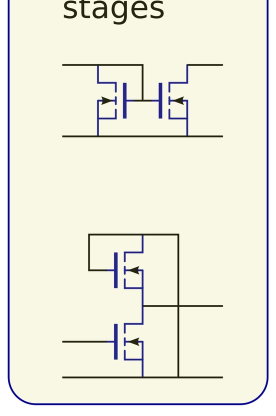
Sensing and comparison
1. Direct
   A. Current sensing: series load feedback
   B. Voltage sensing: parallel load feedback
   C. Current comparison: parallel source feedback
   D. Voltage comparison: series source feedback
2. Model based
   A. Indirect sensing
   B. Indirect comparison

Advantages negative feedback
1. High-accuracy of ideal transfer (inverse of feedback network)
2. Error with respect to ideal transfer minimized by controller gain
3. Performance aspects can be designed independently

Direct passive feedback stages



Indirect feedback stages



Two-step design approach

Design of ideal gain: feedback networks around nullor
1. Noise addition
2. Power losses
3. Energy storage

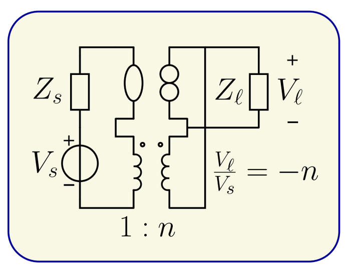
$$A_f = A_{f\infty} \frac{-L}{1-L} + \frac{\rho}{1-L}$$

Source to load transfer

Influence of direct transfer often negligible up to very high frequencies

Asymptotic transfer equals ideal gain if
1. Controller can be modeled as natural two-port
2. Unity-gain transfer from:
   A. Source to amplifier
   B. Amplifier to load

Servo function describes error due to finite loop gain L



Servo function

Low-pass cut-off at:

$$f_{lp} = \left((1 - L_0) \left| \prod_{i=i}^{n} p_i \right| \right)^{\frac{1}{n}}$$

Differential gain error:

$$\varepsilon = \frac{\varepsilon_L}{|L_Q|}$$

High loop gain cannot reduce:
1. Influence of input noise sources of input stage
2. Power losses and energy storage in output of output stage

Design of controller
1. Input stage should approximate nullor behavior. Then, noise of subsequent stages does not contribute to amplifier noise.
2. Output stage should approximate nullor behavior. Then, the differential gain error of preceeding stages does not contribute to amplifier differential gain and these stages do not contribute to power losses or energy storage.

Controller structure
1. Common-source, common-emitter stages preferred
2. The number of stages is determined by:
   A. Accuracy at low or mid-band frequencies
   B. Required loop gain poles product
   C. Required differential-error to loop gain ratio
3. Local feedback stages may be used for:
   A. Reduction of interaction between stages
   B. Increase of controller gain without adding dominant poles
4. Complementary-parallel stages for high current-drive
5. Anti-series stages for port isolation with respect to ground

Frequency compensation
1. Phantom zero
2. Pole-splitting
3. Pole-zero canceling
4. Bandwidth reduction
5. Loop gain reduction