Structured Electronics Design

A systems engineering approach to the design of electronic circuits

Solidly based on

- Systems Engineering
- Device physics Signal processing
- Network theory
- Control theory

History

1980: Ernst H. Nordholt: Design of High-Performance Negative-Feedback Amplifiers

1989: Catena Micro Electronics Delft, Product Partners Delft, TU Delft, IMS Stuttgart: Analog Electronics Design Course, COMETT program EU.

2003: C.J.M Verhoeven, A. van Staveren, G.L.E. Monna, M.H.L. Kouwenhoven, E. Yildiz Structured Electronic Design

2018: A.J.M. Montagne: Structured Electronics Desian

Benefits

- Straightforward top-down design
- Specification driven
- Early identification of design risks
- Solid basis for analog design education
- Solid basis for algorithmic design automation

Characteristics

- Hierarchically structured design process
- Identical process flow at each level - Circuit design put in the perspective of
- information processing
- Clear relation between application, requirement specification and design
- Clear distinction between theoretical concepts and their technology-specific implementation
- Takes concepts and their technology-specific implementation, rather than known circuit topologies as starting point for the design.
- Puts circuit analysis in the perspective of design synthesis.
- Provides clear goals for circuit optimization.

Design tools SLiCAP

Symbolic Linear Circuit Analysis Program A python application for deriving and solving design equations of electronic circuits.

Symbolic and numeric determination of design equations, show-stopper values, and

design budgets for:

- DC variance and temperature dependency of component values
- Noise contributions of transistors, resistors. current and voltage sources
- Bandwidth / settling time - Frequency response

Includes MOS (EKV) model and BIT

(Gummel-Poon) model

Symbolic and numeric pole-zero analysis Root-locus plots

Design education tools

Currently under development at the TU Delft.

A computer-based learning system for analog circuit design

Hierarchical design process

Identical structure at each level

Input:

Initial specification of object to be designed At highest level: Application description

Output:

Design data Initial specification of next level objects At lowest level: Final specification of object(s)

Requirement specification

- Functions

- Performance
- Environment - Costs

Figure Of Merit - time

 $FOM = \frac{Weighted product of performance measures}{Weighted product of performance measures}$ - space - matter Weighted product of cost factors

- energy

Put the design of electronic circuits in the perspective of information processing

Electronic information processing systems can be constructed from a limited number of:

Basic references and processing functions / objects

Function	Materialization	Object
Reference in V-I domain		Voltage of current source
Reference in frequency domain	Physical	Harmonic oscillator
Reference in time domain	operating principle in technology	Timer
Impedance matching		Transformer / matching network
Increase of available signal powe	r	Amplifier
Selection in V-I domain		Comparator / limiter
Selection in frequency domain	· ·	Filter
Selection in time domain		Switch
Memorize		Memory

Materialization: create objects that perform functions

The amount of information that can be processed by an object is limited							
A model should provide an answer to a question.	Evaluate the application of design techniques (see below) for improvement of the performance-cost ratio.						
but not simpler!	Evaluate interaction between performance aspects and between performance aspects ans cost factors.						
Models should be as simple as possible,	Evaluate performance limitations and cost factor limitations.						
All models are wrong, but some are useful. A. Einstein:	Model the physical (nonideal) behavior.						
	Find an operating mechanism that can be used for the materialization of this function in an available technology.						
G.P. Box:	Model the desired functional (ideal) behavior.						

mount of information that can be processed by an object is limited

Channel capacity Shannon (1948)

Fundamental limitations

The information processing capacity [bits/s] of physical systems is limited

- addition of noise
- power limitation
- speed (bandwidth, rate of change) limitation

Design techniques

A collection of techniques that can be applied to - improve performance - reduce the costs

Types of design techniques

- optimization of physical implementation - scaling of dimensions
- changing of operating point
- modification of physical implementation
- changing of device
- modification of functional decomposition - application of design techniques
- Examples isolation - auto-zeroing - compensation - modulation balancing - sampling - feedback - quantization





Orthogonalize design techniques - performance requirements

	Per	Cost fa	actors	Environ	Environment			
Structured	Drive Noise capability	Port Isolation	Transfer quality	Electrical resources	Mechanical resources	From environment	To environment	bilit
Amplifier Design CMOS technology	alic V-l drive capability - sker rake	m en in and port impedances or acy	tet ak nonlinearity ali-signal bandwidth iquarcy response opercy stability repeature stability	lescent dis sipation wer efficiency	mendiores 65	rperature Idmical conditions Idmical conditions	mperature rise Vited noise Iste	11
Design techniques	8 3 8	¥ 8 6 2		8 8	N N	ž ž š	Err Vo	TM TM
Geometry Device Operating current Operating voltage								
Direct negative feedback								
Indirect (model-based) negative feedback								
Indirect (model-based) positive feedback								
Feedback Increase DC or mid-band loop gain								
Increase loop gain-poles product								
Decrease differential-error-gain ratio of the loop gain								
Error Direct feedforward Indirect (model-based)								
Balancing Anti-series connection Complementary-parallel connection				esi	gn			
Phantom-zero compensation			lec	nni	que	S		
Pole-splitting (feedback) Frequency			Effe	ctiv	ene	ss		
compensation Pos-spirting P2 carceing Besistive Innathantion								
Bandwidth reduction				Mat	rix			
Impedance correction Brute-force port termination Zobel correction								
Impedance transformation At the source								
At the load								
Modulation Frequency shift					++ 9	strong p	ositive	
Bandwidh - Power					+	positive		
Time multiplex					0	neutral		
Time-space multiplex						negative		
Bertical					9	strong n	egative	
Filtering Mechanical								
Thermal								

Seminar Program Structured Electronics Design

Structured Design of Negative Feedback Amplifiers

- 1. Introduction
- 2. Specification and design of amplifier type
- 3. Specification and design of drive capability and noise performance
- 4. Specification and design of accuracy, bandwidth and weak nonlinearity
- 5. Specification and design of small-signal dynamic response
- 6. SLiCAP a design tool that supports Structured Electronics Design
- 7. Example design in PCA technology: Audio Hearing Loop
- 8. Structured Electronics Design in CMOS technology
- 9. Structured Electronics Design in CMOS technology
- 10. Example design in CMOS technology: CMOS active receiver antenna (0.1-30 MHz) Conclusions: Analog Design education and automation



high costs

 $C = B \log_2 \frac{P+N}{N} \left[\frac{\text{bit}}{s}\right]$

Technological limitations

Imperfect, incomplete, or unavailable

materialization of the desired function

- insufficient performance

or cost factor that cannot be realized under the Show given constaints. stoppe

Identify at earliest possible stage

Impact on the predictability of the design process increases each stage

No propagation of design risks

- Design risks identified at a hierarchical level must be resolved at that level
- No design loops

Only take design decisions if necessary

Design the design process

Requirements

- Identical structure at each hierarchical level
- Show stoppers appear at the earliest possible stage
- No risk propagation, no design loops

Orthogonalization

- Create degrees of freedom for realizing functions and their
- characteristic performance aspects.
- Separate them in:
- parameters - frequency range
- time
- location

Sequencing of activities

The sequence of the design activitie should be such that

- Show stoppers appear at the earliest possible stage:
- Materialization of a function in the desired technology is not available
- The required performance-cost ratio cannot be achieved within the required constraints:
- There is no design technique capable of
- improving a performance aspect to a sufficient quality level - reducing a cost factor to an acceptable level
- Design decisions taken at one stage need not to be reconsidered at a later stage

IC Amplifier Design Process

Stepwise approach to the design of negative feedback amplifiers and bias sources



Function, performance, costs and environment Amplifier type Output stage and over-all biasing concept Input stage Number of stages Frequency compensation Complete biasing concept Distortion Bias sources

Example Designs

TU Delft BSc course EE3C11



Specification, design, build, and test of an audio hearing loop system in PCA technology

TU Delft MSc course



Specification, design, and verification by simulation of an active antenna for receivers with a frequency range of 0.1 - 30 MHz..



data

Safety