

# **LECTURE 1, Analog Filters**

## **Introduction, Recapitulation, and Outline**

Analog Signals, Systems, and Filters

Applications

Mathematical tools

LTI-systems

Differential equation, impulse and step response, convolution

Transfer function, Frequency response

Design process

Synthesis, realization, implementation

# LECTURE 2, Analog Filters

## Filter Synthesis

### LTI Filters

Transfer function, frequency response

Magnitude response, attenuation function

Phase response, group delay, phase delay

(Impulse response, step response)

### Specification - frequency selective LP filters

Magnitude response requirements

Sometimes phase response requirements - (approx.) linear phase

### Standard approximations

Butterworth, Chebyshev I and II, Cauer (Elliptic)

Basic properties and comparisons

### Synthesis procedure

Determine filter order and zeros & poles & gain

Normalization/denormalization (LP  $\rightarrow$  LP frequency transformation)

# **LECTURE 3, Analog Filters**

## **Filter Synthesis - Lowpass**

Synthesis procedure for analog LP

Determine filter order and zeros & poles & gain

Normalization/denormalization (LP  $\rightarrow$  LP frequency transformation)

Characteristic function

Used when solving the approximation problems

# **LECTURE 4, Analog Filters**

## **Filter Synthesis - Highpass, Bandpass, Bandstop**

Synthesis procedure for analog HP, BP, and BS filters

Specification mapping, synthesis of LP filter, pole-zero mapping

Frequency transformations

Pole-zero mappings

Frequency and specification mappings

# **LECTURE 5, Analog Filters**

## **Passive Filter Structures with Discrete Elements**

Resistor, inductor, capacitor

Doubly resistively terminated LC-filters

Maximum power transfer principle

Low sensitivity

Ladder structures - lowpass T-type and Pi-type with and without finite zeros (four types in total)

Computation of element values - three-step procedure

# **LECTURE 6, Analog Filters**

## **Passive Filter Structures with Discrete Elements**

Doubly resistively terminated LC-Filters

Highpass, bandpass, and bandstop filter structures

Frequency transformed lowpass filter structures

Three-step procedure

Transfer function computations

Chain matrix of a two-port

Cascaded two-ports

# LECTURE 7, Analog Filters

## Passive Filter Structures with Distributed Elements

Unit element - lossless transmission line

Richards' variable  $\Psi = \tanh(s\tau)$

Doubly resistively terminated filters

Relation to a  $\Psi$ -domain reference filter - simplifies the design

Ladder structures

Richards' structures

# LECTURE 8, Analog Filters

## Active Filter Structures

Inductors realized using capacitors and active elements

Operational (OP) amplifier

Ideal OP amp - infinite open-loop gain

Practical OP amp - finite gain, first-order model

Unity-gain bandwidth

Gain-bandwidth product

Transfer function computations for closed-loop systems

Filter structures

Coupled forms

Cascade, parallel (sensitive!), multiple feedback

Simulation of LC ladder networks

Topologic simulation: voltages/currents --> signal-flow-graph with adders, integrators, and inverters

Immitance simulation: inductors simulated using e.g. general immitance converters (GICs)

Wave active filters: derived using voltage waves instead of voltages and currents (change of variables)

Focus on cascade form



# **LECTURE 9, Analog Filters**

## **Active Filter Structures**

Cascade form

First-order sections, LP, HP, AP

Second-order sections, LP, HP, BP, LP and HP notch (BS)

# **LECTURE 10, Analog Filters**

## **Active Filter Structures**

Simulation of LC ladder networks

Topologic simulation – Leapfrog filters

Immitance simulation

Wave active filters

## **Summary of the Course**