# 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 -> 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 -> LP frequency transformation)
- Characteristic function
  - Used when solving the approximation problems
- Allpass filters
- Minimum-phase filters

# 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