

EE 508

Lecture 1

Introduction to Course

Catalog Course Description:

E E 508. Filter Design and Applications. (3-3) Cr. 4.
Prereq: 501. Filter design concepts. Approximation and synthesis. Transformations. Continuous-time and discrete time filters. Discrete, active and integrated synthesis techniques.

Instructor: Randy Geiger

contact information:

294-7745

rlgeiger@iastate.edu

course linked at: www.randygeiger.org

Course Coverage

- Filter design process
- Approximation Problem
- Synthesis
- Active and passive realizations
- Integrated Applications
 - Discrete-time filters
 - (SC and digital)
 - Continuous-time filters
- PLLs (if time permits)

Major emphasis will be placed on methods for implementing filters on silicon

COURSE INFORMATION

Room: Lecture - 1157 Sweeny
 Labs - 2046 Coover
-
Time: Lecture - MWF 10:00 – 10:50
 Laboratory - Arranged

Lecture Instructor:

Randy Geiger
2133 Coover

Voice: 294-7745

e-mail: rlgeiger@iastate.edu

Office Hours: I maintain an open-door policy, will reserve 11:00 to 12:00 MWF specifically for students in EE 508. Appointments are welcomed too.

Course Description:

Filter design concepts. Approximation and synthesis. Transformations. Continuous-time and discrete time filters. Discrete, active and integrated synthesis techniques

Course Web Site <http://class.ee.iastate.edu/ee508/>

Homework assignments, lecture notes, laboratory assignments, and other course support materials will be posted on this WEB site. Students will be expected to periodically check the WEB site for information about the course.

Required Text:

There is no required text for this course. There are a large number of books that cover portions of the material that will be discussed in this course and some follow. Part of these focus on the concepts of filter design and some of the best are not new. Those that focus more on integrated applications are mostly rather narrow in scope.

Grading: Points will be allocated for several different parts of the course. A letter grade will be assigned based upon the total points accumulated. The points allocated for different parts of the course are as listed below:

2 Exams	100 pts each
Homework	100 pts.total
Lab and Lab Reports	100 pts.total
Design Project	100 pts. total

Laboratory:

There will be weekly laboratory experiments. Students will be expected to bring parts kits such as those used in EE 230 and EE 330. To the maximum extent possible, students will be expected to work individually in the laboratory.

The design project will be the design of an integrated filter structure. Expectations will be to carry the design through post layout simulation. The option for fabricating this integrated circuit will be available to students in the class.

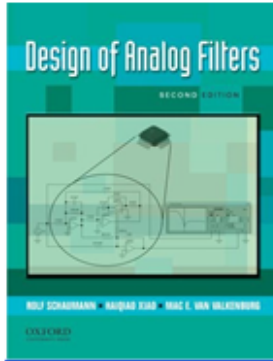
Homework:

Homework assignments are due at the beginning of the class period on the designated due dates. Late homework will be accepted, without penalty, up until 5:00 p.m. on the due date in Room 2133 Coover.

Additional Comments

I encourage you to take advantage of the e-mail system on campus to communicate about any issues that arise in the course. I typically check my e-mail several times a day. Please try to include "EE 508" in the subject field of any e-mail message that you send so that they stand out from what is often large volumes of routine e-mail messages.

Reference Texts:



Design of Analog Filters – Second Edition, by [Schaumann and Van Valkenburg](#), Oxford, 2009.

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Passive, Active, and Digital Filters, by [Wai-Kai Chen](#), CRC Press, 2009.



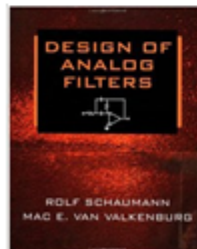
Analog Filters Using MATLAB, by [Wanhammar](#), Springer, 2009.



1V CMOS Gm-C Filters, by [Lo and Hung](#), Springer, 2009.



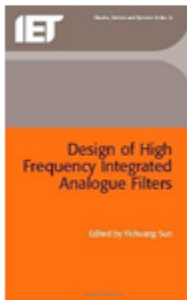
Passive and Active Filters, Theory and Implementations, by [Wai-Kai Chen](#), Wiley, 1986.



Design of Analog Filters, by [Schaumann and Van Valkenburg](#), Oxford, 2001.



Switched-Capacitor Techniques for High-Accuracy Filter and ADC Design, by [Quinn and van Roermund](#), Springer, 1997.



Design of high frequency integrated analogue filters, by [Sun](#), IEE, 2002.



High-Performance CMOS Continuous-Time Filters, by [Silva-Martinez, Steyaert, and Sansen](#), Kluwer, 1993



Introduction to the Design of Transconductor-Capacitor Filters, by [Kardontchik](#), Kluwer, 1992.



Integrated Video-Frequency Continuous-Time Filters: High-Performance Realizations in BiCMOS, by [Willingham and Martin](#), Kluwer, 1995.

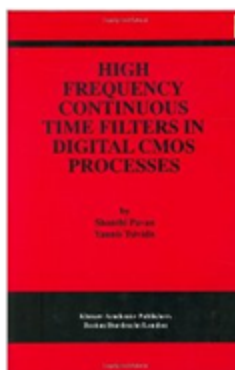
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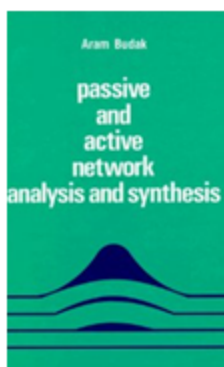
Switched Capacitor Filters: Theory, Analysis, and Design, by [Mohan, Ramachandran and Swamy](#), Prentice Hall, 1995.



Continuous-Time Active Filter Design, by [Deliyannis](#), [Sun](#), and [Fidler](#),
CRC Press, 1998.



High Frequency Continuous-Time Filters in Digital CMOS Processes, by
[Tsividis](#) and Springer, 2000.



Passive and Active Network Analysis and Synthesis, by [Budak](#), Waveland
Press, 1991.



Handbook of Filter Synthesis by [Zverev](#), Wiley, 1967 and 2005.

Digital Filters, Analysis, Design, and Applications, Second Edition, by [Antoniou](#), McGraw Hill, 1993.

Introduction to the Theory and Design of Active Filters, by [Huelsman and Allen](#), McGraw Hill, 1980.

MOS Switched-Capacitor and Continuous-Time Integrated Circuits and Systems, by [Unbehauen and Cichocki](#), Springer, 1989.

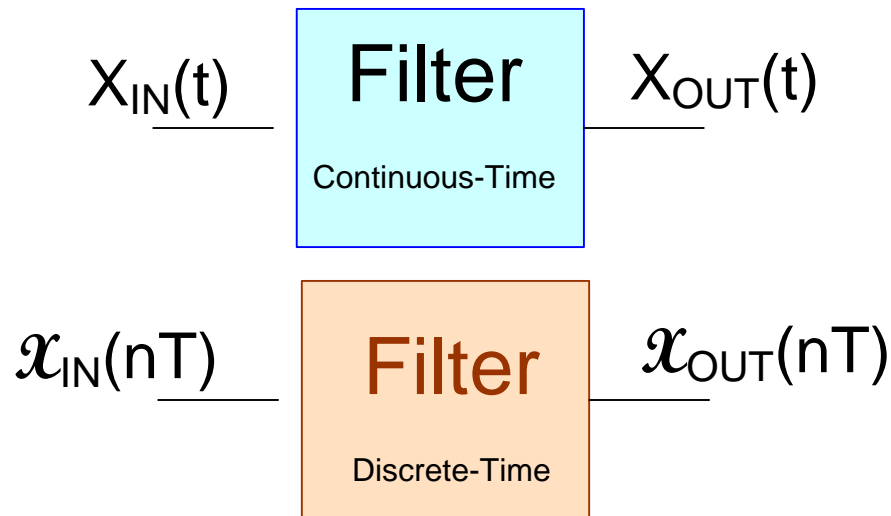
What is a filter?

Conceptual definition:

A filter is an amplifier or a system that has a frequency dependent gain

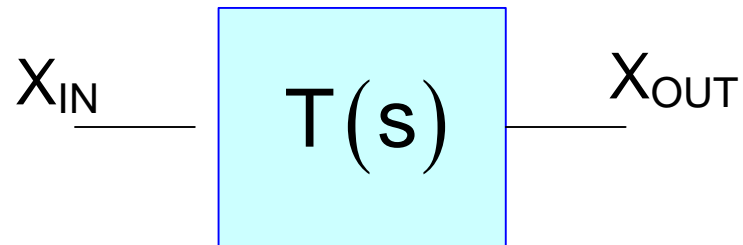
Note:

Implicit assumption is made in this definition that the system is linear. In this course, will restrict focus to filters that are ideally linear



Filters can be continuous-time or discrete-time

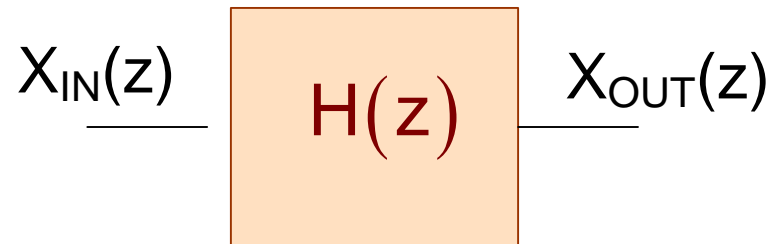
Continuous-time filters



Continuous-time filters are often characterized in the frequency domain

$$T(s) = \frac{X_{OUT}(s)}{X_{IN}(s)}$$

Discrete-time filters



Discrete-time filters are often characterized in the frequency domain

$$H(z) = \frac{X_{OUT}(z)}{X_{IN}(z)}$$

Observations:

- Some (if not most) filters will exhibit some undesired nonlinearities
- Frequency response characteristics often of most interest in filters but in some filters, other characteristics may be of interest

Time delay

Spectral leakage

Inter-modulation distortion

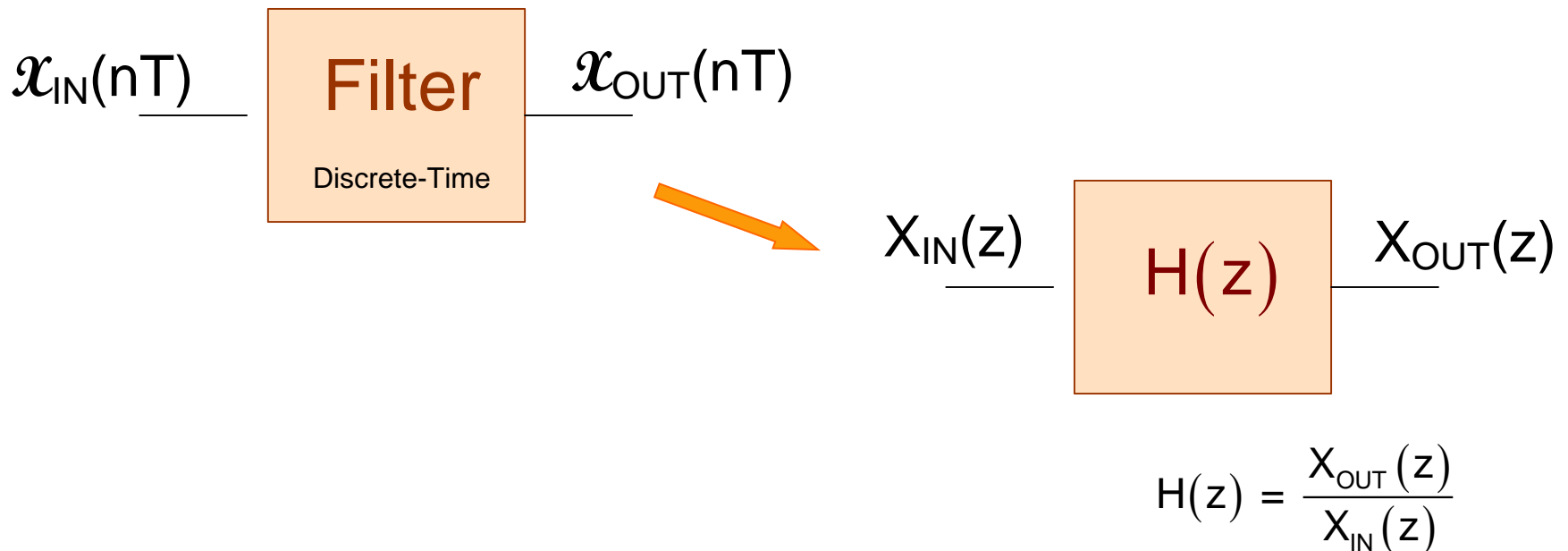
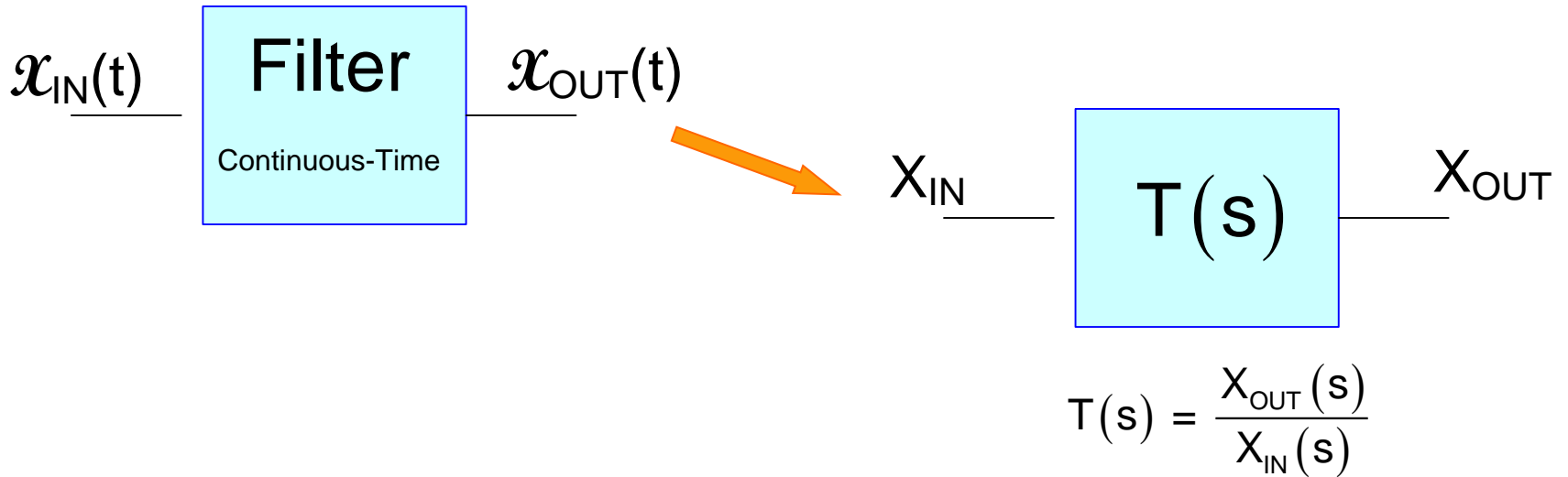
- Some classes of nonlinear circuits that are also termed “filters” and that have fundamentally different operational characteristics exist (but are not covered in this course)

Median Filters

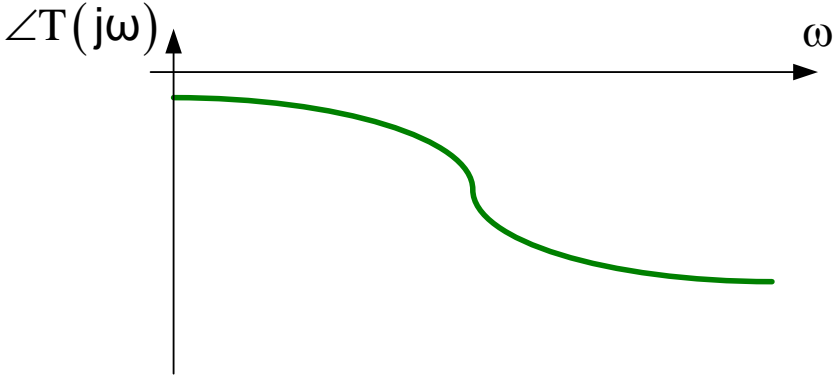
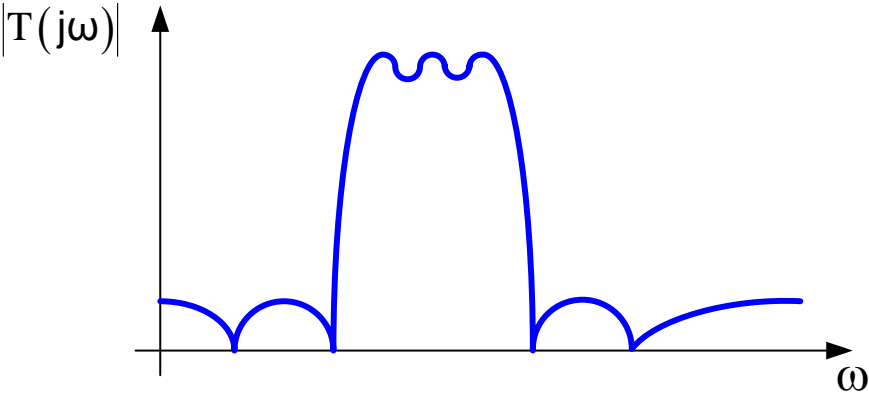
Log Domain Filters

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Most classical filter applications stipulate gain vs f or phase vs f as the desired operating characteristics

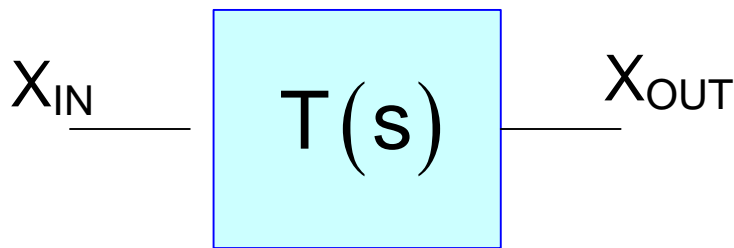


Representation of magnitude and phase characteristics of a filter:



Key properties of filters:

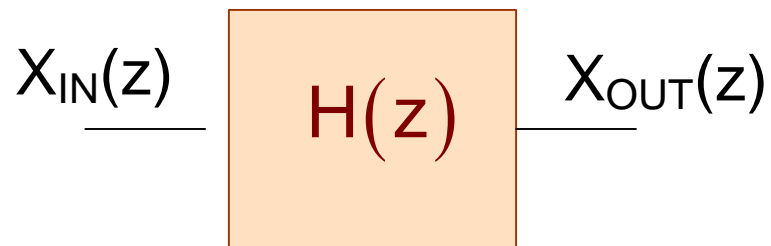
Transfer functions of continuous-time filters with finite number of lumped elements are rational fractions with real coefficients



$$T(s) = \frac{\sum_{i=1}^m a_i s^i}{\sum_{i=1}^n b_i s^i} = \frac{N(s)}{D(s)}$$

Key properties of filters:

Transfer functions of discrete-time filters with finite number of real additions are rational fractions with real coefficients



$$H(z) = \frac{\sum_{i=0}^m a_i z^i}{\sum_{i=0}^p b_i z^i} = \frac{N(z)}{D(z)}$$

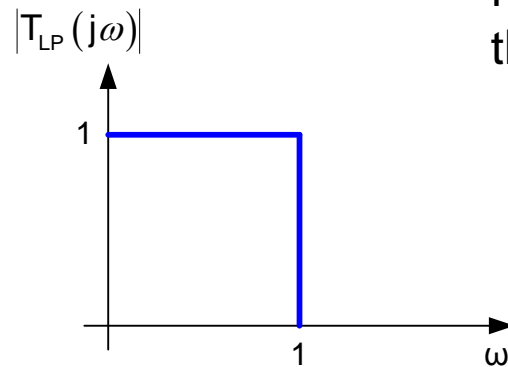
Key properties of filters:

Transfer functions of any realizable filter (finite elements) have no discontinuities in either the magnitude or phase response

Is this property good or bad?

BAD !

Often want filters that will perfectly pass a signal in some frequency range and perfectly block it outside this range



Ideal lowpass filter

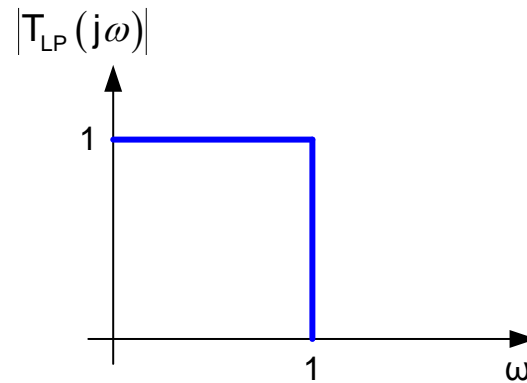
Key properties of filters:

Transfer functions of any realizable filter (finite elements) have no discontinuities in either the magnitude or phase response

Often system designer will “want” overly challenging specifications but really only “need” something somewhat less demanding

Critical that the circuit and system designer agree upon an appropriate relaxed filter requirement so overall system performance is met and designing time and circuit cost is acceptable

Observations:



Ideal lowpass filter

The closer the designer comes to realizing the ideal lowpass characteristics, the more complicated and expensive the design becomes

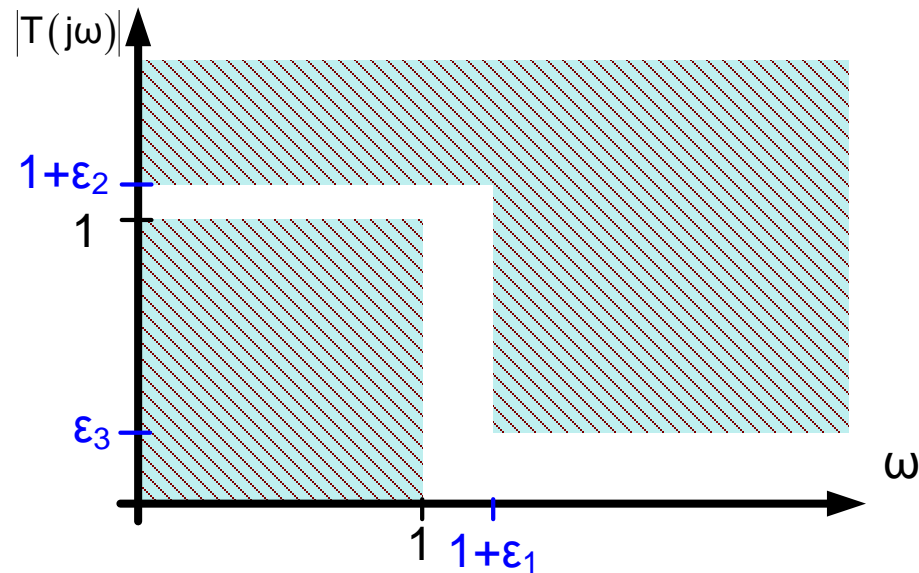
Filter applications often have strict requirements on where major changes in magnitude or phase occur

Window of transition from “pass-band” to “stop-band” often very narrow

Filter design field has received considerable attention by engineers for about 8 decades

- Passive RLC
- Vacuum Tube Op Amp RC
- Active Filters (Integrated op amps, R,C)
- Digital Implementation (ADC,DAC,DSP)
- Integrated Filters (SC)
- Integrated Filters (Continuous-time and SC)

Filter specifications often given by bounds for acceptable characteristics in frequency domain

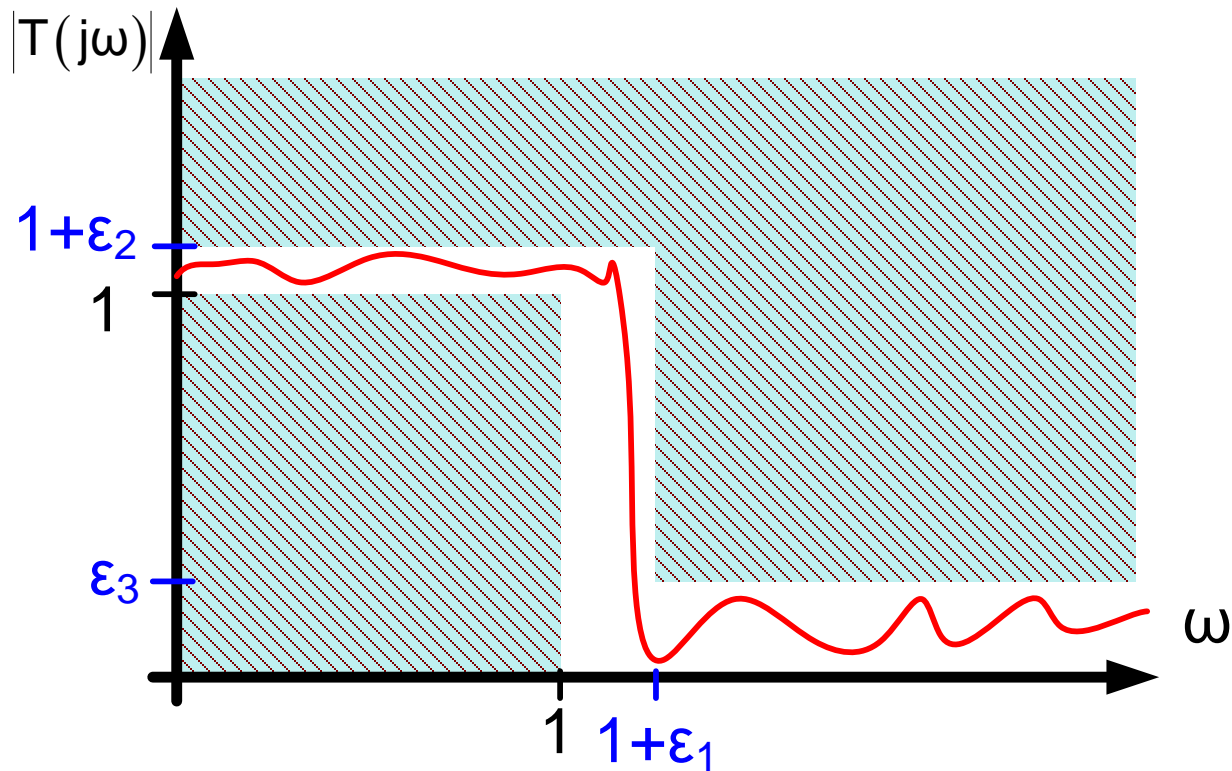


This example characterized by the three parameters $\{\epsilon_1, \epsilon_2, \epsilon_3\}$

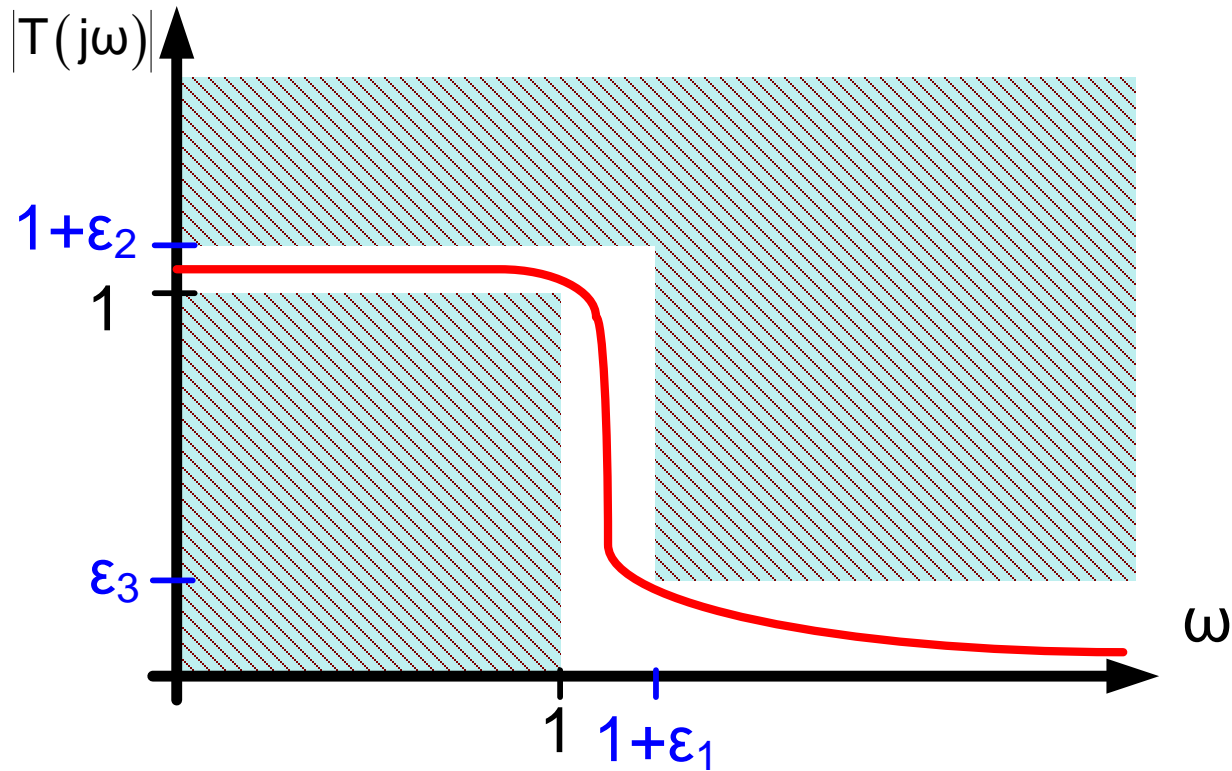
Any circuit that has a transfer function that does not enter the forbidden region is an acceptable solution from a performance viewpoint

Filter design must provide margins for component tolerance, temperature dependence, and aging

Any circuit that has a transfer function that does not enter the forbidden region is an acceptable solution from a performance viewpoint



Any circuit that has a transfer function that does not enter the forbidden region is an acceptable solution from a performance viewpoint



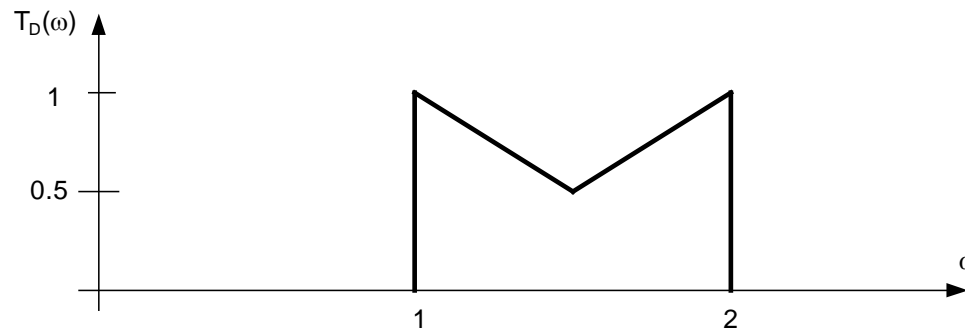
- Minor changes in specifications can have significant impact on cost and effort for implementing a filter
- Work closely with the filter user to determine what filter specifications are really needed
- This will become increasingly important as many (most) system designers in the future will have weak background in filter issues

EE 508
HW 1
Fall 2012

Short Assignment – due Friday of this week

The seemingly simple problem of obtaining a rational fraction that approximates a desired transfer function can become quite involved and, with the exception of a few standard approximations, there is still often no known technique for obtaining a transfer function. In this assignment, you will be asked to use whatever techniques you have available to obtain a transfer function that approximates a given magnitude response. A metric defined below will be used to assess how good your approximation is for this assignment.

Consider the desired “M” transfer function shown below where the frequency axis is linear.



Mathematically, the desired transfer function magnitude is characterized by the function

$$T_D(\omega) = \begin{cases} 0 & 0 \leq \omega \leq 1 \\ 2 - \omega & 1 < \omega \leq 1.5 \\ \omega - 1 & 1.5 < \omega \leq 2 \\ 0 & \omega > 2 \end{cases}$$

Obtain a rational fraction approximation, $T(s)$, to this transfer function magnitude. Your approximation is constrained to $m + n \leq 6$ where m is the degree of the numerator polynomial and n is the degree of the denominator polynomial. That is

$$T(s) = \frac{\sum_{i=1}^m a_i s^i}{\sum_{i=1}^n b_i s^i}$$

The “goodness” of your approximation should be assessed by the L_2 norm defined by

$$\varepsilon = \int_{\omega=0}^4 \left| |T(j\omega)| - T_D(\omega) \right|^2 d\omega$$

You should include your approximation $T(s)$, a plot of the magnitude of your transfer function along with that of $T_D(\omega)$ with a linear frequency axis for $0 < \omega < 5$, the value you obtain for ε , and a brief description of how you obtained your approximation.

Keep track of your time and spend at most 3 hours on this assignment. The major purpose of this assignment is to establish an appreciation for the approximation problem.

End of Lecture 1