



Subject: Filter Design  
Code: 18480  
Institution: Escuela Politécnica Superior  
Degree: Telecommunication Technologies and Services Engineering  
Level: Graduate  
Type: Course Common to the Telecommunication Branch  
ECTS: 6

## 1. COURSE TITLE

### Filter Design

#### 1.1. Course number

18464

#### 1.2. Course area

Telecommunication Technologies and Services Engineering

#### 1.3. Course type

Common to the Telecommunication Branch

#### 1.4. Course level

Graduate

#### 1.5. Year

2°

#### 1.6. Semester

2°

#### 1.7. Credit allotment

6

#### 1.8. Prerequisites

*Filter Design* belongs to Area 2.3: Signal Processing in Communications, from the *Courses Common to the Telecommunications Branch* module of the Degree of Telecommunication Technologies and Services Engineering.

This area contains three related subjects (Communication Theory, Filter Design and Digital Signal Processing), presenting from fundamentals to advanced techniques of signals and systems analysis and design in the context of Telecommunications Engineering.



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*Filter Design* is clearly based in the concepts presented in the concepts presented in the *Subject 1.5 (Circuits and Systems)* of the *Core Course Module*, and therefore it is recommended to have previously passed *Circuit Analysis* (1<sup>st</sup> year) and to have previously studied *Linear Systems* (2<sup>nd</sup> year).

More specifically, in order to start this course, it is needed to proficiently handle basic mathematical tools such as trigonometric functions, complex numbers and polynomials, basic integration and geometric series. From the *Circuit Analysis* course, it will be necessary to be proficient in techniques for solving circuits, and also the use of basic elements of circuits. From the *Linear Systems* course, it will be necessary to be proficient in the use and characterization of linear, time invariant systems with their impulse and frequency response, and also in the calculus and use of Fourier transforms in discrete and continuous time, and in the sampling and reconstruction techniques in order to transform continuous signals into discrete ones, and vice-versa.

## 1.9. Minimum attendance requirement

Attendance to the theory sessions is considered especially useful for the accomplishments of the objectives of the course, and also to participate in continuous evaluation tests. However, no minimum requirements are needed in order to participate in the continuous evaluation.

Attendance to the practical sessions is mandatory. A student will only be allowed to be absent to two sessions when there will be justified reasons, properly documented. In that case, the work of the session will be redone in no more than one week since the absence, in a schedule agreed with the teacher. Being absent to more sessions; non-justified absences; or not redoing the work of one session in which the student was absent in less than one week time; will mean not to pass the practical work evaluation, which means suspending the course. In order to keep a nice working environment, it will not be allowed to get into the laboratory 10 minutes after the beginning of each session or to leave the session before it ends, unless there is a justified reason.

## 1.10. Faculty data

Add @uam.es to all email addresses below.

### Theory:

**Dr. Daniel Ramos Castro** (Coordinator)  
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#### Practice:

**Dr. Julián Fierrez Aguilar (Coordinator)**  
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**Dr. Daniel Tapias Merino**  
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## 1.11. Course objectives

*Filter Design* is an introductory course to the implementation and design of analogic and digital systems (filters). Thus, the course is structured in three parts, clearly separated, each of them with a Unit dealing with continuous time (analogic filters) and other with discrete time (digital filters).

In the first part (Units 1 and 2) the basic required tools are presented: the Laplace and z transforms. In the second part (Units 3 and 4) the use of these transforms for the analysis and characterization of continuous and discrete time systems is addressed, and essential concepts in signal processing such as the transfer function, the poles or the zeros, are introduced. As the majority of the systems to be analysed or made are defined by differential or difference equations, these kind of systems, which will play an essential role in the design and implementation of filters, are analysed in more detail. Once arrived to this point, we can address the last part of the course (Units 5 and 6), *i.e.* the design and implementation of analogic and digital filters. The starting point of each of these units will be the specification of analogic and digital filters. Then, design methods of both types of filters will be presented. Finally, an introduction of the real implementation of both types of filters will be seen, then completing the objectives of the course.

In parallel to the development of the course, and integrated with the theoretical explanations, six laboratory sessions will be conducted, one for each of the presented Units. Their objective is reinforcing the theoretical knowledge and getting



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a deeper understanding of the available computational tools in order to aid either the analysis or the design of continuous- and discrete-time filters.

The common **competences** to the Telecommunications branch (CO) that will be acquired with this course are the following:

**CO4** Ability to analyse and specify the fundamentals parameters of a communication system.

**CO5** Ability to evaluate the advantages and drawbacks of different technological alternatives in order to deploy or implement communication systems, from the point of view of the signal space, the disturbances and noise, and the analogic and digital modulations.

The objectives to be accomplished with this subject are the following:

<b>GENERAL OBJECTIVES</b>
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G1	Being proficient in Laplace and z transforms.
G2	Being able to analyse and characterize discrete- and continuous-time systems using the Laplace and z transforms.
G3	Being able to understand the specifications of a filter, design and implement it, both for digital and analog filters.

<b>SPECIFIC OBJECTIVES PER UNIT</b>
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<b>UNIT 1.- The Laplace Transform.</b>	
1.1.	Knowing the unilateral and bilateral Laplace transform and its utility.
1.2.	Understanding and handling the relationship between the Laplace transform and the continuous-time Fourier transform.
1.3.	Use the definition of the Laplace transform to calculate simple Laplace transforms and their regions of convergence, and also to demonstrate some of their properties.
1.4.	Using the most typical Laplace transform pairs and the properties of the Laplace transform in order to calculate direct and inverse Laplace transforms.
1.5.	Being able to recognize the forms of the Region of Convergence (ROC) of the Laplace transform, and understanding its relationship to the temporal shape of the signal.
1.6.	Performing inverse Laplace transforms by simple fraction decomposition.
<b>UNIT 2.- The Z Transform.</b>	
2.1.	Knowing the unilateral and bilateral z transform and its utility.
2.2.	Understanding and handling the relationship between the z transform and the discrete-time Fourier transform.
2.3.	Use the definition of the z transform to calculate simple z transforms and their regions of convergence, and also to demonstrate some of their properties.
2.4.	Using the most typical z transform pairs and the properties of the z transform in order to calculate direct and inverse z transforms.
2.5.	Being able to recognize the forms of the Region of Convergence (ROC) of the z



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	transform, and understanding its relationship to the temporal shape of the signal.
2.6.	Performing inverse z transforms by simple fraction decomposition.
<b>UNIT 3.- Analysis and Characterization of Systems Using the Laplace Transform.</b>	
3.1.	Understanding and handling the concept of transfer function, including amongst other questions its relationship with the frequency response of a circuit, and the calculus, using the Laplace transform, of the output of a systems given its input and its transfer function.
3.2.	Being able to obtain the transfer function of a system from the differential equation characterizing it, and vice-versa.
3.3.	Being able to obtain the transfer function (except for a constant gain factor) from the poles and the zeros of the system, and vice-versa.
3.4.	Proficiently handling the zero-pole plot in order to, amongst other uses, determining the properties of systems that can be represented by a zero-pole plot.
3.5.	Being able to geometrically approximate the frequency response of a system as a function of its zero-pole plot.
3.6.	Solving electric circuits using the Laplace transform.
3.7.	Characterizing two-gate electric circuits (quadripoles).
<b>UNIT 4.- Analysis and Characterization of Systems Using the z Transform.</b>	
4.1.	Understanding and handling the concept of transfer function, including amongst other questions its relationship with the frequency response of a circuit, and the calculus, using the z transform, of the output of a systems given its input and its transfer function.
4.2.	Being able to obtain the transfer function of a system from the difference equation characterizing it, and vice-versa.
4.3.	Being able to obtain the transfer function (except for a constant gain factor) from the poles and the zeros of the system, and vice-versa.
4.4.	Proficiently handling the zero-pole plot in order to, amongst other uses, determining the properties of systems that can be represented by a zero-pole plot.
4.5.	Being able to geometrically approximate the frequency response of a system as a function of its zero-pole plot.
<b>UNIT 5.- Design and Implementation of Continuous-Time Filters.</b>	
5.1.	Understanding and handling the specifications of a continuous-time filter.
5.2.	Understanding the differences between different types of continuous-time filters, and being able to choose the one which best agrees with some given specifications.
5.3.	Designing a filter from its specifications, with several design methods (Butterworth, Chebyshev and elliptic).
5.4.	Being able to generate a passive or active implementation of a filter from its design.
<b>UNIT 6.- Design and Implementation of Discrete-Time Filters.</b>	
6.1.	Understanding and handling the specifications of a discrete-time filter.
6.2.	Obtaining the specifications of a discrete-time filter for continuous-time signal processing from the specification of a continuous-time filter.
6.3.	Understanding the differences between different types of discrete-time filters, and being able to choose the one which best agrees with some given specifications.
6.4.	Designing a filter from its specifications, with several design methods (impulse invariance, bilinear transform, windowing).



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6.5.	Being able to generate an implementation of the filter from its design, analysing its computational cost.
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## 1.12. Course contents

### Summarized program

PART I: The Laplace and Z Transforms.

PART II: Analysis and Characterization of Systems.

PART III: Design and Implementation of Systems.

### Detailed Program

#### **PART I: THE LAPLACE AND Z TRANSFORMS.**

##### **1. The Laplace Transform.**

- 2.1. Introduction.
- 2.2. Definition and interpretation.
- 2.3. Properties of the Region of Convergence (ROC).
- 2.4. Properties of the Laplace Transform.
- 2.5. The inverse Laplace transform.

PRACTICAL SESSION 1: The Laplace Transform.

##### **2. The Z Transform.**

- 2.1. Introduction.
- 2.2. Definition and interpretation.
- 2.3. Properties of the Region of Convergence (ROC).
- 2.4. Properties of the z Transform.
- 2.5. The inverse z transform.

PRACTICAL SESSION 2: The z Transform.

#### **PART II: ANALYSIS AND CHARACTERIZATION OF SYSTEMS.**

##### **3. Analysis and Characterization of Systems Using the Laplace Transform.**

- 3.1. Introduction.
- 3.2. The transfer function.
- 3.3. Systems defined by differential equations.
  - 4.3.1. Form of the transfer function.
  - 4.3.2. Poles, zeros, ROC and system properties.
  - 4.3.3. Pole-zero plot, and frequency response.
- 3.4. Solving electric circuits using the Laplace transform.
- 3.5. Characterization of two-gate circuits (quadripoles).



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PRACTICAL SESSION 3: Analysis and Characterization of Systems Using the Laplace Transform.

#### 4. Analysis and Characterization of Systems Using the Z Transform.

- 4.1. Introduction.
- 4.2. The transfer function.
- 4.3. Systems defined by difference equations.
  - 4.3.1. Form of the transfer function.
  - 4.3.2. Poles, zeros, ROC and system properties.
  - 4.3.3. Pole-zero plot, and frequency response.

PRACTICAL SESSION 3: Analysis and Characterization of Systems Using the Z Transform.

### PART III: DESIGN AND IMPLEMENTATIO OF SYSTEMS.

#### 5. Design and implementation of continuous-time filters.

- 5.1. Introduction.
- 5.2. Specification.
- 5.3. Design of continuous-time filters: Butterworth, Chevyshev and elliptical filters.
- 5.4. Introduction to the implementation of analogic filters.

PRACTICAL SESSION 5: Desing of Butterworth, Chevyshev and elliptic filters.

#### 6. Design and implementation of discrete-time filters.

- 6.1. Introduction.
- 6.2. Specification.
- 6.3. Design of IIR filters by means of bilinear transform and impulse invariance. Design of FIR filters by windowing.
- 6.4. Introduction to the implementation of digital filters.

PRACTICAL SESSION 6: Design of FIR filters by windowing.

## 1.13. Course bibliography

### Bibliography:

Below some texts containing part of the syllabus are listed, classified as basic and complementary bibliography. For the first ones, the parts of the course covered by them are specified.

Basic texts:



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1. Alan V. Oppenheim, Ronald W. Schafer with John R. Buck, “Discrete-time signal processing”, Ed. Prentice-Hall, 2ª edición, 1999. [Covers Unit 2, 4 and 6 completely].
2. Alan V. Oppenheim, Alan S. Willsky y S. Hamid Nawad, “Signals and systems”, Ed. Prentice-Hall, 2ª edición, 1997. [Covers Unit 1 completely, as well as sections 3.1 to 3.3 of Unit 3].
3. James W. Nilsson y Susan A. Riedel, “Circuitos eléctricos”, Ed. Pearson Educación, 6ª edición, 2001. [Covers sections 3.4 and 3.5 of Unit 3].
4. G. C. Temes and J. W. Lapatra, “Introduction to circuit synthesis and design”, Ed. McGraw-Hill, 1ª edición, 1977. [Covers Unit 5].
5. Sigfredo Pagel, “Circuitos y Filtros Radioeléctricos”, Ed. Tórculo Ediciones, 3ª Edición, 2001. [Covers Unit 5 and part of Unit 6, including Matlab examples].
6. R. Schaumann and M. E. Van Valkenburg, “Design of Analog Filters”, Ed. Oxford University Press, 2001. [Covers Unit 5].

#### Complementary texts:

7. Richard C. Dorf y James A. Svoboda, “Introduction to electric circuits”, Ed. Wiley & Sons, 5ª edición, 2001.
8. Francisco López Ferreras, “Análisis de circuitos lineales”, Ed. Ciencia 3, 2ª edición, 1994.
9. David E. Johnson, “Basic electric circuit analysis”, Ed. Prentice-Hall, 5ª edición, 1995.
10. William H. Hayt, Jack E. Kemmerly y Steven M. Durbin, “Engineering circuit análisis”, Ed. McGraw-Hill, 6ª edición, 2002.
11. Roland E. Thomas and Albert J. Rosa, “The Analysis and Design of Linear Circuits”, Ed. John Wiley & Sons, 3ª Edición, 2001.

#### Slides:

As none of the texts cited above covers all the course contents, summary slides will be available for the course, being the texts and chapters in which they are based highlighted for reference and extension.