1. COURSE TITLE

Digital Signal Processing (DSP)

1.1. Code

18482

1.2. Course Area

Signal Processing in Telecommunication

1.3. Course Type

Common to the Telecommunication Branch

1.4. Course Level

Graduate

1.5. Year

3º

1.6. Semester

1º

1.7. Credit allotment

6 ECTS

1.8. Prerequisites

Digital Signal Processing is part of the *Subject 2.3 (Signal Processing in Communications)* of the module of Common Formation of Telecommunication Branch.

This subject is organized as three courses (Communication Theory, Filter Design and Digital Signal Processing) which present from fundamentals to advanced techniques for the design and analysis of signals and systems in the field of Telecommunication engineering.

The course of Digital Signal Processing, apart from requiring certain mathematical base is clearly based on concepts presented in the following subjects: Filter Design, Linear Systems and Probability and Statistics. For this reason it is advisable to have passed these courses before.

In particular, the course requires managing trigonometric functions, complex numbers and polynomials, basic integration and geometric series. From the course of linear systems it will be necessary to handle the characterization of linear time-invariant systems by means of their impulse and frequency response, as well as the Fourier transforms (for both continuous and discrete time) and the concepts of sampling and reconstruction. From the course of Filter Design it will be necessary to have the ability to manage the Laplace and Z Transforms and their relation to the Fourier transforms, transfer functions and block and signal flow diagrams. From the course Probability and Statistics it will be necessary to handle the random variable and descriptive statistics.

1.9. Minimum attendance requirement

Attendance to theory sessions is considered very useful to reach the goals of the course. However, there are no minimum attendance requirements to participate in the continuous evaluation.

Attendance to practice sessions is compulsory. Missing practice sessions will only be allowed due to justified and properly documented reasons, and only to two practice sessions. In that case, the session work should be carried out in the next week, as arranged with the practice professor. Missing more or unjustified sessions will imply failing in the practice part of the course, which implies failing the whole course.

1.10. Faculty data

Add @uam.es to all email addresses below.

Theory:

Dr. Doroteo Torre Toledano (Coordinator)
Departamento de Tecnología Electrónica y de las Comunicaciones
Escuela Politécnica Superior
Room: C-215 Building C – 2nd Floor
Phone: +34 914972217
e-mail: doroteo.torre
Web: http://doroteo.ii.uam.es

Practice:

Dr. Doroteo Torre Toledano (Coordinator)
Departamento de Tecnología Electrónica y de las Comunicaciones
Escuela Politécnica Superior
Room: C-215 Building C – 2nd floor
Phone: +34 914972217
e-mail: doroteo.torre
Web: http://doroteo.ii.uam.es

Dr. Javier González Domínguez
Departamento de Tecnología Electrónica y de las Comunicaciones
Escuela Politécnica Superior
Room: C-213 Building C – 2nd floor
Phone: +34 914977558
e-mail: javier.gonzalez

1.11. Course objectives

Digital Signal Processing (DSP) is a course centered on practical aspects of spectral signal characterization. The course is structured into two parts clearly different parts.

The first part (Themes 1 to 3) is devoted to establish the bases for the temporal and spectral characterization of random signals, finishing with the analysis of the behavior of linear systems with random inputs. In the second part (Themes 4 to 6) is devoted to the Discrete Fourier Transform (DFT) and its fast implementation Fast Fourier Transform (FFT), presenting its practical application in filter implementation and spectral estimation. In spectral estimation the course will analyze more complex cases such as the spectral estimation of time-varying signals with the Short-Time Fourier Transform (STFT) and the spectral analysis of random signals.

Integrated with the theory six practical sessions will be developed, followed by a final practical project.

The competences common to the branch of telecommunication (CO) to acquire with this course are the following:

CO4 Capacity to analyze and specify the fundamental parameters of a communication system.
CO5 Capacity to evaluate the advantages and disadvantages of different technological alternatives for the deployment or implementation of communication systems, from the point of view of the signal space, perturbations and noise, as well as the analog and digital modulation systems.

The goals of this course are:

GENERAL GOALS	
G1	Handle random signals, its characterization and its interaction with linear time-invariant systems.
G2	Be able to understand in depth and manage the Discrete Fourier Transform (DFT) and use it for spectral analysis of stationary and time-varying signals, both determistic and random.
G3	Be able to understand and implement the Fast Fourier Transform (FFT) and use it for spectral analysis and filter implementation using block convolution methods.

SPECIFIC GOALS PER THEME	
THEME 1.- Stochastic Processes: temporal characterization	
1.1.	Understand and manage the concept of stochastic process.
1.2.	Understand and manage the properties of stationarity and Independence of stochastic processes.
1.3.	Understand and manage the correlation functions of the stochastic processes, as well as their properties and computation.
THEME 2.- Stochastic Processes: spectral characterization	
2.1.	Know and manage the power density spectrum and its properties.
2.2.	Be able to compute the power density spectrum from the autocorrelation function.
2.3.	Know and manage the cross power density spectrum and its properties.
2.4.	Be able to compute the cross power density spectrum based on the cross correlation function.
2.5.	Be able to characterize and handle random noises, both white and colored.
THEME 3.- Linear systems with stochastic processes as input	
3.1.	Be able to temporally characterize the output of a linear time-invariant system with random input.
3.2.	Be able to characterize a linear time-invariant system using white noise.
3.3.	Be able to spectrally characterize the output of a linear time-invariant system with random input.
TEMA 4.- The Discrete Fourier Transform (DFT)	
4.1.	Know the Discrete Fourier Transform (DFT), its practical utility and properties.
4.2.	Understand and manage the relationship between the DFT and the Discrete-Time Fourier Transform (DTFT).
4.3.	Be able to obtain a sampling of the DTFT using the DFT, applying if necessary zero padding or temporal overlapping.
4.4.	Know and manage the Discrete Fourier Series (DFS) and its relation with the DFT.
4.5.	Understand and handle the differences and similarities between the linear convolution and the circular convolution, and in particular know under which circumstances they coincide.
4.6.	Be able to use the DFT to implement linear systems with finite impulse response by

	means of block convolution.
4.7.	Know DFT related transforms such as the Discrete Cosine Transform (DCT) as well as its main properties.
TEMA 5.- Efficient Computation of the Discrete Fourier Transform: The Fast Fourier Transform (FFT).	
5.1.	Know and be able to compute the computational cost of a direct DFT implementation.
5.2.	Know and be able to analyze the computational cost of an implementation of the DFT by means of the FFT by decimation in time or frequency.
5.3.	Be able to program the FFT algorithm in an efficient way.
TEMA 6.- Fourier Analysis of Signals using DFT.	
6.1.	Know and understand the basic scheme for spectral analysis using DFT.
6.2.	Know and be able to manage the limitations in frequency resolution imposed by windowing and spectral sampling that implies using the DFT.
6.3.	Know and be able to use and program the Short-Time Fourier Transform (STFT) for the analysis of time varying signals.
6.4.	Understand and be able to manage the limitations in spectral and temporal resolution of the spectral analysis using STFT.
6.5.	Understand and be able to use the periodogram for the spectral analysis of stationary random signals.
6.6.	Understand and be able to use the autocorrelation sequence for the spectral analysis of random signals.

1.12. Course contents

Synthetic Program

PART I: Stochastic Processes.
PART II: DFT, FFT and Spectral Estimation.

Detailed Program

PART I: STOCHASTIC PROCESSES.

1. **Stochastic Processes: temporal characterization.**
    - 1.1. Introduction.
    - 1.2. Concept of stochastic process.
    - 1.3. Stationarity and independence.
    - 1.4. Correlation functions.
    - 1.5. Measurement of correlation functions.

2. **Stochastic Processes: spectral characterization.**
    - 2.1. Introduction.
    - 2.2. Power Spectral Density and its properties.

- 2.3. Relationship between power spectral density and autocorrelation function.
- 2.4. Cross Power Spectral Density and its properties.
- 2.5. Power spectrum for discrete processes and sequences.
- 2.6. White and colored noise.

3. **Linear systems with random inputs.**
   - 3.1. Introduction.
   - 3.2. Response of linear systems with random inputs.
   - 3.3. Evaluation of systems using white noise.
   - 3.4. Spectral characteristics of system response.

PART II: DFT, FFT AND SPECTRAL ESTIMATION.

4. **The Discrete Fourier Transform (DFT).**
   - 4.1. Introduction.
   - 4.2. Representation of periodic sequences: Discrete Fourier Series (DFS).
   - 4.3. Properties of the DFS.
   - 4.4. The Fourier Transform of periodic signals.
   - 4.5. Sampling of the Fourier Transform.
   - 4.6. Representation of finite-length sequences: The Discrete Fourier Transform (DFT).
   - 4.7. Properties of the DFT.
   - 4.8. Computation of the linear convolution with the DFT: block convolution.
   - 4.9. Introduction to the Discrete Cosine Transform (DCT).

5. **Efficient Computation of the Discrete Fourier Transform: The Fast Fourier Transform (FFT).**
   - 5.1. Introduction.
   - 5.2. Direct computation of the DFT.
   - 5.3. FFT by decimation in time.
   - 5.4. FFT by decimation in frequency.

6. **Fourier Analysis of signals using DFT.**
   - 6.1. Introduction.
   - 6.2. Basic scheme for the Fourier analysis of signals using DFT.
   - 6.3. Analysis of sinusoidal signals using DFT.
   - 6.4. The Short-Time Fourier Transform (STFT).
   - 6.5. Examples of Fourier analysis of non-stationary signals.
   - 6.6. Fourier analysis of stationary random signals: the Periodogram.
   - 6.7. Spectral Analysis of random signals.

1.13. Course Bibliography

Bibliography:

There are two textbooks that are followed in the first and second part of the course that are considered basic textbooks. There are also other textbooks that can be used as complementary textbooks.

Basic textbooks:

1. Peyton Z. Peebles Jr., "Probability, Random Variables, and Random Signal Principles", Ed. McGraw Hill Higher Education, 4th revised edition, 2000. [Basic reference for themes 1 to 3].
2. Alan V. Oppenheim, Ronald W. Schafer, "Discrete-time signal processing", Ed. Pearson - Prentice-Hall, 2nd (or 3rd) edition, 1999 (2007). [Basic reference for themes 4 to 6].

Complementary textbooks:

3. Proakis J. G. and Manolakis D. G., "Digital Signal Processing: Principles, Algorithms, and Applications", Ed. Pearson, 4ª Edición, 2006.
4. Haykin, S. "Adaptive Filter Theory", Ed. Prentice-Hall, 4ª Edición, 2001.
5. Alan V. Oppenheim, Alan S. Willsky y S. Hamid Nawad, "Signals and systems", Ed. Prentice-Hall, 2ª edición, 1997.

Slides:

Slides with a summary of the course will be provided.