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# 230474 - TS - Signal Theory

Coordinating unit: 230 - ETSETB - Barcelona School of Telecommunications Engineering
Teaching unit: 739 - TSC - Department of Signal Theory and Communications
Academic year: 2019
Degree: BACHELOR'S DEGREE IN ENGINEERING PHYSICS (Syllabus 2011). (Teaching unit Compulsory)
ECTS credits: 6 Teaching languages: Catalan, Spanish, English

## Teaching staff

Coordinator: Pascual Iserte, Antonio

Others: Rey Micolau, Francesc

## Opening hours

Timetable: To be agreed with the lecturer

## Prior skills

- Fundamental algebra and calculus: complex numbers, matrix algebra, eigen-decomposition, fundamental calculus (limits, derivation, integration, series), multi-variable functions, conditioned optimization (Lagrange multipliers).
- Ordinary differential equations, Laplace transforms, residue calculation for inverse Laplace transform, Fourier series and transforms, convolutions, discrete Fourier transform.
- Probability and statistics: random variables and processes, mean, variance, stationarity.
- Linear circuits analysis: Laplace transform, network function, convolution, stability, sinusoidal steady-state analysis, filters and frequency analysis.

## Degree competences to which the subject contributes

Specific:

1. Understanding and mastering the basic concepts of linear systems, and functions and their transforms in the continuous and discrete domains. Ability to analyze signals with noise, applying the Wiener-Khinchin theorem and calculate the averaged power spectrum. Ability to sample and filter signals.

Generical:

9. ABILITY TO IDENTIFY, FORMULATE, AND SOLVE PHYSICAL ENGINEERING PROBLEMS. Planning and solving physical engineering problems with initiative, making decisions and with creativity. Developing methods of analysis and problem solving in a systematic and creative way.

Transversal:

2. ENTREPRENEURSHIP AND INNOVATION - Level 1. Showing enterprise, acquiring basic knowledge about organizations and becoming familiar with the tools and techniques for generating ideas and managing organizations that make it possible to solve known problems and create opportunities.
3. SUSTAINABILITY AND SOCIAL COMMITMENT - Level 3. Taking social, economic and environmental factors into account in the application of solutions. Undertaking projects that tie in with human development and sustainability.
4. THIRD LANGUAGE. Learning a third language, preferably English, to a degree of oral and written fluency that fits in with the future needs of the graduates of each course.
5. EFFICIENT ORAL AND WRITTEN COMMUNICATION - Level 2. Using strategies for preparing and giving oral presentations. Writing texts and documents whose content is coherent, well structured and free of spelling and grammatical errors.
6. TEAMWORK - Level 2. Contributing to the consolidation of a team by planning targets and working efficiently to favor communication, task assignment and cohesion.
7. EFFECTIVE USE OF INFORMATION RESOURCES - Level 3. Planning and using the information necessary for an

academic assignment (a final thesis, for example) based on a critical appraisal of the information resources used.

8. SELF-DIRECTED LEARNING - Level 3. Applying the knowledge gained in completing a task according to its relevance and importance. Deciding how to carry out a task, the amount of time to be devoted to it and the most suitable information sources.

## Teaching methodology

There will be approximately three theoretical hours, one hour for exercises and one hour in the lab in mean per week. The theoretical lectures are devoted to a careful presentation of the basic concepts and the main results which will be illustrated with some examples. The practical hour is devoted to the solution of a variety of exercises and problems. In the hour in the lab some exercises and simulations to be carried out with a computer are proposed.

## Learning objectives of the subject

- To understand the basic concepts related with signals and systems in the time domain both for the case of continuous time and discrete time.
- To understand and be able to use the main transformations for the case of continuous time (Laplace, Fourier) and discrete time (Z, Fourier, DFT) and their application to signals and frequency response of systems.
- To be able to characterize the A/D and D/A conversion processes.
- To be able to characterize stochastic processes.
- To understand the fundamentals of estimation theory in terms of the characterization of estimators for the two main families: classical and Bayesian estimation.
- To understand the fundamentals of non-parametric and parametric spectral estimation.
- To understand the fundamentals and the main applications of Wiener filtering.

## Study load

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|---|---|---|---|
| Total learning time: 150h | Hours large group: | 52h | 34.67% |
| | Hours small group: | 13h | 8.67% |
| | Self study: | 85h | 56.67% |

## Content

| 1.- SIGNALS AND SYSTEMS IN THE TIME DOMAIN | Learning time: 18h<br>Theory classes: 5h<br>Practical classes: 1h<br>Laboratory classes: 2h<br>Self study : 10h |
|---|---|

Description:

1.1.- Analog and discrete-time signals. Basic signals. Energy and power.
1.2.- Analog and discrete-time systems. Examples (including transformations over the time variable) and properties/classification.
1.3.- Linear time invariant systems:
- 1.3.1.- impulse response and convolution: properties
- 1.3.2.- differential equations for analog systems
- 1.3.3.- finite differences equations for discrete-time systems (FIR/IIR systems)

Related activities:

Theoretical lectures and exercises at class.
One session of 2 hours in the lab.

Specific objectives:

To understand the basic concepts related with signals and systems in the time domain both for the case of continuous time and discrete time.

| 2.- SIGNALS AND SYSTEMS IN TRANSFORM DOMAINS | Learning time: 31h<br>Theory classes: 9h<br>Practical classes: 2h<br>Laboratory classes: 2h<br>Guided activities: 1h<br>Self study : 17h |
|---|---|

Description:

2.1.- Analog signals and systems:
- 2.1.1.- Laplace transform and transfer function
- 2.1.2.- Fourier transform/series and frequency response (analog filters)
- 2.1.3.- examples and properties

2.2.- Discrete-time signals and systems:
- 2.2.1.- Z transform and transfer function
- 2.2.2.- Fourier transform and frequency response (digital filters)
- 2.2.3.- DFT and FFT
- 2.2.4.- examples and properties

Related activities:

Theoretical lectures and exercises at class.
One session of 2 hours in the lab.

Specific objectives:

To understand and be able to use the main transformations for the case of continuous time (Laplace, Fourier) and discrete time (Z, Fourier, DFT) and their application to signals and frequency response of systems.

| 3.- A/D AND D/A CONVERSION | Learning time: 18h<br>Theory classes: 4h<br>Practical classes: 2h<br>Laboratory classes: 2h<br>Self study : 10h |
|---|---|

Description:
3.1.- Sampling and alias generation: antialiasing filter.
3.2.- Quantization noise.
3.3.- Change of the sampling frequency: decimation and interpolation.
3.4.- Signal reconstruction: ideal and zero-order hold (ZOH) interpolators

Related activities:
Theoretical lectures and exercises at class.
One session of 2 hours in the lab.

Specific objectives:
To be able to characterize the A/D and D/A conversion processes.

| 4.- STOCHASTIC PROCESSES - RANDOM SIGNALS | Learning time: 11h<br>Theory classes: 4h<br>Practical classes: 1h<br>Self study : 6h |
|---|---|

Description:
4.1.- Statistical characterization.
4.2.- Strict-sense and wide-sense stationary processes. Cyclo-stationary processes.
4.3.- Ergodicity in mean and correlation.
4.4.- Autocorrelation and power spectral density. Wiener-Khinchin theorem.
4.5.- Filtering of random signals.
4.6.- Gaussian processes.

Related activities:
Theoretical lectures and exercises at class.

Specific objectives:
To be able to characterize stochastic processes.

| 5.- FUNDAMENTALS OF ESTIMATION THEORY | Learning time: 25h<br>Theory classes: 6h<br>Practical classes: 2h<br>Laboratory classes: 2h<br>Guided activities: 1h<br>Self study : 14h |
|---|---|

Description:
5.1.- Introduction to estimation theory:
- 5.1.1.- definition of estimator
- 5.1.2.- quality criteria: bias, variance, mean square error (MSE), consistency
- 5.1.3.- example: estimation of the mean of a process

5.2.- Classical estimation theory:
- 5.2.1.- minimum variance unbiased estimator (MVUE)
- 5.2.2.- efficient estimators: Cramer-Rao bound
- 5.2.3.- maximum likelihood (ML) estimation

5.3.- Bayesian estimation theory:
- 5.3.1.- parameter characterization: prior distribution
- 5.3.2.- Bayesian risk: maximum-a-posteriori (MAP), posterior mean, posterior median estimators

Related activities:
Theoretical lectures and exercises at class.
One session of 2 hours in the lab.

Specific objectives:
To understand the fundamentals of estimation theory in terms of the characterization of estimators for the two main families: classical and Bayesian estimation.

| 6.- SPECTRAL ESTIMATION | Learning time: 24h<br>Theory classes: 6h<br>Practical classes: 2h<br>Laboratory classes: 2h<br>Self study : 14h |
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Description:
6.1.- Non-parametric spectral estimation:
6.1.1.- periodogram: bias (leakage), variance, and consistency
6.1.2.- smoothing the periodogram through windowing (Blackman-Tukey): Bartlett, Hamming, Kaiser, Blackman, etc.
6.1.3.- Bartlett-Welch spectral estimation techniques: average of periodograms
6.1.4.- estimators based on bank of matched filters (Capon)
6.2.- Parametric spectral estimation:
6.2.1.- linear models of processes: AR, MA, ARMA
6.2.2.-Yule-Walker equations

Related activities:
Theoretical lectures and exercises at class.
One session of 2 hours in the lab.

Specific objectives:
To understand the fundamentals of estimation theory in terms of the characterization of estimators for the two main families: classical and Bayesian estimation.

| 7.- OPTIMAL WIENER FILTERING | Learning time: 23h<br>Theory classes: 5h<br>Practical classes: 2h<br>Laboratory classes: 2h<br>Guided activities: 1h<br>Self study : 13h |
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Description:
7.1.- Linear Bayesian estimator of minimum MSE.
7.2.- Wiener filter and Wiener-Hopf equations.
7.3.- Adaptive implementation (steepest descent-SD, least mean square-LMS, normalized LMS-NLMS).
7.4.- Linear predictors. Examples.

Related activities:
Theoretical lectures and exercises at class.
One session of 2 hours in the lab.

Specific objectives:
To understand the fundamentals and the main applications of Wiener filtering.

## Qualification system

The evaluation will be based on the following three items:

- PE: partial exam
- FE: final exam (including all the contents of the course)
- LS: lab sessions

The final score will follow from

Final mark = max { 0.60*FE + 0.25*PE + 0.15*LS , 0.85*FE + 0.15*LS }

Only when the final mark is not passed in the ordinary call, an extraordinary exam (EE) will be carried out including all the contents of the course. In this case, the final mark will be calculated as follows, where it is taken into account that the 15% corresponding to the lab sessions (LS) cannot be re-evaluated:

Final mark = max { 0.60*FE + 0.25*PE + 0.15*LS , 0.85*FE + 0.15*LS , 0.85*EE + 0.15*LS }

## Regulations for carrying out activities

The rules to be applied in the exams will be specified in the calls for the exams.

## Bibliography

### Basic:

Oppenheim, A.V.; Willsky, A.S.; Nawab, S.H. Signals and systems. 2nd ed. Essex: Pearson, 2014. ISBN 9781292025902.

Hayes, M.H. Statistical digital signal processing and modeling. New York: John Wiley, 1996. ISBN 0471594318.

Kay, S.M. Fundamentals of statistical signal processing:vol. 1: estimation theory. Englewood Cliffs: Prentice-Hall, 1993. ISBN 0130422681 (V. 1).

### Complementary:

Papoulis, A. Probability, random variables, and stochastic processes. 4th ed. Boston: Mc-Graw-Hill, 2002. ISBN 0073660116.

Proakis, J.G.; Manolakis, D.G. Digital signal processing. 4th ed. New Jersey: Prentice-Hall International, 2007. ISBN 0131873741.

Haykin, S.; Veen, B.V. Signals and systems. 2nd int. ed. John Wiley & Sons, 2003. ISBN 9780471378518.

Oppenheim, A.V.; Schafer, R.W. Discrete-time signal processing. 3rd ed. Upper Saddle River, NJ: Prentice-Hall, 2010. ISBN 9780131988422.

Scharf, L.L. Statistical signal processing: detection, estimation, and time series analysis. Readig, MA: Addison-Wesley, 1990. ISBN 0201190389.

Manolakis, D.G.; Ingle, V.K.; Kogon, S.M. Statistical and adaptive signal processing: spectral estimation, signal modeling, adaptive filtering, and array processing. Boston: Artech House, 2005. ISBN 9781580536103.