



# Course guide

## 300019 - CSL - Linear Circuits and Systems

**Last modified:** 01/06/2023

**Unit in charge:** Castelldefels School of Telecommunications and Aerospace Engineering  
**Teaching unit:** 739 - TSC - Department of Signal Theory and Communications.

**Degree:** BACHELOR'S DEGREE IN NETWORK ENGINEERING (Syllabus 2009). (Compulsory subject).  
BACHELOR'S DEGREE IN TELECOMMUNICATIONS SYSTEMS ENGINEERING (Syllabus 2009). (Compulsory subject).

**Academic year:** 2023    **ECTS Credits:** 6.0    **Languages:** Catalan, Spanish, English

### LECTURER

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**Coordinating lecturer:** Definit a la infoweb de l'assignatura.

**Others:** Definit a la infoweb de l'assignatura.

### PRIOR SKILLS

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- Basic circuit analysis. Formulation of a system of equations based on the analysis of resistive circuits using KCL (node method) and KVL (mesh method).
- Circuit analysis with operational amplifiers and transformers.
- Operations with matrices. Equations in matrix form using Cramer's rule.
- Operations with complex numbers. Sum and product of complex numbers; rationalisation; inverse, modulus and phase of a complex number.
- Basic laboratory equipment: oscilloscopes, function generators, power supplies and multimeters.
- Basic electronic instruments in a laboratory: breadboards, resistors, coils, capacitors and operational amplifiers.
- Internal functioning of the basic elements of RLC circuits (Ohm's, Faraday's and Ampere's laws). Basics of magnetic coupling.

### REQUIREMENTS

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### DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

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**Specific:**

1. CE 4 TELECOM. Students will acquire an understanding and a command of the basic concepts of linear systems, functions and related transfer functions, electric circuit theory, electronic circuits, the physical principle of semiconductors and logic families, electronic and photonic devices, materials technology and its application to engineering problems. (CIN/352/2009, BOE 20.2.2009)

**General:**

3. EFFICIENT USE OF EQUIPMENT AND INSTRUMENTS - Level 1: Using instruments, equipment and software from the laboratories of general or basic use. Realising experiments and proposed practices and analyzing obtained results.

**Transversal:**

2. 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.

## TEACHING METHODOLOGY

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Thanks to the material prepared by the lecturers (slides, lecture notes, solved exercises, etc.) that is available on the digital campus, students have the tools required to work independently, whether individually or in teams, and can use face-to-face sessions to increase their understanding of concepts and ask questions.

In theory-based lectures (groups of up to 40 students), lecturers combine formal presentations with informal questions that are designed to enhance students' understanding of the basic topics on the course. The course material ensures students' active participation as they are not simply taking notes during class.

In problem-solving sessions (groups of up to 20), students work in groups of up to three on exercises related to the information given during lectures. The lecturer will solve some of the exercises and may give students more exercises to be worked on during self-directed learning hours.

In laboratory sessions (groups of up to 20), students will work in pairs. Each group member will be asked to carry out a background study. On completion of the practicals, the members of the group will write a report or scientific article (one per pair) briefly describing the work undertaken and linking it to the concepts explored in the theory-based sessions and the main conclusions drawn from the practicals.

The directed activities (groups of up to ten) will consist of workshops in which the lecturer will answer any questions that may have come up during students self-directed learning assignments. The lecturer may also set cooperative learning exercises. An example is given below:

Students prepare a topic and give a brief presentation using slides. A different group will be chosen each time and only those above a minimum mark will be asked to participate. At the end of the presentation, the other students will ask their colleagues questions and the lecturer will elaborate further on the concepts presented. The lecturer will then propose exercises and the students who gave the presentation will be the first to help those with questions. The lecturer will then intervene if necessary. Finally, students will take a self-assessment test. The marks of students who give the presentation will vary depending on the average mark of the group.

## LEARNING OBJECTIVES OF THE SUBJECT

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On completion of Linear Circuits and Systems, students will be able to:

- Analyse linear resistive and dynamic circuits and set out and solve (using Cramer's rule) a system of equations in matrix form based on node analysis.
- Describe the following in the Laplace transform: variables ( $v$ ,  $i$ ), laws (Kirchoff's, Ohm's), elements (coils, capacitors, resistors) and basic analogue signals (impulse, step, ramp, exponential, sinusoid, cosinusoid, damped or undamped) for the purposes of analysing dynamic circuits in the Laplace domain. Later on, they will be able to use the inverse Laplace transform to revert signals defined in the Laplace domain back to the time domain.
- Calculate the function of a circuit network with controlled and independent current and voltage sources, dynamic elements, resistors and operational amplifiers in the linear field. Plot the poles and zeros of a linear circuit or system (of order  $n$ ), evaluate the system's stability and identify its free response.
- Design and analyse second-order linear circuits and systems in canonical form and identify levels of damping. Define the oscillation conditions of a linear circuit from its transfer function or express an equivalent network function for interconnected circuits or systems (series, parallel, feedback).
- Obtain an analytical steady-state solution for the response of a linear circuit or system and analyse circuits in the transform domain.
- Represent impedance and admittance of a dipole as a function of frequency.
- Calculate the complex power of a dipole and identify the following: real and dissipated power, reactive power, apparent power and the power factor.
- Define the condition for maximum power transfer in a linear circuit and apply basic impedance matching techniques (L-networks, ideal transformers) to achieve maximum power transfer to load.
- Study signals in the frequency domain using the Fourier transform and Fourier series and apply their main properties.
- Define the concept of signal filtering and identify standard filters according to their frequency response.
- Characterise the frequency response of a circuit and express its amplification or gain as a function of frequency on linear and logarithmic scales (dBs).
- Design elementary first- and second-order filters (low-pass, high-pass, band-pass, band-stop, all-pass) and identify their main parameters: bandwidth, cutoff frequency, gain in the pass band, quality factor.

## STUDY LOAD

Type	Hours	Percentage
Hours medium group	12,0	8.00
Hours small group	14,0	9.33
Guided activities	7,5	5.00
Hours large group	32,5	21.67
Self study	84,0	56.00

**Total learning time:** 150 h

## CONTENTS

### Analysis of Linear Circuit and System Dynamics

**Description:**

In this topic, students acquire the following skills in systematic circuit analysis: formulating and solving equations in matrix form by testing circuits, using the Laplace transform to analyse circuits with dynamic elements (coils, capacitors) and obtaining the transfer functions of linear circuits and systems. Once students have picked up these skills, they go on to analyse the dynamics of first- and second-order circuits (pole-zero plot, stability, types of impulse and step response) and study oscillator design and interconnected linear systems (series, parallel, feedback).

**Related activities:**

- Activity 1: Circuit Dynamics Laboratory
- Activity 2: Circuit Dynamics Test
- Activity 3: Circuit Dynamics Workshop

**Full-or-part-time:** 71h 30m

- Theory classes: 15h
- Practical classes: 8h
- Laboratory classes: 4h
- Guided activities: 2h 30m
- Self study : 42h

### Sinusoidal steady-state circuit analysis, power calculations and impedance matching

**Description:**

In this topic, students focus on the sinusoidal steady-state response and transform domain analysis of circuits. Students also learn to calculate the power input to a dipole and the condition for achieving maximum power transfer to load. Students will develop impedance-matching techniques using matching L-networks of coils and capacitors or ideal transformers.

**Related activities:**

- Activity 4: Laboratory sessions on sinusoidal steady-state circuits
- Activity 5: Sinusoidal steady-state circuits test
- Activity 6: Workshop on sinusoidal steady-state circuits

**Full-or-part-time:** 39h 30m

- Theory classes: 10h
- Practical classes: 4h
- Laboratory classes: 2h
- Guided activities: 2h 30m
- Self study : 21h



### Circuit response to multiple frequencies: analogue filtering

**Description:**

In this topic, students will begin to study analogue filtering. In order to analyse the frequency response of a circuit, students will revise Fourier series and the Fourier transform, which they have previously studied in Mathematics for Telecommunications. Students will work on analysing and designing first- and second-order filters and will become acquainted with basic filter design parameters.

**Related activities:**

Activity 7: Analogue Filtering Laboratory  
Activity 8: Analogue Filtering Workshop  
Activity 9: Laboratory test

**Full-or-part-time:** 39h

Theory classes: 7h 30m  
Laboratory classes: 8h  
Guided activities: 2h 30m  
Self study : 21h

## ACTIVITIES

### CIRCUIT DYNAMICS LABORATORY

**Description:**

Two 2-hour sessions. The practicals will be carried out in pairs.

Over the two sessions, students will work as they do for the background study or laboratory practicals.

- Analysis and characterisation of a circuit's transfer function using simulation software.
- Implementation, measurement and characterisation of the dynamics of an active (Sallen-Key) circuit based on an operational amplifier, resistors and capacitors.
- Implementation of a Colpitts oscillator.

**Specific objectives:**

On completion of the practical, students will be able to:

- Use simulation software to characterise the transfer function of linear circuits and systems, analyse their dynamics, discuss the stability of a circuit and interpret its impulse and step response.
- Use basic laboratory instruments: oscilloscopes, power supplies, function generators and multimeters.
- Apply the laboratory skills needed to identify dynamic first- and second-order circuits and design and analyse the performance of basic circuits.
- Implement and characterise a Colpitts oscillator.
- Present a synthesis and critical analysis on the work carried out in the laboratory in the form of a report or article.

**Material:**

Students must bring their laboratory kits.

**Delivery:**

Attendance is compulsory. Students' practical laboratory skills will be assessed in view of:

- Attendance and performance
- Individual background study
- The report or article on the practical to be undertaken in pairs

**Full-or-part-time:** 12h

Laboratory classes: 4h  
Self study: 8h



## CIRCUIT DYNAMICS TEST

### Description:

Students will take a test to demonstrate the knowledge acquired during theory-based lectures, problem-solving sessions and laboratory practicals.

### Specific objectives:

The test is designed to evaluate the attainment of students, who should, at this point in the course, be able to:

- Analyse linear resistive and dynamic circuits and set out and solve (using Cramer's rule) a system of equations in matrix form based on node analysis.
- Explain the uses of the Laplace transform and apply it and its properties.
- Describe the following in the Laplace transform: variables ( $v$ ,  $i$ ), laws (Kirchoff's, Ohm's), elements (coils, capacitors, resistors) and basic analogue signals (impulse, step, ramp, exponential, sinusoid, cosinusoid, damped or undamped) for the purposes of analysing dynamic circuits in the Laplace domain.
- Understand the concepts of admittance and impedance, calculate admittance and impedance values of basic circuit elements and formulate equations for equivalent admittance and impedance of circuits containing dynamic elements.
- Use the inverse Laplace transform to revert signals obtained in the Laplace domain back to the time domain in order to obtain the time response.
- Define the concepts of network function and transfer function, and study and interpret their properties.
- Calculate the function of a circuit network with controlled and independent current and voltage sources, dynamic elements, resistors and operational amplifiers in the linear field.
- Identify and parametrise standard time responses: free, forced, transient and steady-state.
- Plot the poles and zeros of a linear circuit or system (of order  $n$ ) and evaluate the system's stability.
- Draw and obtain an analytical solution for the time responses of a second-order linear circuit or system from its pole-zero plot.

### Delivery:

The test counts for 15% of the final mark.

### Full-or-part-time: 1h

Practical classes: 1h

## CIRCUIT DYNAMICS WORKSHOP

### Description:

The directed activity will be carried out in groups of ten students and will involve working on complementary activities (presentations and additional assignments) and solving queries related to problems in circuit dynamics.

Students will receive personal guidance on queries regarding their self-directed learning assignments, which will help them to prepare for their mid-semester examination.

### Specific objectives:

Students receive feedback on their self-directed learning assignments, such as presentations on a complementary subject, class exercises and the practicals report/article.

### Material:

The lecturer will provide support over the course of the session.

### Full-or-part-time: 7h 30m

Guided activities: 2h 30m

Self study: 5h



## SINUSOIDAL STEADY-STATE CIRCUITS LABORATORY

### Description:

One 2-hour session. The practicals will be carried out in pairs.

Laboratory work will involve measuring and characterising amplification curves and phase shifts in RLC circuits in the sinusoidal steady state.

### Specific objectives:

On completion of the practical, students will be able to:

- Use basic laboratory instrumentation: oscilloscopes, power supplies, function generators and multimeters.
- Apply the necessary laboratory skills to perform amplification measurements and phase shifts in RLC circuits.
- Present a synthesis and critical analysis on the work carried out in the laboratory in the form of a report or article.

### Material:

Students must bring their laboratory kits.

### Delivery:

Attendance is compulsory. Students' practical laboratory skills will be assessed in view of:

- Attendance and performance
- Individual background study
- The report or article on the practical to be undertaken in pairs

**Full-or-part-time:** 6h

Laboratory classes: 2h

Self study: 4h

## SINUSOIDAL STEADY-STATE CIRCUITS TEST.

### Description:

Students will take a test to demonstrate the knowledge acquired during theory-based lectures, problem-solving sessions and laboratory practicals.

### Specific objectives:

The test is designed to evaluate the attainment of students, who should, at this point in the course, be able to:

- Analyse linear circuits in the transform domain. Find voltage and current phasors at any point in the circuit and then the corresponding time waveform associated with the phasor.
- Calculate equivalent impedances and the Thévenin equivalent of the source.
- Analyse the asymptotic behaviour of complex impedance and admittance as a function of frequency.
- Calculate the complex power of a dipole and identify the following: real power, reactive power, apparent power and the power factor.
- Define the condition for maximum power to load and calculate the maximum power transfer.
- Design impedance matching networks from L-networks, using coils and capacitors, or from the ideal transformer.

### Delivery:

The test counts for 15% of the final mark

**Full-or-part-time:** 1h

Practical classes: 1h



## WORKSHOP ON SINUSOIDAL STEADY-STATE CIRCUITS.

### Description:

The directed activity will be carried out in groups of ten students and will involve working on complementary activities (presentations and additional assignments) and solving queries related to problems in sinusoidal steady-state circuits and power calculations.

Students will receive personal guidance on queries regarding their self-directed learning assignments, which will help them to prepare for their mid-semester examination.

### Specific objectives:

Students receive feedback on self-directed learning assignments such as class exercises and the practicals report/article.

### Material:

The lecturer will provide support over the course of the session.

**Full-or-part-time:** 7h 30m

Guided activities: 2h 30m

Self study: 5h

## ANALOGUE FILTERING LABORATORY

### Description:

Three 2-hour sessions. The practicals will be carried out in pairs.

Lesson 1: Characterisation.

- Measurement and characterisation of first- and second-order analogue filters.

Lesson 2: Simulation.

- Design of analogue filters and evaluation of their performance using simulation software.

Lesson 3: Implementation.

- Implementation of the analogue filters designed using simulation software.

### Specific objectives:

On completion of the practical, students will be able to:

- Use simulation software to design and characterise analogue filters.
- Use basic laboratory instruments: oscilloscopes, power supplies, function generators and multimeters.
- Apply the laboratory skills needed to implement and characterise first- and second-order analogue filters.
- Present a synthesis and critical analysis on the work carried out in the laboratory in the form of a report or article.

### Material:

Students must bring their laboratory kits.

### Delivery:

Attendance is compulsory. Students' practical laboratory skills will be assessed in view of:

- Attendance and performance
- Individual background study
- The report or article on the practical to be undertaken in pairs

**Full-or-part-time:** 18h

Laboratory classes: 6h

Self study: 12h



### ANALOGUE FILTERING WORKSHOP

**Description:**

The directed activity will be carried out in groups of ten students and will involve working on complementary activities (presentations and additional assignments) and solving queries related to analogue filtering problems. Students will receive personal guidance on queries regarding their self-directed learning assignments, which will help them to prepare for their mid-semester examination.

**Specific objectives:**

Students receive feedback on self-directed learning assignments such as class exercises and the practicals report/article.

**Material:**

The lecturer will provide support over the course of the session.

**Full-or-part-time:** 7h 30m

Guided activities: 2h 30m

Self study: 5h

### LABORATORY TEST

**Description:**

Students will be assessed according to the knowledge and skills acquired during the laboratory sessions. The laboratory test accounts for 10% of the final mark for Linear Circuits and Systems.

**Specific objectives:**

Students must demonstrate that they have achieved the skills needed to carry out a laboratory assembly and to measure it and characterise it using the basic instrumentation of previous practicals.

**Material:**

Students must bring their laboratory kits.

**Full-or-part-time:** 6h

Laboratory classes: 2h

Self study: 4h

## GRADING SYSTEM

- 50% Examinations: mid-semester (30%) and final (30%)
- 30% Class assignments: assignments and/or tests
- 10% Final laboratory examination
- 10% Laboratory work (practical laboratory skills)

## EXAMINATION RULES.

Attendance at practicals, background study and the submission of reports/articles are compulsory.

## BIBLIOGRAPHY

**Basic:**

- Thomas, Roland E.; Rosa, Albert J.; Toussaint, Gregory J. The Analysis and design of linear circuits. 6th ed. Hoboken, NJ [etc.]: John Wiley & Sons, 2009. ISBN 9780470383308.
- Bertran Albertí, Eduard; Montoro López, Gabriel. Circuitos y sistemas lineales : curso de laboratorio [on line]. Barcelona: Edicions UPC, 2000 [Consultation: 15/04/2020]. Available on: <http://hdl.handle.net/2099.3/36416>. ISBN 848301372X.



## RESOURCES

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### Computer material:

- Software: FilterPro (Texas Instruments)
- Software: Scilab