# Course guide
# 230922 - CIAF - High Frequency Circuits

**Last modified:** 06/06/2024

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

**Degree:** BACHELOR'S DEGREE IN ELECTRONIC ENGINEERING AND TELECOMMUNICATION (Syllabus 2018). (Compulsory subject).

**Academic year:** 2024 **ECTS Credits:** 6.0 **Languages:** Catalan, Spanish, English

## LECTURER

**Coordinating lecturer:** JORDI JOAN MALLORQUI FRANQUET

**Others:** Primer quadrimestre:
JORDI JOAN MALLORQUI FRANQUET - 11, 12, 13

## PRIOR SKILLS

Mathematics: phasors, operations with complex numbers, complex exponentials, basic matrix algebra (determinant, matrix by vector product), solving systems of linear equations, logarithmic relations (dB and Nepers).

Physics: basic electromagnetism, Maxwell's equations (just existence and their intuitive interpretation).

Circuit Theory: Circuit Elements (R, L, C), Basic Circuit Analysis (Ohm's Law, Kirchoff's Laws), power calculations in complex impedances. Systematic analysis of networks: matrix characterization.

Radiation and Propagation: concepts of energy and power, sinusoidal steady-state, transmission lines, propagation in transmission lines, Smith chart, impedance matching, attenuation, waveguides, scattering, antenna concept.

## DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

**Specific:**
CE9. (ENG) GEELEC: Capacitat d'analitzar i especificar els paràmetres fonamentals d'un sistema de comunicacions. (Mòdul comú a la branca de telecomunicació).
CE13. (ENG) GREELEC: Capacitat per comprendre els mecanismes de propagació i transmissió d'ones electromagnètiques i acústiques, i els corresponents dispositius emissors i receptots. (Mòdul comú a la branca de telecomunicació).
CE10. (ENG) GEELEC: Capacitat per avaluar els avantatges i inconvenients de diferents alternatives tecnològiques de desplegament o implementació de sistemes de comunicacions, des del punt de vista de l'espai del senyal, les perturbacions i el soroll i els sistemes de modulació analògica i digital. (Mòdul comú a la branca de telecomunicació).
CE22. (ENG) GREELEC: Capacitat per a seleccionar circuits i dispositiu electrònics per a la transmissió, l'encaminament o enrutament i els terminals, tant en entorn fixs com mòbils. (Mòdul de tecnologia específica - Sistemes Electrònics).
CE28. (ENG) GREELEC: Capacitat per especificar i utilitzar instrumentació electrònica i sistemes de mesura. (Mòdul de tecnologia específica- Sistemes electrònics).

**Transversal:**
CT5. (ENG) GREELEC: ÚS SOLVENT DELS RECURSOS DE LA INFORMACIÓ. Gestionar l'adquisició, l'estructuració, l'anàlisi i la visualització de dades i informació en l'àmbit de l'especialitat i valorar de forma crítica els resultats d'aquesta gestió.

## TEACHING METHODOLOGY

The subject will be developed through a face-to-face combination of expository classes, application classes and laboratory classes. In all of them, the student's participation will be maximized in such a way as to avoid, even in the expository ones, having a spectator role. In the laboratory practices, the student will be encouraged to use professional microwave instrumentation and be able to develop a critical spirit with its use, measuring different types of devices.

To this end, individual work (non-face-to-face) will be promoted, which in some cases will allow them to prepare the content of the expository and application classes in advance, and, above all, to consolidate knowledge through individual work. This individual work will consist of solving type problems that cover the different aspects of the syllabus, design and simulation of high-frequency circuits using specific software, and preparation of laboratory practices.

## LEARNING OBJECTIVES OF THE SUBJECT

The student will learn the basic techniques of analysis, design and measurement of microwave circuits, both active and passive, and will learn about the different technologies used in this frequency range.

In the course, the general descriptions of the application of the different circuits are prioritized over the mathematical demonstrations, showing a functional vision of them. However, the basic knowledge is provided to the student so that, despite not having seen these demonstrations, he is able to follow them without excessive difficulties in any of the bibliographical references.

Much importance will be given to the applicability of the subject, so the theoretical classes will be put into practice, first in problem sessions and, later, through microwave circuit design and simulation software tools and laboratory sessions with instrumentation.

## STUDY LOAD

| Type | Hours | Percentage |
|---|---|---|
| Hours large group | 52,0 | 34.67 |
| Hours small group | 13,0 | 8.67 |
| Self study | 85,0 | 56.67 |

**Total learning time:** 150 h

## CONTENTS

### 1. Transmission Lines review

**Description:**
Transmission line theory bridges the gap between field analysis and basic circuit theory. The wave propagation in transmission lines can be approached from an extension of circuit theory or from the Maxwell’s equations. Both approaches are presented, but the latter only under an intuitive point of view to be able to understand the physics associated with transmission lines.
a. Field analysis of a transmission line with Maxwell’s equations.
b. The lumped-element circuit model for a transmission line
c. The telegrapher equations.
d. Propagation constant, impedance and power flow in a transmission line.
e. The terminated transmission line and reflection coefficient. Reflection coefficient and total impedance along the transmission line. Stationary waves.
f. Generator and load mismatches. Generator available power.
g. Lossy transmission line: losses in conductors and dielectrics.

**Full-or-part-time:** 5h 40m
Theory classes: 1h 30m
Guided activities: 1h
Self study : 3h 10m

### 2. Planar lines

**Description:**
Planar transmission lines are transmission lines with conductors and dielectric (insulating) strips, that are flat. They are used to interconnect components on printed circuits and integrated circuits working at microwave frequencies because the planar type fits in well with the manufacturing methods for these components. The geometry of the line can be precisely controlled so that its electrical behaviour and is highly predictable.
a. Propagation modes: TEM, quasi-TEM, transverse modes and longitudinal-section modes
b. Dispersion in transmission lines
c. Microstrip, stripline, coplanar, slotline, finline, etc. lines.
d. Analysis and synthesis mathematical equations.
d. Transitions and distortions in microstrip lines (corners, connections, holes, …).
e. Substrates and conductors for planar lines.

**Full-or-part-time:** 6h 50m
Theory classes: 2h
Guided activities: 1h
Self study : 3h 50m

### 3. Smith Chart and Impedance matching

**Description:**
The Smith Chart is a graphical aid useful for solving transmission line problems and represent the frequency behaviour of circuits. It represents impedances in terms of reflection coefficients.
a. The Smith chart derivation: polar plot of the reflection coefficient and constant resistance/conductance and reactance/susceptance circumferences.
b. Usage of the Smith chart as transmission line calculator.
c. Impedance matching circuits for maximum power delivery: single stub tuning, quarter-wave transformer and L networks.

**Full-or-part-time:** 9h 10m
Theory classes: 2h 30m
Guided activities: 1h 30m
Self study : 5h 10m

### 4. Matrix representation for high frequency circuits

**Description:**
The electrical behaviour of a network in a wide range of frequencies can be fully characterized as a matrix. This representation is extremely useful to determine the behaviour of a circuit under different conditions of sources and loads without needing to know its internal structure.
a. Impedance (Z) and admittance (Y) matrices and properties.
b. Scattering (S) matrix and properties.
c. Transmission (ABCD) matrix and properties.
d. Conversion between two-port networks parameters.

**Full-or-part-time:** 6h 50m
Theory classes: 2h
Guided activities: 1h
Self study : 3h 50m

### 5. Microwaves passive circuits

**Description:**
Common microwave circuits and their common applications are presented.
a. Two-port networks.
i. Basic properties: input and output reflections coefficients, transmission coefficients, power gains, return loss and insertion loss.
ii. Attenuators and applications.
iii. Filters and applications.
b. Three-port networks.
i. Basic properties of dividers.
ii. Resistive power divider and applications.
iii. Wilkinson divider and applications.
iv. Circulators and applications.
c. Four-port networks.
i. Basic properties.
ii. 90º and 180º hybrids and applications.
iii. Directional coupler and applications.
d. Commercial circuits catalogues.

**Full-or-part-time:** 45h
Theory classes: 14h
Guided activities: 5h
Self study : 26h

### 6. Active microwave circuits

**Description:**
Amplification is one of the most basic and prevalent microwave circuit functions. The design techniques for transistors-based amplifiers are presented. Oscillators are also a key element on any microwave system.
a. Dynamic range and sources of noise in microwaves systems.
i. Dynamic range of a realistic amplifier.
ii. Sources of noise.
iii. Noise power, equivalent noise temperature and noise factor
iv. Noise figure of a cascade system. Friis formula.
b. Detectors and mixers
c. Microwave amplifiers.
i. Microwave transistor characteristics.
ii. Amplifier gain and stability
iii. One-stage amplifier design.
1. Design for maximum gain (conjugate matching).
2. Constant gain circles and design for specific gain.
3. Constant noise figure circles and design for low noise.
f. Oscillators design
i. One-port negative resistance oscillator.
ii. Transistor oscillators.

**Full-or-part-time:** 31h 10m
Theory classes: 10h 30m
Guided activities: 3h 30m
Self study : 17h 10m

### 7. Hybrid and monolythic circuits

**Description:**
The basic characteristics and application fields of hybrid and monolythic circuits are presented. Monolithic and hybrid microwave integrated circuits are two types of components that provide diverse functions for high frequency microwave systems. Monolithic microwave integrated circuits (MMICs) provide greater advantages at high frequencies, as they are built on semiconductors other than silicon. Advanced RF products make use of microwave monolithic integrated circuits (MMICs) to provide standard RF capabilities in standardized packages. The other common type of RF component is a hybrid microwave integrated circuit (HMIC). Both monolithic and hybrid microwave integrated circuits have their place in today's RF systems, but they provide different capabilities and functionalities.

**Full-or-part-time:** 3h
Theory classes: 1h
Guided activities: 0h 30m
Self study : 1h 30m

### 8. CAD Tools for high frequency circuits simulations and design.

**Description:**
The working principles and usage of CAD tools for circuit analysis and design will be presented.
a. Signal flow charts and its application to circuit analysis.
b. QUCS CAD tool is an integrated circuit simulator that allows to setup a circuit with a graphical user interface (GUI) and simulate the large-signal, small-signal and noise behaviour of the circuit. After that simulation has finished the simulation results can be viewed. This tool will be used to simulate all circuits presented along the course and for solving different assignments.

**Full-or-part-time:** 5h 40m
Theory classes: 2h
Laboratory classes: 1h
Self study : 2h 40m

### 9. Basic microwaves instruments.

**Description:**
The basic principles of the microwave instruments usually available in a laboratory are presented, highlighting their main characteristics, limitations, calibration and usage.
a. Spectrum Analyzer measures the magnitude of an input signal versus frequency within the full frequency range of the instrument. The primary use is to measure the power of the spectrum of known and unknown signals.
b. Vector Network Analyzer is an instrument that measures the network parameters of electrical networks, commonly measure s–parameters. Network analyzers are often used to characterize two-port networks such as amplifiers and filters, but they can be used on networks with an arbitrary number of ports.
b. Noise Figure meter is an instrument for measuring the noise figure of an amplifier, mixer, or similar device.

**Full-or-part-time:** 3h
Theory classes: 2h
Self study : 1h

## GRADING SYSTEM

Continuous assessment (40%):
- Controls (15%)
- Computer and laboratory practices (25%)
Final exam (60%)

Practices are mandatory and not re-evaluable.

## BIBLIOGRAPHY

**Basic:**
- Barlabé Dalmau, A.; Muñoz Porcar, C. La Carta de Smith: aplicacions. 1a ed. Aula Politècnica. Barcelona: Edicions UPC, 2001. ISBN 8483015056.
- Pozar, D.M. Microwave engineering [on line]. 4th ed. Hoboken: Wiley, 2012 [Consultation: 09/04/2021]. Available on: https://ebookcentral.proquest.com/lib/upcatalunya-ebooks/detail.action?docID=2064708. ISBN 9780470631553.
- Bará Temes, J. Circuitos de microondas con líneas de transmisión [on line]. Barcelona: Edicions UPC, 1994 [Consultation: 10/07/2019]. Available on: http://hdl.handle.net/2099.3/36161. ISBN 9788489636552.