The American University in Cairo

CENTER OF NANOELECTRONICS & DEVICES

CND 203
RF CIRCUIT DESIGN
2023

Course Description

This course aims to develop a comprehensive understanding of RF design circuits concepts, including impedance matching, signal propagation, transmission lines, noise analysis and minimization as well as the behavior of RF circuits at different frequencies. One of the goals is to enhance the capability of the design and integration of modern RF circuits blocks including LNAs, mixers, antennae, filters, voltage-controlled oscillators, …etc. Also, students will gain hands on experience on RF circuit design, simulation and optimization using commercial simulation tools.

Contact Hours

Credit Hours	Lecture Hours	Lab Hours	Student work	Total
6	24 (1.25x2)/week	21 (3x1)/week	48	93

Prerequisites

Introduction to Analog Electronics

Learning Outcomes

After successful completion of this course, the student will be able to:

1. Define the wireless system design aspects and RF system specifications.
2. Design and simulate Low noise amplifiers, Mixers, filters, oscillators and get an overview of system integration.
3. Understand the relationship and limitations of circuit topology and device characteristics to achieve competitive specifications.
4. Understand the practical challenges and considerations in high frequency circuits design and how this impacts the design techniques.
5. Use modern advanced CAD tools to design, simulate, and create layout of RFIC.

Course Materials

Textbook:

- Behzad Razavi, RF Microelectronics, 2nd Edition, Pearson
- Pozar, D. M. (2011). *Microwave Engineering.* Wiley.

References:

- Tony Chan Carusone, David Johns, Kenneth Martin, analog Integrated Circuits, 5th Edition, Wiley.
- Matthaei, G. L., Young, L., & Jones, E. M. T. (1980). *Microwave Filters, Impedance-Matching Networks, and Coupling Structures.* Artech House.
- Gonzalez, G. (2017). *Microwave Transistor Amplifiers: Analysis and Design.* Prentice Hall.
- Hong, J., & Lancaster, M. (2001). *Microstrip Filters for RF/Microwave Applications.* Wiley.
- I.C. Hunter, Theory and Design of Microwave Filters, London: IEE Press, 2001.
- R. J. Cameron, C. M. Kudsia, and R. R. Mansour, Microwave Filters for Communication Systems, Hoboken, New Jersey, John Wiley & Sins, 2007
- Constantine A. Balanis, *Antenna Theory and Analysis*. 4th Edition , Wiley
- Thomas H. Lee, The design of CMOS radio-frequency integrated circuits, 2nd Edition. Cambridge: Cambridge University Press.
- Material derived from the IEEE Journal, Transactions, and the International Solid-state Circuits Conference (ISSCC) proceedings.

CAD Tools:

- Cadence Virtuoso (Schematic Editor for simulating lumped circuits elements and transistor-level circuits, Layout Editor & EMX for simulating the layout view of passive elements and structures).
- Suitera for simulating passivise circuit elements.
- CST for simulating passive microwave components, structures, and microwave antennas.

Course Project: By the end of this course the students are required to deliver a complete project (chosen from variety of proposals) assigned by the industry experts and university professors instructors.

Course Topics and Schedule

Week	Lecture	Lab
1	**Introduction to RF Circuits** ➢ Overview of RF frequency bands ➢ Importance of RF in communication systems ➢ Evolution of personal communication systems ➢ Challenges in high frequency design (coupling, radiation, parasitic, EM simulation) ➢ Challenges in passive design in high frequencies	Lab_1: Introduction to EM Simulation Tools using a Simple Spiral Inductor Model.

	➢ Basic Concepts in RF design	
2	**Communication Concepts RAZAVI CH.3** ➢ Analog Modulation (AM, FM, PM) ➢ Digital modulation (ASK, FSK, PSK, GMSK, GFSK, QAM) ➢ Multiple Access Techniques (FDMA, TDMA, CDMA, Hybrid FDMA and TDMA) ➢ Wireless Standards (GSM, IS-95 CDMA, WCMDA, LTE (4G), 5G)	Lab_2: Introduce Suitera tool on a spiral inductor & use as sub-circuit in Virtuoso to simulate active circuit.
3	**Transmission Lines and Smith Chart** ➢ Fundamentals of transmission lines ➢ Distributed impedance ➢ Impedance invertors ➢ Impedance matching techniques ➢ Introduction to the Smith Chart ➢ Quarter Wave Transformer ➢ Transmission line as a resonator ➢ Matching and maximum power transfer ➢ S-parameters	Lab_3: Transmission Lines
4	**RF Passive Components** ➢ **Inductors** - Basic structure and inductor geometries - Inductance equations and parasitic capacitance - Self-resonant frequency of an inductor - Inductor modelling ➢ **Capacitors** - MOS Capacitors - Metal insulator metal capacitors (MIM Cap) Metal plate capacitor Finger Capacitor ➢ **Resistors** - Film Resistors - Diffused Resistors ➢ **Transmission Lines Suitable T-Lines for integration** - Microstrip line - Coplanar lines - Suspended Stripline	Lab_4: Investigate Inductor design including optimization. EM simulation of inductor in high frequencies using Suitera.
5	**Low Noise Amplifiers** ➢ General Considerations ➢ The Input Matching Problem ➢ LNA Configurations ➢ Gain Switching ➢ Band Switching	Lab_5: Testing R, L, C in High Frequencies and Simulating an RLC 2nd Order Filter

	➢ Differential LNAs	
6	**RF Filters and Matching Networks** ➢ Filter types ➢ Filtering Functions ➢ Filter approximation techniques ➢ Low frequency prototypes (ladder network, impedance invertors, coupled resonator filters, Transversal coupling matrix model (Eigen mode model)) ➢ The RF filter design problem ➢ Filter parameter extraction and optimization techniques ➢ Filter design example	Lab_6: Design and simulate full LNA - we use transistor level schematic.
7	**RF Mixers** ➢ Principles of RF mixing ➢ General considerations - Performance parameters - Mixer noise figure - Single balanced and double balanced mixers ➢ Downconversion mixers ➢ Upconversion mixers ➢ Improved Mixer Topologies	Lab_7: Design of a coupled line bandpass filter on microstrip line
8	**Lecture 8: RF Oscillators** ➢ Basic Principles ➢ Cross Coupled Oscillators ➢ Voltage Controlled Oscillators ➢ VCOs with Wide Tuning Range ➢ Phase Noise ➢ Design Procedure ➢ Quadrature Oscillators	Lab_8: Design of a Cross-Coupled LC Oscillator using EMX
9	**Lecture 9:Antenna and Arrays** ➢ Basic radiation mechanism ➢ Antenna types ➢ Antenna parameters ➢ Printed antennas ➢ Antenna noise temperature ➢ Antenna measurements ➢ Antenna Arrays ➢ Beam Steering ➢ Phased Arrays	Lab_9: Design of a Cross-Coupled LC Oscillator using EMX
10	**Lecture 10: Receiver Design Example** ➢ System Level Considerations ➢ Receiver Design - LNA - Mixer - AGC	Lab_10: Mixer Design