EE 411 – RF Integrated Circuits Design
Fall-2021

Instructor: Prof. Dr. Yaşar Gürbüz
yasar@sabanciuniv.edu
Room# 1044 (MDBF)
Phone# 9533
https://sabanciuniv.zoom.us/j/2554580251
https://sabanciuniv.zoom.us/my/yasar.gurbuz
Meeting ID: 255 458 0251

TA: Tahsin Alper Özkan
alper.ozkan@sabanciuniv.edu

Ali Bahadır Özdöl
alibahadir@sabanciuniv.edu

RF Integrated Circuits - 10576 - EE 411 - 0

Scheduled Meeting Times
In-Class 10:40 am - 12:30 pm M Fac.of Arts and Social Sci. 1102
In-Class 8:40 am - 9:30 am R Fac. of Engin. and Nat. Sci. G032

RF Integrated Circuits Lab. - 10577 - EE 411L - A1

Scheduled Meeting Times
Class 2:40 pm - 4:30 pm MSchool of Management G060
In-class

- **Textbooks:** RF Microelectronics (2nd Edition), *Behzad Razavi* *(Required)*
- The Design of CMOS Radio-Frequency Integrated Circuits, Thomas H. Lee **(Strongly Suggested)**
- Radio Frequency Integrated Circuit Design, J. W.M. Rogers and C. Plett **[Suggested]**

Prerequisite: Analog Integrated Circuit Design and Intro. to RF

Office Hour: 13:40 – 14:30 M (Instructor)
Office Hour: 17:40 – 18:30 R (TA)

It would be more convenient if you could send us email when coming at any time other than these hours.

Course Outcomes:
A student who succesfully fulfills the course requirements will be able to demonstrate:

1) To understand the concept of analog and RF integrated circuits technology, devices, components, using CMOS and SiGe BiCMOS technology, and their RF- models.
2) To understand fundamental design parameters of RF integrated circuits such as S-parameters, nonlinearity, sensitivity, efficiency, noise figure, input, output dynamic ranges etc.
3) To design matching and impedance transformation networks using in integrated circuits and components.
4) To understand fundamentals of the following RF integrated devices, circuits and systems: Low Noise Amplifiers, Mixers, Oscillators, Frequency Synthesizers, Power Amplifiers, Phase Shifters, Attenuators, Switch, Filters, etc.
5) To be able to analyze, design and simulate integrated RF circuits as such.
6) To be able to use and implement RF integrated circuits design and simulation tools such as ADS, Cadence Spectra, MOMENTUM.
7) To be able to understand RF integrated system specifications and breakdown these specs to building block and circuit levels.
8) To be able to measure and characterize RF integrated components and circuits.

Objectives:

1) To understand the concept of RF integrated circuits
2) To analyze RF circuit building blocks building blocks (through lectures, homework and recitations)
3) To design these RF circuit building blocks (through lectures, homework and recitations.).
4) To design, simulate and optimize RF circuits with the aid of Cadence tools (through recit).
5) To design spiral inductors and transmission lines with the aid of SONNET tools (through recit).
6) To practice layout techniques in Cadence design environment (through recit).
7) To understand applications of RF circuits.

Summary of course content;

- Overview of RF integrated circuits technology, III-V, CMOS, SiGe BiCMOS tech.
- RF and microwave SiGe BiCMOS transistor technologies and their RF-Models
- Fundamental design parameters of RF integrated circuits such as S-parameters, nonlinearity, sensitivity, efficiency, noise figure, input, output dynamic ranges etc.
- Matching and impedance transformation networks

- Detailed examination of each of the blocks in the transceiver architectures: Low Noise Amplifiers, Mixers, Oscillators, Frequency Synthesizers, and Power Amplifiers, Phase Shifters, Attenuators, Switches, etc.
- Theoretical and computer-aided analysis,
- Simulation and design of RF integrated circuits,
- RF integrated system specifications and breakdown these specs into building block and circuit levels.

Seminar

There will be two major projects in this course; a seminar talk that you will give on a topic you have researched, and a course project (discussed under Project). The seminar will be spread out in throughout the course. Please plan your schedule so that you do not end up being swamped at the end of the course.
Points to take note of:

- Your talk should last for at least 40 minutes.
- Your seminar will be a review of the state of the art of one topic. E.g.:
    - Future of RF CMOS and BiCMOS fabrication
    - Future silicon processes for RF Applications
    - Integration of microwave analog and digital systems
    - 5G Front End Challenges
    - Performance enhancement for varactors, high Q, wider tuning range
    - Micromaching for silicon RF circuits
    - Substrate noise for RF Applications
    - Device crosstalk in silicon for RF Applications
    - RF MEMS for high speed systems
    - System-on-chip for RF Systems
    - You can also suggest topics, …
- The topics can be any of the "theoretical" concepts that are to be covered in class
- Your topic should not be on a specific circuits like amplifiers, mixers, etc., as those will be used for the project
- The material covered in the seminar presentations is fair game for latter assignment questions.
- It is recommended that you prepare some slides beforehand. Please email your slides to the rest of the class, incl. us, a couple of days before your scheduled talk.
- You will be graded on your technical content and your presentation technique.
- All other students should come up with at *least* two questions for the presenter by the end of the talk as a question-and-answer session will follow the presentation. Everyone will be graded on their participation in the discussion.

Projects:

There will be several numbers of design projects about RF Integrated Circuits topics like LNA, PA. These projects will be conducted by using cadence, ADS,sonnet etc.

The course project will be the second major task in EE 633/EE 411 (along with the seminar presentation). Your project should involve a literature review of the topic chosen, a discussion of the general topology, theoretical calculations showing the general operation, and simulation results using Cadence and supporting tools.
Several different performance metrics will be given (noise figure, power, area, linearity), and students will be ranked against one another in each category to determine an overall performance score. Most of the emphasis will be placed on having a well thought-out and justified design approach (i.e., analytical design rather than trial/error simulation game).
Suggested topics are below;

- Low noise amplifier (common gate, common source, inductive degenerated, feedback, ...)
- VGA (current-steering,...)
- Single Pole Double Throw Switch (lambda/4 based, ...)
- Power amplifier (class A, class B, ...)

Progress and Final Report

The course project is to be submitted for marks in the form of a final report, as well as all electronic materials. The final report is to include all of the design procedure, calculations, citations, and simulated results.
You will also present the final results of your project in class at the end of the course. This will be a 30 minutes summary (including time for questions), and should include the same items as your report (though with less detail).
Note that you will be graded on technical content, the written format and style, and the oral presentation style.
There will also be at least two short progress report and presentations until the final due date of the project.

Exams:
There will be a midterm and final exam.

Grading:
Assignments . . . . 12 %
Projects (incl. seminar). . . . . 32 %
Midterm . . . . 28 %
Final Exam . . . . 28 %

Late Policy:
No late homework assignments or projects will be accepted.

Tentative Lecture Topics:
Introduction, Applications, RF Transceiver Overview
RFIC Devices and Technology
RF Concepts: Passive RLC Networks, Smith Chart
RF Concepts: Nonlinearity
RF Concepts: Noise

RF Concepts: Sensitivity, Dynamic Range
RF Integrated Circuits: Low Noise Amplifiers (LNA)

Midterm Exam

RF Integrated Circuits: Power Amplifiers (PA)
RF Integrated Circuits: Mixers
RF Integrated Circuits: Voltage Controlled Oscillators (VCO)
RF Integrated Circuits: Phase Shifter (PS)
RF Integrated Circuits: Attenuators (ATT)
RF Integrated Circuits: Variable Gain Amplifier (VGA)
RF Integrated Circuits: Single Pole Double Throw Switch (SPDT)
RF Concepts: Modulation
Architectures: Receivers
Architectures: Transmitters
RF Integrated Circuits: Frequency Synthesis (PLL)

Final Exam

Instructor has right to change grading policy after announcing in the class.

Make-up for final and midterm exams will only be offered to students who produce officially accepted valid excuses. Otherwise, students cannot have make-up option.

The due date of the homework/project is one week later from the assignment date, unless otherwise stated.

Late project/Homework submissions will be penalized 25% for first 6 hours and 50% for the first 24 hours. Late project submissions more than 24 hours will not be accepted.

Discussion on homework/project assignments is encouraged. Turning in identical homework/project solutions is considered cheating.

Cheating in exams and project will **NOT** be tolerated and will be subjected to disciplinary action.

Attendance will be taken randomly according to YOK regulations.

Last Words of the first Lecture 💻

I hope that you find the course enjoyable and rewarding in terms of the learning experience.

Keys to success in the course are:

1) **Good time management - designate fixed time slots in your schedule for watching the lectures and doing the guided cadence-software assignments.**
2) **Keep yourself "in sync" with the rest of the class - don't allow material to accumulate.**
3) **Work independently on the homework projects - this hands-on experience is crucial for fully understanding the theory.**
4) **Keep open channels of communication with the course instructor (and TAs) - e-mail, call on the phone or visit during office hours.**
5) **Never allow yourself to "get stuck" on a homework problem - seek help. You may do it by e-mailing the professor and make sure to include your problem statement clearly.**
6) **Whenever you feel "stuck" reading the theory or doing the hands-on assignments, try to articulate in words what exactly it is that you don't understand. Then e-mail your questions. You may also write your questions on a "post-it" notes, tacked to the appropriate written notes locations. When you come to an office hour visit, we may go through your specific questions one-by-one.**
7) **Make Recitations/Office Hours more productive, if you take the effort, ahead of the meeting, to do some preliminary work, and have some specific questions.**
8) **Allow at least an hour or two a week to go over recommended practice exercises from the book.**
9) **Always keep a "cool head" during exams. Exam questions will never be tricky. They are designed only to assess your knowledge in a**

straightforward manner, and reward you if you did all the homework and went through the practice exercises.

10) **When preparing for an exam, don't skip topics. Announcements will be very explicit regarding test topics. Typically, exams attempt to cover ALL topics. Every one of the problems may feature a mix of several topics.**

11) **We provide formula paper in advance of the exam. But you will not have enough time to find right formula or understand the formula "in real-time" during exams. Come well organized - know exactly where / what each given formulas are.**

12) **Always bring your calculator to exams. All problems will feature real circuits with real-life component values. Therefore you should not expect the numerical answers to always be "nice numbers".**

13) **Keep in mind that in the field of Electronics, most formulas are rarely "global". Circuit modifications (i.e. adding a load, adding source resistance etc.) may cause some of the formulas to slightly change appearance. Try always to grasp the ideas behind each formula. Then apply the ideas to modify the formulas to fit a new circuit. Don't blindly substitute numbers into any formula that catches your eye.**

Useful General Sites

- Radio-Frequency and Microwave Communication Circuits (online textbook similar to Pozar's).
- Course notes for "RF CMOS Transceiver design" (Linkoping University).
- Scilab - A free, downloadable numerical computation package (similar to MATLAB).
- TRLINE - Interactive Transmission Line Program - you may download it, and run it on any Windows machine.
- Agilent(HP) Educator's Corner - RF resources - Agilent's RF Tools page, providing web-based courses, labs, and basic simulation.
- IEEE Microwave Theory and Techniques Society
- RF Globalnet Simulation and Software - Links to various online simulation software

- RFCafe Application Notes
- Microwave Resources at University of Surrey
- Microwave Techniques from Postacademic Interuniversity Course in Telecommunications (has some solved problems)
- Quicktime movies of waves on transmission lines, antennas and arrays (Iowa State University)
- Electronic Warfare, Radar, and Microwave Handbook (U.S. Naval Air Warfare Center)
- MATLAB toolbox for electromagnetics
- Circuit Sage - Useful links to various tutorials and resources on circuit design.

Introduction

Wireless background

1. Fixed wireless (IEEE Spectrum, September 1999 - restricted to IEEE members only)
2. The Rebirth of Radio (IEEE Spectrum, January 2001)
3. Wireless Circuits Research at Queen's University

Bluetooth http://www.globalstar.com/pages/fact.html

1. Official Bluetooth Website
2. Bluetooth Specifications
3. Bluetooth Demo (Agilent)
4. Silicon RF for Bluetooth (Parthus)

Cell phones

1. How cell phones work

LMCS/LMDS/BWA

1. LMCS/LMDS Information

Mobile satellite

1. Iridium
2. GlobalStar

Impedance Matching

L-section matching networks

Impedance Matching Game (Agilent's Educator's Corner)

Passive Circuits

Transmission lines

1. RF Systems Overview

Standing Waves

1. Wave Propagation on TL (Agilent Educator's Corner)
2. Standing Wave Tutorial

TDR

1. Time Domain Reflectometry of Microstrip Lines (PDF)

Smith Charts

1. Smith Chart tutorial (Agilent Educator's Corner)
2. Smith Chart resources

Lumped Elements

1. Resistor catalog (from Token Passive Components)
2. Spiral and wound microwave inductors
3. Small high frequency inductors (Murata)

Antennas

Antenna Theory

1. Antenna Tutorial (ATI)

Integrated Antennas

1. Integration of Antennas (IMEC)

Active Devices and Amplifiers

1. Wireless Technologies and Information Networks (WTEC)

Monolithic circuit fabrication

1. IC Fabrication Pictures
2. Early circuit masks (Smithsonian)
3. Brief outline of integrated circuit fabrication

Transistors

1. Materials, Devices, and Circuit Fabrication - RF Globalnet (many good links to transistor sites)
2. RF Transistor Design (Motorola)

HBTs

1. Advantages of HBTs (RF Micro Devices)
2. HBT background (RF Micro Devices)

GaAs MESFETs

1. Applications of Microwave GaAs FETs (California Eastern Laboratories)
2. GaAs FET characteristics

High speed Silicon

1. Low Power VLSI Design (Purdue ECE)
2. Silicon bipolar electrical characteristics (Agilent)
3. Silicon MOSFET Technology for Wireless Communications (Motorola - published paper)
4. Silicon Microwave Broadband Amplifier ICs (California Eastern Laboratories)
5. Stanford Microwave Integrated Circuits Laboratory (dedicated to high speed CMOS circuits)

Microwave Amplifier Design

1. FET RF Amplifier Design Techniques (Motorola)
2. Transistor Parameters (Motorola)

Mixers

Microwave Mixer Background

1. Mixer Terminology (Mini-Circuits)
2. Transistor Parameters (Motorola)

Harmonic Balance Analysis

1. Harmonic Balance simulation speeds RF mixer design (Microwave Engineering Online)
2. HbFree (free downloadable harmonic balance simulator for Linux and Windows)
3. Harmonic Balance Simulation in ADS (Tutorial from UCSB)
4. ADS Circuit Simulation Documentation (Queen's CASLAB)

Oscillators

Dielectric Resonator Oscillators

1. DROs (EFM Systems)
2. DROs (Remec Magnum)

Dielectric (ceramic) resonators

1. Tiny Resonators for Low Frequencies (Murata)

2. Microwave Ceramic Resonators (Murata)

Wireless Communication Systems

Wireless receiver design

1. LNA/Mixers Ease Wireless Receiver Design (RF Micro Devices)
2. Bluetooth Design Tutorial (RF Micro Devices)

Searching for Journal Articles

Locating journal articles is easiest using either Google Scholar, or IEEExplore, IEEE's online database of conference proceedings, journal articles, and standards. Articles of interest for this course are often found in *IEEE Journal of Solid State Circuits*, *IEEE Transactions of Microwave Theory and Techniques*, *IEEE Microwave and Wireless Components Letters*, *Electronics Letters*, and a variety of conferences.
The publications below from other research groups are provided for quick reference only. You will be able to access some of them only if you access this library from your computer (or a computer on campus), or by using the web proxy.

Book Chapters

Review of Radio Science: 1999-2002 URSI, Chapter 16: Microwave and Millimeter-Wave Silicon and SiGe Devices

Clock Generation

R. Farjad-Rad et al., A low-power multiplying DLL for low-jitter multigigahertz clock generation in highly integrated digital chips, *IEEE JSCC*, December 2002, 1804-1812.

Design in CMOS and SiGe BiCMOS

S. Kim et al., Advanced Model and Analysis of Series Resistance for CMOS Scaling Into Nanometer Regime - Part I: Theoretical Derivation, *IEEE Transaction on Electron Devices*, March 2002, 457-466.

J. S. Dunn et al., Foundation of RF CMOS and SiGe BiCMOS technologies, *IBM Journal of Research and Development*, March/May 2003, 101-138.

D. L. Harame et al., Design automation methodology and rf/analog modeling for rf CMOS and SiGe BiCMOS technologies, *IBM Journal of Research and Development*, March/May 2003, 139-175.

Digital Modulator

G. Brenna et al., A 2GHz Direct-Conversion WCMA Modulator in 0.25um CMOS, *2002 IEEE International Solid-State Circuits Conference*, 3-7 February 2002, 244-464 vol.1.

H.-S. Kao et al., A Compact CMOS 2V Low-Power Direct-Conversion Quadrature Modulator Merged with Quadrature Voltage-Controlled Oscillator and RF Amplifier for 1.9GHz RF Transmitter Applications, *IEEE International Symposium on Circuits and Systems*, May 28-31 2000, 765-768.

B. C. Wong et al., A 200-MHz All-Digital QAM Modulator and Demodulator in 1.2-um CMOS for Digital Radio Applications, *IEEE Journal od Solid-State Circuits*, December 1991, 1970-1980.

C.-Y. Wu et al., A 2-V Low-Power CMOS Direct-Conversion Quadrature Modulator With

Integrated Quadrature Voltage-Controlled Oscillator and RF AMplifier for GHz RF Transmitter Applications, *IEEE Transactions on Circuits and Sytems - II: Analog and Digital Signal Processing*, February 2002, 123-134.

C.-Y. Wu et al., A 3V 1.9GHz CMOS Low-Distorsion Direct-Conversion Quadrature Modulator with a RF Amplifier, *N/A*, 1999, 777-780.

H. Zarei et al., A 37-mW Fully Integrated GMSK Modulator for DRRS Standard in 0.6-mm Digital CMOS Process, *IEEE Transactions on Circuits and Systems - II: Analog and Digital Signal Processing*, July 2002, 513-520.

Direct Conversion Receivers

A. Abidi, Direct Conversion Radio Tranceivers, *IEEE JSSC*, Dec 1995, 1399-1410.

Fixed Wireless

A. Boudiaf et al., Low Phase-Noise PHEMT-Based MMIC VCOs for LMDS Applications, *2001 IEEE MTT-S International Microwave Symposium Digest*, 20-25 May 2001, 1559-1562 vol.3.

Communications Research Centre Canada, Broadband Wireless Access (BWA) / Multipoint Distribution Systems, *WISELAB*, N/A, N/A.

R. Flint, The CABSINET Project: A Flexible Cellular Broadband Architecture, *1998 International Zurich Seminar on Broadband Communications, 1998. Accessing, Transmission, Networking. Proceedings.*, 17-19 February 1998, 149-154.

IEEE, IEEE WirelessMAN 802.16, *IEEE 802.16 Working Group Broadband Wireless Access Standards*, N/A, N/A.

IEEE, 802.16a, *IEEE Standards*, 1 April 2003, 1-318.

J. Izadian, Considering Antenna Options For LMDS, *MICROWAVES & RF*, November 2001, 65-74 and 107.

P. Mähönen et al., Wireless Internet over LMDS: Architecture and Experimental Implementation, *IEEE Communications Magazine*, May 2001, 126-132.

H. Sari, Some Design Issues in Local Multipoint Distribution Systems, *1998 URSI International Symposium on Signals, Systems, and Electronics*, 29 September-2 October 1998, 13-19.

S. Seidel, Radio Propagation and Planning at 28 GHz for Local Multipoint Distribution Sevice (LMDS), *Antennas and Propagation Society International Symposium, 1998*, 21-26 June 1998, 622-625.

S. Subbanna et al., Using SIlicon-Germanium Mainstream BICMOS Technology for X-Band and LMDS (25-30 GHz) Microwave Applications, *2002 IEEE MTT-S International Microwave Symposium Digest*, 2-7 June 2002, 401-404.

G. Torregrosa-Penalva et al., Low Cost Ka Band Transmitter Modules for LMDS Equipment Mass Production, *2001 IEEE MTT-S International Microwave Symposium Digest*, 20-25 May 2001, 953-956 vol.2.

L. Verweyen et al., LMDS up- and down-converter MMIC, *2000 IEEE MTT-S International Microwave Symposium Digest*, 11-16 June 2000, 1685-1688 vol.3.

Frequency Dividers

H. Chengiming et al., Design of 10 GHz, 2.6 mW Frequency Divider in 0.25 um CMOS, *Proceedings. 6th International Conference on Solid-State and Integrated-Circuit Technology, 2001*, 22-25 October 2001, 1136-1138.

H. Knapp et al., 25 GHz Static Frequency Divider and 25 Gb/s Multiplexer in 0.12 um CMOS, *Solid-State Circuits Conference, 2002*, 3-7 February 2002, 302-468 vol.1.

M. Nogawa et al., A 16.3-GHz 64:1 CMOS Frequency Divider, *Proceedings of the Second IEEE Asia Pacific Conference on ASICs, 2000*, 28-30 Aug. 2000, 95-98.

U. Singh et al., Dynamics of High-Frequency CMOS Dividers, *IEEE International Symposium on Circuits and Systems, 2002*, 26-29 May 2002, V-421-V-424 vol.5.

H. Wang, A 1.8 V 3 mW 16.8 GHz Frequency Divider in 0.25 um CMOS, *Solid-State Circuits Conference, 2000*, 7-9 February 2000, 196-197.

H.-D. Wohlmuth et al., A High Sensitivity Static 2:1 Frequency Divider up to 19 GHz in 120 nm CMOS, *2002 IEEE Radio Frequency Integrated Circuits (RFIC) Symposium*, 2-4 June 2002, 231-234.

H. Wu et al., A 19 GHz 0.5 mW 0.35 um CMOS Frequency Divider with Shunt-Peaking Locking-Range Enhancement, *Solid-State Circuits Conference, 2001*, 5-7 February 2001, 412-413, 471.

High-Frequency CMOS Design

T. Manku, Microwave CMOS - Device Physics and Design, *IEEE Journal of Solid-State Circuits*, March 1999.

C. Enz et al., MOS Transistor Modeling for RF IC Design, *2000 IEEE Transactions on Solid-State Circuits*, February 2000, 186-201.

A. Hajimiri, Distributed Integrated Circuits: An alternative Approach to High-Frequency Design, *IEEE Communications Magazine*, February 2002, 168-173.

M. Madihian, A 1-10 GHz 0.18um-CMOS chipset for multi-mode wireless applications, *2001 IEEE MTT-S International Microwave Symposium Digest*, 20-25 May 2001, 1865-1868 vol.3.

W. Simbfirger, Recent advances in CMOS circuits towards 40 Gb/s and 50 GHz, *2003 Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems*, 9-11 April 2003, 76-79.

Low Noise Amplifiers

D. Shaeffer, A 2.5-V, 1.5-GHz CMOS low noise amplifier, *IEEE JSCC*, May 1997, 745-759.

D. Triantis et al., Optimal Current for Minimum Thermal Noise Operation of the Submicrometer MOS Transistors, *IEEE Transactions on Electron Devices*, November 1997, 1990-1995.

H. Yano et al., Performance of K u-Band On-Chip Matched Si Monolithic Amplifiers Using 0.18-um-Gatelength MOSFETs, *IEEE Transactions on Microwave Theory and Techniques*, June 2001, 1086-1093.

P. Andreani et al., Noise Optimization of an Inductively Degenerated CMOS Low Noise Amplifier, *IEEE Transactions on Circuits and Systems*, September 2001, 835-841.

C. Chen et al., Extraction of the Induced Gate Noise, Channel Noise, and Their Correlation in Submicron MOSFETs from RF Noise Measurements, *IEEE Transactions on Electron Devices*, December 2001, 2884-2892.

R. Fujimoto et al., A 7-GHz 1.8-dB NF CMOS low-noise amplifier, *IEEE JSSC*, July 2002, 852-856.

J. Goo et al., A Noise Optimization Technique for Integrated Low-Noise Amplifiers, *IEEE JSSC*, August 2002, 994-1002.

X. Guan et al., A 24GHz CMOS Front-End, *28th European Solid-State Circuits Conference*, 24-26 September 2002, 155-158.

X. Guan et al., A 24GHz CMOS Front-End, *Lee Center Workshop*, 18 October, 2002, 1-23.

L.M. Franca-Neto et al., 17 GHz and 24 GHz LNA Designs based on Extended-S-Parameter with Microstrip-on-Die in 0.18um Logic CMOS Technology, *ESSCIRC*, September 2003, 149-152.

K. Yu et al., 24 GHz low-noise amplifier in 0.18 um CMOS technology, *Electronics Letters*, 30 Oct. 2003, 1559-1560.

K. Yu et al., K-band Low Noise Amplifiers using 0.18 um CMOS technology, *IEEE MWCL*, March 2004, p. 106-108.

MOSFET Modeling

C. Huang, The Minimum Noise Figure and mechanism as Scaling RF MOSFETs from 0.18 to 0.13 um technology nodes, *RFIC Digest 2003*, June 2003, 373-376.

M. Yang etc. al, Broadband Small-Signal Model and Parameter Extraction for deep Sub-Micron MOSFETS Valid up to 110 GHz, *RFIC Digest 2003*, June 2003, 369-372.

Optical Applications

G. Keeler, OPTICAL INTERCONNECTS TO SILICON CMOS: INTEGRATED OPTOELECTRONIC MODULATORS AND SHORT PULSE SYSTEMS, *Ph.D. Thesis*, December 2002, Stanford University.

Phase Locked Loops, Delay Locked Loops, Costas Loops

B. Razavi et al., Design of high-speed, low-power frequency dividers and phase-locked loops in deep submicron CMOS, *IEEE JSCC*, February 1995, 101-109.

Planar Inductors and Transformers

Theses

Tony Yeung, Analysis and Design of On-chip Spiral Inductors and Transformers for Silicon RF Integrated Circuits, *M.Sc. Thesis*, December 1998, The Hong Kong University of Science and Technology.

Papers

J. Burghartz et al., Novel Substrate Contact Structure for High-Q Silicon-Integrated Spiral Inductors, *IEDM*, 1997, 55-58.

Y. Chen et al., Investigation of Q Enhancement for Inductors Processed in BiCMOS Technology, *1999 Radio and Wireless Conference*, 1999, 263-266.

Y. Chen et al., Q-Enhancement of Spiral Inductor with N+-Diffusion Patterned Ground Shields, *IEEE-MTT-S Digest*, 2001, 1289-1292.

J. Gil et al., A Simple Wide-Band On-Chip Inductor Model for Silicon-Based RF ICs, *IEEE MTT*, September 2003, 2023-2028.

N. Itoh et al., Influence of Flip-Chip Assembly on On-Chip Spiral Inductor, *Wiley Int. J. RF and Microwave CAD*, May 2004, 236-243.

D. Kehrer et al., Modeling of Monolithic Lumped Planar Transformers up to 20 GHz, *IEEE Conference on Custom Integrated Circuits*, 6-9 May 2001, 401-404.

K. Kim et al., Characteristics of an Integrated Spiral Inductor with an Underlying n-Well, *IEEE Transactions on Electrons Devices*, September 1997, 1565-1567.

J. Long, Monolithic transformers for silicon RF IC design, *IEEE JSSC*, Sepr 2000, p. 1368-1382.

J. Long et al, The modeling, characterization, and design of monolithic inductors for silicon RF ICs, *IEEE JSSC*, March 1997, p. 357-369.

S. Mohan, The Deisgn, Modelling and Optimization of On-Chip Inductor and Transformer Circuits, *Ph.D. Thesis*, December 1999, 1-215.

S. Mohan et al., Simple Accurate Expressions for Planar Spiral Inductances, *IEEE Journal of Solid-State Circuits*, October 1999, 1419-1424.

K. Murata et al., Effect of a ground Shield of a Silicon On-Chip Spiral Inductor, *2000 Asia-Pacific Microwave Conference*, 2000, 1-4.

A. Niknejad et al., Analysis, Design, and Optimization of Spiral Inductors and Transformers for Si RF IC's, *IEEE Journal of Solid-State Circuits*, October 1998, 1470-1481.

A. Niknejad et al., Analysis of Eddy-Current Losses Over Conductive Substrates with Applications to Monolithic inductors and Transformers, *IEEE Transactions on Microwave Theory and Techniques*, January 2001, 166-176.

E. Ragonese et al., A Comparative Analysis of Monolithic Spiral Inductors in Silicon Bipolar Technology, *2003 Southwest Symposium on Mixed-Signal Design*, 2003, 144-149.

S. Hamedi-Hagh et al, Modeling Monolithic Inductors with Complex Metal Fill Structures, *2003 IEEE North East Workshop on Circuits and Systems*, ??, ??.

M. Tiebout, Physical Scaling of Integrated Inductor Layout and Model and its Application to WLAN VCO Design at 11GHz and 17GHz, *Proceedings of the 2003 International Symposium on Circuits and Systems*, 25-28 May 2003, 637-640.

Y.-C. Wu, On-chip high-Q (>3000) transformer-type spiral inductors, *Electronics Letters*, 31 January 2002, 112-113.

T. Yeung, Analysis and Design of On-chip Spiral Inductors and Transformers for Silicon RF Integrated Circuits, *Master's Thesis*, December 1998, 1-92.

S. Yim et al., The Effects of a Ground Shield on the Characteristics and Performance of Spiral Inductors, *IEEE Journal of Solid-State Circuits*, February 2002, 237-244.

C. Yue et al., A Physical Model for Planar Spiral Inductors on Silicon, *IEDM*, 1996, 155-158.

C. Yue et al., Design Strategy of On-Chip Inductors for highly Integrated RF Systems, *1999 Design Automation Conference*, 1999, 982-987.

C. Yue et al., On-Chip Spiral Inductors with patterned Ground Shields for Si-Based RF IC's, *1997 Symposium on VLSI Circuits Digest of Technical Papers*, 12-14 June 1997, 85-86.

SiGe Overview

Flash Comm, SiGe Technology: The Enabling Technology for Entering HF Markets, *Market Overview*, N/A, 1-23.

S. Wolf, Si:Ge Devices and Technology for Telecommunications IC Applications, *SILICON PROCESSING FOR THE VLSI ERA - Vol. 4: Deep-Submicron Technology*, LATTICE PRESS 2002, Chapter 10.

Superstrates

S. Gevorgian et al., Application notes - basic parameters of coplanar-strip waveguides on multilayer dielectric/semiconductor substrates, Part 1: high permittivity superstrates, *IEEE Microwave Magazine*, June 2003, 60-70.

C. Huang et al., Compact Microstrip Antenna Loaded with a High Permittivity Superstrate, *Antennas and Propagation Society International Symposium*, June 1998, 680 - 683 vol.2.

Substrate Noise

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