ELEC9702

RF Integrated circuits

Course Outline – Semester 2, 2015

Never Stand Still | Faculty of Engineering | School of Electrical Engineering and Telecommunications

Course Staff

Course Convener: Prof. Chee Yee KWOK, Room 242, cy.kwok@unsw.edu.au

Consultations: You are encouraged to ask questions on the course material, during and after the lecture class times in the first instance, rather than via email. Lecturer consultation times will be advised during lectures. You are welcome to email the lecturer, who can answer your questions on this course and can also provide you with consultation times. ALL email enquiries should be made from your student email address with ELEC9702 in the subject line, otherwise they will not be answered.

Keeping Informed: Announcements may be made during classes, via email (to your student email address) and/or via online learning and teaching platforms – in this course, we will use Moodle https://moodle.telt.unsw.edu.au/login/index.php. Please note that you will be deemed to have received this information, so you should take careful note of all announcements.

Course Summary

An essential module in any mobile and wireless communication system is the transceiver. The receiver transforms incoming RF signals from the antenna in to signals that can eventually be processed digitally. The transmitter transforms the analog version of the digital stream at baseband into a RF signal of sufficient power level to be delivered to the antenna.

Over the past 10 years, the market drive has been to integrate the complete transceiver onto a single substrate as a multi-chip module in silicon technology with comparable performance to what's existing. This includes the integration of passive components like inductors, varactors, bondpads and electrostatic protection devices on chip. Today, the technology has achieved more than 50% reduction in discrete components and more that 60-70% reduction in PCB area, using state of the art IC technology in the technology nodes below 100nm.

The drive to reduce complexity and chip area requirements has led to the implementation of direct conversion techniques - the RF signal is down converted to baseband with a single local oscillator frequency (also known as zero-IF architecture). The building blocks include low noise amplifiers, filters, mixers and oscillators, phase locked loops and RF power amplifiers.

This course is meant to teach students the art of designing RF transceiver modules in CMOS integrated circuit technology as distinct from the traditional RF design with discrete component on PCB. The course will discuss each of the building blocks in some detail. This course complements the knowledge taught in ELEC4602 dealing with basic microelectronics design and ELEC9701 dealing with mix-signal IC design.

Contact Hours

This postgraduate course consists of 3 hours of lectures in the evenings. Problem discussions are included in the lectures and will not be treated as separate tutorials.

Lectures	Day	Time	Location
	Tuesday	6-9pm	Rm 214

Context and aims

The growth of the RF and wireless market over the last 4 decades has been incredibly fascinating and challenging. From the early days of the cordless phone, pagers to todays smart phones, RF identification tags, WiFi/modems, they have become indispensable tools of everyday life. Needless to say, semiconductor companies have strived hard to capture their respective market share.

Whilst vast knowledge of high frequency circuit design skills have accumulated for almost 5 decades, the last few decades have seen a seen spectacular focus on RF due to the possibilities of miniaturisation arising from Integrated Circuit technology. Consider the size of the first generation mobile phones compared to what it is now! The RF modules for the Transceiver integrated on a chip with the other mixed-signal and digital components of the communication system. Clearly, in this course we deal with the design of RF modules for integration on a chip in CMOS technology. We will not be dealing with RF PCB design.

Aims:

The course aims to expose students to the RF Integrated Circuit design techniques from the system and functional module perspective, and appreciate the many advances in the IC technology that has facilitated it advancement. But an essential aspect of the course, is for the student to understand the trade-offs in design specifications like noise, power, bandwidth etc.

Indicative Lecture Schedule

Period	Summary of Lecture Program	
Week 1 (27/7)	Intro. RF communication systems; Non-linearity , cascaded stages.	
Week 2 (3/8)	Noise models, device noise, Noise figure calculations, Friis eqn.; Dynamic range; RF passive IC components	
Week 3 (10/8)	Revision of transmission line principles; Smith chart; S-parameter; matching networks	
Week 4 (17/8)	LNA: intrinsic 2 port MOSFET noise parameters, power match vs noise match, power constrained optimisation	
Week 5 (24/8)	LNA: design examples, power gain, stability	
Week 6 (31/8)	Mixers: fundamentals, nonlinear system based , multiplier based,	

Week 7 (7/9)	Mixers: potentiometric mixers, diode mixers, noise analysis of mixers	
Week 8 (14/9)	Oscillators: voltage controlled, phase noise	Assignment 1 due
Week 9 (21/9)	RF power amplifiers	
	MID-SESSION BREAK	
Week 10 (5/10)	RF power amplifiers	
Week 11 (12/10)	Phase locked loops	
Week 12 (19/10	Phase locked loops	
Week 13 (26/10)	Course review	Assignment 2 due

Assessment

2 Assignments/project	40%
Final Exam (3 hours)	60%

Course Details

Credits

This is a 6 UoC course and the expected workload is 5-10 hours per week throughout the 13 week semester.

Relationship to Other Courses

This is a postgraduate courses offered to students in the Master of Engineering Science at the University of New South Wales. ELEC 4602 and ELEC9701 provides important fundamentals which will be useful for this course.

Pre-requisites and Assumed Knowledge

Familiarity with Cadence or PSpice simulation tools would be helpful.

Learning outcomes

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

1. Understand a range of technologies used for RF circuit implementation on chip.
2. Understand the principle of operations of Transceivers Systems, noise, linearity, etc.
3. Analyse and design low noise amplifiers
4. Analyse and design mixers
5. Analyse and design RF power amplifiers
6. Analyse and design voltage controlled oscillators
7. Analyse and design PLL
8. Exposure to the use of Cadence software

This course is designed to provide the above learning outcomes which arise from targeted graduate capabilities listed in ***Appendix A***. The targeted graduate capabilities broadly support the UNSW and Faculty of Engineering graduate capabilities (listed in ***Appendix B***).

This course also addresses the Engineers Australia (National Accreditation Body) Stage I competency standard as outlined in ***Appendix C***.

Syllabus

Introdcution to RF communication systems; Non-linearity , cascaded stages; Noise models, device noise, Noise figure calculations, Friis eqn.; Dynamic range; RF passive IC components ; Revision of transmission line principles; Smith chart; S-parameter; matching networks ; LNA: intrinsic 2 port MOSFET noise parameters, power match vs noise match, power constrained optimisation , design examples, power gain, stability; Mixers: fundamentals, nonlinear system based , multiplier based, potentiometric mixers, diode mixers, noise analysis of mixers; Oscillators: voltage controlled, phase noise ; RF power amplifiers; PLL

Teaching Strategies

Delivery Mode

The teaching in this course aims at establishing a good fundamental understanding of the areas covered using:

- Formal face-to-face lectures, which provide you with a focus on the core analytical material in the course, together with qualitative, alternative explanations to aid your understanding;
- There are no separate tutorials but done lectures from time to time. Some self-paced exercises will be given out in class during the course.
- Where possible, lectures will be videoed and uploaded to the school website for students to clarify specific aspects of the lecture. It is not a substitute for missed lectures.

Learning in this course

You are expected to attend all lectures, and attempt assignments in order to maximise learning. In addition to the lecture notes/video, you should read relevant sections of the recommended text. Reading additional texts will further enhance your learning experience. Group learning is also encouraged. UNSW *assumes* that self-directed study of this kind is undertaken in addition to attending face-to-face classes throughout the course.

Tutorial classes

There are no separate tutorial classes.

Laboratory program

There are no laboratory programs. Where necessary some of the Cadence familiarisation may be done in the class session.

Assessment

2 Assignments	40%
Final Exam (3 hours closed book)	60%

The assessment scheme in this course reflects the intention to assess your learning progress through the semester..

Final Exam

The exam in this course is an closed-book 3 hour written examination, comprising four compulsory questions. University approved calculators are allowed. The examination tests analytical and critical thinking and general understanding of the course material in a controlled fashion. Questions may be drawn from any aspect of the course, unless specifically indicated otherwise by the lecturer. Marks will be assigned according to the correctness of the responses.

Relationship of Assessment Methods to Learning Outcomes

	Learning outcomes							
Assessment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Assignment1	x	x	x					x
Assignment 2				x	x	x	x	x
Final exam	x	x	x	x	x	x	x	

Course Resources

Textbooks

In the view of the wide range of disciplines in this course, there is no single textbook that appropriately covers all the course material. The prescribed textbook is listed below. Another key reference book is by Prof. Razavi. However, the following reference books and articles are recommended:

Textbooks: Prescribed textbook
The following textbook is prescribed for the course:
Lee: Design of CMOS RF integrated circuits, Cambridge,2004, 2nd edition.

Reference books
The following books are good additional resources for topics on RF Electronics and Circuits:
Razavi: RF Microelectronics, Prentice Hall, 1998
D. Leenaerts, et.al. : Circuits design for RF transceivers, Kluwer 2001
Pozar: Microwave and RF design of Wireless Systems, Wiley 2001
Everhard: Fundamentals of RF Circuit Design with low noise oscillators, Wiley, 2001
Ludwig & Bretchko: RF Electronics – Theory and Applications, Prentice Hall 2000

Technical papers from the IEEE Journal of Solid State Circuits.

Books covering assumed knowledge
The following books cover material which is assumed knowledge for the course:

A.S. Sedra and K. C. Smith, *Microelectronic Circuits*. Oxford University Press, 4th ed., 1998.

On-line resources

Moodle

As a part of the teaching component, Moodle may be used to disseminate teaching materials, host forums and occasionally quizzes. Assessment marks will also be made available via Moodle: https://moodle.telt.unsw.edu.au/login/index.php.

Mailing list

Announcements concerning course information will be given in the lectures and/or on Moodle and/or via email (which will be sent to your student email address).

Other Matters

Academic Honesty and Plagiarism

Plagiarism is the unacknowledged use of other people's work, including the copying of assignment works and laboratory results from other students. Plagiarism is considered a form of academic misconduct, and the University has very strict rules that include some severe penalties. For UNSW policies, penalties and information to help you avoid plagiarism, see http://www.lc.unsw.edu.au/plagiarism. To find out if you understand plagiarism correctly, try this short quiz: https://student.unsw.edu.au/plagiarism-quiz.

Student Responsibilities and Conduct

Students are expected to be familiar with and adhere to all UNSW policies (see https://my.unsw.edu.au/student/atoz/ABC.html), and particular attention is drawn to the following:

Workload

It is expected that you will spend at least **ten to twelve hours per week** studying a 6 UoC course, from Week 1 until the final assessment, including both face-to-face classes and *independent, self-directed study*. In periods where you need to need to complete assignments or prepare for examinations, the workload may be greater. Over-commitment has been a common source of failure for many students. You should take the required workload into account when planning how to balance study with employment and other activities.

Attendance

Regular and punctual attendance at all classes is expected. UNSW regulations state that if students attend less than 80% of scheduled classes they may be refused final assessment.

General Conduct and Behaviour

Consideration and respect for the needs of your fellow students and teaching staff is an expectation. Conduct which unduly disrupts or interferes with a class is not acceptable and students may be asked to leave the class.

Work Health and Safety

UNSW policy requires each person to work safely and responsibly, in order to avoid personal injury and to protect the safety of others.

Special Consideration and Supplementary Examinations

You must submit all assignments and attend all examinations scheduled for your course. You should seek assistance early if you suffer illness or misadventure which affects your course progress. All applications for special consideration must be **lodged online through myUNSW within 3 working days of the assessment**, not to course or school staff. For more detail, consult https://my.unsw.edu.au/student/atoz/SpecialConsideration.html.

Continual Course Improvement

This course is under constant revision in order to improve the learning outcomes for all students. Please forward any feedback (positive or negative) on the course to the course convener or via the Course and Teaching Evaluation and Improvement Process. You can also provide feedback to ELSOC who will raise your concerns at student focus group meetings. As a result of previous feedback obtained for this course and in our efforts to provide a rich and meaningful learning experience, we have continued to evaluate and modify our delivery and assessment methods.

Administrative Matters

On issues and procedures regarding such matters as special needs, equity and diversity, occupational health and safety, enrolment, rights, and general expectations of students, please refer to the School and UNSW policies:
http://www.engineering.unsw.edu.au/electrical-engineering/policies-and-procedures
https://my.unsw.edu.au/student/atoz/ABC.html

Appendix A: Targeted Graduate Capabilities

Electrical Engineering and Telecommunications programs are designed to address the following targeted capabilities which were developed by the school in conjunction with the requirements of professional and industry bodies:

- The ability to apply knowledge of basic science and fundamental technologies;
- The skills to communicate effectively, not only with engineers but also with the wider community;
- The capability to undertake challenging analysis and design problems and find optimal solutions;
- Expertise in decomposing a problem into its constituent parts, and in defining the scope of each part;
- A working knowledge of how to locate required information and use information resources to their maximum advantage;
- Proficiency in developing and implementing project plans, investigating alternative solutions, and critically evaluating differing strategies;
- An understanding of the social, cultural and global responsibilities of the professional engineer;
- The ability to work effectively as an individual or in a team;
- An understanding of professional and ethical responsibilities;
- The ability to engage in lifelong independent and reflective learning.

Appendix B: UNSW Graduate Capabilities

The course delivery methods and course content directly or indirectly addresses a number of core UNSW graduate capabilities, as follows :

- Developing scholars who have a deep understanding of their discipline, through lectures and solution of analytical problems in tutorials and assessed by assignments and written examinations.

- Developing rigorous analysis, critique, and reflection, and ability to apply knowledge and skills to solving problems. These will be achieved by the laboratory experiments and interactive checkpoint assessments and lab exams during the labs.
- Developing capable independent and collaborative enquiry, through a series of tutorials spanning the duration of the course.
- Developing independent, self-directed professionals who are enterprising, innovative, creative and responsive to change, through challenging design and project tasks.

Appendix C: Engineers Australia (EA) Professional Engineer Competency Standard

	Program Intended Learning Outcomes	
PE1: Knowledge and Skill Base	PE1.1 Comprehensive, theory-based understanding of underpinning fundamentals	✓
	PE1.2 Conceptual understanding of underpinning maths, analysis, statistics, computing	✓
	PE1.3 In-depth understanding of specialist bodies of knowledge	✓
	PE1.4 Discernment of knowledge development and research directions	
	PE1.5 Knowledge of engineering design practice	✓
	PE1.6 Understanding of scope, principles, norms, accountabilities of sustainable engineering practice	
PE2: Engineering Application Ability	PE2.1 Application of established engineering methods to complex problem solving	✓
	PE2.2 Fluent application of engineering techniques, tools and resources	✓
	PE2.3 Application of systematic engineering synthesis and design processes	✓
	PE2.4 Application of systematic approaches to the conduct and management of engineering projects	✓
PE3: Professional and Personal Attributes	PE3.1 Ethical conduct and professional accountability	
	PE3.2 Effective oral and written communication (professional and lay domains)	
	PE3.3 Creative, innovative and pro-active demeanour	✓
	PE3.4 Professional use and management of information	✓
	PE3.5 Orderly management of self, and professional conduct	
	PE3.6 Effective team membership and team leadership	✓