Department of Electrical Engineering

Taught Masters in Radar and Electronic Defence

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EEE5113S MICROWAVE DEVICES AND MODULES

1 Prerequisites

The formal entry requirements are a South African 4 year bachelors degree or equivalent. A Science honours degree is acceptable with the appropriate subject content.

The course requires students to have a good background in Mathematics and Physics, the latter with an exposure to propagating electromagnetic waves. This course will provide some revision, but students may need to carry out extra reading. Students should also be familiar with the use of a computer to carry out calculations: the use of spreadsheets and a programming language is essential. Some packages may be introduced in the course.

2 Course Format and Dates

The course is given in a five day, intensive format, followed by a further five tutorial and seminar sessions over the weeks following the intensive session. These sessions are based on problem sets which the student must attempt in order to gain benefit from the seminars. In addition, students may book appointments with the Course Convener and the Tutor.

The course Calendar is the governing document for planning: please monitor it frequently.

https://sites.google.com/site/radarmasters/schedule

Course interaction is via the UCT Vula System. You will have access to this information once you have registered for the course. It is important that you provide your preferred email address (one that it checked frequently) for your Vula registration.

3 Staff

Convener	Prof. M.R. Inggs	UCT	mikings@gmail.com
Lecturers:	Prof. M.R. Inggs	UCT	mikings@gmail.com
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Tutor:	Roaldje Nasjiasnagar	UCT	neddje@gmail.com

4 Course description:

This course presents the technology underlying the implementation of the RF and Microwave parts of Radar and Electronic Defence (ED) Systems. Although digital components and signal processing are very important for modern systems, high performance RF and Microwave devices and modules are key to overall system implementation. Specific course topics include:

4.1 Overview of RF and Microwaves in Radar and ED.

Introduction and Radar Overview, covering the basic concepts of radar and the format of the course itself.

The Radar Equation, which allows us to estimate the performance of a radar system, and thus, to design radars for a specific purpose.

Radar search and overview of detection and interference, which improves our models of performance, to be used in design.

4.2 Circuits and Transmission Lines

Revision of Transmission Line Theory and Circuits. The majority of Radars and Radar systems operate in the microwave frequency range between 1GHz and 100 GHz. Lumped element passive devices such as resisters inductors and capacitors and interconnecting wires can also not be used. Transmission line circuits and special device packaging and techniques are required. It will be assumed that you have a basic understanding of transmission lines theory.

Coaxial Microstrip and Waveguide Circuits. There are many types of transmission line structures but the most common transmission lines used at microwave frequencies are coaxial, microstrip and waveguide transmission line circuits. The theory and different structures will be covered in this section of the course.

4.3 Solid State Oscillators

Solid State Oscillators Do not produce sufficient power for a radar transmitter. Either valve oscillator transmitters or solid state oscillators followed by valve amplifiers are used to generate high power levels. Medium power solid state oscillators or low power solid state oscillators followed by medium power amplifiers are used for short range radar applications. This section covers the design and operation of Gunn, Impatt and GaAs FET oscillators.

4.4 Solid State Amplifiers

Solid State Power Amplifiers and Low Noise Amplifiers Solid state power amplifiers only produce sufficient power for limited radar range performance. The performance is enhanced by using CW radars techniques such a FMCW or long pulses using pulse compression. Silicon BJT’s are restricted to the lower end of the microwave spectrum. Gallium arsenide Solid state Power Amplifiers and Low Noise amplifiers operate about 4 times higher in frequency than BJT amplifiers. This section explains the operation and limitations of Power Amplifiers and Low Noise Amplifiers with particular emphasis on GaAs FET's

4.5 PIN Diodes in Switches and Phase Shifters

PIN diodes are used to electronically switch power propagating along a transmission line by connecting the diode in series or parallel in a transmission line. Improved isolation is achieved by connecting several diodes in series and in parallel. Several PIN diode circuits will be described and analysed. PIN diode circuits which produce a phase shift usually consist of a combination of a PIN diode switch and propagation delay from a length of transmission line.

4.6 Mixers and Receivers

Noise in receivers plays a large part in determining the range performance of a radar. The effect of bandwidth, antenna gain and other critical components of a Radar receiver will be considered in some detail. The effect of added noise introduced by amplifier stages and mixers will be dealt with. Different types of mixers and mixer circuits will be considered such as single ended mixers, balanced mixers and image rejection mixers.

4.7 Filters and Multiplexing

Microwave Filters are used in radar receivers to separate the desired mixer output from mixer output signals at other frequencies.

Diplexers are three port devices or filters used to separate signals from one input to two different paths, and vice-versa, based on frequency content of the input.

Duplexers are three-port devices used to combine two ports into one port, typically operating in the same frequency band. It can be used to connect a transmitter and receiver to the same antenna.

The *insertion loss method* for filter design allows a filter response to be specified systematically based on passband and stopband characteristics.

Low-pass filters are two-port reciprocal devices that allow signals from DC to to the edge of the passband to be filtered to the output. These filters are the basis for design of stopband and bandpass filters. Standard lowpass prototype designs, based on lumped-element (L and C) components, are available in design tables, for various types of filter responses.

Bandpass filters separate signals at frequencies within a designated range from signals outside this range. Their design are typically based on transformations of low-pass filter circuit representations.

Filter transformations allow frequency scaling of low-pass filter responses, impedance scaling and also transformation from load-pass to bandpass or bandstop filter responses.

Microwave filters using lumped elements are impractical at microwave frequencies. Equivalent representations of lumped-element filters using transmission line sections are found using the *Richard's transformation*.

Coupled resonator bandpass filters are based on a cascade of series or parallel resonator circuits coupled electromagnetically.

Full-wave EM simulators solve Maxwell's equations numerically for passive devices such as filters and antennas. These may provide a very accurate predicted response, provided that the modeling of the physical configuration is accurate and that the method used (i.e. method of moments (MoM), Finite element Method (FEM) or Finite Difference Time Domain (FDTD)) is appropriate for the specific application.

Electronic design aids (EDA) using models are used to predict responses of passive and active microwave devices and systems. These results are based on very accurate models and provide fast results. Some of these tools also incorporate full-wave EM solver capabilities, or the option to link to one.

4.8 Ferrites in Circulators and Isolators

Ferrites or ferromagnetic materials display anisotropic properties when biased by a DC magnetic field. The propagation of microwave signals depends on the direction of propagation. These materials are useful for a number of microwave components used in radar systems.

An *isolator* is a non-reciprocal two-port device allowing transmission only in one direction. In radar systems it may be used between a high-power source and the load to avoid reflections damaging the source.

A *gyrator* is a non-reciprocal two-port device generating 180 degrees phase difference between the reverse and forward direction of propagation.

A *circulator* is a non-reciprocal three-port device. It allows power-flow only in one direction, from one port to an adjacent port. Y-junction circulators will be discussed.

4.9 Power Tubes

Microwave tubes are used as microwave power sources and amplifiers, mostly at high power levels and higher frequencies.

Linear beam devices:

- *Klystron* -narrow bandwidth
- *Travelling wave tube (TWT)*

Crossed field devices:

- *Magnetron*
- *Crossed-field amplifier*
- *Gyratron*

5 Learning outcomes:

Having successfully completed this course, the student will have:

5.1 Knowledge Base:

1. Understand EM wave propagation in guiding structures used to implement distributed RF and Microwave components;
2. Understand the use of modern solid state devices in RF and Microwaves components;
3. Understand the range restrictions introduced by noise generated in receivers;
4. Understand the basis of microwave filter design using the insertion loss method;
5. Understand the operation of devices commonly encountered in radar systems based on ferrite materials.
6. Understand the use of power tubes as microwave power sources and amplifiers.

5.2 Engineering ability:

1. Explain in simple words the working principles and basic RF and Microwave building blocks of a different types of radar system;
2. Be able to identify the best RF and Microwave technology to implement a radar architecture;
3. Model RF and Microwave devices and modules using appropriate mathematical techniques, including modern electronic design aids (EDA);
4. Have a top level understanding of important parameters relating to subsystems to be able to design a radar system with a given performance;

5.3 Practical skills:

1. Carry out top level designs and trade-offs of RF and Microwaves devices, taking into

account the important characteristics of the subsystems and other factors;

2. Simulate all or part of an RF or Microwave chain using appropriate tools;
3. Calculate results of designs using programming techniques (languages or spreadsheets).

6 Textbook

For system level discussions, "Principles of Modern Radar" Volume 1, Ed. Richards, Scheer and Holm, Scitech Publishing, 2010, is an important source of information.

"Microwave Engineering", third edition (but any edition will do), M. Pozar.

7 Lecture Programme

Table 1: EEE51113S 2012 Programme

Time	Mon 25th June	Tue 26th June	Wed 27th June	Thu 28th June	Fri 29th June
08h00	Overview	Overview	Noise in receivers	Basic tools for design	Bandpass filters part 2
09h00	Transmission line theory	Gunn Oscillators	Noise in Receivers	Filter background	EDA tools
10h00	Transmission line Theory	Impatt Oscillators	Mixers	Filter design using the insertion loss method	Ferrimagnetic components: Isolators, Gyrators and circulators
11h00	Tea	Tea	Tea	Tea	Tea
11h30	Coaxial Lines & Microstrip	Ga As FET Oscillators	Mixers	Bandpass filters part 1	Microwave tubes
12h30	Lunch	Lunch	Lunch	Lunch	Lunch
13h30	Waveguides	Amplifiers	Break[1]	Demonstration	Pract/tut in Blue Lab

1 It is likely that a visit to an RF and Microwave systems company will be organised during the afternoon.

14h30	Waveguides	Amplifiers	Break	Prac/tut in Blue Lab	Pract/tut in Blue Lab
15h30	Waveguides	PIN Diodes	Break	Prac/tut in Blue Lab	Pract/tut in Blue Lab
16h30	Tea	Tea	Break	Tea	Tea
17h00	Gunn Oscillators	PIN Diodes	Break	Prac/tut in Blue Lab	Discussion of design assignment
18h00	Close	Close	Break	Close	Close

8 Drill Problems

Students are expected to complete five sets of Drill Problems, handed out after the intensive lecture period. Students will be provided with at least 5 seminar opportunities of about an hour each with the lecturer, convener and tutors, and will be expected to attend 4 out of the 5 seminars, and attendance is only creditted if the solutions have been submitted. The student's solutions to the problem set must be submitted on Vula before the start of the seminar. The seminars will be carried out with access by Skype for students off campus after the lecture session. For bandwidth reasons, the number of parallel sessions will have to be limited. For example, all students resident in the same city will be expected to attend at a common venue, and students will have to organise their own venue and projection facilities. Within reason, and with prior arrangement, students can approach the tutor / and / or the lecturer for help with problem sets.

9 Course Assessment and Examination

The assessment of this course is based on a three hour, written examination, as well as the Duly Performed (DP) requirement of 4 out of 5 seminars attended. Tutorial material/assignments will be marked and count 20% of the course mark.

The examination is closed book, i.e. no notes may be brought into the examination venue. Students are not expected to memorise any formulas: all formulas and results will be supplied on the examination paper. Students may write the examination in their home location, provided satisfactory supervision of the examination can be arranged in good time.

10 Course Load

Item	Number	hrs/per	Hours
Lectures	40	1	40
Assimilation	40	2	80
Seminar Attendance	5	2	10
Drill Problems	5	12	60
Examination preparation	1	8	8
Examination	1	3	3
TOTAL			201