POSTGADUATE TUTORIAL LECTURE COURSE:
RADIO FREQUENCY ENGINEERING
Dr Stepan Lucyszyn (Imperial College London)

RATIONALE

This is a radio frequency (i.e. from dc to sub-millimetre-wavelength) engineering course, with 6 tutorial lectures, aimed at postgraduate physics and engineering students wishing to bridge their gap in knowledge of how theoretical principles can be engineered for real life applications. A coherent theme runs throughout this course, with a view to 'seeing' interrelated technologies from different perspectives. It is hoped that the physics students will be able to discover synergies between these RF engineering topics and their existing understanding of photonic principles.

Lecture #1: Passives

The main objective of this lecture is to introduce passive components, discuss their technological limitations and give modern examples of how they can be realised. The basic concepts outlined here will also act as a basic introduction to subsequent lectures.

- Lumped elements
    - 'Active' implementations
- Distributed elements
    - Measurement reference impedances
- Directional couplers
- Resonators
- Radiating structures
- Material Losses

Lecture #2: Detectors, Mixers and Modulators

The main objective of this lecture is to introduce a range of basic semiconductor devices and to give examples of how they can be employed in various analogue signal processing building blocks. The technological limitations of simple implementations and more complex solutions will be discussed.

- Diodes (*p-n*, Schottky and PIN)
- Field-Effect Transistors (MESFET and HEMT)
- Detectors
- Mixers
- Variable Attenuators
- Variable Phase shifters
- Negative differential-phase group delay synthesiser
- Vector Modulators and software-defined radio/radar

Lecture #3: Radio Frequency Microelectromechanical Systems (RF MEMS)

The main objective of this lecture is to give a basic overview of RF MEMS. Emphasis will be placed on the potential applications and technological limitations of this relatively new technology.

- Defining Terms
- Enabling Technology Roadmap
- Fabrication Technologies
- Electromechanical Actuation
- Generic RF MEMS Components (switches, variable capacitors and antennas)
- Circuits (phase shifters, tuneable matching networks, filters and antennas)
- Reconfigurable architectures and applications

Lecture #4: Scattering (S)-Parameter Analysis

The main objective of this lecture is to teach a useful tool for enabling a student to derive analytical transfer functions for practical circuits. Problems with worked-though solutions will be given in class.

- S-Parameter revision
- Vector network analyser
    - Principle of calibration
- Mason's non-touching loop rule
    - Stability analysis of active networks
    - Cascaded 2-port networks
- Direct inspection approach
    - Reflection topologies
    - Tandem topologies
    - Michelson interferometer

Lecture #5: Metal-pipe Rectangular Waveguides

The main objective of this lecture is to explore modern methods of implementing this traditional guided-wave technology, for both low frequency and THz applications.

- Solution to Maxwell's equations revision
    - TEmn mode waveguide
    - TEmno mode cavity resonator
- THz waveguides
- Half-mode waveguides
- Substrate integrated waveguides
    - Picket fence metamaterial approach
    - Multilayer approach
    - THz multi-chip module technology
    - REconfigurable THz INtegrated Architecture (RETINA)

Lecture #6: *Engineering Approach* for Analytical Electromagnetic Modelling of THz Metal Structures

The main objective of this lecture is to teach a useful tool for enabling a student to derive analytical expressions for a number of electromagnetic problems relating to THz metal structures. The traditional approach when using the classical relaxation-effect model can be mathematically cumbersome and not insightful. This lecture briefly introduces various interrelated electrical engineering concepts as tools for characterizing the intrinsic frequency dispersive nature of normal metals at room temperature. This *Engineering Approach* dramatically simplifies the otherwise complex analysis and allows for a much deeper insight to be gained into the classical relaxation-effect model. Problems with worked-though solutions will be given in class.

- Drude's frequency dispersion model
- The *Engineering Approach*
    - Equivalent transmission line model
    - Q-factor for metals
    - Kinetic inductance
    - Complex skin depth
    - Boundary resistance coefficient
- Applications
    - Metal-pipe rectangular waveguides
    - Cavity resonators
    - Single metal planar shield
    - Quasi-metal structures

Biography

Stepan Lucyszyn is currently an *Associate Professor in Millimetre-wave Electronics* at Imperial College London. He spent the first 12 years of his research career working on microwave and millimetre-wave integrated circuits and in 2001 co-edited a seminal book on the subject. This book was translated into Chinese in 2007. For his contributions, he was made an *Adjunct Professor* at UESTC (Chengdu, China) in 2008. For his contributions to radio frequency microelectromechanical systems (RF EMMES), he was made a *Guest Professor* at Tsinghua University (Beijing, China) in 2008. With contributing chapters, he also edited a book entitled “Advanced RF MEMS”, published by Cambridge University Press in 2010.

For over 15 years, Dr Lucyszyn has been working on millimetre-wave electronics and, since 2004, investigating the behaviour of materials and passive structures operating at THz frequencies. In 2010, he was awarded the DSc degree (higher doctorate) of Imperial College for his contributions to *Millimetre-wave and Terahertz Electronics*.

To date, Dr Lucyszyn has (co-)authored approximately 125 technical papers in applied physics and engineering, and delivered many invited presentations at international conferences and workshops. In 2005, he was elected *Fellow* of the Institution of Electrical Engineers (UK) and *Fellow* of the Institute of Physics (UK), and in 2008 was invited as a *Fellow* of the Electromagnetics Academy (USA). In 2009 he was appointed an *IEEE Distinguished Microwave Lecturer* for 2010-2012.