Course Description

Course name	**#019 - RF and Microwave Circuit Design: Applications and Theory**
Duration	**5 days**
Format	**Public Classroom or Inhouse Event. Not suitable Online**

Overview

Dr. Rowan Gilmore, Adjunct Professor, University of Queensland, and former CEO of EM Solutions Pty Ltd., Australia, is teaching this 5-day course in Microwave Circuit Design.

Combining classical approaches to circuit design with modern simulation tools, this course will help you understand the background to the various building blocks that make up modern microwave circuits and systems.

By using tools ranging from the Smith Chart to the latest CAD suite, you will be able to match, design, and optimize circuits like single transistor amplifiers, oscillators, and mixers, or instead utilize complex functional IC building blocks more effectively with better matching elements and filters.

This course focuses on the design of discrete RF and microwave circuits and uses classical microwave design techniques to unpack the challenges in designing high frequency electronic circuits.

Technical Focus

Although **RF circuits** are generally considered to be circuits that operate from tens of MHz up to several GHz, and M**icrowave circuits** at frequencies beyond that, boundaries based purely on frequency are rarely appropriate. Analog integrated circuits based on lower-frequency design methodologies can now operate well into the microwave range, purely because of smaller feature sizes that are available in CMOS and silicon-germanium technologies. Integrated circuits that operate in the microwave frequency range, designed using low frequency architectures, are now abundant.

However, don't think that the art of circuit design is no longer needed because of the ready availability of drop-in building blocks that do it for you! Using ready-made IC chips still requires matching, tuning, bias and stabilization networks that must be modelled and designed.

Classical high frequency microwave circuit design techniques are still relevant and important to engineers even if they never need to build a bespoke circuit from scratch themselves. It is still critical to be able to model and understand problems arising from noise, mismatch, circuit losses, and limited bandwidth in integrated building blocks and the matching elements and filters that surround them.

We will focus on the design of discrete circuits that are differentiated from their historically lower-frequency counterparts by several features. In RF and microwave design, the phase shift of the component is significant because its size is comparable with a wavelength, its reactances and parasitics must be accounted for, and reflections occur between elements. These all-limit bandwidth. We also need to consider circuit losses that degrade the Q of an element as well as introduce noise, and nonlinearities that introduce distortion into the signal path. Electromagnetic radiation and capacitive coupling will also be features of such circuits. Such 'RF and microwave' effects are most commonly observed when using discrete or custom devices, or when assembling integrated circuits together at higher frequencies into systems. Ignorance of such effects can result in reduced bandwidth, unwanted spurious signals, elevated noise, unexpected oscillation, or degraded linearity.

Course Content

While focusing on the design of discrete **RF and Microwave circuits** to show classical microwave design techniques, examples of system integrated on chip are presented to compare the 'two worlds'. As CMOS design now extends even beyond Ka-band frequencies, many classical microwave design insights and techniques are forgotten. For instance, the use of a source inductor in a CMOS low-noise amplifier stage is widespread for simultaneously improving gain and noise match, but why? This course gives a renewed understanding of why and how such tricks are effective.

Impedance matching, circuit stability, power output, distortion, power combining, and component losses and parasitics are all examined in the context of microwave circuits in modern systems. We will also explore device modelling using state-of-the-art low-voltage transistors so we can reconcile small signal and large signal design techniques. This is illustrated in a number of applications such as small-signal, large-signal, low-noise, and feedback amplifiers with discrete transistors. Low-noise design considerations are also introduced, using CAD modelling of reactive and resistive types of applications. Reflecting its importance as a fundamental building block of most systems, and as an opportunity to demonstrate computer modelling of most other circuit types, amplifier design is treated exhaustively, using both small signal S-parameter methodologies (for noise, gain, and matching) and large signal models (for power and distortion).

Oscillators and mixers are also designed to meet demanding systems requirements. The course first explains the fundamental operating principles of these components in great simplicity and then illustrates the theory elegantly through practice. We show the importance of modeling parasitic elements that arise in design or when interconnecting components at high frequencies. We also consider oscillator and mixer performance using a system simulator, reviewing how these components need to be specified for use in communication systems, for instance to maintain I and Q channel orthogonality, and how this relates to the system performance. We will also look at higher level RF and microwave subsystems, such as LNBs and BUCs.

Nonlinear design techniques are also examined with a harmonic balance simulator, using bipolar, FET, and HEMT devices. The course emphasizes hands-on design and simulation of many circuit types, considering their linearity, efficiency, and power requirements. We develop an intuitive understanding of how non-linearity arises, and its impact on design, together with more detailed circuit modeling to examine quantitative impact.

To benefit most, bring your own laptop computer, and prior to attending the course, obtain a free trial license of Microwave Office (MWO) from AWR at www.awrcorp.com .

On completion of the course, you will be able to:

- Understand matching circuits and topologies to create the most important elemental building blocks of systems, using single transistors or fully integrated chip sets
- Design small-signal, low-noise, and power amplifiers
- Perform RF stability analysis and eliminate potential instabilities

- Design oscillators and VCOs for low-phase noise or output power
- Design mixers using FETs, bipolars, and diodes
- Understand the power of microwave CAD tools, achieve better first-pass design success, and be better placed to troubleshoot problems when circuits don´t work as expected.

Who should attend?
This course is most helpful for engineers with some understanding of electronic circuits already, but who may be wishing to move into microwave or RF circuit design – either active or passive.

The course is suitable for engineering managers, design engineers, and experienced test and production engineers.

Past participants have benefited most from gaining a more thorough and systematic approach to the design and use of microwave circuits. They typically work in companies designing microwave components or subsystems, in defense, radar, communications, or in the emerging 'new space' and Internet-of-Things industries.

Course Daily Schedule

Day 1

Classical small-signal RF Circuit Design

To introduce linear active circuits, we review the fundamental principles of impedance matching and move on to examine the effect of mismatch on gain, circuit stability and power performance.

- Revision of S-parameters, Matching and the Smith Chart
- Gain in a distributed circut - impedance transformation
- Unilateral Gain Circles in Small-signal Amplifier Design
- Complex conjugate matching for maximum gain
- RF Circuit Stability: Graphical and analytical techniques
- K- and µ-Factors, Nyquist Stability Analysis

Example: Broadband Transistor Stabilization

- Simultaneous Conjugate Match, Bandwidth Considerations
- GMAX and MSG Definition

Example: 1900MHz Amplifier Design for Maximum Gain

Day 2

Discrete Low-Noise and Broadband Amplifiers

We examine the three commonly used techniques used in maximum small-signal gain, low-noise, and linear power amplifiers.

- Transducer-, Operating-, and Available-Gain Techniques
- RF Noise Sources, Noise Figure and Noise Measure
- Constant-Noise and Constant-Gain Circles in LNA Design
- Available-Gain Design for Minimum Noise
- Trade-Offs Between Gain, Match, and Noise Performance

Example: 900MHz Discrete LNA Design

- Broadband Amplifier Design Techniques
- Reactive Mismatch and Lossy Matching Techniques
- Feedback Amplifiers Combined with Impedance Matching
- Circuit Optimization for Gain, Match and Stability

Example: 1-4000 MHz Feedback Amplifier Design

Day 3

Power Amplifier Design

- Design for Optimal Power - nonlinear circuit analysis
- Quasi-Linear Methods to Achieve Power Matching
- Load Line Characterization
- Load Pull Characterization - Measurement and Prediction
- Classes of Power Amplifiers: A, AB, B, C, and F
- Harmonic Tuning to Optimize Efficiency

Day 4

Power Amplifier Design (cont'd)

- Distortion Reduction Techniques

Example: Bipolar Power Amplifier Design Example (CDMA)

Next, we look at the fundamentals of high Q oscillators, paying particular attention to phase noise and tuning bandwidth.

Low Noise (LC) Oscillators

- Oscillator Design Considerations
- Device - Circuit Interaction (Series and Shunt Resonances)
- Deriving the VCO Tuning Curve
- Phase Noise and its impact on System Performance
- Why a system engineer worries about phase noise

Day 5

Low Noise (LC) Oscillators (cont'd)

Example: Bipolar Transistor (HBT) VCO Design in the 4 GHz Band

Finally, we consider mixers and frequency translation, and by simple consideration of mixing theory, uncover the secret to good mixer design.

Mixer Design

- Revision of Diode Mixers
- Bipolar and MESFET Mixer Analysis
- Comparison of Mixer Types
- The Importance of Quadrature Balance
- Modulators, Image-Reject, and Single Sideband Mixers

Example: FET and Bipolar Transistor Active Mixer Designs

Instructor Biography

Dr. Rowan Gilmore, D.Sc., Adjunct Professor, University of Queensland, and former CEO and Managing Director at EM Solutions Pty Ltd, Australia

Dr. Gilmore was a pioneer in developing and applying harmonic balance analysis to RF and microwave circuit design, enabling for the first time the accurate modeling of non-linear behaviour in microwave circuits. While Vice President of Engineering with Compact Software, he led the introduction of Microwave Harmonica, the world's first commercial simulator applicable to the nonlinear design of microwave and RF circuits, and that is now commonplace in designers' toolkits.

Dr. Gilmore gained his RF circuit and systems experience over a number of years at Schlumberger and at Central Microwave, where he designed and developed numerous linear microwave power amplifiers, as well as oscillators and switching components. Subsequently, while at Compact Software, he was responsible for the development of their entire software suite of computer aided design tools. He was later Vice President at SITA-Equant, operator of the world's most extensive data network (now part of France Telecom's Orange Network), where he worked with a number of airlines and multinationals on their data telecommunications and IT needs. He has been CEO of EM Solutions since 2011, where he leads an award-winning team of engineers who are involved in the design of multi-band, high power receivers, transmitters, and mobile terminals used in satellite communications systems sold around the world.

He has published more than thirty articles in the field of microwave systems and circuit design and has served on the editorial boards of the IEEE Transactions on Microwave Theory and Techniques, and of Wiley's International Journal of RF and Microwave Computer-Aided Engineering. With Dr. Les Besser, he is co-author of the widely read two-volume textbook Practical RF Circuit Design for Modern Wireless Systems. He is a Fellow of the Australian Academy of Technological Scientists and Engineers.

Dr. Gilmore has been a member of the Continuing Education Institute-Europe faculty since 1995.

Publications:

Dr. Rowan Gilmore and his colleague Dr. Les Besser have written two books that they recommend, however, the books are not compulsory for the course:

Publisher: Artech House

Title: **Practical RF Circuit Design for Modern Wireless Systems**

Volume I: Passive Circuits and Systems. ISBN 1-58053-521-6 (2003)

Title: **Practical RF Circuit Design for Modern Wireless Systems**

Volume II: Active Circuits and Systems. ISBN 1-58053-522-4 (2003)

Students may order the books over the Artech House website, https://us.artechhouse.com/ and receive a 15% discount by entering the promotion code "CEI" in the online order form.