Course Description

Course name	**Course 008 Advanced RF Power Amplifier Techniques for Modern Wireless and Microwave Systems**
Duration	**5 days**
Format	**Public classroom, Online or Inhouse event.**

Overview
Dr. Steve C. Cripps University of Cardiff and Hywave Associates, UK, Dr. Jeff Powell, Skyarna Ltd, UK, and Dr. Roberto Quaglia, Cardiff University, are teaching this course that deals with the theory and design **of RF Power Amplifiers** for wireless, satcom, and microwave applications and features in-depth treatment of PA design, PA modes, envelope power management, and non-linear effects.
In any system, the **power amplifier** is a critical component. It is typically the most costly single item and consumes most of the supply power. Knowledge of the possibilities for trading power per unit cost with efficiency and linearity often forms the basis for the entire system architecture design.

Technical Focus
In any system, the **power amplifier** (PA) is a critical component. It is typically the most costly single item and consumes most of the supply power. Knowledge of the possibilities for trading power per unit cost with efficiency and linearity often forms the basis for the entire system architecture design.
The increasing use of linearisation techniques, and especially the emergence of high speed digital processing as an enabling technology to implement predistortion on the PA input signal, represent an important paradigm shift in PA design.
The PA component can now be designed with more emphasis on efficiency, without the traditional constraints of meeting stringent linearity specs simultaneously. Maximising the utility of a lineariser in order to obtain optimum efficiency has thus become a new subject area in modern **RF PA design**.

Course Content
This is a newly revised and updated 5-day **RF PA design course**, dealing with the theory and design of RF power amplifiers for wireless, satcom, and microwave applications.
The course features in-depth treatment of PA design, PA modes, envelope power management, and non-linear effects.
Benefits of this course is that it enhance your understanding of:

- Power amplifier basic concepts, classes of operation, stability, linearity, bias technique
- Impedance matching techniques based on lumped elements and transmission lines
- High-efficiency techniques including well-know Classes F and E and newly developed classes, Efficiency Enhancement Techniques
- Power Amplifier Non-Linearities and Signal Environments
- PA Architecture

Who should attend?
This course presents an overview, fundamentals, theory, practical and advanced power amplifier design which will be of interest to:

- engineers and technical staff
- managers and business development personnel

who plan to pursue this technology, or compete with it.

Course daily schedule

Day 1
Power Amplifier Basics and Signal Environments
Linear amplifier modes are described with quantitative analysis of power, efficiency and linearity tradeoffs in uncompensated form leading into a discussion of the device technologies currently available for PA design, including LDMOS, GaAs MESFET and HBT, SiC and GaN. Differences between bipolar and FET devices, and the effects of different kinds of parasitic effects will be discussed using circuit analysis and CAD models. Possibilities for tailoring the characteristics of devices for optimum efficiency and linearity will be presented. Particular emphasis is given to correct fundamental and harmonic matching. The impact of non-ideal harmonic terminations in practical Class AB designs will be analysed quantitatively. Various modulation systems (QPSK, EDGE, CDMA, OFDM) will be reviewed from the viewpoint of PA requirements.

- Introduction
- Classical PA Modes, Class A, Class AB, Class B, Class C
- PA Device Technology
- Optimum Device Characteristics for Class AB Operation
- Modulation Systems in Wireless Communications QPSK, GSM, EDGE, OFDM
- Effect of Signal Environment on RFPA Design

Day 2
Class AB PA Design
We will focus on practical issues in the design and manufacture of PAs for RF and MW Systems. Several design examples will be demonstrated, including a GaAs MESFET, a GaAs HBT, and a high power LDMOS device.

- Class AB circuits
- Harmonic Terminations
- CAD Design Examples

Day 3
Power Amplifier Non-Linearity and Signal Environments
We will focus on the non-linear properties of RF PAs, their source, manifestation, and methods for their characterization and modeling. A topical issue of great impact in modern linearised multi-carrier PA (MCPA) applications is memory effects. This subject will be illustrated with device measurements, and physical causes and remedies will be discussed.

There will be a full treatment of bias network design. The process of converting a measured PA gain compression and AM-PM characteristic into spectral and EVM distortion, and the issues involved, will be discussed using several different modulation environments, including GSM-EDGE and WCDMA.

- Non-Linear PA Characteristics, Gain Compression, AM-PM
- Physical Origins of AM-PM, Analysis
- Peak to Average Power Ratio Issues in Modern Signal Environments
- Spectral Regrowth and EVM
- Power Series, Volterra Series. Model Fitting using Measured Data
- Envelope Simulation using EDGE, OFDM signals
- Memory Effects, Definition, Dynamic Gain/Phase Measurements, Causes and Remedies
- Bias Network Design and Stability

Day 4
Efficiency Enhancement Techniques
We will focus on the key issue of power back-off (PBO) efficiency, and LINC (linear amplification using non-linear components). Envelope management methods and tracking techniques in PA design will be presented. These include classical techniques such as the Chireix out-phasing method, the Khan and the Polar Loop envelope reconstruction approaches and the Doherty PA. Other less well-known techniques will be discussed, with emphasis on the broader band requirements, which future WiMax systems will require. Ultra high efficiency amplifier modes, Classes C, D, E, and F will be analyzed as possible candidates for LINC implementation and as stand-alone possibilities in systems using digital pre-distortion or feed forward linearization. Finally, PA architecture, including multistage effects, power combining techniques, and load pull design will be discussed. Step-by-step examples of two MMIC PA designs, one with modest, and a further example with wideband operation will be given – this will include technology evaluation to packaging considerations.

- Power Combining Techniques
- Balanced and Push-Pull Operation
- Load-Pull Techniques
- Microwave PA Design – including step-by-step MMIC PA design examples

Day 5
An introduction to mm-wave components and applications

mm-wave circuits are becoming more commonplace as semiconductor technologies mature which provide performance up to 100 GHz and beyond. This Session will offer an introduction to the technologies and components operating at mm-wave and some of the key applications. Amplifier design at mm-wave will be discussed with a design example. Differences in the approach of amplifier design at mm-wave compared to lower frequency will be highlighted. In addition, an introduction will be given for other common component types at mm-wave: mixers, multipliers, oscillators, and mixed (analogue/digital) signal techniques. Packaging, interconnection, and combining will also be considered. Finally, the emerging field of sub-mm-wave (Terahertz) components will be introduced.

- Applications in mm-wave
- mm-wave technologies

Continuing Education Institute Professional Learning

- Amplifiers – including a design example
- Common mm-wave components
- Packaging at mm-wave
- Terahertz

Instructor´s biography

Professor Steve C. Cripps obtained his Ph.D. degree from Cambridge University, England. He worked for Plessey Research (now GECMM) on GaAsFET hybrid circuit development. Later he joined Watkins-Johnson's solid state division, Palo Alto, CA, and has held Engineering and Management positions at WJ, Loral, and Celeritek. During this period, he designed the industry's first 2-8 Ghz and 6-18 Ghz 1 watt solid state amplifiers, and in 1983 published a technique for microwave power amplifier design, which has become widely adopted in the industry.
In 1990, he became an independent consultant and was active in a variety of commercial RF product developments, including the design of several cellular telephone power amplifier MMIC products. In 1996 he returned to England, where his consulting activities continue to be focused in the RF power amplifier area.
In 2006 Dr. Cripps published a second edition of his best-selling book, "RF Power Amplifier Design for Wireless Communications" (Artech House). He is currently vice-chair of the High Power Amplifier subcommittee of the Technical Co-ordination and Technical Program Committees of the IEEE Microwave Theory and Techniques Society and writes the regular "Microwave Bytes" column in the IEEE Microwave Magazine. He is the recipient of the 2008 IEEE Microwave Applications Award.

Dr. Cripps has been a member of the Continuing Education Institute-Europe faculty since 1998.

Dr. Jeff Powell received his Ph.D. in 1996 from the University of Birmingham, UK.
Since then, he has worked in the field of microwave component design and packaging, using MMIC and hybrid circuit techniques in multiple technologies and various applications. Dr. Powell was a Principal Microwave Engineer at QinetiQ, UK, between 2001 to 2011 where he designed a wide variety of circuit functions using GaAs, InP and GaN technologies in the frequency range from 1 GHz to 110 GHz. He also contributed to the development of a GaN MMIC process at QinetiQ, demonstrating GaN MMIC components. He currently works as a freelance design engineer working for a variety of industrial and university clients.
Dr. Powell has published more than 40 papers and 2 issued or pending patents and has made many technical presentations at international conferences and seminars.

Dr. Powell has been a member of the Continuing Education Institute-Europe faculty since 2013.

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Dr. Roberto Quaglia obtained his Ph.D. in 2012 from Politecnico di Torino, Italy. He then worked at Politecnico di Torino as a Research assistant, on the design, characterisation and linearization of integrated power amplifiers for microwave backhaul.
In 2015 he worked in Huawei Technologies, Milano, Italy, as a MMIC designer, developing components for the first 5G millimetre-wave demonstrators. He later joined Cardiff University as a Marie Skłodowska Curie fellow, working on a project with Prof. Steve Cripps on advanced power amplifier techniques. In September 2017, he became a Lecturer at the School of Engineering of Cardiff University. His current research involves advanced techniques for the characterisation of millimetre-wave transistors, the design of high efficiency broadband amplifiers, and the development of methods for the improvement of linearity/efficiency trade-offs in millimetre-wave transmitters.

Dr. Quaglia has published more than 80 peer-reviewed papers and co-authored 2 books. In 2009 he received the Young Graduated Research Fellowship from the Gallium Arsenide Application Symposium (GAAS) Association. He is an elected member of the IEEE MTT Technical Committee 12 (Microwave High Power Techniques).

Dr. Quaglia has been a member of the Continuing Education Institute-Europe faculty since 2020.