

## Orthogonal Frequency Division Multiplexing (OFDM)

is a bandwidth efficient digital modulation technique which forms the basis of many wireless standards currently under development. OFDM techniques are now extremely popular for wireless communications and form the basic technology for standards such as 802.11, 802.16, and 802.20. It is also found in the more general broadcasting world of DVB (Digital Video Broadcast) and DAB (Digital Audio Broadcast). Future evolutions of 3G (LTE) will likely see the adoption of OFDM, as will different modes of the evolving ultra wideband "standards".

Prior to its use in wireless systems, OFDM was more commonly known as DMT (Discrete Multitone) and found widespread use in ADSL (Asynchronous Digital Subscriber Line), where it allowed efficient use of the available bandwidth and a straightforward way to "drop" certain bands either due to other signals or high levels of noise being present at these frequencies. OFDM is a complex technology to implement, however improvements in integrated circuit technology in the last few years mean that it is now suitable for modern mobile wireless applications.

This intensive 3 day course incorporates everything from the fundamentals, advantages and disadvantages of OFDM modulation to receiver synchronisation techniques and case studies of cutting edge wireless standards such as 802.11a/g (WLAN), 802.16 (WiMAX), 802.20 (MBWA). The course is presented in an intuitive manner, and is underpinned by a strong practical element in which attendees are invited to design and simulate physical layer elements of OFDM systems.

### 1-DAY DVB-H COURSE

This one day course builds on the OFDM principles and introduces the physical layer of Digital Video Broadcast for Handheld (DVB-H). This technology, based on DVB-T, facilitates the delivery of digital TV services to handheld devices. The key OFDM parameters for DVB-T and DVB-H are presented.

### COURSE PRESENTATION

DSP and wireless system physical layer design is clearly a very mathematical subject and often seen as somewhat esoteric. In this course the necessary mathematical theory is presented on a "need to know basis" in an intuitive style. Through the use of simulations and DSP demonstrations attendees shall quickly learn the key principles required for a more complete understanding. This presentation style and ethos has been used with considerable success to many companies, both small and large. As such, on return of the notes, we will offer a full refund to attendees who are not fully satisfied with their own personal learning outcomes.

The course format is:

- 45% Lectures
- 15% Tutorial Discussion
- 40% DSP software hands-on simulation

## LABORATORY SESSIONS

Professional DSP design software will be used for the laboratory session. This advanced software provides a comprehensive and state of the art DSP toolbox for modern signal processing.

### PRE-REQUISITES

This course has been carefully designed to present the complex mathematical theory often associated with wireless systems in an intuitive and straightforward style to a wide audience of engineers and project managers. The following prior experience is useful but not essential: (i) Fundamentals of DSP; (ii) Basic communication systems; (iii) Bachelor level mathematics.

If attending the 1-day DVB-H seminar only, a good understanding of OFDM shall be required.

### COURSE MATERIALS

All participants receive more than 1200 pages of notes in six professionally bound A5 volumes:

1. Introductory DSP Class Notes
2. Advanced DSP Class Notes
3. Introductory Communications Class Notes
4. Advanced Communications Class Notes
5. Mobile and Wireless Standards Notes
6. DSP/Wireless Simulation Workbook

The notes provided form a superset of the materials presented on the course, and will allow further in depth study of wireless systems and DSP after the course.

### MULTIMEDIA CD

Each attendee will receive a a multimedia CD featuring:

1. Electronic versions of all printed notes
2. More than 100 DSP audio demonstrations
3. More than 300 DSP and digital communications demos

### LEARNING OBJECTIVES

On completion of this course, we anticipate that attendees will have a good understanding of:

1. Key DSP algorithmic techniques for implementation of OFDM wireless systems.
2. The main components of an OFDM transmitter
3. Components of an OFDM based receiver.
4. The use of OFDM within various wireless standards.
5. The advantages (and some disadvantages) over techniques such as spread spectrum.
6. Methods for channel equalisation and channel coding.
7. Synchronisation techniques for OFDM based systems.
8. Future evolution of OFDM systems towards more beamforming and MIMO systems.
9. Differences between DVB-T and DVB-H.\*
10. DVB-T & DVB-H physical layer understanding.\*
11. Introduction to other mobile TV standards.\*

(\* applies to DVB-H course)

## OFDM Course Syllabus

### Single Carrier Modulation Review

- Single Carrier: Transmit & Receive
- Quadrature amplitude modulation (QAM)
- Orthogonal carrier principles
- Symbol Mapping: from QPSK to 256-QAM
- Pulse shaping techniques (RRC)
- Matched filtering techniques
- Channel noise and other imperfections
- QAM - Complex Arithmetic Representations
- Complex baseband multipath channels
- Time & frequency channel dispersion
- Inter-Symbol Interference (ISI)

### DSP OFDM "Components" Review

- The generic wireless communication system
- The Discrete Fourier Transform (DFT)
- The Fast Fourier Transform (FFT)
- The inverse FFT (IFFT)
- Windowing for FFTs
- Digital FIR/IIR filters, adaptive filtering

### OFDM Principles

- Historical perspective: DMT
- Motivation for multi-carrier vs single-carrier
- Introduction to OFDM
- The structure of an OFDM signal
- Sub-carrier symbol structure
- Generation of OFDM symbols using the IFFT
- Cyclic prefix (guard interval)
- OFDM signal bandwidth

### Pragmatic OFDM Implementation

- Applications: ADSL, 802.11, 802.16, DAB
- Multipath interference on an OFDM symbol
- Protecting against multipath using cyclic prefix
- Reducing bandwidth (windowing vs filtering)
- Oversampling strategies
- The use of channel coding COFDM
- Generic OFDM transmitter structure

### Power Considerations

- OFDM dynamic range considerations
- Peak-to-average power ratio (PAR)
- Crest factor measurements and limits

- RF Amplifier clipping considerations
- Intermodulation components
- General out of band power generation
- Minimising / reducing PAR

### Propagation Channels

- AWGN and Multipath Propagation Channels
- Delay Spread Values and Time Variations
- Loss of orthogonality in OFDM signals
- Fast and slow fading environments

### Single Carrier Synchronisation and Receiver Design

- Optimal receiver structure
- Maximum Likelihood parameter estimation
- Phase and frequency recovery
- Symbol recovery
- Equalisation techniques
- Error Vector Magnitude (EVM) measurements

### OFDM Receiver Design

- Inter-Carrier Interference (ICI)
- Carrier frequency offset
- Sensitivity to timing errors
- Symbol timing recovery
- Frequency domain equalisers (subcarrier)
- Effects of phase noise
- Synchronisation using training symbols
- Synchronisation using cyclic extension

### Advanced and Emerging OFDM Architectures

- Beamforming strategies for OFDM
- Flash-OFDM
- MIMO techniques for OFDM
- Multicarrier CDMA (MC-CDMA)
- Frequency hopping OFDMA
- OFDMA vs MC-CDMA

### OFDM based Standards

- 802.11 - Physical Layer and MAC
- 802.16 - Physical Layer and MAC
- WiMax and 802.16e
- 802.20: Mobile Broadband Wireless Access (MBWA)
- 802.20: FDD and TDD Proposals
- 3GPP Long Term Evolution (LTE)
- LTE E-UTRA: DL OFDMA and UL SC-FDMA

## 1 - day DVB-H Course Syllabus

### DVB-T - Digital Video Broadcasting - Terrestrial

- Multiple Frequency Networks
- Single Frequency Networks
- Channel Coding
- Channel Modulation
- Supported Operating Modes
- OFDM Frame Structure
- Reference Signals
- Transmission Parameter Signalling
- Spectral Characteristics

### DVB-H - Digital Video Broadcasting - Handheld

- Backward compatibility to DVB-T

- Additional operating modes
- Time slicing techniques for power saving
- Multiprotocol Encapsulation (MPE)
- MPE Forward Error Correction (MPE-FEC)
- Physical Layer additions - signalling & interleaving
- Frequency Domain Parameters for DVB-H
- Typical link budget
- DVB-H signal acquisition

### Mobile TV Standard (Overview)

- Introduction to digital TV
- Media Flo
- T-DMB
- ISDB-T
- MBMS
- DVB-H+