OFDM Orthogonal Frequency Division Multiplexing Tutorial

- OFDM: Orthogonal Frequency Division Multiplexing, is a form of signal modulation that divides a high data rate modulating stream placing them onto many slowly modulated narrowband close-spaced subcarriers, and in this way is less sensitive to frequency selective fading.

OFDM TUTORIAL INCLUDES

- OFDM basics tutorial
- Cyclic Prefix, CP
- Synchronization
- OFDMA / OFDM CDMA comparison

Orthogonal Frequency Division Multiplexing or OFDM is a modulation format that is being used for many of the latest wireless and telecommunications standards.

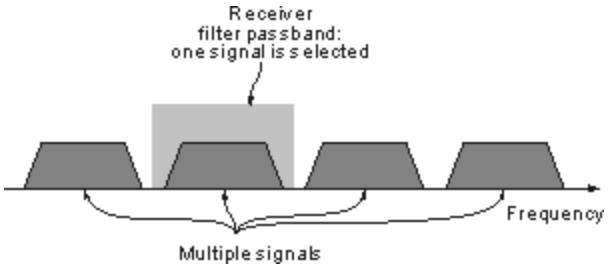
OFDM has been adopted in the Wi-Fi arena where the standards like 802.11a, 802.11n, 802.11ac and more. It has also been chosen for the cellular telecommunications standard LTE / LTE-A, and in addition to this it has been adopted by other standards such as WiMAX and many more.

Orthogonal frequency division multiplexing has also been adopted for a number of broadcast standards from DAB Digital Radio to the Digital Video Broadcast standards, DVB. It has also been adopted for other broadcast systems as well including Digital Radio Mondiale used for the long medium and short wave bands.

Although OFDM, orthogonal frequency division multiplexing is more complicated than earlier forms of signal format, it provides some distinct advantages in terms of data transmission, especially where high data rates are needed along with relatively wide bandwidths.

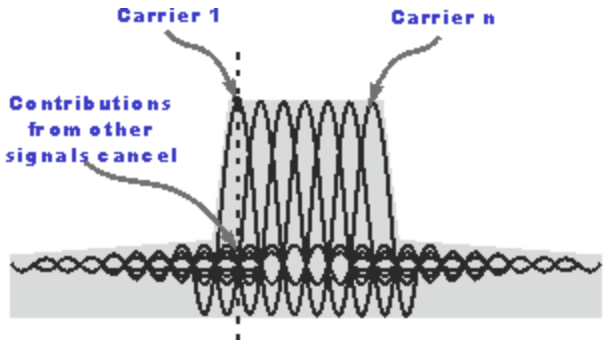
What is OFDM? - The concept

OFDM is a form of multicarrier modulation. An OFDM signal consists of a number of closely spaced modulated carriers. When modulation of any form - voice, data, etc. is applied to a carrier, then sidebands spread out either side. It is necessary for a receiver to be able to receive the whole signal to be able to successfully demodulate the data. As a result when signals are transmitted close to one another they must be spaced so that the receiver can separate them using a filter and there must be a guard band between them. This is not the case with OFDM. Although the sidebands from each carrier overlap, they can still be received without the interference that might be expected because they are orthogonal to each another. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period.



Traditional view of receiving signals carrying modulation

To see how OFDM works, it is necessary to look at the receiver. This acts as a bank of demodulators, translating each carrier down to DC. The resulting signal is integrated over the symbol period to regenerate the data from that carrier. The same demodulator also demodulates the other carriers. As the carrier spacing equal to the reciprocal of the symbol period means that they will have a whole number of cycles in the symbol period and their contribution will sum to zero - in other words there is no interference contribution.



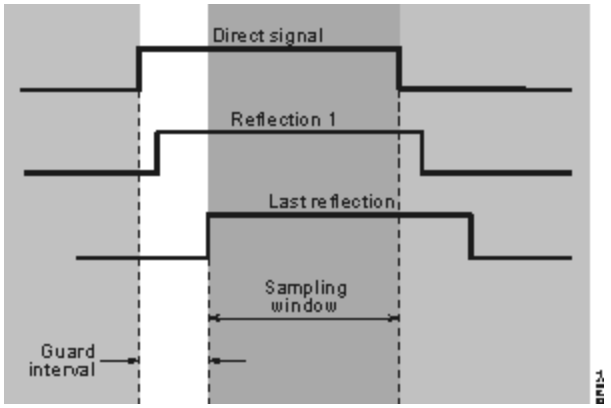
OFDM Spectrum

One requirement of the OFDM transmitting and receiving systems is that they must be linear. Any non-linearity will cause interference between the carriers as a result of inter-modulation distortion. This will introduce unwanted signals that would cause interference and impair the orthogonality of the transmission.

In terms of the equipment to be used the high peak to average ratio of multi-carrier systems such as OFDM requires the RF final amplifier on the output of the transmitter to be able to handle the peaks whilst the average power is much lower and this leads to inefficiency. In some systems the peaks are limited. Although this introduces distortion that results in a higher level of data errors, the system can rely on the error correction to remove them.

Data on OFDM

The data to be transmitted on an OFDM signal is spread across the carriers of the signal, each carrier taking part of the payload. This reduces the data rate taken by each carrier. The lower data rate has the advantage that interference from reflections is much less critical. This is achieved by adding a guard band time or guard interval into the system. This ensures that the data is only sampled when the signal is stable and no new delayed signals arrive that would alter the timing and phase of the signal.



Guard Interval

The distribution of the data across a large number of carriers in the OFDM signal has some further advantages. Nulls caused by multi-path effects or interference on a given frequency only affect a small number of the carriers, the remaining ones being received correctly. By using error-coding techniques, which does mean adding further data to the transmitted signal, it enables many or all of the corrupted data to be reconstructed within the receiver. This can be done because the error correction code is transmitted in a different part of the signal.

OFDM advantages & disadvantages

OFDM advantages

OFDM has been used in many high data rate wireless systems because of the many advantages it provides.

- ***Immunity to selective fading:*** One of the main advantages of OFDM is that is more resistant to frequency selective fading than single carrier systems because it divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels.
- ***Resilience to interference:*** Interference appearing on a channel may be bandwidth limited and in this way will not affect all the sub-channels. This means that not all the data is lost.
- ***Spectrum efficiency:*** Using close-spaced overlapping sub-carriers, a significant OFDM advantage is that it makes efficient use of the available spectrum.
- ***Resilient to ISI:*** Another advantage of OFDM is that it is very resilient to inter-symbol and inter-frame interference. This results from the low data rate on each of the sub-channels.
- ***Resilient to narrow-band effects:*** Using adequate channel coding and interleaving it is possible to recover symbols lost due to the frequency selectivity of the channel and narrow band interference. Not all the data is lost.
- ***Simpler channel equalisation:*** One of the issues with CDMA systems was the complexity of the channel equalisation which had to be applied across the whole channel. An advantage of OFDM is that using multiple sub-channels, the channel equalization becomes much simpler.

OFDM disadvantages

Whilst OFDM has been widely used, there are still a few disadvantages to its use which need to be addressed when considering its use.

- ***High peak to average power ratio:*** An OFDM signal has a noise like amplitude variation and has a relatively high large dynamic range, or peak to average power ratio. This impacts the RF amplifier efficiency as the amplifiers need to be linear and accommodate the large amplitude variations and these factors mean the amplifier cannot operate with a high efficiency level.
- ***Sensitive to carrier offset and drift:*** Another disadvantage of OFDM is that is sensitive to carrier frequency offset and drift. Single carrier systems are less sensitive.

OFDM variants

There are several other variants of OFDM for which the initials are seen in the technical literature. These follow the basic format for OFDM, but have additional attributes or variations:

- ***COFDM:*** Coded Orthogonal frequency division multiplexing. A form of OFDM where error correction coding is incorporated into the signal.
- ***Flash OFDM:*** This is a variant of OFDM that was developed by Flarion and it is a fast hopped form of OFDM. It uses multiple tones and fast hopping to spread signals over a given spectrum band.
- ***OFDMA:*** Orthogonal frequency division multiple access. A scheme used to provide a multiple access capability for applications such as cellular telecommunications when using OFDM technologies.
- ***VOFDM:*** Vector OFDM. This form of OFDM uses the concept of MIMO technology. It is being developed by CISCO Systems. MIMO stands for Multiple Input Multiple output and it uses multiple antennas to transmit and receive the signals so that multi-path effects can be utilised to enhance the signal reception and improve the transmission speeds that can be supported.
- ***WOFDM:*** Wideband OFDM. The concept of this form of OFDM is that it uses a degree of spacing between the channels that is large enough that any frequency errors between transmitter and receiver do not affect the performance. It is particularly applicable to Wi-Fi systems.

Each of these forms of OFDM utilise the same basic concept of using close spaced orthogonal carriers each carrying low data rate signals. During the demodulation phase the data is then combined to provide the complete signal.

OFDM, orthogonal frequency division multiplexing has gained a significant presence in the wireless market place. The combination of high data capacity, high spectral efficiency, and its resilience to interference as a result of multi-path effects means that it is ideal for the high data applications that have become a major factor in today's communications scene.

OFDM Cyclic Prefix, CP

- the cyclic prefix used in Orthogonal Frequency Division Multiplexing provides an essential element of the overall signal acting as a guard band between each OFDM symbol.

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Use of cyclic prefix is a key element of enabling the OFDM signal to operate reliably.

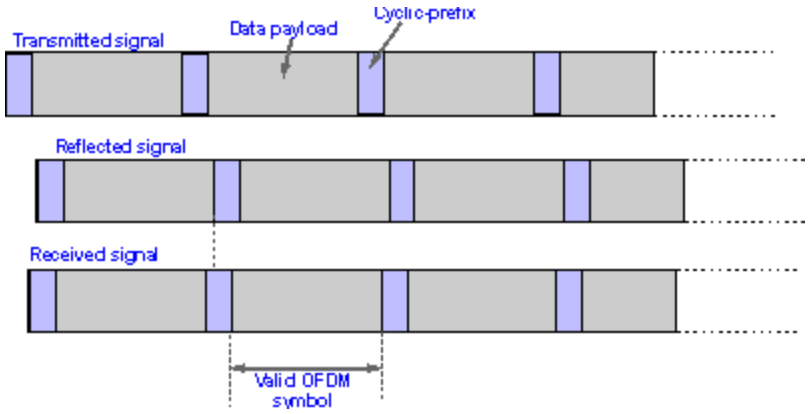
The cyclic prefix acts as a buffer region or guard interval to protect the OFDM signals from intersymbol interference. This can be an issue in some circumstances even with the much lower data rates that are transmitted in the multicarrier OFDM signal.

Cyclic prefix basics

The basic concept behind the OFDM cyclic prefix is quite straightforward.

The cyclic prefix is created so that each OFDM symbol is preceded by a copy of the end part of that same symbol.

Different OFDM cyclic prefix lengths are available in various systems. For example within LTE a normal length and an extended length are available and after Release 8 a third extended length is also included, although not normally used.



OFDM signal with cyclic prefix

Cyclic prefix advantages and disadvantages

There are several advantages and disadvantages attached to the use for the cyclic prefix within OFDM.

Advantages

- ***Provides robustness:*** The addition of the cyclic prefix adds robustness to the OFDM signal. The data that is retransmitted can be used if required.
- ***Reduces inter-symbol interference:*** The guard interval introduced by the cyclic prefix enables the effects of inter-symbol interference to be reduced.

Disadvantages

- ***Reduces data capacity:*** As the cyclic prefix re-transmits data that is already being transmitted, it takes up system capacity and reduces the overall data rate.

OFDM synchronization

- overview of the timing and frequency synchronization required for the successful use of OFDM, orthogonal frequency division multiplex.

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While OFDM has been successfully deployed in many different radio communications systems, one of the main problems that needs to be overcome is that if OFDM synchronization.

Effective OFDM synchronization enables the data error rates to be kept to a minimum, whereas if the system is not accurately synchronized, then errors will result and the system will become less effective.

The need for OFDM synchronization

OFDM offers many advantages in terms of resilience to fading, reflections and the like. OFDM also offers a high level of spectrum efficiency. However to reap the rewards, it is necessary that the OFDM system operates correctly, and to achieve this, it is necessary for the OFDM synchronization to be effective.

There are a number of areas in which the OFDM synchronisation is critical to the operation of the system:

- ***OFDM synchronization in terms of frequency offset:*** It is necessary that the frequencies are accurately tracked to ensure that orthogonality is maintained.
- ***OFDM synchronisation in terms of clock accuracy:*** It is necessary that the sampling occurs at the correct time interval to ensure that the samples are synchronized and data errors are minimised.

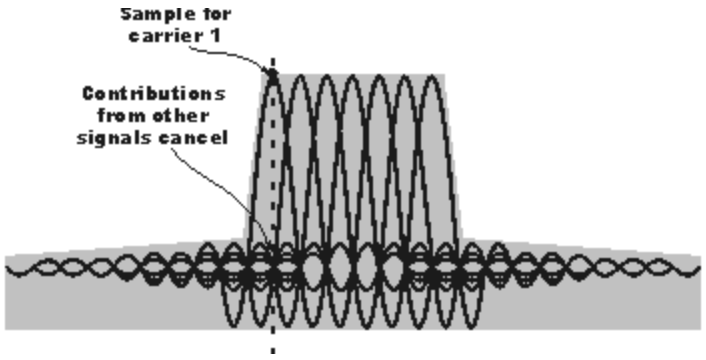
In order to ensure that the OFDM system works to its optimum, it is necessary to ensure that there are schemes in place to ensure the OFDM synchronization is within the required limits.

Frequency offset OFDM synchronization

It is particularly important that the demodulator in an OFDM receiver is able to synchronize accurately with the carriers within the OFDM signal. Offsets may arise for a number of reasons including any frequency errors between the transmitter and the receiver and also as a result of Doppler shifts if there is movement between the transmitter and receiver.

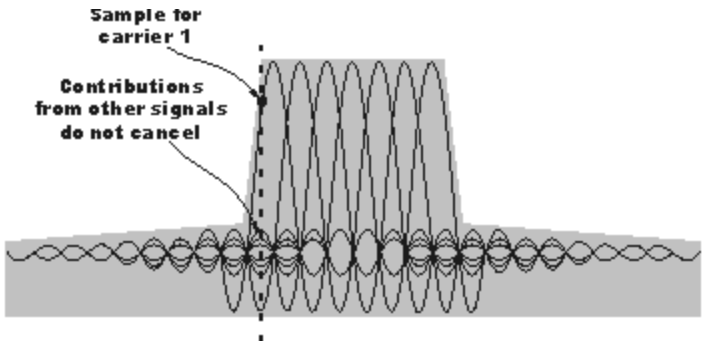
If the frequency synchronisation is impaired, then the orthogonality of the carriers is reduced within the demodulation process and error rates increase. Accordingly it is essential to maintain orthogonality to reduce errors and maintain the performance of the link.

First look at the way that sampling should occur. With the demodulator in synchronisation, all the contributions from the other carriers sum to zero as shown. On this way all the carriers are orthogonal and the error rate is at its minimum.



An OFDM signal where demodulation is in synchronisation

If a situation is encountered where the OFDM synchronisation for the frequency aspects are poor, then the demodulator will centre its samples away from the peak of the signal, and also at a point where the contributions from the other signals do not sum to zero. This will lead to a degradation of the signal which could in turn lead to an increase in the number of bit errors.

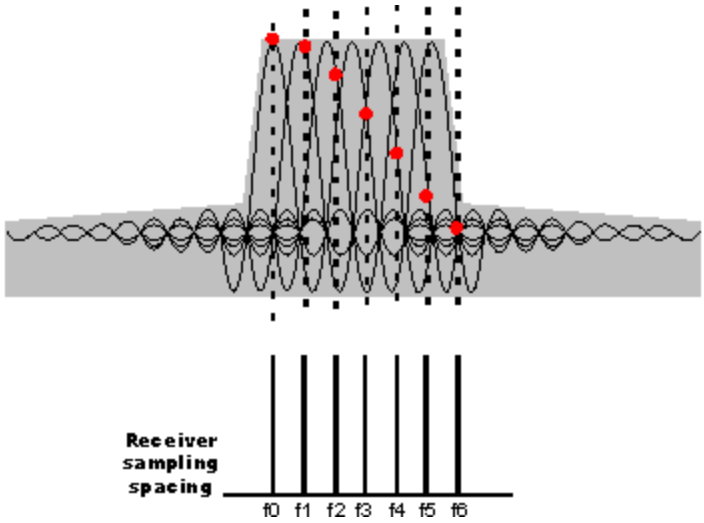


An OFDM signal where demodulation has poor synchronisation

Clock offset OFDM synchronization

It is also necessary to maintain OFDM synchronization in terms of the clock. Gain if the clock synchronisation is not accurate, sampling will be offset and again orthogonality will be reduced, and data errors will increase.

When looking at OFDM synchronization with regard to the clock offset, the carrier spacing used within the receiver for sampling the received signal will be based upon the internal clock rate. If this differs from that used within the transmitter, it will be found that even if the first carrier within the multiplex is correct, then there will be a growing discrepancy with each carrier away from the first one. Even small levels of discrepancy will cause the error rate to increase.



OFDM synchronization problem with clock offset problem

OFDMA, OFDM vs CDMA Comparison

- comparison of the advantages and disadvantages of OFDM and OFDMA against CDMA.

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With OFDM and OFDMA being used in many wireless systems these days, a comparison of the advantages and disadvantages of OFDMA / OFDM and CDMA is often necessary to choose the correct system.

Both CDMA and OFDM / OFDMA have their own advantages and disadvantages and therefore an OFDMA / OFDMA CDMA comparison can be beneficial.

When undertaking an OFDM CDMA comparison, or more correctly an OFDMA CDMA comparison, it is necessary to take a look at all the advantages and disadvantages. Often the OFDM CDMA choice will not be easy, but many systems these days are tending to opt for the OFDM / OFDMA solution over the CDMA solution.

OFDM OFDMA advantages and disadvantages

The tables below outline some of the advantages and disadvantages of OFDM and OFDMA. These need to be considered when looking at an OFDM CDMA comparison.

First the advantages and disadvantages of OFDM will be detailed in the table below:

OFDM ADVANTAGES	OFDM DISADVANTAGES
• OFDMA can easily adapt to severe channel conditions without the need for complex channel equalisation algorithms being employed • It is robust when combatting narrow-band co-channel interference. As only some of the channels will be affected, not all data is lost and error coding can combat this. • Intersymbol interference, ISI is less of a problem with OFDM because low data rates are carried by each carrier. • Provides high levels of spectral efficiency. • Relatively insensitive to timing errors • Allows single frequency networks to be used - particularly important for broadcasters where this facility gives a significant improvement in spectral usage.	• OFDM is sensitive to Doppler shift - frequency errors offset the receiver and if not corrected the orthogonality between the carriers is degraded. • Sensitive to frequency timing issues. • Possesses a high peak to average power ratio - this requires the use of linear power amplifiers which are less efficient than non-linear ones and this results in higher battery consumption. • The cyclic prefix used causes a lowering of the overall spectral efficiency.

It is also necessary to look at the advantages of OFDMA when undertaking an OFDM CDMA comparison.

OFDMA ADVANTAGES	OFDMA DISADVANTAGES
• With spectrum becoming more fragmented, especially for systems such as LTE and LTE advanced, fact that OFDMA provides flexibility of deployment across a variety of frequency bands with little need for modification is of paramount importance. • When used in a cellular system, it is possible to minimise interference from neighbouring cells by using different carrier permutations between the two cells.	• It has a relatively high sensitivity to frequency offsets as this degrades the orthogonality between the carriers • It is sensitive to phase noise on the oscillators as this degrade the orthogonaility between the carriers • Requires complex electronics to run the software - DSP including FFT algorithms needed for the forward error correction. This is always active regardless of data rate, although when no data is being transmitted the system

• Again when used with a cellular system, interference within the cell are averaged by using allocation with cyclic permutations. • A single frequency network can be used to provide excellent coverage and good frequency re-use. • Offers frequency diversity by spreading the carriers all over the used spectrum	can hibernate. However power consumption can be an issue. • If only a few carriers are assigned to each user the resistance to selective fading will be degraded or lost. • When used in a cellular system, co-channel interference from neighbouring cells is more complicated to combat than with CDMA as allocation of carriers needs to be coordinated between the two. • The fast channel feedback information and adaptive sub-carrier assignment is more complex than CDMA fast power control

OFDM CDMA comparison

Both OFDM and CDMA have significant benefits.

OFDM ADVANTAGES	CDMA ADVANTAGES
• OFDM can combat multipath interference with greater robustness and less complexity. Equalisation can be undertaken on a carrier by carrier basis. • OFDMA can achieve higher spectral efficiency with MIMO than CDMA using a RAKE receiver. • Cell breathing does not occur as additional users connect to the base station. • Can be used to provide a single frequency network. • It is relatively easy to aggregate spectrum. • It can be scaled according to the requirements relatively easily	• Not as complicated to implement as OFDM based systems • As CDMA has a wide bandwidth, it is difficult to equalise the overall spectrum - significant levels of processing would be needed for this as it consists of a continuous signal and not discrete carriers. • Not as easy to aggregate spectrum as for OFDM

While both CDMA (DSSS) and OFMD with its variants of OFDMA and SC-FDMA have advantages, many of the systems being implemented now are erring towards the use of OFDMA. With the increase in processing power, it is possible to generate and demodulate OFDM signals with relative ease. As increasing bandwidths are needed, OFDM is being used as it is relatively easy to scale and lends itself to the high data rates being required for many applications.

Radio Frequency, RF, Technology and Design

- concise guides, information, tutorials and data about radio frequency, RF, technology and RF design.

RF technology is key to many aspects of electronics these days. With many systems from cellular to other wireless technologies including, Wi-Fi, WiMAX, NFC, RFID, and many other systems using RF signals.