Multicarrier modulation:

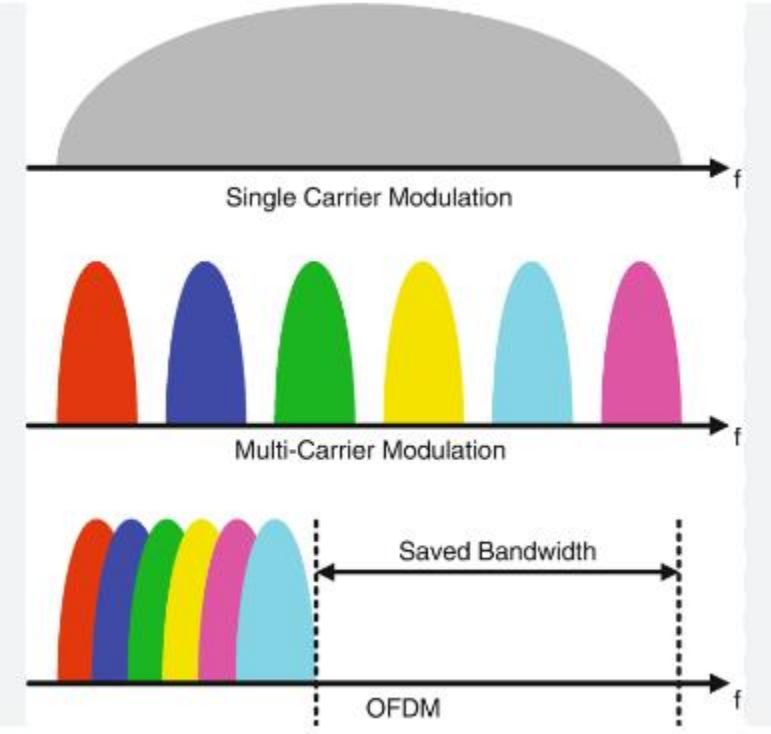
Multicarrier modulation, MCM is a technique for transmitting data by sending the data over multiple carriers which are normally close spaced.

Multicarrier modulation has several advantages including resilience to interference, resilience to narrow band fading and multipath effects.

As a result, multicarrier modulation techniques are widely used for data transmission as it is able to provide an effective signal waveform which is spectrally efficient and resilient to the real world environment.

Introduction: Multi-Carrier Modulation (MCM) is a modulation technique used in telecommunications and digital communication systems. It involves dividing the available bandwidth into multiple subcarriers, each carrying its own low-rate data stream. MCM has gained widespread adoption due to its ability to combat frequency-selective fading, high spectral efficiency, and compatibility with modern communication standards like Orthogonal Frequency Division Multiplexing (OFDM).

Principle: The fundamental principle behind MCM is to transmit data simultaneously over multiple subcarriers, each modulated with low-rate data. By dividing the available bandwidth into these subcarriers, MCM effectively converts a frequency-selective channel into multiple flat-fading subchannels, simplifying equalization at the receiver.



Components:

1. **Transmitter:** The transmitter in an MCM system consists of a bank of modulators, each modulating a separate subcarrier with low-rate data. The modulated subcarriers are then combined and transmitted over the channel.
2. **Channel:** The channel refers to the medium through which the modulated signals propagate. In MCM systems, the channel may introduce frequency-selective fading, which affects the transmission of individual subcarriers.
3. **Receiver:** At the receiver, the transmitted signal is received and demodulated. Each subcarrier is individually demodulated, and the resulting data streams are combined to recover the original transmitted data.

Operation:

1. **Subcarrier Generation:** The available bandwidth is divided into multiple subcarriers using techniques such as Fast Fourier Transform (FFT). Each subcarrier carries a low-rate data stream, and the total data rate is distributed among these subcarriers.
2. **Modulation:** Each subcarrier is modulated with its respective data stream using techniques like Quadrature Amplitude Modulation (QAM) or Phase Shift Keying (PSK). Modulation formats are chosen based on factors such as spectral efficiency and robustness to noise.
3. **Combining:** The modulated subcarriers are combined to form the composite MCM signal, which is transmitted over the channel.
4. **Demodulation:** At the receiver, the transmitted signal is received and demodulated. Each subcarrier is individually demodulated, and the resulting data streams are combined to reconstruct the original transmitted data.

Advantages of MCM:

1. **Frequency Diversity:** MCM provides frequency diversity by distributing data across multiple subcarriers, making it robust against frequency-selective fading.
2. **High Spectral Efficiency:** By efficiently utilizing the available bandwidth, MCM offers high spectral efficiency, enabling the transmission of large amounts of data within limited bandwidth.
3. **Robustness to Interference:** MCM's ability to distribute data across multiple subcarriers helps mitigate the effects of narrowband interference, improving overall system performance.

Types of MCM:

There are many forms of multicarrier modulation techniques that are in use of being investigated for future use. Some of the more widely known schemes are summarized below.

1. ***Orthogonal frequency division multiplexing, OFDM:*** OFDM is possibly the most widely used form of multicarrier modulation. It uses multiple closely spaced carriers and as a result of their orthogonality, mutual interference between them is avoided.
2. ***Generalised Frequency Division Multiplexing, GFDM:*** GFDM is a multicarrier modulation scheme that uses closed spaced non-orthogonal carriers and provides flexible pulse shaping. It is therefore attractive for various applications such as machine to machine communications.

3. ***Filter Bank Multi Carrier, FBMC:*** FBMC is a form of multicarrier modulation scheme that uses a specialised pulse shaping filter known as an isotropic orthogonal transform algorithm, IOTA within the digital signal processing for the system. This scheme provides good time and frequency localisation properties and this ensures that inter-symbol interference and inter-carrier interference are avoided without the use of cyclic prefix required for OFDM based systems.
4. ***SEFDM:*** Spectrally efficient frequency division multiplex uses multiple carriers in the same way as OFDM, but they are spaced closer than OFDM. However it is stil possible to recover the data, although with a slight power penalty.

Multicarrier modulation basics

Multicarrier modulation operates by dividing the data stream to be transmitted into a number of lower data rate data streams. Each of the lower data rate streams is then used to modulate an individual carrier.

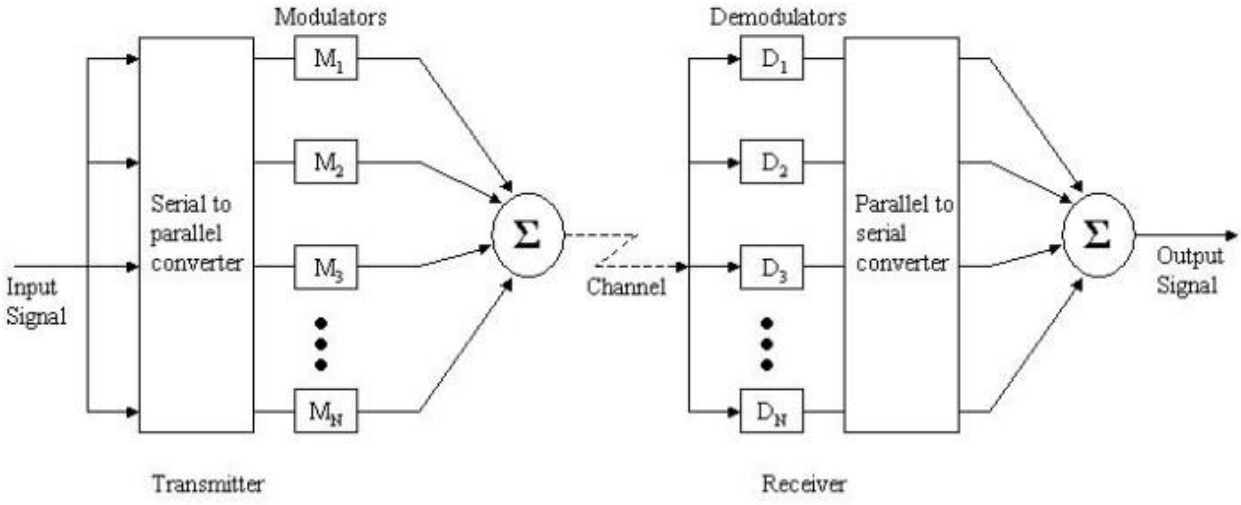


Fig: Structure of multicarrier modulation system.

When the overall transmission is received, the receiver has to then re-assembles the overall data stream from those received on the individual carriers.

It is possible to use a variety of different techniques for multicarrier transmissions. Each form of MCM has its own advantages and can be sued in different applications.

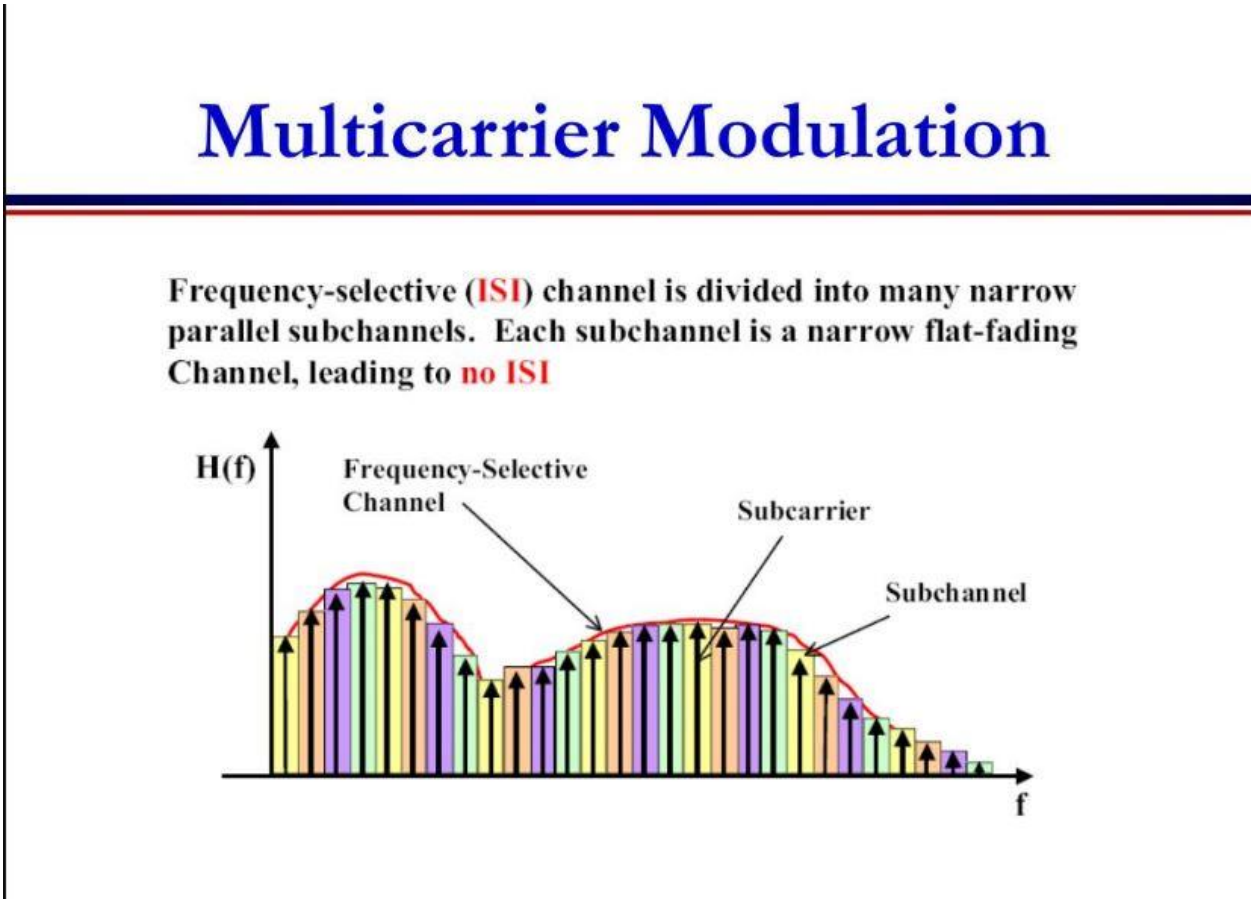
Development of MCM

The history of multicarrier modulation can said to have been started by military users. The first MCM were military HF radio links in the late 1950s and early 1960s. Here several channels were sued to overcome the effects of fading.

Originally the concept of MCM required the use of several channels that were separated from each other by the use of steep sided filters of they were close spaced. In this way, interference from the different channels could be eliminated.

However, multicarrier modulation systems first became widely used with the introduction of broadcasting systems such as DAB digital radio and DVB, Digital Video Broadcasting which used OFDM, orthogonal frequency division multiplexing. OFDM used processing power within the receiver and orthogonality between the carriers to ensure no interference was present.

The various forms of multicarrier modulation each have their own characteristics and advantages. This means that they are applicable in different circumstances, providing improvements in certain areas according to the type of multicarrier modulation used.



Multicarrier Modulation
Non-Overlapping Subchannels

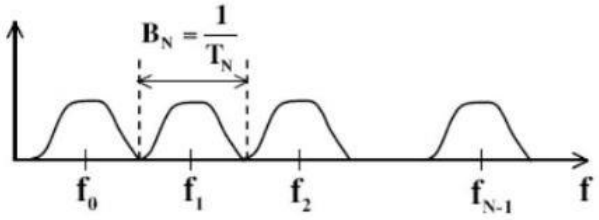
R: Total Data Rate

B: Total Bandwidth

N: No. of Subchannels

$B_N = B/N, \quad T_N = 1/B_N$

$f_i = f_0 + i\,B_N$, $i = 0,1, \ldots, N-1$ subchannel frequencies



Drawbacks of Standard MCM

In practice:

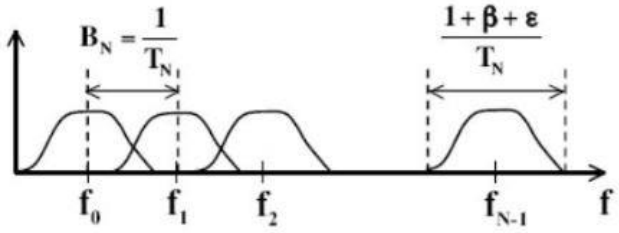
(i) Sharp BPF at receiver not practical
(ii) N independent modulator/demodulators needed
(ii) Subchannel bandwidths are larger

Total BW: $B = \dfrac{N(1+\beta+\varepsilon)}{T_N} > NB_N$

β/T_N additional BW of raised cosine pulse shape
ε/T_N additional BW of time-limiting raised cosine

MCM - Overlapping Subchannels

Solution: **overlapping subchannels**
(eliminates sharp filtering requirements)



$$B = \frac{N+\beta+\varepsilon}{T_N} \approx \frac{N}{T_N} = NB_N$$

Multi-Carrier Modulation (MCM) is a versatile modulation technique widely used in modern communication systems. By dividing the available bandwidth into multiple subcarriers, MCM offers high spectral efficiency, robustness to frequency-selective fading, and compatibility with various communication standards. Its applications span across wireless communication, digital broadcasting, DSL internet access, and more, making it an indispensable technology in today's interconnected world.