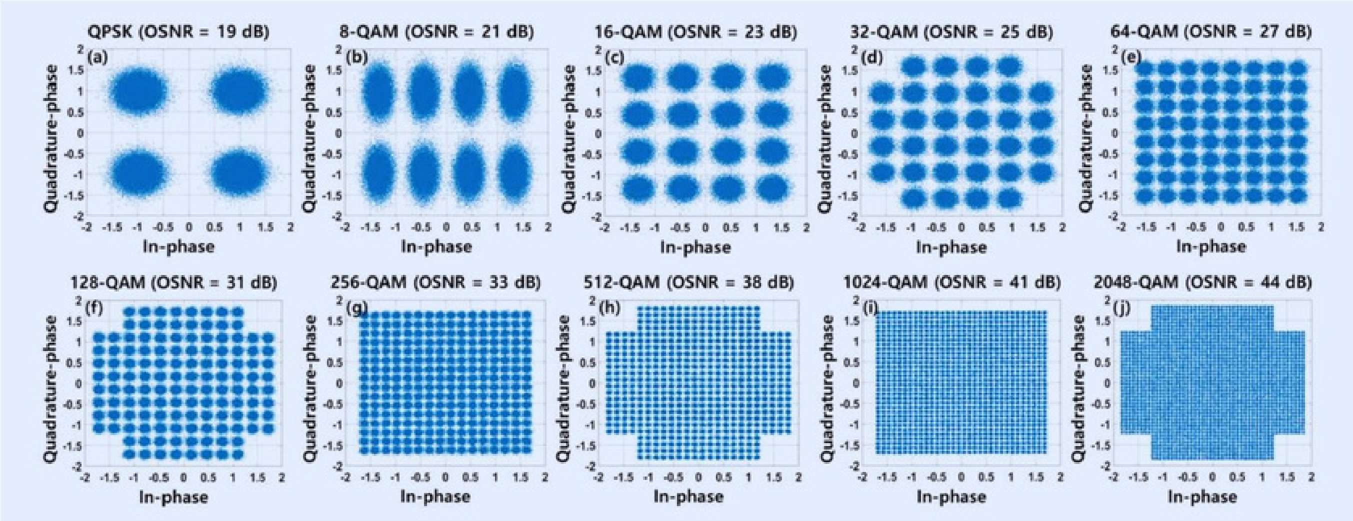
# EION ByTES

## Modern Digital Modulation Techniques used in both Wireless and Wired Communications




### What is Modulation?

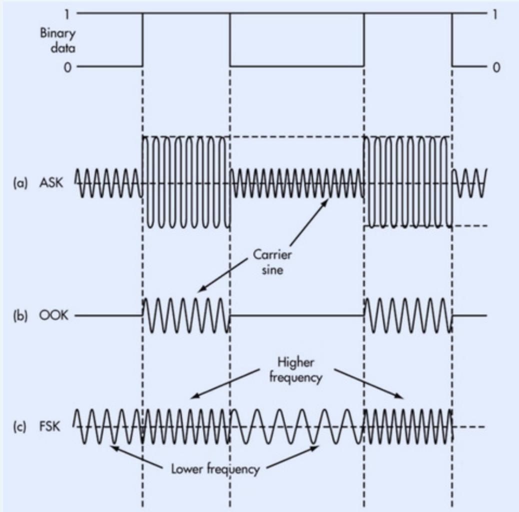
Modulation is fundamental for all wireless communications. It is the process of impressing the data to be transmitted on the radio carrier. Most wireless transmissions today are digital, and with the limited spectrum available, the type of modulation is critical.

Our main modulation goal today is to squeeze as much data into the least amount of spectrum as possible. That objective, known as Spectral Efficiency, measures how quickly data can be transmitted in an assigned bandwidth. The unit of measurement is bits per second per Hz (b/s/Hz).

In this article, we will discuss the multiple techniques that have emerged to achieve and improve the Spectral Efficiency.

# Amplitude Shift Keying (ASK) and Frequency Shift Keying (FSK)

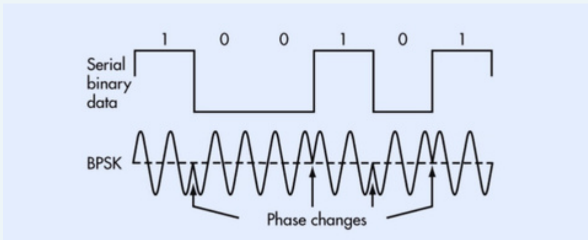
There are three basic ways to modulate a sine wave radio carrier: modifying the amplitude, frequency, or phase. More sophisticated methods combine two or more of these variations to improve spectral efficiency. These basic modulation forms are still used today with digital signals.

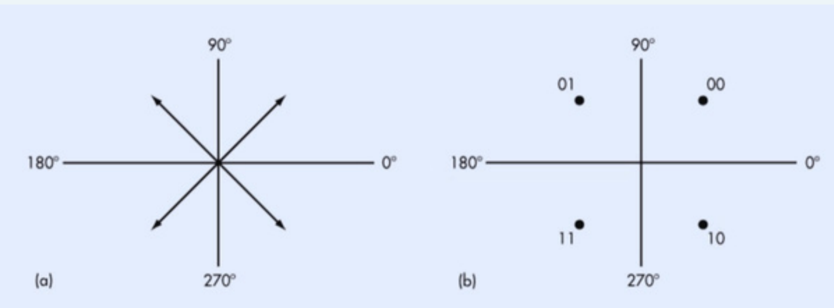



The figure shows a basic serial digital signal of binary zeros and ones to be transmitted and the corresponding AM and FM signals resulting from modulation. (a) The carrier amplitude is shifted between two amplitude levels to produce ASK, and (b) Frequency shift keying (FSK) shifts the carrier between two different frequencies.

# Binary Phase Shift Keying (BPSK) And Quadrature Phase Shift Keying (QPSK)

A very popular digital modulation scheme, binary phase-shift keying (BPSK), shifts the carrier sine wave 180° for each change in the binary state. In the binary phase-shift keying figure, note how a binary 0 is 0º while a binary 1 is 180º. The phase changes when the binary state switches so the signal is coherent.



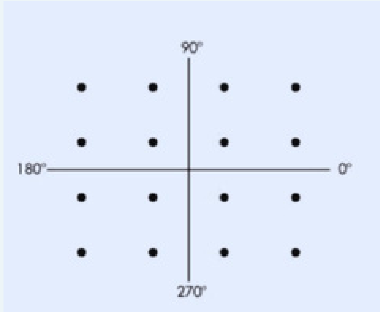




A popular variation of BPSK, quadrature PSK (QPSK), the modulator produces two sine carriers 90º apart. The binary data modulates each phase, producing four unique sine signals shifted by 45º from one another. The two phases are added together to produce the final signal. Each unique pair of bits generates a carrier with a different phase.

QPSK can be represented with a phasor diagram where the phasor represents the carrier sine amplitude peak and its position indicates the phase. A constellation diagram is also another representation for QPSK that shows the same information. QPSK is very spectrally efficient since each carrier phase represents two bits of data. The spectral efficiency is 2 bits/Hz, meaning twice the data rate can be achieved in the same bandwidth as BPSK.

## Quadrature Amplitude Modulation (QAM)

QPSK can be represented with a phasor diagram where the phasor represents the carrier sine amplitude peak and its position indicates the phase. A constellation diagram is also another representation for QPSK that shows the same information. QPSK is very spectrally efficient since each carrier phase represents two bits of data. The spectral efficiency is 2 bits/Hz, meaning twice the data rate can be achieved in the same bandwidth as BPSK.

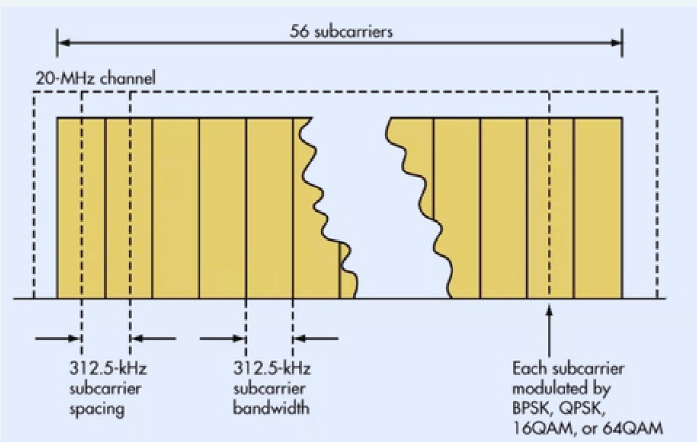



In the figure above, 16 QAM uses a mix of amplitudes and phases to achieve 4bits/Hz. In the above example, there are three amplitudes and 12 phase shifts.

While QAM is enormously efficient in the spectrum, it is more difficult to demodulate in the presence of noise, which is mostly random amplitude variations. Linear power amplification is also required. QAM is very widely used in cable TV, Wi-Fi wireless local-area networks (LANs), satellites, and cellular telephone systems to produce maximum data rate in limited bandwidths.

## Orthogonal Frequency Division Multiplexing (OFDM)

Orthogonal frequency division multiplexing (OFDM) combines modulation and multiplexing techniques to improve spectral efficiency. A transmission channel is divided into many smaller subchannels or subcarriers. The subcarrier frequencies and spacings are chosen so they're orthogonal to one another. Their spectra won't interfere with one another, then, so no guard bands are required.




In the OFDM Signal example above (802.11n), 56 Subcarriers are spaced 312.5 KHz in a 20 MHz channel. The data rate calculated is 300 Mbps and can be achieved using the 64QAM.

The serial digital data to be transmitted is subdivided into parallel slower data rate channels. These lower data rate signals are then used to modulate each subcarrier.

The complex modulation process is only produced by digital signal processing (DSP) techniques. An inverse fast Fourier transform (IFFT) generates the signal to be transmitted. An FFT process recovers the signal at the receiver.

OFDM is very spectrally efficient. That efficiency level depends on the number of subcarriers and the type of modulation, but it can be as high as 30 bits/s/Hz.

**Because of the wide bandwidth it usually occupies and a large number of subcarriers, it also is less prone to signal loss due to fading, multipath reflections, and similar effects common in UHF and microwave radio signal propagation.**

**Currently, OFDM is the most popular form of digital modulation. It is used in Wi-Fi LANs, Long Term Evolution (LTE) 4G cellular systems, digital subscriber line (DSL) systems, and in most power-line communications (PLC) applications.**

## Spectral Efficiency Comparison

**Again, spectral efficiency is a measure of how quickly data can be transmitted in an assigned bandwidth, and the unit of measurement is bits/s/Hz (b/s/Hz). Each type of modulation has a maximum theoretical spectral efficiency measure. See the below table:**

### Spectral Efficiency for Popular Digital Modulation Methods

| Type of modulation | Spectral efficiency (bits/s/Hz) |
|---|---|
| FSK | <1 (depends on modulation index) |
| GMSK | 1.35 |
| BPSK | 1 |
| QPSK | 2 |
| 8PSK | 3 |
| 16QAM | 4 |
| 64QAM | 6 |
| OFDM | >10 (depends on the type of modulation and the number of subcarriers) |

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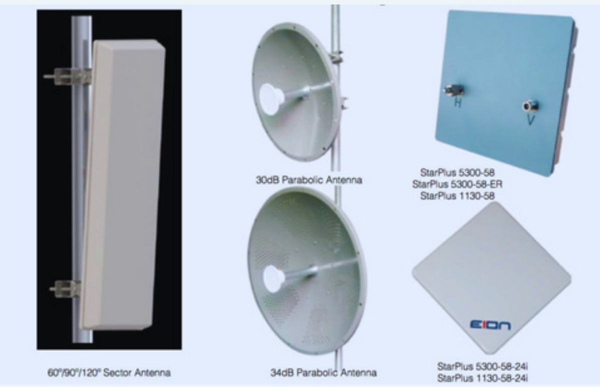


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