23.10: Quadrature Amplitude Modulation

The digital modulation schemes described so far modulate the phase or frequency of a carrier to convey digital data and the constellation points lie on a circle of constant amplitude. The effect of this is to provide some immunity to amplitude changes to the signal. However, much more information can be transmitted if the amplitude is varied as well as the phase. With considerable signal processing it is possible to reliably use quadrature amplitude modulation (QAM) in which amplitude and phase are both changed.

A 16-state rectangular QAM, 16-QAM, constellation is shown in Figure 2.8.18(c). Since there are $16 (= 2^4)$ symbols the values of 4 binary bits are uniquely specified by each symbol. In Figure 2.8.18(c) a gray-scale assignment of 4 bit values is shown. Several QAM schemes are shown in Figure 2.8.20. These constellations can be produced by separately amplitude modulating an I carrier and a Q carrier. Both carriers have the same frequency but are 90° out of phase. The two carriers are then combined so that the fixed carrier is suppressed. The most common form of QAM is square QAM, or rectangular QAM with an equal number of I and Q states. The most common forms are

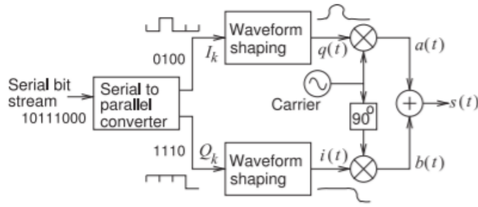

Figure $23.10.1$: QAM modulator block diagram. In QAM modulation $i(t)$ and $q(t)$ address the real and imaginary components of a phasor. The wave-shaping block ensures that the symbol has the correct amplitude and phase at each clock tick.

Modulation	$\mathrm{bits/s/Hz}$
BPSK (ideal)	1
BFSK (actual)	1
QPSK (ideal)	2
GMSK (an actual FSK method)	1.354
$\pi/4$-DQPSK (an actual QPSK method)	1.63
8-PSK (ideal)	3
$3\pi/8$-8PSK (an actual 8PSK method)	2.7
16-QAM (ideal)	4
16-QAM (actual)	2.98
32-QAM (ideal)	4
32-QAM (actual)	3.35
64-QAM (ideal)	6
64-QAM (actual)	4.47
256-QAM (ideal)	8
256-QAM (actual, satellite & cable TV)	6.33
512-QAM (ideal)	9
1024-QAM (ideal)	10
2048-QAM (ideal)	11

Table $23.10.1$: Modulation efficiencies of various modulation formats in $\mathrm{bits/s/Hz}$ (bits per second per hertz). The maximum (or ideal) modulation efficiencies obtained by modulation schemes (e.g., BPSK, BFSK, 64- QAM, 256-QAM) result in broad spectra. Actual modulation efficiencies achieved are less in an effort to manage bandwidth. For example, the values for $pi/4$-DQPSK and $3pi/8$-8PSK are actual. This reduction from ideal arises since symbol transitions are of different lengths and length corresponds to time durations. Since the symbol interval is fixed, it is the longest path that determines the bandwidth required.

16-QAM, 64-QAM, and 128-QAM, in 4G, and 256-QAM additionally in 5G. The constellation points are closer together with high-order QAM and so are more susceptible to noise and other interference. Thus high-order QAM can deliver more data, but less reliably than lower-order QAM.

The constellation in QAM can be constructed in many ways, and while rectangular QAM is the most common form, non rectangular schemes exist; for example, having two PSK schemes at two different amplitude levels. While there are sometimes minor advantages to such schemes, square QAM is generally preferred as it requires simpler modulation and demodulation.

One possible architecture of a QAM modulator is shown in Figure $23.10.1$and this can only be implemented in DSP since it is not sufficient to use analog lowpass filtering to implement the wave-shaping function as the $i(t)$ and $q(t)$ must be precisely the real and imaginary parts of the symbol at each clock tick.