QAM(Quadrature Amplitude Modulation)

QAM is a combination of ASK and PSK

Two different signals sent simultaneously on the same carrier frequency ie, M=4, 16, 32, 64, 128, 256.

As an example of QAM, 12 different phases are combined with two different amplitudes. Since only 4 phase angles have 2 different amplitudes, there are a total of 16 combinations. With 16 signal combinations, each baud equals 4 bits of information (2 ^ 4 = 16). Combine ASK and PSK such that each signal corresponds to multiple bits. More phases than amplitudes. Minimum bandwidth requirement of QAM is same as ASK or PSK.

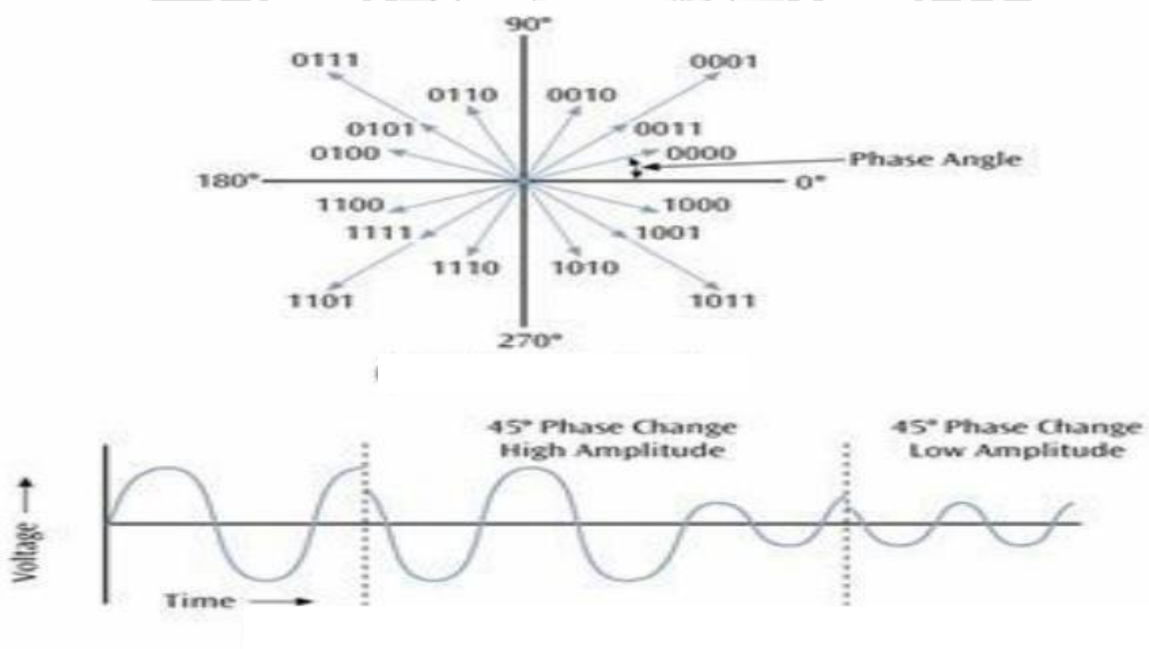

Fig: Phase change with two amplitudes

(Source:Brainkart)

In an *M*-ary PSK system, the in-phase and quadrature components of the modulated signal are interrelated in such a way that the *envelope is constrained to remain constant*. This constraint manifests itself in a circular constellation for the message points, as illustrated in Figure 7.21a. However, if this constraint is removed so as to permit the in-phase and quadrature components to be independent, we get a new modulation scheme called *M-ary* QAM. The QAM is a *hybrid* form of modulation, in that the carrier experiences amplitude as well as phase-modulation. In *M*-ary PAM, the signal-space diagram is one-dimensional. *M*-ary QAM is a twodimensional generalization of *M*-ary PAM, in that its formulation involves two orthogonal passband basis functions:

$$\phi_1(t) = \sqrt{\frac{2}{T}}\cos(2\pi f_c t), \qquad 0 \le t \le T$$

$$\phi_2(t) = \sqrt{\frac{2}{T}}\sin(2\pi f_c t), \qquad 0 \le t \le T$$

Let *d*min denote the minimum distance between any two message points in the QAM

constellation. Then, the projections of the *i*th message point on the ❐1- and ❐2-axes are respectively defined by *ai d*min ❐2 and *bi d*min ❐2, where *i* = 1, 2, ❐, *M*. With the separation between two message points in the signal-space diagram being proportional to the square root of energy, we may therefore set

$$\frac{d_{\min}}{2} = \sqrt{E_0}$$

where *E*0 is the *energy of the message signal with the lowest amplitude*. The transmitted

M-ary QAM signal for symbol *k* can now be defined in terms of *E*0

$$s_k(t) = \sqrt{\frac{2E_0}{T}}a_k\cos(2\pi f_c t) - \sqrt{\frac{2E_0}{T}}b_k\sin(2\pi f_c t), \qquad \begin{cases} 0 \le t \le T \\ k = 0, \pm1, \pm2, \ldots \end{cases}$$

The signal *sk*(*t*) involves two phase-quadrature carriers, each one of which is modulated by a set of discrete amplitudes; hence the terminology “quadrature amplitude modulation.” In *M*-ary QAM, the constellation of message points depends on the number of possible symbols, *M*. In what follows, we consider the case of *square constellations*, for which the number of bits per symbol is even.

QAM Square Constellations

With an *even* number of bits per symbol, Under this condition, an *M*-ary QAM square constellation can always be viewed as the *Cartesian product of a one-dimensional L-ary PAM constellation with itself*. By definition,

the Cartesian product of two sets of coordinates (representing a pair of one-dimensional

constellations) is made up of the set of all possible ordered pairs of coordinates with the

first coordinate in each such pair being taken from the first set involved in the product and

the second coordinate taken from the second set in the product.

Thus, the ordered pairs of coordinates naturally form a square matrix, as shown by

$$\{a_i, b_i\} = \begin{bmatrix} (-L+1, L-1) & (-L+3, L-1) & \cdots & (L-1, L-1) \\ (-L+1, L-3) & (-L+3, L-3) & \cdots & (L-1, L-3) \\ \vdots & \vdots & & \vdots \\ (-L+1, -L+1) & (-L+3, -L+1) & \cdots & (L-1, -L+1) \end{bmatrix}$$

To calculate the probability of symbol error for this *M*-ary QAM, we exploit the following

property:

A QAM square constellation can be factored into the product of the

corresponding *L*-ary PAM constellation with itself.

To exploit this statement, we may proceed in one of two ways:

Approach 1: We start with a signal constellation of the *M*-ary PAM for a prescribed *M*, and then build on it to construct the corresponding signal constellation of the *M*-ary QAM.

Approach 2: We start with a signal constellation of the *M*-ary QAM, and then use it to construct the corresponding orthogonal *M*-ary PAMS.

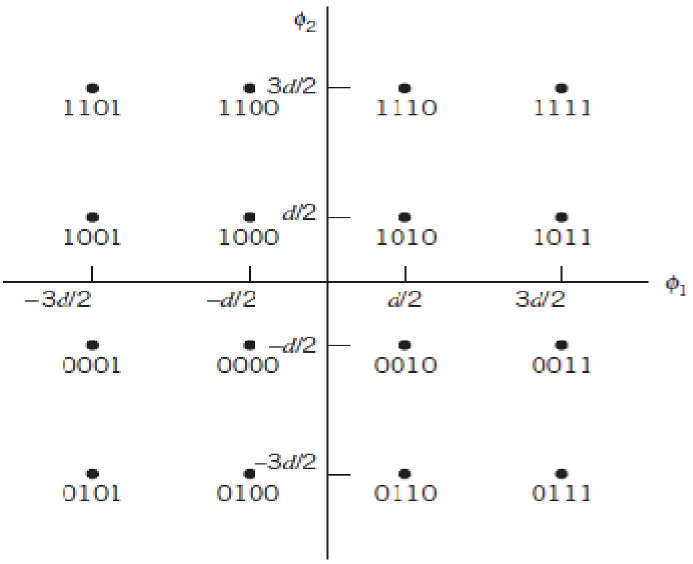

Fig: Signal-space diagram of *M*-ary QAM fo *M* = 16; the message points in each quadrant are identified with Gray-encoded quadbits.

(Source: S. Haykin, ―Digital Communications‖, John Wiley, 2005-Page- 373)