4.2 Advanced Modulation Schemes

Quadrature Amplitude Modulation (QAM)

- **Allowing both amplitude and phase modulated by data**
  - two orthogonal basis functions in quadrature phase

$$\phi_1(t) = \left(\frac{2}{nT}\right)^{1/2} \cos(2\pi f_c t)\ ,\ [0, T_s = nT]$$

$$\phi_2(t) = \left(\frac{2}{nT}\right)^{1/2} \sin(2\pi f_c t)\ ,\ [0, T_s = nT]$$

$M = 2^n$ symbols, n bits/symbol

$S = \{ \bar{s}_i , i = 1, 2, \ldots M\}$ signal set

$\bar{s}_i = (a_i(\frac{d}{2}), b_i(\frac{d}{2}))$, d : minimum distance between 2 symbols

$$s_i(t) = a_i\left(\frac{d}{2}\right)\left(\frac{2}{nT}\right)^{1/2}\cos(2\pi f_c t)+b_i\left(\frac{d}{2}\right)\left(\frac{2}{nT}\right)^{1/2}\sin(2\pi f_c t)$$
$$[0, T_s = nT]$$

  - receiver structure 2

$$2 = N < M = 2^n$$

two arms to identify the received signal vector $\bar{x}$ on the 2-dim plane

Quadrature Amplitude Modulation (QAM)

- **Square/Cross Constellation**
  - Square constellation (n even)

$$L = M^{1/2}$$

$$L \times L \text{ square}$$

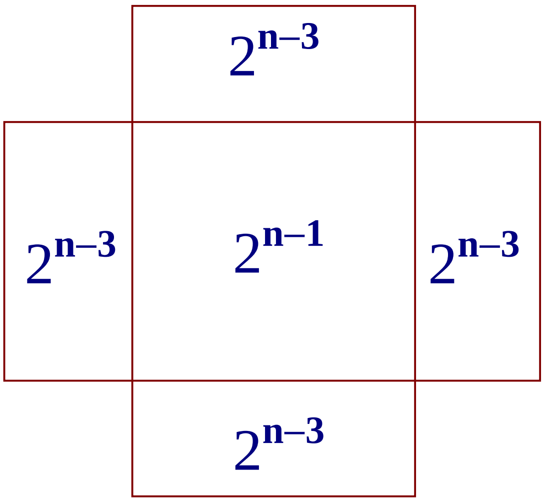
$$\{ a_i , b_i \} = \begin{bmatrix} (-L+1, L-1), (-L+3, L-1), \ldots (L-1, L-1) \\ (-L+1, L-3), (-L+3, L-3), \ldots (L-1, L-3) \\ \vdots \qquad\qquad \vdots \qquad\qquad \vdots \\ (-L+1, -L+1), (-L+3, -L+1), \ldots (L-1, -L+1) \end{bmatrix}$$

example: 16QAM , $M = 16$, $L = 4$
$N = 4$ bits/symbol

$$\{ a_i , b_i \} = (\pm 1, \pm 3)$$

See Fig. 6.17(a) , p. 370 of Haykin

  - Cross constellation (n odd)



$$(2^{n-3}) \times 4 + 2^{n-1} = 2^n$$

Quadrature Amplitude Modulation (QAM)

- **With pulse shaping function**

$g(t)$: pulse shaping function
e.g. raised-cosine

$$s_{\mathbf{i}}(t) = a_{\mathbf{i}}\left(\frac{d}{2}\right)g(t)\mathit{cos}(2\pi f_{\mathbf{c}}t)+b_{\mathbf{i}}\left(\frac{d}{2}\right)g(t)\mathit{sin}(2\pi f_{\mathbf{c}}t)$$

$$, i = 1, 2,\ldots M = 2^{\mathbf{n}}, [0, T_{\mathbf{s}} = nT]$$

$$p(t) \in \{ s_{\mathbf{i}}(t), i = 1, 2,\ldots M \}$$

$$s(t) = \sum_{k=-\infty}^{\infty} p(t-kT)$$

$$= \sum_{k=-\infty}^{\infty} [a_{\mathbf{k}}g(t-kT)\mathit{cos}(2\pi f_{\mathbf{c}}t)+b_{\mathbf{k}}g(t-kT)\mathit{sin}(2\pi f_{\mathbf{c}}t)]$$

- **Examples :**

V. 32 modem, *See Fig. 6.50 ,   p. 424 of Haykin*

V. 34 modem, *See Fig. 6.53 ,   p. 430 of Haykin*

Minimum Shift Keying (MSK)

- **Variation of QPSK**
  - QPSK

    $s_i(t)=A/(2^{1/2})[\pm cos(2\pi f_c t) \pm sin(2\pi f_c t)]$

    $[\ 0, T_s = 2T\ ]$
  - MSK

    $s_i(t)=A/(2^{1/2})[\pm cos(\frac{\pi t}{2T})cos(2\pi f_c t)\pm sin(\frac{\pi t}{2T})sin(2\pi f_c t)]$

    $[\ 0, T_s = 2T\ ]$

    $cos(\frac{\pi t}{2T})$, $sin(\frac{\pi t}{2T})$: pulse shaping

    orthogonal basis :

    $\phi_1(t) = (\frac{2}{T})^{1/2}cos(\frac{\pi t}{2T})cos(2\pi f_c t)$, $[\ 0, T\ ]$

    $\phi_2(t) = (\frac{2}{T})^{1/2}sin(\frac{\pi t}{2T})sin(2\pi f_c t)$, $[\ 0, T\ ]$

    final signal is continuous in both waveform and phase, with constant envelope

    See Fig. 6.30, p. 393 of Haykin

- **Gaussian-Filtered MSK (GMSK)**

  data stream filtered by a Gaussian filter before MSK modulated

  - used in GSM wireless system

Multichannel Modulation

- transmission over a difficult channel replaced by parallel transmission of many subchannels each viewed effectively as a simple channel

- difficult problems for complicated wideband channels eliminated

  See Fig. 6.54, p. 433 of Haykin

- data stream divided into many substreams of symbols for the subchannels

  $(a_{\mathbf{n}}, b_{\mathbf{n}})$, $n = 1, 2, \ldots N$

  N : total number of subchannels

  basis functions for the subchannels

  $\{\phi(t)\mathit{cos}(2\pi f_{\mathbf{n}}t)\ ,\ \phi(t)\mathit{sin}(2\pi f_{\mathbf{n}}t)\}$, $n = 1, 2, \ldots N$

  See Fig. 6.55, p. 434 of Haykin

• **Extensions**

- Discrete Multitone (DMT)

- Orthogonal Frequency-Division Multiplexing (OFDM)

  Ref : 6.4, 6.5, 6.12, 6.13 of Haykin