QUADRATURE AMPLITUDE MODULATION: (QAM)

M-ary QAM

There are M symbols.

Similar to Quadrature Phase Shift keying (QPSK), there are two pulses $p_1(t)$, $p_2(t)$

$$x(t) = a_1 p_1(t) \pm a_2 p_2(t)$$

2 Separate PAM symbols.

a_1, a_2 are independent symbols from a PAM constellation.

$$p_1(t) = \sqrt{\frac{2}{T}} \cos(2\pi F_c t)$$

$$p_2(t) = \sqrt{\frac{2}{T}} \sin(2\pi F_c t)$$

$$0 \leq t \leq T$$

$$T = \frac{k}{F_c}$$

Identical to QPSK. $\mathcal{E}_p = 1$ Pulse Energy

$p_1(t)$, $p_2(t)$ are in Quadrature

$$\left(\sqrt{\frac{2}{T}} \sin\left(2\pi F_c t + \frac{\pi}{2}\right) = \sqrt{\frac{2}{T}} \cos(2\pi F_c t)\right)$$

$p_1(t)$, $p_2(t)$ differ in phase by $\pi/2$.

The total number of symbol is constellation $= M$

M-ary QAM.

Each a_1, a_2 is drawn from a PAM with $\sqrt{M}$ symbols.

Total # symbols in QAM

$$= \sqrt{M} \times \sqrt{M} = M.$$

Similar to PAM,

we are now using

$a_1, a_2 \in \sqrt{M}$ – ary PAM.

$$a_1 = \pm (2i+1) A$$

2A is separation between levels of PAM.

$$0 \le i \le \frac{\sqrt{M}}{2} - 1$$

$$a_2 = \pm (2j+1) A$$

$$0 \le j \le \frac{\sqrt{M}}{2} - 1$$

Naturally means $\frac{\sqrt{M}}{2}$ must be integer

Ex: 64 QAM

$M = 64$

$\sqrt{M} = 8$

$\frac{\sqrt{M}}{2} = 4$

Each constituent PAM comprises of 8 symbols.

Total #bits/symbol

$= \log_2 64 = \log_2 M$

$= 6$

3 bits/Each PAM.

Average Symbol Energy = E_s.

Average energy per a_1 = $\frac{E_s}{2}$

Average Energy per a_2 = $\frac{E_s}{2}$

Each constituent PAM has $\frac{1}{2}$ the symbol Energy i.e. $E_s/2$.

$\sqrt{M}$ — any PAM.

Distance between levels = 2A.

$\Rightarrow$ Average energy

$$\frac{\mathcal{E}_{s.}}{2} = \frac{A^2}{3} \cdot \left(\left(\sqrt{M}\right)^2 - 1 \right).$$

$$\Rightarrow \boxed{A = \sqrt{\frac{3\mathcal{E}_{s.}}{2(M-1)}}}$$

Ensures average energy $\mathcal{E}_s$ for M-ary QAM.