EEEN 462 – ANALOGUE COMMUNICATION

ANALOGUE QUADRATURE AMPLITUDE MODULATION (QAM) - STUDY GUIDE/REVISION

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1. INTRODUCTION TO ANALOG QAM

Key Concepts:

1. **Definition**

Analog QAM transmits two independent message signals simultaneously over the same carrier frequency by modulating **in-phase (I)** and **quadrature (Q)** carriers (90° out of phase).

2. **Core Principle**: Utilizes **orthogonality** of sine/cosine to separate signals.

3. Motivation for QAM

   - **Spectral efficiency:** Transmits two signals in the same bandwidth as one AM/DSB-SC signal.
   - Foundational for modern digital QAM (e.g., Wi-Fi, cable modems).

4. **Comparison**:

Modulation	Bandwidth Efficiency	Demodulation Complexity
AM	Low (2×B)	Simple (envelope detect)
DSB-SC	Moderate (2×B)	Coherent required
QAM	**2×B for 2 signals**	Coherent required

2. MATHEMATICAL REPRESENTATION

Modulated Signal:

$$s(t) = I(t)\cos(2\pi f_c t) - Q(t)\sin(2\pi f_c t)$$

I(t): In-phase baseband signal (e.g., voice, data).

Q(t): Quadrature baseband signal.

f_c: Carrier frequency.

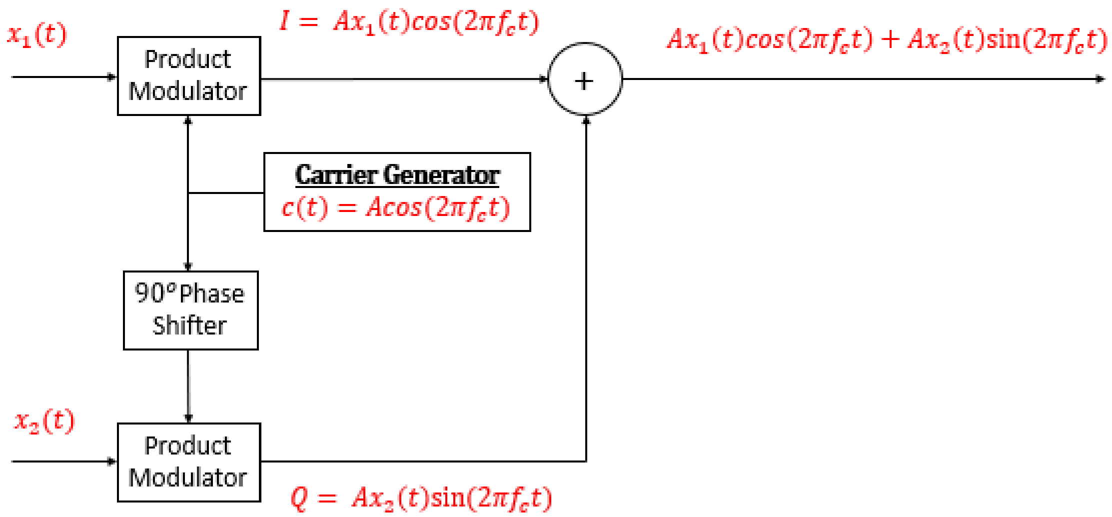
Bandwidth:

- Each baseband signal (I(t), Q(t) has bandwidth *B*.
- **QAM bandwidth = 2*B*** (same as DSB-SC but carries **two signals**).

Orthogonality Proof:

$$\int_0^T \cos(2\pi f_c t)\sin(2\pi f_c t)dt = 0 \quad (\text{for } f_c \gg 1/T)$$

3. MODULATION PROCESS



Steps:

1. Multiply I(t) by $\cos(2\pi f_c t)$.
2. Multiply Q(t) by $-\sin(2\pi f_c t)$.
3. Sum the results to form s(t).

Example:

$$I(t) = m_1(t) = \cos(2\pi f_m t), Q(t) = m_2(t) = \sin(2\pi f_m t)$$

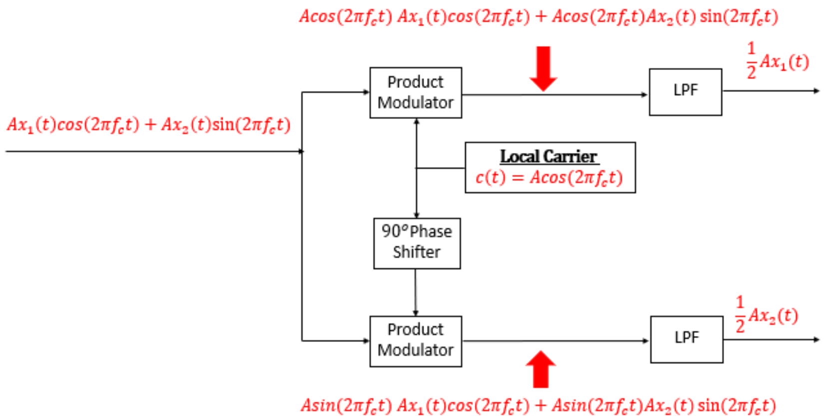
Modulated signal:

$$s(t) = \cos(2\pi f_m t)\cos(2\pi f_c t) - \sin(2\pi f_m t)\sin(2\pi f_c t) = \cos(2\pi(f_c + f_m)t)$$

4. DEMODULATION PROCESS

Coherent Detection Required:

- Local oscillators must match transmitter carrier frequency/phase.



Steps:

1. Multiply s(t) by cos($2\pi f_c t$) and low-pass filter to recover I(t)/$I(t)$:

$$s(t)\cos(2\pi f_c t) = I(t)\cos^2(2\pi f_c t) - Q(t)\sin(2\pi f_c t)\cos(2\pi f_c t)$$

$$\text{LPF output} = \frac{I(t)}{2}$$

2. Multiply s(t) by −sin($2\pi f_c t$) and filter to recover Q(t):

$$\text{LPF output} = \frac{Q(t)}{2}$$

Impact of Phase Error (ϕ):

- Recovered signals:

$$I'(t) = I(t)\cos\phi - Q(t)\sin\phi, \quad Q'(t) = I(t)\sin\phi + Q(t)\cos\phi$$

Crosstalk: I(t) leaks into Q(t) and vice versa.

5. ADVANTAGES & DISADVANTAGES

Advantages:

- **Bandwidth efficiency**: Two signals in the bandwidth of one DSB-SC signal.
- **Compatibility**: Forms the basis for digital QAM (e.g., 16-QAM, 64-QAM).

Disadvantages:

- **Sensitivity**: Requires precise carrier synchronization (phase/frequency).
- **Vulnerability**: Susceptible to channel noise and amplitude distortion.

6. APPLICATIONS

1. **Analogue Television**
   - **NTSC/PAL**: Chrominance (colour) signals modulated via QAM on a subcarrier.
2. **Legacy Microwave Systems**: Analog point-to-point communication.
3. **Software-Defined Radio (SDR)**: Demonstrates analogue QAM principles.