EEEN 462 – ANALOGUE COMMUNICATION

AMPLITUDE MODULATION (AM) STUDY GUIDE

1. INTRODUCTION

Amplitude Modulation (AM) is an analogue modulation technique where the **amplitude** of a high-frequency carrier wave is varied **in proportion** to the instantaneous amplitude of a lower-frequency message (modulating) signal. It's fundamental in radio broadcasting (AM radio) and forms the basis for understanding many other modulation schemes.

1. **Signals & Systems:**
    - Continuous-Time (CT) vs. Discrete-Time (DT) signals.
    - Periodic vs. Aperiodic signals.
    - Basic signal operations (scaling, shifting, addition, multiplication).
    - Concept of frequency (Hz).
2. **Fourier Analysis:**
    - Understanding the frequency domain representation of a signal (Fourier Transform - FT).
    - Concept of bandwidth (BW) - the range of frequencies a signal occupies.
    - Spectrum of a pure sinusoid (impulse at $\pm f_c$).
    - Spectrum of a baseband message signal (occupying 0 to f_m Hz).
3. **Need for Modulation:**
    - Antenna size proportional to wavelength ($\lambda = c/f$). Low-frequency signals require impractical antenna sizes.
    - Frequency Division Multiplexing (FDM): Multiple signals transmitted simultaneously over the same medium using different carrier frequencies.
    - Ease of radiation for higher frequencies.
    - Overcoming noise/interference limitations at baseband.

2. AM: MATHEMATICAL REPRESENTATION

1. **The Carrier Wave:** $c(t) = A_c * \cos(2\pi f_c t + \phi_c)$
    - A_c: Carrier Amplitude (Constant in unmodulated state)
    - f_c: Carrier Frequency (>> message frequency f_m)
    - ϕ_c: Carrier Phase (Often assumed 0 for simplicity)

2. **The Message Signal:** m(t)
   - Represents the information (e.g., audio, data).
   - Bandwidth = B Hz (Occupies 0 to B Hz).
   - Maximum Amplitude = m_p.
3. **Standard AM (DSB-FC - Double Sideband Full Carrier):**
   - **Time Domain Expression:**
     s_AM(t) = A_c * [1 + μ * m_n(t)] * cos(2πf_c t)
     - s_AM(t): Modulated AM signal.
     - m_n(t) = m(t) / m_p: Normalized message signal (-1 ≤ m_n(t) ≤ 1).
     - μ = k * m_p: **Modulation Index** (Critical Parameter!)
       - k: Sensitivity constant of the modulator (V^{-1}).
       - 0 ≤ μ ≤ 1 required to avoid distortion (Overmodulation).
   - **Envelope:** The term A_c * [1 + μ * m_n(t)] is the **envelope** of the AM signal. The message m_n(t) *must* lie within this envelope for distortion-free demodulation.

3. MODULATION INDEX (M)

1. **Definition:** μ = (A_max - A_min) / (A_max + A_min)
   - A_max: Maximum amplitude of the modulated wave envelope.
   - A_min: Minimum amplitude of the modulated wave envelope.

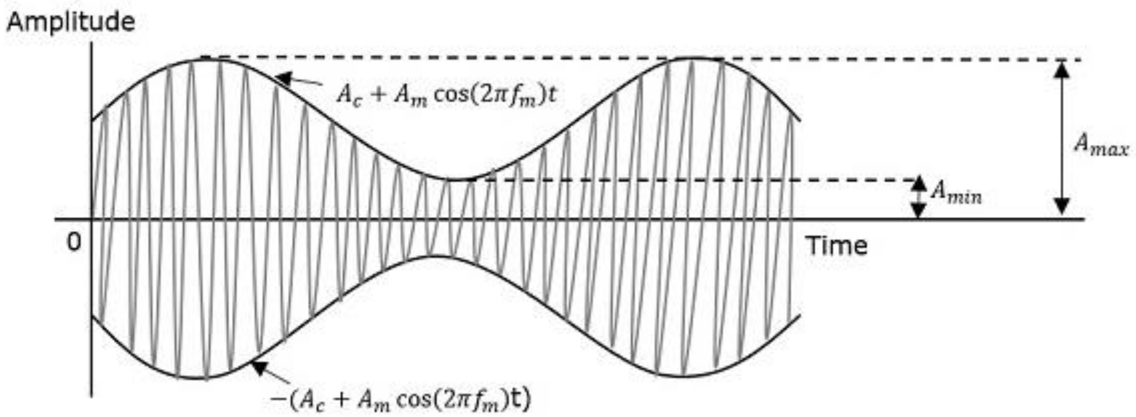

Figure 1. AM Modulation Index

2. **Significance:**
   - **μ = 0:** No modulation (Carrier only).
   - **0 < μ < 1:** Under-modulation (Correct operation).
   - **μ = 1:** 100% modulation (Envelope touches zero at minima).
   - **μ > 1:** Over-modulation (Envelope crosses zero, causing severe distortion - "Envelope Inversion").

3. **Percentage Modulation:** % Modulation = μ * 100%

4. FREQUENCY DOMAIN ANALYSIS (SPECTRUM)

1. **Assume Simple Message:** $m(t) = A_m * \cos(2\pi f_m t)$ (Single tone for clarity).
2. **AM Signal:** $s_{AM}(t) = A_c [1 + \mu \cos(2\pi f_m t)] \cos(2\pi f_c t)$
3. **Trigonometric Expansion:**
   $s_{AM}(t) = A_c \cos(2\pi f_c t) + (A_c \mu / 2) \cos(2\pi(f_c + f_m)t) + (A_c \mu / 2) \cos(2\pi(f_c - f_m)t)$
4. **Spectrum Components:**
   - **Carrier:** Amplitude = A_c, Frequency = f_c.
   - **Upper Sideband (USB):** Amplitude = $A_c \mu / 2$, Frequency = $f_c + f_m$.
   - **Lower Sideband (LSB):** Amplitude = $A_c \mu / 2$, Frequency = $f_c - f_m$.

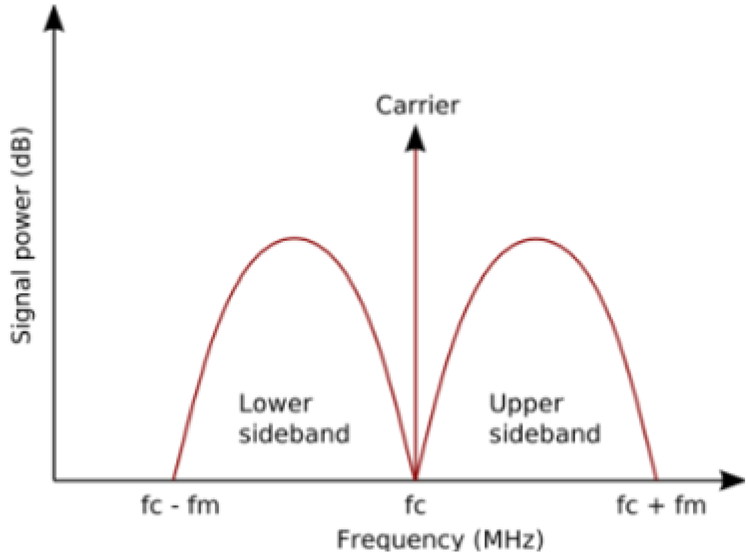

Figure 2. Spectrum Components in AM signal

5. **General Message Spectrum:**
   - Carrier remains at f_c.
   - USB: Exact replica of the *message spectrum* shifted up to frequencies f_c to $f_c + B$.
   - LSB: Exact replica of the *message spectrum* shifted down to frequencies $f_c - B$ to f_c.
   - **Bandwidth (BW):** $BW_{AM} = 2 * B$ (Twice the message bandwidth).

5. POWER DISTRIBUTION

1. **Total Transmitted Power (Pt):**
   $P_t = P_c + P_{usb} + P_{lsb}$

2. **Carrier Power** (Pc)**:**
   Pc = (Ac^2) / 2$\frac{A_c^2}{2}$ (Average power of $A_c \cos(\omega_c t)$ across 1Ω resistor)

3. **Sideband Power (Each):**
   $P_{usb} = P_{lsb}$ = ((A_c μ / 2)^2) / 2 = (A_c^2 μ^2) / 8

4. **Total Sideband Power** (P_sb)**:**
   $P_{sb} = P_{usb} + P_{lsb}$ = (A_c^2 μ^2) / 4

5. **Total Power** (P_t)**:**
   P_t = P_c + P_sb = (A_c^2 / 2) + (A_c^2 μ^2 / 4) = (A_c^2 / 2) * [1 + (μ^2 / 2)]

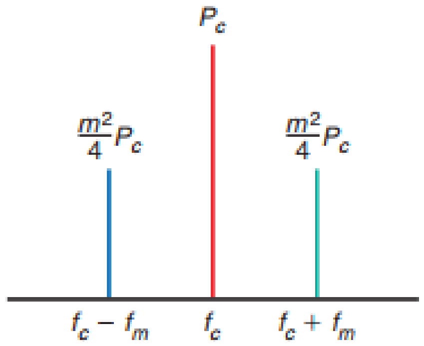

Figure 3. Power distribution in AM signal

6. **Power Efficiency** (η_AM)**:**
   η_AM = (P_sb / P_t) * 100% = (μ^2 / (2 + μ^2)) * 100%
   - **Maximum Efficiency:** At μ=1, η_max = (1 / (2 + 1)) * 100% = 33.3%. **Most power (≥66.7%) is wasted in the carrier!**

6. GENERATION METHODS (CONCEPTUAL)

1. **Square Law Modulator:** Uses the non-linear (square-law) region of a device (e.g., diode, transistor). s_AM ≈ k1*c(t) + k2*[c(t) + m(t)]^2.

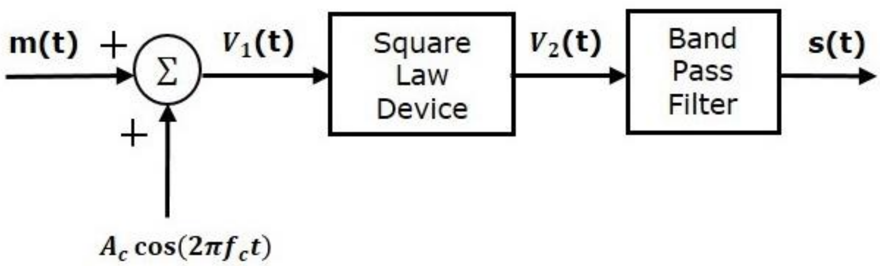

Figure 4. AM square law Modulator

2. **Switching Modulator:** Uses a device (e.g., diode, FET) acting as a switch controlled by the carrier. Effective multiplication.

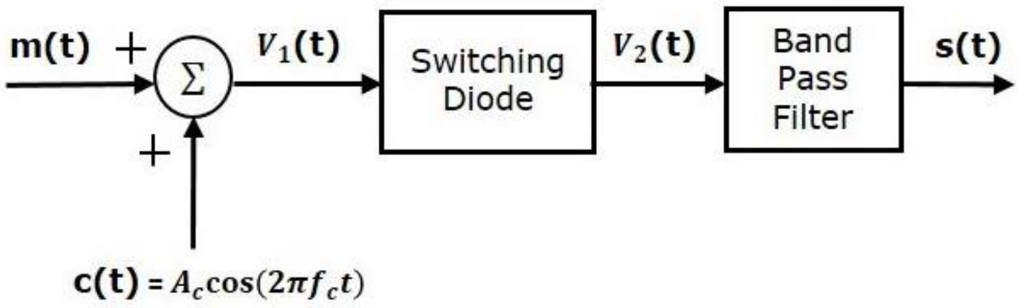

Figure 5. Switching AM modulator

3. **Balanced Modulator (for DSB-SC)** consists of two identical AM modulators. These two modulators are arranged in a balanced configuration in order to suppress the carrier signal as shown below.

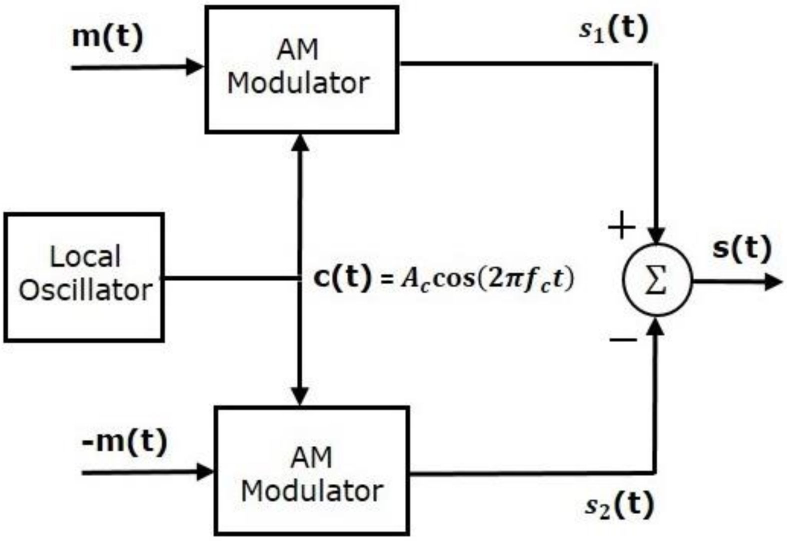

Figure 5. Balanced AM Modulator

7. DEMODULATION (DETECTION) METHODS

1. **Envelope Detector:**
   - **Principle:** Extract the envelope of the AM wave.
   - **Circuit:** Simple diode (half-wave rectifier) + RC low-pass filter.
   - **Pros:** Very simple, cheap, used in most AM radios.
   - **Cons:** Requires μ ≤ 1 (no overmodulation); Performance degrades significantly with noise; Cannot demodulate DSB-SC/SSB.

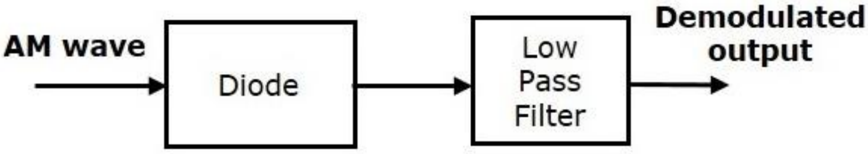

Figure 6. Envelope detector

2. **Synchronous Detection (Coherent Detection):**
   - **Principle:** Multiply the received signal r(t) = s_AM(t) by a *local oscillator* signal cos(2πf_c t) synchronized in frequency and phase with the original carrier.
   - **Process:** r(t) * cos(ω_c t) = s_AM(t) * cos(ω_c t) = ... = (A_c/2)[1 + μ m_n(t)] + (A_c/2)[1 + μ m_n(t)] cos(2ω_c t)
   - **Low-Pass Filtering:** Removes the high-frequency 2ω_c component, leaving (A_c/2)[1 + μ m_n(t)]. DC blocking recovers m_n(t).
   - **Pros:** Can demodulate DSB-SC and SSB; More resilient to noise than envelope detector (in theory).
   - **Cons:** Requires generating a *coherent* local carrier (f_c and ϕ_c match precisely) - complex and expensive; Carrier recovery needed for suppressed carrier schemes.

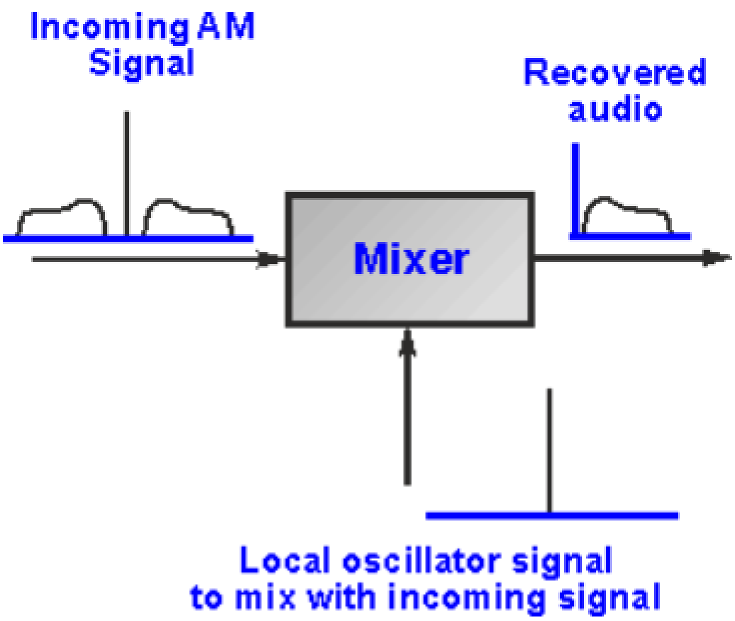

Figure 7. Synchronous AM demodulator

8. DRAWBACKS OF STANDARD AM (DSB-FC)

1. **Low Power Efficiency:** ≥66.7% of power wasted in the carrier (esp. when μ<1).
2. **Inefficient Spectrum Usage:** Bandwidth is 2B, while the information is duplicated in both sidebands.
3. **Susceptibility to Noise:** Noise affects the amplitude directly, corrupting the information. Envelope detectors are particularly noise-sensitive.

9. IMPROVED AM VARIANTS (CONCEPTUAL)

1. **Double Sideband Suppressed Carrier (DSB-SC):**
   - s_DSB-SC(t) = A_c m(t) cos(ω_c t)

- **Spectrum:** Carrier absent; Only USB & LSB present.
- **Bandwidth:** 2B (Same as AM).
- **Efficiency:** 100% of power is in sidebands (theoretically more efficient).
- **Demodulation:** Requires synchronous detection (complex).

2. **Single Sideband (SSB):**
   - $s_{SSB}(t) \approx A_c m(t) \cos(\omega_c t) \mp A_c \hat{m}(t) \sin(\omega_c t)$ (USB/LSB)
   - **Spectrum:** Carrier absent; *Either* USB *or* LSB present.
   - **Bandwidth:** B (Half of AM/DSB-SC).
   - **Efficiency:** 100% of power in one sideband (most efficient spectrum & power usage).
   - **Generation/Demodulation:** More complex (requires filters or phasing methods; demodulation requires synchronous detection).
3. **Vestigial Sideband (VSB):** A compromise between DSB and SSB, used in analog TV transmission. One full sideband + a "vestige" of the other.

10. KEY APPLICATIONS

1. **AM Radio Broadcasting (535-1705 kHz):** Standard DSB-FC. Simplicity of receivers (envelope detectors) was crucial historically.
2. **Aircraft VHF Communications (118-136 MHz):** Sometimes uses AM for voice.
3. **Video Transmission in Analog TV:** Used VSB to save bandwidth.
4. **QAM (Quadrature Amplitude Modulation):** Digital modulation scheme building on DSB-SC principles (uses I/Q channels).

11. IMPORTANT CONSIDERATIONS & TERMINOLOGY

- **Overmodulation:** Causes distortion and "envelope inversion". Avoid $\mu > 1$.
- **Sideband Suppression:** Techniques to remove one sideband (SSB) or the carrier (DSB-SC).
- **Coherent vs. Non-Coherent Detection:** Envelope detector is non-coherent; Synchronous detector is coherent.
- **Selective Fading:** Affects different spectral components differently. Can cause distortion in AM, especially if carrier fades.

12. STUDY TIPS

1. **Master the Math:** Derive the time-domain expression and spectrum for a single-tone AM signal.
2. **Visualize Spectra:** Sketch spectra for carrier, message, and AM signal.
3. **Understand Modulation Index (μ):** Calculate it, understand its impact on waveform, spectrum, and power.

4. **Know the Trade-offs:** Why use DSB-FC despite its inefficiency? (Receiver simplicity). Why use SSB? (Bandwidth/power efficiency).
5. **Compare Techniques:** Make a table comparing DSB-FC, DSB-SC, SSB, VSB (Carrier? Sidebands? BW? Efficiency? Demod Complexity? Apps).
6. **Practice Power Calculations:** Be able to derive and calculate P_c, P_{sb}, P_t, η_{AM}.
7. **Know Demodulation Principles:** How envelope detector and synchronous detector work, their pros/cons.

12. LAB COMPONENT

1. Generate AM signals using a function generator and oscilloscope. Measure modulation index.
2. Write a MATLAB function to simulate amplitude modulation.
3. Build a simple diode envelope detector circuit. Observe output vs. input.
4. Use a spectrum analyzer to view AM, DSB-SC, and SSB spectra.