EEEN 462 – ANALOGUE COMMUNICATION

AMPLITUDE MODULATION (AM) - STUDY GUIDE/REVISION

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1. INTRODUCTION TO AMPLITUDE MODULATION (AM)

1.1 Definition of AM

Amplitude Modulation varies the amplitude of a high-frequency carrier wave proportionally to the instantaneous amplitude of a lower-frequency message (modulating) signal.

1.2 Purpose of AM

Enables efficient transmission of information (e.g., audio, data) over long distances via radio frequencies.

1.3 Components of AM Signal

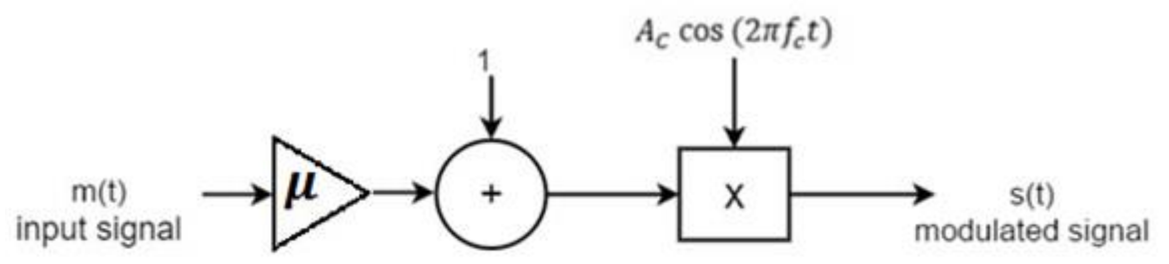

Figure 1. Block diagram of Amplitude Modulator

(a) Carrier wave:

High-frequency sinusoid

$$c(t) = A_c cos(2\pi f_c t)$$

(b) Modulating signal

Baseband signal containing information usually represented as single tone:

$$m(t) = A_m \cos(2\pi f_m t)$$

2. MATHEMATICAL REPRESENTATION

2.1 Standard AM Equation

$$S(t) = A_c(1 + \mu\, m(t))\cos(2\pi f_c t)$$

where,

A_c: Carrier amplitude.

μ: Modulation index ($0<\mu\leq 1$).

m(t): Normalized message signal ($|m(t)|\leq 1$).

2.2 Equations for Single tone AM Modulation

$$s(t) = A_c cos(2\pi f_c t) + \frac{\mu A_c}{2} cos(2\pi(f_c + f_m)t) + \frac{\mu A_c}{2} cos(2\pi(f_c - f_m)t)$$

3. MODULATION INDEX (M)

3.1 Definition of AM Modulation Index

$$\mu = \frac{Peak\ Message\ Amplitude}{Peak\ Carrier\ Amplitude} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

- **Under-modulation**

  Under-modulation occurs when the modulation index is less than one, i.e $\mu < 1$ *or* the amplitude of the modulating signal is less than the amplitude of the carrier signal. Under-modulation results in a signal that is distortion-free as shown in Figure 2.

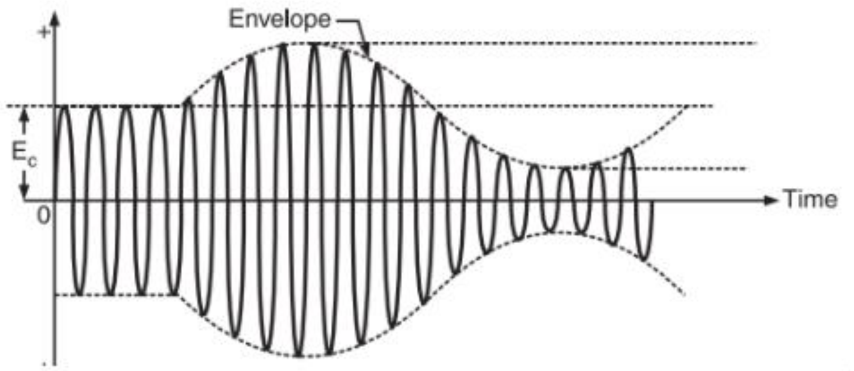

Figure 2. AM under-modulation

- **Critical modulation** (μ=1): Optimal use of power.

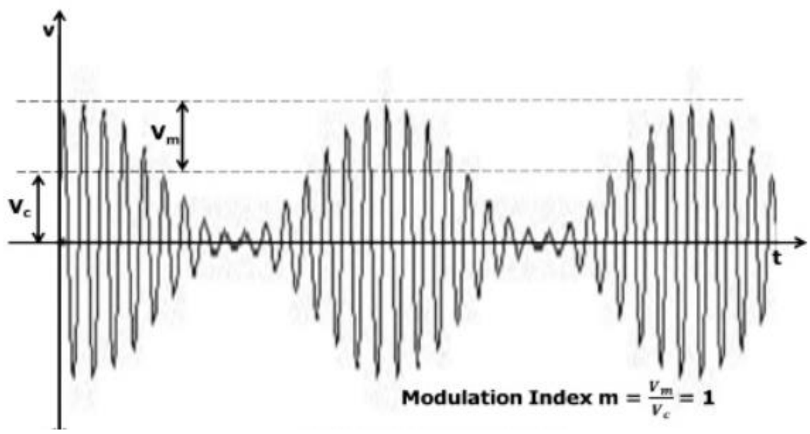

Figure 2. AM critical Modulation

- **Over-modulation**

Overmodulated occurs when the amplitude of the modulating signal is too high, causing the carrier wave's envelope to exceed 100% modulation (or $\mu > 1$.)

Overmodulation leads to the carrier's phase reversing at the zero crossings, creating distortion, unwanted harmonics, and potential interference with adjacent channels.

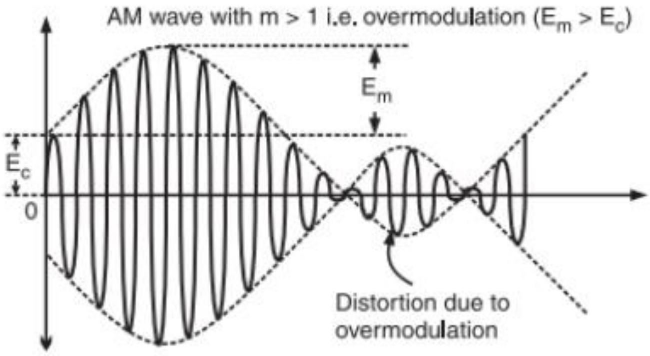

Figure 3. AM Overmodulation

Table 1. Comparison of under-modulation, critical modulation and over modulation

Condition	Modulation Index	Amplitude Min.	Distortion?	Envelope Detection
Under-modulation	$\mu < 1$	$A_{min}>0$	No	Works
Critical	$\mu = 1$	$A_{min}=0$	**Borderline**	Works (barely)
Over-modulation	$\mu > 1$	$A_{min}<0$	**Yes**	Fails

AM Broadcast Radio: Typically uses $\mu \approx 0.3–0.8$ to avoid noise-induced distortion near critical modulation.

3.2 Percentage Modulation

Percentage modulation, in the context of amplitude modulation (AM), refers to the extent to which the amplitude of a carrier wave is varied by the modulating signal, expressed as a percentage.

Percentage modulation = $\mu \times 100\%$.

4. SPECTRUM AND BANDWIDTH

4.1 Frequency Domain

- **Carrier**: Component at f_c.
- **Upper Sideband (USB)**: f_c+f_m
- **Lower Sideband (LSB)**: f_c-f_m.

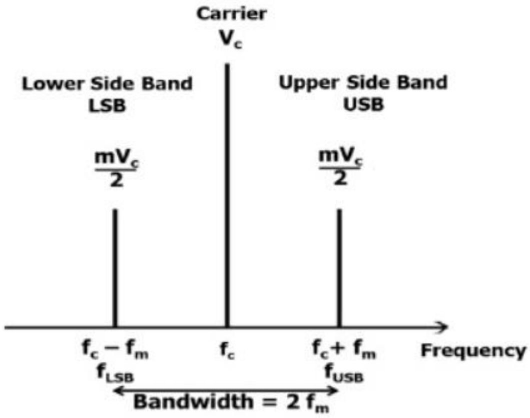

Figure 1. Spectrum of single tone AM signal

4.2 Bandwidth Requirement

Bandwidth of an amplitude modulation signal (BW) is twice the highest frequency component of the modulating signal

$$BW = 2 \times f_{m(max)}$$

where $f_{m(max)}$ is the highest frequency in m(t).

- **Example**: For telephone signal (300 Hz to 3.4 kHz), BW = 3.1 kHz.

5. POWER DISTRIBUTION

5.1 Total Transmitted Power

$$P_t = P_c\left(1 + \frac{\mu^2}{2}\right)$$

- **Carrier Power**: $P_c = \frac{A_c^2}{2}$, dissipates 50–95% of total power.
- **Sideband Power**: $\frac{\mu^2 P_c}{4}$ is what carries useful information.

5.2 Efficiency

The efficiency of amplitude modulation (AM) is the ratio of the power in the sidebands (which carry the information) to the total power transmitted.

$$\eta = \frac{\mu^2}{2 + \mu^2}$$

η is maximum at $\mu=1$ ($\eta=33.3\%$).

6. METHODS OF GENERATING AM WAVES

Linear time-invariant (LTI) systems can't generate frequencies other than those present in the input signal. Since modulation shifts input frequencies to a different range at the output, it requires circuits that are nonlinear, time-varying, or both.

6.1 Nonlinear Devices:

- Square-law modulators (using diodes/transistors).

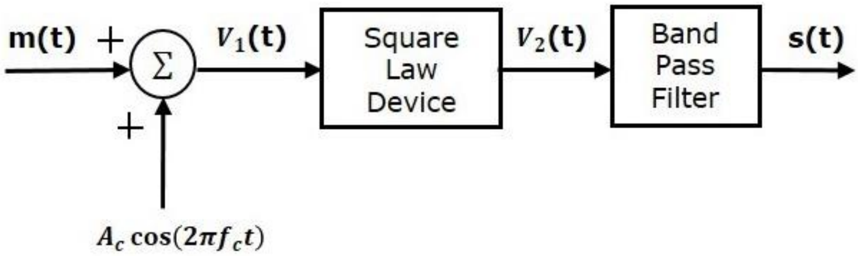

Figure 1. Suare-law AM modulator

6.2 Switching Modulators:

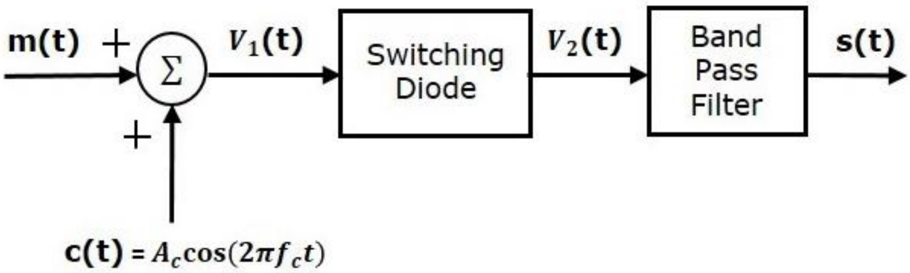

Figure 2. Switching AM modulator

To read more about switching AM modulators, click here.

6.3 Analog Multipliers

Amplitude modulation (AM) using multipliers works by taking two input signals – a carrier wave and a modulating signal – and multiplying them together. Figure x shows two ways of realizing the multiplication.

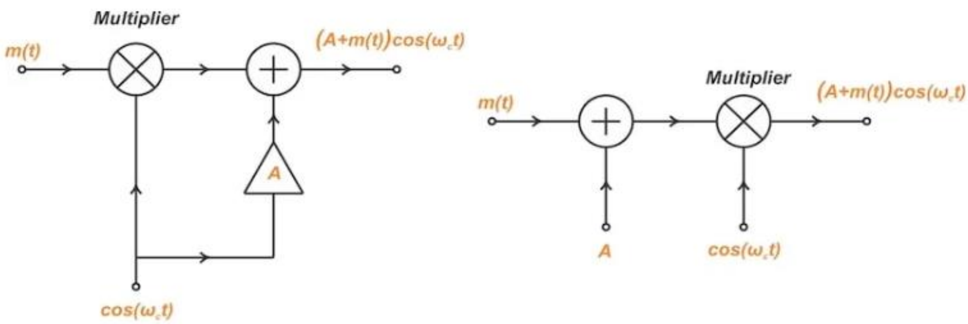

Figure x. Two possible ways of generating AM signals using analogue multipliers.

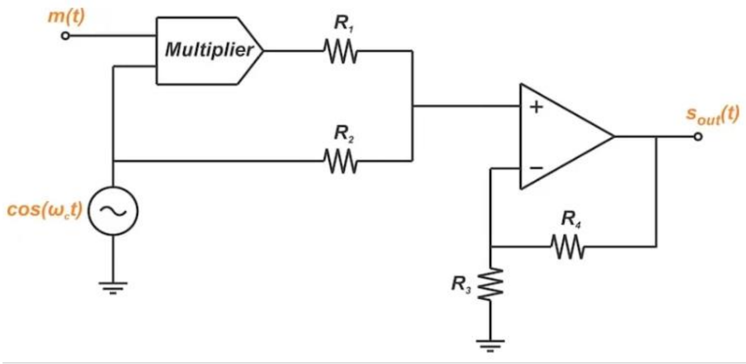

Figure x1 Block diagram of AM modulator using a multiplier.

Click here to read more about AM switching and multiplier circuits.

7. METHODS OF DEMODULATING AM WAVES

7.1 Envelope Detector

- **Components**: Diode, resistor, capacitor.
- **Operation**: Tracks peaks of AM wave (simple but requires μ≤1μ≤1).

7.2 Synchronous Detection

- **Requirement**: Local oscillator synchronized to carrier.
- **Process**: Multiply received signal by cos(2πfct)cos($2\pi fct$), then low-pass filter.
- **Advantage**: Works for μ>1.

8. ADVANTAGES AND DISADVANTAGES

8.1 Advantages

- Simple circuitry for modulation/demodulation.
- Low-cost receivers (envelope detectors).

8.2 Disadvantages

- Low power efficiency (η≤33.3%).
- Vulnerable to noise (affects amplitude).
- Wastes bandwidth (transmits two sidebands + carrier).

9. APPLICATIONS

9.1 AM Radio Broadcasting

- MW/LW bands (530–1700 kHz).
- Bandwidth of AM channel = 10 kHz per channel.

9.2 Aviation

- Aircraft communication (108–137 MHz).
- Instrument Landing System (ILS)

9.3 QAM (Quadrature AM)

- Digital TV
- WiFi
- Wireless Cellular Communication

10. PRACTICE PROBLEMS

1. An AM wave has A_{max}=10 V and A_{min}=5. Calculate the modulation index.
   Solution:

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} = \frac{10-5}{10+5} = \frac{5}{15} = 0.333$$

2. A 1 MHz carrier is modulated by 5 kHz audio. What is the bandwidth?
   Solution:

   BW = 2×5 kHz=10 kHz

3. For AM modulation index of 0.8, calculate efficiency η.
   Solution:

$$\eta = \frac{\mu^2}{2+\mu^2} = \frac{0.8^2}{2+0.8^2} = \frac{0.64}{2.64} = 0.242\ (24.2\%)$$

4. **Simulation**: Generate AM waves in MATLAB/Python for μ=0.5 and μ=1.2. Analyse distortion.