Faculty of Engineering & Technology

Electrical & Computer Engineering Department

Communication Systems _ ENEE 3309

Assignment NO.1
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Section 2

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Contents

BASIC AMPLITUDE MODULATION THEORY

Amplitude modulation is the process of transferring information signals to the amplitude of a high-frequency continuous-wave carrier. The modulated AM waveform can be described by

$s(t) = [Ac + m(t)] \cos(2\pi fct)$,

where Ac is the carrier amplitude, m(*t*) is the arbitrary message signal, and *fc* , is the carrier frequency. As a result of the modulation property of the Fourier transform, the signal spectrum is given by

$$S(f) = \frac{A_c}{2}[\delta(f - f_c) + \delta(f + f_c)] + M(f - f_c) + M(f + f_c),$$

where the carrier spectrum is composed of two Dirac delta functions at *+-f*, and the message signal spectrum is translated to *+-fc*.

Creation of the AM waveform of Equation (1) can be realized in a three-step process depicted in figure 1.

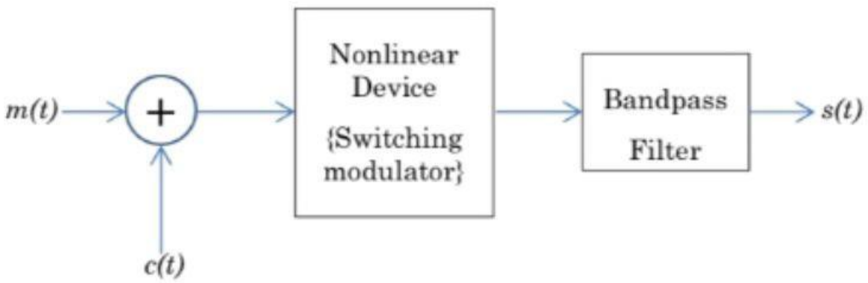

Figure 1: Amplitude modulation block diagram

Part 1: AM Modulator Circuit Analysis

A. Designed Normal AM Modulator Circuit :

1. I've used PCpice to implement the circuit shown in Figure (3) of an AM modulator

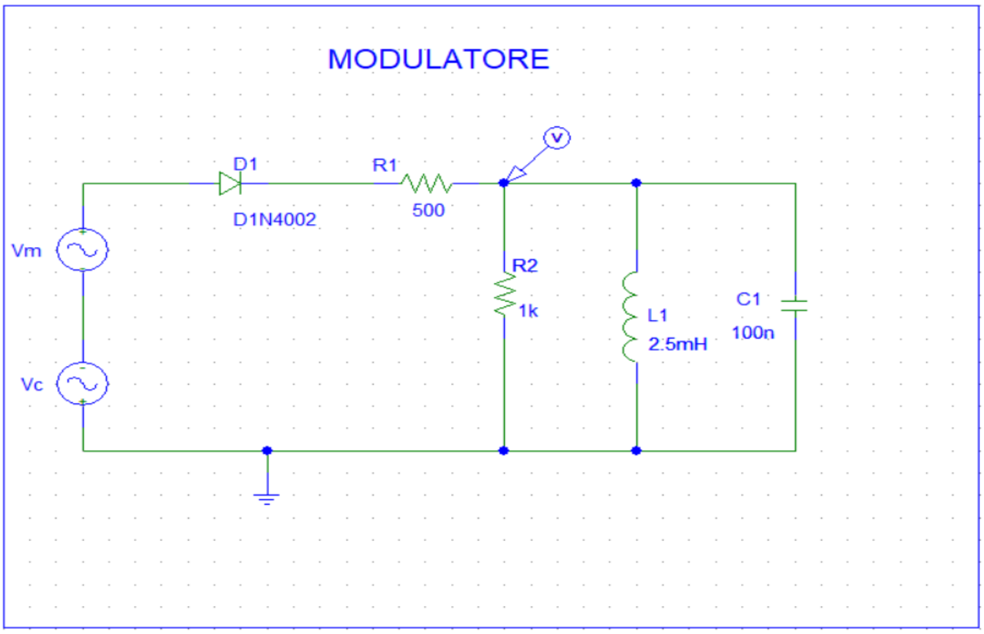

Figure 2: AM diode modulator.

2. I've set the values of the components as shown in the figure.

3. I've applied a sinusoidal signal of 10 kHz and amplitude of 2 Vp to the input Vc which represents the carrier signal.

4. I've applied a sinusoidal signal of 1k Hz and amplitude of 0.8 Vp, voltage offset 1 V to the input Vm which represents the message signal.

5. I connected Vi and Vz and adjust the voltage and the time scales appropriately.

6. then modulated the output from the probe mark shown in the figure and record the output.

7. I've decrease the amplitude of the carrier signal to 1 Vp then repeated with amplitude of 0.8 Vp and 0.5 V and record the output in each case.

B. Mathematical Analysis :

a switching modulator circuit can be constructed as shown in figure 2. The large signal carrier Vc and single tone message Vm are placed in series. The carrier signal causes the diode D1 to turn on and off periodically at the carrier frequency resulting in the modulation of the message signal m(t) onto the carrier c(t). The frequencies and amplitudes were chosen for illustration purposes, not to simulate any particular AM system. to generate the circuit of figure 2 to implement the signal

s(t) = 2[1 + 0.8 cos (2 π (103)t)] cos(2π (10^4)t).

The assignment directs them to reproduce and explain the time-domain and frequency-domain plots and to relate them to the circuit implementation.

the Fourier series coefficients as

$$\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{(2n-1)}\ .$$

Bandpass Filter Design

Carrier frequency: fc=10 kHz , Inductor: L=2.5 mH , Capacitor: C=100 nF , Resistance: R=1 kΩ .
fc=1/(2π√(LC)) = 1/(2π√ ((2.5×10−3)(100×10−9))) = 10kHz .

1. Expression for the Modulated Signal

Carrier: c(t) = Ac cos(2πfc t) .
Message: m(t)=Amcos(2πfmt) .

The AM signal is:

s(t)=Ac[1+μcos(2πfmt)]cos(2πfct)

Where Ka=1/Ac so μ=Ac / Am is the modulation index.

Ac=2 V , Am=0.8 V So, μ=0.4

s(t)=2[1+0.4cos(2π·10^3 t)] cos(2π·10^4 t)

2. Time and Frequency Domain Analysis

Time Domain:

the expression to see the envelope more clearly:
s(t)=2cos(2π·104t)+0.8cos(2π·103t)cos(2π·104t)

Carrier period: Tc=1/10,000=0.1 ms

Envelope period: Tm=1/1,000=1 ms

Frequency Domain:
Using the modulation theorem:

$S(f)=Ac/2\ [\delta(f-fc)+\delta(f+fc)]+Ac\mu/4\ [\delta(f-fc-fm)+\delta(f-fc+fm)+\delta(f+fc-fm)+\delta(f+fc+fm)]$

Substitute the values:

$S(f)=(2/2)*[\delta(f-10{,}000)+\delta(f+10{,}000)]+((2\cdot0.4)/4)[\delta(f-11{,}000)+\delta(f-9{,}000)+\delta(f+11{,}000)+\delta(f+9{,}000)]$

$S(f)=[\delta(f-10{,}000)+\delta(f+10{,}000)]+0.2[\delta(f-11{,}000)+\delta(f-9{,}000)+\delta(f+11{,}000)+\delta(f+9{,}000)]$

Carrier Component:
Peaks at ±10,000 Hz
Amplitude: 1 (scaled Dirac delta functions)
Upper Sidebands:
Peaks at f=±11,000 Hz (fc+ fm)
Amplitude: 0.2
Lower Sidebands**:**
Peaks at f =±9,000 Hz (fc−fm)
Amplitude: 0.2

The bandwidth = BW = 2fm = 2×1,000=2,000Hz.

3. Modulation Index Impact:

- A low μ : weaker sidebands, smaller message signal content.
- μ=1: Normal modulation.
- μ>1: overmodulation → distortion.
- No clipping or distortion is visible (under modulation) , so modulation is within bounds (since μ=0.4<1).

C. Simulation and Practical Implementation

1. AM modulator circuit Simulation using PSPICE

Ac = 2 Vp

Am = 0.8 Vp

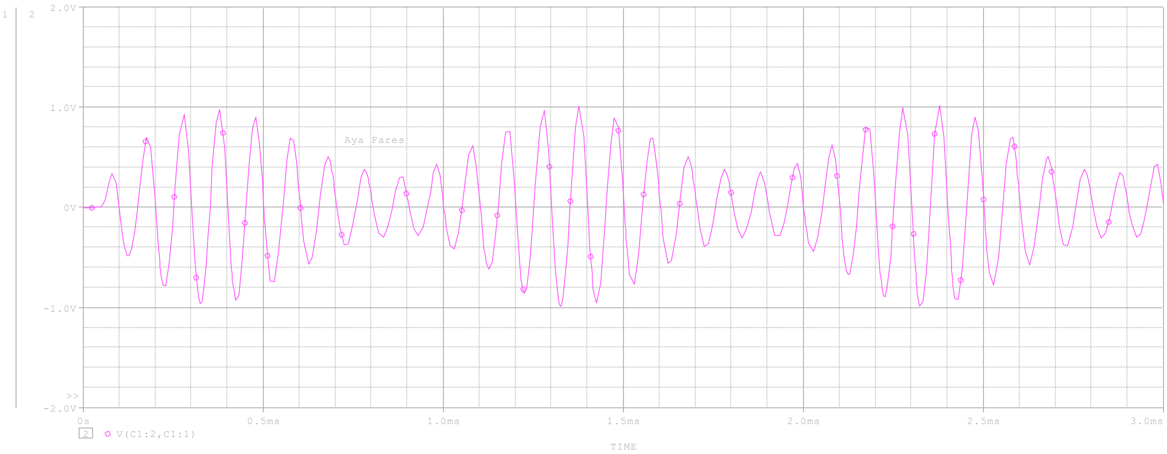

Figure 3: AM diode modulator waveform in the time domain .

Ac = 0.5 Vp

Am = 0.8 Vp

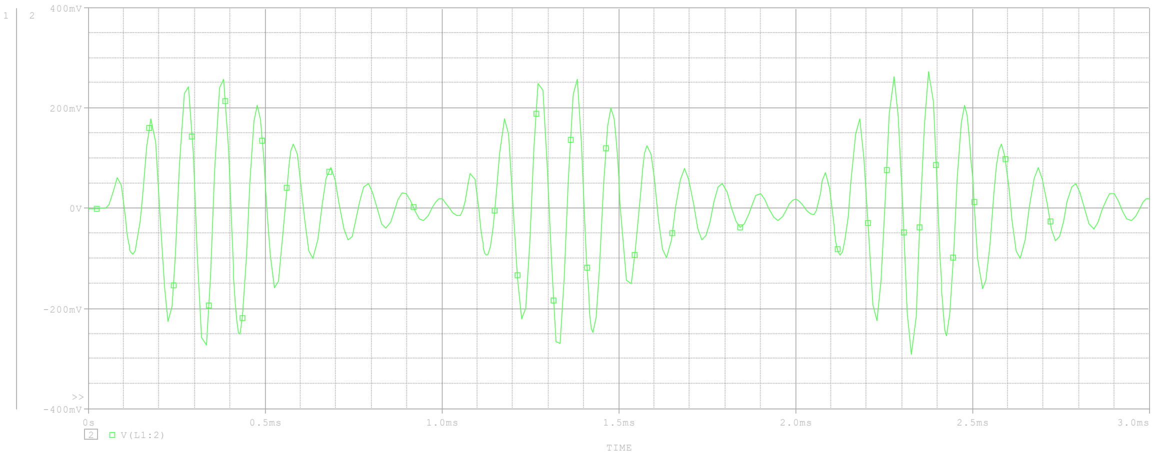

Figure 4: AM diode modulator waveform in the time domain .

2. The impact of circuit parameters on modulation performance.

Parameter	Effect on Modulation
Carrier Amplitude (Ac)	Controls modulation index. Low Ac increases μ, leading to distortion if μ>1 here we have high Ac so it leads to if μ<1.
Message Amplitude (Am)	Directly affects μ. Higher Am leads to stronger sidebands.
Diode Nonlinearity	Affects switching behavior. An ideal diode works best for clean modulation.
Biasing and Offset Voltage	Ensures the diode operates in the proper region for modulation. A poor offset can suppress the message signal.
Frequency Ratio (fc≫fm)	Must be maintained to ensure proper AM operation.

Part 2: AM DeModulator Circuit Analysis

A. Designed Normal AM Demodulator :

1. circuit diagrams for ((Envelope detector)) :

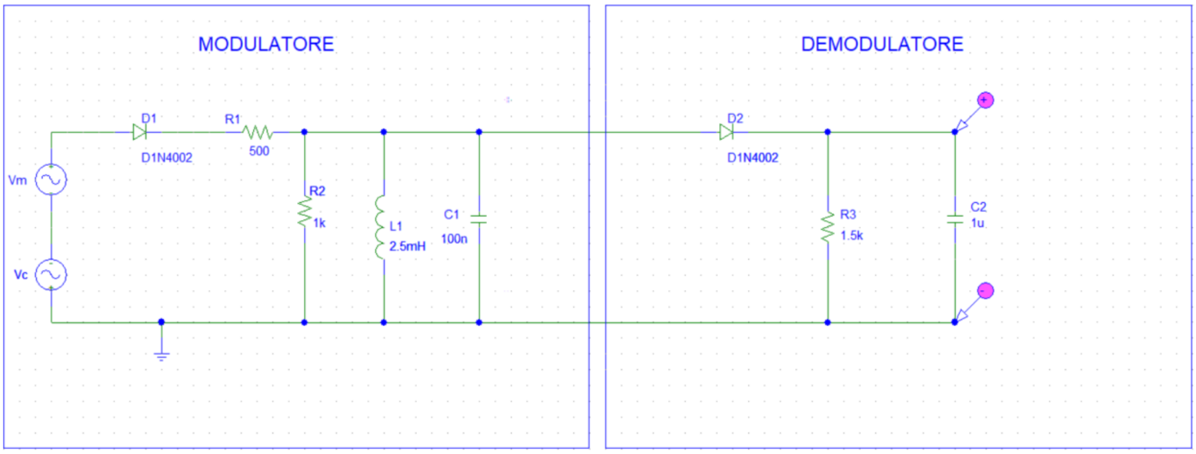

Figure 5: AM diode Demodulator peak detector circuit.

2. Working principles and advantagesor:

D2 (1N4002): Diode for rectification.

R3 (1.5kΩ): Discharge resistor. & C2 (1 µF): Smoothing capacitor. (for low-pass filtering)

- Working Principle

  Recovery of the message signal m(t) from the modulated waveform s(t) is accomplished for large signal AM via an envelope detector, or peak-following circuit. Since the information of the message will reside in the amplitude variations of the AM wave, by tracing the amplitude variations of the high-frequency carrier, the message signal is recovered. Not coincidentally, the simplicity of the demodulation is the reason for the popularity of broadcast AM. Figure 5 shows the addition of a diode and RC circuit to accomplish the demodulation and recovery of the message signal.

1. Rectification:
   The diode D2 allows only the positive half of the incoming AM signal to pass through (half-wave rectification).

2. Filtering:
   The capacitor C2 charges up to the peak of the signal and follows the envelope. The resistor R3 helps discharge the capacitor between peaks — forming a low-pass filter that tracks the message signal.

3. Output:
   At the output (across R3), we get the envelope of the modulated signal — essentially recovering the original message m(t).

- Advantages

  Simple and low-cost , Effective for high carrier frequencies with moderate modulation index & Works well when $\mu<1$ (i.e., no overmodulation).

B. Mathematical Analysis :

1. Expression for the Demodulated Signal

- The standard **AM signal** is:

$s(t)=[A+m(t)]\cos(2\pi f c t)$

$fc=10$ kHz carrier frequency

- Envelope Detection Output

An envelope detector rectifies and filters the signal to recover:

Envelope of $s(t) \approx A + m(t)$

The diode + RC filter follows the envelope, so the output after filtering is:

$vo(t) \approx A + m(t)$

To extract the original message m(t), we subtract the DC bias A:

$m(t)=vo(t)-A$

$R=1.5\ k\Omega$, $C=1\ \mu F$, $fc=10kHz \Rightarrow T=0.1ms$

RC time constant: $\tau=RC=1500\times10^{-6}=1.5$ ms

This means the circuit can track envelope variations **much slower** than the carrier (which is good), but **fast enough** to follow a 1 kHz message signal (period = 1 ms).

$s(t)=[1+\sin(2\pi\cdot1000t)]\cdot\cos(2\pi\cdot10000t)$

The demodulated output after envelope detection and DC removal:

$m(t)=\sin(2\pi\cdot1000t)$

Which is the original **1 kHz message signal**.

Note :

The assignment asked for an **envelope detector**, not full demodulation — it uses a diode to **rectify** the AM signal, and the **capacitor that follows** extracts the envelope, giving a signal that **resembles m(t)** but is not exactly the original message.

2. The effect of noise and distortion on demodulation performance.

Category	Issue	Cause/Condition	Effect on Output	Rule / Value	Solution
Noise	Additive Noise	Channel noise added: $r(t)=s(t)+n(t)$	Noisy or distorted envelope	SNR≫1	Use band-pass filters; increase transmitter power
	High-Frequency Noise	Noise affects capacitor charging	Ripple, false peaks, distortion	Filter outside carrier band	Pre-filter with tuned band-pass; RF shielding
Distortion	Overmodulation	$A + m(t)<0$: message exceeds carrier amplitude	Envelope reversed; heavy distortion	(\mu = \frac{\max	m(t)
	Diode Threshold	Small signals below 0.7 V (for silicon diodes)	Clipping, missing parts of signal	Signal >0.7 V or use lower threshold	Use Schottky diode (~0.2 V threshold)
	RC Too Small	RC ≪ 1/fm	Capacitor discharges too fast; signal drops	RC too short for tracking envelope	Increase RC to match signal bandwidth
	RC Too Large	RC ≫ 1fm	Slow discharge; signal lag, smearing	RC too long; doesn't respond quickly	Decrease RC to match signal bandwidth
	RC Match (Ideal)	Proper balance between charge/discharge rates	Accurate envelope tracking	RC≈1/fm	For fm=1 kHz , use RC=1 ms
		In my circuit: R=1.5kΩ , C=1μF	RC = 1.5 ms ✔ (good for 1 kHz)		

C. Simulation and Practical Implementation

1. AM modulator circuit Simulation using PSPICE

where T is the period of the carrier. The recovered signal can be seen below in figure 6.

Carrier: 10 kHz, 2 V peak, **Message**: 1 kHz, 0.8 V peak with 1 V offset.

The output waveform shows the **envelope** of the modulated signal — a smoothed waveform resembling the original message signal.

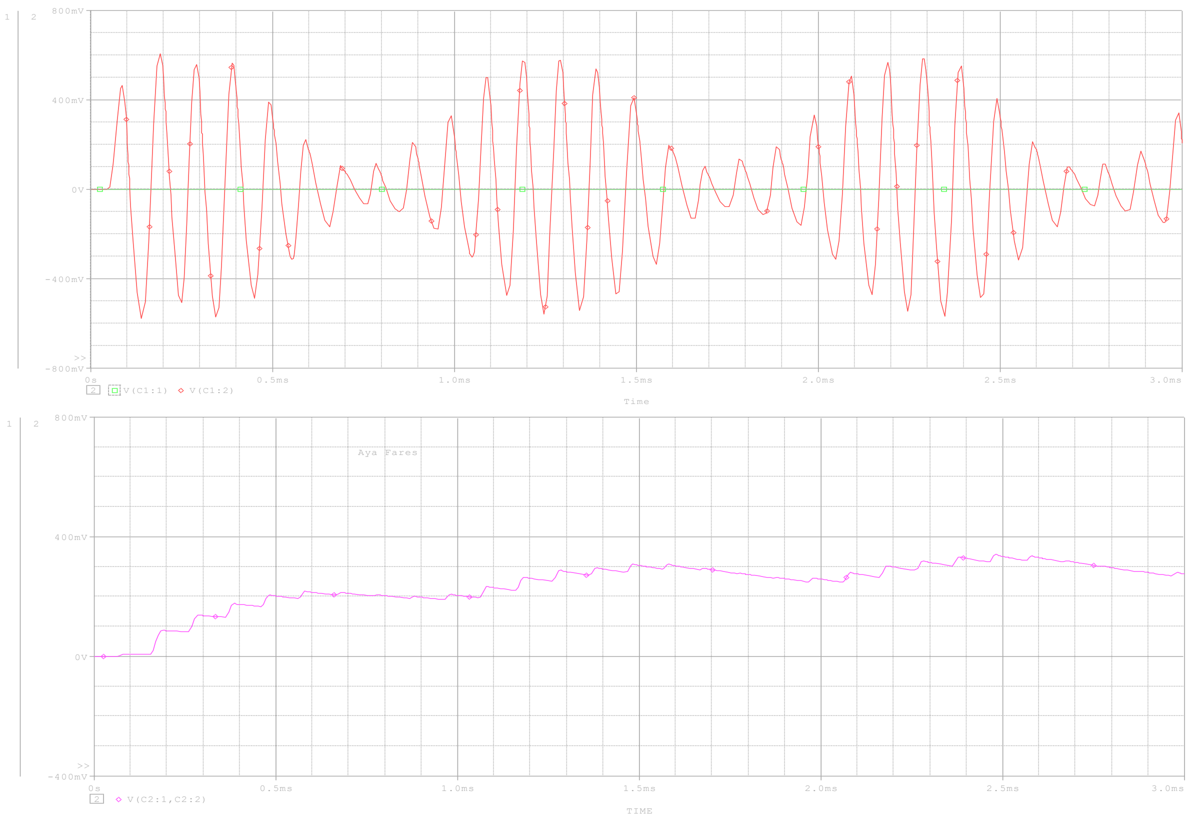

Figure 6: Modulated (top) and recovered (bottom) signal in time domain

2. Output Analysis

The output is not the original message signal m(t) but its envelope.

The diode rectifies the AM waveform, and the capacitor-resistor (RC) network filters out the carrier, leaving behind the envelope, which approximates the amplitude variations of the original message.

Some distortion or ripple may appear depending on the chosen RC time constant — it must be carefully tuned to follow the message signal without tracking the high-frequency carrier.

This circuit is not a full demodulator; it performs envelope detection only.
To fully recover m(t), an additional capacitor (or further low-pass filtering) is needed to remove residual high-frequency components and isolate the original message signal more accurately.

3. Practical Challenges in Real-World Implementation

Diode Forward Voltage Drop

Standard diodes (e.g., 1N4002) have a ~0.7 V drop, which can distort or block low-amplitude signals.
→ Solution: Use Schottky diodes with lower voltage drop.

RC Time Constant Tuning

If the RC values aren't carefully selected, the circuit may either follow the carrier (causing ripple) or react too slowly (causing distortion).
→ Solution: Choose RCRCRC so it's large compared to the carrier period but small compared to the message period.

Noise Sensitivity

AM is prone to noise, especially near the carrier frequency, which affects detection accuracy.

Envelope Distortion

Sharp changes in the message signal can’t be tracked perfectly by the capacitor, leading to waveform distortion.

Temperature and Component Variability

Real components (diodes, resistors, capacitors) change behavior with temperature or aging, affecting performance