BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

Department of Electrical and Electronic Engineering

Course No. : EEE 310
Course Title : Communication Laboratory
Section : B1

Project Tittle: Double Sideband AM Generation and Detection

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Date of Submission : 3/03/2023

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INTRODUCTION:

We have built an amplitude modulation and demodulation circuit in this project. In the actual world, amplitude modulation is utilized to send message signals over vast distances with the least amount of distortion. The message signal conveyed, which are often audio and video signals, has a low frequency, which is a significant disadvantage for long-distance transmission. Such signals weaken over extended distances, making reconstruction at the receiving end difficult, if not impossible. The attenuation decreases with increasing signal frequency. Consequently, the message signal is modulated into a high frequency carrier signal to reduce attenuation (usually a sine wave). As a result, the attenuation is much reduced, and the signal may be nearly perfectly recreated following demodulation. This is what we have implemented in our project at the most fundamental level, using simply sine, triangle, and rectangular waves with set frequencies as message signals. The same procedure can be applied to a signal with various frequencies, such as voice.

A sine oscillator circuit is an electronic circuit that generates a sinusoidal wave output signal. Sine oscillator circuits work by using a feedback loop to produce a stable oscillation at a specific frequency. The feedback loop typically consists of an amplifier and a filter circuit that selects the desired frequency. The amplifier amplifies the signal, and the filter circuit selects the frequency and removes any unwanted harmonics.

For an electronic circuit to oscillate at a specific frequency, a set of conditions called Barkhausen criteria must be satisfied. The Barkhausen criteria consist of two conditions:

1. The magnitude of the total loop gain around the circuit must be equal to or greater than unity. This means that the gain of the circuit must be enough to compensate for the losses in the circuit and maintain the oscillation.

2. The phase shift around the loop must be equal to a multiple of 2π (or 360 degrees). This means that the phase shift must be such that the signal fed back to the input is in phase with the original signal.

<u>Basic theory of Amplitude Modulation:</u>

Modulation is a process where some characteristic of a high frequency carrier wave is varied in accordance with the amplitude of an information-bearing signal.
In communication system, message signal is not transmitted directly rather it is slightly modified. Because

1. For efficient utilization of frequency spectrum
2. To suite the channel requirement
3. To decrease antenna length
4. To increase the operating range

The amplitude of the wave is altered in proportion to the message signal, such as an audio signal, in amplitude modulation. Amplitude modulation is a modulation technique extensively used in electronic communication to send messages through radio waves.

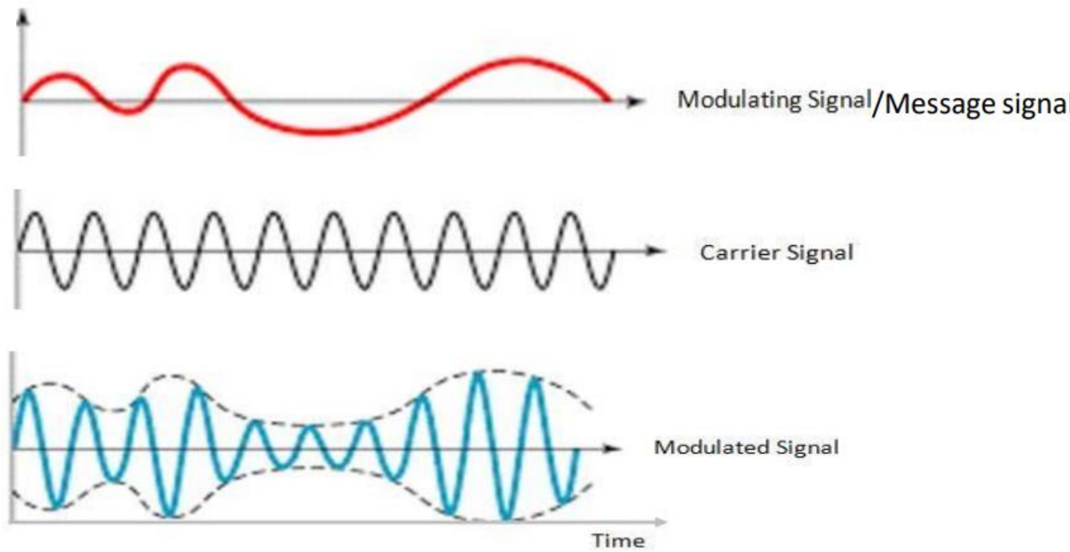
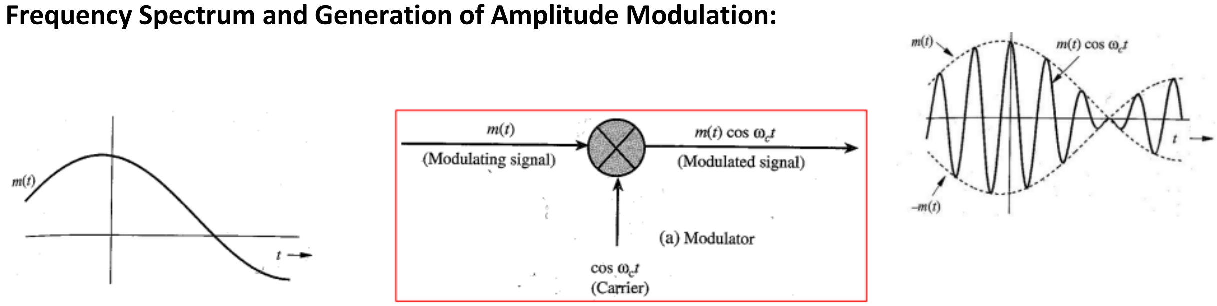


Figure 1: AM signal

Frequency Spectrum and Generation of Amplitude Modulation:



$$m(t) \Longleftrightarrow M(\omega)$$

$$m(t)\cos\omega_c t \Longleftrightarrow \tfrac{1}{2}[M(\omega+\omega_c)+M(\omega-$$

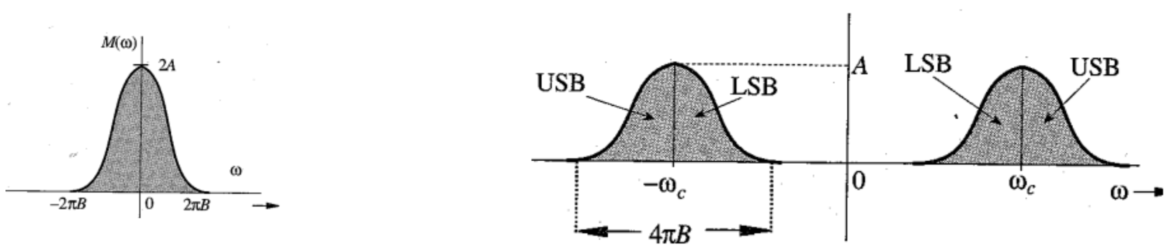


Figure 2: Frequency Spectrum

In amplitude signal, message signal is multiplied by a high frequency sinusoidal carrier signal by any of the following methods:

1. Multiplier Modulator.
2. Non-linear Modulator.
3. Switching Modulator.
    a. Diode Bridge Modulator.
    b. Ring Modulator.

By doing this, the frequency spectrum is now shifted to the corresponding carrier frequency to fulfill the requirement stated above.

Demodulation:

Demodulation is the process of getting back the original message signal from the modulated signal at the receiver end.

There are two methods for demodulation:

1. Coherent/Synchronous Demodulation.
2. Non-coherent Demodulation.
    a. Envelope Detector.
    b. Rectifier Detector.

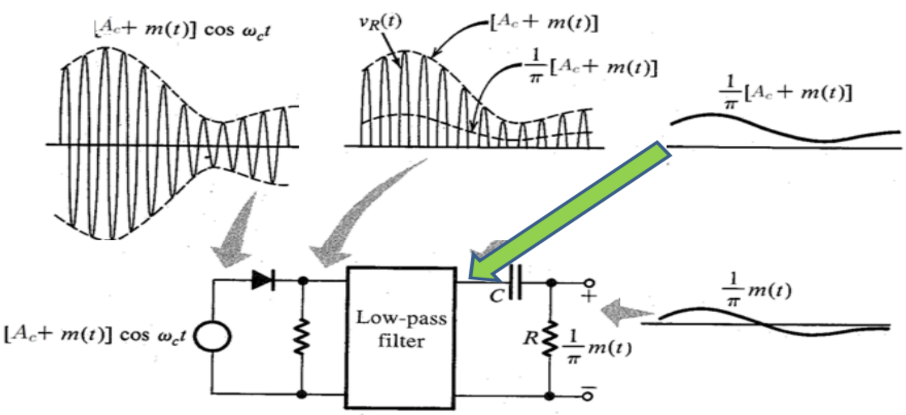


Figure 3:Envelope Detector

Circuit Diagram:

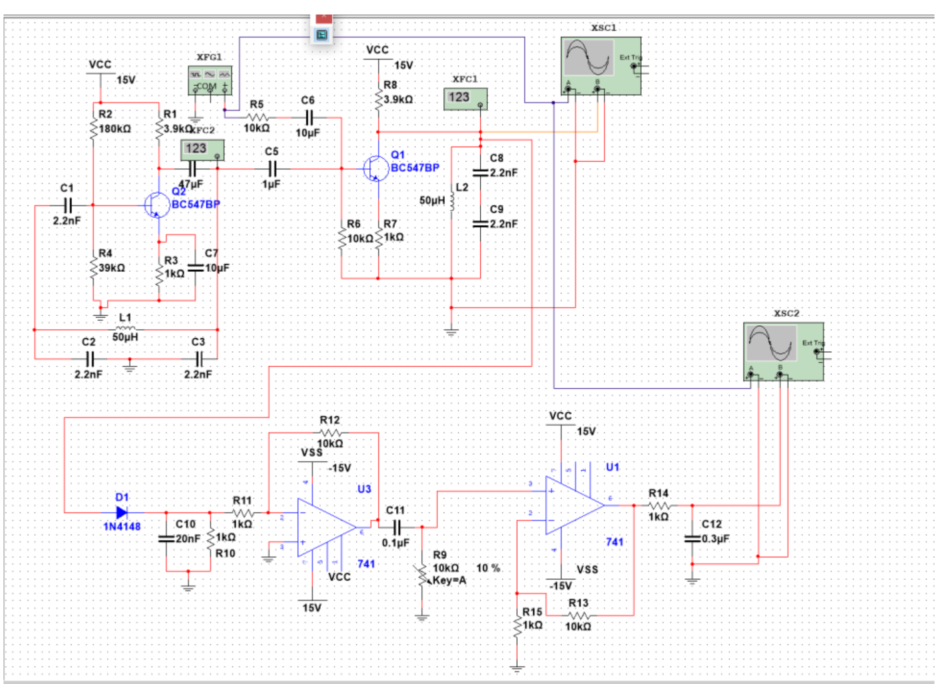


Figure 4: Circuit Diagram

Breadboard Implementation:

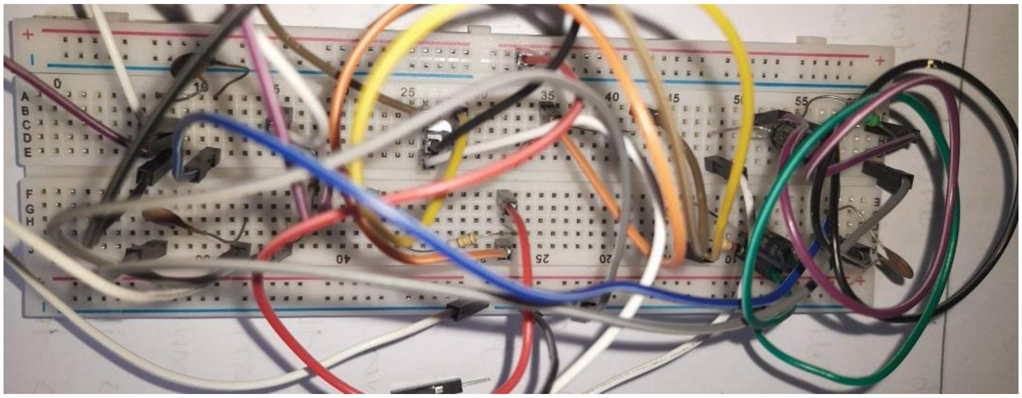


Figure 5: Oscillator

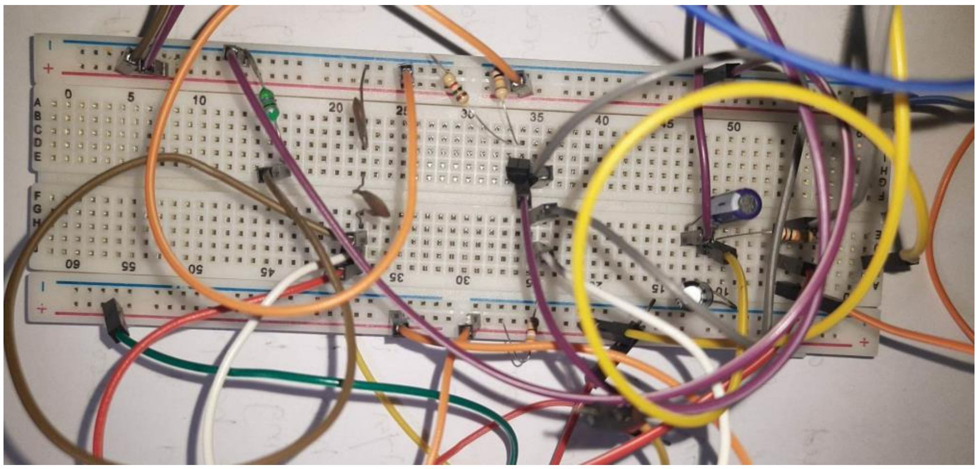


Figure 6: Modulator

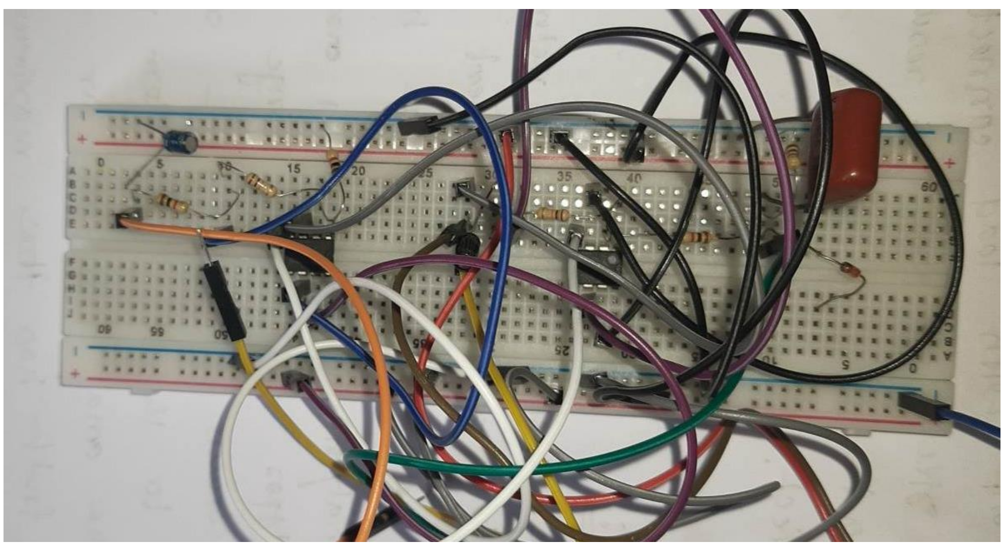


Figure 5: Demodulator

Step by Step Analysis:

Colpitts Oscillator[1]:

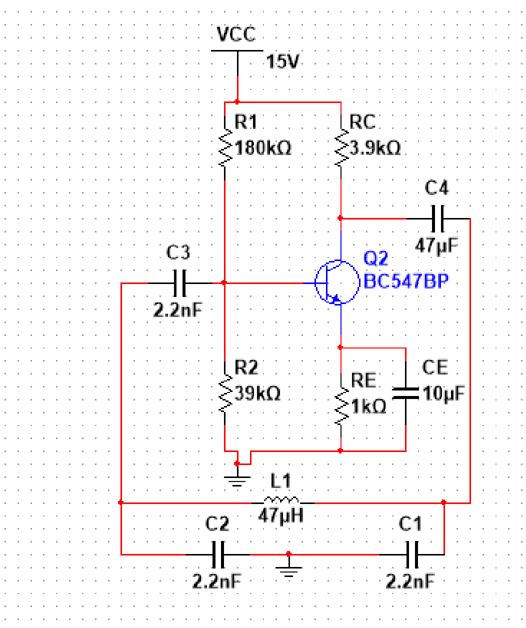


Figure 6: Oscillator Circuit

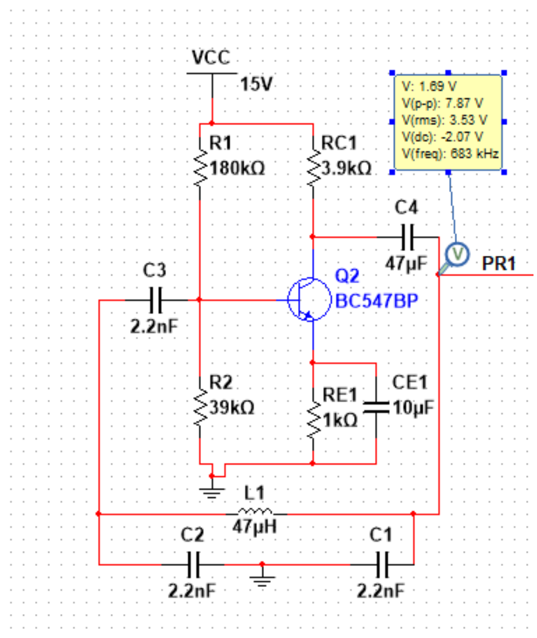


Figure 8: Oscillator Circuit Output

The Colpitts oscillator is a type of LC oscillator circuit that is commonly used to generate high-frequency sine waves. It is named after its inventor, American engineer Edwin Colpitts.

The Colpitts oscillator consists of an LC tank circuit (inductor and capacitor in parallel) and a transistor amplifier. The transistor is used as an active device to amplify and feedback the output signal to the LC tank circuit. The feedback is done through a voltage divider network made up of two capacitors (C1&C2) and a resistor, connected in series with the inductor(L1) of the LC tank circuit.

When the circuit is first turned on, the transistor is biased into its active region, allowing it to amplify the initial noise or signal applied to its input. The amplified signal, feedback through the voltage divider network, causes the LC tank circuit to resonate at a frequency determined by the values of the inductor and capacitors. Here, transistor collector output is the oscillator's output which is applied across C1 and feedback of the tank circuit is the voltage across C2 which is re-applied at the base of the transistor. The transistor amplifies this resonant signal and feeds it back into the tank circuit, creating a self-sustaining oscillation.

Barkhausen Criteria in Colpitts Oscillator:

1. The transistor amplifier is in Common Emitter configuration where the output signal at the collector is 180 degrees out of phase with regards to the input signal in base. The two capacitors connected in series but in parallel with the inductive coil results in phase shift of 180 degree. So the net phase shift is 360 degree.

2. Here, output for voltage of transistor is the input voltage of the tank circuit. Again, output of the tank circuit is inputted to the transistor, creating unit loop gain.

Frequency of oscillation in Colpitts oscillation:

The resonant frequency of the tank circuit = oscillator's frequency =fr

$$fr = \frac{1}{2\pi\sqrt{\{L1\frac{C1C2}{C1+C2})\}}}$$

For our circuit: $fr = \frac{1}{2\pi\times\sqrt{(47u*\frac{2.2n}{2})}}$ =700kHz

From the figure, it is clear simulation provides similar result as theoretical frequency.

Hardware Output:

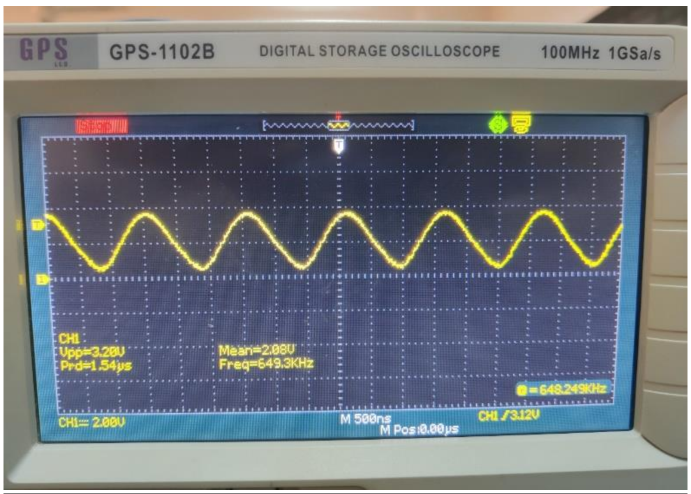


Figure 9:Carrier Signal

AM Modulation[2]:

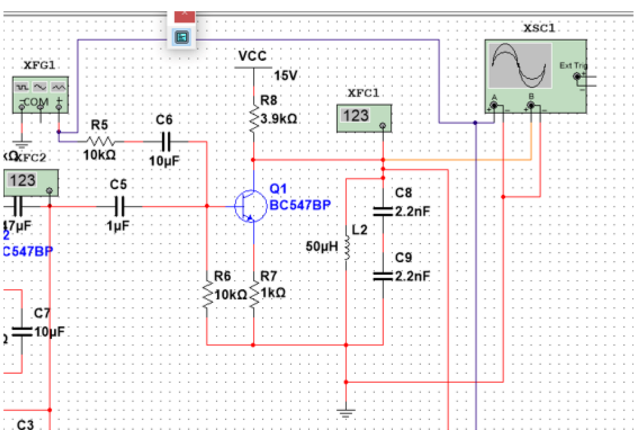


Figure 10: Circuit Diagram

The circuit shows an AM modulator. The two signals, NF and HF are additively superimposed before the modulation on the base resistance (1). NF denotes the modulating signal and HF denotes carrier signal.

At first step, modulating and carrier signals are summed in node (1) [by adding their corresponding currents]. The amplitude of the sum signal is sufficiently large in the positive range and follows the variation of the modulating signal.

At 2^{nd} step, the sum signal (actually the base current proportional to sum signal) is amplified by a class C amplifier to produce a train of current pulses(truncated carrier signals actually) who follow the amplitude variation of the modulating signal. As class C power amplifier conducts less than 180 degree in a complete cycle, the output waveshape looks like this.

At third step, this truncated class C amplified current pulses (who follow the envelope of the modulating signal) are fed to LC tank circuit (band pass filter with very high Quality factor) which is tuned to carrier frequency, eliminates all the frequencies and produces a complete sinusoidal output(negative portion also) with varying amplitude still proportional to the modulating signal and this signal is none other than the modulated signal. And this method of producing complete sinusoid wave from truncated sinusoid using a tunable LC tank circuit is called 'The Flywheel Effect'.

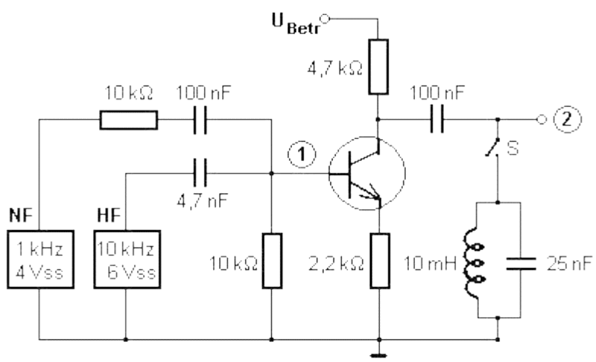


Figure 11: Class C amplifier with tank circuit

Now, the outputs of all the steps written above will be shown below:

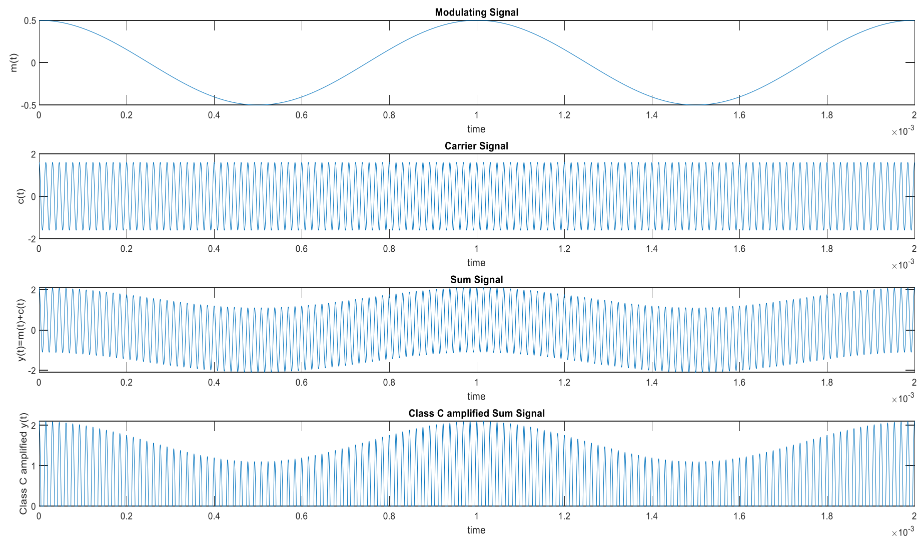


Figure 12: AM output

The flywheel effect and calculation of LC tank resonance frequency, quality factor Q will be discussed later.

The 3rd step is explained further:

In order to generate the AM wave, it is necessary merely to apply the series of current pulses of to the LC tuned (resonant) circuit.

Then each pulse, if it were the only one, would initiate a damped oscillation in the tuned circuit. The oscillation would have an initial amplitude proportional to the size of the current pulse and a decay rate dependent on the time constant of the circuit. Since a train of pulses is fed to the tank circuit here, each pulse will cause a complete sine wave proportional in amplitude to the size of this pulse. This will be followed by the next sine wave, proportional to the size of the next applied pulse, and so on.

Bearing in mind that at least 10 times as many pulses per audio cycle are fed to a practical circuit as are shown in the figure below, we see that an extremely good approximation of an AM wave will result if the original current pulses are made proportional to the modulating voltage(which is already done in the base node by superimposition). The process is known as the flywheel effect of the tuned circuit, and it works best with a tuned circuit whose Q is not too low.

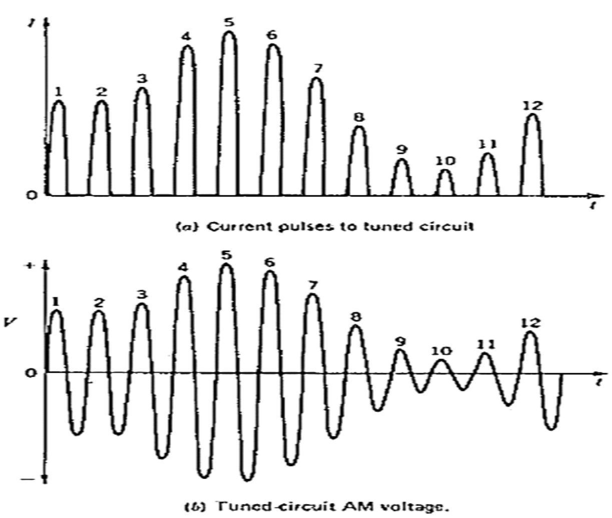


Figure 13: Tank Cirucuit input and output

<u>Type of modulation:</u>

The circuit used for modulation is actually switching modulator circuit. As the BJT is operating in class C amplification region (cutoff region), it crops the complete negative portion and a little positive portion of the input sum signal (sum of two currents proportional to modulating signal and carrier signal). And that's why it produces a cropped/truncated train of current pulses at the collector. As the whole negative portion and some positive portions are cropped, that's why we can say this type of modulation is switching modulation. Time domain switching produces multiple copies in frequency domain. That' why the truncated series of current pulses are actually a combination of many impulses of different frequencies. After a band pass filtering tuned at the carrier frequency, only the carrier frequency and shifted spectrum of modulating signal at carrier frequency will remain.

<u>The reason for using class C Amplifier:</u>

DC analysis of modulation part of our circuit:

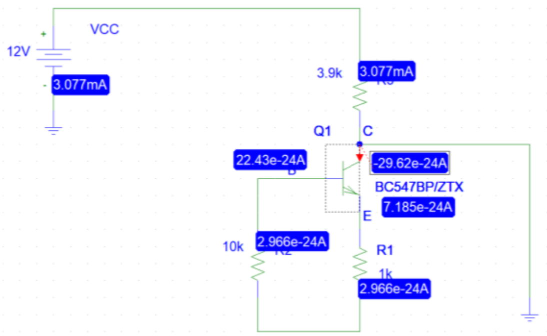


Figure 14: Bias current

We can clearly see from the PSpice dc simulation that collector current is negative and very very small compared to active region current. And current gain is 1.32.

As the value of β is very low and the collector current is small and negative, we can say that the BJT is operating in cutoff region (class C) region.

Reasons:

Class C power amplifier is a type of amplifier where the active element (transistor) conducts for less than one half cycle of the input signal. Less than one half cycle means the conduction angle is less than 180° and its typical value is 80° to 120°. The reduced conduction angle improves the efficiency to a great extend but causes a lot of distortion. Theoretical maximum efficiency of a Class C amplifier is around 90%.

Due to the huge amounts of distortion, the Class C configurations are not used in audio applications. The most common application of the Class C amplifier is the RF (radio frequency) circuits like RF oscillator, RF amplifier etc where there are additional tuned circuits for retrieving the original input signal from the pulsed output of the Class C amplifier and so the distortion caused by the amplifier has little effect on the final output. Input and output waveforms of a typical Class C power amplifier is shown in the figure below.

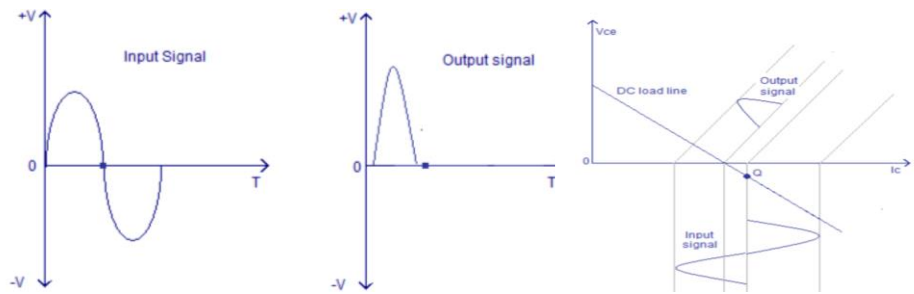


Figure 15: Output characteristics of class C amplifier.

Advantages of Class C power amplifier.

1. High efficiency.
2. Excellent in RF applications.
3. Lowest physical size for a given power output.

Mainly to reduce the power loss and to increase efficiency, class C power amplifier is used here instead of class A or class B power amplifier.

Tank Circuit:

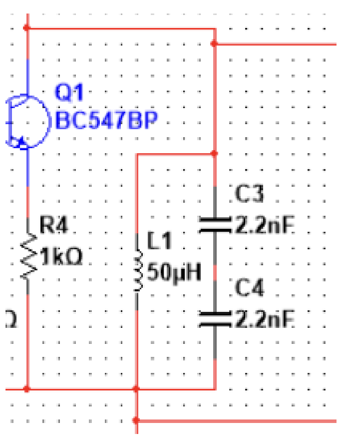


Figure 16: Tank Circuit

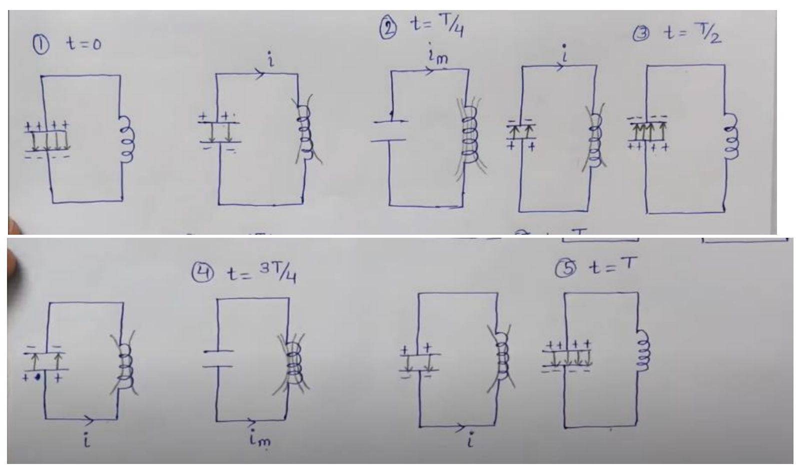


Figure 17: Tank Circuit Working Diagram

Here, we will explain the sinusoidal case only for simplicity. When the truncated current pulse passes through a LC tank bandpass filter of appropriate frequency, it will eliminate all the high frequency component except the carrier frequency and shifted frequency spectrum of the modulating signal. That's how it produces a modulated signal.

A tank circuit is a type of resonant circuit that consists of an inductor, a capacitor, and a source of alternating current (AC). Tank circuits are also sometimes called LC circuits, because they contain an inductor (L) and a capacitor (C).

When an AC voltage is applied to a tank circuit, the capacitor and inductor store energy and exchange it back and forth in a continuous cycle. This results in a resonance effect, where the circuit can be made to resonate at a particular frequency. The resonant frequency of a tank circuit is determined by the values of the inductor and capacitor, and can be calculated using the formula:

$f = 1 / (2\pi\sqrt{LC})$

where f is the resonant frequency in hertz (Hz), L is the inductance in henries (H), and C is the capacitance in farads (F).

Tank circuits are commonly used in electronic circuits for applications such as tuning radio receivers, filtering signals, and generating oscillations.

Here we have used an LC tank circuit. It has frequency of same scale with the oscillator. It gets an current impulse from the Amplifier collector and capacitor gets charge. Initially, when the voltage is applied, the capacitor charges and stores energy in the form of an electric field. As the voltage starts to decrease, the capacitor discharges its stored energy into the inductor, causing a magnetic field to be created around the inductor. The magnetic field around the inductor continues to increase as the capacitor discharges.

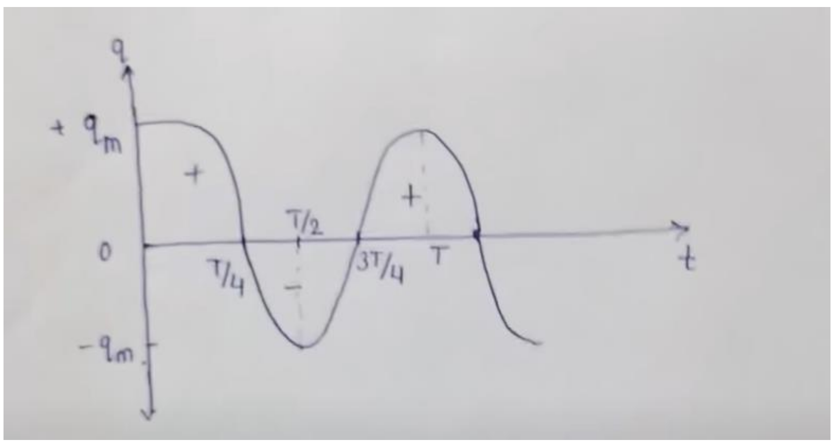


Figure 18: Capacitor Charging and discharging

As the voltage reaches its minimum value, the inductor has stored maximum energy in the form of a magnetic field. At this point, the capacitor has completely discharged its stored energy into the inductor. The magnetic field around the inductor then starts to collapse, which causes the capacitor to start charging again.

This process continues, with the capacitor and inductor alternately storing and releasing energy back and forth. As time is gone, the tank circuit continue with decaying behavior. Here we use a number of current impulse and the tank circuit produce a signal varying with the current pulse.

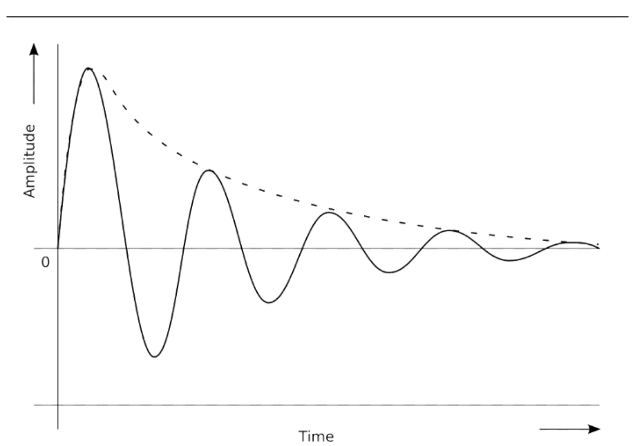


Figure 19: Decaying output

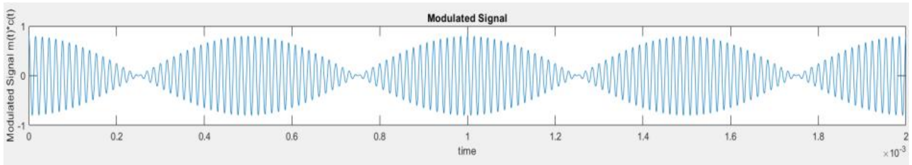


Figure 20: DSB-SC signal=l

Outputs of Software Implementation:

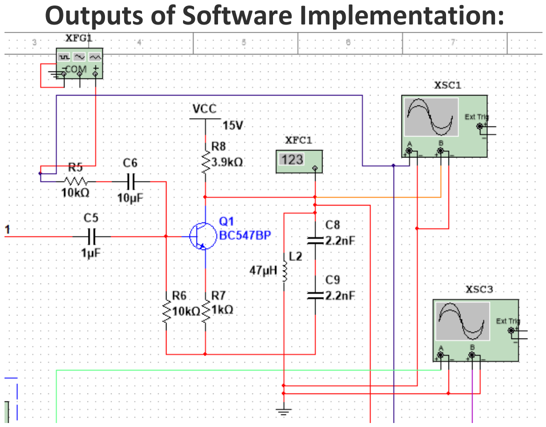
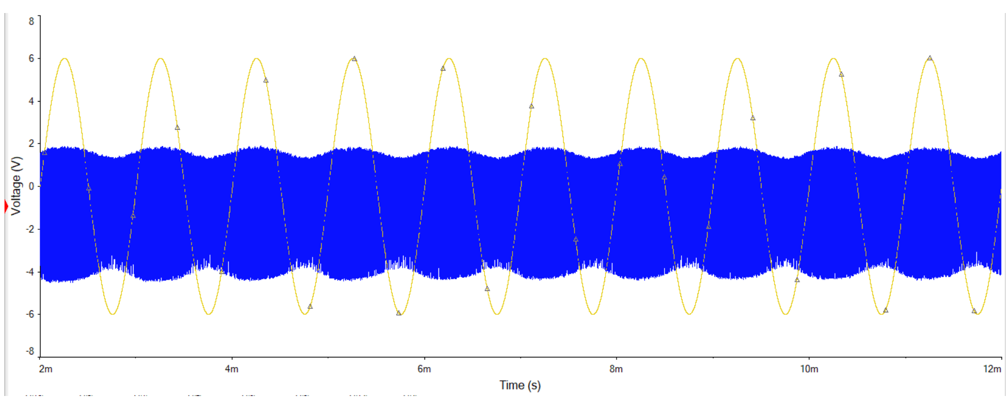
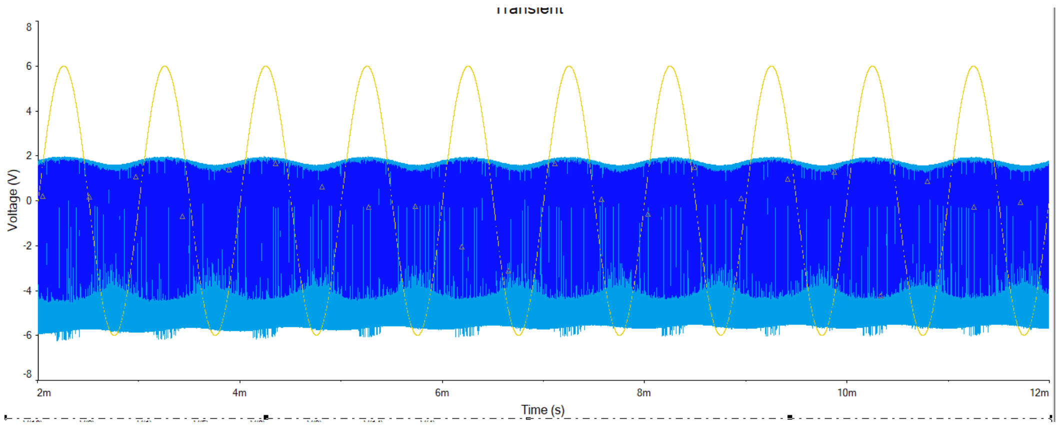


Figure 21: AM circuit





Outputs of Hardware Implementation:

Pic2: Image of sinusoid modulating signal (from signal generator) 1.07V p-p and almost 1kHz frequency

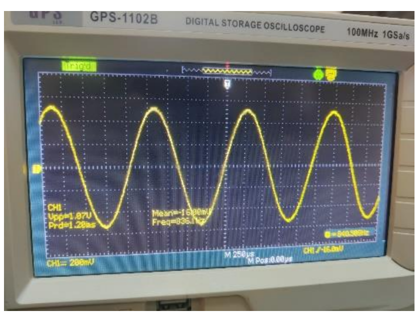


Figure 22: message Signal

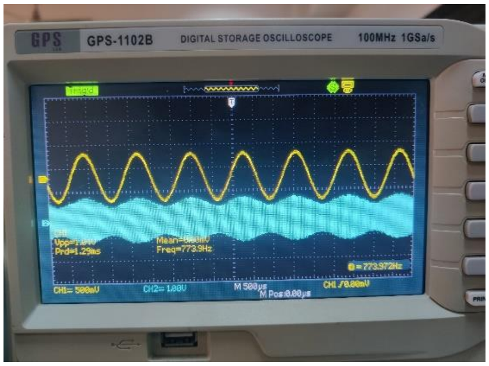


Figure 23: Modulated Sin wave

Figure 24: Modulated Triangular Wave

Figure 25: Modulated Rectangular Wave

Why DSB+C is used?

The type of modulation used here is DSB+C, which results in a modulated signal that shows a DC shift version of the original modulating signal, despite the absence of any DC component in the first stage of modulation. The tank circuit capacitor is charged by the current pulse from the BJT collector, with higher amplitude pulses leading to more significant DC shifting. As a result, a carrier is automatically added to the modulated signal, making it suitable for demodulation using a diode detector circuit.

How to control the carrier component of the modulated signal?

Lowering the Q point of the amplifier can help reduce the amplitude of the current pulse in the tank circuit, which in turn can reduce the amount of DC shift in the modulated signal. Alternatively, reducing the amplitude of the modulating signal can also lead to a lower DC shift in the modulated signal. Both approaches can help to minimize the impact of DC shift on the modulated signal and improve the overall quality of the signal.

Demodulation[3]:

Demodulator Circuit Diagram:

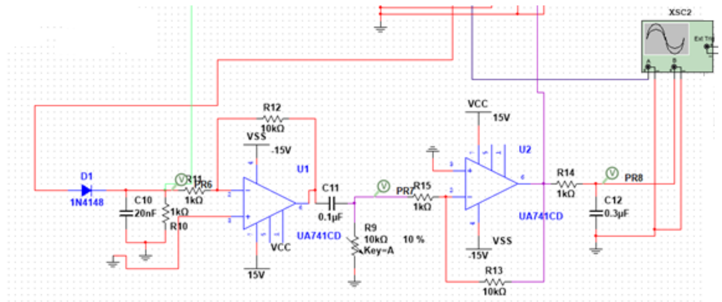


Figure 26: Demodulator Circuit

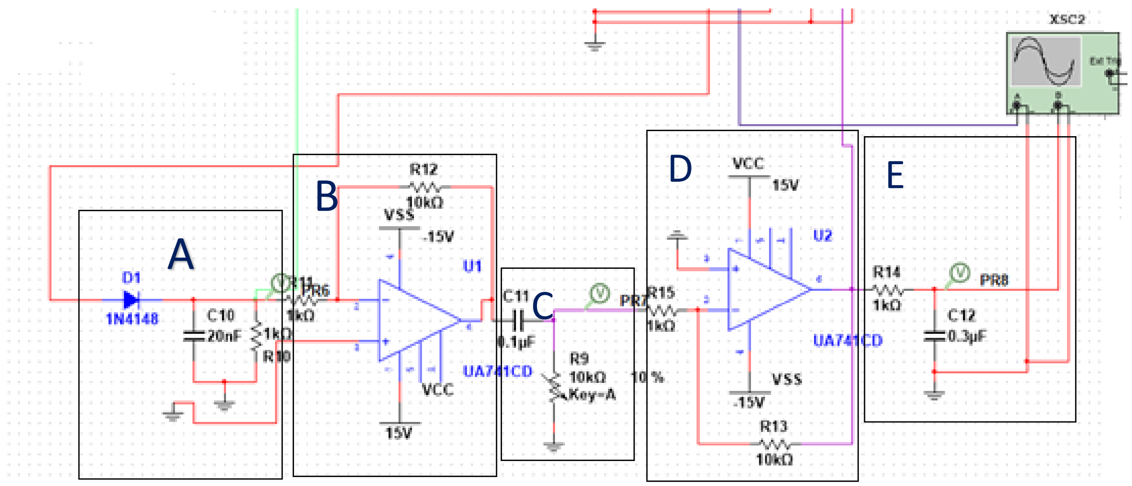


Figure 27: Demodulator circuit (Partwise)

<u>Part A:</u> Part A is a half-wave rectifier with capacitor. Diode D1 blocks negative part of input signal and decreases the positive part by 0.7V.

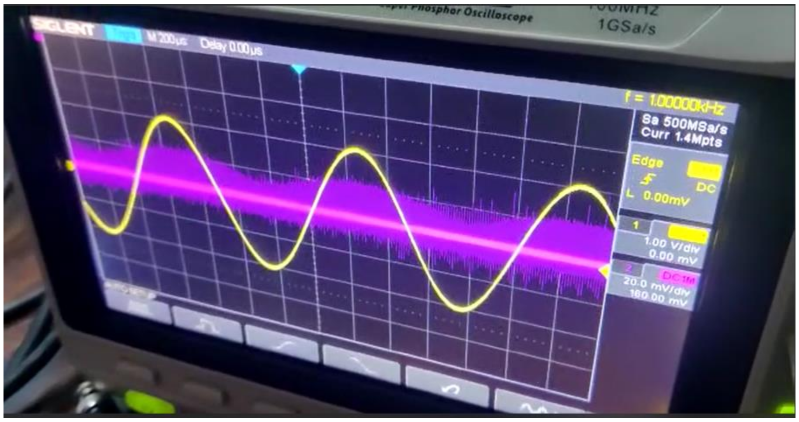


Figure 28: Diode Rectified AM

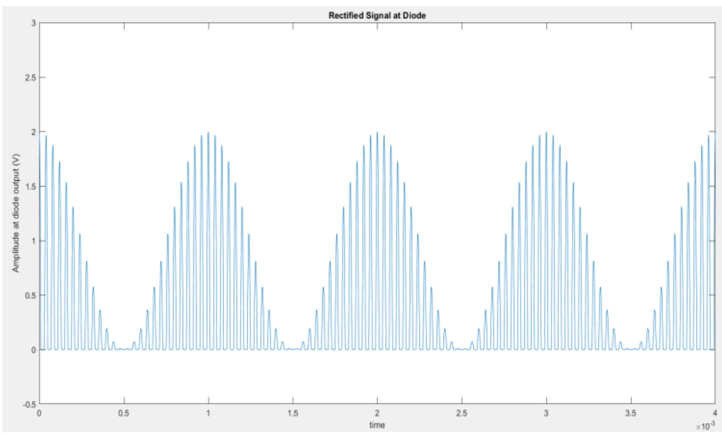


Figure 29: Diode Rectified AM

C10 stores charges in the increasing part and discharges in the decreasing part. In this way it follows the envelope of the message signal.

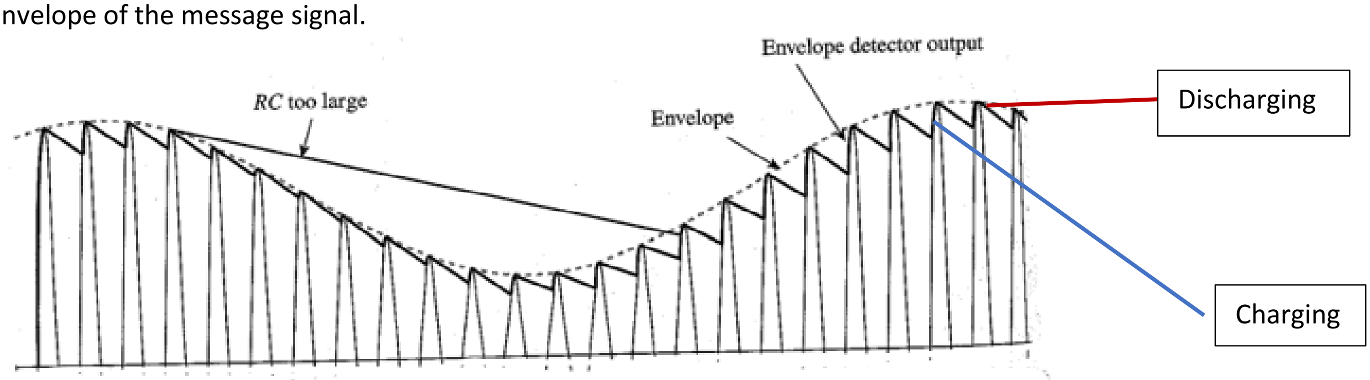


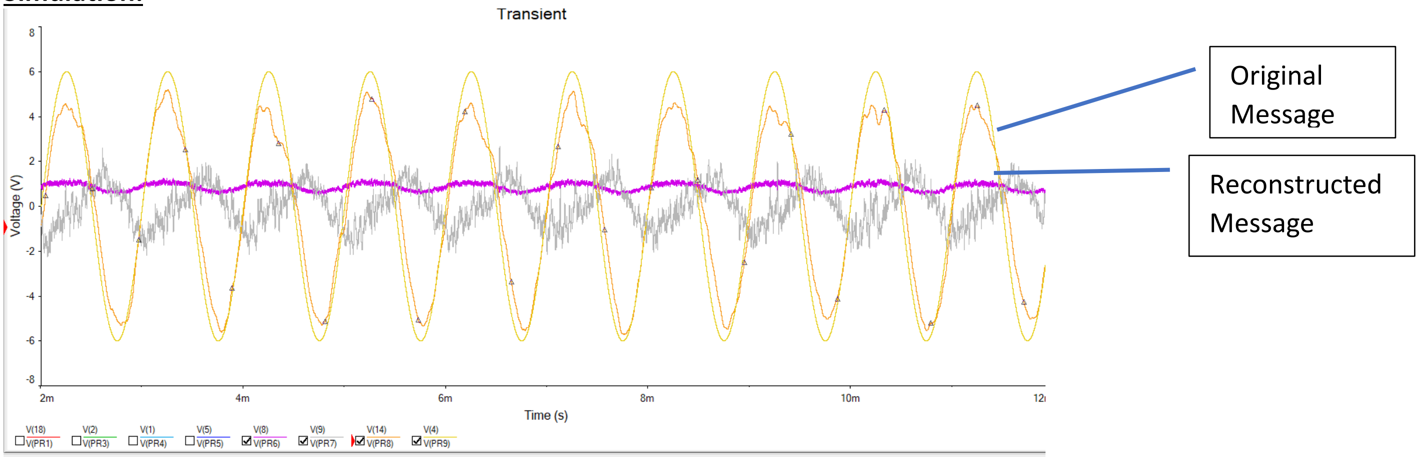
Figure 30: RC charging and Discharging

From theory we know that time constant RC needs to follow the condition $-\left(\frac{1}{wc}\right) \ll RC < (\frac{1}{2\pi B})$ = $1.54 * 10^{-6} \ll RC < \left(\frac{1}{2\pi B}\right)$.Here time constant RC=$20 * 10^{-9} * 1 * 10^{3} = 2 * 10\wedge - 5$ fulfils the criteria.

Part B: Part B is an inverting amplifier with gain=10. It is used to amplify the signal from Part A.

Part C: part C is a high pass filter which is used to nullify the DC offset. It also reduces the noise in the negative part of the diode detector output. A potentiometer is used in place of a resistor to reduce noise.
Part D: Part D is another inverting amplifier with gain =10.
Part E: part E is a low pass filter. It is used to nullify high frequency components which are associated with ripple.

Simulation:



Demodulator Output:

1. Output for sinusoidal case

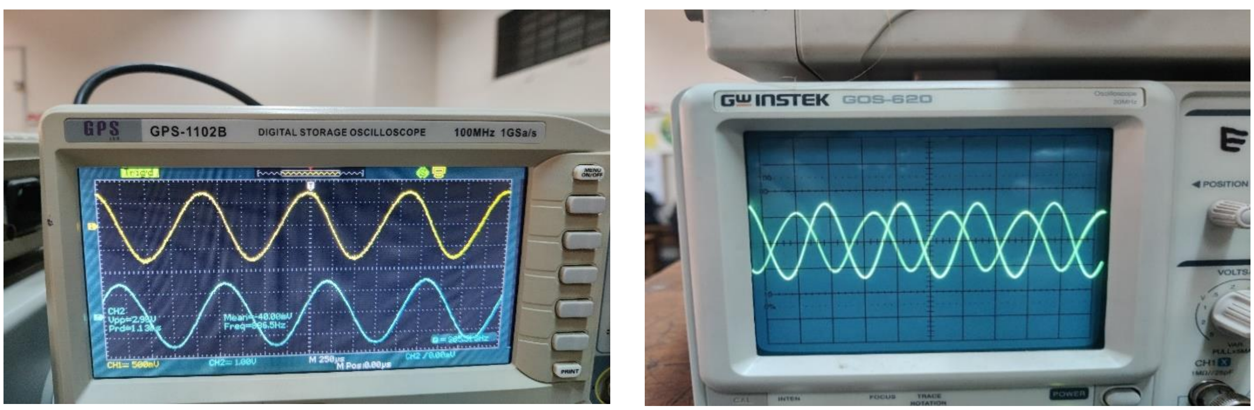


Fig 31: Demodulator output for sinusoidal message

The circuit appears to have successfully demodulated the sinusoidal input signal based on the output graph, despite a slight phase difference between the input and output signals. However, the difference in phase is relatively small and may not have a significant impact on the quality of the demodulated signal.

2. Output for Triangular case:

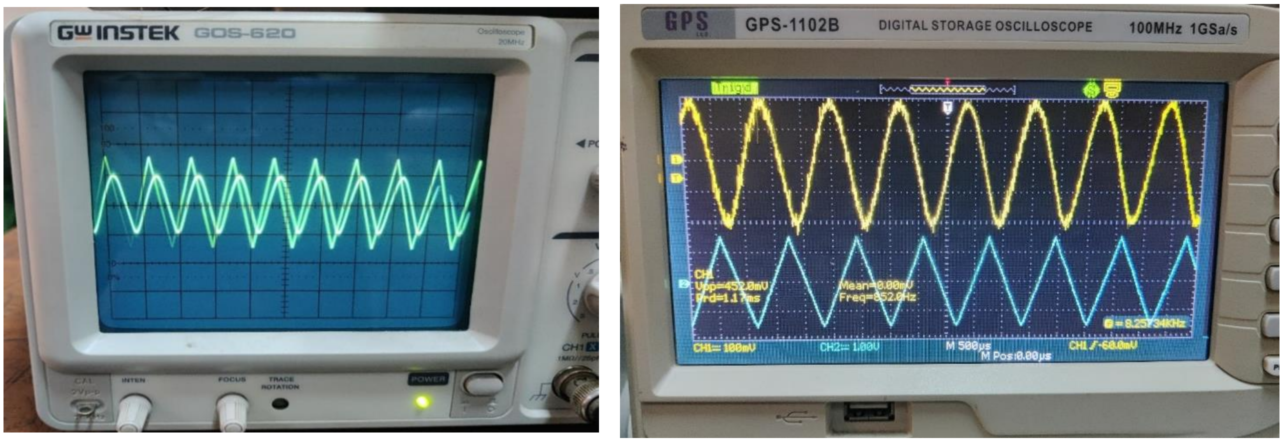


Fig 32: Demodulator output for triangular message

In this scenario, our modulating signal is a triangular wave that contains several high-frequency components. These high-frequency components are responsible for the sharp changes that occur in the edges of the triangular waveform. However, our demodulator includes an active low-pass filter that is designed to attenuate these high-frequency components. As a result, the sharp changes in the edges of the triangular waveform are smoothed out, resulting in a smoother waveform overall.

3. Output for Square waveform:

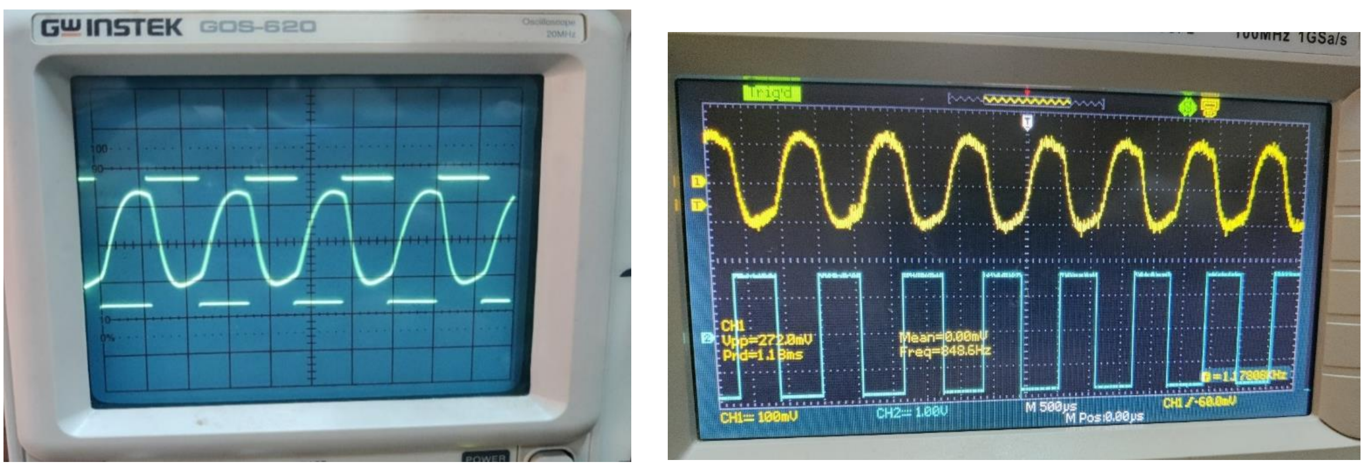


Fig 33: Demodulator output for rectangular message

In this case, we are using a square wave as the message signal, which has quicker transitions than a triangular signal and contains more significant high-frequency components. However, we are using an LPF filter in the demodulating part, which removes the high-frequency components and results in a smoother transition instead of a sharp one.

Conclusion:

A popular modulation method in communication systems, amplitude modulation, was successfully applied in this research. We put what we had learned in our theory course into practice, which allowed us to gain a lot more knowledge about amplitude modulation. We only employed sin, triangle, and square waves in our research, but our system will also work for speech signals. However, since the frequency of voice signals is in this range, a band pass filter will need to be added with cutoffs at 300Hz and 3400Hz. The whole transmitter and receiver circuit is identical for voice transmission except from that. Our circuit's inability to generate DSB-SC signals, which would have improved the efficiency of our design, is one of its limitations.

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