BIRZEIT UNIVERSITY

Faculty of Engineering and Technology

Electrical and Computer Engineering

ENEE3309 Communication Systems, 2023-2024-1st semester Project

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Date: 31 Dec.2023

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Introduction:

The project at hand delves into the intricate realm of amplitude modulation (AM) and demodulation, serving as a comprehensive exploration of both theoretical concepts and practical implementation. AM, a fundamental modulation technique, finds wide applications in communication systems, broadcasting, and signal processing. The project unfolds in two distinct phases—firstly, the generation of a normal AM waveform through a switching modulator circuit, and secondly, the demodulation of this waveform using an envelope detector circuit.

Problem Specification:

1. General Problem Description:

The problem at hand involves the modulation and demodulation of an amplitude-modulated (AM) signal. In a general sense, we are looking to create a mathematical representation for the process of AM modulation and its subsequent demodulation. This encompasses the transformation of a message signal into an AM waveform, followed by the recovery of the original message signal from the modulated waveform.

2. General Formulation:

Let $m(t)$ represent the message signal, $c(t)$ represents the carrier signal, and $p(t)$ represent the diode switching signal in the modulation process. The AM-modulated signal $s(t)$ is given by:

$m(t) = Ac\cos(2\pi f\mathrm{m}t)$

$c(t) = Am\cos(2\pi fct)$

$s(t)=(1+m(t))\cdot\cos(2\pi fct)$

where fc is the carrier frequency.

The diode switching signal p(t) as assumed to follow a specific pattern:

$$p(t) = \begin{cases} 1, & \frac{-Tc}{4} \leq \mathrm{x} \leq \frac{Tc}{4} \\ 0, & \frac{-Tc}{2} \leq \mathrm{x} < \frac{-Tc}{4} \\ 0, & \frac{Tc}{4} \leq \mathrm{x} < \frac{Tc}{2} \end{cases}$$

The demodulation process involves the use of an envelope detector, and the demodulated signal $y(t)$ can be expressed as:

$y(t)=A\cdot\text{envelope}(s(t))$

where A is a scaling factor and envelope($s(t)$) denotes the envelope of the modulated signal $s(t)$.

Data:

➔ **Modulator1**

1.1

- Message and Carrier in time-domain.

- m(t) = 2.5 × cos (2 π 10^3 t)

- c(t) = 4 × cos (2 π 10^4 t)

Notice that:

Carrier's frequency $>$ Message's frequency

- Message and Carrier in frequency-domain.

- M(f) = 1.25 [$\delta(f - 10^3) + \delta(f + 10^3)$]
-
- C(f) = 2 [$\delta(f - 10^4) + \delta(f + 10^4)$]

➔ **Bandpass Filter**

Using an RLC Filter.

With a constant value of C = 25nF

- Using fc= $\frac{1}{2\pi\sqrt{LC}}$ = 10^4=$\frac{1}{2\pi\sqrt{L\times25n}}$ → L=10 mH

- Using B.W=$\frac{R}{2\pi L}$ = 2000=$\frac{R}{2\pi.10m}$ → R=125.66 Ω

➔Envelop Detector

With the same constant value of the capacitor C = 25nF

We know that the range of the time constant τ should be between:

$\frac{1}{fc} < R_LC < \frac{1}{W}$

$1 \times 10^{-4} < R_LC < 5 \times 10^{-4}$

We assumed τ =RC

τ=12k ×25n = 3×10^{-4} ,so it's in the range

Approach:

The aim of this problem was to design a modulator and simulate how a modulated signal is transmitted and then received. At the start of solving the problem we wanted to design a modulator. For the normal AM modulation, the modulator practically consists of a connecting the message and the carrier in series and then passing the outcome to a diode that works as a switch to eliminate negative components of the signal (which is now the sum of the message and the carrier). The signal is then passed to a band pass filter so we can get a specific frequency component of the normal AM.

To design a bandpass filter practically we used a simple series RLC circuit, this series of components works to eliminate frequencies outside a certain band. The band-pass filter allows a specific range of frequencies to pass through the circuit and attenuates frequencies outside that range. The RLC combination relies on the resonance behavior of the RLC circuit and the impedance properties of its components. In an RLC circuit, resonance occurs at a specific frequency where the inductive reactance and capacitive reactance are equal in magnitude but opposite in phase. At resonance frequency (which is the same as fc in our case), the impedance of the circuit is minimized. At frequencies significantly below the resonant frequency the inductive reactance is higher, and at frequencies significantly above the resonant frequency, the capacitive reactance is higher. [3]

In our design through the calculations (as explained in Data part), we were able to select suitable values for L, C and R. These values allowed us to design a filter centered around fc and with bandwidth double the bandwidth of the original message.

After we designed the RLC filter, we connected its output to a demodulator to view the received signal/ message. The demodulator for normal AM modulation is a simple envelope detector. To design the detector practically we used a diode (switching signal), then use a filter(RC circuit) so we can in a way using the filter trace the envelope of the signal, remove DC component (from carrier) and thus get the original message.

Evaluation Criteria:

Again, the aim of this problem was to design a normal AM modulation scheme and simulate how a modulated signal is transmitted and then received. To test the outcome in a correct way we basically connected the modulator, band pass filter and demodulator in the same circuit so we can compare the outcome and ensure that the modulated message form the modulator is the same message received by the demodulator.

To evaluate our system, we basically used the objective approach, where we implemented all parts then compared the original message with the received. We were able to evaluate our solution based on the graphs that we concluded in our simulation through pspice. With every step we plotted the time domain and frequency domain solution, observed the outcomes and analyzed it with the expected graphs or spectrum which are theoretically known to us. We tried multiple cases and we had to adjust the circuit so we could reach a state where visually the received message after envelope detector was very similar to the original.

Results and Analysis1:

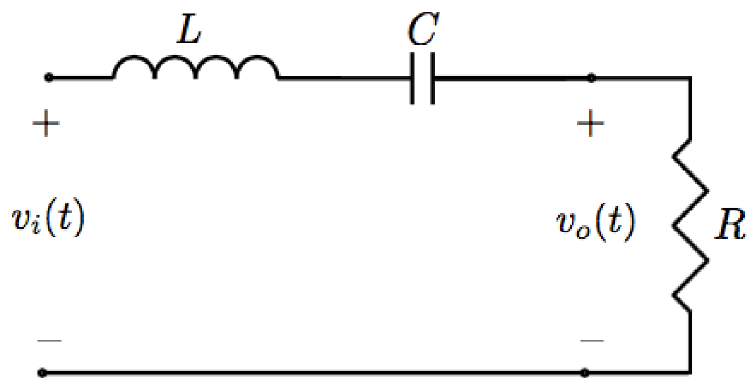


Figure 1: Low Pass Filter [1]

1.2 To find the complex exponential Fourier Series of the signal p(t):

Cn= $\frac{1}{To}\int_{<To>} p(t)\, e^{-jn\omega ot}\,.dt \;=\; \frac{1}{To}\int_{-T/4}^{T/4}(1)\; e^{-jn\omega ot}\,.dt$

$= \frac{1}{To}\left[\frac{e^{-jn\omega o\frac{To}{4}}}{-jn\omega o} + \frac{e^{jn\omega o\frac{To}{4}}}{jn\omega o}\right]$, $\underline{\underline{\omega oTo = 2\pi}}$

$= \frac{1}{n\,\pi}\left[\frac{e^{j\,n\,2\pi} - e^{-j\,n\,2\pi}}{2j}\right] = \frac{1}{n\,\pi}$ Sin $(n\;2\pi\;)$

Co= $\frac{1}{To}\int_{-T/4}^{T/4}(1)\,.dt = \frac{1}{To}\left[\frac{To}{4} - \frac{-To}{4}\right] = \frac{1}{2}$

$$Cn = \begin{cases} \frac{1}{2} & ,n = 0 \\ 0 & ,n: even \\ \frac{1}{n\,\pi} & ,n = 1,5,9,.. \\ \frac{-1}{n\,\pi} & ,\; \mathrm{n} = 3,7,11,\ldots \end{cases}$$

1.3 Evaluate the output modulated signal $s(t)$.

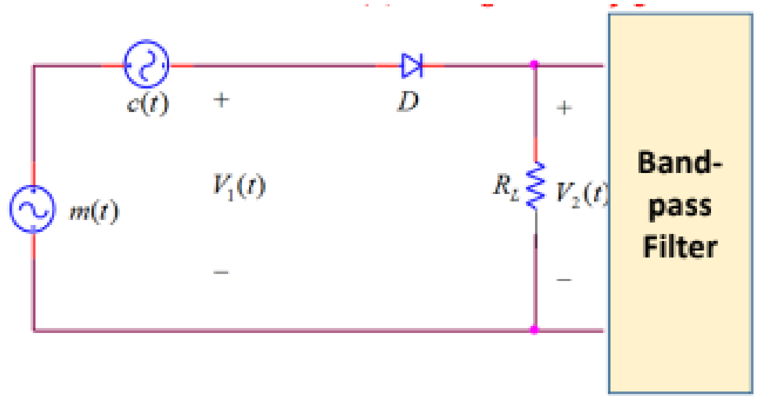


Figure 2:Generation of a Normal Amplitude Modulation: The Switching Modulator [2]

V2(t) = [m(t) + c(t)] p(t)

After founding p(t) in trigonometric form:

$V2(t) = [\, m(t) + c(t)\,]\, [\, \frac{1}{2} + \frac{2}{\pi}[\mathrm{Cos}(\omega_c t) - \frac{1}{3}\mathrm{Cos}(3\,\omega_c t) + \frac{1}{5}\mathrm{Cos}(5\,\omega_c t) + \ldots]$

$V2(t) = \frac{m(t)+c(t)}{2} + \frac{2}{\pi}\,[m(t) + c(t)]\,\mathrm{Cos}(\omega_c t) + \ldots$

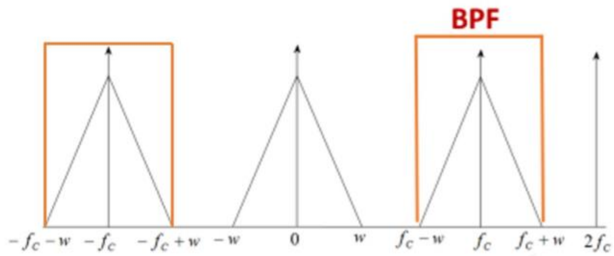


Figure 3: A band-pass filter with a bandwidth=2w, centered at fc [2]

To get S(t) using BPF:

$S(t) = \frac{Ac}{2}[1 + \frac{4}{\pi Ac}\, m(t)]\,\mathrm{Cos}(2\pi fct)$

$S(F) = \frac{Ac}{2}\,[\delta(f-fc) + \delta(f+fc)] + \frac{4}{2\pi Ac}[M(f-fc) + M(f+fc)]$

1.5 Use MATLAB or Pspice software to plot the modulating signal, carrier signal, switching signal, and modulated signal in the time domain and frequency domain. Explain your results.

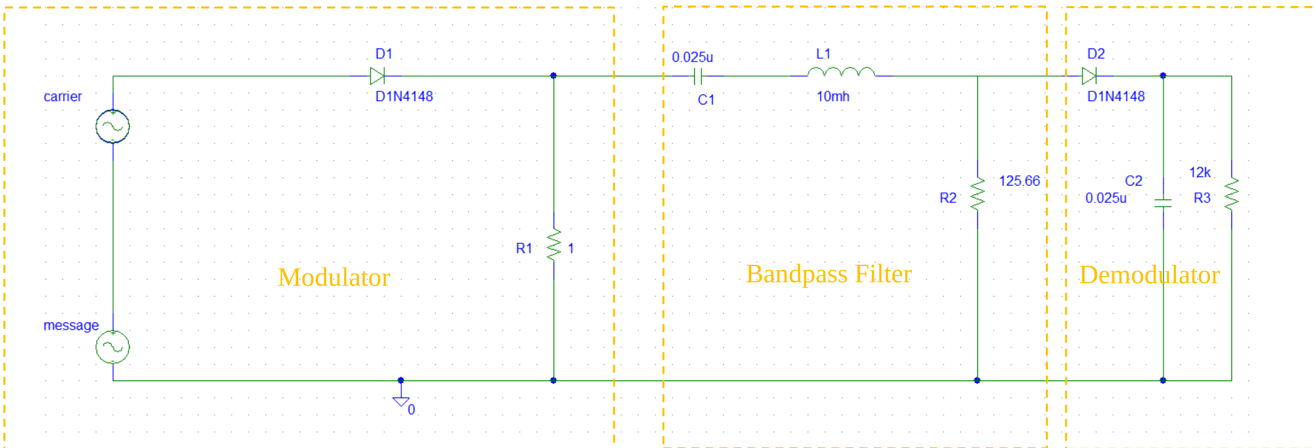


Figure 4: Normal AM modulation and Demodulation

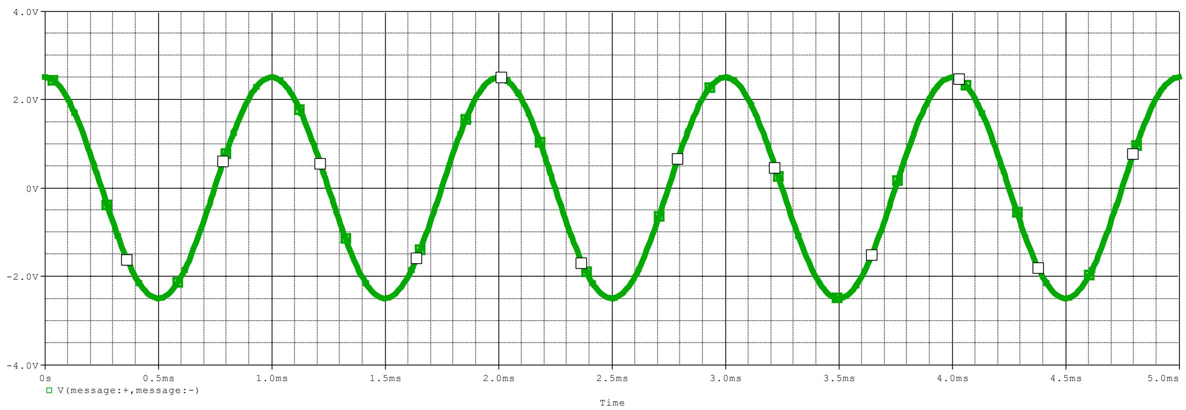


Figure 5: Modulating Signal (The Message) in t-domain

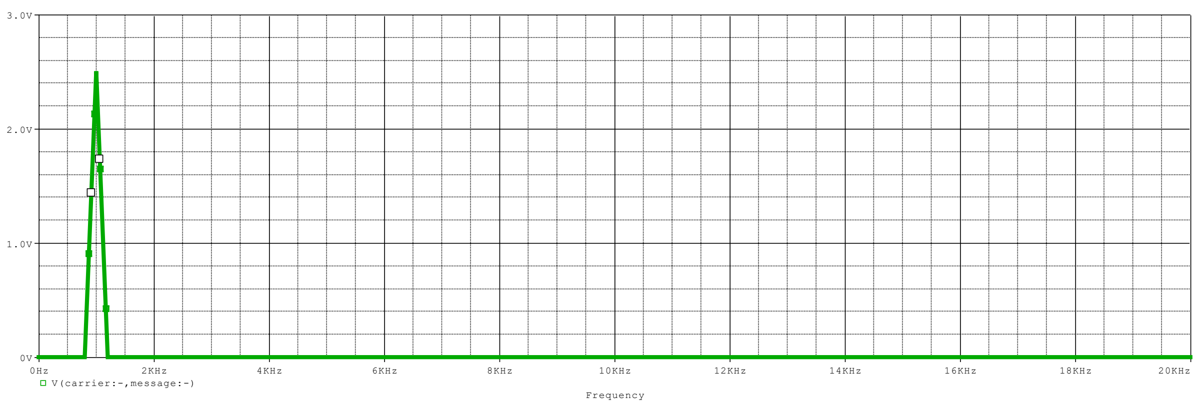


Figure 6: Modulating Signal (The Message) in f-domain

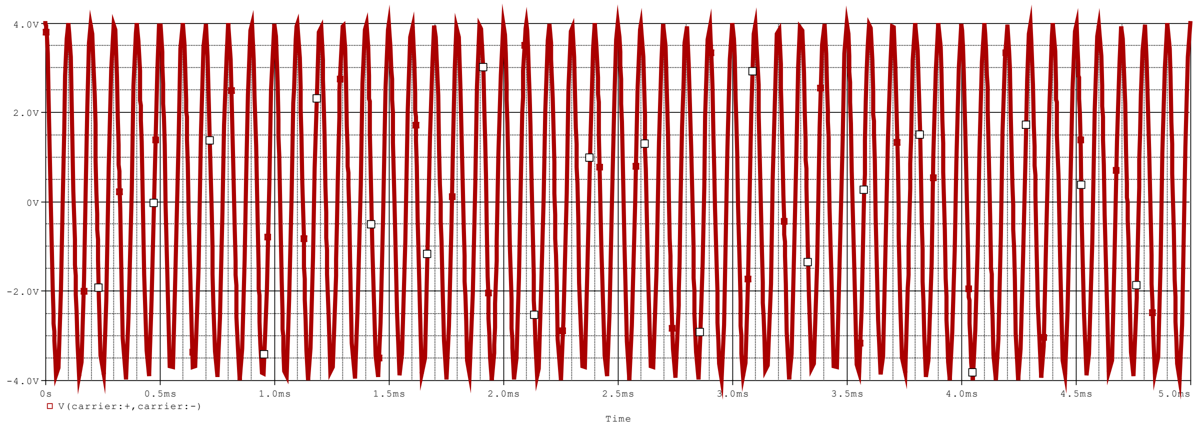


Figure 7: Carrier Signal in t-domain

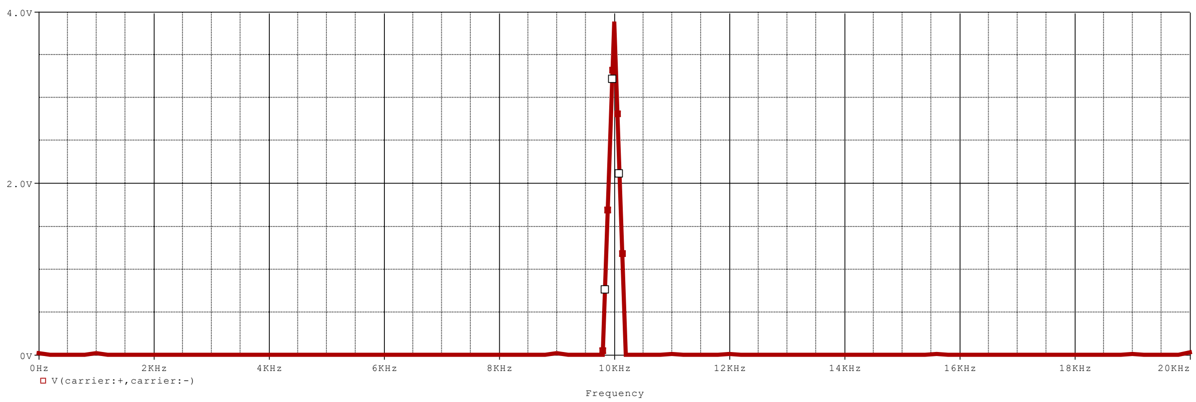


Figure 8: Carrier Signal in f-domain

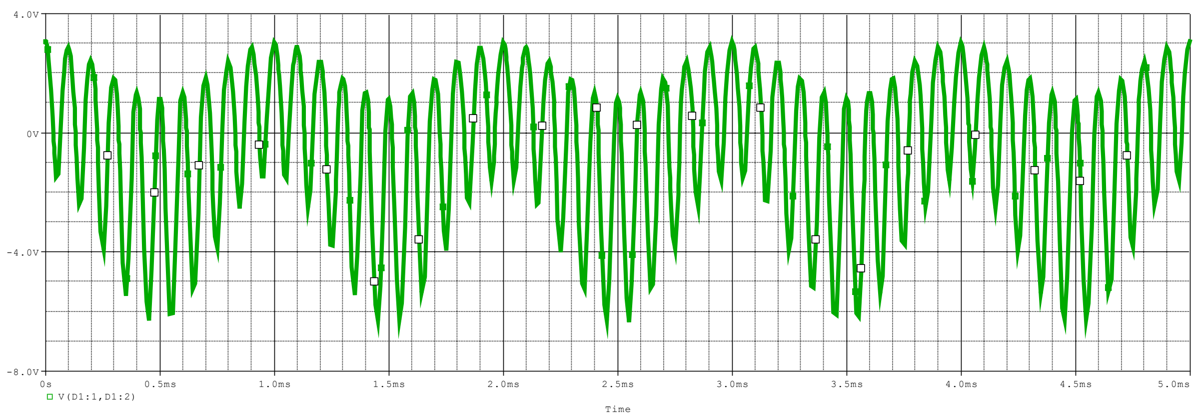


Figure 9: Switching Signal in t-domain

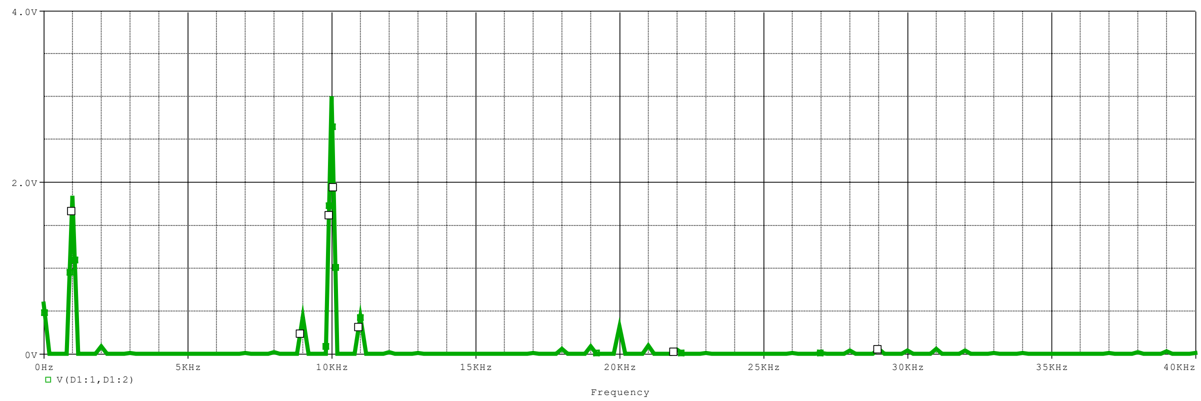


Figure 10: Switching Signal in f-domain

➔ The following figure 12 below shows the signal after passing through the diode. Notice in the time domain the diode eliminated all the negative component of the signal. In the frequency domain in figure 13 we can notice multiple carriers and messages spectrums repeated along the frequency axis, this is why we need a bandpass filter to be able to choose one repetition (one repetition in the positive and the other repetition is symmetric in the negative). This repetition represents the normal AM modulation correctly.

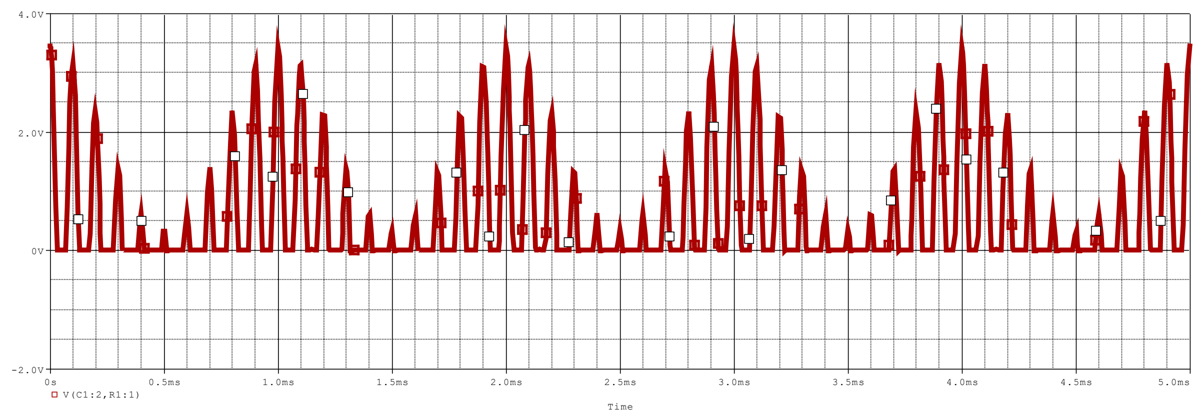


Figure 11: Output at R1 In t-domain

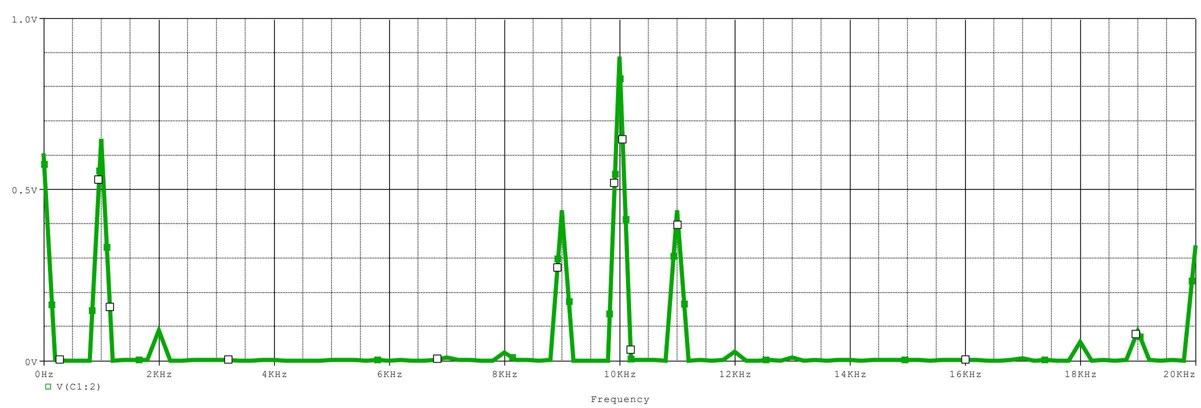


Figure 12: Output at R1 In f-domain

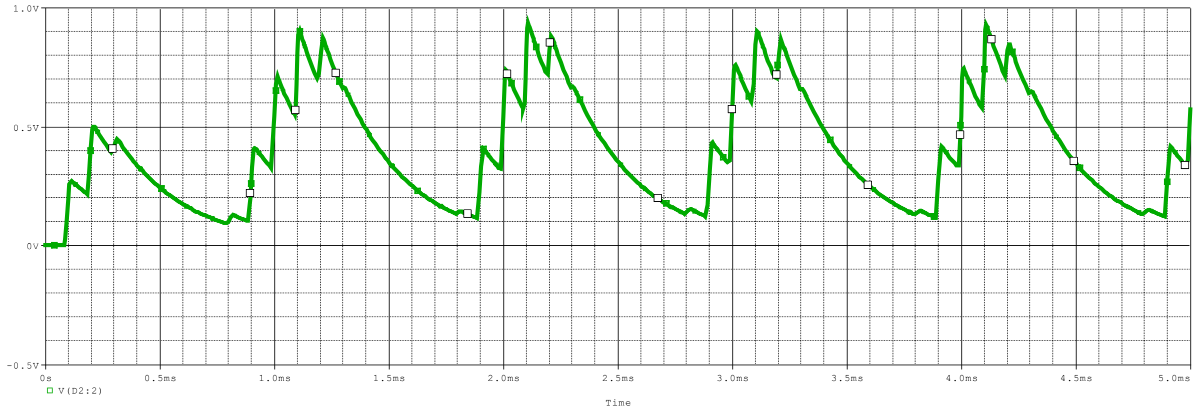


Figure 13: Message after envelope detection in time domain

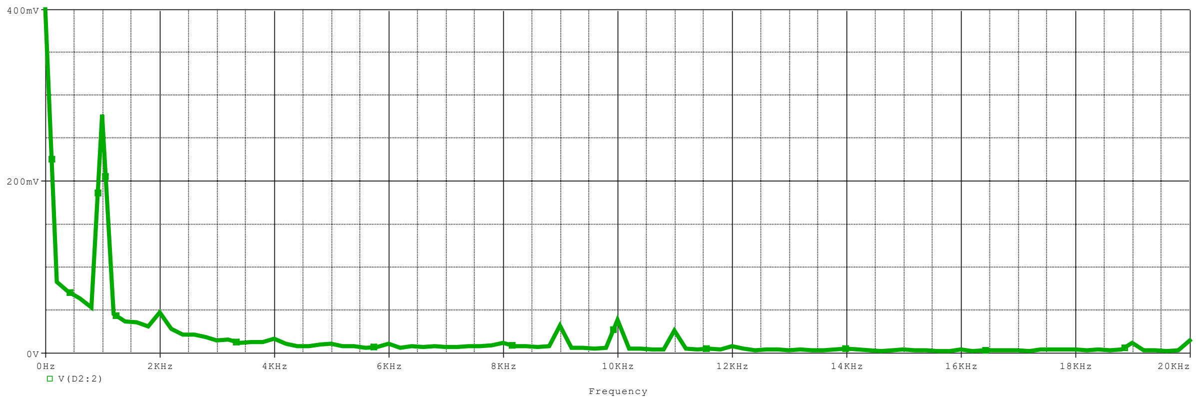


Figure 14: Message after envelope detection in frequency domain

➔Modulator2

After we designed the modulator 1 in our original designed, we experimented with different values of the carrier to notice the difference. We noticed that increasing the frequency of the carrier gave us better results and the recovered message was closer to the original message. In this modulator we experimented with a frequency of 5*10^4 and noticed the message shown in figure 19. Compared to the original it is closer to the real message.

1.1

- Message and Carrier in time-domain.

- m(t) = $2.5 \times \cos(2\,\pi\, 10^3\, t)$

- c(t) = $4 \times \cos(2\,\pi\, 5 * 10^4\, t)$

Notice that:

Carrier's frequency $\gg$ Message's frequency

- Message and Carrier in frequency-domain.

- M(f) = 1.25 [$\delta(f - 10^3) + \delta(f + 10^3)$]
-
- C(f) = 2 [$\delta(f - 5 * 10^4) + \delta(f + 5 * 10^4)$]

➔Bandpass Filter

Using an RLC Filter.

With a constant value of C = 25nF

- Using fc= $\frac{1}{2\pi\sqrt{LC}} = 5 * 10^4 = \frac{1}{2\pi\sqrt{L\times 25n}}$ → L=405 uH

- Using B.W= $\frac{R}{2\pi L}$ = 2000= $\frac{R}{2\pi.405u}$ → R=5 Ω

➔Envelop Detector

With the same constant value of the capacitor C = 25nF

We know that the range of the time constant τ should be between:

$$\frac{1}{fc} < R_L C < \frac{1}{W}$$

$$3.18u < R_L C < 5 \times 10^{-4}$$

We assumed τ =RC

τ=12k $\times$25n = 2.5×10^{-4} ,so it's in the range

Results and Analysis2 using PsPice:

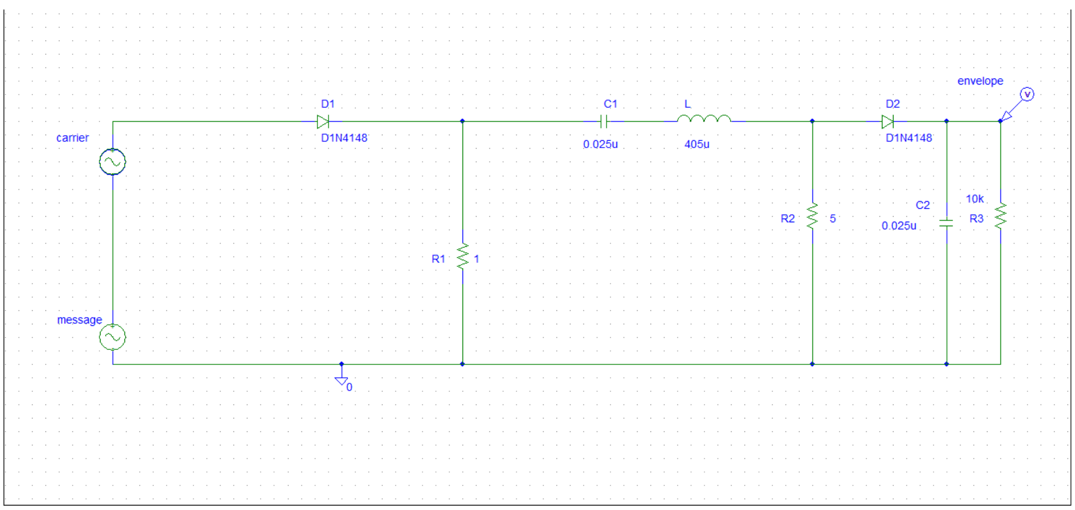
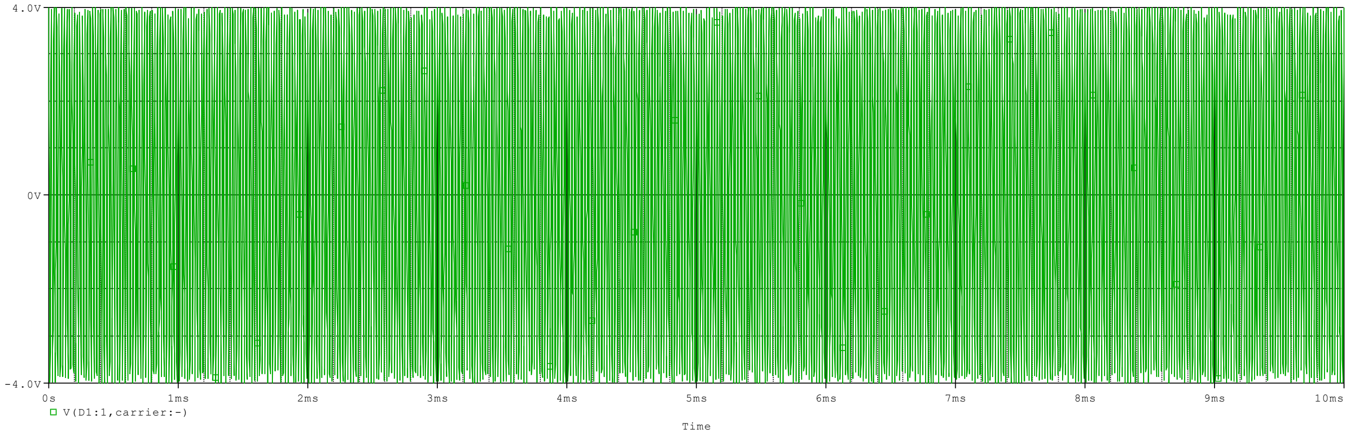


Figure 15:Normal AM modulation and Demodulation



:

Figure 16:Carrier Signal in t-domain

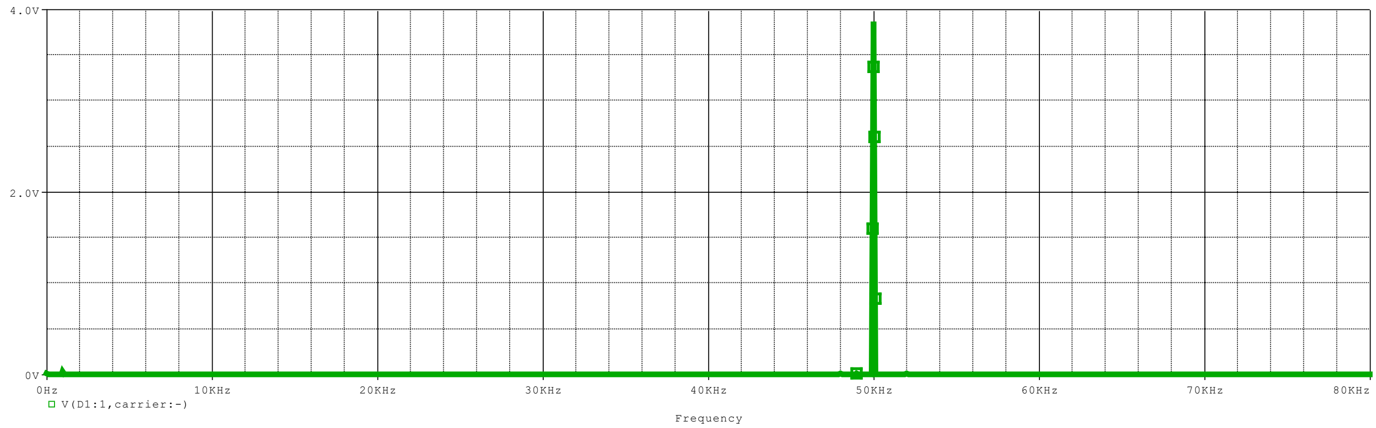


Figure 17: Carrier Signal in f-domain

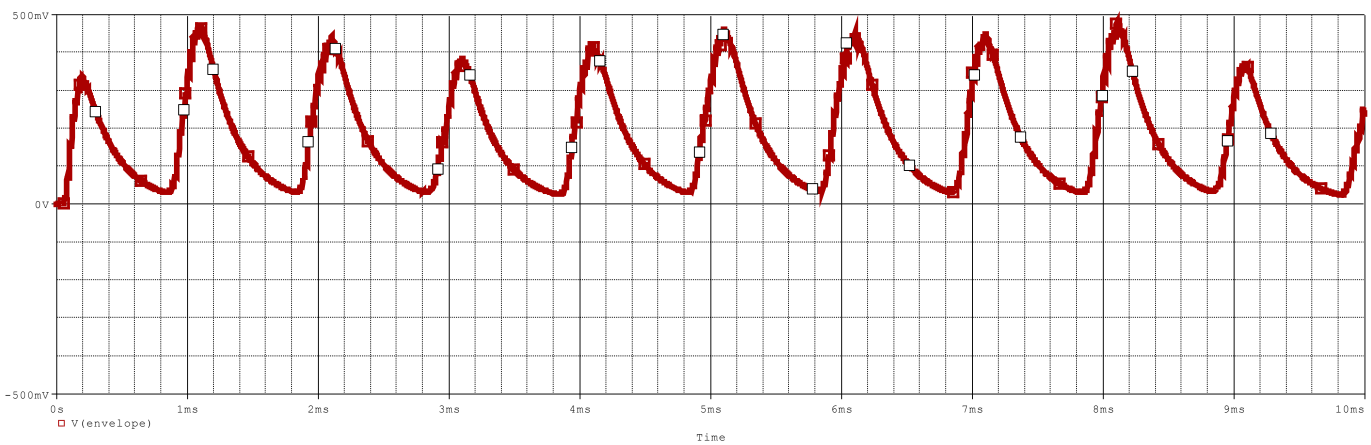


Figure 18: Massege after envelope detection in time domain

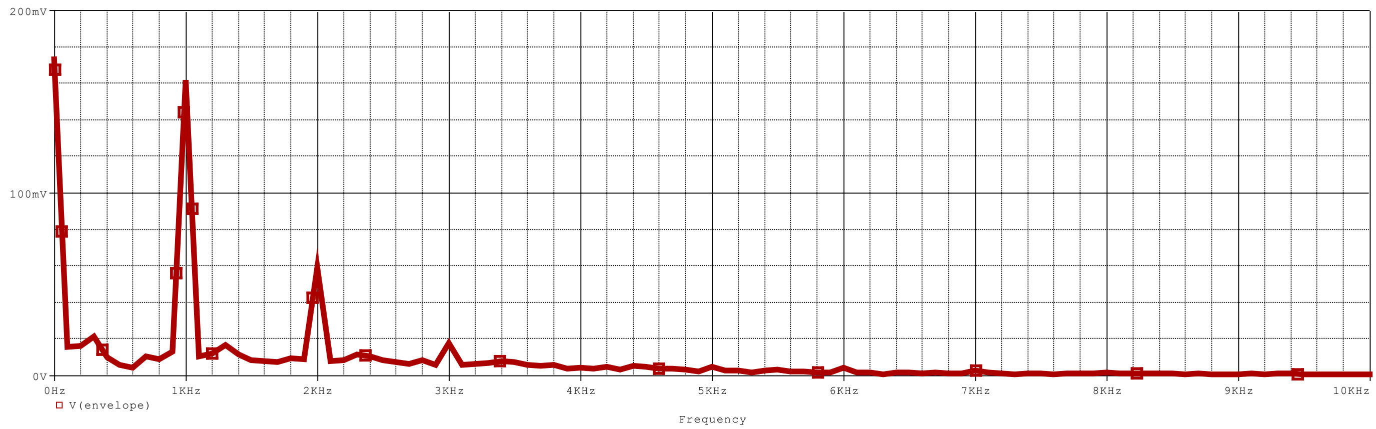


Figure 19: Massege after envelope detection in frequency domain

Conclusion:

In conclusion of this project, we learned more about how to generate and design a Communications system. We explored how to generate a Normal Am modulation by switching modulator and then built the Envelop detector (demodulation to recover the message). The design was done using Pspice Software, so we became more familiar with the Tool. In implementing this design, we were able to explore the challenges from implementing the theory into practice and how to test the outcomes step by step. We designed the modulator and plotted the signal each step of the way, we also designed the band pass filter, and we noticed that designing an ideal filter in practice is hard. In addition to not having and ideal filter (we can notice that clearly in frequency domain), choosing the right type, implementation and the right values represent a challenge and needed many testing and adjustments. On the other hand, through designing modulator 2, we were able to conclude that increasing the frequency of the carrier gives us a better modulation in general and allowed us to recover the message more precisely. Finally, through meticulous simulation, we dealt with the complexities of working with signals, and exploring how modulating signals and carrier signals interact with each other.

References:

[1]: https://images.app.goo.gl/aRsD8XLY9JdiHWbu7

[2]:https://drive.google.com/drive/folders/18J3vFPPvT8CtpNjvFmNySIaRiBLhTmSE?fbclid=IwAR3k4Me1XFzMjr9YHVo7RkR6NhUiM0y5vEEl9VSkP7T2E3s3HWdpoRFCvB8&sort=13&direction=a

[3]: How to Create Bandpass Filters - Technical Articles (eepower.com)