Faculty of Engineering and Technology
Electrical and Computer Engineering Department

Computer Communication Lab
ENEE 4113

Experiment No. 4 Report
Frequency Modulation

Prepared by:
Abdel Rahman Shahen 1211753

Partners:

Mahmoud Awad: 1212677

Student2: num2

Instructor:
Dr. Ashraf Rimawi

Section: 2
Date: 3/13/2024
Time: 10:50 AM --- 1:10 PM
Place: Birzeit university communication laboratory: Aggad341

Abstract

"This report delves into Frequency Modulation (FM), blending theoretical insights with practical experiments to demystify FM's principles and applications in telecommunications. It covers the FM signal's derivation, modulation and demodulation techniques, including software simulations and hands-on lab work. Key aspects explored include signal extraction methods, the impact of modulation depth on signal characteristics, and the effectiveness of phase-locked loop and envelope detector in demodulation. The experiments aim to familiarize students with FM's underlying concepts, enhancing their understanding through theoretical and practical exposure." .[1]

Table of Contents

Table of Figures

Table of tables

Theory

"Frequency Modulation (FM) encodes information by varying the frequency of a carrier wave, contrasting with amplitude modulation (AM), where the amplitude varies but the frequency remains constant. FM's resilience against noise makes it ideal for high-fidelity broadcasting. The FM signal is mathematically described as $s(t) = A_c \cos(2 \pi f_c t + 2 \pi k_f \int_0^t m(\tau)\, d\tau)$, with A_c as the carrier amplitude, f_c the carrier frequency, k_f the frequency deviation sensitivity, and $m(t)$ the message signal." .[1]

"Demodulating FM involves differentiating the signal to convert it into an AM form, then applying an envelope detector, or using a phase-locked loop (PLL) for more precise message signal extraction. The experiment examines FM's spectral characteristics and modulation depth's impact, offering practical insights into FM's bandwidth requirements and its behavior under varying conditions. This comprehensive approach aims to enhance understanding of FM's principles and applications in telecommunications." .[1]

Procedure and data analysis

1. Modulation, Time Domain

1.1 Displaying the FM signal in the time domain

We connected the modules as explained in the lab manual to generate a sinusoidal message signal with Vss = 20V and fm = 1kHz.

The black signal here refers to the message signal and the red one refers to the frequency modulated signal

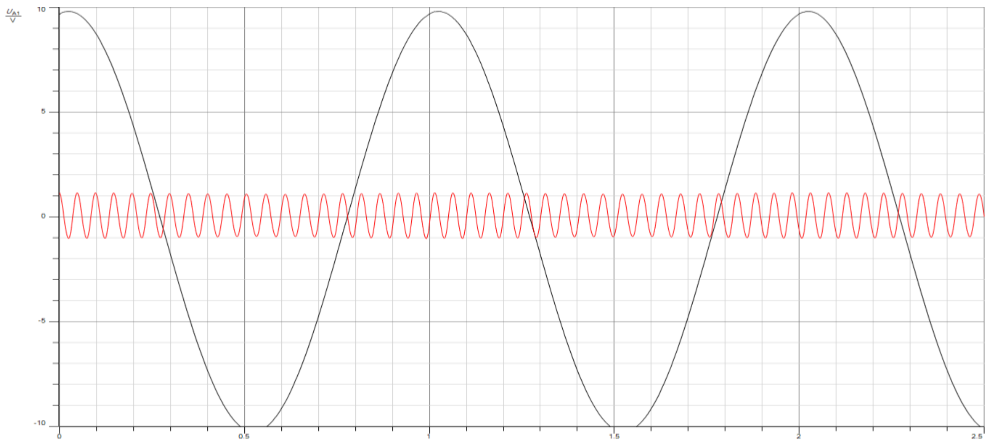

Fig.1 Message signal and frequency modulated signal in time domain

Here is a better view for the same scheme.

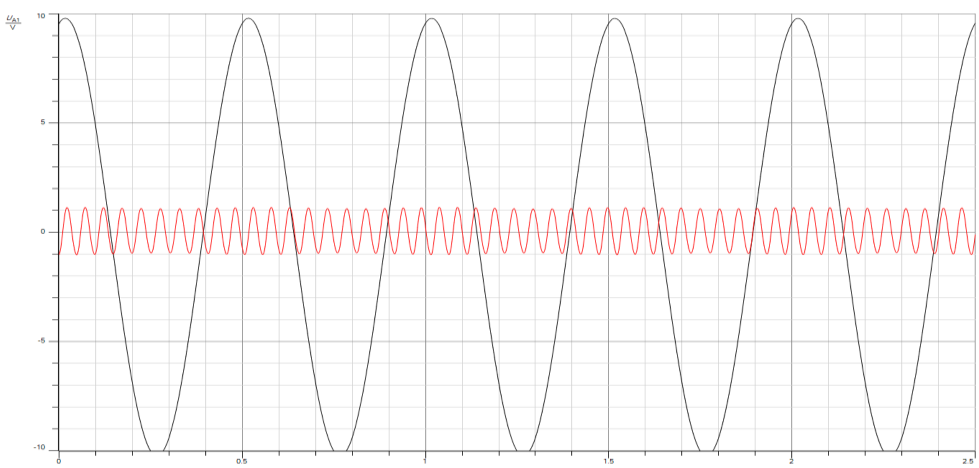

Fig.2 A better view for message signal and frequency modulated signal in time domain

In this view you can notice the variation in the frequency with the variation of the amplitude of the message signal, where as amplitude goes up frequency get larger and vice versa.

Q: Does the modulated signal frequency changes with respect to the message amplitude? Can you explain what is happing?

A: Yes! The modulated signal frequency changes with respect to the message amplitude as the instantaneous frequency of s(t) is given by fi(t) = fc + kf m(t) where m(t) = Am cos (2 π fc t) so in this linear relation fi(t) which is the modulated signal's frequency is proportional with the amplitude of the message signal.

1.2 Displaying the FM signal in the Frequency Domain (Spectrum)

after applying FFT the frequency domain schema is as follows:

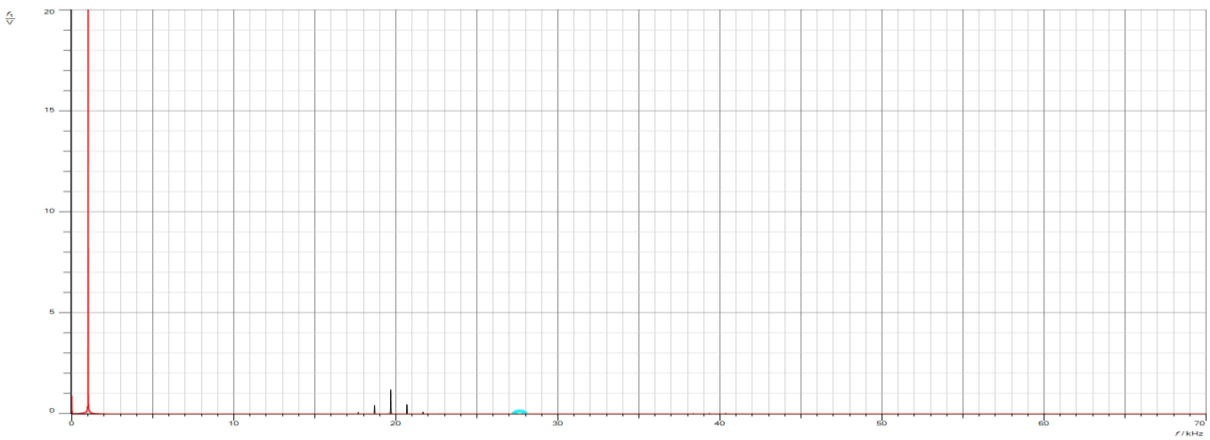

Fig.3 Message signal and frequency modulated signal in frequency domain

2.3: Setting the carrier frequency to exactly 20kHz

Set the function generator to give a Vss = 0V message signal. Now the modulated signal s(t) is representing the carrier signal alone. How? Prove it by equation.

when setting the Vss to 0V this means Am = 0

s(t) = Ac cos (2 π fc t + 2 π kf ∫ 0→t m(τ) dτ), since m(t) = Am cos (2 π fm t)

Am = 0 → m(t) = 0 → ∫ 0→t m(τ) dτ = 0 → 2 π kf ∫ 0→t m(τ) dτ = 0 →

s(t) = Ac cos (2 π fc t + 0) → s(t) = Ac cos (2 π fc t) → s(t) = c(t) #

And here we can see the results: in time domain and frequency domain:

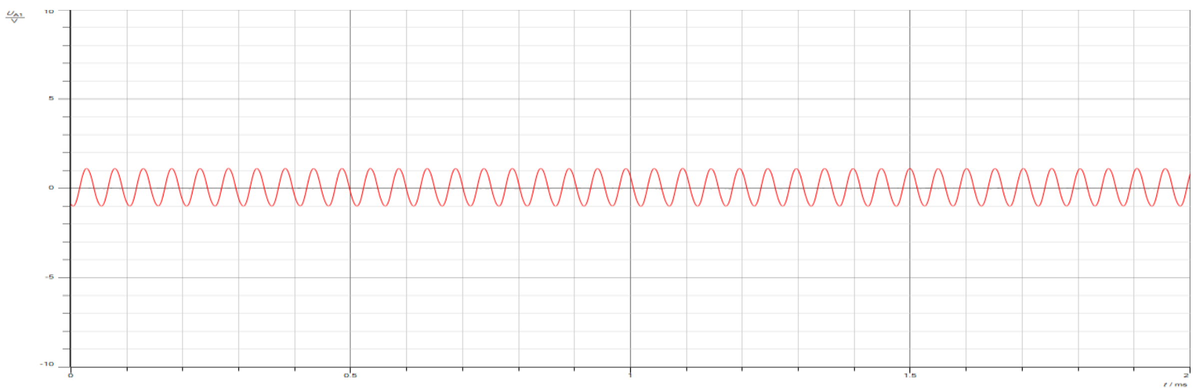

Fig.4 frequency modulated signal when Am = 0 in time domain

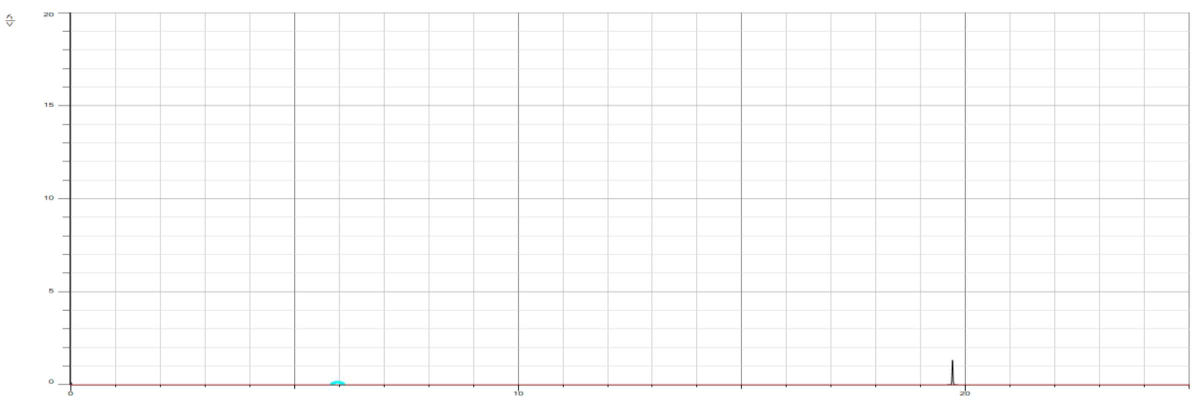

Fig.5 frequency modulated signal when Am = 0 in frequency domain

2.3 The Characteristic of the FM Modulator

Remember: The instantaneous frequency fi(t) of the FM modulator is related to the message signal by: fi(t) = fc + kf m(t). What will happen if the message signal is set to be constant?

If the message signal is set to be constant then the frequency of the modulated signal will stay constant due to this relation: fi(t) = fc + kf m(t). between the modulated signal and the modulated signal.

Using the 20 kHz carrier signal, modulate a DC-signal message signal starting with -10V. After that determine the carrier frequency from the spectrum. Increment the DC voltage in steps of 2V and repeat the measurement of the carrier frequency filling the following table.

Table 1 values of message voltage and carrier frequency

Message Voltage	Carrier Frequency	Message Voltage	Carrier Frequency
-10	19.032 kHz	2	19.87 kHz
-8	19.203 kHz	4	20.03 kHz
-6	19.341 kHz	6	20.14 kHz
-4	19.49 kHz	8	20.31 kHz
-2	19.62 kHz	10	20.42 kHz
0	19.73 kHz		

Determine the coefficient of the FM modulator kf:

Their we have the equation: fi(t) = fc + kf m(t). → assume fc = y and Am = y →

Then y = kf x then to get kf we take the derivative so the slope would be kf since y' = kf

So, let's take the slope of these values in the table. M = ([y2-y1] / [x2-x1])

([20.42 – 19.032] K / [10 -- 10]) = 1388/20 = 64.5, Hence, kf = 64.5

Determining of the frequency deviation for a 10V message signal:

df = Kf Am → Kf = 64.5, Am = 10 → df = 10*64.5 = 645 → df = 645 Hz

2.4 Displaying the FM signal spectrum

2.4.1 Sinusoidal Message signal

After the requested circuit setup, we got these results:

@ fm = 3000Hz

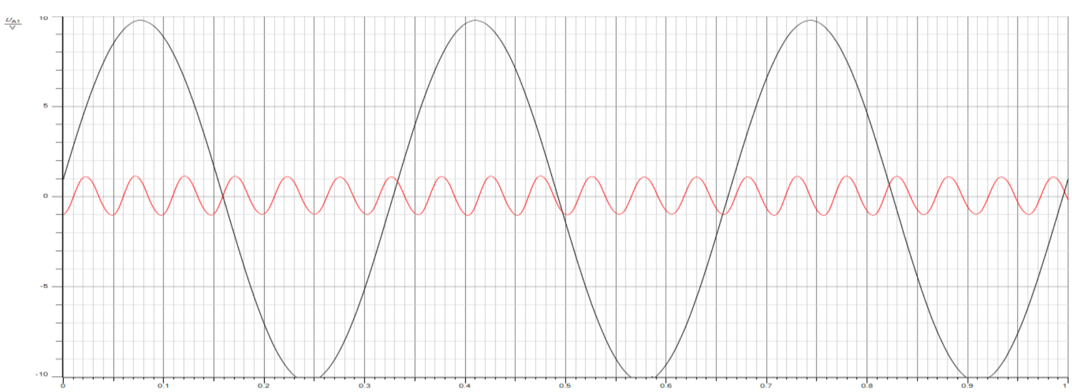

Fig.6 @ fm = 3000 Hz in time domain

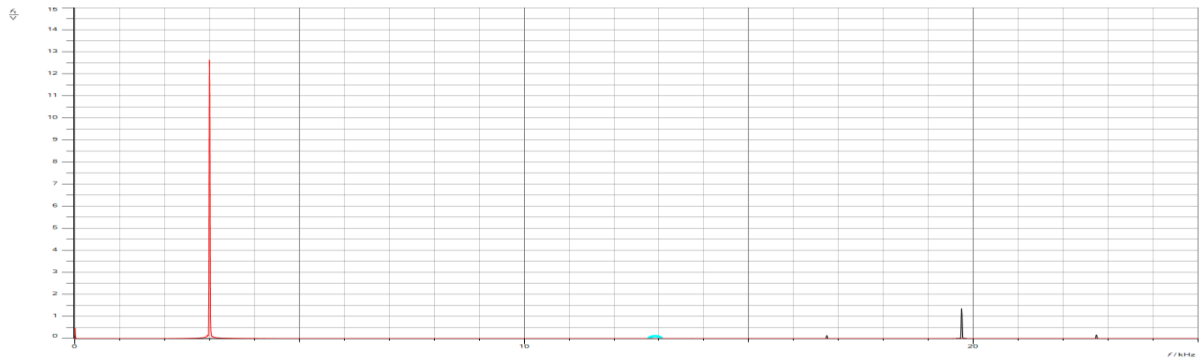

Fig.7 @ fm = 3000 Hz in frequency domain

@ fm = 200Hz

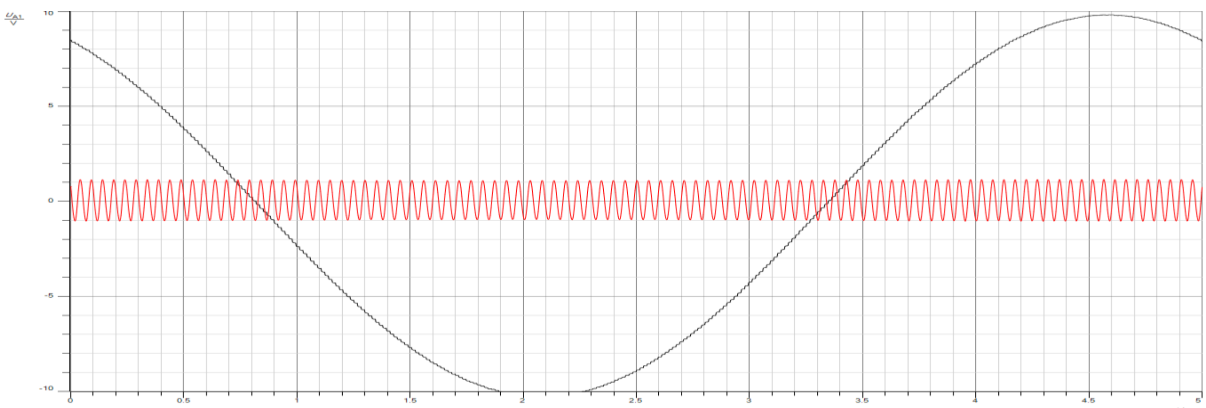

Fig.8 @ fm = 200 Hz in time domain

Fig.9 @ fm = 200 Hz in frequency domain

Compare changes in the spectrum for different m(t) frequency.

- When comparing the two spectrums, note the spacing between the sidebands. The frequency of the message signal determines the spacing.
- With a higher message frequency (3000Hz), the sidebands will be more widely spaced, and the overall bandwidth of the FM signal will be greater.
- With a lower message frequency (200Hz), the sidebands will be closer to the carrier frequency, resulting in a narrower bandwidth.

When you carry out this procedure, make sure to capture the spectral plots as images for your report, and adjust the x-axis range of the spectrum analyzer to clearly show the sidebands around the carrier frequency. The comparison will illustrate the effect of message frequency on FM bandwidth, a fundamental concept known as Carson's Rule, which predicts that the total bandwidth used by FM signals is approximately twice the sum of the deviation frequency and the modulating frequency.

2.4.2 Square Message signal

After the setup the results are as follow:

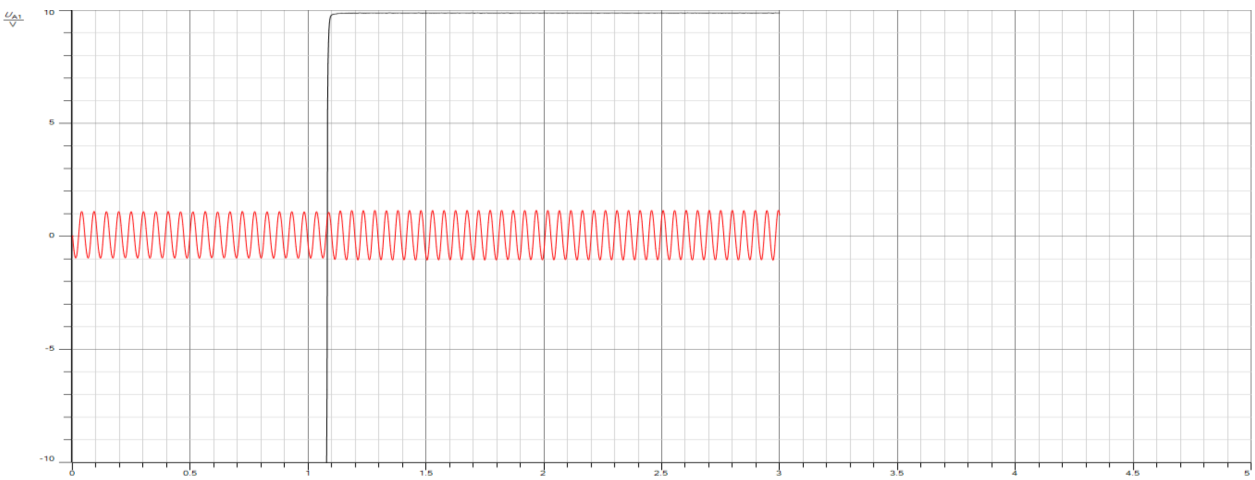

Fig.10 Square Message signal in time domain

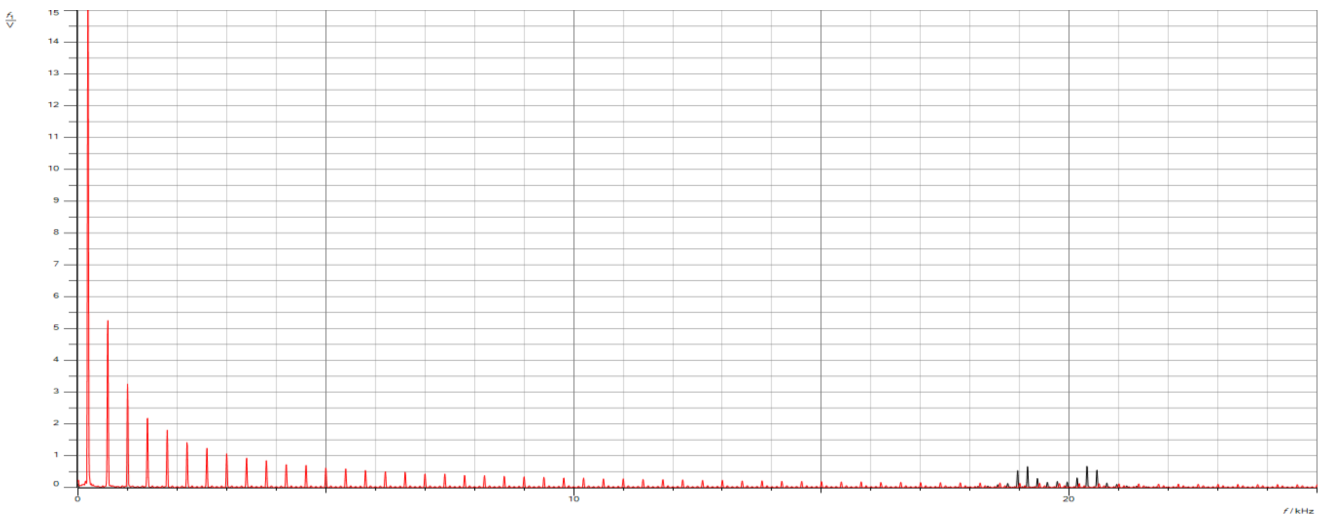

Fig.11 Square Message signal in frequency domain

Compare changes in the spectrum for different m(t) types.

- Unlike the sinusoidal message signal, which produces sidebands at intervals equal to the message frequency, the square wave results in a more complex spectrum due to its harmonic content.
- The spectrum for the square wave message signal will show sidebands at each odd harmonic of the fundamental frequency (200Hz, 600Hz, 1000Hz, etc.), which is a characteristic of square wave modulation.
- The spacing between the sidebands will still be influenced by the fundamental frequency of the message signal, but there will be more sidebands present due to the harmonic content of the square wave.

2.5 Determining the zero carrier crossings

2.5.1 Varying the message amplitude while keeping the frequency constant

@ B = 2.4048, Vss =7.4

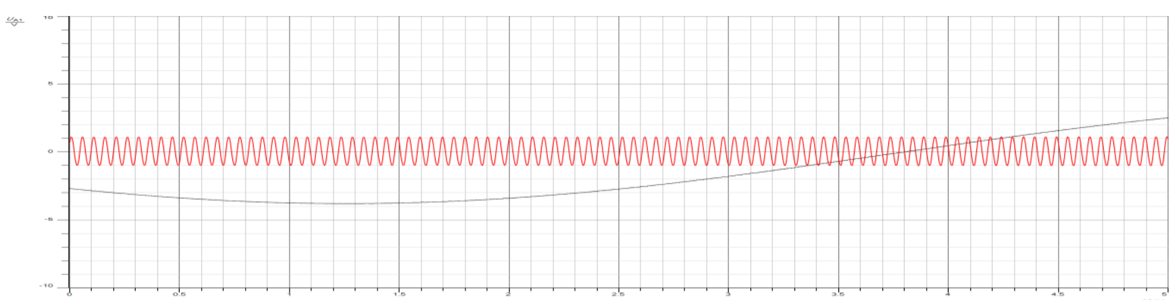

Fig.12 @ B = 2.4048, Vss =7.4 in time domain

Fig.13 @ B = 2.4048, Vss =7.4 in frequency domain

@ B = 5.5201, Vss = 17.1

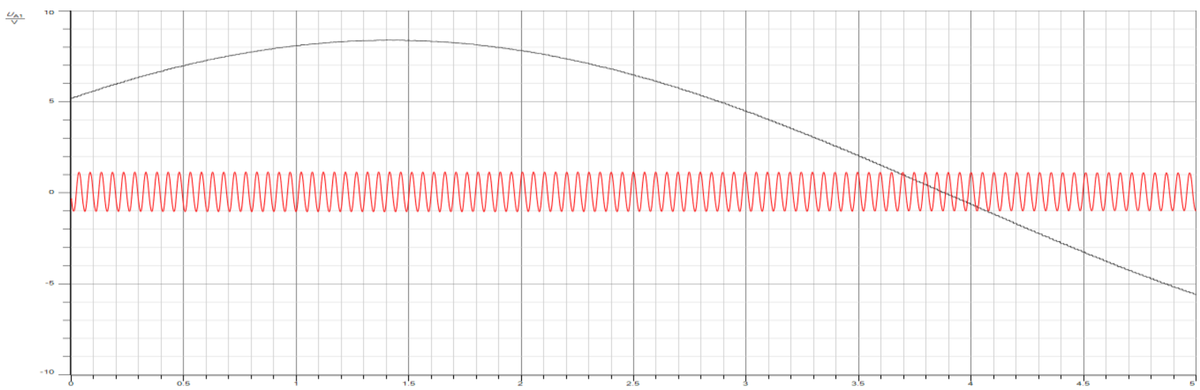

Fig. 14 @ B = 5.5201, Vss =17.1 in time domain

Fig.15 @ B = 5.5201, Vss =17.1 in frequency domain

2. FM Demodulation

2.1 Time domain FM demodulated signal

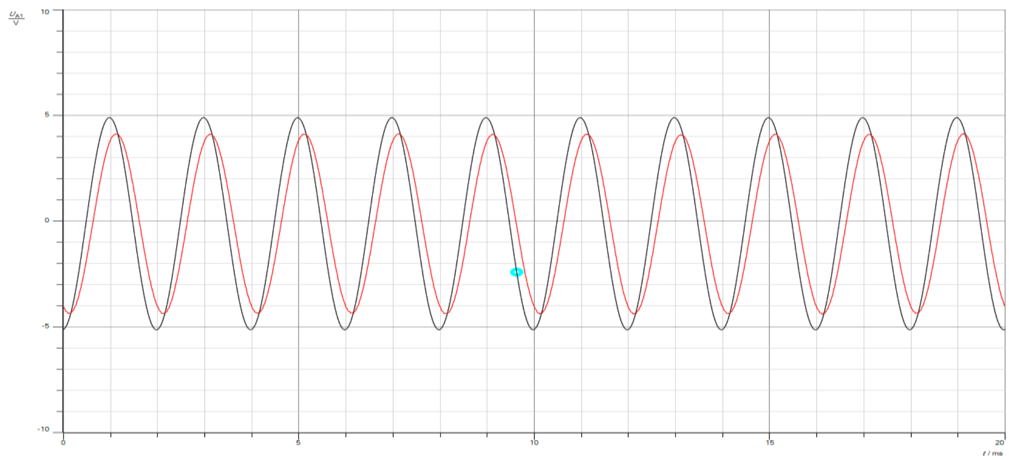

Fig.16 Time domain FM demodulated signal

Does the PLL demodulator works for the FM?

Looking at the result, and comparing the message with the demodulated signals we can say that the PLL demodulator does work for FM.

2.2 : Studying the effect of the receiver loop filter

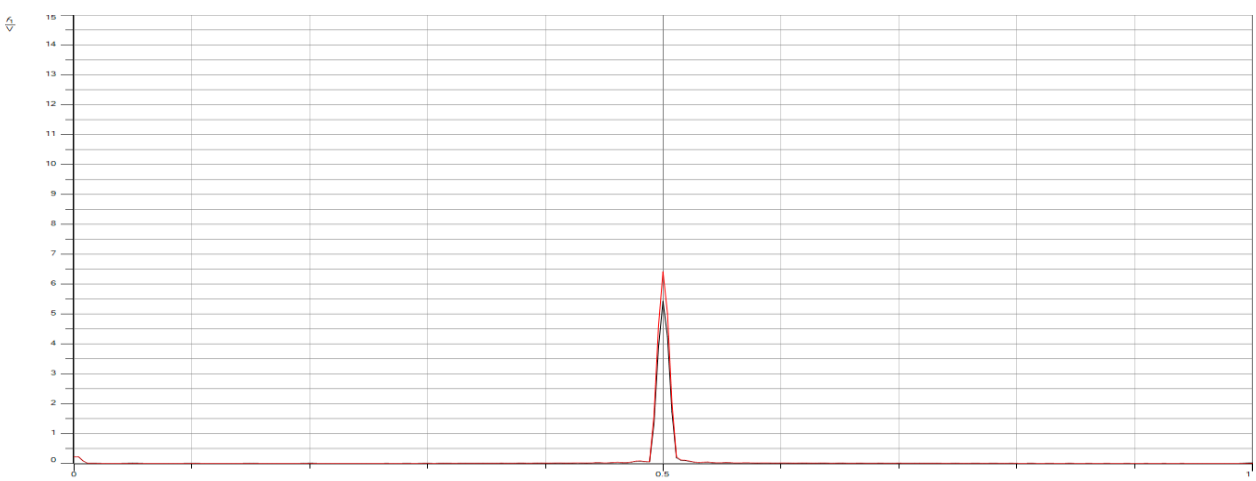

Fig. 17 frequency domain FM demodulated signal

2.2.1 Studying Loop filters τ1 and τ2 without pre-emphasis

Table 2 2.2.1 Studying Loop filters τ1 and τ2 without pre-emphasis

Without the Pre-emphasis						
Message Frequency (Hz)	500	1000	1500	2000	3000	4000
Ad using τ1 filter	9.28	5.46	3.05	2.11	1.39	0.85
Ad using τ2 filter	2.51	2.15	2.10	1.95	1.70	0.86

2.2.2 Studying Loop filters τ1 and τ2 with pre-emphasis

Table 3 2.2.2 Studying Loop filters τ1 and τ2 with pre-emphasis

With the Pre-emphasis						
Message Frequency (Hz)	500	1000	1500	2000	3000	4000
Ad using τ1 filter	12.99	9.09	6.67	5.34	3.93	3.43
Ad using τ2 filter	3.04	4.86	5.87	5.84	4.03	3.06

What are the different characteristics between the two loop filters?

"The two loop filters, τ1 and τ2, exhibit differences in time constants, bandwidths, gain-bandwidth products, damping ratios, phase margins, and noise rejection capabilities, influencing their demodulation efficiency, stability, and response to varying signal conditions." .[2]

How does the Pre-emphases affect the filters responses?

"Pre-emphasis in FM demodulation amplifies higher-frequency components of the input signal, enhancing their representation in the demodulated output. This adjustment alters the frequency response of the filters, typically increasing their sensitivity to high-frequency variations. As a result, pre-emphasis can improve the demodulator's ability to accurately track and reproduce rapid changes in the input signal, particularly in scenarios where high-frequency components are crucial for fidelity, such as in audio transmission systems." .[3]

Conclusion

"In conclusion, this experiment aimed to explore various aspects of frequency modulation (FM) and its demodulation techniques. The objectives included familiarizing with FM modulation and demodulation methods, understanding FM modulator sensitivity, and examining the characteristics of different loop filters. Through the experiment, we learned how to extract message signals from modulated signals, determine modulator sensitivity constants, and observe the effects of message signal characteristics on the FM spectrum. Additionally, the experiment provided insights into the performance of PLL demodulators and the impact of pre-emphasis on filter responses. Overall, this experiment facilitated a comprehensive understanding of FM principles and demodulation techniques, essential for various communication applications.".[1]

References

1- [Lab manual]

2- [https://www.researchgate.net/figure/Second-Order-Loop-Filter-Transient-Response-as-a-Function-of-Time-for-Different-Loop_fig1_224154939] research gate

3- [https://www.daenotes.com/electronics/communication-system/pre-emphasis-and-de-emphasis] DAEnotes