Design and Implementation of Monotone and Audio Signal Transmission/Reception Using ADALM-Pluto

Communication Systems Project

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***Abstract*—This project explores the implementation of a communication system using the Lower Sideband Single Sideband (LSSB) modulation technique in GNU Radio. The system is designed to simulate, transmit, and receive modulated signals through the ADALM-Pluto radio. Key findings demonstrate the effectiveness of LSSB in transmitting both tone and audio signals with high clarity and optimized bandwidth. Adjustments to transmission parameters, including power and gain, further enhance reception quality. This hands-on project highlights the practical applications of LSSB modulation and provides insights into optimizing communication systems for real-world scenarios.**

I. Introduction

In modern communication systems, achieving efficient utilization of bandwidth and power is critical for delivering reliable and high-quality signal transmission. Single Sideband (SSB) modulation is a widely used technique that addresses this need by transmitting only one of the sidebands, reducing bandwidth usage and improving power efficiency. Lower Sideband (LSSB) modulation, a specific variant of SSB, is particularly advantageous for conserving spectral resources while maintaining signal fidelity [1].

The emergence of Software-Defined Radio (SDR) has revolutionized the design and testing of communication systems by providing a flexible and reconfigurable platform. The ADALM-Pluto radio, a compact and affordable SDR device, enables real-world signal transmission and reception, making it an invaluable tool for both educational and research purposes [2]. By integrating the capabilities of SDR hardware with GNU Radio, an open-source software toolkit, this project demonstrates the practical application of LSSB modulation in communication systems [3].

To lay the groundwork for this project, the principles of Amplitude Modulation (AM) and demodulation are explored, along with an analysis of the characteristics of monotone and audio signals. These foundational concepts inform the design and simulation of a communication system capable of transmitting and receiving both signal types. The project also includes the optimization of system parameters such as power and gain to enhance transmission and reception quality [4].

By combining software-based simulations in GNU Radio with hardware testing using the ADALM-Pluto radio, this project provides a comprehensive understanding of LSSB modulation in practical scenarios. The visualization tools in GNU Radio further enhance the learning experience by offering step-by-step insights into the modulation and transmission processes. This work highlights the advantages of LSSB modulation and SDR technology in modern communication systems, showcasing their potential to meet the demands of efficient and reliable signal transmission [5].

II. System Design

A. Task 1

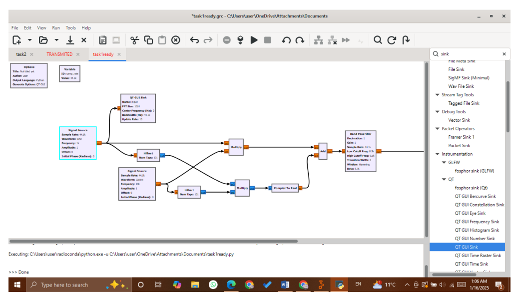

Fig. 1. modulated system

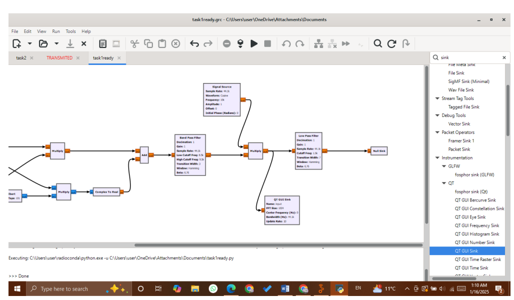

Fig. 2. Demodulated system

Blocks configurations: The modulation process involves generating two signals, a baseband signal (message) with a frequency of 1 kHz using a sine wave signal source,a carrier signal with a frequency of 10 kHz(ten times bigger than fm) using a cosine wave signal source. Pass each signal into Hilbert Transform block, its applied to shift the two signals, then a multiply blocks, multiply the message with carrier,then multiply the shifted signals too as shown in fig.3

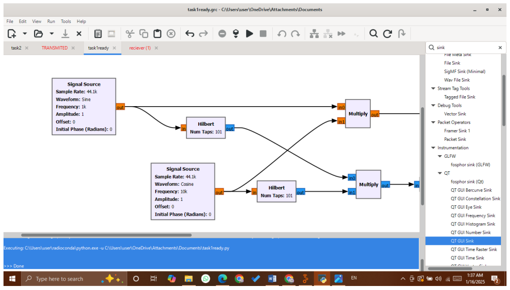

Fig. 3. sources and multiply blocks

These resulting multiplied signals, the complex result passed into complex to real block to convert it to real then combined them using an add block then pass the result of the add block into a Band Pass Filter to form the final modulated signal. The Band Pass Filter is applied to remove unwanted frequencies (upper side) outside the modulation range (8.5 to 9.5 kHz), ensuring signal clarity. The frequency spectrum of the modulated signal and the input baseband signal are displayed using the QT GUI Frequency Sink for visualization and analysis as shown in fig.4

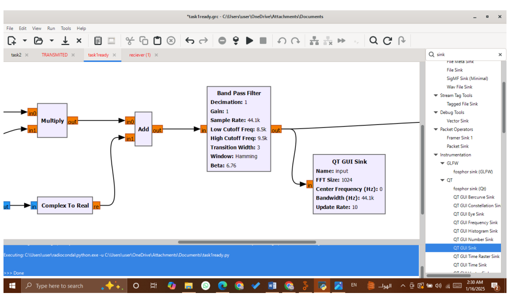

Fig. 4. add and band pass filter blocks

In the demodulation process the coherent demodulation was used.the received signal (LSSB SIGNAL) is multiplied with a cosine wave signal source at 10 kHz, the same as the modulation carrier frequency, The received signal is multiplied with the carrier signal to shift it back to the baseband. A Low Pass Filter with fc= 1.5 kHz (around the message frequency) is applied to remove any high-frequency components resulting from the multiplication process, extracting the original message signal. Finally, the frequency spectrum of the demodulated signal is displayed using the QT GUI Frequency Sink, allowing verification of the recovered information as shown in fig.5

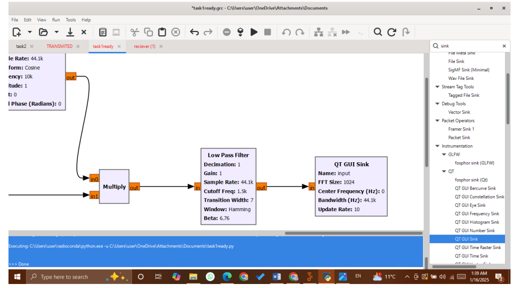

Fig. 5. low pass filter block

B. Task 2:

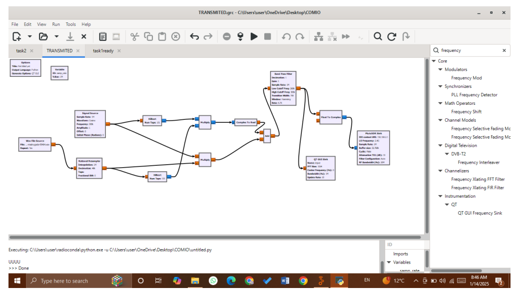

Fig. 6. Transmitter system

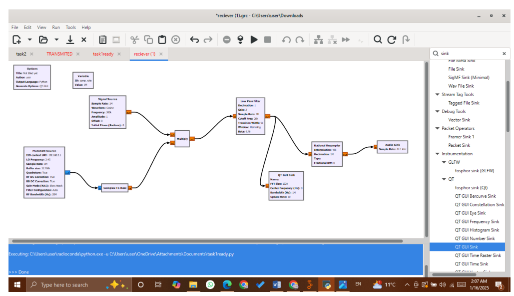

Fig. 7. Receiver system

Blocks configurations: The modulation with a high sample rate 1M to match the adalm-pluto high frequency need ,the process involves generating an audio source of frequency 48 kHz (.wav),a carrier signal with a frequency of 300kHz (ten times bigger than fm”20kHz”) using a cosine wave signal source. Pass the audio source into rational re-sampler block signal with decimation 48kHz as the input and interpolation 1MHz as the system sample rate, its applied to make the audio source suitable with the system sample rate.shown in Fig. 8

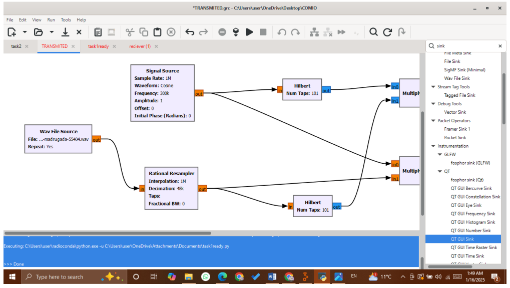

Fig. 8. source blocks

the rest is as same as task 1, then pass the result of the add block into a Band Pass Filter to form the final modulated signal. The Band Pass Filter is applied to remove unwanted frequencies (upper side) outside the modulation range (260 to 300 kHz), with transition width=700 then pass the result into float to complex block to match the pluto SDR Sink which it used to transmit the LSSB result to the reciver using adalm pluto as shown in fig.9

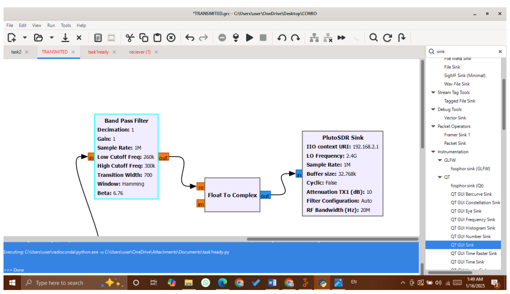

Fig. 9. bandpass, adalm sink blocks

In the demodulation process the coherent demodulation was used,the received signal from the pluto SDR source (LSSB SIGNAL) then pass it into complex to real block then multiplied with a cosine wave signal source at 300 kHz, the same as the modulation carrier frequency, The received signal is multiplied with the carrier signal to shift it back to the baseband. as shown in fig.10

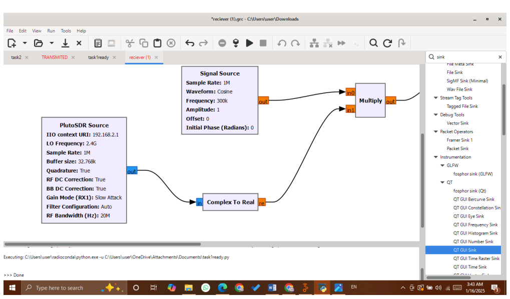

Fig. 10. adalm source, carrier blocks

A Low Pass Filter with fc= 20kHz (around the audio frequency) is applied to remove any high-frequency components resulting from the multiplication process, extracting the original audio then pass it into rational resampler block signal with decimation 1MHz as the input and interpolation 48kHz as the output , its applied to make the audio source able to hear Finally, an audio sink was applied to lestien to the demodulated sound , shown in fig.11

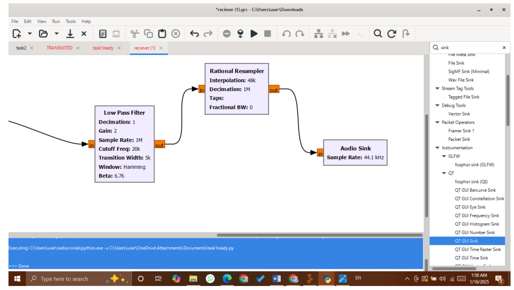

Fig. 11. low pass filter,rational resampler blocks

III. Experiments and Results

A. Task 1:

The figure 12 shows the result of the Signal Source block using frequency sink. This result was obtained because the block generates clean sine wave at frequencies of 1 kHz. These signals serve as input for further processing.

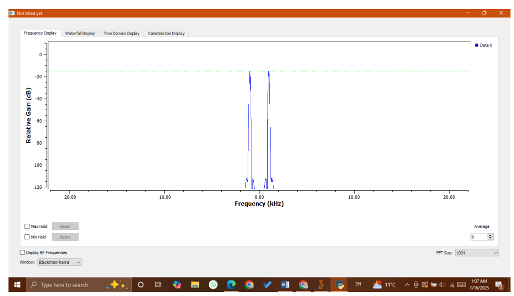

Fig. 12. Input of transmitter in frequency domain

Figure 13 shows the result of the Signal Source block using frequency sink. This result was obtained because the block generates clean cosine waves at frequencies of 10kHz, respectively. This signal serve as carrier for further processing.

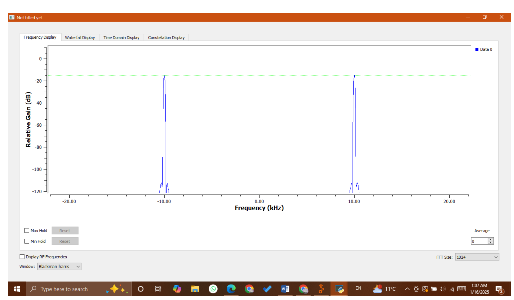

Fig. 13. transmitter carrier in frequency domain

Figure 14 shows The frequency spectrum after multipling input with carrier. This shows that the input doubled arround the fc which helps further refine the modulated signal or isolate the desired frequency range, depending on the application in the flowgraph.

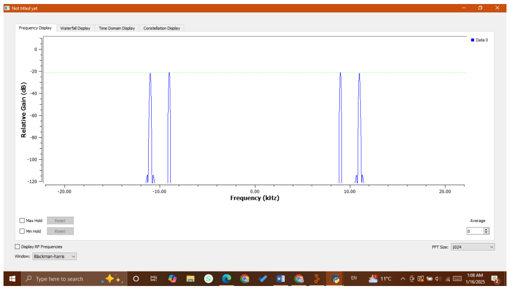

Fig. 14. frequency result of multiplexing the carrier with input

Figure 15 shows The frequency spectrum result of Hilbert input multiplied to Hilbert carrier , where the signal components are shifted to the modulated frequency range. This step ensures the signal is prepared for modulation with proper phase and amplitude representation in the complex domain .Hilbert Transform block used because the block creates an analytic signal by applying a 90-degree phase shift. This allows the signal to be represented in the complex domain with both real and imaginary components, which is essential for modulation.In Addiotion to this Real to complex block ,the signal contains only the real frequency components. This simplifies the spectrum by removing any phase-related information from the imaginary component.

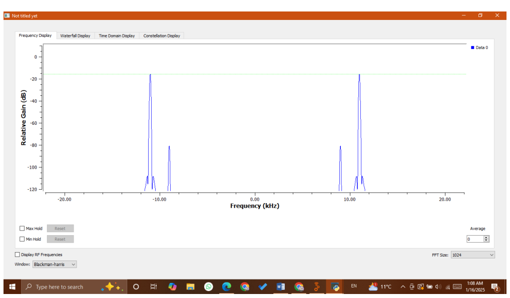

Fig. 15. frequency result of multiplexing hilbert version of each the input and the carrier

Figure 16 shows spectrum produced as a result of the Add block. This happened because the block summed the amplitudes of multiplication the real part + Hilbert part , combining their frequency components into a single output signal and both the upper side and lower side are rounded the fc

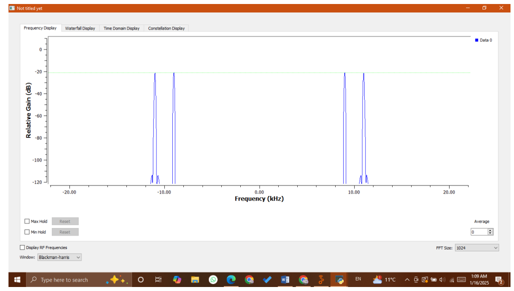

Fig. 16. frequency result of adding the two multiplication result

Figure 17 shows the result of the Band Pass Filter block. This result occurred because the block allowed only the desired frequency range (8.5–9.5 kHz) to pass through, filtering out the upper side frequencies and isolating the modulated signal lssb as we want.

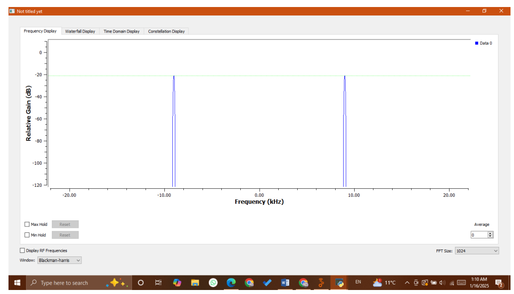

Fig. 17. frequency result after apply band pass filter

Figure 18 represents coherent demodulation by multiply the carrier signal with the modulated signal(LSSB), which aims to bring the signal back to its original frequency range, allowing it to be processed or analyzed further.

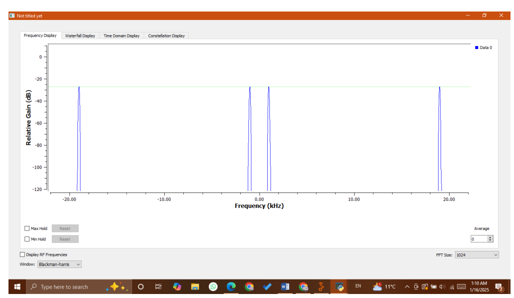

Fig. 18. Frequency result of multiplying carrier whit LSSB modulated signal

Figure 19 spectrum was obtained as a result of the Low Pass Filter block. This result occurred because the block filtered out high-frequency components, isolating the baseband signal and suppressing the carrier frequency to get the original input signal

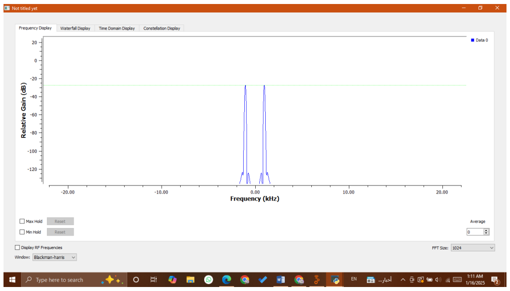

Fig. 19. frequency result after apply the lowpass filter to get the original

B. Task 2:

- Transmitter:

figure 20 shows the frequency spectrum of the signal taken directly after the WAV File Source in the transmitter. At this stage, the signal is unprocessed and consists mostly of noise spread across the frequency range, without any clear peaks or distinct features. This is expected because the WAV file contains raw baseband data that hasn't yet been modulated or filtered. The figure represents the signal in its original, unmodified form before any further processing is applied in the transmitter.

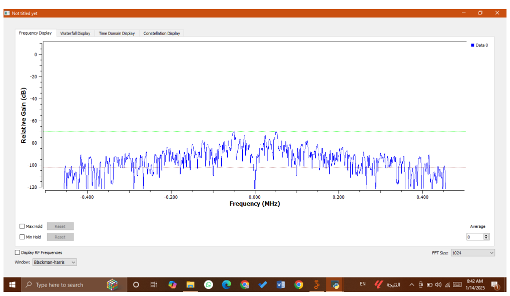

Fig. 20. The frequency spectrum of the WAV File Source

figure 21 represents the frequency spectrum of the carrier signal generated by the signal source. The graph shows two sharp peaks, which correspond to the positive and negative frequencies of the carrier wave. These peaks are well-defined and isolated, indicating that the carrier is a clean sinusoidal signal without any significant interference or noise. This is expected since the carrier at this stage has not yet been modulated or altered by any other processing steps.

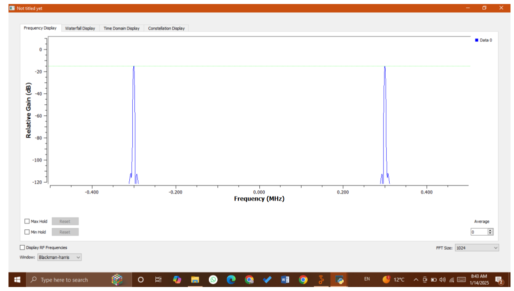

Fig. 21. The frequency spectrum of the carrier signal

figure 22 shows the frequency spectrum of the signal. The peak in the graph represents the frequency of the modulated signal, which confirms that the multiplication has correctly combined the two signals. This process is essential for modulation, as it shifts the signal to the desired frequency range for transmission. The graph helps us visualize and verify that the modulation is working as expected.

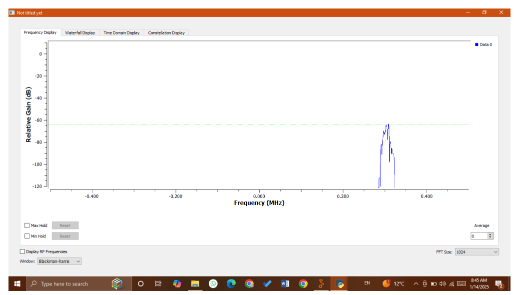

Fig. 22. The frequency spectrum of the multiplication of two complex

figure 23 shows the frequency spectrum of their product. In this case, the multiplication generates new frequency components, including the sum and difference of the input signal frequencies. These components are visible as peaks in the spectrum, demonstrating how the signals combine during the multiplication process. This visualization helps us understand and verify the behavior of real signals and their interaction, confirming that the operation is functioning as intended.

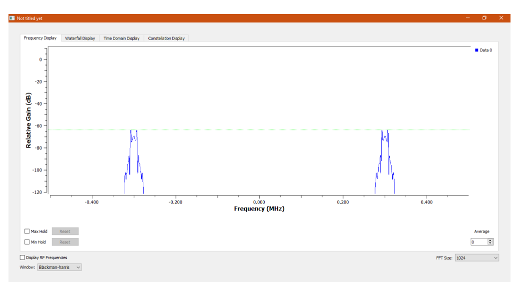

Fig. 23. The frequency spectrum of the multiplication of two real

When the sink is placed after the band-pass filter, the spectrum clearly illustrates the filtering effect, where only the frequencies within the defined passband are visible, while all other frequencies outside this range are attenuated. This behavior is reflected in the graph, showing peaks concentrated in the passband with minimal signal or noise elsewhere. The purpose of the band-pass filter is to isolate the desired signal by removing unwanted noise or out-of-band frequencies, ensuring that only the target frequencies are passed through. This step is vital in the receiver chain, as it enhances the signal quality for subsequent stages of processing.

Fig. 24. The frequency spectrum of the band pass filter

When the sink is placed after the Add block, the output spectrum displays the combined effect of the two input signals. The Add block performs a mathematical summation of these signals, which could include a modulated signal and another input, such as noise or an interfering signal. This results in a spectrum that shows frequency components from both inputs. The combined signal can be analyzed to observe how the addition affects the overall system performance, which is useful for studying signal interference, reference signal integration, or multi-path signal processing in communication systems.

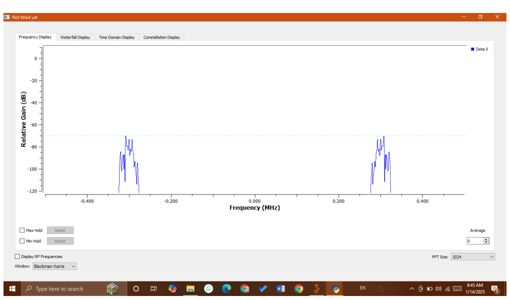

Fig. 25. The sink after add block

- Receiver:

Figure 26 shows the frequency domain representation of the received signal after the Complex to Real block, visualized using a QT GUI Sink. The central peak at 0.140 MHz represents the transmitted carrier signal, while the surrounding sidebands indicate the modulated signal components. The noise floor, observed around -80 to -100 dB, reflects typical SDR system noise. The clear separation between signal and noise confirms the successful reception and processing of signals.

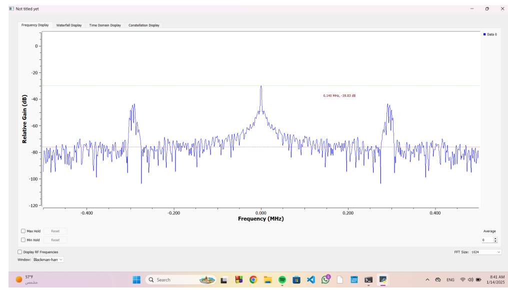

Fig. 26. The frequency spectrum of the received signal

The spectrum in the figure 27 shows the result of adding the QT GUI Sink after the Multiplication block, which combines the signal from the ADALM-Pluto Source and the Signal Source. The central peaks around 0 MHz represent the carrier signal, while the symmetrical sidebands correspond to the modulated components created by the multiplication process. The noise floor, around -80 to -100 dB, reflects typical SDR system noise.

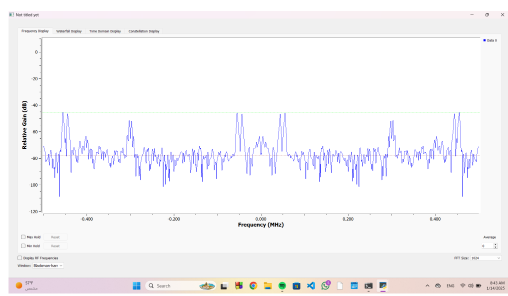

Fig. 27. The frequency spectrum after the Multiplication block

figure 28 represents the frequency spectrum at the receiver after the Low Pass Filter block. The central peak at 0 MHz corresponds to the filtered carrier signal, while the sidebands reflect the modulated components of the received signal. The Low Pass Filter has effectively eliminated high-frequency noise and unwanted components, isolating the desired signal. This filtering ensures that the signal is properly prepared for further demodulation and processing, demonstrating the successful operation of the receiver's signal conditioning stage.

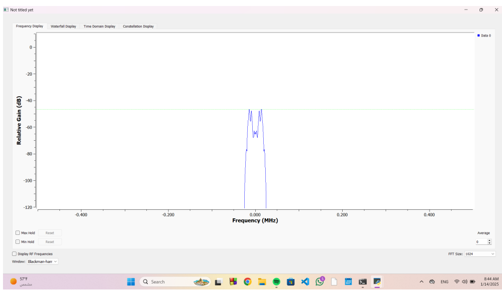

Fig. 28. The frequency spectrum after the Low Pass Filter block

IV. Conclusion

This project successfully demonstrated signal modulation and demodulation using components such as filters, sinks, and signal sources. The modulation process effectively combined baseband and carrier signals, while the demodulation process accurately recovered the original signal. Band-pass and low-pass filters played key roles in isolating the desired frequency ranges and removing noise, ensuring signal clarity. However, noise and minor inefficiencies in filtering suggest areas for improvement. Future work could focus on advanced noise reduction, optimized filtering, exploring modulation schemes like QAM or PSK, and implementing real-time signal processing. These enhancements would improve the system's performance, reliability, and scalability for more complex communication scenarios.

V. References

1) Haykin, S. (2001). Communication Systems (4th ed.). Wiley.

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