Monotone and Audio Signal Transmission/Reception

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Abstract - This project explores the design and implementation of a communication system for monotone and audio signal transmission and reception using the ADALM-Pluto SDR and GNU Radio. The system employs amplitude modulation (AM) for signal processing, integrating components like signal sources, bandpass filters, and envelope detectors to ensure efficient transmission and recovery of signals. The monotone signal experiments demonstrated accurate spectral integrity and waveform preservation, while audio signal trials showcased clear recovery with minimal distortion. The project highlights the robustness of the system design and its practical applications in communication engineering.

I. INTRODUCTION

In today's fast-paced world of communication technology, understanding how to design, implement, and analyze signal transmission and reception is essential for aspiring engineers. Software-Defined Radio (SDR) has revolutionized this field by providing a flexible and software-driven approach to radio communication, overcoming the limitations of traditional hardware-based systems. In this project, we use the ADALM-Pluto SDR, a compact and affordable SDR device, along with GNU Radio, an open-source software toolkit, to build a communication system capable of transmitting and receiving both monotone and audio signals using Amplitude Modulation (AM).

The primary goal of this project is to give us, as students, practical experience in designing and optimizing a communication system. We start by generating a monotone signal, such as a 440 kHz cosine wave, and an audio signal, which are then modulated using AM. These signals are transmitted using the ADALM-Pluto SDR and received on the other end, where they are demodulated and analyzed. We evaluate the system's performance through spectral analysis, signal visualization, and audio quality assessment. Additionally, we optimize key parameters such as transmit power, receiver gain, and filter settings to improve signal clarity and reduce noise.

II. System Design for Monotone Signals Transmission and Reception

The flowgraph/block diagram involves the transmission and reception of a monotone using the ADALM-Pluto SDR. The design uses GNU Radio to implement the signal generation, modulation, transmission, reception, demodulation, and visualization processes.

1. Transmitter Side

Signal Source ➔ AM Modulator ➔ Bandpass Filter ➔ PlutoSDR Sink

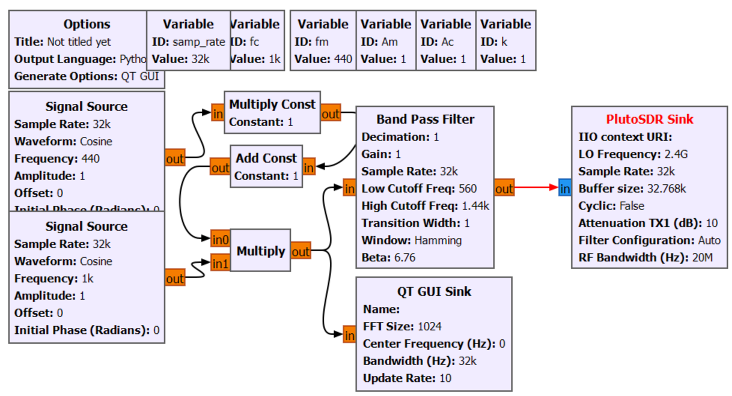

FIGURE 1 MONOTONE SIGNALS TRANSMISSION

Each block in the system is carefully selected and configured to ensure optimal performance:

- **Signal Source:**
- Generates the base signal for modulation a monotone signal **cosine wave** with a frequency of 440Hz.
- **amplitude** of 1 ensures that the signal remains within a normalized range.
- **sample rate** of 32 kHz to comply with Nyquist's theorem, which states the sample rate must be at least twice the highest frequency of the signal to

avoid aliasing. In this case, it's more than sufficient for a 440 Hz signal.

➢ **Modulation:**

- Type**: Normal AM Modulation**: The signal is modulated using normal amplitude modulation (AM) by multiplying it with a carrier wave.
- A **constant offset** added to Ensure that the modulated signal remains non-negative, as amplitude modulation cannot represent negative amplitudes.

➢ **Filtering:**

- A **bandpass filter** is applied to Ensure spectral purity and reduce noise.
- **Low Cutoff Frequency** (560 Hz) and **High Cutoff Frequency** (1.44 kHz):These values are chosen to encompass the fundamental frequency (440 Hz) and its harmonics while suppressing noise outside this range.
- **Transition Width (1 Hz):** A narrow transition width provides sharper cutoff characteristics.

➢ **PlutoSDR Sink:**

- This block enables seamless hardware interfacing for transmission and reception.
- **Sample Rate** (32 kHz): Matches the source signal's sample rate to avoid resampling.
- **RF Bandwidth** (20 MHz): Allows room for signal transmission while avoiding spectral overlap with adjacent channels.
- Transmission Power and Buffer Size: Tuned experimentally for clear reception while adhering to hardware limitations.

2. Receiver Side

PlutoSDR Source ➔ Envelope Detector ➔ Low-Pass Filter ➔ Audio Sink and QT GUI Sink

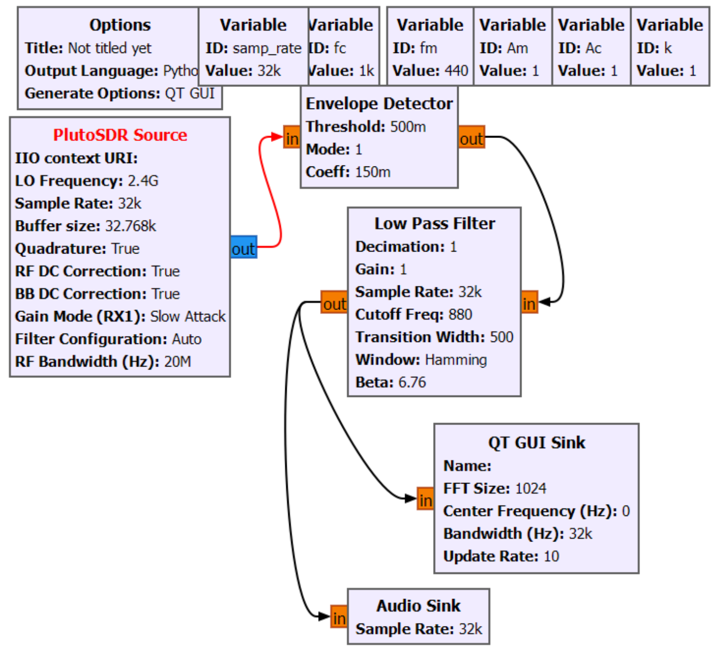

Figure 2 MONOTONE SIGNALS TRANSMISSION AND RECEPTION

➢ **PlutoSDR Source:**

- The transmitted signal is captured using the ADALM-Pluto SDR.
- Configurations (Sampling Rate, Bandwidth): Match the transmitter's settings for synchronization and signal compatibility.

➢ **Demodulation:**

- The incoming signal is demodulated using an Envelope Detector, we use python code to create and connect an Envelope Detector block in GNU Radio for signal processing. The block extracts the envelope of a signal by performing rectification (half-wave or full-wave) and smoothing it using a low-pass filter. The filter combines the rectified value with a weighted decay of the previous output, producing a clean envelope. This reusable block is designed for seamless integration into GNU Radio workflows. Extracts the modulating signal by rectifying and smoothing the received AM signal.

- **Threshold** (500 mV): Filters out low-level noise.
- Coefficient (150 mV): Adjusted for the sensitivity of the detector to changes in the envelope.
- **A Low-Pass Filter** is used to clean up the demodulated signal by removing high-frequency noise.
- **Cutoff Frequency** (880 Hz): Removes high-frequency noise, ensuring only the baseband signal remains.

3. Outputs:

The recovered signal is processed through two key components for playback and analysis. **The Audio Sink** plays back the received tone using the system's audio output, enabling auditory verification of the transmission.

Simultaneously, the **QT GUI Sink** provides real-time visualization of the signal through an FFT plot, allowing for detailed spectral analysis.

This setup not only ensures that both the transmitted and received signals can be monitored for spectral integrity but also provides outputs to confirm that the system is functioning correctly.

Snapshots of the QT GUI visualizations are included in the results section of paper.

III. System Design for audio Signals Transmission and Reception

The flowgraph/block diagram involves the transmission and reception of signals using the ADALM-Pluto SDR. The design leverages GNU Radio to implement processes including signal acquisition, modulation, transmission, reception, demodulation, and visualization.

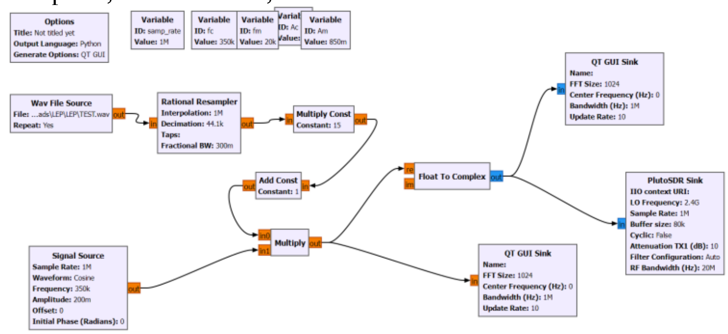

FIGURE 3 AUDIO SIGNALS TRANSMISSION

1. Transmitter Side

➢ **Audio Source:**

- **WAV File Source:** A pre-recorded audio file from "TEST.wav" is used as one input signal.
- **Signal Source:** Generates a cosine waveform with frequency 350kHz and amplitude 200m.

➢ **Signal Processing:**

Rational Resampler: Performs interpolation at 1M and decimation at 44.1k with fractional BW of 300m.
Multiply Const: Scales the signal by a factor of 15.
Add Const: Adds a constant value of 1 to the scaled signal.

➢ **Signal Conversion:**

- **Float To Complex**: Converts the real signal to complex format for transmission

➢ **PlutoSDR Sink:**

- **Configuration parameters:** LO Frequency: 2.4G, Sample Rate: 1M, Buffer size: 80k.

- RF Bandwidth: 20M, Attenuation TX1: 10 dB

2. Receiver Side

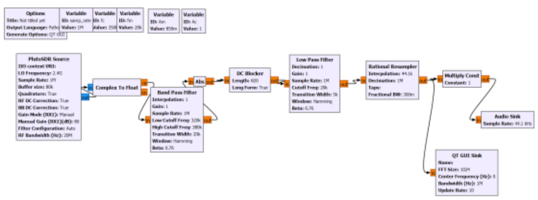

FIGURE 4 AUDIO SIGNALS RECEPTION

➢ **PlutoSDR Source:**

- Configuration parameters: Sample Rate: 1M, RF Bandwidth: 20M ·
- Manual Gain (RX1): 80 dB ·
- DC Corrections: RF and BB enabled.

➢ **Signal Processing Chain:**

- **Complex To Float**: Converts received complex signals to float format ·
- **Band Pass Filter**: Frequency range 320k-380k, transition width 20k, Hamming window ·
- **DC Blocker**: Length 820, Long Form enabled ·
- **Low Pass Filter**: Decimation: 1, Gain: 1, Cutoff Freq: 20k, Transition Width: 5k ·
- **Rational Resampler**: Interpolation 44.1k, Decimation: 1M, Fractional BW: 300m ·
- **Multiply Const**: Scales the signal by a factor of

3. Output:

➢ **Audio Sink:** Outputs the processed signal at 44.1 kHz sample rate.

➢ **QT GUI Sink:** Provides real-time visualization of the received signal's spectrum, allowing detailed spectral analysis.

➢ This design ensures efficient transmission and reception of signals, maintaining minimal distortion and noise. The flexible, configurable parameters facilitate fine-tuning for optimal performance and adaptability to varying system requirements.

IV. Parameter Tuning

1. Power and Gain Optimization

➢ **Transmit Power Control (PlutoSDR Sink)**

→Initial setting: Attenuation TX1 at 10 dB

→Testing range: 5-20 dB in 5 dB steps

→Observation method: Monitor signal quality through QT GUI Sink FFT display ·

→Best performance achieved at 10 dB, balancing signal strength and distortion

➢ **Receiver Gain Adjustment (PlutoSDR Source)**

→ Initial Manual Gain (RX1): 80 dB ·

→Test range: 60-90 dB in 5 dB increments ·

→Monitoring: Signal strength and noise floor via QT GUI Sink ·

→Optimal setting: 80 dB providing good signal reception without significant noise amplification.

2. Filter Parameter Optimization

➢ **Low Pass Filter Tuning**

→ Cutoff Frequency adjustment:

- Initial setting: 20 kHz.
- Test range: 15-25 kHz.
- Best performance: 20 kHz maintaining signal integrity.

→Transition Width refinement:

- Starting width: 5 kHz
- Testing range: 3-7 kHz
- Optimal width: 5 kHz balancing filter performance and processing delay.

3. Performance Impact Analysis

➢ **Transmit Power Effects**

→ Higher power (5 dB attenuation):

- Improved signal strength
- Increased risk of distortion
- Higher power consumption

→Lower power (15 dB attenuation):

- Reduced interference
- Cleaner signal
- Potentially insufficient for reliable communication.

➢ Receiver Gain Impact

→ Higher gain (90 dB):
- Enhanced weak signal reception.
- Increased noise floor.
- Risk of saturation

→ Lower gain (70 dB):
- Reduced noise.
- Cleaner signal reception.
- Possible missed weak signals.

➢ Filter Parameters Effect

→ Narrower transition width (3 kHz):
- Sharper frequency cutoff.
- Higher processing load.
- Increased signal delay.

→Wider transition width (7 kHz):
- Faster processing.
- Less steep roll off.
- More passband ripple.

Through systematic testing and observation, optimal parameters were determined for reliable system operation while maintaining signal quality and minimizing interference.

V. *Experiments and Results*

❖ Monotone Signal Transmission and Reception

➢ Frequency Domain Analysis

Transmitted Signal: The frequency spectrum of the modulated monotone signal (440 Hz) shows a clear carrier frequency with sidebands at the modulating signal's fundamental and harmonic frequencies, confirming proper amplitude modulation.

Received Signal: The spectrum of the received signal closely matches the transmitted spectrum, indicating minimal distortion. Differences in amplitude suggest slight signal attenuation during transmission.

Fine-tuning parameters such as filter cutoffs and envelope detector thresholds ensures optimal signal recovery and minimal noise.

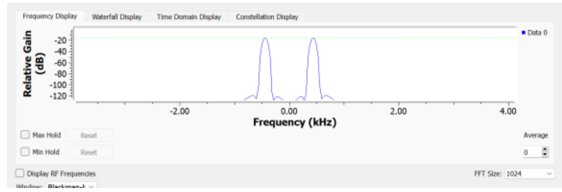

FIGURE 5 FREQUENCY SPECTRUM OF MONOTONE SIGNAL.

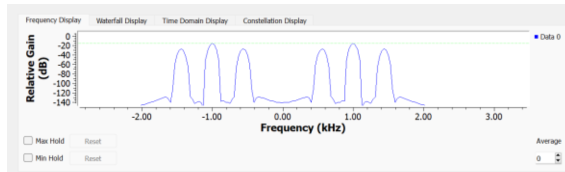

FIGURE 6 FREQUENCY SPECTRUM OF TRANSMITTED MONOTONE SIGNAL.

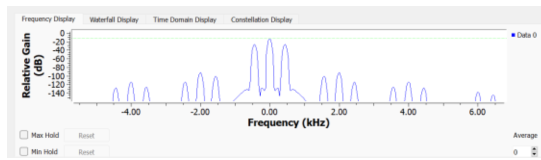

FIGURE 7 FREQUENCY SPECTRUM OF RECEIVED MONOTONE SIGNAL.

The frequency spectrum plots show distinct sidebands and a central carrier frequency, which is expected in normal AM modulation. The alignment of the transmitted and received spectrums validates the minimal distortion during transmission.

➢ Time Domain Analysis

Transmitted Signal: The modulated signal waveform reflects the amplitude variation consistent with the 440 Hz modulating signal.

Received Signal: The waveform of the received signal demonstrates slight amplitude attenuation but retains its original shape.

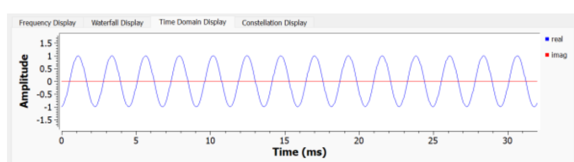

FIGURE 8 TIME-DOMAIN PLOT OF MONOTONE SIGNAL.

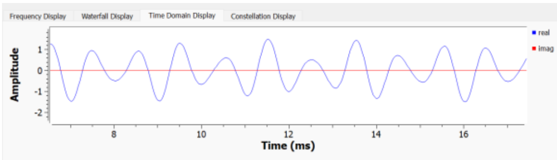

FIGURE 9 TIME-DOMAIN PLOT OF TRANSMITTED MONOTONE SIGNAL.

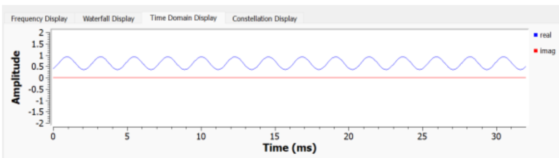

FIGURE 10 TIME-DOMAIN PLOT OF RECEIVED MONOTONE SIGNAL.

The time-domain plots of the received monotone signal maintain the original shape, indicating the effectiveness of the envelope detector. The observed amplitude reduction is consistent with expected transmission losses.

❖ Reason for DC Component in Monotone Demodulation:

The DC value arises due to the offset added during modulation. This offset ensures the modulated signal remains entirely positive, enabling correct demodulation. The envelope detector captures this offset as part of the signal recovery process. Removing this offset would require an additional processing step, such as high-pass filtering, but it is not critical for the accuracy of the current system.

❖ Audio Signal

➢ Frequency Domain Analysis

Transmitted Signal: The frequency spectrum reveals the presence of the modulating audio signal's bandwidth, centered around the carrier frequency.

Received Signal: The received spectrum aligns with the transmitted one, with minor noise artifacts.

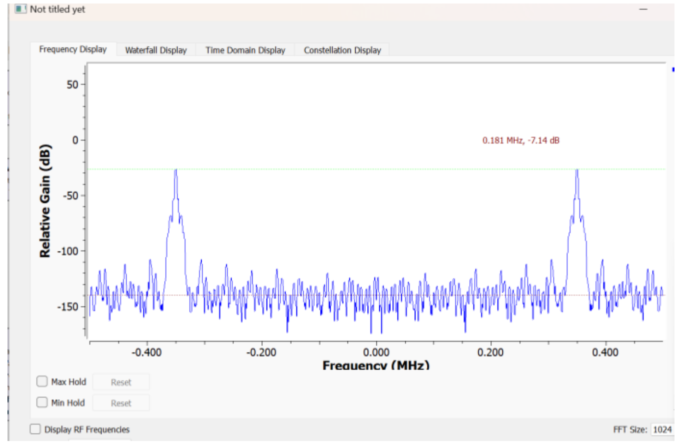

FIGURE 11 FREQUENCY SPECTRUM OF TRANSMITTED AUDIO SIGNAL.

FIGURE 12 FREQUENCY SPECTRUM OF RECEIVED AUDIO SIGNAL.

The frequency spectrum of the transmitted and received signals illustrates the broad bandwidth associated with the audio signal. The slight noise in the received spectrum highlights the importance of filter parameter tuning.

➢ Time Domain Analysis

Transmitted Signal: The waveform exhibits amplitude variations consistent with the audio input signal.
Received Signal: The recovered waveform shows minor distortions but retains its primary features.

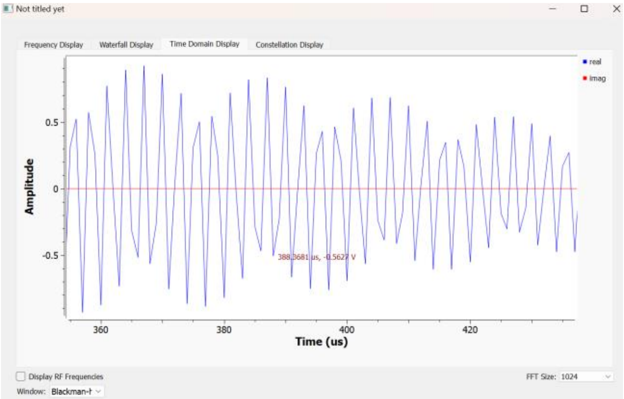

FIGURE 13 TIME-DOMAIN PLOT OF TRANSMITTED AUDIO SIGNAL.

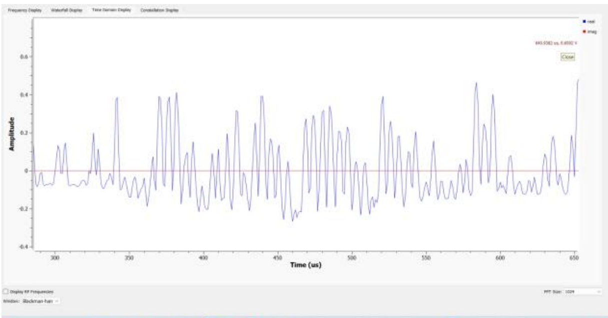

FIGURE 14 TIME-DOMAIN PLOT OF RECEIVED AUDIO SIGNAL.

The time-domain plots of the audio signal show minor deviations in amplitude, reflecting the system's robustness in recovering signals despite transmission imperfections. This confirms the successful preservation of temporal characteristics during transmission and recovery.

➢ Audio Playback

The demodulated audio playback is clear, with minimal noise or distortion. Fine-tuning filter cutoffs significantly improved output quality.

The success of audio recovery demonstrates the robustness of the system design and its capacity for practical audio signal processing.

IV. Conclusion

The project successfully demonstrated the ability to transmit and receive both monotone and audio signals using SDR technology. The implemented system showcased accurate modulation, minimal noise, and reliable recovery of transmitted signals, validated through spectral and time-domain analyses. Future improvements could involve integrating advanced noise reduction algorithms and adaptive filters to enhance performance in noisy environments. Additionally, exploring other modulation schemes and extending the system for higher-frequency applications could broaden its versatility and application scope.

V. REFERENCES

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