Design and Implementation of an AM Transmitter and Receiver

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***Abstract*—This report details the design and implementation of an Amplitude Modulation transmitter and receiver. The project involves amplifying an audio signal and mixing it with an 800 kHz carrier signal for transmission. The transmitted signal is received within a short range, down converted to a 100 kHz intermediate frequency, filtered, and demodulated using an envelope detector. The resulting audio signal is then amplified and output through a speaker.**

I. Introduction

Amplitude modulation is a radio communication technique where the amplitude of a carrier wave is varied according to the audio signal being transmitted. This modulation method is typically used in broadcasting radio transmissions. AM radios receive signals by demodulating the received electromagnetic waves and separating the original audio signal from the carrier wave to then output the audio.

For the transmitter, an audio signal was combined with a high frequency carrier signal generated by a local oscillator. After mixing, an AM signal was generated which was transmitted over the radio frequency channel.

For the receiver, the superheterodyne design was found to be the most suitable for our purpose. In the superheterodyne receiver, incoming radio frequency signals were mixed with a locally generated oscillator signal to produce a fixed intermediate frequency. This signal was then amplified and filtered to extract the original audio signal using envelope detection.

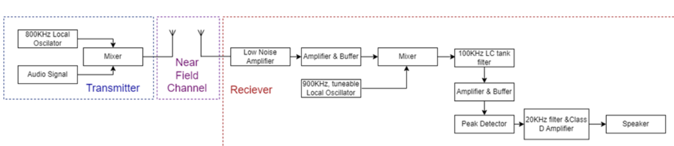

Fig. 1: Block diagram of the AM transmitter and receiver.

AC signal analysis was used to ensure signal integrity across the cascaded stages as it helps to reduce clipping. Note that clipping was also minimised by making the gain variable in every stage to reduce it as much as possible. The transmitter was utilising a 9v supply and a biasing collector current of 10mA, while the receiver had a larger supply voltage of 12v but a smaller dc biasing current of 1mA. This was done to increase output swing of receiver while still keeping similar dc power consumption. Hence this configuration kept the transistors in their active region, which was essential for effective linear amplification and stable operation of the system.

II. Transmitter Design and Results

The first stage involves a Colpitts oscillator that generates an 800kHz carrier frequency via an LC tank circuit. This carrier frequency is then utilised in the modulation stage, which incorporates a class-A common emitter amplifier circuit using a NPN transistor. Here, the carrier is fed to the base of the transistor to amplify the signal, while the modulating signal is AC coupled to the same transistor base, making the gain of this stage proportional to the amplitude of the modulating signal. The amplified and modulated signal is taken from the transistor's collector and transmitted via an antenna connected to the output. A PCB was designed and built to improve the system's robustness.

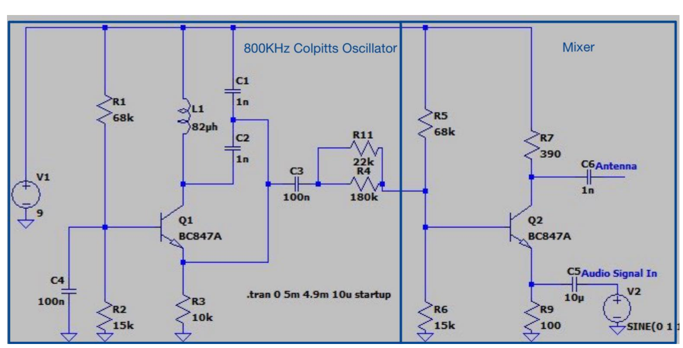

Fig. 2: Schematic of the transmitter.

A. Local oscillator

The displayed frequency reads approximately 813 kHz, slightly higher than the intended 800 kHz. This deviation underscores a common challenge in oscillator design: the component tolerances of the inductors and capacitors can lead to slight variations from the desired frequency. The waveform is smooth and continuous, indicating a stable oscillation.

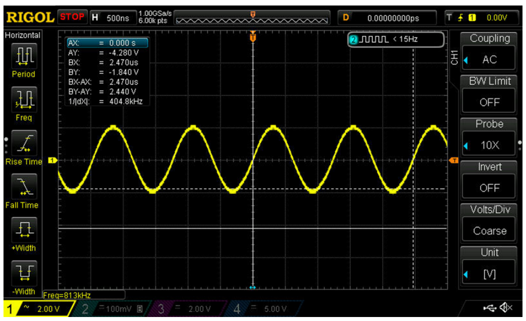

Fig. 3: Sinusoidal waveform generated by the local oscillator.

B. Mixer

The mixer combines the RF audio signal with a higher frequency carrier signal from the local oscillator to produce an amplitude-modulated signal. Using the trigonometric identity for the product of two sine waves, we can describe the output of the mixer as follows;

The product of sines can be expressed as $\sin x \sin y = \frac{1}{2}[\cos(x-y) - \cos(x+y)]$.

By substituting $x = 2\pi f_a t$ and $y = 2\pi f_b t$, the mixer's output can be expressed as:

$$\mathbf{a} \cdot \mathbf{b} = \frac{AB}{2}\cos(2\pi[f_a - f_b]t) - \frac{AB}{2}\cos(2\pi[f_a + f_b]t) \tag{1}$$

In the equation, $f_a - f_b$ and $f_a + f_b$ represent the lower sideband and the upper sideband of the modulated signal, respectively. The mixer was implemented by using a BJT with audio input connected to the emitter and carrier from the local oscillator connected to base and envelope obtained from the collector.

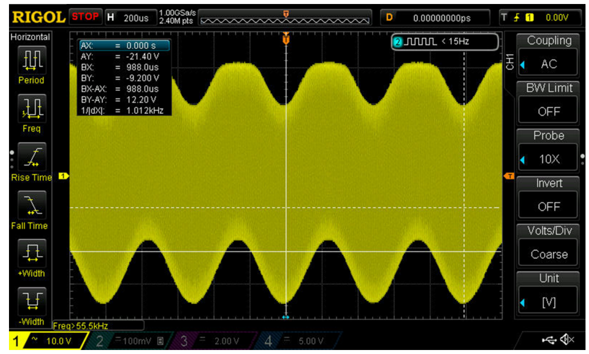

Fig. 4: Sinusoidal signal output at Mixer.

C. Antenna

When it comes to the antenna for the transmitter and receiver, theoretically for efficient transmission the length of the antenna should be $\lambda/4$ of the carrier frequency. However since we are using such a low frequency of 800kHz, this would have resulted in a very large antenna. Analytically, the wavelength for an 800 kHz frequency is approximately 375m, making a $\lambda/4$ antenna about 93.75m long, which is very impractical for our application.

This was compensated by employing near-field transmission, limited to 30 cm, where the antennas don't radiate energy into space but rather couple it to nearby antennas, similar to how transformers function. Hence this method allows the use of smaller antennas while still maintaining effective transmission between the transmitter and receiver.

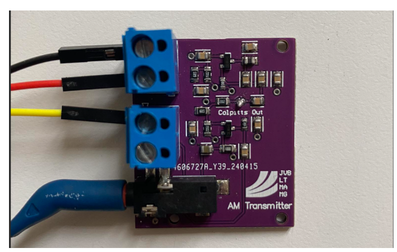

Fig. 5: The Transmitter constructed on a PCB.

III. Receiver Design and Results

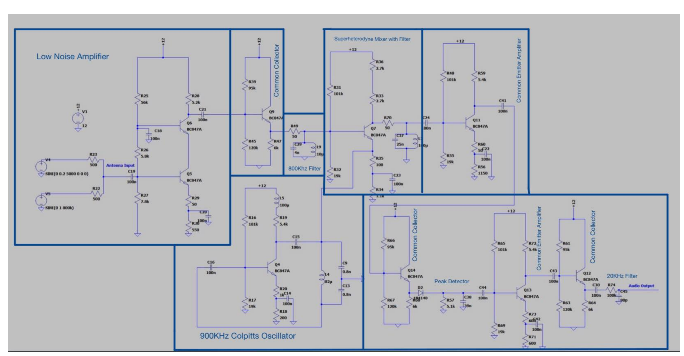

Fig. 6: Schematic of the Receiver.

A. *Low noise amplifier*

The signal received at the transmitter often arrives attenuated and laden with noise due to the imperfections in the transmission channel. To improve the quality of the received signal, a combination of amplification and filtering is used in the receiver's design. A cascode amplifier is utilised for its great gain-bandwidth product, which enhances the signal's strength while maintaining its integrity over a broad frequency range. Also with the cascode amplifier we get great impedance matching, which optimises the power transfer between stages. Complementing the amplifier, a shunt LC tank filter with a passband centred at 800 kHz is implemented to filter the desired signal. This setup effectively isolates the useful signal from unwanted noise and interference, ensuring a clean output suitable for further processing.

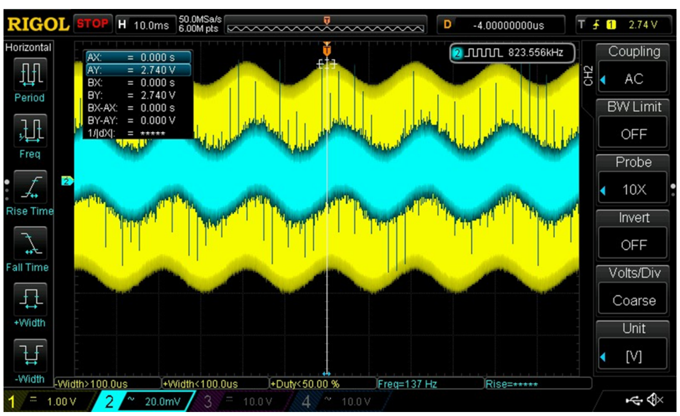

Fig. 7: Oscilloscope snapshot of the signal being transmitted (yellow) and the signal received (blue).

B. *Intermediate frequency step down Mixer*

The next step in the Superheterodyne Receiver was to design a mixer to step down the 800kHz carrier frequency to a 100kHz intermediate frequency. To get this desired frequency, a local oscillator was used to generate a 900kHz signal. The local oscillator's frequency is made tunable with a variable capacitor, allowing the receiver to adapt to different carrier frequencies.

The mixer utilised a BJT, where the RF input (800kHz) was applied to the base and the local oscillator (900 kHz) was fed into the emitter. The mixer exploits the non-linear properties of the BJT to multiply these input signals, producing sum (900 kHz + 800 kHz = 1700 kHz) and difference (900 kHz - 800 kHz = 100 kHz) frequencies at the collector. In this context, non-linear properties refer to the transistor's ability to generate new frequencies that are not present in the original signals. To isolate the 100 kHz intermediate frequency from other spectral components a shunt LC tank circuit was utilised as a bandpass filter. This filter is precisely tuned to 100 kHz, effectively filtering out all other frequencies except the desired IF. Which is verified by simulating a Fourier transform;

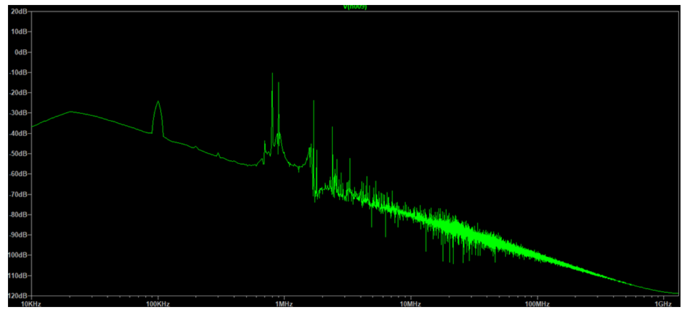

Fig. 8: Fourier transform signal in the Superheterodyne receiver.

C. *Peak detector*

Peak detector is simply made up of a diode, resistor and capacitor. The job of this is to only allow the peak of the envelope to pass though. A Schottky diode was used as it has a low forward voltage and the time constant of the RC combination was chosen to reduce as much HF noise as possible. This essentially retrieves the original audio signal from the envelope. The envelope detector is accompanied by a 20 kHz butterworth active LPF to smoothen out the signal.

Fig. 9: Peak Detector with Envelope detection.

D. *Output stage*

The primary role of this Class D amplifier in the setup is to supply sufficient current to drive the speaker. It does this by converting the low-level audio signal received from the previous stages into a high-power output. This conversion is necessary to produce the sound levels required for audible playback through the speaker, ensuring that the audio signal is amplified adequately without compromising the quality.

E. Filter

RLC tank circuits were used in LNA and mixer due to their large Q-factor and ability to work well at high frequencies unlike active filters. The RLC filters excel in selectivity passing a narrow band of frequencies while rejecting others, hence making them ideal for our application since we needed precise frequency selection and minimal signal distortion.

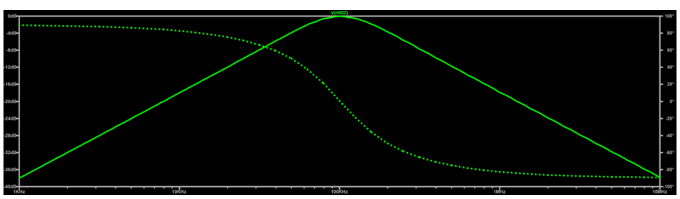

Fig. 10: Frequency Response of the Bandpass Filter.

F. Amplifier and Buffer

After most stages a common emitter is used to amplify the signal because of attenuation, mainly due to filters. Also a common collector is used to buffer stages so that they don't load each other. Signal integrity was maintained through the application of amplifiers and buffers across the multiple stages used. Amplification of attenuated signals was achieved using common emitter configurations due to their effective gain characteristics. To ensure operational independence and minimise inter-stage loading effects, common collector configurations were implemented as buffers.

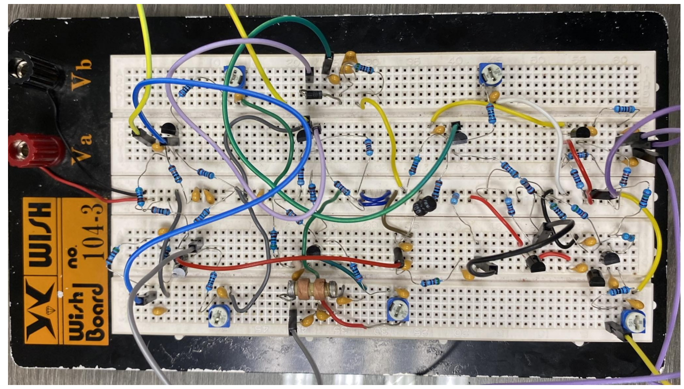

Fig. 11: The Superheterodyne Receiver constructed on a breadboard.

IV. Justification of Components used

Careful consideration was given to the selection of components based on performance criteria and cost efficiency. Inductors and resistors were chosen for their appropriate power ratings, balancing functionality with cost-effectiveness. Capacitors were selected with specific values to ensure a flat response across the operating frequency range, aimed at avoiding undue attenuation of signals at both the lower and higher ends of the spectrum. Additionally, the tolerances for inductors and capacitors were minimised as much as feasible to closely meet the 800 kHz frequency requirement. For the active components, NPN transistors (BC847) were used due to their high gain characteristics and sufficient power dissipation capabilities.

V. Final Results

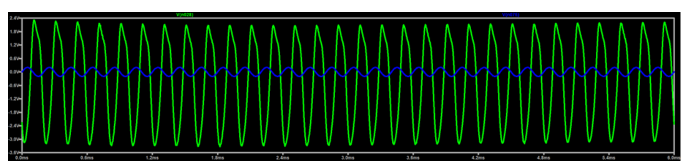

Fig. 12: Shows the unamplified input audio signal of 5kHz in (blue) compared to the amplified receiver output in (green).

The blue waveform represents the original audio signal at a frequency of 5 kHz, showing a relatively lower amplitude. The green waveform illustrates the same audio signal post-amplification by the receiver, clearly displaying a significantly higher amplitude while maintaining the original frequency hence demonstrating the receiver's effective amplification capabilities, enhancing the signal strength without altering its frequency, crucial for clear and audible output in audio applications.

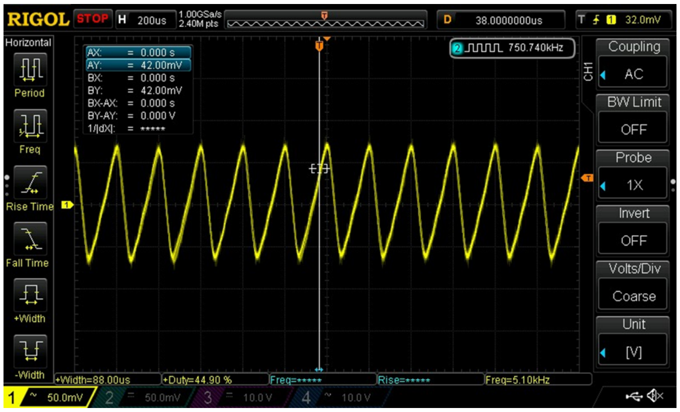

Fig. 13: Final Amplitude Modulated Waveform at the end of the receiver.

Figure 13 displays the final waveform obtained at the output of the receiver when a 5kHz sine wave is applied as an audio input, depicting a clear and distinct amplitude modulated waveform.

VI. Conclusion

This report presents the implementation of an amplitude modulation transmitter and receiver, demonstrating effective short-range radio communication. The transmitter, which employed a Colpitts oscillator, generated an 800 kHz carrier frequency. While this was effective, the performance could have been further enhanced by applying a variable capacitor to make the oscillator tunable. This adjustment would allow for fine-tuning the carrier frequency to compensate for any drift and to adapt to different transmission conditions. Additionally, incorporating a common emitter transistor amplifier in the transmission stage could significantly amplify the modulated signal, thereby increasing the transmission power and improving the signal-to-noise ratio. Higher transmission power would enable longer-range communication while maintaining signal integrity.

The superheterodyne receiver implementation was successful, as it effectively converted the 800 kHz signal to a 100 kHz intermediate frequency with the aid of precise filtering. The use of a shunt LC tank circuit as a band pass filter was crucial in isolating the desired signal from noise and interference. Despite the challenges posed by the large antenna size required for efficient transmission at 800 kHz, the system functioned within a limited range thanks to the use of near-field transmission. This technique meant that the antennas operated effectively as transformers, coupling energy over short distances without significant radiation losses.

Negative feedback mechanisms were incorporated throughout the system to enhance stability and noise immunity, ensuring consistent performance. DC biasing and proper emitter degeneration techniques were employed to keep the transistors in their active region, a critical factor for effective linear amplification and reduced noise. These measures contributed to an improved SNR, increased transmission distance, and overall noise reduction. The inclusion of these techniques is essential in maintaining the integrity of the transmitted and received signals, particularly in environments with substantial electromagnetic interference.

Future work could focus on several areas to further improve the system. One potential improvement is the design and implementation of a PCB for the receiver. While a PCB was implemented for the transmitter to enhance robustness and reduce distortion, extending this to the receiver would further improve system stability and noise immunity. Additionally, incorporating advanced modulation techniques, such as QAM, could be explored to increase data transmission rates and efficiency.

Furthermore, enhancing the antenna design to achieve better impedance matching and radiation efficiency could significantly improve the system's performance.

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