Design and Optimization of an AM Demodulator Circuit

1 Introduction

In this project, I designed and tuned values for an AM demodulator circuit. The objective was to optimize the RC time constant for effective demodulation and mitigate issues such as signal lag or distortion. This document outlines the iterative design process, calculations, and results obtained.

2 Circuit Overview

The AM demodulator circuit, shown in Figure 1, demodulates an AM signal with a carrier frequency of 88.7 MHz and a modulation frequency of 10 kHz. These frequencies were chosen for practical reasons: the carrier frequency aligns with FM radio standards, and the modulation frequency represents typical audio signal bandwidth.

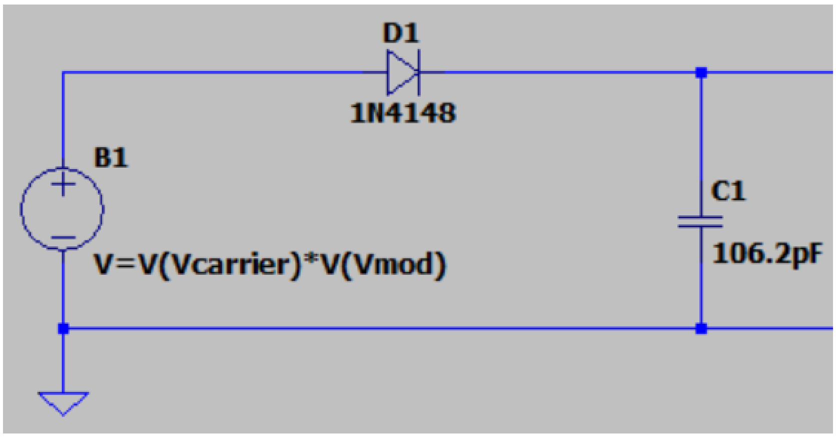

Figure 1: AM demodulator circuit

3 Initial Design and Results

Initially, I used arbitrary values of $R = 5$ kΩ and $C = 0.01$ μF The demodulated signal, shown in Figure 2, exhibited significant lag and distortion due to the incorrect RC value.

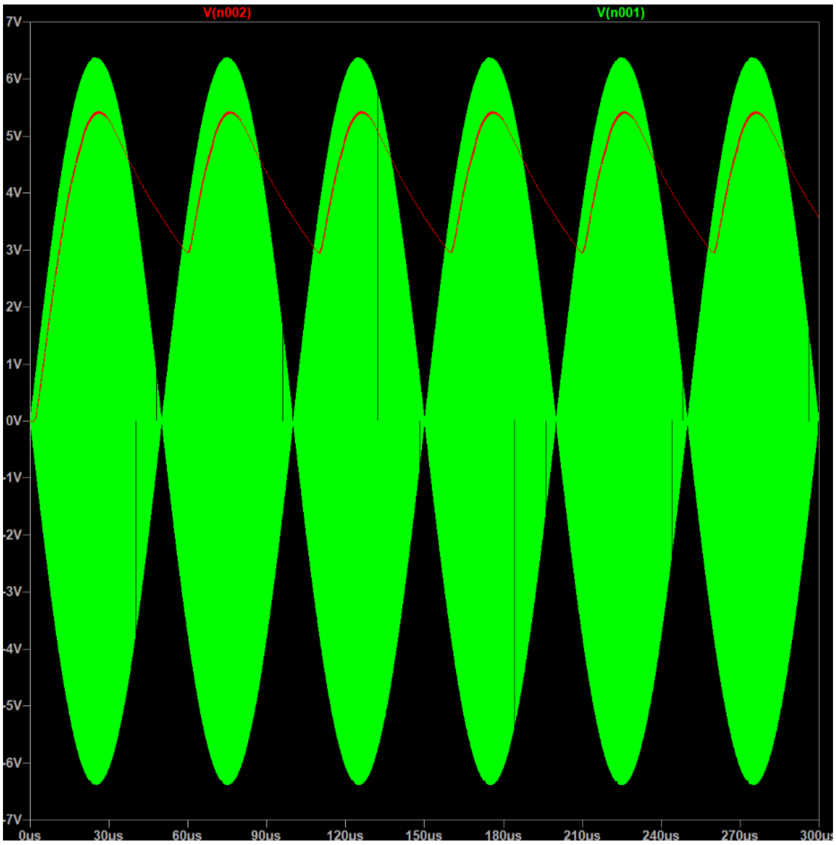

Figure 2: RC value too large: Modulated signal lagging response

4 Design Constraints and Geometric Mean Approach

The design constraint for the RC time constant is given by:

$$\frac{1}{f_c} \ll RC \ll \frac{1}{f_m},$$

where:

$$\frac{1}{f_c} = 1.127 \times 10^{-8} \text{ s},$$
$$\frac{1}{f_m} = 1.000 \times 10^{-4} \text{ s}.$$

To find a balanced RC value, I calculated the geometric mean:

$$RC = \sqrt{\frac{1}{f_c f_m}} = 1.062 \times 10^{-6} \text{ s}.$$

The results are shown in Figure 3. However, the demodulated signal dropped too quickly, indicating that the RC value was still suboptimal.

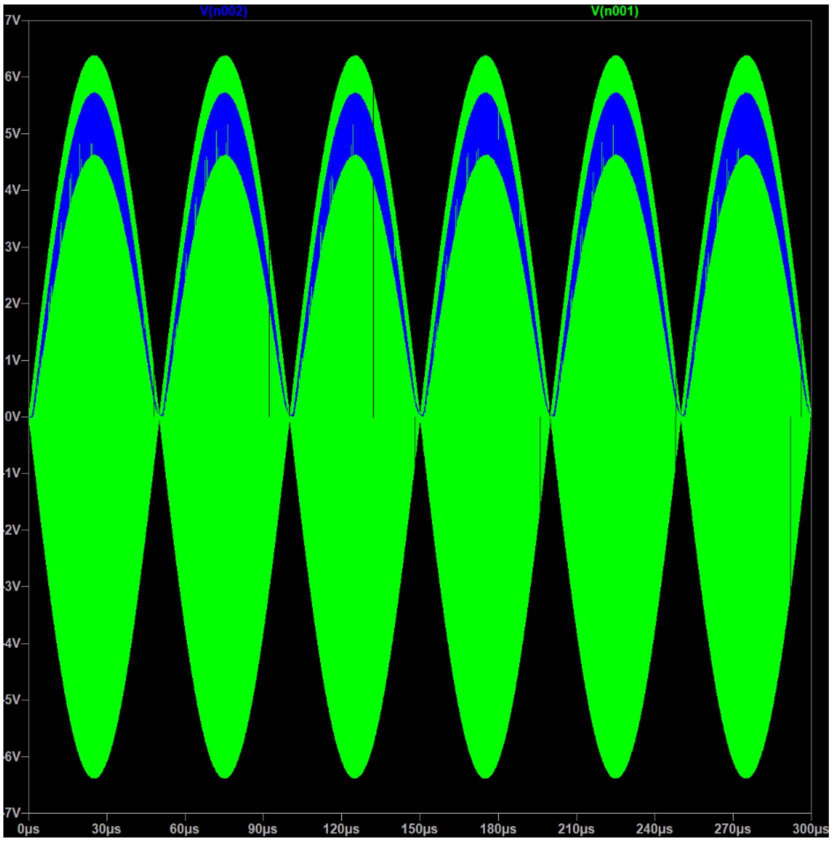

Figure 3: Result of choosing RC value based on geometric mean

5 Low-Pass Filtering to Mitigate Issues

To address the rapid drop in the demodulated signal, a low-pass RC circuit was added to attenuate high-frequency ripples. The cutoff frequency of the low-pass filter was designed to meet the condition:

$$f_m < f_c < \frac{1}{2\pi RC},$$

where $RC = 1.062 \times 10^{-6}$ s.

This design ensures that the cutoff frequency allows the modulation signal ($f_m = 10\,\text{kHz}$) to pass through while filtering out high-frequency ripples, which occur at approximately $f_{\text{ripples}} = \frac{1}{2\pi RC} \approx 150\,\text{kHz}$. Therefore, the cutoff frequency was chosen within the range:

$$10\,\text{kHz} < f_c < 150\,\text{kHz}.$$

To achieve this, resistor and capacitor values were selected to produce a cutoff frequency of approximately $f_c = 50\,\text{kHz}$. Specifically:

$$f_c = \frac{1}{2\pi RC},$$

where $R = 10\,\text{k}\Omega$ and $C = 318\,\text{pF}$. Substituting these values:

$$f_c = \frac{1}{2\pi \cdot 10^4 \cdot 318 \times 10^{-12}} \approx 50\,\text{kHz}.$$

This choice ensures that the modulation signal at 10 kHz is preserved while significantly attenuating the ripples at higher frequencies. The resulting filtered signal, as shown in Figure 5, demonstrates the effectiveness of this approach.

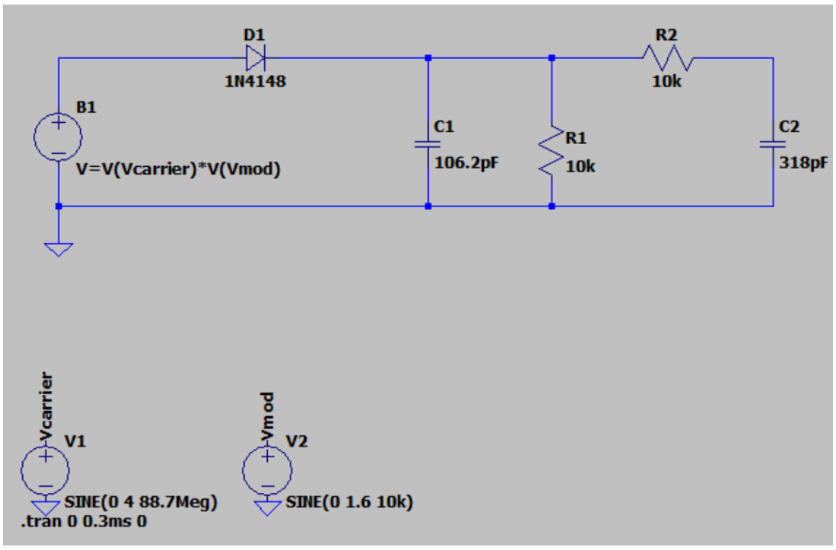

Figure 4: Circuit with low-pass filter applied to mitigate rapid drop

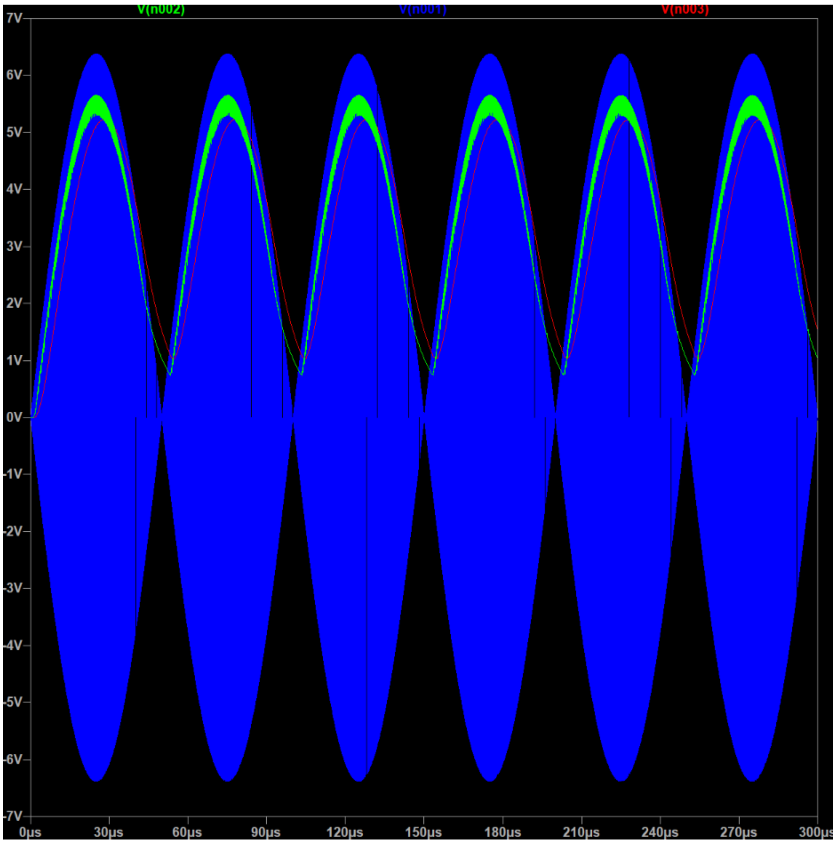

Figure 5: Low pass filter eliminates ripples

6 Middle-Range RC Value and Final Results

I further refined the RC value by selecting a middle range based on the updated constraint:

$$10 \times \frac{1}{f_c} \ll RC \ll \frac{1}{10 \times f_m},$$

which resulted in:

$$RC = 5.056 \times 10^{-6} \text{ s}.$$

The demodulated signal with this RC value is shown in Figure 5. This value provided better performance than the geometric mean approach.

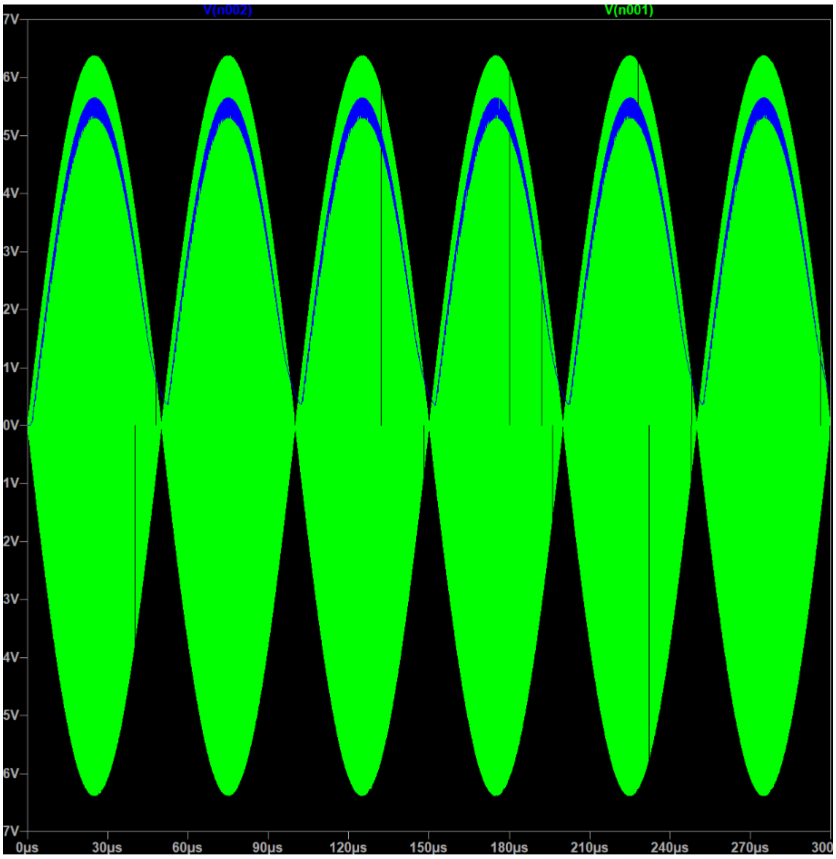

Figure 6: Result of choosing RC value directly in the middle of bounds

7 Final Low-Pass Filter Design

A low-pass filter was applied again to eliminate remaining ripples. The cutoff frequency was recalculated based on the new RC value. The final demodulated and filtered signal is shown in Figure 6.

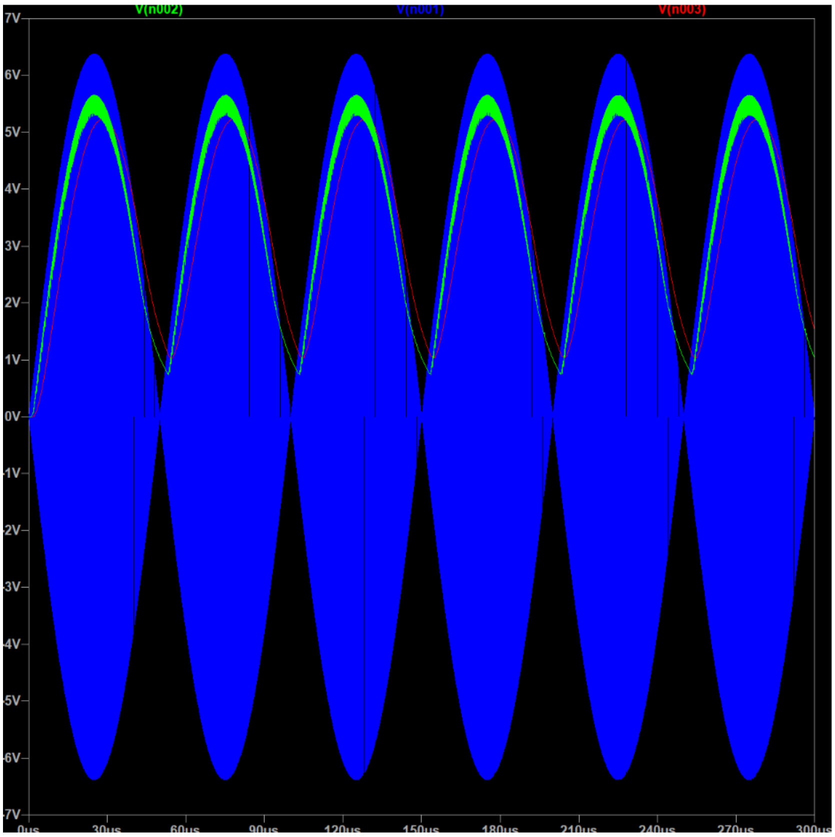

Figure 7: Blue: Modulated signal, Green: Demodulated Signal, Red: Final Filtered Signal

8 Conclusion

This project demonstrated iterative design and optimization for an AM demodulator circuit. By exploring geometric mean, middle-range RC values, and low-pass filtering, I achieved a smooth and accurate demodulated signal.