Modulation Waveforms Lab Report

EXPERIMENT CP-SRP EE20017

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Contents

1 Introduction

This report presents the findings from the "Modulation Waveforms" lab, part of the EE20017 Communication Principles module. The primary objective was to explore AM modulation and its signal processing intricacies utilizing Matlab for practical experiments.

2 Modulation Tests

Utilizing the AM_2.m script, square and triangle waves were modulated by adjusting modulation parameters including amplitude, frequency, and phase to align with predefined specifications. Adjustments were also made to load resistance and loss parameters as required. The script generates insightful plots for signal analysis, which, combined with additional calculations integrated into the Matlab scripts, facilitated a thorough examination of Peak Envelope Power (PEP) and Peak to Average Power Ratio (PAPR).

```
        % AM Power
        R = 50; % Ohms
        Power = (Signal.^2) / (2*R); % RMS Power in Watts V^2/2R
        % Peak Envelope Power
        PEP = max(Power)
        % Peak to Average Power Ratio
        PAPR = PEP/mean(Power)
```

Listing 1: Signal processing calculations

2.1 Results

Square Wave Modulation Analysis

The modulation of a carrier signal with a square wave was conducted using the script and parameters provided. The process involved adjusting the modulation parameters to achieve the desired waveform and analyzing the outcome using MATLAB for signal processing calculations.

To compute the Peak Envelope Power (PEP), the formula $PEP = \frac{(V_{peak}/\sqrt{2})^2}{R}$ was employed, where V_{peak} denotes the maximum amplitude of the waveform. This calculation was facilitated by MATLAB, performing an element-wise operation to determine the power for each sample point in the modulated signal and identifying the maximum value.

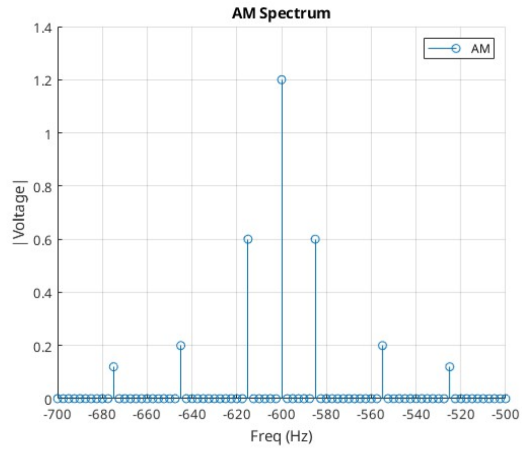
The mean power, P_{mean}, was calculated using the formula:

$$P_{\text{mean}} = \frac{V_c^2}{2R} + \sum_{i=1}^{n} \frac{V_{m_i}^2}{2R}$$

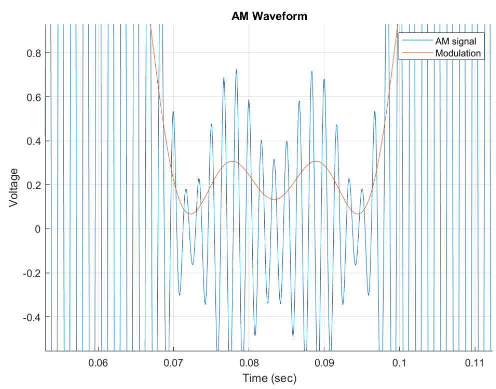
where V_c represents the RMS voltage of the carrier signal, V_{m_i} the RMS voltage of each modulation signal, R the load resistance, and n the number of modulation frequencies. The Peak to Average Power Ratio (PAPR) was then determined as $PAPR = \frac{PEP}{P_{mean}}$.

The results for the square wave modulation were as follows:

- PEP: 214.7 mW
- P_{mean}: 45.4 mW
- $PAPR$: 4.7312



(a) AM Spectrum of square modulated signal



(b) Modulation signal indicating no distortion

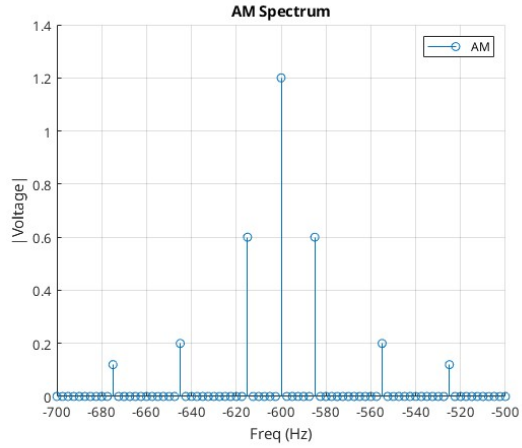
Figure 1: Analysis of square wave modulation

An analysis of the AM spectrum revealed the following power distribution in mW for the carrier and modulation frequencies: 14.4000, 3.6000, 0.3992, 0.1440 for f_c, f_{m1}, f_{m2}, f_{m3}, respectively. The sidebands accounted for 28.47% of the total power. The inspection confirmed that the modulation process introduced no distortion, as evidenced by a clean FFT plot and the absence of unintended harmonics.

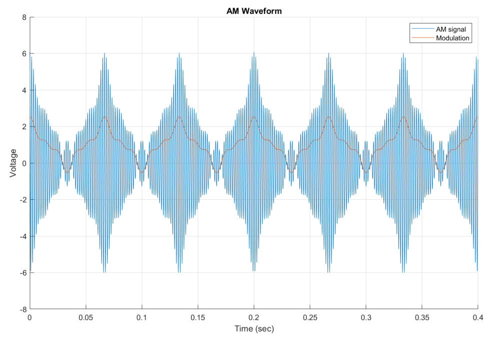
Triangular Wave Modulation Analysis

In this experiment, the modulation signal's parameters were fine-tuned as per the laboratory instructions to closely replicate a triangular waveform. The methodology for calculating the Peak Envelope Power (PEP) and the Peak to Average Power Ratio (PAPR) mirrored the approach utilized for the square wave modulation, leading to the following findings:

- PEP: 369.6 mW
- $PAPR$: 8.14



(a) AM spectrum of triangular modulated signal



(b) Overall view of AM and triangular modulation signal

Figure 2: Spectral and signal analysis of triangular wave modulation

Analysis of the AM spectrum revealed power distributions identical to those observed for the square wave, indicating consistent carrier and modulation frequencies' powers: 14.4000, 3.6000, 0.3992, 0.1440 for f_c, f_{m1}, f_{m2}, f_{m3}, respectively. The sidebands contributed to 28.47% of the total power, attributed to the similar frequency components present in both the square and triangular waves, albeit with slight phase variations (see 2a).

The examination of the triangular wave modulation confirmed the absence of crossover distortion. The modulated signal maintained a smooth profile without any noticeable distortion or unintended harmonics, as validated by the FFT analysis.

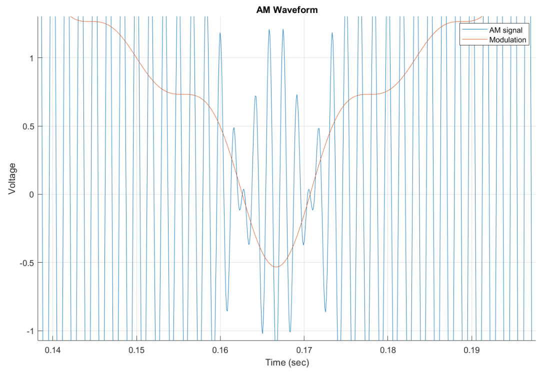


Figure 3: Detailed view of AM and triangular modulated signal, indicating absence of distortion

3 Demodulation/detection

3.1 AM Detection

The script "AM_RX_1.m" was configured as per lab guidelines, with waveform fidelity closely mirroring input modulations. Notably, no distortion, clipping, or overmodulation was observed. The signal o_S exhibited a significantly higher amplitude due to carrier multiplication during modulation, with all signals maintaining phase coherence.

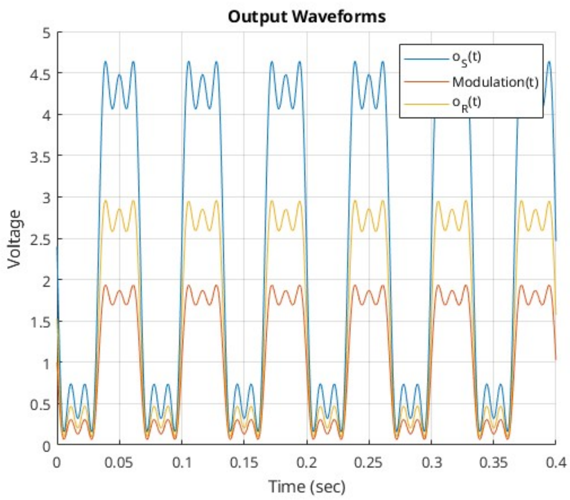


Figure 4: RX outputs comparison

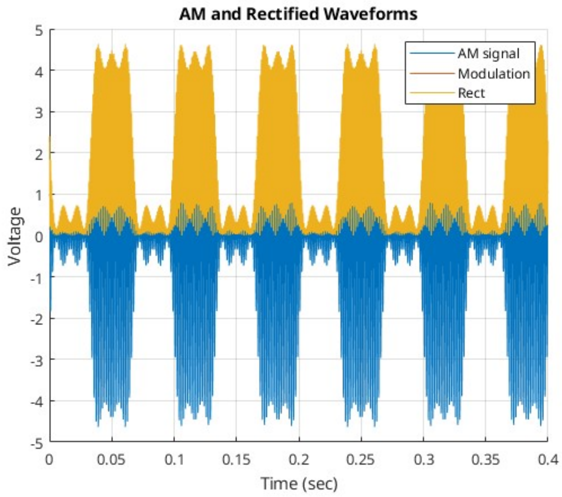


Figure 5: AM and rectified waveform

The waveform parameters were then changed to modulate using a triangle wave approximation. Almost identical behaviour is observed with no distortion or clipping or phase shifts. However there is one key difference - the effects of rectification are clearly seen on the o_R signal. We can see the negative components being mirrored into the positive half (Figure 8).

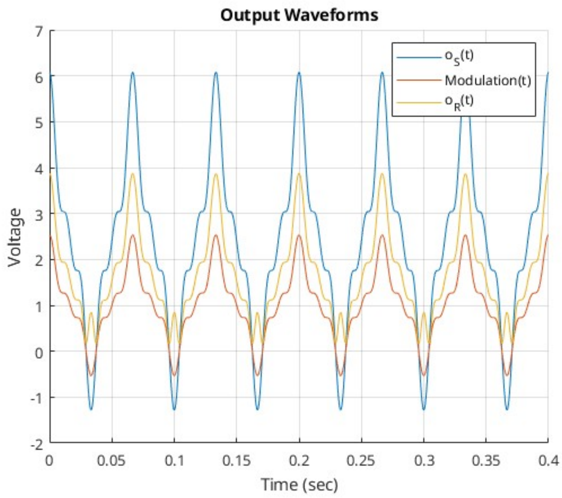


Figure 6: RX output comparison for triangle modulation

Phase Offset in Receiver Carrier

Incremental adjustments to the receiver carrier's phase (in $\pi/4$ increments) revealed amplitude variations in the demodulated signal, notably a downshift in o_s by up to -6V and a reduction in o_R's peak-to-peak amplitude. These effects stem from the phase mismatch between transmission and reception carriers, leading to amplitude modulation and phase shifts.

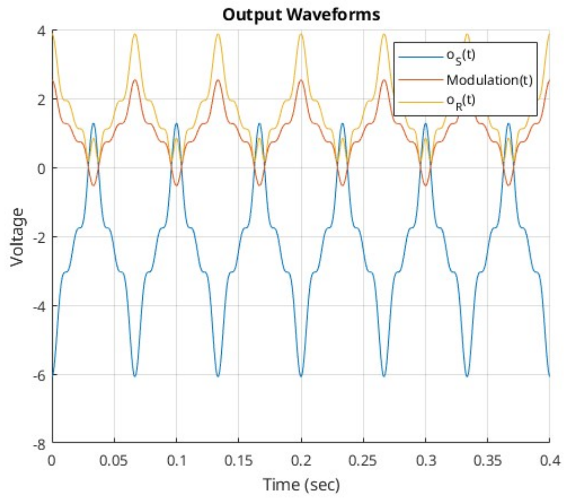


Figure 7: Triangle wave demodulated with receiver carrier phase offset to 4π

These changes appear due to the mismatch in phase of the sender and receiver carrier which results in destructive , reducing and shifting the amplitude.

Frequency Offset in Receiver Carrier

Setting the modulation and carrier signals' parameters as specified, it was observed that while o_R demodulated correctly without distortion, o_S was adversely affected. This discrepancy arises from the dependence of o_S on the precise frequency alignment of the carrier and receiver carriers, highlighting the importance of frequency synchronization for accurate demodulation.

4 Orthogonal Frequency Division Multiplexing (OFDM)

4.1 OFDM Baseband Signal

The parameters in the provided Matlab script were set as per the lab script. The following values were calculated:

"S" Symbol @ 1V

- PEP: 41.44W
- $PAPR$: 8.22

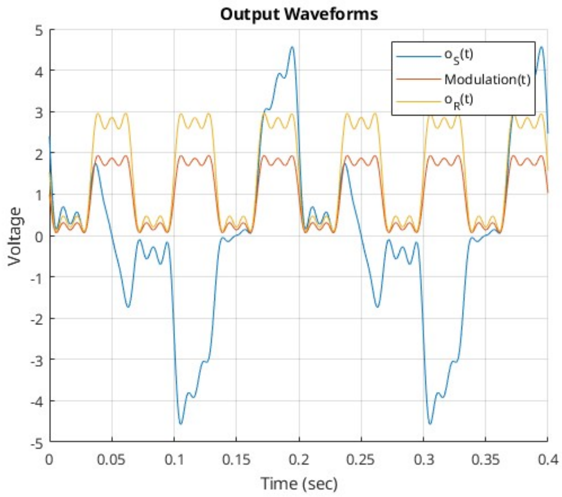


Figure 8: Square wave with mismatched TX and RX frequencies

"S" Symbol @ 2.5V

- PEP: 1.8W
- $PAPR$fair: 8.22

4.2 64-QAM on OFDM

Matlab was used to calculate PEP and PAPR for each of the following symbols:

Symbols	PEP	PAPR
"X"	141W	2
"+"	150W	3.99
"Y"	425W	3.99
"<"	11.4W	3.97
"3"	57.4W	3.98
"X+Y<3"	1372W	5.92

5 Summary and Comments

AM modulation relies on envelope detection, which is susceptible to noise and distortion. In contrast, OFDM signals benefit from coherent detection schemes, offering superior performance in complex multipath environments and effectively mitigating inter-symbol interference, thus presenting a more robust alternative to the traditional AM demodulation techniques.