ELECTRONIC SYSTEMS ENGINEERING
FACULTY OF ENGINEERING & APPLIED SCIENCE
UNIVERSITY OF REGINA

ENEL 390 PROJECT REPORT

TITLE: MODULATION INDEX, POWER EFFICIENCY AND DISTORTION

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DATE: AUGUST 14, 2019

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Introduction:

Communication is essential in today's world because through the development and improvement of transmission and reception of information, it has helped change the world and will in the future change the world even further. This project focuses on how we can produce desired signals to be transmitted and received, which can be achieved by varying the modulation index such that no distortion envelope detection is possible. Also, we are to examine the trade-off between power efficiency and distortion of signals while varying different modulation indexes.

Description:

For determining the distortion level and power efficiency as values of modulation index varies and, defining the relationship between the distortion and power efficiency, the Simulink model below, having the required components is used to achieve this.

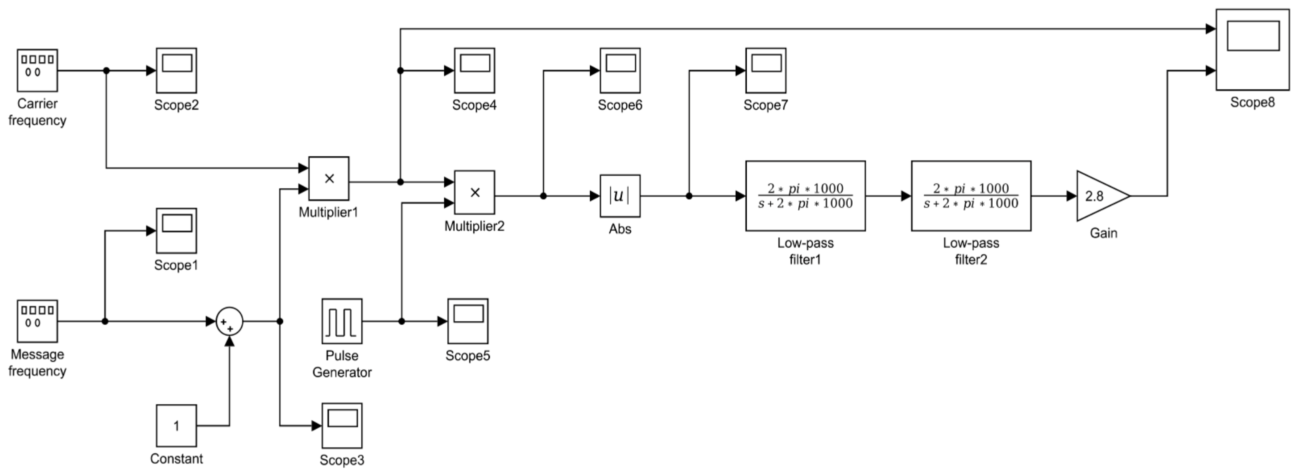

Figure 1.1 Simulink model

In this model, *Constant* is used to represent the value of the amplitude. *Multiplier1* modulates the message signal by multiplying it with the carrier signal and *Multiplier2* demodulates the input signal which is multiplied with a pulse signal with fifty percent pulse width. The *Abs* function returns the absolute value of the modulation signal, therefore, flipping negative values to positive values. *Low-pass filter1* and *Low-pass filter2* are represented by transfer functions which is used to get recovered signals, the value of the transfer function is $2\pi f_c / (s + 2\pi f_c)$. The *Scopes* are used display all the generated signals.

For this project, the Simulink model in Figure 1.1 will be used but also, an alternative method shown in Figure 1.2 can be used to achieve the same result, where *Multiplier* modulates the signal, squaring (*Square*) the signal effectively demodulates the input signal by using itself as its own carrier signal and taking a *Square root* of the signal to reverse the scaling distortion that resulted from the squared signal.

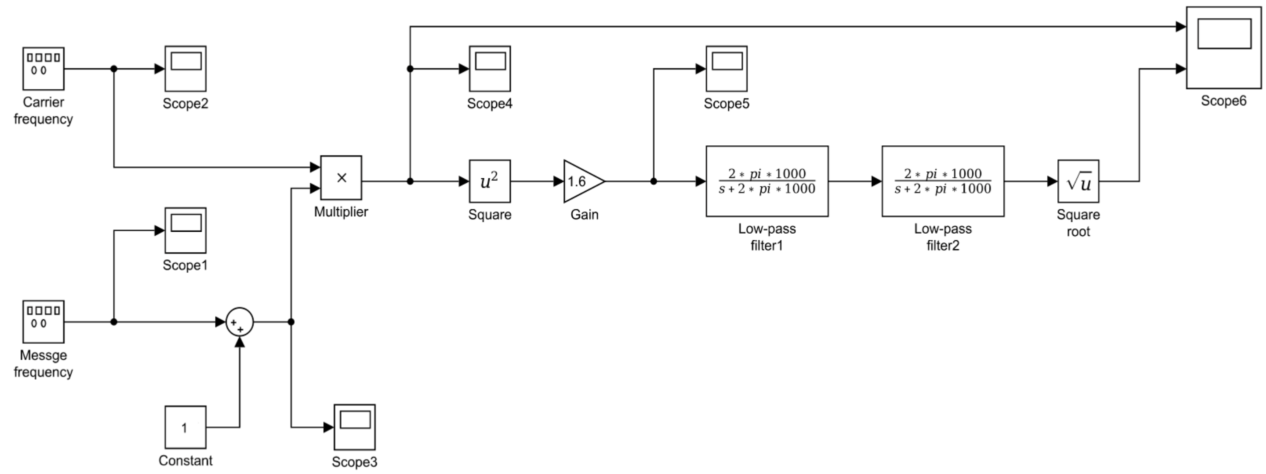

Figure 1.2: Simulink model (alternative method)

Calculation:

The message frequency, f_m = 100 Hz.

The carrier frequency, f_c =10000 Hz.

Signal power, $m^2(t) = C^2 / 2$ = 1 / 2

Bandwidth of the modulated signal, *BW* = 2 * *baseband signal frequency* = 2 * 10 = 20 Hz.

Modulation index, µ = *m(p) / A* = 1 / 0.67 = 1.5

Power efficiency, $\eta = m^2(t) / (A^2 + m^2(t)) * 100\%$ = 0.5 / (0.67^2 + 0.5) * 100% = 52.7%.

Low-pass filter, $H(s) = 1 / [(s / w_c) + 1]$

$w_c = 2\pi f_c = 1 / RC$

$H(s) = 1 / [(s\ RC) + 1]$

Multiplying both the numerator and denominator by 1/ RC, we would get

$H(s) = (1 / RC) / [s + (1 / RC)]$

Recollect that $1 / RC = 2\pi f_c$

Therefore, $H(s) = 2\pi f_c / (s + 2\pi f_c)$

Time constant, $\tau = RC = 1 / (2\pi f_c)$ 1 / (2 * π * 1000) = 1 / 6283.19 = 0.000159 s = 0.16 ms

Analysis:

In this project, we will examine several signals using a time span of 0.1 s.

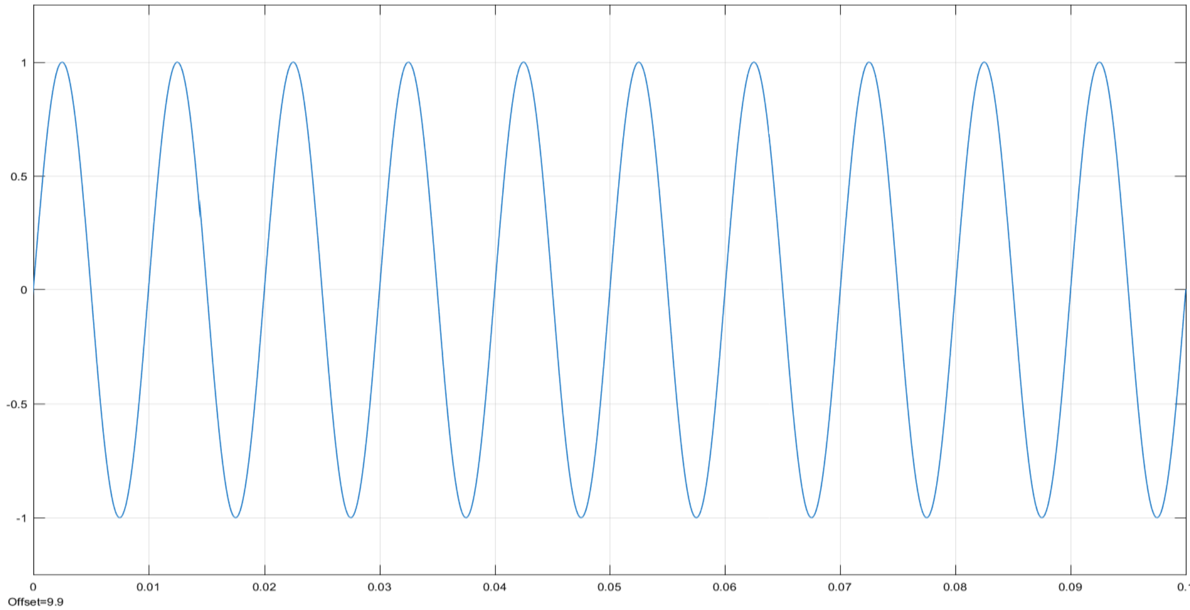

Figure 2: Message signal

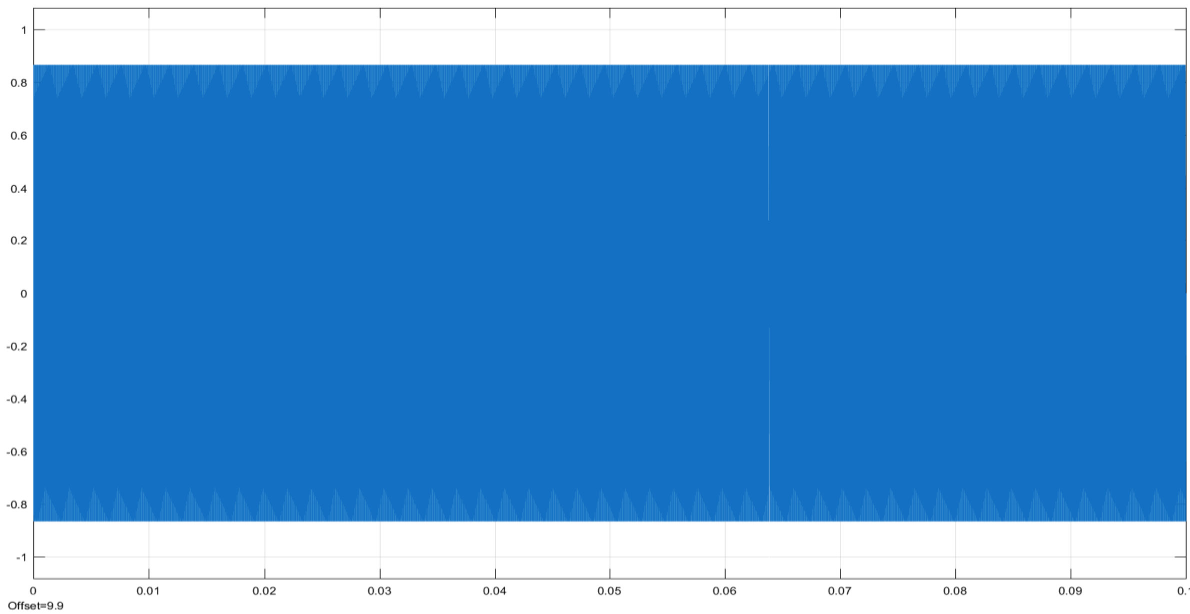

Figure 3: Carrier signal

Modulation index = 1.0

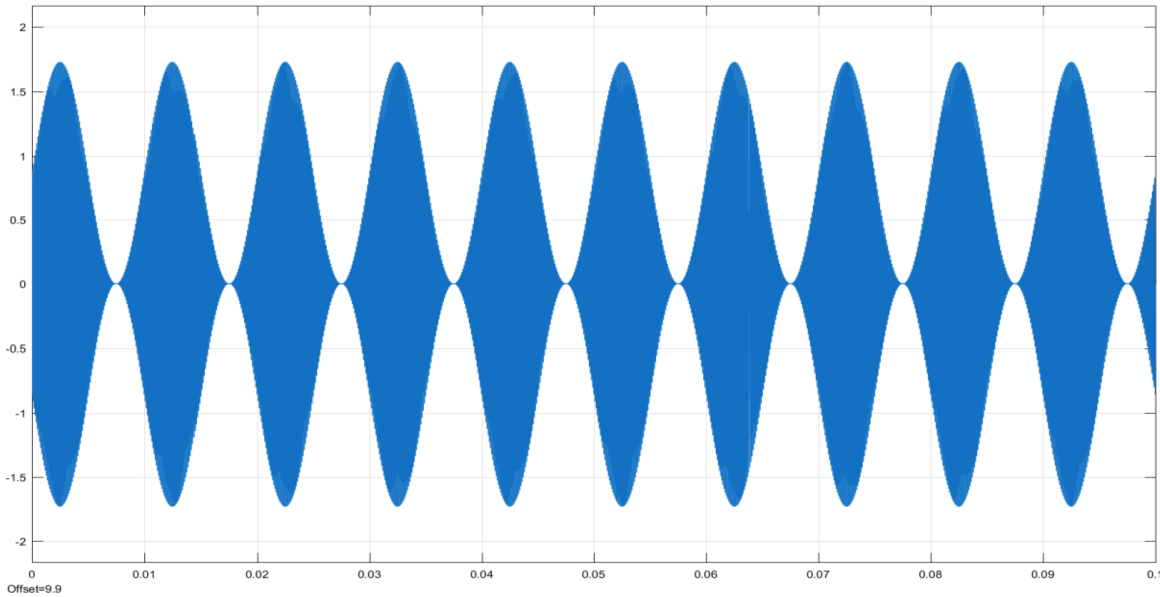

Figure 4.1: Modulated signal with μ = 1.0

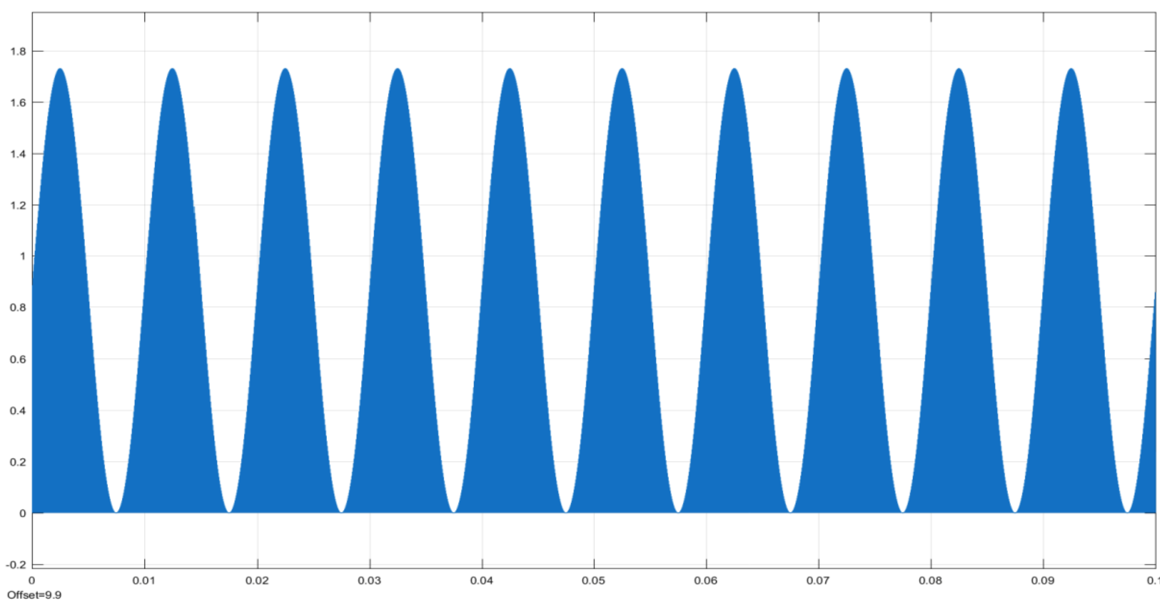

Figure 4.2: Demodulated signal with μ = 1.0

Modulation index = 1.0

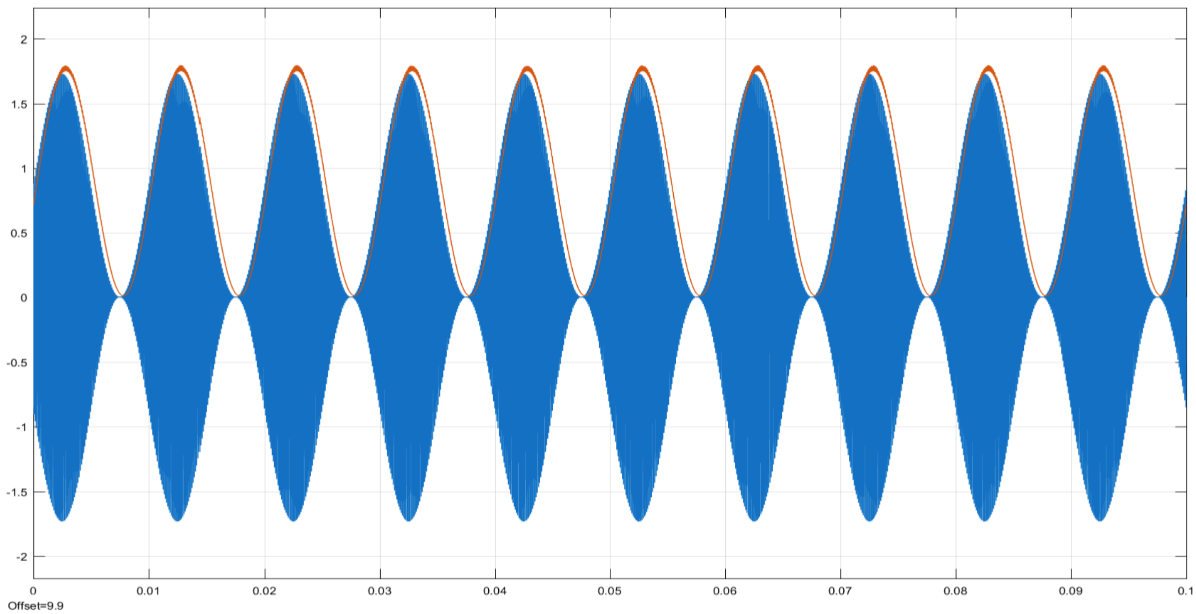

Figure 4.3: Recovered message signal with $\mu = 1.0$

Calculation:

Modulation index, $\mu = m_p / A$

$m_p = 1.0$

$\mu = 1.0$

The modulation index falls within the desired range of $0.5 \leq \mu \leq 1.5$

Therefore, $A = mp / \mu = 1.0 / 1.0 = 1.0$

Maximum power efficiency, $\eta = m^2(t) / (A^2 + m^2(t)) * 100\%$

$\eta = 0.5 / (1.0^2 + 0.5) * 100\% = 33.3\%$

Note: The recovered message signal is the orange signal in Figure 4.3.

In this case, the amplitude of the signal is 1.0. According to analysis, the maximum value of the modulation index (μ) where no distortion in the envelope detection is possible is 1.0. During this process, the power efficiency is higher when compared to that of μ < 1.0 and lower when compared to that of μ > 1.0. Fewer distortions are present when compared to that of μ > 1.0 and more when compared to that of μ < 1.0.

Modulation index = 1.5

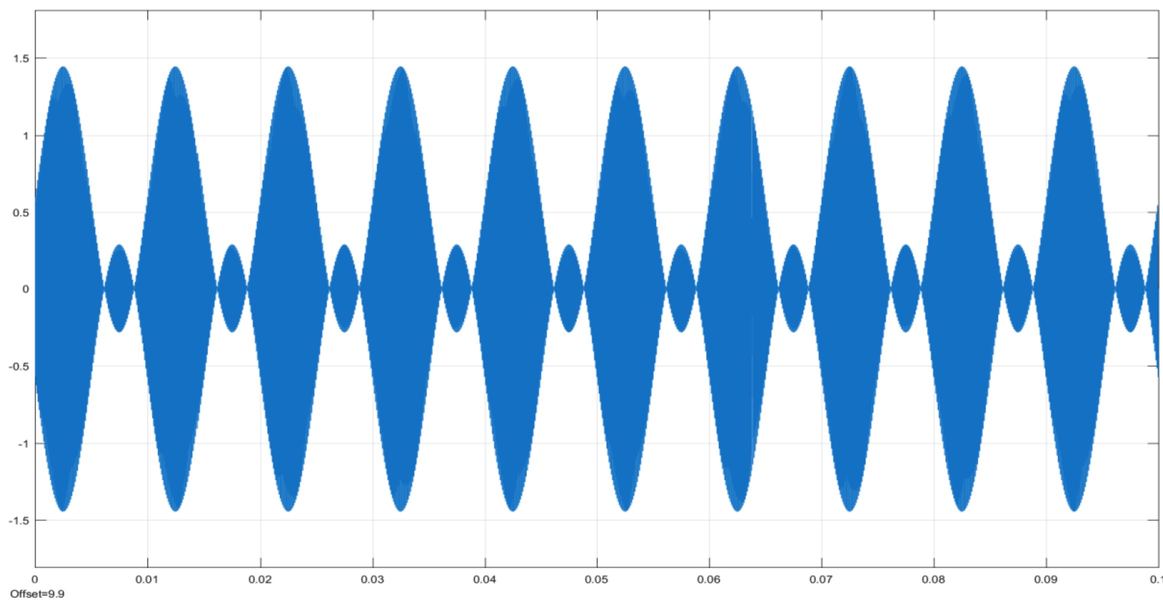

Figure 5.1: Modulated signal with μ = 1.5

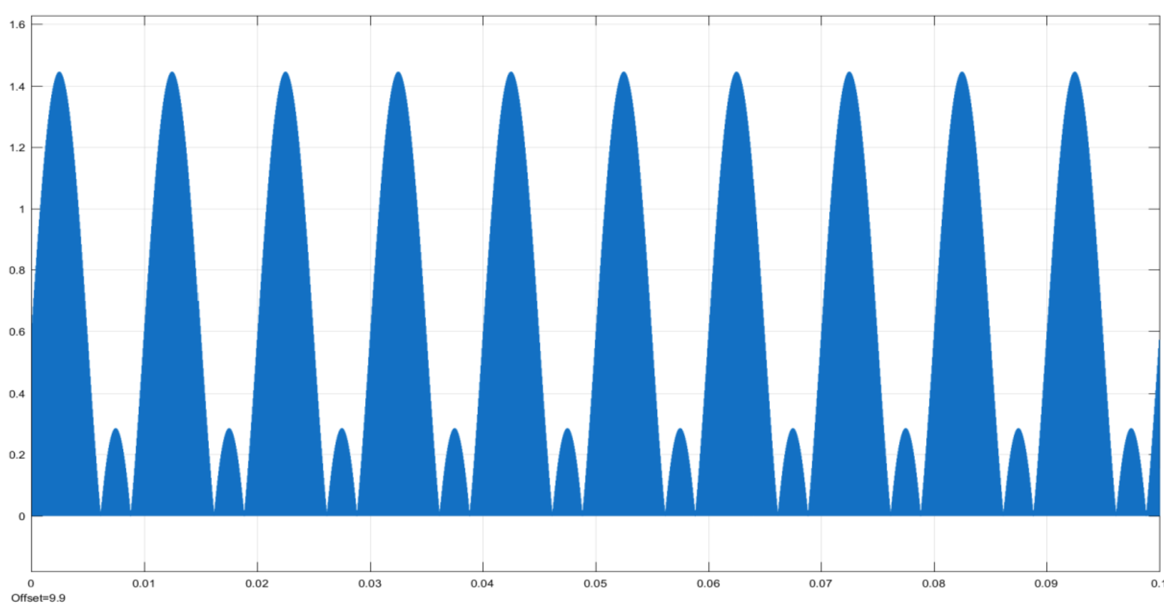

Figure 5.2: Demodulated signal with μ = 1.5

Modulation index = 1.5

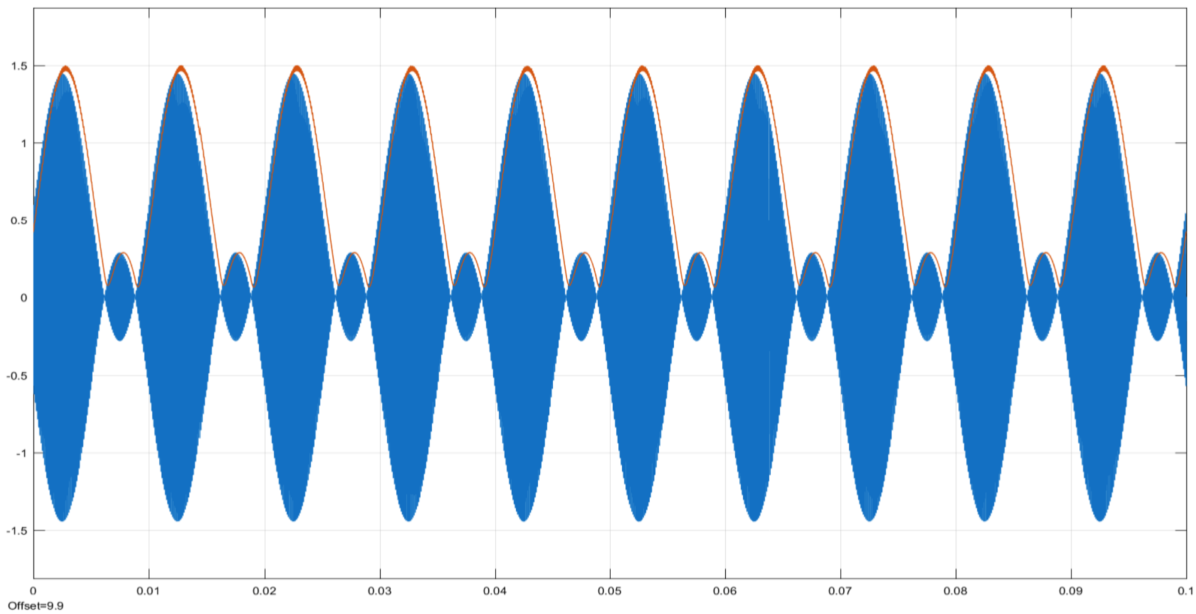

Figure 5.3: Recovered message signal with μ = 1.5

Calculation:

Modulation index, $\mu = m_p / A$

$m_p = 1.0$

μ = 1.5

The modulation index falls within the desired range of $0.5 \leq \mu \leq 1.5$

Therefore, $A = mp / \mu = 1.0 / 1.5 = 0.67$

Maximum power efficiency, $\eta = m^2(t) / (A^2 + m^2(t)) * 100\%$

$\eta = 0.5 / (0.67^2 + 0.5) * 100\% = 52.7\%$

Note: The recovered message signal is the orange signal in Figure 5.3.

In this case, the amplitude of the signal is 0.67. With the modulation index greater than 1.0, over-modulation occurs which causes the modulating signal to have a greater amplitude. During this process, the power efficiency is the highest when compared to other values of μ examined. A larger portion of the information is lost, and more distortions are present when compared to that of the remaining values of μ examined.

Modulation index = 1.2

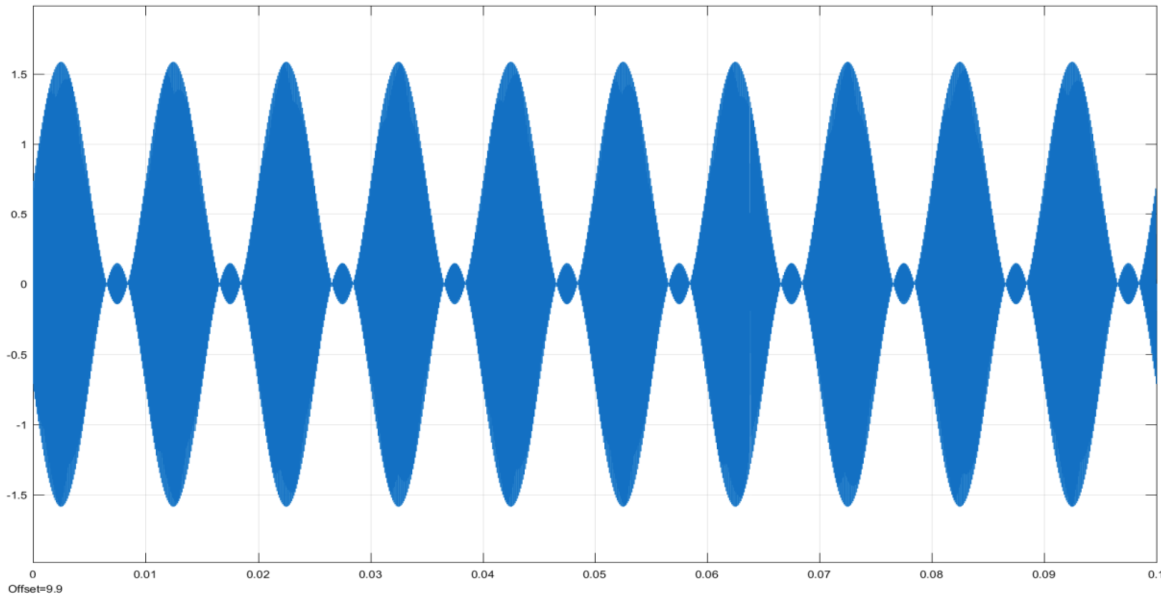

Figure 6.1: Modulated signal with μ = 1.2

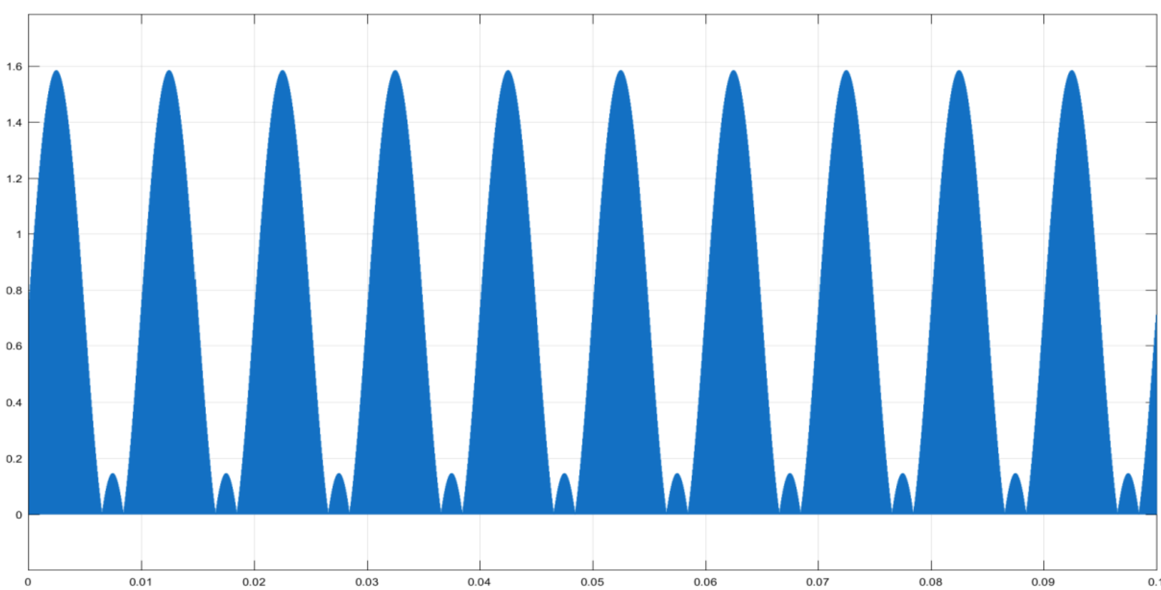

Figure 6.2: Demodulated signal with μ = 1.2

Modulation index = 1.2

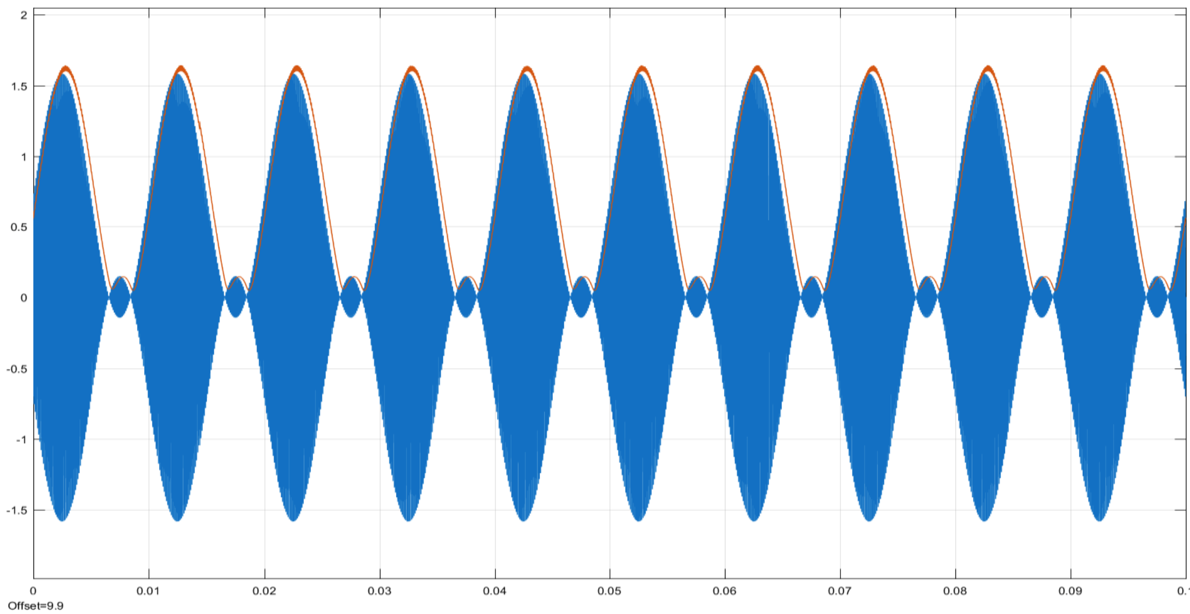

Figure 6.3: Recovered message signal with μ = 1.2

Calculation:

Modulation index, $\mu = m_p / A$

$m_p = 1.0$

$\mu = 1.2$

The modulation index falls within the desired range of $0.5 \leq \mu \leq 1.5$

Therefore, $A = mp / \mu = 1.0 / 1.2 = 0.83$

Maximum power efficiency, $\eta = m^2(t) / (A^2 + m^2(t)) * 100\%$

$\eta = 0.5 / (0.83^2 + 0.5) * 100\% = 42.1\%$

Note: The recovered message signal is the orange signal in Figure 6.3.

In this case, the amplitude of the signal is 0.83. Again, the modulation index is greater than 1.0, therefore, over-modulation occurs causing the modulating signal to have a greater amplitude. During this process, the power efficiency is lower that of μ = 1.5 and greater than that of the remaining values of μ examined. A smaller portion of the information is still lost, fewer distortions are present when compared to that of μ = 1.5 and more when compared to that of the remaining values of μ examined.

Modulation index = 0.67

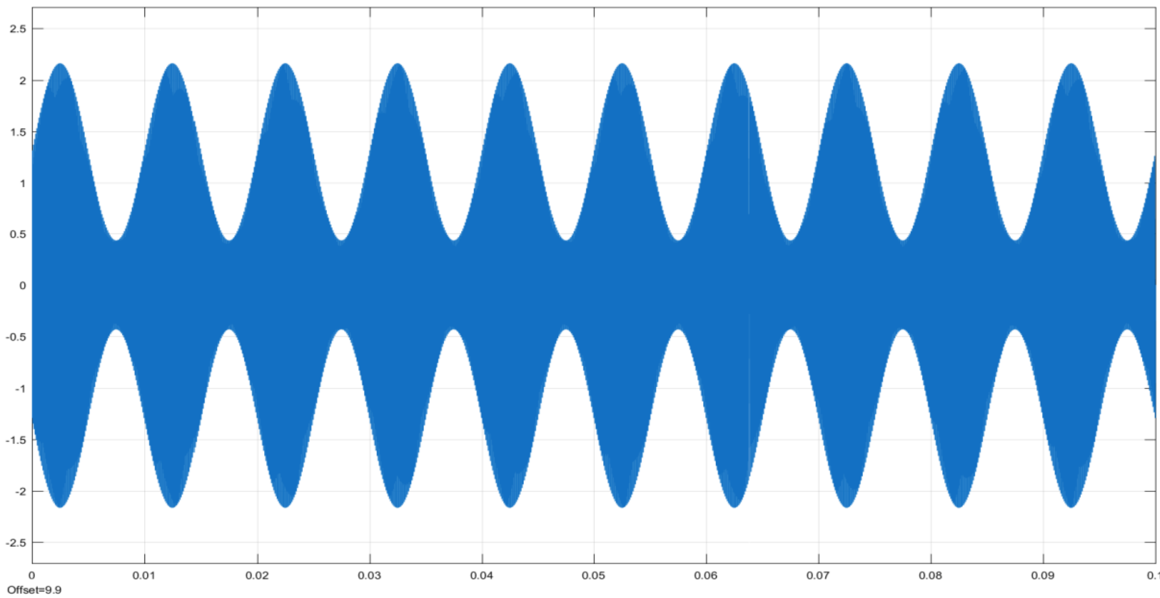

Figure 7.1: Modulated signal with μ = 0.67

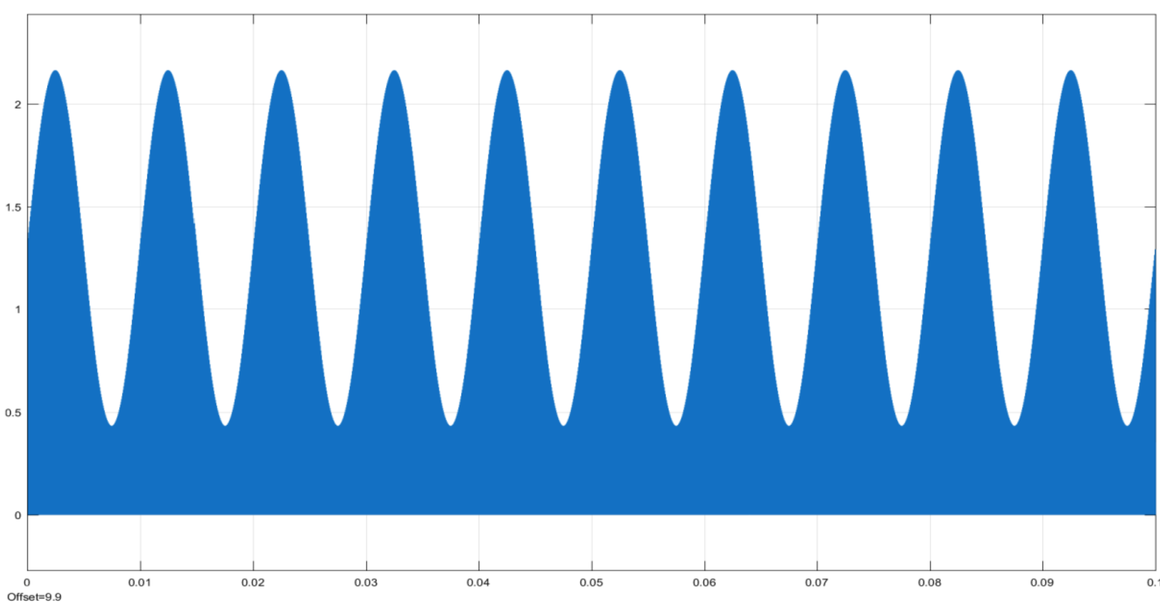

Figure 7.2: Demodulated signal with μ = 0.67

Modulation index = 0.67

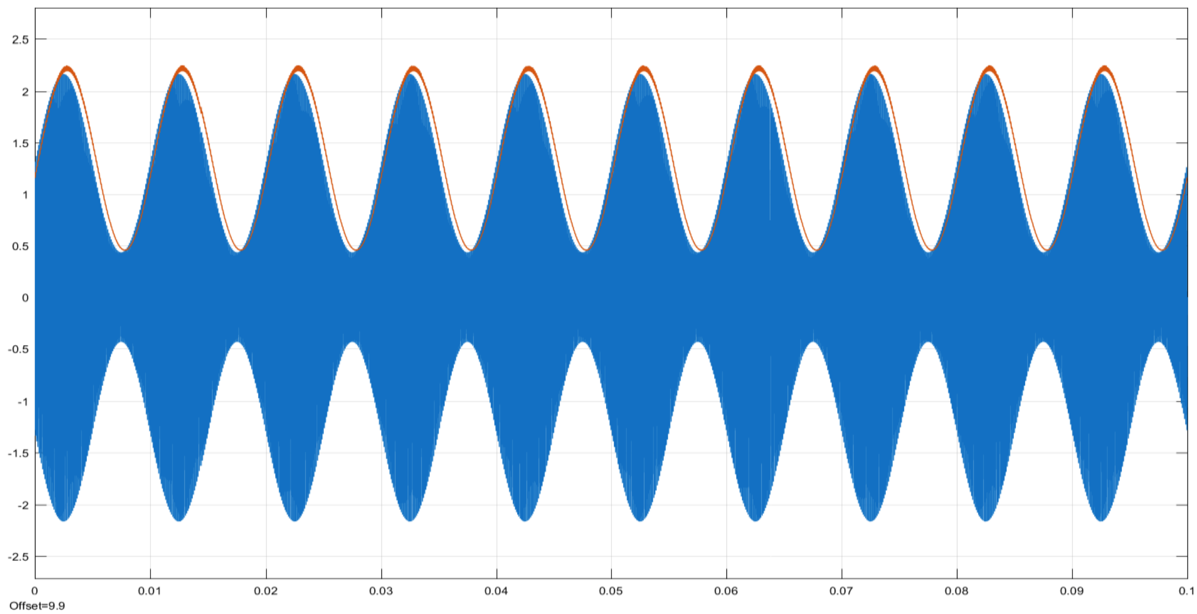

Figure 7.3: Recovered message signal with μ = 0.67

Calculation:

Modulation index, $\mu = m_p / A$

$m_p = 1.0$

$\mu = 0.67$

The modulation index falls within the desired range of $0.5 \leq \mu \leq 1.5$

Therefore, $A = mp / \mu = 1.0 / 0.67 = 1.5$

Maximum power efficiency, $\eta = m^2(t) / (A^2 + m^2(t)) * 100\%$

$\eta = 0.5 / (1.5^2 + 0.5) * 100\% = 18.2\%$

Note: The recovered message signal is the orange signal in Figure 7.3.

In this case, the amplitude of the signal is 1.5. The modulation index is lesser than 1.0, therefore, over-modulation does not occur, and the modulating signal will have a much greater amplitude. During this process, the power efficiency is low but higher than that of μ = 0.5. No portion of the information is lost but distortions tend to be present in the signal and are more when compared to that of μ = 0.5 but fewer when compared to that of the remaining values of μ examined.

Modulation index = 0.5

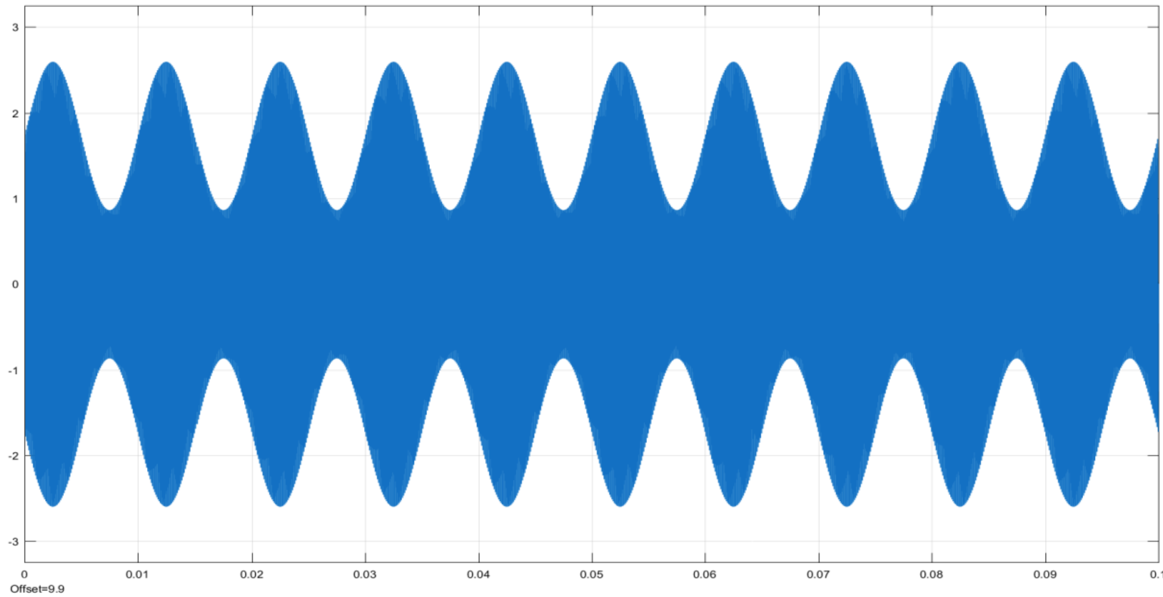

Figure 8.1: Modulated signal with μ = 0.5

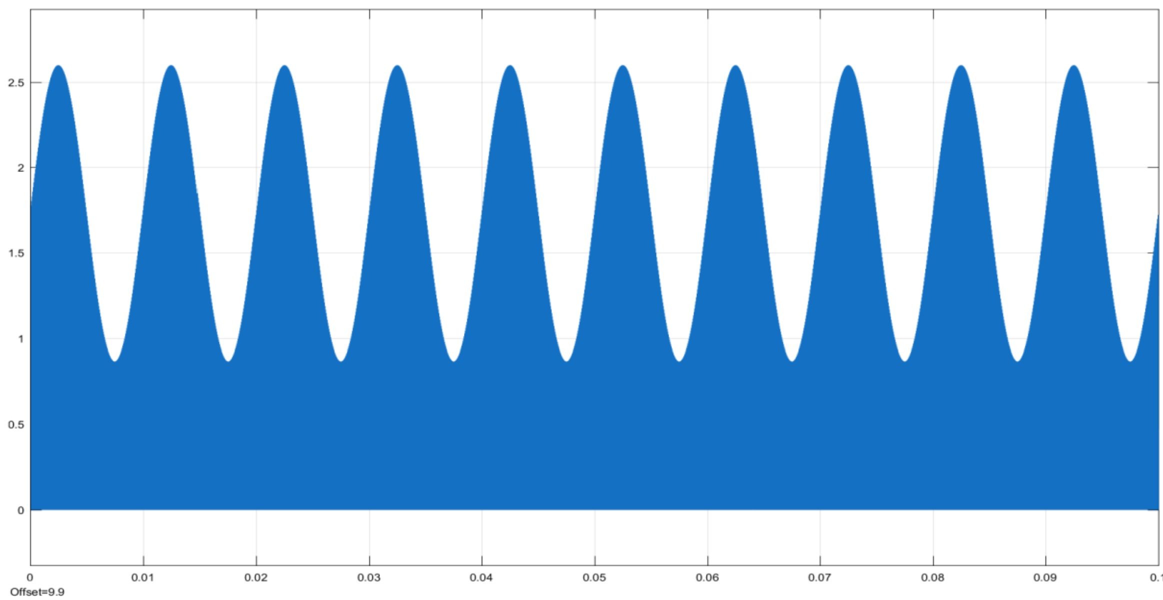

Figure 8.2: Demodulated signal with μ = 0.5

Modulation index = 0.5

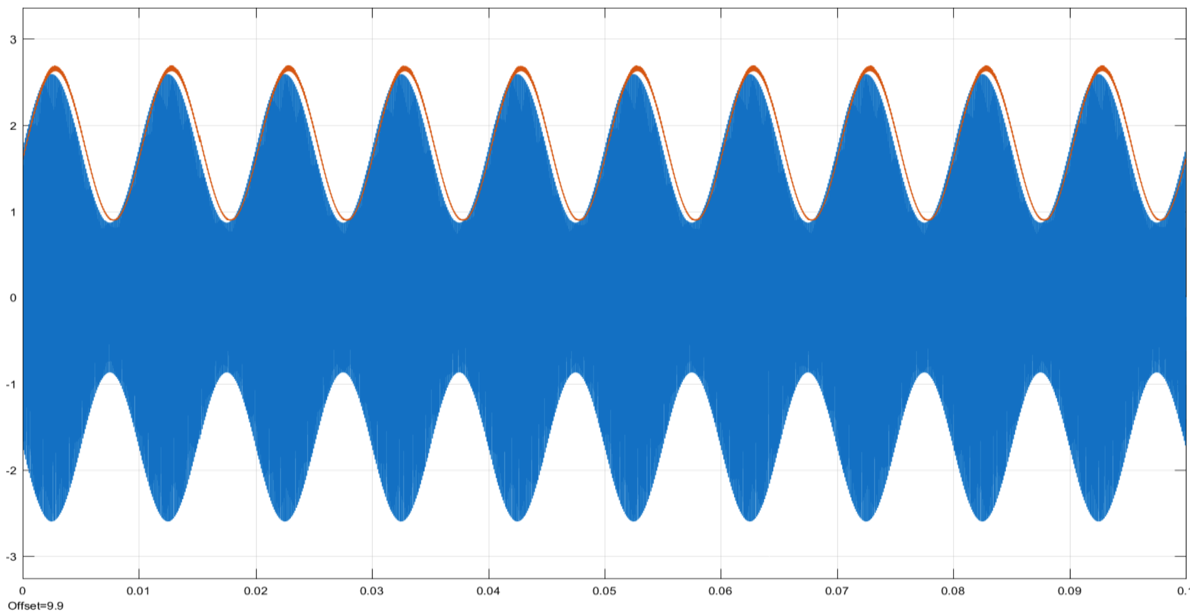

Figure 8.3: Recovered message signal with μ = 0.5

Calculation:

Modulation index, $\mu = m_p / A$

$m_p = 1.0$

$\mu = 0.5$

The modulation index falls within the desired range of $0.5 \leq \mu \leq 1.5$

Therefore, $A = mp / \mu = 1.0 / 0.5 = 2.0$

Maximum power efficiency, $\eta = m^2(t) / (A^2 + m^2(t)) * 100\%$

$\eta = 0.5 / (2.0^2 + 0.5) * 100\% = 11.1\%$

Note: The recovered message signal is the orange signal in Figure 8.3.

In this case, the amplitude of the signal is 2.0. The modulation index is lesser than 1.0, therefore, over-modulation does not occur, and the modulating signal will have the greatest amplitude. During this process, the power efficiency is the lowest. No portion of the information is lost and even though distortions are present in the signal, it is the lowest when compared to that of the remaining values of μ examined.

Discussion:

By observation, we can see that the amplitude is inversely proportional to the modulation index; therefore, as the value of the amplitude varies, it yields a change in the value of the modulation index. This is to say that as the value of amplitude increases, the value of the modulation index decreases and as the value of amplitude decreases, the value of the modulation index increases. This also affects the power efficiency, which is directly proportional to the modulation index. As seen with the different modulation indexes examined, we see that when $\mu = 0.5$, the power efficiency is 11.1%; when $\mu = 0.67$, the power efficiency is 18.2%; when $\mu = 1.0$, the power efficiency is 33.3%; when $\mu = 1.2$, the power efficiency is 42.1% and when $\mu = 1.5$, the power efficiency is 52.7%. This implies that as the value of the modulation index increases, the value of the power efficiency increases and as the value of the modulation index decreases, the value of the power efficiency decreases.

As the modulation index varies, different distortion levels occur, we can detect more or lesser distortions depending on the value of the modulation index. By observation, we can see that as the value of the modulation index increases, the distortion increases and as the value of the modulation index decreases, the distortion decreases but this is only applicable when the value of the modulation index falls between a specific range, which is between 0.5 and 1.5. Therefore, $0.5 \leq \mu \leq 1.5$ and if the modulation index falls above this range, the distortion greatly increases, and an overlap occurs when it is higher than 1.

To achieve a message signal with no distortion, the power efficiency must very low, further implying that more power must be provided to achieve lesser distortion. In other words, more power efficiency yields more distortion in the signal. In this case, we need to have a trade-off between the power efficiency and distortion and my preferred modulation index is 0.67, this is chosen because it falls between the $0.5 \leq \mu \leq 1.5$ range and despite having a low power efficiency, fewer distortions are present, and no information is lost.

Conclusion:

When determining the preferred modulation index in transmission of signals, a trade-off between the distortion and power efficiency is essential. To avoid a great amount of distortion, the required value for the modulation index should be chosen for the perfect combination of distortion and power efficiency. A low amount of distortion can be considered if it falls between the range while also taking into consideration, a lower power efficiency.

References:

Lathi, B.P. (2009). Modern Digital and Analog Communication Systems. New York, NY: Oxford University Press.