ENSC 327 – Communication Systems

Lab 2: Amplitude Modulation

Group 17

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1. Objective

In this lab, we will be studying the effects of changing the modulation factor levels on amplitude modulated and demodulated signals. We will observe our results and compare them to the theoretical results behind amplitude modulation and demodulation. An analysis of our data in time domain and frequency domain will then confirm if our experimental results were close or not to the theoretical results.

2. Theory

A message signal is represented by equation 1.

$$m(t) = A_m \cos(2\pi f_m t) \qquad (1)$$

A DC bias is then applied to the message signal and then modulated with a carrier signal. The combination of these two signals become an amplitude modulated signal, s(t), which shown below in equation 2.

$$s(t) = A_c[1 + k_a m(t)]\cos(2\pi f_c t) \qquad (2)$$

where k_a is a constant called amplitude sensitivity of the modulator which is responsible for the generation of the modulated signal s(t). It is measured in volt^{-1} while the carrier amplitude, A_c and m(t) is measured in volts.

From Figure 1, because of amplitude modulation, the information contained in m(t) is within the envelope of the AM wave (b) and (c). In addition, for an envelope to be visualized, the carrier frequency, f_c must be greater than the highest frequency component of the m(t).

It is also preferable to recover m(t) from a modulation signal s(t). This is achieved by a demodulator called envelope detector. Envelope of the original signal m(t) can be detected when AM wave is a narrowband and the percentage of the modulation in the AM wave is less than 100%. An envelope detector consists of a diode and a resistor-capacitor filter shown below:

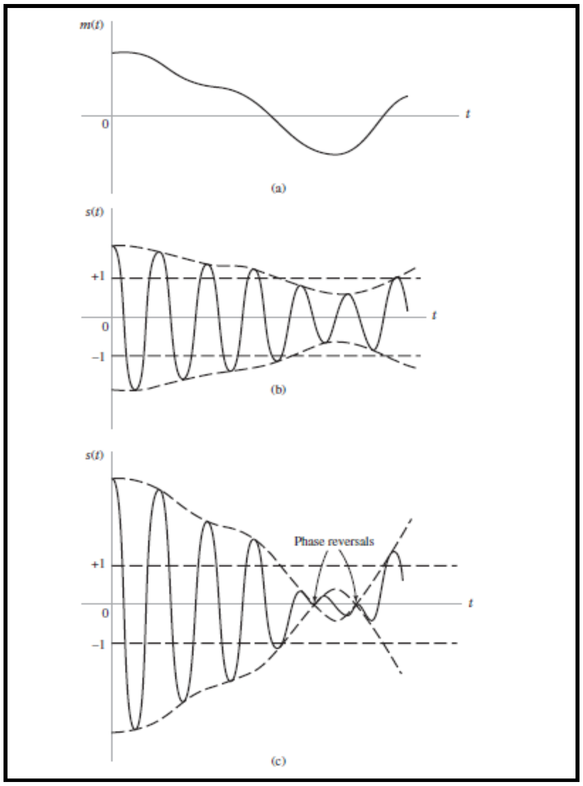

Figure 1: Amplitude Modulation of the (a) the message signal m(t) and the (b) modulated signal s(t) when it $|k_a m(t)| < 1$ and when (c) $|k_a m(t)| > 1$

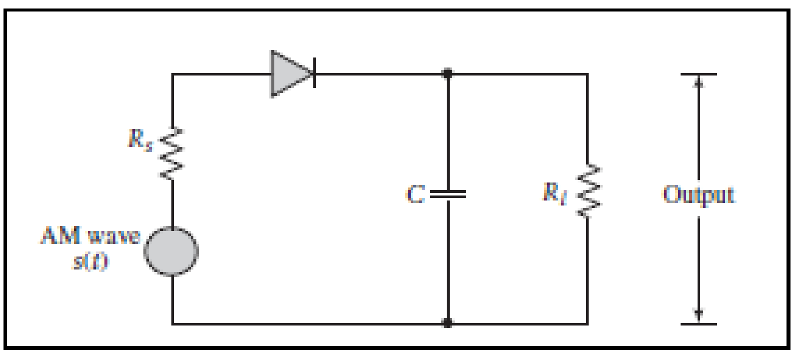

Figure 2: Envelope Detector Circuit

When the diode is forward biased, the capacitor charges up rapidly. In contrast, when the diode is reverse biased, the capacitor discharges slowly. The diode in series allows current flow only when the positive input terminal is higher than the negative input terminal.

In part 2 of lab, we will use demodulation to recover our message signal from the modulation signal s(t). We will also be using the theory of amplitude modulation for both part 1 and 2, analyzing the AM wave in both frequency and time domains.

3. Methods

3.1 AM Modulation with TIMS Machine

We set used the AUDIO OSCILLATOR (AO) to create a message signal at 10.073 kHz. This was done by connecting the output of the AO into the FREQUENCY COUNTER (FC) and then turning the Δt knob of the AO. After setting up the frequency, the output of the AO is wired to the top input of an ADDER. A DC bias is wired to the bottom input of the ADDER from VARIABLE DC with its ΔV turned all the way counter-clockwise. This creates the signal $A_m[1 + \mu\cos(2\pi f_m t)]$.

To set up the peak – peak value, we want μ to be 1. We use the equation $[1 + \mu\cos(2\pi f_m t)]$ to find the maximum and minimum. We know that maximum and minimum for $\cos(2\pi f_m t)$ is going to +1 and -1 respectively. Setting the μ to 1 we then get our maximum and minimum to be 2 and 0 respectively.

From the minimum and maximum of 2 and 0 above we get our desired peak – peak value of 2 Volts. We set the output of the ADDER to the SCOPE SELECTOR (SS) to view our signal in the oscilloscope. On the ADDER, we first set the gains of both inputs to 0 and set up the zero-volt reference line. The gain on the AO input is increased to increase the voltage peak – peak which we increase until the signal reaches 2 Volts peak – peak. At this moment, our signal is 2 Volts peak – peak but its maximum and minimum are +1 and -1 because we started from the zero-volt reference line. So, we increase the DC bias gain because it will move our signal to the position of desired maximum and minimum which are +2 and 0 respectively.

Now we create the carrier signal. We input a 5 Volt DC from VARIABLE DC into a VCO module. Making sure the switch on the side of the VCO is switched to FSK mode. Then check the VCO frequency by wiring its output to the FC and we got around 300 kHz. After checking the frequency, the VCO output is wired to a MULTIPLIER. The adder output from above is also wired to the same MULTIPLIER. This MULTIPLIER output is then wired to the SS for us to view our signal in the oscilloscope or spectrum analyzer. The signal should now be an amplitude modulated signal.

For different values of percentage modulations, we change the value of μ from 1 to 0.8, 0.5, and 0.2. The new μ values will give us different peak – peak voltages, different maximums and minimums, and different modulated signals.

To get the modulation factor from our oscilloscope result we look at Figure 3,

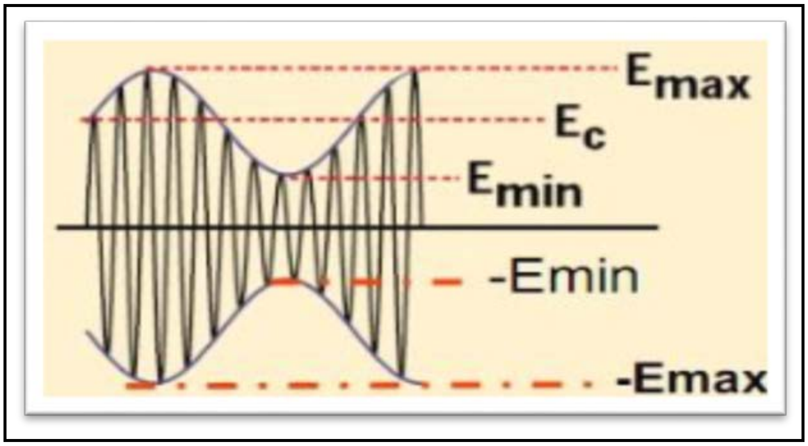

Figure 3: Oscilloscope output for an amplitude modulated signal

Then we use equation 3 below to find the modulation factor:

$$\mu = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \tag{3}$$

To get the modulation factor from our spectrum analyzer result we look at *Figure 4* below,

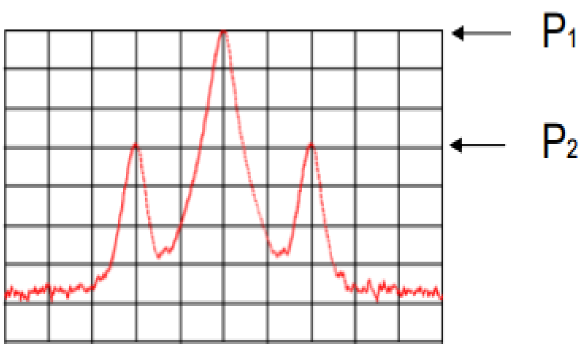

Figure 4: Spectrum analyzer output for an amplitude modulated signal

Equation 4 is used to find the modulation factor:

$$\mu = 2 \times 10^{-\frac{P_1 - P_2}{20}} \tag{4}$$

With our modulation factor values we can find the power efficiency formula for single tone modulation which is equation 5:

$$Power\ Efficiency = \frac{\mu^2}{\mu^2 + 2} \times 100\% \tag{5}$$

3.2 AM Demodulation with Envelope Detection Using TIMS Machine

Using the same techniques above we set up the AO with 1kHz and 2 Volts peak – peak. We are using the same procedures to find the amplitude modulation. This time the carrier is a 100-kHz signal from MASTER SIGNALS on the TIMS Front Panel. Then the input of the MULTIPLIER is wired to a RECTIFER module. The RECTIFIER output is then wired to the input of a TUNABLE LPF. The TUNABLE LPF is set to its widest bandwidth by toggling the switch to WIDE and its TUNE control turned fully clockwise. The output of the TUNABLE LPF is our demodulated signal.

We then look at both modulated and demodulated signals by inputting CH1 of the SS with the output of the TUNABLE LPF and CH2 with the output of the MULTIPLIER. For our results, we change the μ to 0.5 and 1.5 to see the effects of modulation index above and below 100%.

4. Results

4.1 AM Modulation with TIMS Machine

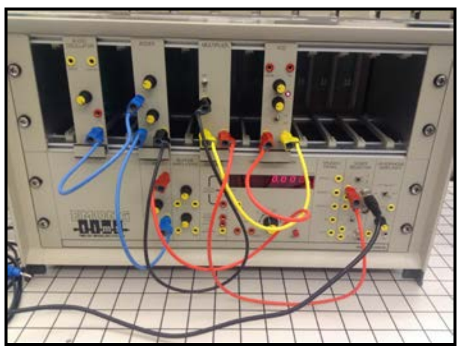

Figure 5: TIMS machine wiring for amplitude modulation

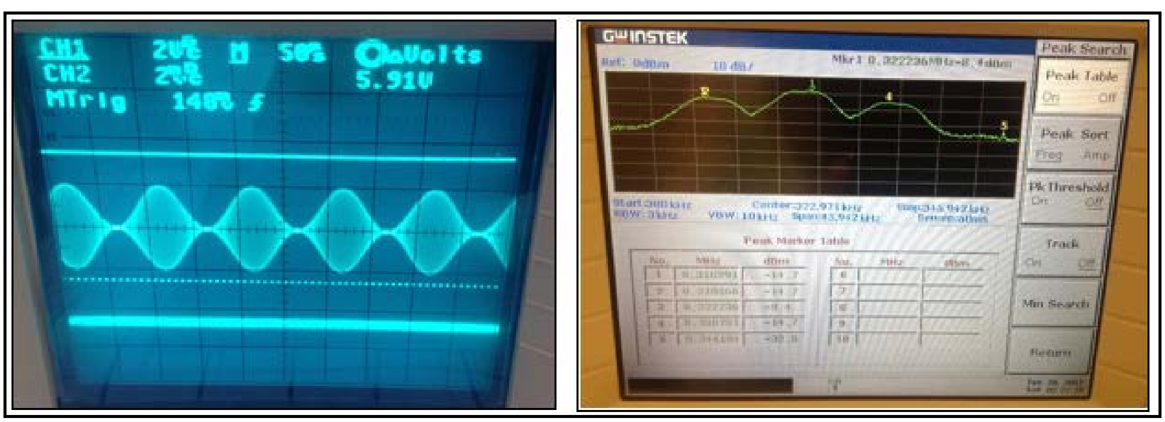

Figure 6: Picture of the oscilloscope on the left and of the spectrum analyzer on the right for a signal at 100% amplitude modulation

Figure 7: Picture of the oscilloscope on the left and of the spectrum analyzer on the right for a signal at 80% amplitude modulation

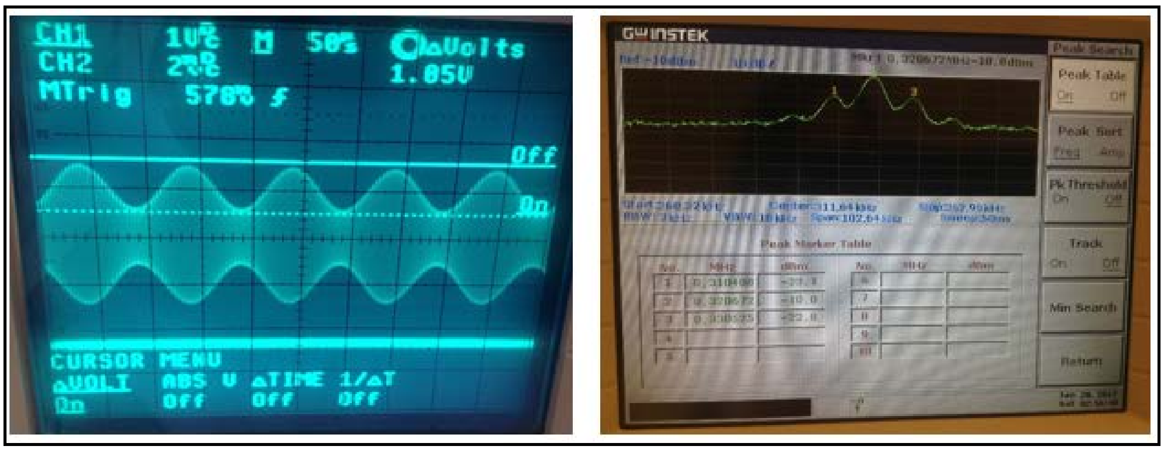

Figure 8: Picture of the oscilloscope on the left and of the spectrum analyzer on the right for a signal at 50% amplitude modulation

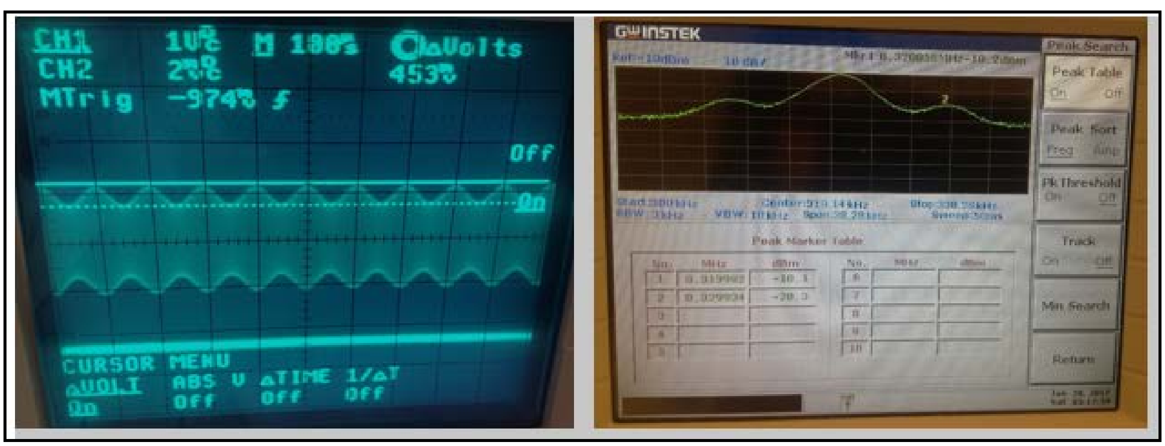

Figure 9: Picture of the oscilloscope on the left and of the spectrum analyzer on the right for a signal at 20% amplitude modulation

Table 1: Calculations for our oscilloscope result of an amplitude modulated signal

Percentage Modulation (%)	E_{max} peak – peak (V)	E_{min} peak – peak (V)	Modulation Factor (μ)	Power Efficiency (%)
100	2.01	0.03	0.97	32.02
80	1.80	0.21	0.79	23.83
50	1.50	0.52	0.49	10.53
20	1.21	0.80	0.20	2.04

Table 2: Calculations for our spectrum analyzer result of an amplitude modulated signal

Percentage Modulation (%)	P_1 (dBm)	P_2 (dBm)	Modulation Factor (μ)	Power Efficiency (%)
100	-8.4	-14.7	0.97	31.92
80	-10.6	-19.2	0.74	21.63
50	-10.0	-22.8	0.46	9.50
20	-10.1	-28.3	0.25	2.94

4.2 AM Demodulation with Envelope Detection Using TIMS Machine

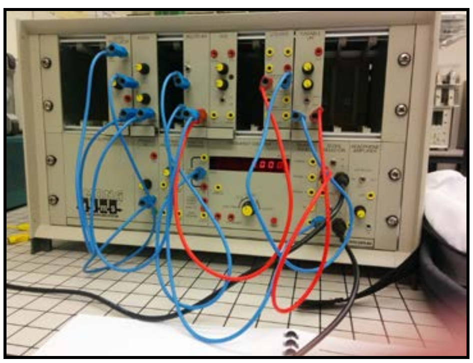

Figure 10: TIMS machine wiring for amplitude modulation and demodulation

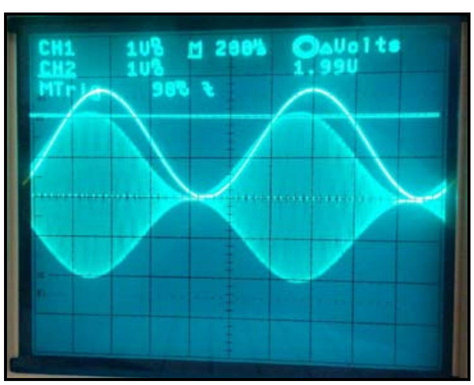

Figure 11: Modulated and demodulated signal at 100% modulation

Figure 12: Modulated and demodulated signal at 50% modulation

Figure 13: Modulated and demodulated signal at 150% modulation

5. Discussion

5.1 AM Modulation with TIMS Machine

When we obtained 100% modulation for the first steps of the lab the envelope closely matched that of the modulated signal and the sidebands were close to that of the center frequency. Also at 100% modulation the carrier level is at 0. When we turned the knob of the ADDER module to change that of the gain the carrier level moves away from the zero line and the sidebands on the spectrum analyzer move further and further away from the center frequency.

Our experimental values of the measured power efficiencies from the spectrum analyzer were close to that of the theoretical values. For example, the theoretical value for 100% modulation is 33.33% and our calculated value was 31.92%. The reason for the discrepancy in the numbers could be due to noise or signal fluctuations. The efficiency of modulated signals is very low in general. When a carrier signal is modulated two sidebands appear at both sides of the carrier signal in the frequency domain. When the signal is modulated at 100% the sidebands power is half that of the carrier, so each is a quarter and that makes it have a power efficiency maximum of only 33.33%.

When you decrease, the modulation factor the power efficiency decreases as well. This is clearly seen in Tables 1 and 2 above. The relationship between the modulation factor and the power efficiency is that they are proportional to each other starting from power efficiency 33.33% and modulation factor of 1.

When we target a specific μ lower than 1, that means the modulated factor should also be at that percentage, 1 being at 100%. Looking at our results in Tables 1 and 2, we can see that from our calculations, the lower modulated percentages also had a lower power efficiency. This was from both the time domain and frequency domain. This follows that our experimental results were spot on and that it resembled the theoretical results. As clearly seen in Figure 14 below.

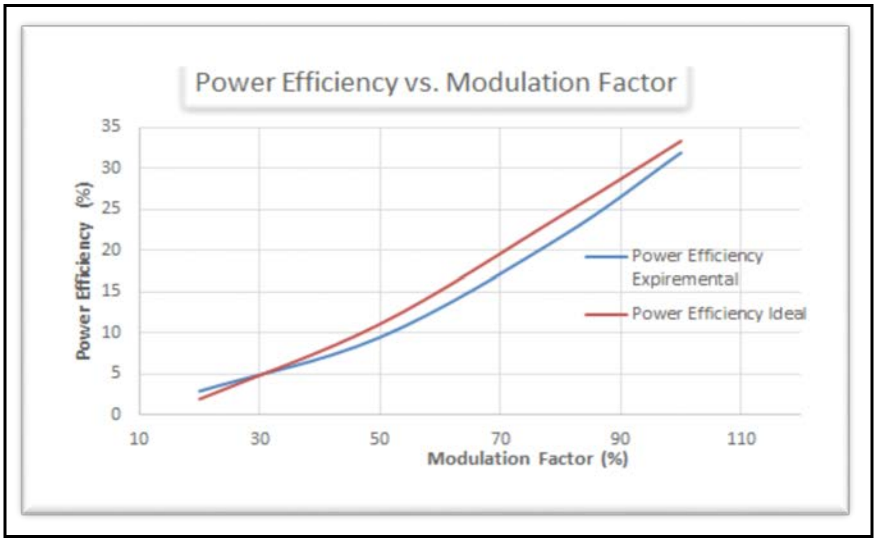

Figure 14: Power Efficiency versus Modulation Factor

5.2 AM Demodulation with Envelope Detection Using TIMS Machine

The demodulated AM signal was analyzed to retrieve the envelope of the modulated signal. What we observed was is once you increase the modulation index over 100% overlapping occurs and phase reversal occurs because the envelope cannot fall below 0. Figure 13 shows this phase reversal.

6. Conclusion

We were able to create an amplitude modulated and demodulated signal using the TIMS machine. We have learned that the amplitude of the message signal can be changed using the ADDER module. This amplitude or finding the peak – peak part was hard to figure out using the TIMS Machine when starting out. The amplitude modulated signal we got was viewed using an oscilloscope for the time domain and the spectrum analyzer for the frequency domain. After calculating our results from our experimental data we found that our results matched very closely with the theoretical results.