ECE 440L

Experiment 3: AM
(2 weeks)

I. OBJECTIVES

Upon completion of this experiment, you should be able to:

1. Modulate a carrier signal with a message to generate an AM (double side-band large carrier) signal with a specified modulation index.
2. Measure the modulation index of an AM signal.
3. Demodulate an AM signal using an envelope detector.
4. Build a multi-station receiver with super-heterodyne front-end.

II. INTRODUCTION

AM or DSBLC (Double Side-band Large Carrier) is a linear analog modulation technique. Given a message $m(t)$, the corresponding AM signal is given by:

$$s(t) = A_c \left(1 + a \frac{m(t)}{\max(|m(t)|)} \right) \cos(2\pi f_c t).$$

Here a is the modulation index. The process is illustrated in Figure. 1.

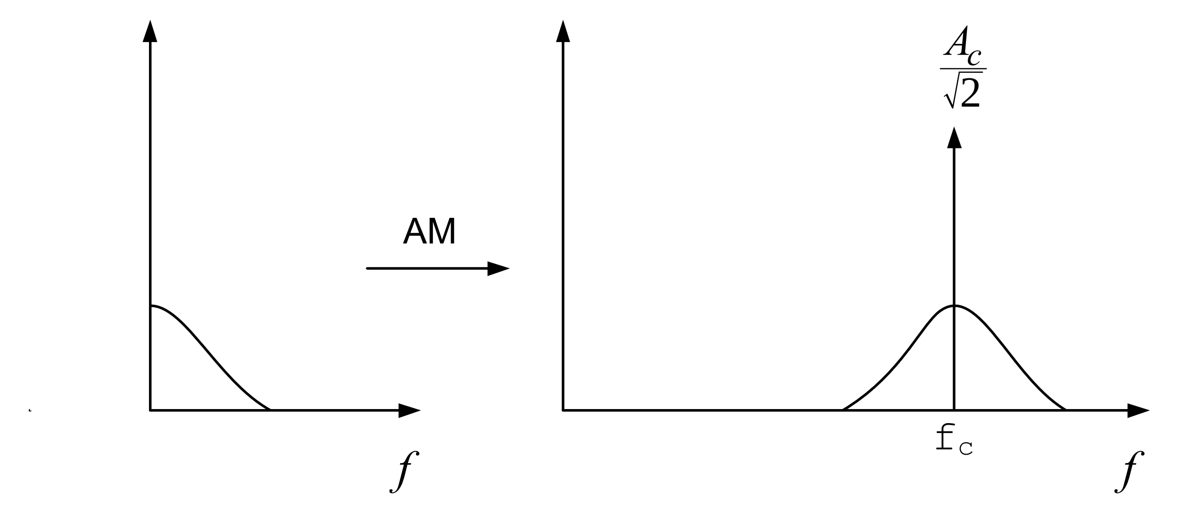

Fig. 1: DSBLC Modulation.

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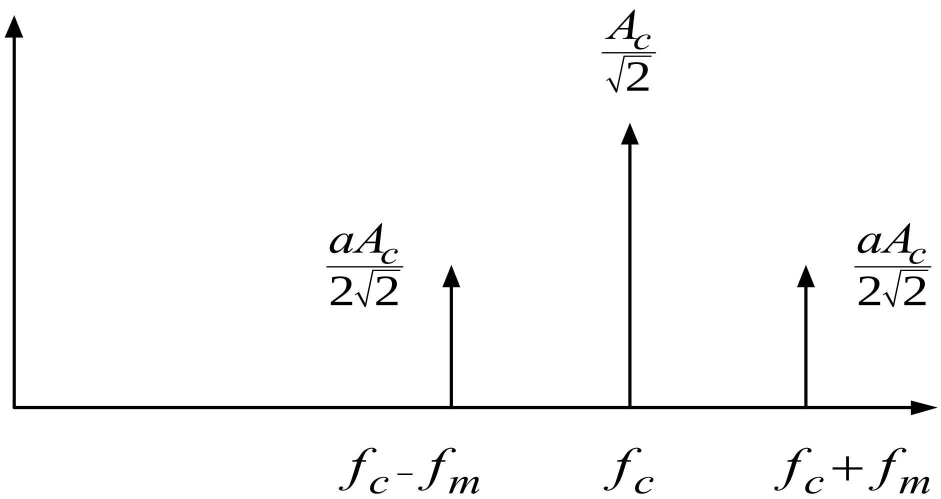

Fig. 2: AM signal with sinusoidal message.

If the message is a tone, the AM signal will be as shown in Figure 2. (RMS values are shown in Figure 2; hence the factor of $\sqrt{2}$.) Furthermore, the spectrum analyzer provides no phase information (it is a scalar radio receiver); it displays the one-sided spectrum. On the other hand, a óVector Signal Analyzerô is capable of processing phase information and is frequently used to analyze digitally modulated signals.

The advantage of DSBLC is that it can be very easily demodulated. However, it is not very power-efficient.

III. PRELAB

1. If $m(t) = A_m \cos(2\pi f_m t)$, show that the AM signal is given by:

$$s(t) = A_c \cos\left(2\pi f_c t\right) + \frac{aA_c}{2}\cos\left(2\pi(f_c - f_m)t\right) + \frac{aA_c}{2}\cos\left(2\pi(f_c + f_m)t\right).$$

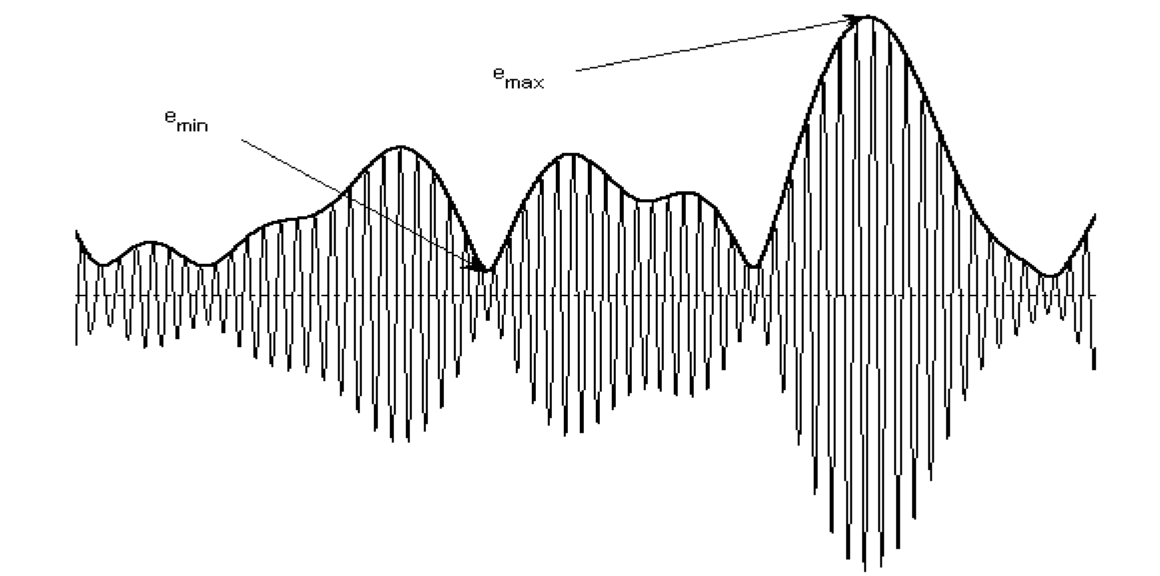

Fig. 3: Band-pass signal and its envelope.

2. In Figure 3, $e_{\max}$ and $e_{\min}$ are the maximum and minimum of the envelope of $s(t)$. Assume that $\max(m(t)) = \max(-m(t))$ and show that the modulation index is:

$$a = \frac{e_{\max} - e_{\min}}{e_{\max} + e_{\min}} \ .$$

3. With Figure 2 as a guide, specify a technique to determine the modulation index from the spectrum analyzer display when the message is a single tone.[1]
Extend the technique to apply to a message that is a sum of two tones at f_{m1} and f_{m2} where the ratio: f_{m2} / f_{m1} is irrational.

4. A technique to determine the modulation index is to generate a trapezoidal pattern using the X-Y mode of your scope. The modulated output is displayed on the vertical, Y, axis and the message signal is displayed on the horizontal, X, axis. The oscilloscope pattern will be similar to that shown in Figure 4.

[1] According to the definition, the modulation index indicates the relative variation of peaks and valleys of the carrier envelope. By just observing $s(t)$ on the spectrum analyzer, all phase information regarding the components of $s(t)$ are lost; and since the phase information determines the relative peaks and valleys of the envelope, it is difficult to measure the modulation index in the frequency domain.

III. Prelab, Question 4 (continued)

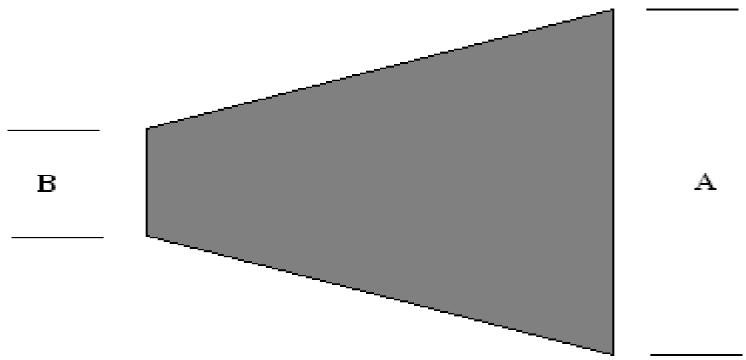

Fig. 4. Trapezoidal Pattern

Use the definitions of the trapezoidal pattern and modulation index to show that the modulation index may be determined from the scope display[2] by: $a = \dfrac{A-B}{A+B}$.

5 a. Draw a diagram of an envelope detector using a diode and one RC section. Explain how it works.

5 b. The values for R and C can be found from $\dfrac{1}{f_c} \ll RC \ll \dfrac{1}{W}$. Here, f_c is the carrier frequency and W is the bandwidth of the message. Why is RC chosen this way?

5 c. What is failure-to-follow distortion? How can you observe it in the lab?

6 a. What is a super-heterodyne radio?

6 b. If the carrier frequency is 93.5 MHz and the intermediate frequency is 10.7 MHz, what are the two possible choices for the local oscillator frequency?

6 c. What are the corresponding image frequencies? (Read the relevant sections of your textbook if necessary.)

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[2] The trapezoidal pattern is a very useful technique to measure the modulation index when a general base-band signal like music or speech is used. In fact, the trapezoidal pattern is used to show if the modulation has any non-linearities or if the modulation index is greater than one. A real world modulator will usually cutoff if the base-band signal gets too large. The result of overmodulation is called splatter.

IV. EXPERIMENT

1. Generating AM Signals

Modulate a 455 kHz carrier with a 1 kHz sinusoid. Use Figure 5 as a guide. Choose the DC offset and the message amplitude for a modulation index is 0.5. Record time and frequency domain displays for the resultant AM signal.

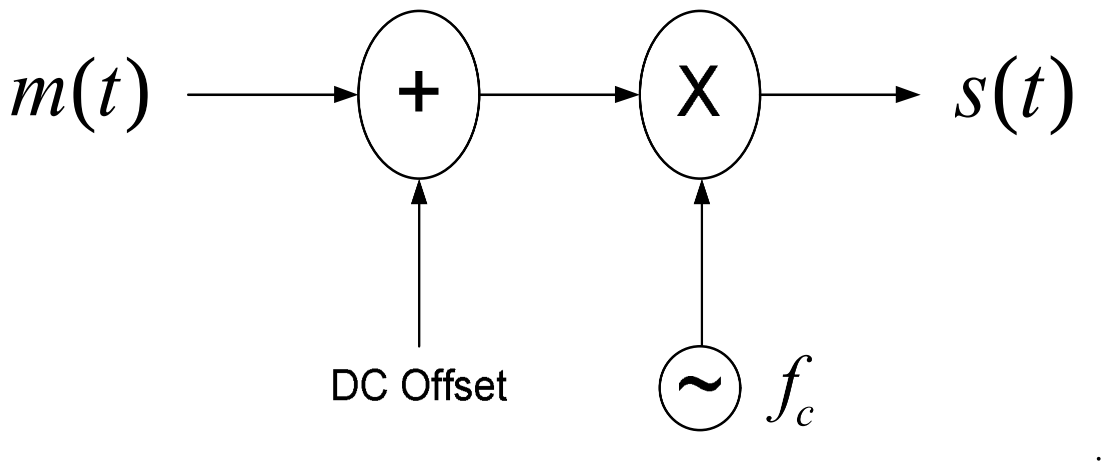

Fig. 5: Generating an AM signal.

2. Measuring the Modulation Index.

Measure the modulation index of the AM signal generated above using the three methods suggested in the pre-lab. They are:

- Observe the AM signal on an oscilloscope and determine the maximum and minimum values of the envelope. Calculate the modulation index as in the pre-lab.
- Generate a trapezoidal pattern by connecting the AM signal as Y-input and the message signal as X-input and measure the modulation index.
- Observe the signal on a spectrum analyzer and deduce the modulation index. Use Figure 2 as your guide.

3. AM Demodulation: Envelope Detector.

3 a. Set up an envelope detector using a diode and RC section.
Choose the R and C values according to the guidelines in the pre-lab.
Observe "failure-to-follow" distortion by adjusting the RC section of the envelope detector. In your report, provide two oscilloscope screenshots, one of the properly functioning envelope detector and a second one demonstrating the failure-to-follow distortion.
Also determine the maximum allowable modulation index.

3 b. Why is the maximum index less than one?
Hint: Think about the turn-on voltage of the diode.

4. Super-heterodyne Receivers[3]

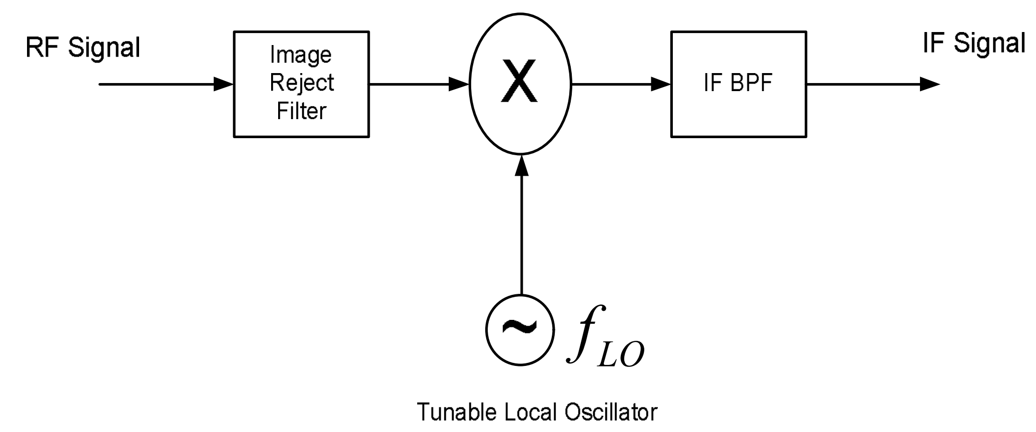

Fig. 6: The super-heterodyne front-end.

A simple super-heterodyne front-end consists of:

a tunable (and not-very-sharp) image-reject filter-amplifier,
a down-conversion stage,
a sharp (high-quality) intermediate-frequency (IF) filter.

The front-end is followed by a demodulator that is designed to work at the IF frequency. For AM, an envelope detector demodulates the signal.

To receive different stations, only the frequency of the local-oscillator (LO) in the down-converter needs to be tuned.[4] The demodulator or the IF filter need not be tuned; they are optimized to work at the fixed intermediate-frequency.

Many applications have standardized IF frequencies:

AM Radio	-	typical bandwidth: 9 kHz with carrier centered at 455 kHz
FM Radio	-	typical bandwidth: 180 kHz with carrier centered at 10.7 MHz ,
TV set (video AM[5])	-	typical bandwidth: 4.5 MHz bandwidth (41.5 to 45.0 MHz) with picture carrier at 45.75 MHz.
TV set (audio FM)	-	typical bandwidth: 50 kHz with carrier centered at 41.25 MHz.

[3] An AM receiver needs to be able to demodulate any of the available AM signals present. The earliest way of doing this was the tuned-RF (radio-frequency) receiver. Tuned-RF receivers had a tunable RF BPF at the front-end that would allow only the desired signal (station) to pass through. The band-passed signal would then be demodulated. Building sharp tunable RF filters is very difficult; tuning the following demodulator stages is nearly impossible for all but the simplest modulation techniques. Such radios were therefore of poor quality.

Most modern radio receivers (including spectrum analyzers, network analyzers, TVs, cell-phones, radios, etc.) are built on the super-heterodyne concept. (Some radio receivers like certain pagers and cell-phones use the homodyne or zero-IF architecture. Look it up on the web or ask your TA about it.)

[4] The image-reject filter needs to be tuned to a limited extent.
[5] Vestigial Sideband is a special form of AM that greatly suppresses the carrier.

4 a. Investigate portable super-heterodyne receiver in the AM-Band.[6]

Create a modulated signal in the AM-Band. Use the circuit of Figure 5 with a 10 volt peak-peak 1 MHz carrier, a 1 kHz message tone, and a modulation index of 0.5. Connect a jiffy-clip cable to the output of the multiplier and lay it on the bench.[7]

Turn on the portable receiver provided and set it to the AM mode.
Tune the receiving frequency to until you hear to find the 1 kHz tone.
Change the carrier frequency to another frequency in the AM band and re-tune.
Adjust the message signal to different frequencies and shapes.

Replace the sinusoidal message with the output of the provided CD player.
With 10 Vpp carrier, adjust the CD volume. Is 0.5 modulation index possible?
Record a typical display indicating the modulation index.
Adjust the receiverôs volume control to hear the music clearly.
Can the radio receive and play music with a 0.1 modulation index?

4 b. Build a super-heterodyne receiver.

Use the front-end shown in Figure 6.with the provided equipment:

Image Reject Filter = Krohn-Hite Band Pass Filter
Multiplier = one of the two wide-band multipliers
IF Filter = 455 kHz BPF
The envelope detector developed in 3, above.

The sum of three amplitude modulated carriers is available on patch-panel jack B. These carriers are at frequencies of 600, 700, 800 and 900 kHz. Using the spectrum analyzer, verify that this is true. Use your super-heterodyne receiver to determine the message signal each carrier. Note that, for a given IF frequency f_{IF} and a given carrier frequency f_C, there are two choices[8] for the local-oscillator frequency f_{LO} corresponding to high-side and low-side injection. These are (respectively)

$$f_{LO} = f_C + f_{IF}$$
$$f_{LO} = f_C - f_{IF}$$

Did you know?

In the zero-span mode, the spectrum analyzer can be used as an AM receiver!
To use this mode, first set the RBW to be **larger** (yes!) than the message bandwidth.
Then, put the SA into zero-span mode.

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[6] The standard AM band spans 540 kHz to 1700 kHz.

[7] An AM radio in the vicinity will be able to pick up the signal. The whip antenna you see on the portable radios in the lab is an FM antenna. The AM antenna is a small loop antenna wound on a ferrite core and is present inside the radio casing.

[8] For a general radio receiver, the choice between the two depends on many factors. For AM receivers, the first (high-side) is invariably used.

Discuss with your TA, if necessary.

V. REPORT

Document all the readings you have obtained and any conclusions you draw in your report. Attach a copy of your lab record to the report. Answer any specific questions asked in the lab manual.

VI. APPENDIX

REFERENCES

[1] R. E. Ziemer and W. H. Tranter, *Principles of Communications*, 5th ed. Hoboken, NJ: John Wiley, 2002. (See reference[1], 3.1.2 Amplitude Modulation PP 106)