EE 160: Principles of Communication Systems
Experiment 3: Amplitude modulation and up-conversion

I. INTRODUCTION

a. Objectives
   i. Generate amplitude modulated (AM) signals in the lab
   ii. Study conventional (DSB-LC) AM signals
   iii. Listen to a conventional AM signal through an AM radio

b. Required reading
   i. Proakis and Salehi, chapter 3

c. List of parts
   i. AM/FM radio with DC adapter

Note: Keep the circuit from Experiment 2 – do NOT dismantle it!!

II. THEORY

II.1 Double-sideband suppressed-carrier (DSB-SC) AM modulation

A double sideband suppressed carrier (DSB-SC) signal u(t) has the form:

$$u(t) = m(t)\cos(2\pi f_c t),$$

where m(t) is the baseband (lowpass) modulating (or message) signal and f_c is the carrier frequency. The spectral density of u(t) is given by

$$U(f) = \tfrac{1}{2} M(f + f_c) + \tfrac{1}{2} M(f - f_c) \qquad \text{(eq. 1)}$$

For the special case of narrowband sinusoidal modulation with $m(t) = \cos(2\pi f_m t)$ and $f_m << f_c$, the DSB-SC signal has spectral density

$$U(f) = \frac{1}{4}[\delta(f + f_c + f_m) + \delta(f + f_c - f_m) + \delta(f - f_c + f_m) + \delta(f - f_c - f_m)] \qquad \text{(eq. 2)}$$

Consequently, the spectrum analyzer should display an <u>upper sideband</u> consisting of a "spike" at the frequency $f = f_c + f_m$, as well as a <u>lower sideband</u> line at the frequency $f = f_c - f_m$. Note that the sideband amplitudes (powers in the spectrum analyzer) will be equal. Figure 3-2 shows a simulated time domain representation of a DSB-SC signal with a sinusoidal modulation, as you might see it on the oscilloscope.

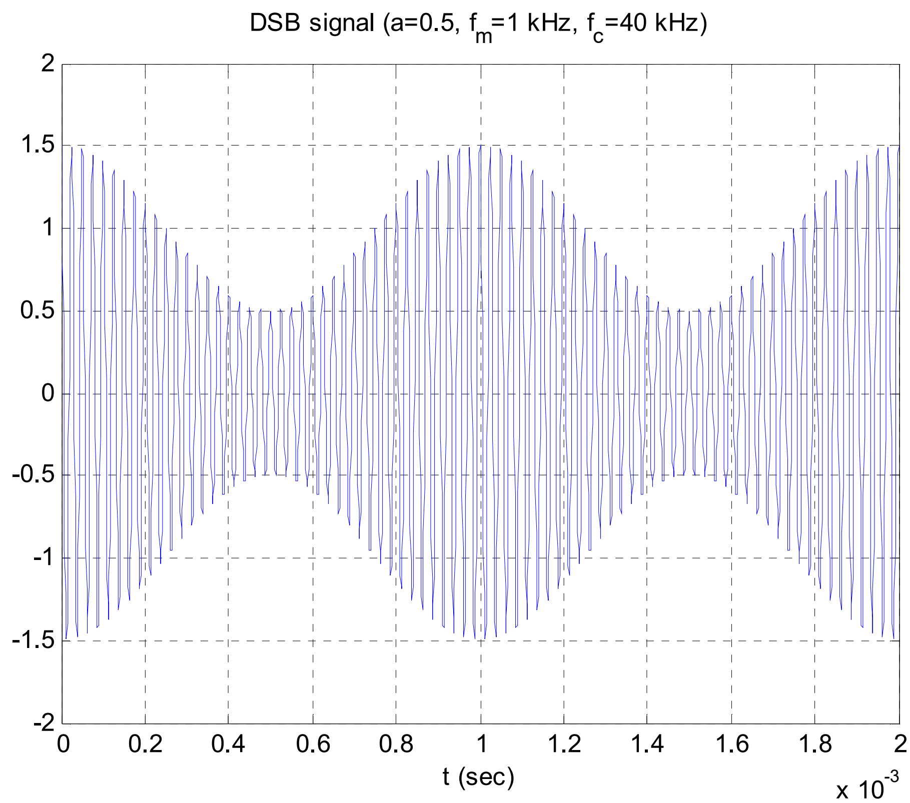

Figure 3.2: A DSB-SC AM signal

Recall from Experiment 2 that the output of a periodic gate sampler contains not only frequency terms like those in Eq. 1, but also similar terms near f =0, $\pm 2f_c$, $\pm 3f_c$, and so on. Also, in Experiment 2, the sampled signal $x_s(t)$ was passed through a low pass reconstruction filter in order to recover the original signal x(t). In this experiment, you will generate a DSB-SC signal by multiplying a message signal by a carrier signal of frequency f_c (recall that multiplication in the time domain is convolution in the frequency domain.) As a result, the only significant difference between the circuits of Experiment 2 and 3 is the absence of a filter at the output.

II.2 Conventional double-sideband amplitude modulation (DSB-AM)

The spectral density for a DSB-SC signal with sinusoidal modulation (eq. 2) does not include terms at the carrier frequency $\pm f_c$. Thus, the name "suppressed-carrier" is used to refer to this type of amplitude modulation. However, by explicitly adding a $\cos(2\pi f_c t)$ term to eq. 1, the general form of a conventional AM (DSB-AM) signal is obtained:

$$u(t) = [A_c + m(t)]\cos(2\pi f_c t), \qquad \text{(eq.3)}$$

with spectral density

$$U(f) = \frac{1}{2}[M(f+f_c) + M(f-f_c)] + \frac{A_c}{2}[\delta(f+f_c) + \delta(f-f_c)]$$

In the lab, the spectrum analyzer display of this DSB-AM signal will not only exhibit the same upper and lower sidebands as the corresponding DSB-SC signal, but it will also include a (usually large) "spike" at the carrier frequency f_c.

For the special case of a narrowband sinusoidal signal m(t), eq. 3 becomes

$$u(t) = A_c[1 + a\cos(2\pi f_m t)]\cos(2\pi f_c t), \qquad \text{(eq. 4)}$$

where a is the modulation index. Figure 3-3 shows a simulated time domain view of a DSB-AM signal with a=0.5.

When a≤1, the value of a can be computed from an oscilloscope display by the formula:

$$a = \frac{E_{\max} - E_{\min}}{E_{\max} + E_{\min}}, \qquad \text{(eq. 5)}$$

where $E_{max}=max[1+m(t)]$ and $E_{min}=min[1+m(t)]$ are the minimum and maximum values of the envelope of the modulated signal *u(t)*, respectively. Although this formula is also valid for overmodulated signals, in which a>1, E_{min} in this case must be interpreted as a negative number. Figure 3.4 shows DSB-AM signals for four values of a.

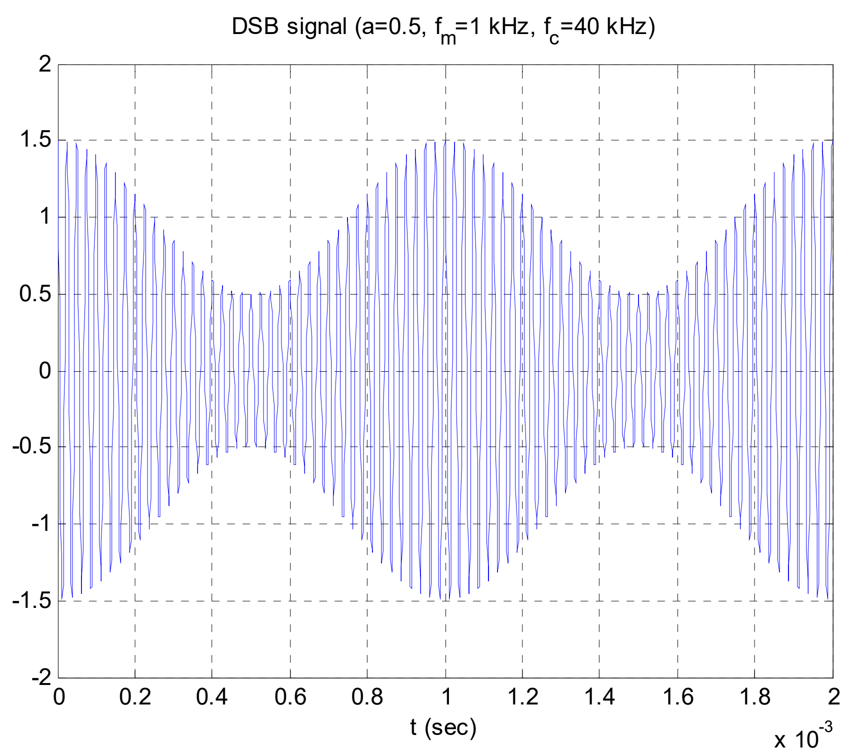

Figure 3.3: A DSB-AM signal

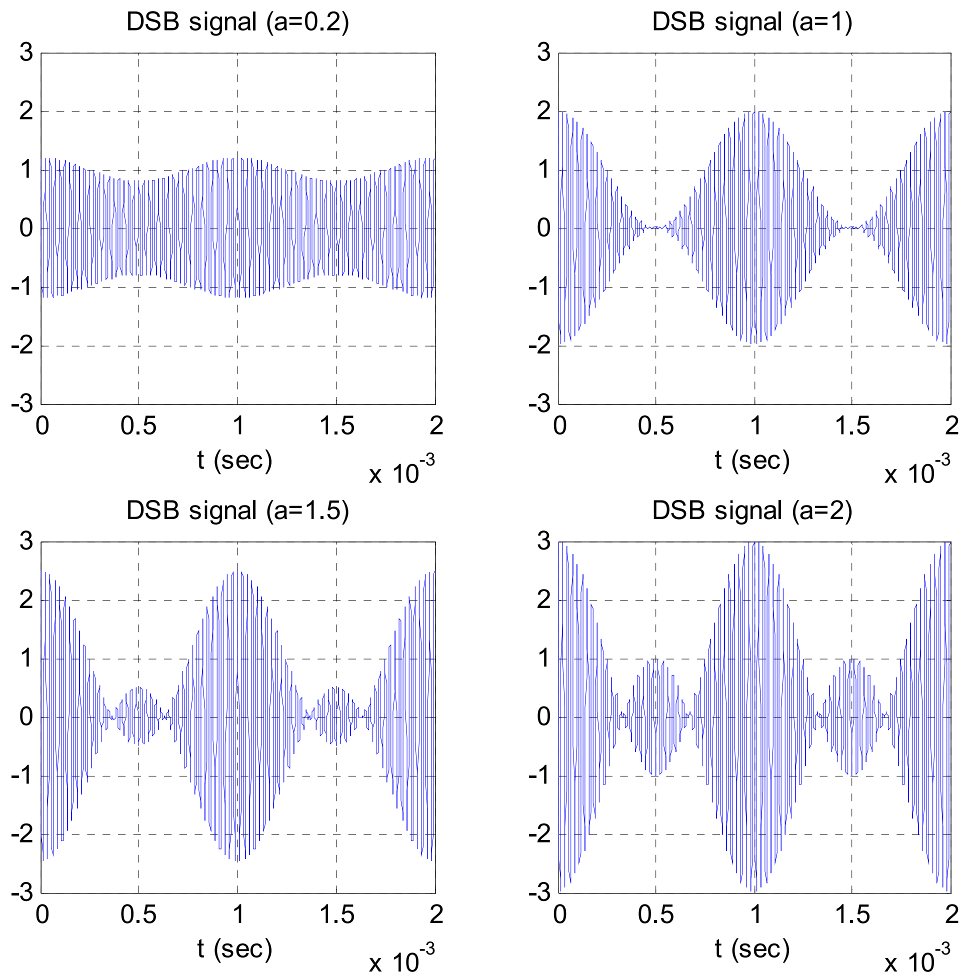

Figure 3.4: DSB-AM signals for various values of modulation index

In a spectrum analyzer display of the DSB-AM signal shown in Eq. 4, the power in each sideband peak will be $a^2/4$ of the power content in the carrier. Thus, the individual sideband power level will be $20 \log_{10} a - 6.02$ dBc. The unit designation “dBc” is a common abbreviation for “dB relative to the carrier.”

III. INSTRUMENTS AND MATERIAL

III.1 Instrument techniques

No new measurement techniques or devices are used in this experiment.

IV. PRE-LAB WORK

IV.1 Sideband power

For DSB-AM modulation with a narrowband sinusoidal message signal, plot the power S in one sideband (in dBc) versus the modulation index a, for $0 \leq a \leq 1$.

IV.2 Matlab script

Download script *DSBAMsignals.m* from the web page of the course. This script was used to produce Fig. 3.4 of this procedure. Modify the script to estimate the percentage of the total power of the sidebands, for values of modulation index a=0.8, a=0.6 and a=0.2. Compare these with the theoretical values derived in class.

V. MEASUREMENTS

V.1 Conventional DSB-AM modulation: Sinusoidal message signal

Set up the output load (impedance) of the signal generator to high. Generate a 20 kHz, 4 $V_{p\text{-}p}$, sinusoidal carrier signal. Verify the voltage using the oscilloscope. Then AM modulate a sinusoidal waveform with a 100% modulation index. Make and record the following measurements:

(1) Capture the oscilloscope display of the modulated signal, labeling its maximum and minimum envelope amplitudes (E_{max} and E_{min} respectively). Compute the modulation index using these measurements.

(2) Vary the modulation index from 20% to 80% in 20% increments. At each modulation index value, record:

   (a) The E_{max} and E_{min} values (with the scope).

   (b) The power levels of the carrier and sidebands with the spectrum analyzer via the ATT-SA circuit. You may want to use the analyzer's markers to directly obtain the relative sideband powers in dBc.

V.2 Conventional DSB-AM modulation: Triangular message signal

With the same carrier signal, AM modulate now with a 1 kHz triangular waveform with a 100% modulation index. Repeat the measurements (1) and (2) indicated in section V.1 above.

V.3 FM modulation

Using the same carrier signal, FM modulate with a 1 kHz sinusoidal waveform and frequency deviation of 2 kHz. Capture the oscilloscope display of the modulated signal as well as the spectrum of the signal (using the spectrum analyzer via the ATT-SA circuit). Attach these to your report. Try other frequency deviation values and observe the effect that this has on the FM signal.

V.4 DSB-LC AM signals on an AM radio

Now that you have produced a modulated signal, you can listen to the message signal on an AM radio, provided that the carrier frequency is within the AM radio frequency band. For this purpose, change the message waveform to produce a 180 Hz sinusoidal and modify the carrier sinusoidal frequency to 1.4 MHz.

Plug in and turn on the AM radio and tune it according to the carrier frequency. Move the antenna close to the signal generator output cable end (red), **without touching it**. You should hear the message signal tone on the radio; if the tone is difficult to hear or if the channel is noisy, move the radio around so that the tone is loudest. Change the message signal to any frequency you desire, within a range and volume that does not annoy your lab mates.

Try changing the carrier frequency to another value between 560 kHz and 1.7 MHz and tune the radio to that frequency.

VI. ANALYSIS OF RESULTS

- Using the data collected in section V.1, step 2.b, use Matlab to plot the single sideband power (in dBc) versus modulation index values. Present these results in your report. Include in the plot the theoretical values.
- How well does the spectrum of the DSB-LC signal compare with the theoretical model?
- How well does your measured relationship of single sideband power (dBc) versus modulation index agree with theory?