ECE 146A: Communication Systems
Lab 3: Amplitude modulation and envelope detection

1 Objective

The goal of this lab to illustrate amplitude modulation and envelope detection using digitally modulated messages.
Equipment: Matlab is available in the workstations in the software lab.
Reading: Amplitude modulation (Chapter 3)

2 Amplitude modulation and envelope detection

1) Generate a message signal $m(t)$ using binary digital modulation with a sine pulse by modifying Code Fragment 2.3.2 to use random bits. Set the symbol time T to 1 millisecond. Take a waveform segment spanning n_s symbols and take its Fourier transform by modifying Code Fragment 2.5.1 (or using the code from Lab 1), choosing the length of the FFT (and hence n_s) so as to get a frequency resolution of 1 Hz. Plot the magnitude squared of the Fourier transform, divided by n_sT, the length of the observation interval. This is an estimate of the *power spectral density (PSD)* $S_m(f)$, which is formally defined later, in Chapters 4 and 5.
2) Repeat the PSD estimation in 1) over multiple runs and average the estimates, choosing the number of runs large enough so as to get a smooth estimate of the PSD. Eyeball the PSD to estimate the bandwidth of the signal (the units should be consistent with our assumption of $T = 1$ ms).
3) Now, generate the DSB signal $u(t) = m(t) \cos 2\pi f_c t$, where $f_c = 10/T$. Choose the sampling rate for generating discrete time samples as $4f_c$. Plot the DSB signal over 4 symbols.
4) Estimate the PSD $S_u(f)$ of the DSB signal generated in 3) by choosing a large enough number of symbols as in 1), and averaging over several runs as in 2). What is the relationship with the PSD obtained in 2)?
5) Repeat 3) and 4) for the AM signal $u(t) = (A_c + m(t)) \cos 2\pi f_c t$, where $f_c = 10/T$ and A_c is chosen to have the smallest possible value that allows envelope detection. As before, choose the sampling rate for generating discrete time samples as $4f_c$. Do you run into difficulty when computing the PSD? Explain.
6) Starting with an AM signal as in 5), implement an envelope detector as follows:
(a) Pass $u(t)$ through an idealized diode to obtain $u_+(t) = u(t) I_{u(t) \geq 0}$.
(b) Pass $u_+(t)$ through an RC filter with impulse response $h(t) = e^{-\frac{t}{RC}} I_{t \geq 0}$. You can use the *contconv* function in Lab 1 for this purpose. Choose the value of RC based on the design rule of thumb discussed in Chapter 3.

(c) Implement a DC block simply by subtracting out the empirical mean from the output of (b). Plot the output of the envelope detector, along with the original message $m(t)$.
7) Repeat 6) for different values of RC (both too large and too small), and comment on how the resulting message estimate is affected by the value of RC.

3 Envelope detector based I/Q downconversion

We know from Chapter 2 that a passband signal can be downconverted to complex baseband by mixing with the cosine and sine of the carrier and then low pass filtering. However, implementing mixers may not be easy at really high carrier frequencies (e.g., for coherent optical communication). Envelope detection, after adding strong locally generated carrier components to the received waveform, provides an alternative approach for downconversion that may be easier to implement in such scenarios. Consider the QAM received signal

$$v(t) = v_c(t) \cos 2\pi f_c t - v_s(t) \sin 2\pi f_c t \tag{1}$$

where v_c, v_s are real baseband messages. The receiver's local oscillator generates $A_c \cos(2\pi f_c t + \theta)$ and $A_c \sin(2\pi f_c t + \theta)$, where θ is the offset between the carrier reference used at the transmitter to generate the QAM signal and the local copy of the carrier at the receiver. Instead of mixing the local oscillator outputs against $v(t)$, we add them to $v(t)$ and then perform envelope detection, as described in 6). That is, we perform the following operations:
- Pass $v(t) + A_c \cos(2\pi f_c t + \theta)$ through an envelope detector to obtain $\tilde{v}_c(t)$.
- Pass $v(t) + A_c \sin(2\pi f_c t + \theta)$ through an envelope detector to obtain $\tilde{v}_s(t)$.

8) For A_c large enough, can you find simple relationships between $\tilde{v}_c(t)$, $\tilde{v}_s(t)$ and the original messages $v_c(t)$, $v_s(t)$? Is there a simple relationship between the complex baseband waveforms $v(t) = v_c(t) + jv_s(t)$ and $\tilde{v}(t) = \tilde{v}_c(t) + j\tilde{v}_s(t)$?
9) Generate v_c and v_s as in 1), using different sequences of random bits, and generate $v(t)$ as in (1), setting $f_c = 10/T$ as in 3). Implement the preceding envelope detection operations, first setting $\theta = 0$. Plot $\tilde{v}_c(t)$ and $\tilde{v}_s(t)$ for A_c "large enough." Also plot for reference $v_c(t)$ and $v_s(t)$. Comment on whether the results conform to your expectations from 7). How small can you make A_c while still getting "good" results?
10) Repeat 9) for $\theta = \frac{\pi}{4}$.
11) Assuming that the receiver knows θ, can you recover estimates of $v_c(t)$ and $v_s(t)$ from $\tilde{v}_c(t)$, $\tilde{v}_s(t)$? Implement these operations and show plots of the estimates and the original waveforms.

4 Lab Report

- Answer all questions and print out the most useful plots to support your answers.
- Write a paragraph about any questions or confusions that you may have experienced with this lab.