THE One Big Hairy Laboratory Project for

EE 2170, Signals and Systems!

Professor Duncan L. MacFarlane

Introduction

EE 2170, the MATLAB laboratory for Signals and Systems comprises on single semester long project: Model a typical Amplitude Modulated (AM) communication link.

This is not as audacious as it sounds. The project is made up of a series of five parts, each readily doable in a week or two. As your group works on the modules (not in any order, and probably iteratively, the TA and I will be happy to provide review and feedback. Use your semester wisely; if you wait to the end of the semester you won't have time to get feedback and you'll be overwhelmed by the scope of the project.

At the end of the semester your grade will be determined by a single final report that presents and critically analyzes the link, your work and your results.

A question on this project will also appear on the final exam.

The System

In Figure 1 is a block diagram of a generic communication system. There is an input signal (the message) m(t) and the output signal (the received message), m′(t). I use the prime on the output to remind us that while we would like m′(t) to be exactly m(t) there will be distortion and impairments that make m′(t) only approximately like m(t).

The link itself comprises a transmitter, a channel and a receiver. Note the intermediate signals x(t) and y(t).

I'll discuss each element in turn.
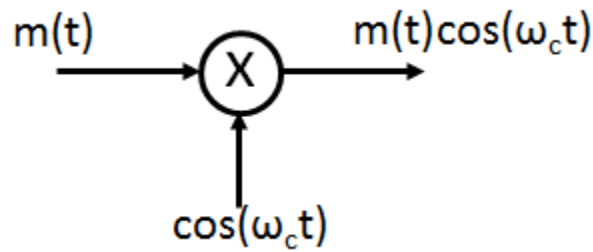
Figure 1

The Message Signal:

For the purposes of this project, think of the message signal as voice (2-2000 Hz). In your work, you should consider different message signals. Starting off, you might consider something very simple, like a sine wave. Then you might try something more complicated such as a square wave, a triangle wave, or a pulse train. Finally, if you are inspired you might record your voice into your computer and use that as the message signal. It is an interesting tenet of information theory that the more information contained in a message signal, the more random that signal appears in the time domain. However, the frequency content of such a signal might still be quite well defined.

Actions:

- Get used to the MATLAB methods of working with signals, (Chapter 1) including: delays and time shifts, scaling in amplitude and frequency, and in general, the various transformations of an independent variable.

- Plot the time domain and frequency domain representations of different m(t)'s. Try sines and cosines, square or triangle waves, and your own voice.

- Explain in detail the plots.

- Discuss quantitatively, issues of sampling rate (number of samples per period) and record length (number of samples).

The Transmitter

The Transmitter in this project consists of a simple amplitude modulator shown in Figure 2. The message signal is 'mixed' (multiplied)

Figure 2

by a carrier signal, $\cos(\omega_c t)$. Typically The carrier frequency, ω_c, is much larger than the highest frequency in the message signal m(t). The mixer moves the information in m(t) to the frequency band around ω_c. Reasons to do this include noise reduction and the ability to take advantage of the propagation properties of high frequency signals.

Actions:

- Plot the time domain and frequency domain representations of x(t) for different m(t)'s.

- Explain in detail the plots. In frequency space, what exactly happens to the message signal when it is multiplied by the carrier? Is this a linear or nonlinear transformation?

- Discuss quantitatively, issues of sampling rate (number of samples per period) and record length (number of samples).

- AM-QAM (quadrature amplitude modulation) allows two message signals to share the same channel. There are two local oscillators, one a $\cos(\omega_c t)$ assigned to one message signal, the other a $\sin(\omega_c t)$ which is assigned to the second message signal. This scheme works because sines and cosines are orthogonal to each other.

The Channel

The medium between transmitter and receiver is termed the channel. It is fair to say that the characteristics of the channel define the design of the link. A

good communication engineer overcomes the specific impairments a given channel in the most economical manner, trading off signal-to-noise for capacity or distance.

Thus channels can be brutal on a signal. An antenna that broadcasts a signal a few km will see an attenuation of 10^{-6} (-60 dB) due to diffraction alone. In a wireless point-to-point link, even the wind can distort and steer the beam off target. Wireline (copper – twisted pair and coaxial cable) suffer, in addition to attenuation, from dispersion; different frequency components of the transmitted signal propagate at different velocities, stretching the signal in time. Fiber optic links are lossy (25dB/100km), dispersive and also nonlinear.

Actions:

- Model some simple channels: Transfer functions of 1 (a channel that does nothing to the signal), with delay, with attenuation, with dispersion, and with delay, attenuation and dispersion.

- Harder channels include nonlinearity ($y(t)=x(t)+ax^2(t)+bx^3(t)$) and fading. These impairments can also be modeled.

- Plot the time domain and frequency domain representations of $y(t)$ for different m(t)'s.

- Explain in detail the plots. In frequency space, how exactly do the different channels act on the input x(t).

The Receiver

A powerful and easily modeled receiver for the AM link comprises another mixer followed by a low pass filter (LPF). The arrangement is shown in Fig. 3. You will want to look at y(t) and the output of the mixer, w(t), in the time and frequency domains. That will tell you why you need the low pass filter, and also, what the design (cutoff frequency) of that low pass filter needs to be.

Matlab provides a number of options for implementing the low pass filter, and it probably doesn't matter too much which one(s) you select. You could also implement the low pass filtering as a convolution, or a rolling average.
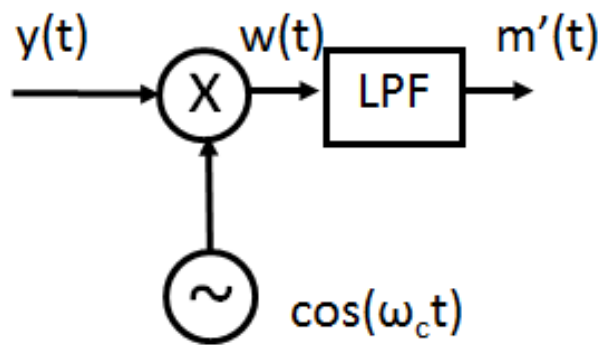

Figure 3

Another very real issue to include in the model is noise in the system. Noise is actually a very rich and, at times, difficult area of study. But that doesn't mean we can't begin with some simple formulations here. At its core, noise is a random process. Hence it should come as no surprise that noise is typically created in Matlab using the random number generator. This topic of noise is appropriately included in this section on the receiver because, in a model, noise is injected (added) at the end of the channel, just before the receiver. This is when the signal is weakest and most vulnerable.

Actions:

- Plot the time domain and frequency domain representations of y(t), w(t) and m'(t).
- Explain how the mixer works and then why the LPF is needed.
- What happens if the local oscillator at the receiver is detuned in frequency or phase from the local oscillator at the transmitter.
- Play around with different filter choices.
- Inject different levels of noise (Signal-to-Noise Ratio; SNR).
- An AM-QAM receiver has two local oscillators, one a $\cos(\omega_c t)$ assigned to recover one message signal, the other a $\sin(\omega_c t)$ which is assigned to recover the second message signal.

Summary and Logistics

You may work in teams of 2 or 3 people; one report per team.

On the last day of lab you will demo your models and will also submit a final report with copies of your code. In addition to the Matlab code, you will also want to explore Simulink, which is a really nice GUI for these system level analyses. You should document this work as well.

The final report should contain rich discussion and interpretation of your results. Extensive examples, sensitivity studies, summary graphs and commentary of your explorations will impress me.

The reports should be of professional quality.

The Table below outlines different activities in m(t), Transmitter, Channel and Receiver. The activities are sorted by level of difficulty, green-to-red. To get an A, a project should have at least two "orange" activities. To get a B, a project should have at least one orange activity. Implementing "red" activities may win you extra credit in EE2370.

Remember, I would like everyone to get an A.

m(t)	Transmitter	Channel	Receiver
sinusoid	Simple mixer AM	Transfer function =1, the channel does nothing.	Simple mixer and LPF
Square waves, triangle waves, pulse trains		Attenuation,	-Simple mixer out of phase or out of frequency -advanced filter
Voice (recorded)	AM-QAM Two m(t)'s, two mixers out of phase	-Attenuation plus Dispersion -Nonlinearity	AM-QAM receiver to demux the two signals.
Psuedorandom pulse trains		Channel fading with random fades	Noise injected before receiver