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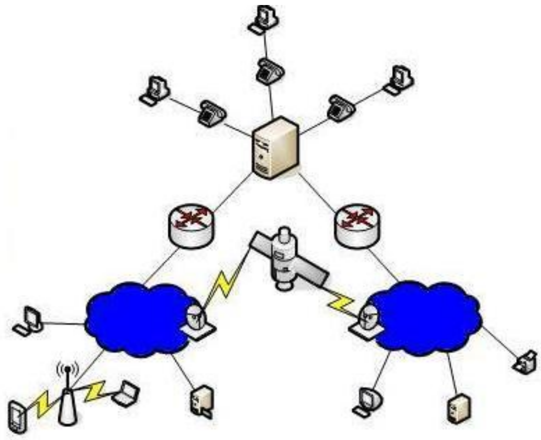

# EECE 442L – Communications Laboratory

## Experiment on
## Amplitude Modulation and Demodulation

Version: August 2009

# Amplitude Modulation and Demodulation

## OBJECTIVES

- Review the basic concepts of amplitude modulation and demodulation.
- Demonstrate and analyze the behavior of various amplitude modulation and demodulation schemes.

## PREPARATION EXERCISE FOR AMPLITUDE MODULATION EXPERIMENT

In this document students are offered a series of exercises to prepare for an experiment on amplitude modulation. A brief introduction to the subject is given with an overview table of key concepts. It is assumed that students are already familiar with the subject but need to refresh their knowledge. To this end, they are guided through a set of simulations using a demonstration program, provided as a LabVIEW VI file.

### A. INTRODUCTION

*Analog Modulation* is the process whereby an analog message signal, occupying a limited bandwidth at or near 0 Hz (baseband), is transformed and shifted to a frequency band around a carrier frequency usually much higher than the frequencies of the baseband. Varying the instantaneous amplitude of the sinusoidal carrier signal with the message signal leads to *amplitude modulation (AM)*. We may also vary the instantaneous phase or frequency leading to *phase or frequency modulation (FM)*. Both are sometimes referred to as angle modulation.

Simultaneous transmission through the same medium or transmission line of multiple message signals is achieved by applying different carrier frequencies to each message such that each modulated signal occupies a distinct slot in the frequency spectrum. Before transmission these signals are superimposed. This whole process is called (frequency) multiplexing. For wireless transmission, an antenna is needed. The size of the antenna must be consistent with the wavelength of the modulated signal. At higher frequencies, the wavelength will be shorter and, thus, the antenna size will be smaller.

**Table 1:** Key concepts.

| *Concept* | **Definition / Explanation** |
|---|---|
| Message signal | Signal that contains information to be transmitted, such as audio (speech, music), video, and computer data. |
| Message signal in time domain | m(t) |
| Message signal in frequency domain (spectrum) | M(f) |
| Carrier Wave | Sinusoidal signal with parameters amplitude $A_c$, frequency $f_c$, and phase $\varphi_c$. |
| Modulated signal | Signal derived from the carrier wave by varying the instantaneous amplitude, frequency, or phase as a function of the message signal. |
| Modulated signal in time domain | s(t) |
| Modulated signal in frequency domain (spectrum) | S(f) |
| DSB-LC modulated signal in time domain | $s(t) = (1 + k_a m(t))\, A_c \cos(2\pi f_c t)$ |
| DSB-SC modulated signal in time domain | $s(t) = m(t)\, A_c \cos(2\pi f_c t)$ |

## B. SIMULATIONS WITH DEMO-VI

### B.1 DSB-LC

There are several variants of AM. We will explore these using the “**eh_Demo_AM_ DSB _SSB.vi**” file. In this VI you can supply a variety of message signals and vary several parameters. Message and modulated signals are displayed in time and frequency domains. The common form of AM is DSB-LC (double sideband-long carrier). LC indicates that the carrier as such is present in the signal to be transmitted. To this end, we add a constant (DC) signal to the message signal and multiply with the carrier signal.

#### B.1.1 DEMONSTRATION WITH A SINGLE TONE MESSAGE

On the front panel use the following settings for a demonstration:

| **Quantity/Setting** | **Value** |
|---|---|
| *Choice of message signal* | function |
| *signal type* | Sine Wave |
| *amplitude* | 1.0 |
| *Frequency (Hz)* | 500 |

| | |
|---|---|
| *AM modulation type* | DSB |
| *modulation index* | 1 |
| *carrier frequency (Hz)* | 5000 |
| *suppress carrier* | (F)alse |

Observe the time domain signal. By inspection it is obvious that the envelope of the carrier signal is shaped by the message signal. Because of this property, demodulation is very simple as we will see later on. By inspection, it is also clear that the amplitude of the message must not be greater than the amplitude of the carrier in order to maintain this property. Vary the modulation index and observe how the time domain signal changes shape. For what values of m do we keep an envelope with the shape of the message?

As mentioned, a modulated signal should occupy a certain frequency band. It is therefore important to observe the spectrum after modulation. Vary the modulation index and observe how the spectrum varies. Explain the spectrum and identify the components. Change the message signal frequency to 1000 Hz and observe the change in the spectrum. What do you expect to happen if we now increase the carrier frequency to 8000 Hz? Verify.

### B.1.2 A FREQUENCY SWEEP MESSAGE

A single tone message may be of interest for testing and initial understanding. In practice, message signals occupy a frequency band. A controlled way of obtaining such a message signal is to 'sweep' the frequency of a sinusoidal signal. Our demo front panel offers the choice of such a signal for a controlled duration. We can set the initial and final frequencies as well as the initial and final amplitudes. Set the following values:

| Quantity/Setting | Value |
|---|---|
| *Choice of message signal* | Freq sweep |
| *Duration (s)* | 0.01 |
| *fstart (Hz)* | 200 |
| *fend (Hz)* | 1000 |
| *Astart* | 1 |
| *Aend* | 1 |
| *AM modulation type* | DSB |
| *modulation index* | 1 |
| *carrier frequency (Hz)* | 8000 |
| *suppress carrier* | (F)alse |

Make sure that the time range on the plots of *m(t)* and *s(t)* is between 0 and 0.01 s. We can see clearly how the frequency of *m(t)* varies continuously from a low to a high value as set on the front panel. Verify that M(f) is a smooth continuous function with significant values between fstart and fend. We observe more clearly that s(t) is formed by varying the envelope of a sinusoidal carrier with m(t). Finally, describe and explain S(f). Compare the sidebands in S(f) with M(f).

#### B.1.3 AN ARBITRARY MESSAGE

In practice we will not always encounter controlled signals as above; rather signals will appear to be arbitrary. If we select 'message' as the choice of message signal there is a set of seemingly arbitrary signals available. We will observe AM of such signals by setting the following values on the front panel:

| Quantity/Setting | Value |
|---|---|
| *Choice of message signal* | message |
| *Message number* | 2 |
| *AM modulation type* | DSB |
| *modulation index* | 0.2 |
| *carrier frequency (Hz)* | 20000 |
| *suppress carrier* | (F)alse |

In the plot of *s(t)* zoom in to verify how the carrier envelope follows the message signal. Adjust the scales for *M(f)* and *S(f)* to observe the complete spectra. Compare the sidebands in S(f) with M(f). Repeat this observation with different message numbers.

### B.2 DEMODULATION OF DSB-LC

Since the envelope of the modulated carrier follows the shape of the message signal, all we have to do for demodulation is to detect this envelope. A simple non-linear circuit can achieve this detection. Explain how the circuit in Figure 1 functions. What are the design considerations for the time constant?

During the lab you will build an envelope detector using functions available in LabVIEW. This detector is based on selecting the maximum values of the modulated signal. How do you expect the output of the detector to look like if the input was an over-modulated signal?

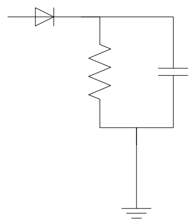

**Figure 1:** Envelope detector to demodulate DSB-LC.

## B.3 DSB-SC

DSB-LC may be easy to detect, it is not efficient in bandwidth and power. If we suppress the carrier we obtain a DSB-SC (suppressed carrier) signal. In the front panel we have the option of suppressing the carrier. Repeat the single tone exercise, but now with the carrier suppressed. Observe again the time domain signals and corresponding spectra.

If we compare this spectrum with that of the message baseband, we see that the spectrum has merely shifted by $\pm f_c$. Properly expressed the message spectrum has been convolved with the spectrum of the carrier ( $\delta(f+f_c) + \delta(f-f_c)$ ), which corresponds to the multiplication of the message signal with the cosine carrier in the time domain. If it is not possible yet to view the complete spectrum on the front panel draw this spectrum for yourself to demonstrate this part of the modulation process.

We may repeat this operation and obtain replicas of the message spectrum at $f = \{-2f_c, 0, 2f_c\}$. A low-pass filter can now select the spectrum replica around $f = 0$ and the original message signal is recovered. This method of demodulation is called coherent detection.

## B.4 SSB

In the previous step we have saved on power, but not on bandwidth. From the spectrum plots it is clear that there are two sidebands which are completely symmetric. Both contain the same information and if we omit one of these sidebands we should still be able to recover the original message entirely at the receiver end. Use the demo VI again to observe SSB time domain and frequency domain plots. Can we apply coherent detection?

## B.5 Note on baseband modulation and upconversion

LabVIEW provides us with a Modulation Toolkit, containing many VI's with different functions related to communications. Many types of modulation schemes are available. In the LabVIEW approach, modulation is separated in two steps: baseband modulation and upconversion. For a complete and correct modulation process baseband modulation must be described in terms of a 'complex envelope', i.e., a signal represented as a complex quantity:

$$g(t) = g_I(t) + j\,g_Q(t)$$

Depending on the type of modulation, $g_I(t)$ and $g_Q(t)$ may have different forms and are a transformation of the message signal. To obtain the modulated signal $u(t)$ at a carrier frequency $f_c$ we apply 'upconversion' as follows:

$$u(t) = g_I(t)\cos(2\pi f_c t) - g_Q(t)\sin(2\pi f_c t)$$

The corresponding description the frequency domain is written as:

$$U(f) = G_I(f - f_c) + G_I(f + f_c) + G_Q(f - f_c) - G_Q(f + f_c)$$

We will now illustrate these concepts using SSB as an example. Usually SSB is described in the frequency domain as removing one of the side bands and maintaining the other sideband (LSB or USB) in the spectrum of an AM modulated signal around a carrier frequency. In other words we multiply the spectrum with a unit step function shifted by $\pm f_c$. The procedure to achieve such a spectrum with baseband modulation and upconversion is as follows.

### B.5.1 Baseband modulation

The quantity $g_I(t)$ is set equal to the message signal. $g_Q(t)$ is a transformation such that its spectrum $G_Q(f)$ is related to $G_I(f)$ by $G_Q(f) = \mathrm{sgn}(f)G_I(f)$. The corresponding operation in the time domain is the Hilbert transform: $g_Q(t) = j\int \frac{1}{t} g_I(t)dt$. For example, with a single tone message $m(t) = A_m\cos(2\pi f_m t)$ we obtain the following complex baseband modulation signal: $g(t) = A_m\left[\cos(2\pi f_m t) + j\sin(2\pi f_m t)\right]$. For a more general message signal with a certain band limited spectrum the spectrum of the baseband modulated signal $G(f)$ is shown in Figure 2.

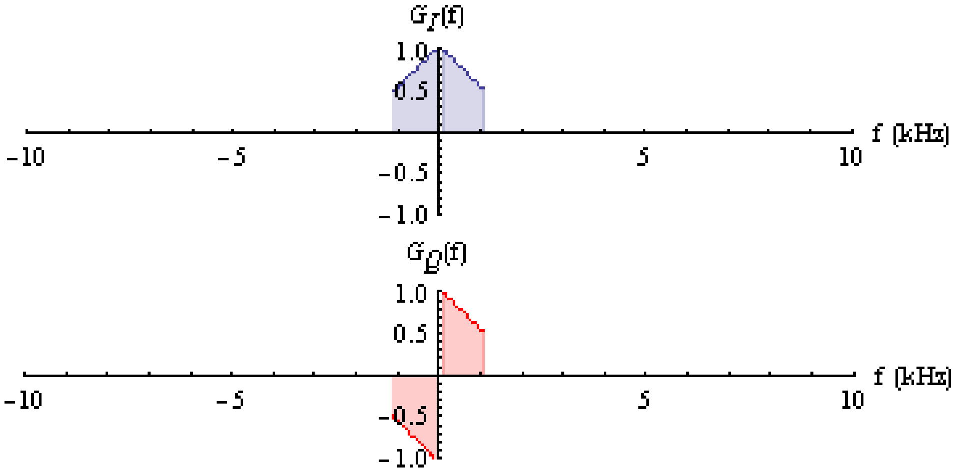


**Figure 2:** Spectrum of SSB at baseband, real and imaginary parts.

### B.5.2 UPCONVERSION

Above we indicated the procedure for the upconversion in both time and frequency domains. For our single-tone message signal we found $g(t) = A_m\left[\cos(2\pi f_m t) + j\sin(2\pi f_m t)\right]$, the up converted signal is then written as:

$$u(t) = A_m\left[\cos(2\pi f_c t)\cos(2\pi f_m t) - \sin(2\pi f_c t)\sin(2\pi f_m t)\right] = \cos\left(2\pi(f_c + f_m)t\right)$$

So there is only one frequency component at $f_c + f_m$, which agrees with what we expect in a SSB-USB modulated signal. In the frequency domain the parallel process is illustrated with the spectra in Figure 2 where the real part is convolved with the spectrum of a carrier at 10 kHz and the imaginary part with the quadrature companion as shown in Figure 3. After the convolution step the resulting spectra are added and yield the total SSB-USB spectrum.

Students that want to explore this issue further may build a simple VI using the VIs for AM and upconversion and examine the waveforms produced. Try to answer the question what we should change in the cases above to generate an SSB-LSB modulated signal.

**For more background information on amplitude modulation and demodulation, check Sections 3.1 and 3.2 in [1] and/or Sections 3.1-3.7 in [2].**

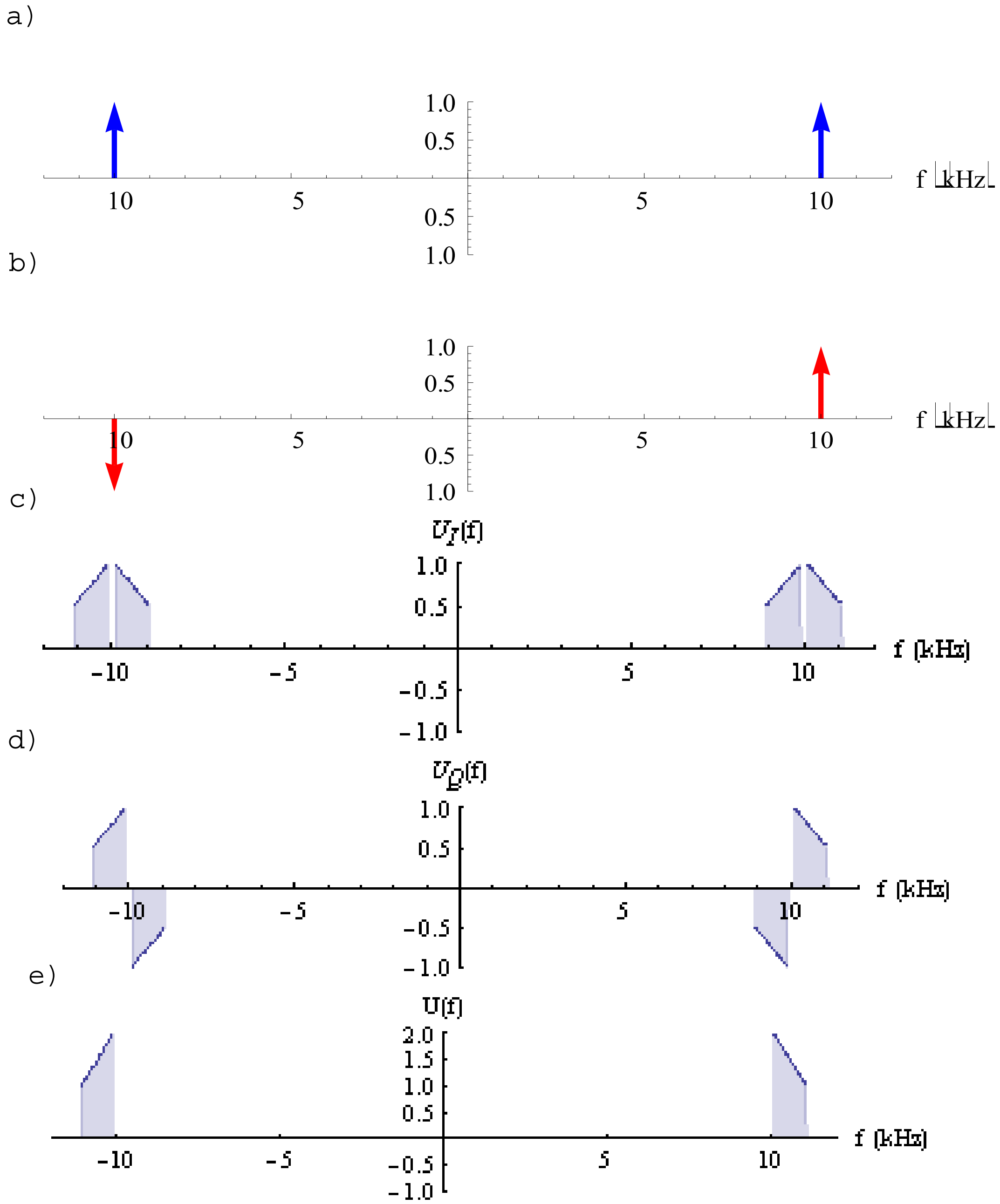


**Figure 3:** Upconversion process in frequency domain. In a) and b) we see the spectra of the in-phase and quadrature components of a carrier wave at 10 kHz. In c) and d) we see respectively the convolution of $G_I(f)$ and $G_Q(f)$ with the carrier components in a) and b). Note that also the spectrum in d) is now real. In e) we have added the spectra of c) and d), resulting in a SSB-USB spectrum.

## EXPERIMENT DESCRIPTION

### GENERAL RULES

- If you open a VI and are not asked to do any changes in it, then close it without saving changes by clicking on "Defer decision".
- Save VIs as ***[GroupID]_name of VI.vi.***
- Save plots as ***[GroupID]_Question number.jpg***. For questions with more than one plot, append extra info to the name to differentiate between the plots.
- Remember to zip and upload only the files you created without the ones given to you in "AM.zip".

### PART I: PROCEDURE AND ANALYSIS: DSBC-SC MODULATION/DEMODULATION

***Q.1 Why do we need to modulate a signal?***

***Q.2 How does modulation affect the antenna size?***

Implement a DSB-SC amplitude modulator. Assume the carrier and the modulating signals to be sinusoidal.

**a)** Use the NI-FGEN to generate a sinusoidal analog signal of frequency *20 KHz* and amplitude *1V*. This will be your message signal *m(t)* (modulating signal). You can access the NI-FGEN by ***Start>>All Programs>> National Instruments>>NI FGEN>>FGEN Soft Front Panel***. Set the required frequency and amplitude then press .

**b)** Start Lab VIEW and create the Block diagram shown in Figure 4. Before completing the whole diagram, finish first the part with the NI-scope and verify it.

**c)** Use the cable supplied by the Lab Instructor to connect Channel 0 of the AWG to the input of the digitizer.

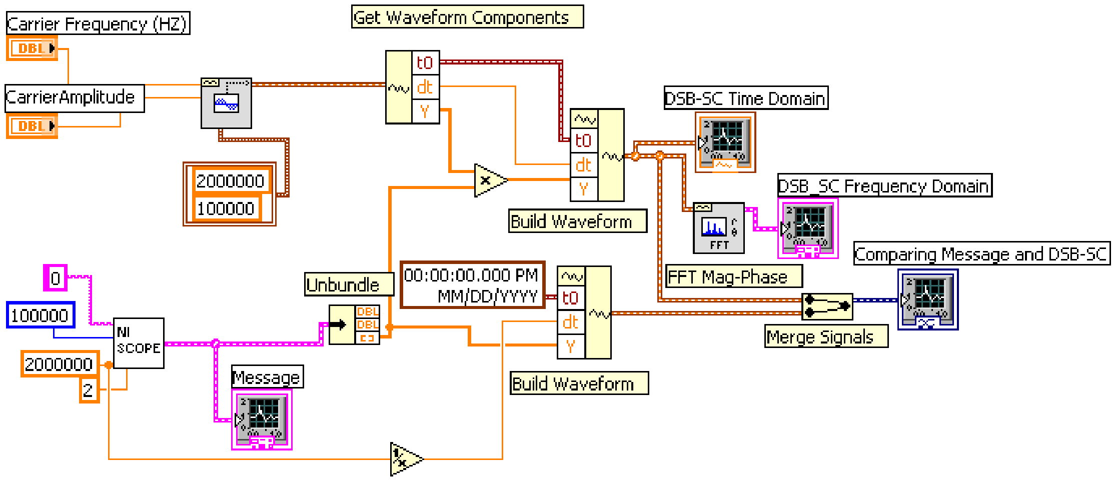


Figure 4: DSB-SC Amplitude Modulation VI Block Diagram.

**d)** Download “ni-Scope.vi” and use it to load the modulating signal to LabVIEW. Set on the Front panel the following parameters:

| | |
|---|---|
| *Channel* | 0 |
| *MinRecordLength* | 100,000 |
| *MinSamplingRate* | 2 M |
| *VerticalRange* | 2 V |

**e)** Double click on “NI SCOPE” and set the input *resource name* of “NI SCOPE INIT” to “DAQ::1” or “DAQ::2” according to what is specified on the PXI.

**f)** Use the “**SineWaveform**” VI to generate a carrier wave. Create user control knobs in the front panel for the carrier frequency and amplitude.

- In your block diagram, add the necessary functions and mathematical manipulations in order to display the time and frequency domains of the DSB-SC AM modulated signal.

**g)** Save your VI as “**DSB-SC_AM_Mod.vi**”.

### *Q.3 Write the equation of a DSB-SC modulated signal.*

### *Q.4 Explain the Block Diagram in details.*

***Q.5 Fix the carrier to 1V amplitude and 200 KHz frequency. Comment on the shape (frequency and amplitude) of the obtained signal.***

***Q.6 Can we use envelope detection for demodulating the DSB-SC modulated signal? Explain.***

***Q.7 Is there any limitation on the amplitude of the modulating signal. Explain.***

***Q.8 Suggest a method for demodulating the DSB-SC AM modulated signal.***

Apply your method to “**DSB-SC_AM_Mod.vi**” to demodulate the DSB-SC AM modulated signal by adding the necessary blocks and functions. Save your VI as “**DSB-SC_AM_Demod.vi**”.

**PART II: PROCEDURE AND ANALYSIS: DSB-LC MODULATION/DEMODULATION**

***Q.9 Write the equation of the DSB-LC modulated signal.***

Implement a DSB-LC amplitude modulator. Assume the carrier and the modulating signals to be sinusoidal.

a) Create a modified version of “**DSB-SC_AM_Mod.vi**” in order to create a real DSB-LC signal.

b) Let the message signal be a sine wave of frequency 20 KHz and amplitude 0.1V, and set amplitude sensitivity($k_a$) to *2*.

c) Create an indicator $m = k_a A_m$ (modulation Index) in the front panel.

*Hint: To find* $A_m$ *use “Array Max & Min”.*

d) Save the following VI as “**AM_MOD.vi**”.

***Q.10 Increase the amplitude of the modulating wave. What is the maximum value of $A_m$ ($A_{max}$) for which the envelope can be recovered completely?***

***Q.11 How does m affect the envelope of the modulated signal? Generate and save time domain plots for m=0.3, m=1, and m=1.3.***

***Q.12 At what value of m will the modulated signal become “overmodulated”?***

***Q.13 What is coherent detection? Give an example of a coherent detection technique for AM.***

Demodulate the AM modulated signal using envelope detection. The following is a list of some useful hints:

a) Use the waveform "**Peak Detection**" VI function to detect the peaks of the modulated signal and set its input *Peaks/valleys* to Peaks.
b) Use the "**Build Waveform**" VI to rebuild the original Signal. You should choose the appropriate 'dt' to build the original waveform and which is equal to the period of the carrier signal, i.e., $(1/carrierfrequency)$.
c) Note: the number of samples taken from the modulating signal should be equal to that of the carrier signal.

Set on the Front panel the following parameters:

| | |
|---|---|
| $f_c$ | *500 kHz* |
| $f_m$ | *20 kHz* |
| $m$ | 0.5 |

***Q.14 Obtain and save plots for the original and demodulated messages in the time domain.***

***Q.15 Does the demodulated message look as you expected? Comment on the effectiveness of the peak detector demodulator.***

***Q.16 Increase the carrier frequency $f_c$ to 1.2MHz. Comment on the error obtained.***

## REFERENCES

[1] J. Proakis and M. Salehi, Communication Systems Engineering. Prentice-Hall, 2nd edition, 2002.

[2] S. Haykin, Communication Systems. John Wiley & Sons, 3rd edition, 1994.