Analog and Digital Communications

2^{nd} Year Electronic Laboratory

Imperial College London

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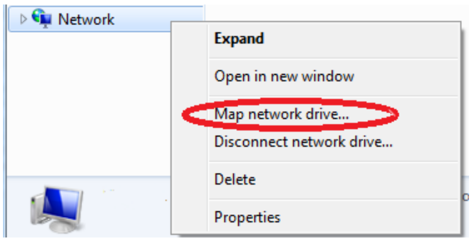
Lab 2: AM Simulation and USRP

In this lab you will build AM and FM communication system simulators. In order to achieve this, you will learn how to use sub-VIs in the LabView environment.

Open **LabVIEW Communications Design Suite** and create **a new project** called “**Lab2**”. All the files created for solving the following exercises should be included in the Lab2 project.

Some files/VIs that will be used in this and subsequent labs have been provided to you. To access these files, right click on the “Network” icon under “Computer”, and then click on “Map network drives” (as shown in the figure on the right). In the window that opens, type the following address in the “Folder” field: **\\ic.ac.uk\group\ee_labs\commslabs**. Then click Finish.



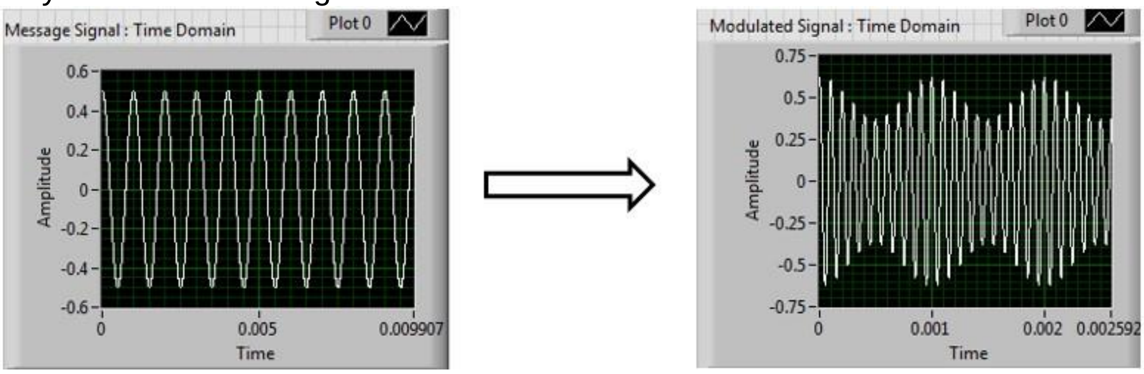
Note: To use any of these files/VIs in any project, download the specific files/VIs from the server and save them in the same folder as the project. If you refresh the Files pane in Labview, with the project open, you will see these files/VIs appear under the project.

Exercise 1: AM Modulator

In the first part of this lab you are going to build an AM modulator. Recalling the theory of AM, the standard equation for modulating a single tone is given by:

$$\boldsymbol{s(t) = [A_c + A_m \cos(2\pi f_m t)]\cos(2\pi f_c t)} \text{ ,}$$

where A_m and A_c are the amplitudes, and f_m and f_c are the frequencies of the message signal and the carrier waveform, respectively. An example of the application of this modulation is shown in the following figure, with the message signal given on the left and the modulated signal on the right. The envelope of the modulated signal is generated by the (shifted) message signal that has a lower frequency than the carrier signal.



Instructions:

1. Create a new VI called “**AM.gvi**”.
2. Create two sine waveforms by using the “**Sine Waveform**” module in the Diagram window. These functions will be used to generate the message and carrier waveforms. Create and populate the values of the necessary terminals of the waveform generators according to the following table.

	Message Signal	**Carrier Signal**
Frequency	1kHz (Control)	10kHz (Control)
Phase	90˚ (Constant)	90˚ (Constant)
Amplitude	Message Amplitude (Control)	Carrier Amplitude (Control)
Sample rate	200k (Control)	200k (Control)
Samples	1000 (Control)	1000 (Control)

3. Obtain the power spectrum of the message signal (remember the waveform exercise in Lab 1). Create graphs in the panel to show the PSD of the message signal, and the waveform plots (in time domain) of both the message and the carrier signals.

4. Perform the necessary operations in order to obtain the AM waveform.
5. As you did in step 3, create an indicator to show the AM waveform and the AM power spectrum.
6. You have now obtained the AM modulated signal. The **modulation index** is defined as $\mu = \frac{A_m}{A_c}$. You can observe the effect of the modulation index on the modulated waveform by changing the values of A_m and A_c via the corresponding controllers in the panel window.
7. The LabView Communications System Design Suite allows users to pack their VI's into **sub-VIs,** which make it easier to include them in other VIs. This also makes your block diagram look neater, and creates a modular code that can be modified easily. In the following steps we will explore this functionality.
    - First, click on the **Edit Icon** button located on the right hand side of the top banner. Now you can click on the various terminals to configure them either as an *input* (left) or an *output* (right). In this example, the **inputs** are: message signal frequency, message signal amplitude, carrier signal frequency, carrier signal amplitude, sampling info; while the **outputs** are: message signal, carrier signal and AM waveform time domain representations, and message signal and AM waveform PSDs.
    - Once saved your VI is ready for future use as a sub-VI**.**

Hint*: Explore the* ***Cleanup Diagram*** *tool ( ), on the top banner of the diagram tab, to make your diagram look neater.*

> ***Hint:*** *If necessary, you can adjust the number of terminals on each side of the icon by dragging and expanding the icon itself. Once you connect the necessary inputs and outputs you can use the palette on the left hand side of the screen to design a suitable image for the icon of your GVI.*

Tasks:

☞ Adjust all the plots you retrieve so that they are clear and easy to understand.

☞ Include the block diagram in your logbook.

☞ Set $A_c = 2$ and change A_m in the panel window to obtain the modulation index values $\mu = \{0.5, 1, 1.5\}$**.** For each value of μ print out the time domain and PSD representations of both the message and modulated signals. Include these plots in your logbook.

☞ What is the impact of the modulation index on the modulated signal? Explain your answer.

☞ Set $A_c = 1$ and $A_m = 1$. Change the frequency of the message signal to $f_m = \{1k, 2k, 5k\}$. What is the impact of the varying frequency value on the modulated signal? Explain your answer.

Exercise 2: AM Demodulators

Create a demodulation module to recover the original message signal. There are two possible methods:

1. **Coherent Demodulation**: Multiply the AM signal with the carrier signal followed by a low pass filter.
2. **Envelope Detection**: Rectify the AM signal, low pass filter it and remove the DC component to obtain the envelope.

Create two VI modules **'AMCoherent.gvi'** and '**AMEnvelopeDetection.gvi**' for the two different types of demodulation techniques.

<u>Exercise 2a: Coherent Detection</u>

Instructions:

1. Open the "AMCoherent.gvi" file.
2. Perform AM signal and carrier signal multiplication:
    a. Add the **Multiply** function to the diagram.

b. Create two controls by searching for “Waveform Array Terminal” and right click on the function and select “Change to Scalar”. Name them as “AM signal” and “carrier”, respectively. Their corresponding graphs will appear on the panel window.

3. Connect the output of the multiplication to a **Butterworth Filter** (recall from Lab 1). Create controls for the **order** and **Low Cut-off Freq** of the filter.
4. Subtract the DC component from the main signal. The DC component can be retrieved by using the **Amplitude Measurements** module, and in the right panel configuring the module to perform “AC DC and RMS” and “Single Shot”.
5. Add waveform graph indicators to view the final results in both time and frequency domains. (When you test this module later with an input signal, you will be able to observe the message signal in both time and frequency domains after demodulation).

Hint: *Pay attention to appropriately scaling the amplitude in order to get the desired message signal.*

Handling Errors in Labview

LabView allows controlling the errors that may occur for different reasons during the execution of a code. Just as data values flow through a VI, so does the error information, and this is the reason why most functions include error input and output terminals. If LabVIEW detects an error, the node passes the error to the next node. The next node does the same thing, and so on. At the end of the execution flow, LabVIEW reports the error. Thus, by wiring the error information from the beginning of the GVI to the end, and by setting appropriate indicators, it is possible to obtain details on the errors in the Panel tab.

In particular, the following functions can be useful in the following exercises:

a. When handling multiple errors, the **Merge Errors** function (available from the function palette) allows merging multiple error clusters into a single one, which can thus be propagated till the end of the function itself.
b. If you need to convert an error code to an error cluster, you will need the **Build Error Cluster** module in the function palette.

It is a good practice to properly handle errors when writing a GVI. Even if it is not a necessary condition in order to obtain the right result.

6. Transform your VI into a sub-VI as in Exercise 1 (Inputs: AM signal, carrier signal, low cut-off frequency, order, and error in. Outputs: demodulated signal in time, demodulated signal PSD, error out).

Tasks:

☞Add the block diagram to your logbook.

☞Explain briefly the mathematical theory behind this demodulation technique. Moreover, why are we using a low pass filter and why do we have to get rid of the DC component? Why do you need to scale the message amplitude?

Adjusting Plots with Labview

When a new plot is added to LabView, a default graph is created, adjusted automatically to the input data. However, in order to visualise and analyse data, further steps may be needed.

1. **Zooming and panning** – after selecting the graph in the panel, tick the **Graph Tools** option on the right hand panel under “Parts”. A menu with zooming and panning options should appear under the graph. 
2. **Renaming axes** – Every graph shows “time” and “amplitude” as default axis labels (independently of the input data). To change the names to something meaningful, just double click on the axis name.
3. **Exporting and visualizing data** – Right click a plot and select **“Capture Data”**. This will export the current data to the “Data” menu (left of the screen) where you can visualize the data in a bigger screen and save it. It is also possible to drag captured data to a graph in the panel, to visualize it.
4. Many other settings can all be found under the right panel.

<u>Exercise 2b: Envelope Detection</u>

This method consists of a **half wave rectifier** and an **RC filter.**

Instructions:

1. Open the ‘AMEnvelopeDetection.gvi’ file.
2. Since the multiplication with the impulse response of the rectifier introduces a loss of π in the signal, we need to amplify it before rectification by the same amount. Thus, multiply the signal with π.
3. To implement the rectifier, we use a **for** loop that runs through all the elements of the AM signal, and selects only the positive values (set the negative values to 0). Thus, inside the **for** loop, you will need to put a condition that checks if an element is positive (have a look at the **Case Structure** or the **Select** function under “Program Flow” in the functions palette).
4. Build a low pass filter using the **Butterworth Filter** with the same values used in Exercise 2a. Also remove the DC component.
5. Transform your VI into a sub-VI as in Exercise 1 (Inputs: AM signal, order, low cut-off frequency, filter type, error in. Outputs: demodulated signal in time, demodulated signal PSD, error out).

Tasks:

☞ Explain briefly the mathematical theory behind this demodulation technique and all the steps implemented.

☞ Add the block diagram to your logbook.

Exercise 3: AM Simulation

In this exercise, all the sub-VIs you have prepared so far will be used, and you will be able to observe the entire process of amplitude modulation and demodulation.

Instructions:

1. First, create a new file and name it “**AMTopLevel.gvi**”.
2. Drag **AM**, **AMCoherent** and **AMEnvelopeDetection** from the file tab on the left side of the screen, and place them on the block diagram.
3. Create necessary control and indicator terminals for each node, and make the necessary connections.
4. Create a while loop with a control that allows you to stop the loop via a stop button. Run the code and observe the process.

Tasks:

☞ Add the block diagram to your logbook.

☞ Set the parameters as in the following table and run the code.

Carrier amplitude	2
Message signal amplitude	See question 2
Sample frequency	200k
Samples	1k
Butterworth low-pass filters	Order: 5 Cut-off frequency: 3 kHz
Carrier frequency	10 kHz
Signal message frequency	1 kHz

☞ Provide the graphs for both time domain and PSD representations of the coherent and envelope demodulated signals for the message signal amplitude changing from 1 to 4 with steps of 1, in your logbook. As you change the message signal amplitude do you observe any changes between the two modulation techniques? If yes, explain the reason.

Exercise 4: AM Communications via USRP

In this exercise, all the required modules have already been provided to you. Your task is to run the modules using the settings provided and explain how the modules work from the code.

Some background information on the modules concerning the USRP:

niUSRP Open Tx Session initiates the USRP device, generates a session handle and an error cluster that are propagated through all four VIs. When you use this VI, you must add a control called “device name” that you will use to inform LabView about the USRP Device ID (either a name or an IP address).

niUSRP Configure Signal is used to set the parameter values. Attach four controls and three indicators to this VI as shown in Figure 1. The controls set the **IQ rate** (in Sample/s), the **carrier frequency**, the **gain**, and the **active antenna**. When the VI runs, the radio returns the actual values of these parameters (called “coerced parameters”). The actual parameters may or may not match the values put as controls. If an input value exceeds the capability of the radio, it will choose the nearest acceptable parameter value, as the coerced value, rather than returning an error.

niUSRP Write Tx Data sends the baseband signal to the USRP for transmission. Placing this VI in a while loop allows a block of baseband signal samples to be sent over and over until the “stop” button is pressed. Note that the while loop is programmed to terminate if an error is detected. Baseband signal samples can be provided to the **Write Tx Data** either as an array of complex numbers, or as a complex waveform data type. Right click on the function and select **Replace**. This will allow you to choose the data type of the function. The input data should be complex in order to introduce I and Q data to the USRP (which corresponds to the real and imaginary parts, respectively). If the baseband discrete time signal is expressed as

$$\tilde{g}[nT_x] = g_I[nT_x] + jg_Q[nT_x]$$

then the continuous time transmitted signal from the USRP is

$$g(t) = Ag_I(t)\cos(2\pi f_c t) - Ag_Q(t)\sin(2\pi f_c t)$$

In this expression, the constant A is set by the “gain” parameter (in dB) and f_c is the carrier frequency. The sampling interval T_X is the reciprocal of the “IQ rate”. Be aware that the USRP internal circuit implements some functions for transmitting and receiving the signal (Appendix A contains details of the USRP's internal operations). The signal g(t) produced by the USRP is a continuous time signal, that is, digital to analog conversion (DAC) is done inside the USRP itself.

niUSRP Close Session terminates transmitting operation once the while loop ends. Note that the VI should be terminated using the STOP button rather than with "Abort Execution" on the toolbar, so that the Close Session VI will correctly close the data structures that the VI uses

niUSRP Open Rx Session works in the same way as **niUSRP Open Tx Session.**

niUSRP Configure Signal works in the same way as in the Tx**.**

niUSRP Initiate sends the parameter values you selected to the receiver, and starts it running.

niUSRP Fetch Rx Data retrieves the message samples received by the USRP. Placing this VI in a while loop allows message samples to be retrieved one block at a time until the "stop" button is pressed. **Number of samples** control allows you to set the number of samples retrieved at each step of the while loop. **Fetch Rx Data** can provide message samples to the user as either an array of complex numbers, or as a complex waveform data type. Right clicking and then selecting **Replace** allows you to choose the data type for the message samples. This function does not output the received signal directly. Instead, *USRP itself multiplies the received signal with the carrier, based on the configurations you set in the panel control, and applies a low pass filter to it* (see Appendix A).

niUSRP Abort stops the acquisition of data once the while loop ends.

niUSRP Close Session works in the same way as in the Tx.

Instructions:
1. Open the files named "**USRP_AM_Rx.gvi**" and "**USRP_AM_Tx.gvi**".
2. In the front panel of each module, set the values of the controls as in the following:

Control	**Tx**	**Rx**
Device names	NI2900	NI2900
IQ rate	500k	500k
Carrier frequency	400M	400M
Gain	0	0
Active antenna	TX1	RX2
Sample rate	500k	N/A
Samples	200k	200k
Low cutoff frequency	N/A	1400
Modulation index	1	N/A
Message frequency	1000	N/A

Tasks:

☞ Run the code and explain in your logbook how the transmitter and receiver work. **Hint:** the USRP does all the modulation and demodulation on its own so the modules only needs to provide the complex data for the USRP to modulate. At the receiver the USRP will return the demodulated data.

☞ Transmit a single-tone message signal with frequency 5kHz and modulation index 1 (you may have to adjust the low cutoff frequency of the filter). Run the receiver, and plot the demodulated signal in time, and its PSD. Adjust the time and PSD plot to the relevant region so that the plot is not just a blur, and rename the axes appropriately. Add the plots to your logbook.

☞ To observe the effect of noise in the demodulated signal, increase the receiver's gain to 20 dB (your receiver will start to detect other weaker signals in addition to the transmitted signal), and adjust the X axis of the demodulated message (in time domain) to show values between 0 second (s) and 0.004 s. Then, change the modulation index (μ) value and observe the effects on the plots of the demodulated signal in both time and frequency. From what value of μ can noise be clearly noticed in the plots? Copy the image of the noisy demodulation into your logbook.

Exercise 5: Listening to AM Music (Bonus)

Inside the lab, there is a USRP broadcasting an AM signal. The signal is a piece of music that you can listen to.

Instructions:

1. Set the USRP_AM_Rx_Music.gvi panel setting to the configuration below, and try to find the message signal.

Hint: *LabView might have problems detecting the right soundcard settings automatically to play your audio.* ***Before running the VI***, *plug-in the earphones, and try to play any audio file first (e.g. a Youtube video), preferably with LabView closed. This will ensure that the right soundcard setting is selected.*

Control	Rx
Device names	NI2900
IQ rate	100k
Carrier frequency	400M
Gain	Adjust as necessary
Active antenna	RX1
Samples	5M

Note: *LabView requires all the samples to be acquired before playing the signal, hence it may take some time before you hear the first note. Once the output signal graph starts changing, it indicates the signal is being played, and you should hear the music.*

Task:

☞ Add the graph of the demodulated signal both in time and frequency domain to your logbook and identify the frequency of the message signal and the song playing.