The University of Calgary

Department of Electrical & Computer Engineering

**ENEL 471-Introduction to Communication Systems and Networks**

# Lab 2 : AM Demodulation

| Section date | B04: Tue. Feb. 25, 2020<br>B03: Tue. Mar. 03, 2020 | B02: Wed. Feb. 26, 2020<br>B01: Wed. Mar. 04, 2020 |
|---|---|---|
| Location | ENA 301 | ENA 301 |

This document consists of 2 parts:

**Part I: Lab 2 Manual**

- The lab consists of Simulink experiments and hardware experiments
- You MUST try to complete as much as you can of the Simulink experiments and answer the corresponding questions prior to Lab #2 session.
- You should download the Simulink files from D2L and run them locally.
- The hardware part involves transmitter & receiver, which will take longer to complete.
- You MUST read Lab #2 Manual prior to the Lab #2 session, otherwise you will have difficulty completing the hardware experiments by 5:00 pm.
- Students MUST leave the lab NO LATER than 5:00 pm.

**Part II: Lab 2 Questions**

- Answers to these questions must be submitted to the TAs at the end of the Lab period.
- Each group submits one set of Lab questions. Ensure names and ID numbers of the group members are written on the Lab answer sheets.

**Acknowledgements**

The ENEL 471- Introduction to Communications and Networks Lab 1 document was originally prepared by Jennifer A. Hartwell and Dr. Mike Potter, revised (January 2013) by Warren Flaman and Dr. Abu Sesay, revised (January 2015) by Mohamed Al Masri and Dr. Mohamed Helaoui, revised (January 2018) by Leanne Dawson and Dr. Mohamed Helaoui, and revised (January 2019) by Yulong Zhao.

# Part 1

# Lab 2 Manual

## Introduction

Laboratory #1 introduced amplitude modulation, where AM, DSB and SSB signals were created and analyzed. It was shown that, by up-conversion to different carriers, several message signals could be added together and sent over the same medium without overlapping in the frequency domain. This lab focuses on the techniques used to receive these types of signals and demodulate them back into the original message signals. This lab has two parts. The first part is simulation of AM demodulation using MATLAB's Simulink tool. The second part of the lab is demodulation of AM signals using the AM transmitter and receiver hardware boards.

## 1 Simulating AM Demodulation Using SIMULINK

### 1.1 Synchronous/Coherent Detection

#### 1.1.1 Ideal Coherent Detection

The generation of AM and DSB signals in Lab #1 was achieved by multiplication with a high frequency carrier. Demodulation of these types of signals is not much more complicated - **if the receiving system has knowledge of the carrier phase and frequency**. In the same way that multiplication with the carrier up-converted the message to be centered at the carrier frequency, multiplication by the carrier again will create a down-converted copy of the message at baseband. In order to multiply the modulated signal by the carrier, an exact copy of the carrier must be available at the receiver. It is for this reason that this type of detection is called synchronous or coherent. Fig. 1 shows a block diagram of a simple coherent detection scheme. Notice that this detection scheme is identical to the AM/DSB modulation scheme except for the addition of a Low Pass Filter (LPF).

- Why is the LPF necessary when multiplying a received signal, centered at $f_c$, with a copy of the carrier (a sinusoid with frequency $f_c$)? **(Q1)**
- The resulting signal from a detection scheme shown above may have a constant other than '1' multiplied in front of the message signal [i.e., $k_D m(t)$]. The constants from

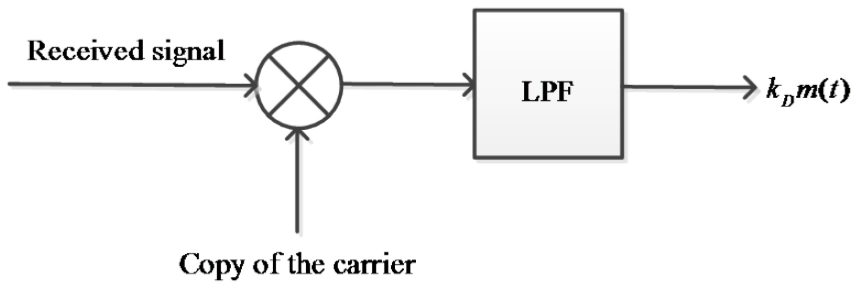



Figure 1: Simple coherent detction scheme.

the mod/demod process that affect the final magnitude of the demodulated message include the magnitudes of the carriers used and the modulation index. Explain whether this type of deviation from the original message will cause distortion. **(Q2)**

Open the file called '**AMd1.mdl**' and look over it. An AM signal is generated and then demodulated.

- Double clicking on the 'AM Tone Modulator' block will reveal the details about the AM signal that is being created.
- The parameter labelled 'constant' refers to the DC term added to the message in AM. Changing the 'constant' parameter to zero will create a DSB signal rather than an AM signal.
- Double-clicking on the two manual switches will change the AM source that is fed to the demodulation section and the time domain scope from double-side band to single-side band. Make sure that both switches always point to the same source to avoid confusion.
- Run the **AMd1.mdl** simulation, with the AM Tone Modulator set for DSB.
- Looking at the DSB signal spectrum, and then the spectrum after down-conversion, the need for the LPF becomes very obvious. Do you notice anything interesting about the magnitudes of the signal at baseband vs. the signal up at 4 kHz? Explain why this would be. **(Q3) Hint:** This can be done mathematically by determining the equation for the demodulated signal or qualitatively by picturing the whole spectrum, not just the positive side, and considering what happens around 0 kHz.
- Look at the original and demodulated signals in the time domain. Zoom into a very small section of the x-axis centered at around 0.1 seconds for each plot. How has the entire mod/demod system affected the message in terms of phase and amplitude? **(Q4)**
- Would you consider the demodulated signal to be distorted? **(Q5)**
- Change the constant value in the AM Tone Modulator pop-up box to '1' so that an AM signal is being generated and run the simulation again.
- Looking at the time domain signals once more, what is the added difference between the original and demodulated signals? **(Q6)**

- Why did this happen? **(Q7)**
- What single component could be added to the detection scheme to correct this difference? (starts with a 'c') **(Q8)**
- Looking at the spectrum of the AM signal, why is the magnitude of the demodulated signal double the magnitude of the signal at $2f_c$. **(Q9)** If you are wondering why, picture the whole spectrum again.
- Double-click both manual switches so that the SSB-USB signal is fed into the detection scheme instead. Double-clicking on the Phase shift modulator will show the innards of the block. Make sure that the message signal is chosen to be the sinusoid. Run the simulation.
- Looking at the spectrum of the SSB signal, you'll see that this time the baseband copy of the signal is not double the magnitude of the signal at $2f_c$. **(Q10)** If you are wondering why, picture the whole spectrum again and think about whether things would overlap this time.
- Looking at the time-domain signals for SSB will reveal that the exact magnitude has been received (since no modulation index was used in this case). Is the phase deviation the same as for the AM/DSB cases? Would you expect this? Why? **(Q11)**

### 1.1.2 Non-Ideal Coherent Detection

In the previous section, the copy of the carrier that was used to demodulate the signals was an exact copy of the carrier used in the modulation process. In other words, the phase and frequency of the carrier was known and used in the detection scheme. This next section will explore what happens if the local oscillator has a phase error, such that:

$$\text{original carrier} = \mathbf{cos}(2\pi f_c t)$$
$$\text{carrier at receiver} = \mathbf{cos}(2\pi f_c t + \varphi_e)$$

The carrier frequency is usually known, and is tunable in most applications such as radio, limiting the likelihood of frequency error. In real applications there can still be 'frequency drift' due to unstable oscillators. By contrast, the phase of the carrier is not easy to predict or determine upon detection, so it is for this reason that we focus on phase error alone in this lab. For a DSB signal that is demodulated by the method demonstrated in 'AMd1.mdl', if there is a phase error, then the resulting signal passed through the LPF is no longer just $\mu m(t)$, it becomes:

$$\mu m(t)\ \mathbf{cos}(\varphi_e)$$

- Setup AMd1.mdl so that a DSB signal is being demodulated.
- Double-click on the 'Local Copy of Carrier' block and note that the phase is set to $\pi/2$. With this setting it matches the carrier phase exactly ($\varphi_e$=0). Using the equation above for the resulting demodulated signal, change the phase setting for the oscillator so that the **phase error** is such that the resulting effect to the signal is the worst possible scenario. (Run it to check your guess). What did you set $\varphi_e$ to? What was the resulting demodulated signal? **(Q12)**

- Describe how the received signal would be affected by a phase error that constantly drifted (changed). **(Q13)**
- The effect of phase error on a SSB signal is not the same as the effect on a DSB signal. For a SSB signal that is demodulated by the method demonstrated in 'AMd1.mdl', if there is a phase error, then the resulting demodulated signal is:

$$m(t)\ \mathbf{cos}(\varphi_e) \pm \hat{m}(t)\ \mathbf{sin}(\varphi_e)$$

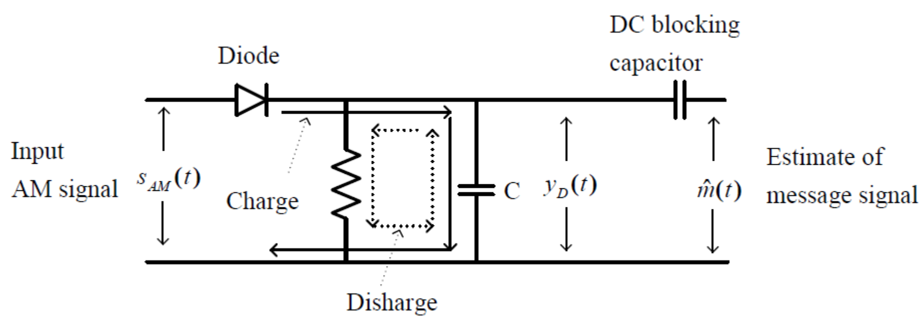
- Recall that the Hilbert transform is just basically a $-\pi/2$ phase shift, so if our message is a sinusoid, we know exactly what a phase-shifted version is going to look like - and it will not appear distorted.
- Close **'AMd1.mdl'**

**Note:** Even though the time signal for SSB with worst case phase error looks very 'garbled', this type of distortion called 'delay distortion' is fairly tolerable by the human ear. This is much better than the worst case scenario for the DSB signal.

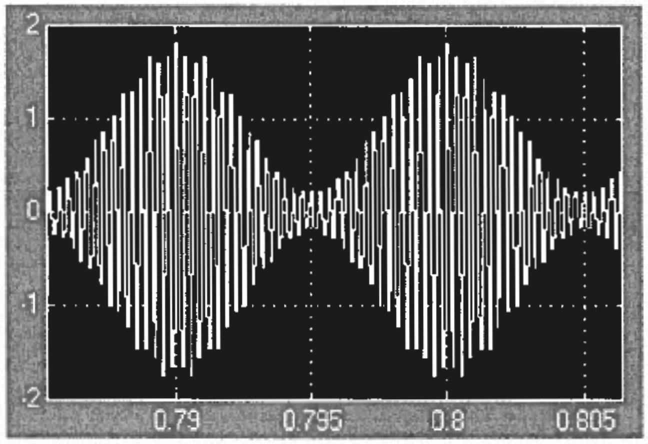
## 1.2 Non-Coherent Detection

What if our receiver does not know the frequency of the carrier, or the phase? Synchronizing the transmitter and the receiver so that the oscillators at each end match is not a trivial thing to do. For this reason, there are detection schemes known as non-coherent detection. The simplest of these is the envelope detector. The envelope detector can be built with only a diode, resistor and capacitor.

Picture an AM signal in the time domain. As long as the modulation index is not greater than one, the envelope defined by the upper half of carrier's amplitude is the message signal.




For example, tracing the peaks on the AM signal shown here, you get a 100 Hz sinusoid, which was the message used when creating the AM signal. The envelope detector extracts the envelope by the following procedure: (1) The diode only passes the positive portion of the AM signal (2) The RC combination interpolates between the peaks of the carrier to create a continuous trace of the envelope. The important thing to keep in mind when designing an envelope detector is the RC time constant. You may recall from circuit theory that once the capacitor is charge, it will discharge at a rate that is dependent on the product RC.




This is how the interpolation between the peaks of the carrier is done. Consider the picture above to be a zoom-in of the upper half of an AM signal. The voltage across the capacitor and resistor corresponds to the thick dotted line. If the RC constant is too small, the capacitor's voltage will discharge too quickly and the connecting line will begin to look more like the humps of the carrier. If the RC constant is too large, the capacitor will discharge too slowly and the connecting line will miss the lower carrier peaks. A rule of thumb to follow when choosing the RC constant is:

$$\frac{1}{f_\mathrm{c}} \ll RC \ll \frac{1}{B}$$

Where $B$ is the one-sided bandwidth of the message signal (or the frequency of the message signal in the case where the message is a sinusoid) and $f_\mathrm{c}$ is the frequency of the carrier.

- Open the file called '**AMenv.mdl**' and look over it. An AM signal is fed directly into an envelope detector.
- The envelope detector for our case is approximated by a few tricks. A switch is used for the diode (meaning that it is an 'ideal' diode that passes only positive signals, and completely shuts off when the voltage across it is negative) and portion of the circuit are implemented by a differential equation, which is easily derived using the capacitor equation:

$$\frac{dV}{dt} = \frac{1}{C} i(t) \tag{1}$$

  where the current across the capacitor (by Kirchhoff's law) is the current across the diode minus the current across the resistor. The R and C values used by the envelope detector are defined in constant blocks on the top level diagram and fed into the envelope detector.
- Look at the values $(R, C, f_\mathrm{c}, f_\mathrm{m})$ currently entered into the simulation. Set $R = 100\,\Omega$ and $C = 10\mu$F. Is the time constant within the range that should work for this particular AM signal? **(Q14)**.
- Run the simulation.

- Look at the diode output. Is it what you expected? **(Q15)**
- Look at the envelope demodulated signal at the output. Does the signal resemble the message signal? **(Q16)**
- Once the output signal has reached steady state, it should resemble the message (don't worry about magnitude or phase shifts). Also, it is okay if it is not perfectly smooth - in real circuits a LPF will take care of the 'jitters' after the envelope detection.
- If you change the capacitor value to 100 nF, what happens to the detected envelope and why? **(Q17)**
- Change the capacitor value back to 10 $\mu$F.
- Change the 'constant' value in the AM Tone Modulator block to zero so that a DSB signal is being generated.
- Do you think that an envelope detector will work on a DSB signal? Run it and verify your prediction. Explain what happened. **(Q18)**
- Conclusion: Can envelope detection be used for DSB-SC? **(Q19)**
- Conclusion: Can coherent detection be used for conventional AM? **(Q20)**

## 2 Demodulating Using Hardware Boards

For this portion of the lab, we will use the AM Tx board from Lab #1 to create amplitude modulated signals (recall it is capable of a SSB signal with a 1 MHz carrier and an AM signal also with a 1 MHz carrier).

**Signal Selection Jumpers Pins / Switches - A Complete List:**

- **J16** Pins 1 & 2 connected, selects an external carrier (J7) for the first mixer. Pins 2 & 3 connected, selects the Hi/Lo VCO:1
- **J15** Pins 1 & 2 connected, sets the Hi/Lo VCO:1 to the 452 kHz range. Pins 2 & 3 connected, sets the Hi/Lo VCO:1 to the 1MHz range.
- **J22** Pins 1 & 2 connected, selects external connector J8 to supply the modulating input signal (the message). Pins 2 & 3 connected, selects the microphone to supply the message.
- **J4** Pins 1 & 2 connected, selects the Hi/Lo VCO:1 to be accessible through J18 for testing. Pins 2 & 3 connected, selects the VCO:2 (Not an option on Ver. 1.00 boards)
- **J21** Having this jumper in place allows the carrier to feed through on the 1st mixer. If it is removed then the carrier will be suppressed.
- **J14** Having this jumper in place allows the carrier to feed through on the 2nd mixer. If it is removed then the carrier will be suppressed.
- **J5** Pins 1 & 2 connected, selects the AM signal path. Pins 2 & 3 connected, selects the SSB signal path. Both are routed to the output TP7 and J9.

Below is the block diagram of the Tx boards from Lab #1.

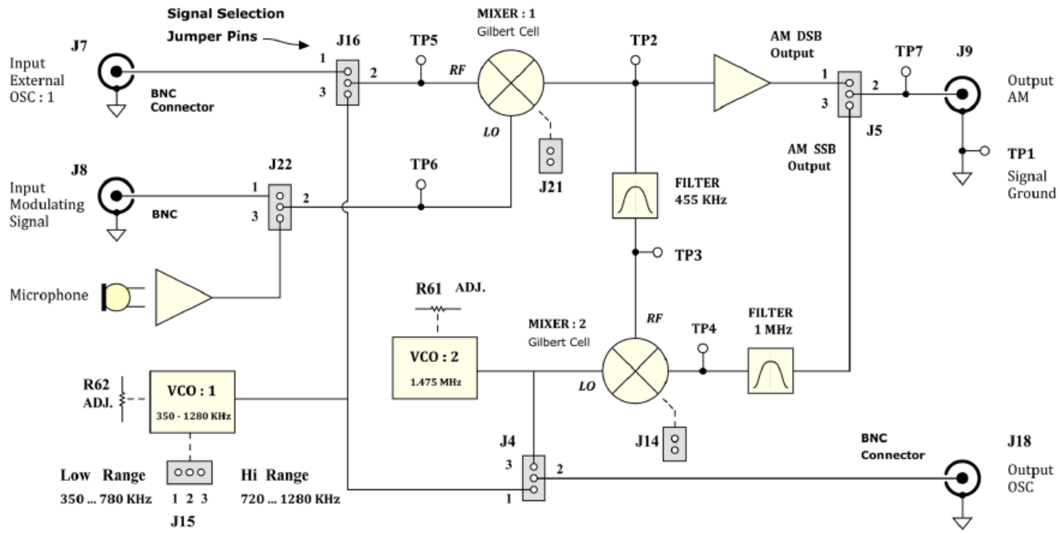



Figure 2: AM DSB/SSB Modulation Transmitter Schematic Diagram.

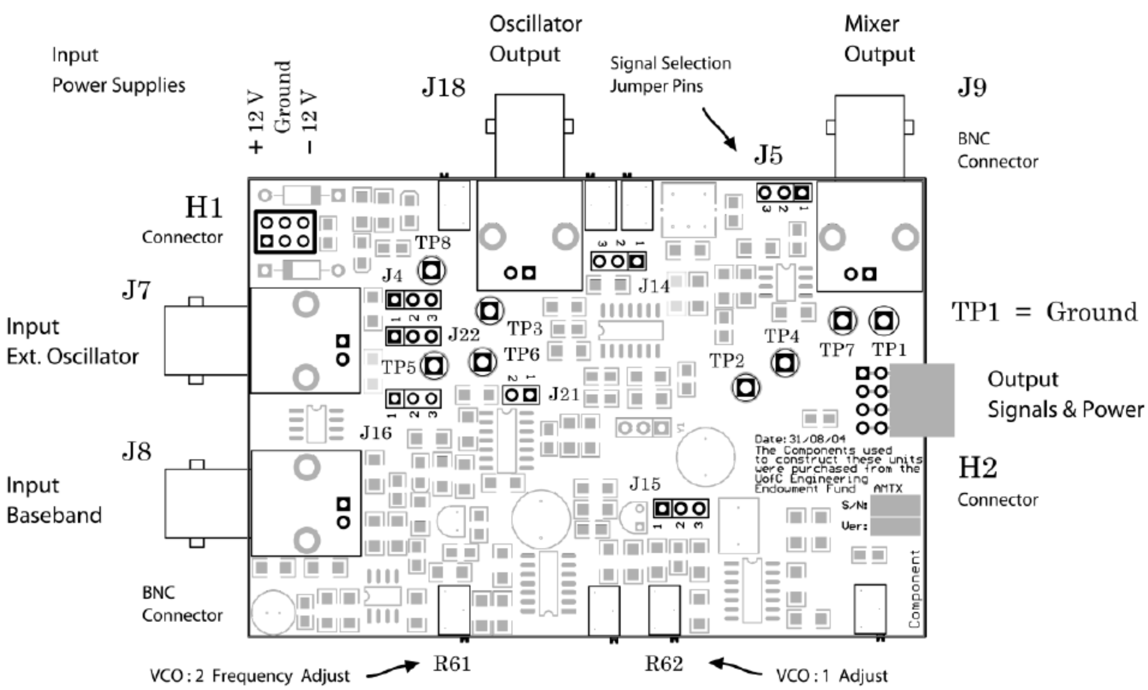



Figure 3: AM DSB/SSB Modulation Transmitter (Board Version 1.1).

*** Caution: Setup DC Power supply before you connect and power up Transmitter board:**

1. Configure the DC Power Supply: Hewlett Packard 3631A - Triple output. Turn on the power, select function output On/Off to Off. This will put the power supply in standby mode (no power on the output terminals)
2. Set Power Supply voltage limits to +12V and -12V respectively for the two outputs: Select function +25 V range button, and select button Display Limit Select the adjust Voltage / Current button if necessary to set voltage adjust mode. Now adjust supply for +12 Volts using position arrows and Jog shuttle wheel. Select function -25 V range button, and repeat adjustments for supply -12 Volts
3. Set Power Supply output current limits to 80 mA for each supply: Select function +25 V range button and select button Display Limit. Use the adjust Voltage/Current button to set current adjust mode. Now adjust supply output current using position arrows and Jog shuttle wheel. Select function -25 V range button. Repeat current adjustments for supply range.
4. If you are unsure if you've set the voltages correctly check the voltage outputs using the multimeter and activating the power supply output 'On/Off' to 'On' mode.
5. Locate connector H1 on the Transmitter board. If the board is orientated so that 'University of Calgary' is right-side up.
6. Carefully connect power supply into connector H1 on the Tx Board using banana leads and hook up wires connected to the Breadboard Station Unit Supply +12V should be connected to the top left pin socket of connector H1.
7. The common wire (ground) goes to the top center pin socket of H1. Supply -12V should be connected the top right pin socket of connector H1.
8. Activate power to Tx Board by selecting output On from the power supply

## 2.1 Receiver Board AM Signal Demodulation

The receiver/demodulating board has been designed to work in conjunction with the Tx board. The two boards can be connected directly together by the connectors marked H1 on the Rx board and H2 on the Tx board. Across H2 the amplitude modulated signal (AM or SSB) is passed over to the Rx board along with the output of both VCOs from the Tx board. This means that coherent demodulation can be done if desired, since the exact same carriers are present on both boards.

The only jumper that you may want/need to switch on the Rx board is J3 which selects whether the coherent or the non-coherent detected signal is routed to the BNC connector J5. Note that the coherent demodulation is done in two stages here, and is output on TP8. The benefits of two stages will not be obvious now, but will be explained in Lab #3.

A block diagram of the Rx board is shown below.

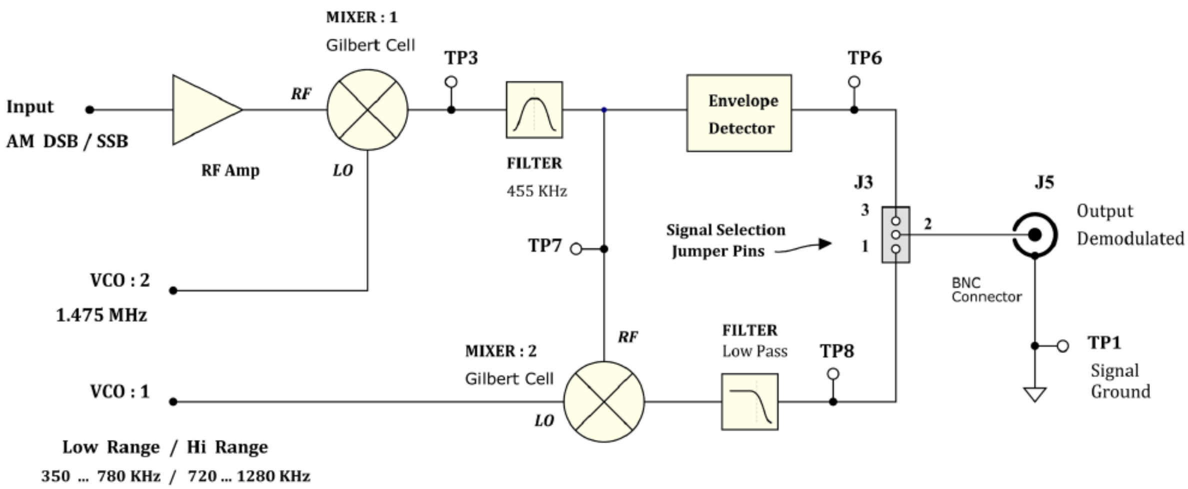



Figure 4: AM DSB/SSB Demodulation Receiver Schematic Diagram.

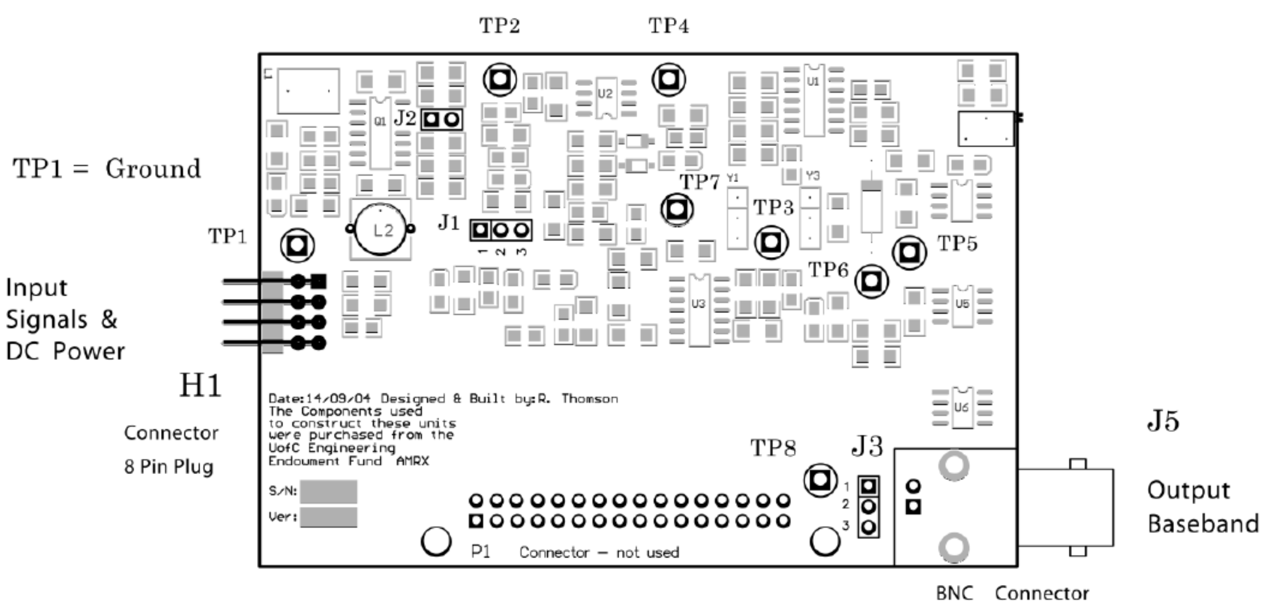



Figure 5: AM DSB/SSB Demodulation Receiver (Board Version 1.1).

## 2.2 Coherent Detection of an SSB Signal

### 2.2.1 Generation of an SSB signal

In Lab #l, you were introduced to the concept of SSB signals with Simulink simulations. Before proceeding to detection of an SSB signal, you will first create an SSB signal using the hardware board. The SSB signal will be generated in a similar fashion as was done in simulations in Lab #1.

The mixer in the first stage will up-convert the message to an intermediate frequency (IF), where one of the sidebands and the carrier will be filtered off. Then, the second mixer will be used to up-convert the signal to a 1 MHz carrier and a final filter centered around 1 MHz will block out the other component. On the Tx board, create an SSB signal with a 1 MHz carrier.

**Tune the IF:**

- Make sure J16 selects the Hi-Lo VCO to be the carrier
- Switch J15 to create the 452 kHz range signal as an input to the first mixer
- View TP5 and using R62 again, tune the VCO to be 455 kHz (This will put the carrier right in the center of the passband of the IF filter)

**Create the Message:**

- Set the Arbitrary Wave Generator (AWG) to a 0.5 $V_{\text{pp}}$ sinusoid with a frequency of 20 kHz
- Feed the message signal to J8
- Set J22 to select J8 as the message input to Mixer:1

**View the IF signal and adjust the carrier:**

- Using an oscilloscope with FFT capabilities, view the spectrum at TP3. TP3 is the AM signal right after the IF filter (see Tx block and board diagrams)

**Setup the FFT function on the oscilloscope:**

- Press the 'Math' button on the scope
- Select the 'Operator' to FFT using configurations button below oscilloscope screen corresponding to software menus displayed on the scope
- Using the Horizontal (Time/Div) knob of the oscilloscope, set the FFT sample rate to 200 MSa/sec.
- Select buttons underneath the screen menus and use the multipurpose knob labeled with the lighted turning arrow, set the center frequency to 455 kHz and the Span to 100 kHz
- **Note**: On the scope screen, a center frequency indicator triangle (color orange) is positioned on the border of the grid frame, top middle area. Use R62 again to tune the VCO if needed

**Recall** from the simulation in Lab 1 that after the IF filter we would hope to have only one sideband left since the filter should knock out the carrier and the other sideband. The filter on the Tx board has a narrow passband centered at 455 kHz. Since 455 kHz is the frequency that we have initialized the first carrier to, all you should see in the spectrum at this point is a single component (the carrier) right in the center. The sidebands, at 20 kHz, are too far away from the center of the filter to be passed through.

- Verify you are looking at the carrier by removing J21 (suppressing the carrier in the first mixer). Does the spike disappear? Replace J21
- Now we will adjust the carrier so that only the LSB is in the passband. Tuning R62 again, increase the carrier frequency until you see it move out of the passband (with reducing level) and the LSB appears (enters the filter passband and attenuates the carrier). Center the LSB on the screen (455 kHz). This means that our new carrier is 455 kHz + 20 kHz = 475 kHz, and our filter is doing what we want it to (passing only the lower sideband)
- Verify that what you are looking at now is a sideband by playing with the amplitude of the message. The component on the screen should change its magnitude accordingly

**Tune the RF final SSB carrier:**

- Select J4 to output the 1.452 MHz range VCO:2 to BNC connector J18
- **Note**: Tx boards version 1.0 (void J4) have VCO:2 permanently connected to J18
- Using an oscilloscope with FFT capabilities, view the spectrum at J18 (sampling frequency: 200 MSa/sec, centre: 1.475 MHz, span: 50 kHz)
- Tune the RF carrier to 1.475 MHz using R61

**Note:** When mixing in two stages, the final carrier that is used can be $f_{\mathrm{RF}} + f_{\mathrm{IF}}$ (as was the case in the simulation), and therefore the RF carrier is lower than the final carrier. However, the final carrier can also be chosen as $f_{\mathrm{RF}} - f_{\mathrm{IF}}$, which is what the Tx board implements. That is why, since we want our final carrier to be 1 MHz , we set the RF carrier to be 1475 MHz. The consequence of having the RF carrier higher than the final carrier is that the sidebands will switch sides! You are about to see proof of this.

**View the Final Signal:**

- Set J5 so that the SSB signal is output to TP7 and J9.
- Inspect the frequency spectrum at TP7 or J9 with the FFT oscilloscope
- Set the FFT sampling to 200 MSa/sec, the center frequency to 1 MHz and the span to 100 kHz. You should see a single spike at 1.02 MHz. This is because the LSB signal that we created at the IF is now residing in the USB of the final signal.
- Verify that the sideband is at 1.02 MHz and that you are definitely seeing a sideband by playing with the message's amplitude
- Show a TA your SSB signal and get your sheet signed **(Q21)**

### 2.2.2 Reception of an SSB Signal

* **Caution: Before attaching the Rx board to the Tx board, set the DC power supply function output to 'off' (standby mode).**
When both Tx and Rx boards are powered on, they typically use 60 mA for each supply rail. Now look at the Rx board and verify that the demodulation process is working.

**Inspect the time-domain signal at TP8 on the Rx board:**

- Is it what it should be? **(Q22)**
- Does changing the signal generator frequency change the demodulated output? **(Q23)**

**Inspect the time-domain signal at TP3 on the Rx board:**

- What does it look like? **(Q24)**
- Why does it have this form? **(Q25) Hint**: there are two main components being added, think about what this would look like in time

## 2.3 Non-Coherent Detection of an AM Signal

Now the Tx board will be setup to create an AM signal centered around 1 MHz and you will check the Rx board's non-coherent demodulation operation.

**Change the TX board settings so it is outputting an AM signal:**

- Switch J15 so that it connects pins 2 & 3 (Hi Range of VCO:1) to create a 1MHz signal rather than a 455 kHz signal
- Inspect the frequency spectrum at TP5 with a FFT oscilloscope (sampling frequency: 200 MSa/sec, centre: 1 MHz, span: 100 kHz)
- Tune VCO:1 carrier signal at TP5 to be 1 MHz using R62
- Make sure that J21 and J14 are in place on the Tx board ( J14 can go on pins 2 & 3 )
- Switch J5 so that it connects pins 1 & 2 (AM signal gets routed to output)
- Using the FFT function, check that TP7 is outputting an AM signal centered around 1 MHz (sampling frequency: 200 MSa/sec, centre: 1 MHz, span: 100 kHz)

**Inspect the time-domain signal at TP6 on the Rx board:**

- Is it about what it should be? How does the quality of the signal compare to the signal that was demodulated coherently in the previous section? **(Q26)**

**Inspect the frequency spectrum at TP6 on the Rx board**:

- Enable the FFT function on the oscilloscope
- Set the FFT sampling rate to 500 MSa/sec, the center frequency to 100 kHz and the span to 200 kHz
- Sketch what you see. Are you seeing just the single spike that should represent the sinusoidal message we sent? **(Q27)**

- Why do you think the spectrum looks the way it does? **(Q28)** **Hint**: the diode in the envelope detector does not have a linear transfer function
- What is a possible solution to fix this problem? **(Q29)**
- Have a TA see your spectrum and get a signature. Ask them about the spectrum if you aren't sure about your answers for the questions above **(Q30)**

You are done! **Answer the questions in the next part, and hand them to the TA.**

# Part 2

# Lab 2 Questions

**Answer the following questions. Write down the names and ID # of the group members and hand in the answer sheets to the TAs before you leave the lab.**

**A. Simulation (Simulink) Questions: (20 points)**

Q1 Why is a low-pass filter (LPF) required, in coherent detection, after multiplying the received modulated signal with a locally generated carrier signal?

Q2 The signal at the output of the demodulator (or detector) is $k_{\mathrm{D}}m(t)$. The constant $k_{\mathrm{D}}$ accounts for attenuation/amplification in the demodulator. Would this type of deviation from the original message cause distortion? Why or why not?

Q3 (AMd1, DSB: constant = 0) Compare the AM (DSB-SC) spectrum and the demodulated (or down-converted) spectrum. Why is the magnitude of the demodulated spectrum double that of the spectrum (around 2 KHz or 4 KHz)?

Q4 (AMd1, DSB: constant=0) Compare the original time-domain message waveform and the demodulated time-domain message waveform. What difference do you observe with respect to the amplitude and phase?

Q5 Would you consider this a distortion? Why or why not?

Q6 (AMd1, AM: constant = 1) Compare the original time-domain message waveform and the demodulated time-domain message waveform. Looking at the time domain signals once more, what is the added difference between the originals and demodulated signals

Q7 Why did this happen?

Q8 What element could be used to fix (remove) this difference, a capacitor, inductor or resistor? Why?

Q9 (AMd1, AM: constant = 1) Why is the magnitude of the demodulated spectrum double that of the modulated signal (at 2 KHz or 4 KHz)?

Q10 (AMd1, SSB-USB) Looking at the spectra, Why is the magnitude of the demodulated spectrum the same as that of the SSB spectrum at 2 KHz or 4 KHz (not double as in DSB or AM)?

Q11 Looking at the time-domain signals for SSB will reveal that the exact magnitude has been received (since no modulation index was used in this case). Is the phase deviation the same as for the AM/DSB cases? Would you expect this? Why?

Q12 (AMd1, Non-ideal coherent; i.e. phase error present) The correct phase is $\pi/2$. What is the amount of phase error ($\varphi_{\mathrm{e}}$ ) that you would add to yield the worst demodulation (i.e., no demodulated output)? Set the local oscillator phase to $\pi/2 + \varphi_{\mathrm{e}}$ and observe the demodulated time- and frequency-domain signals to answer this question.

Q13 Describe how the received signal would be affected by a phase error that constantly drifted (changed).

Q14 (AMenv, Non-coherent Demodulation) Calculate the time constant $RC$. Is it within the range $\dfrac{1}{f_{\mathrm{c}}} \ll RC \ll \dfrac{1}{B}$?

Q15 Compare the input and the output of the diode. What is the diode doing to the input signal? Is this in accordance with theory?

Q16 Look at the envelope demodulated signal at the output. Does the signal resemble the message signal?

Q17 Observe the output signal with $C$=100 nF and $C$=10 $\mu$F. Which one gives you an output that more resembles the message signal? Why?

Q18 What happens to the demodulated signal when the input is a DSB-SC (set constant=0)?

Q19 Conclusion: Can you use envelope detection for DSB-SC?

Q20 Conclusion: Can you use coherent detection for detecting a conventional AM?

**B. Hardware Questions: (10 points)**

Q21 Demonstrate your SSB signal a TA and get your answer sheet signed for Q21.

Q22 Is demodulated signal (at TP8 on the Rx board) what it should be?

Q23 Does changing the signal generator frequency change the demodulated output?

Q24 What does the signal look like at TP3 on the Rx board?

Q25 Why does the signal at TP3 have this form?

Q26 Is demodulated signal (at TP6 on the Rx board) what it should be? How does the quality of the signal compare to the signal that was demodulated coherently?

Q27 Are you seeing just the single spike that should represent the sinusoidal message that was sent?

Q28 Why do you think the spectrum looks the way it does? **Hint:** the diode in the envelope detector does not have a linear transfer function.

Q29 What are some possible solutions to fix this problem?

Q30 Have a TA see your spectrum and get a signature for Q30. Ask the TA about the spectrum if you are not sure about your answers to the questions Q27, Q28, and Q29 above.