EE133 - Lab 1
Amplitude Modulation and Demodulation

1 Lab Notes

- **A Word about Power:** Remember that the SA612 is not rated for 9V. We recommend that you power it up with 4.5V (and remember to use bypass capacitors). Note that this is on the very low end of the recommended voltage range. You will be building a 4.5V midpoint reference voltage supply that will be used by a few other blocks in the receiver (the IF stage, and the phase-locked loop), but because we will ultimately power our circuits with a 9V battery, this voltage can droop and vary as your circuit operates over time (hence your 4.5V supply could sag below 4.5V). You can either plan to use that supply for the SA612 as well, or you can use a different voltage to power it. We have LM7805 5V regulators in lab available. Note that this would require you to have three different voltage references on your receiver board (9V, 4.5V, and 5V), but it would give a more stable supply voltage for the multiplier.

2 Amplitude Modulation

In the first part of this lab, you will use the multifunction signal generator to create some AM waveforms using the built-in modulating function of the signal generator. We will then probe these signals with the oscilloscope and the low-frequency spectrum analyzer to confirm your prelab studies into the shape and form of AM waves.

1. Set Channel A to output an AM signal with f_c=30kHz, V_c=1V f_m=1kHz, and m=0.25.
2. Observe the results on the scope and spectrum analyzer for 25, 50, 75, and 100 percent modulation (sketch roughly in lab notebook).
3. Note the amplitude of the side-bands and carrier in each case and briefly explain the results.

   Unfortunately, although we have three machines which generate AM signals, none of the signal generators will not allow you to use more than 100% modulation.

   To see what happens when over-modulation takes place, you must add three independent sine waves together. We can model overmodulation this way because an AM signal is essentially three sine waves, consisting of a carrier signal (for our case at 30kHz) and two sidebands at 29 and 31 kHz. By adding these three signals together, keeping the two sidebands at the same relative amplitude, and varying their amplitude relative to the carrier signal, we can create an overmodulated signal. Note that to get a true AM signal, each of the sidebands is phase shifted from the carrier by 90 deg.

   - Set channel A to be a 30kHz sine wave, amplitude 2V, phase 0 deg, destination Out1
   - Set channel B to be a 29kHz sine wave, amplitude 1V, phase 90 deg, destination Out1
   - Set channel C to be a 31kHz sine wave, amplitude 1V, phase 270 deg, destination Out1

   At this point, you should have a 100 % amplitude modulated signal. The percent modulation can be varied simply by changing the amplitude of the 30 kHz carrier signal.

4. Set the carrier(channel A) amplitude to be 1 V, 0.5 V, 0V. Compare these results to your prelab results.
5. Observe the effect of overmodulation on the signal envelope (sketch roughly).

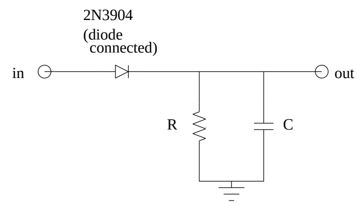

Figure 1: Peak Detector

3 AM Demodulation using the Peak Detector

We now move onto the demodulation of these signals.

Build the peak detector that you designed in the prelab on a breadboard (this is not part of your final project, so you do not need to solder it to your board). Using the signal generator, input an AM signal with a 30kHz, 1V carrier and a 1kHz modulating signal with 50% modulation. For the low-frequency signal generator, this is equivalent to setting Channel A to a 2V amplitude with 30kHz frequency, and setting Channel B to AM (under 'destination') and 50% modulation.

Connect this signal to the oscilloscope and the (low-frequency) spectrum analyzer and check that you have the correct input. Now connect this signal to the input of your envelope detector.

1. Observe and plot the frequency and time domain output of your circut. Compare these plots with your prelab results and comment on any differences you find.

2. Vary the percentage modulation on your AM signal. Measure and record the THD for modulations of 10%, 50%, and 100%. Compare the 50% modulated result with your prelab (give percent error). Note that THD equals the RMS value of the harmonics over the RMS value of the fundamental frequency. THD can be calculated directly by the spectrum analyzer or by the following equation:

$$THD(\%) = 100 * \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2}}{V_{fund}}$$

   NOTE: Be careful when measuring THD with the low-frequency spectrum analyzer. Like many other scopes, it only measures what is actually visible on the screen. Worse, it will only measure a set number of harmonics. If your results do not match your prelab results, please make sure that you are considering all sources of distortion. This may require you to measure and calculate THD by hand.

3. Vary the carrier voltage on your AM signal. Measure and record the THD at m=50% for carrier levels of 100mV, 1V, and 5V (adjusting Channel A accordingly). In the case of the 1V signal, your original input was a modulating signal of 1kHz at 0.5V, what is the amplitude of the signal you received (i.e.: how much of the signal was lost)?

4. Change the resistor values to illustrate diagonal clipping and rippling distortion as you did in the prelab. Plot the time domain results and compare THD values with your prelab results.

4 Characterizing the Four-Quadrant Multiplier

The four-quad (AKA cross-coupled multiplier) is a much more versatile circuit than the basic transconductance multiplier. One of the most important differences is the ability to allow carrier suppression. It should be clear that all the information that is being transmitted in a radio signal is contained in the sidebands.

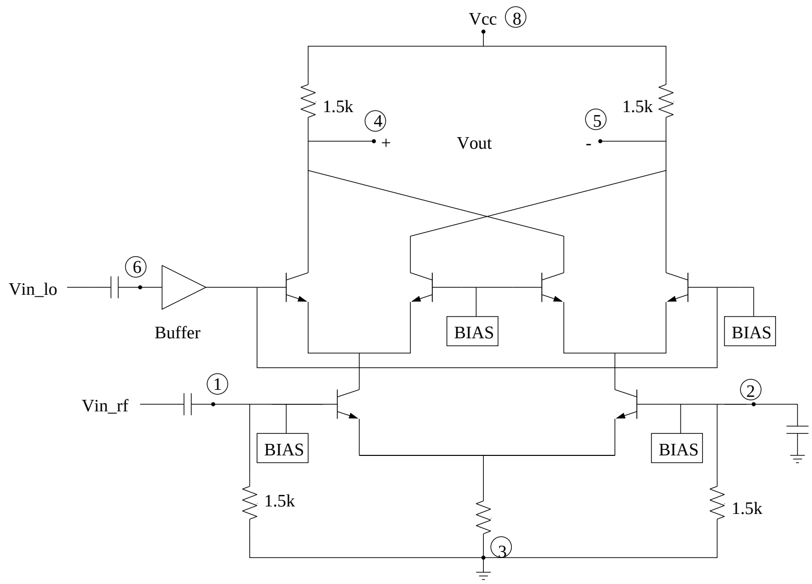

Figure 2: The SA612 Four-Quadrant Multiplier

Thus, transmitting the carrier is a waste of power. One of the key parameters of your cross-coupled multiplier, then, is how much suppression of the carrier can be achieved. This is measured in dB below the sidebands. Thus, if carrier suppression is 50 dB, that means that the carrier was 50 dB below the amplitude of the sidebands.

The cross-coupled multiplier is not perfect however. One of the problems is the distortion that takes place because the carrier signal is not a small signal. When you eventually get your multiplier working, you should notice that the output signal is not a modulated sine wave, but a distorted one. This will result in copies of the carrier and sidebands.

We now will begin testing the cross-coupled multiplier built with the SA612 on the transmitter side:

1. **Gain Conversion and Compression:**

   (a) Start with a carrier frequency of 24 MHz at +1.5 dBm power into the multiplier. Note that there is an impedance mismatch, and that you will want to measure the correct voltage at the input with an active probe. You might recall from the datasheet that using this magnitude of voltage at the input is not recommended for general use. We will now examine why.

   (b) Use a modulating sine wave of frequency 2 MHz with amplitude 50 mV peak-to-peak. Any frequency sinusoid would do, but 2MHz gives clear spacings on the high-frequency spectrum analyzer.

   (c) Observe the output waveform on the oscilloscope and spectrum analyzer. Are these results consistent with your prelab?

   (d) What is the conversion gain? Does it agree with the datasheet?

   (e) Using the oscilloscope to measure your signal, reduce the carrier level in steps until the multiplier ceases to act as a multiplier (we're just after a qualitative assessment, so just estimate this). Switch over to the high-frequency spectrum analyzer and note that the signal is still discernable in the frequency domain (and still discernable by your circuit). What is the smallest level you can discern? You many want to decrease your resolution bandwidth to lower the noise floor. Keep this in mind as you measure your signals in the future.

Now carefully repeat this experiment with the high-frequency oscilloscope. What changes in the frequency spectrum of the resulting output do you observe? Record any change in conversion gain as the carrier power changes, and postulate a reason for any changes. For the most part be qualitative in your records, but be sure to record the output spectrum at 1.5dBm and -45dBm for comparisons to later measurements.

2. **Power Supply Sensitivity:** Vary your power supply voltage from 4.5 between 3-7V. Do you see any changes in conversion gain or the output? Is this what you expected? Plot these changes vs. voltage for your lab report.

3. **THD:** Now, apply two new inputs, $f_{c1} = 1.0MHz$ with +1.5dBm power to the LO port, $f_{c2} = 1.003MHz$ with 50 mV amplitude to the RF port. You should get a 3kHz output that you can view on the low-frequency spectrum analyzer. Use the low-frequency spectrum analyzer to find your THD. Repeat for a RF generator setting of -45dBm for f_{c1}. This information will be useful later on during system integration.

4. **Optimum Inputs:** From your experiments, what should be the carrier input level to your SA612? Is there a limit on the voltage that the modulating signal should have?

   Can you think of other figures of merit that you should be concerned about for your multiplier? Can you think of an experimental setup to measure them? You're not required to find one, but it is a good idea to start thinking about what might be useful figures to know when you start plugging things together. In the future, we will not be prompting you for every figure of merit, it will be up to you to decide what you need and measure them.

   One figure you should add to your list is the frequency response of your SA612. We've actually already measured this for you and the -3dB point is around 350MHz. (Take home message: you won't be hitting any frequency barriers using the multiplier at 24MHz.)

5. **The Receiver SA612:** Make a few measurements of your choice to characterize your receiver-side SA612 and to verify that it is working properly. Please be careful about the frequencies you choose to measure at, the receiver-side has AC coupling caps that only work at high frequencies.

5 AM Demodulation using Syncronous Detection

To investigate demodulation, use the RF signal generator to produce an AM 400Hz signal on a 24 MHz carrier. Connect this output with the lower input of the SA612. The other input should be another 24 MHz sinewave (usually called a local oscillator, or LO) from a signal generator. You will have to use a long cable and hook up a generator from another bench. Be sure that the LO power is large enough to give good conversion gain and carrier supression.

1. **Distortion Measurements:** What is the THD on the received 400Hz signal? How does this change with varying signal and carrier amplitudes? How does this THD compare with your envelope detector of lab 1?

2. **Your First Demodulated Audio Signal:** Now turn off the 400Hz sine wave and modulate the signal with an external input. Use the output from the radio (using the headphone jack available in lab) as this modulating signal. Connect the output of the circuit to the amplifier/speaker and enjoy the music.

Good work! Remember to put all your cables back and to clean up your station before you leave.