ENSC 327
Communication Systems

Lab 2: FM Modulation and Demodulation

Group 17
March 13, 2017

Jyotsna Jaswal	301244386
Emmanuella Lagou	301234127
Lestley Gabo	301170055
Paola Pilaspilas	301086355

Introduction

The aim of this lab is to get familiar with variation in FM modulated wave signal due to various variables likes change in amplitude and frequency of the message signals. We first study the modulation of the FM signal in the time domain and observing the results of different kf and Am values in low frequencies. Then we look at the FM signals in the frequency domain and similarly observe the results of the different kf and Am values, but this time in high frequencies. Lastly, we demodulate the FM signal using a phase locked loop (PLL) and compare the signal before and after FM demodulation.

Equations

In frequency modulation, the signal equation is shown below:

$$s(t) = A_c\, cos(2\Pi f_c t \; + \; 2\Pi k_f \int_0^t m(\varsigma)d\varsigma) \tag{1}$$

Where *kf = frequency* sensitivity of the modulator and *fc= Carrier frequency*.

In this lab, we will study the angle modulation. The modulated signal that will be generated for this lab will be of following form:

$$m(t) = A_m \cos\left[2\pi f_m t\right] \tag{2}$$

Where *Am = Amplitude* and *fm = Message* frequency.

For time domain in FM modulation, the measurements we will obtain can be used to calculate the frequency deviation, *Δf*, and the modulation index, β. The equation below will be used to calculate the frequency deviation:

$$\Delta f = \frac{\max \;\; frequency \;\; - \min \;\; frequency}{2} \tag{3}$$

From here we double checked to see if the frequency calculated matches our expected frequency deviation by using equation 4 below:

$$\Delta f = k_f A_m \tag{4}$$

Then we can calculate the modulation index by using the following equation:

$$\beta = \frac{\Delta f}{f_m} = \frac{k_f A_m}{f_m} \tag{5}$$

In the frequency domain of FM modulation, we will also compare our measured bandwidths with the actual values using Carson's rule. The Carson's rule equation is shown below:

$$BW = \; 2\Delta f + 2f_m \tag{6}$$

For FM demodulation, we recover the message signal from the modulated signal with the equations:

$$s(t) = A_C \cos(2\pi f_c t + 2\pi k_f \int_0^t m(\tau) d\tau) \quad (7)$$

$$\frac{ds(t)}{dt} = -A_C 2\pi \left(f_c + k_f m(t)\right) * sin(2\pi f_c t + 2\pi k_f \int_0^t m(\tau) d\tau) \quad (8)$$

3. FM Modulation

In this part of the lab we generated a message signal by connecting audio oscillator to the VCO at different amplitudes and frequency of the message signal, and altered the frequency sensitivity, kf, of the VCO to generate different FM modulated signals. To obtain the frequency sensitivity, we first supplied the VCO with a 1 DC voltage using the buffer amplifier, and made f_0 = 10 kHz. The frequency sensitivity was applied to The VCO frequency by changing the gain on the VCO module panel.

3.1 Time-Domain Measurements

We supplied a message signal using the audio oscillator at varying amplitude and frequencies, and observed the outcomes on the oscilloscope. The results for the highest frequencies and lowest frequencies were measured by moving the cursor measure to the starting and end points on both the very left and the very right most sine signals.

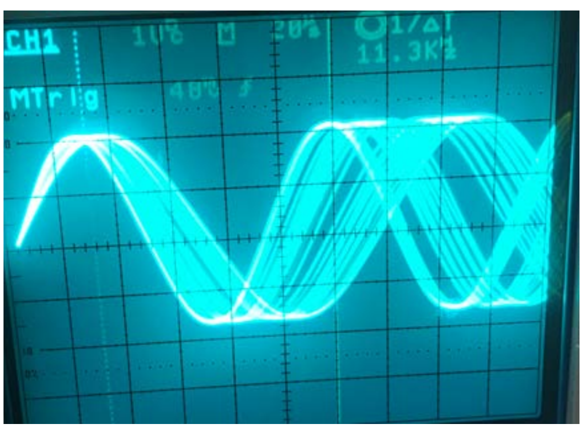

Figure 1: 2v pk-p kf = 1kHz/V highest frequency

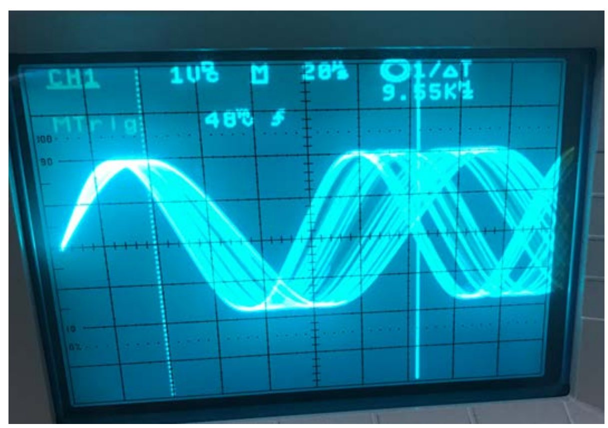

Figure 2: 2v pk-pk kf = 1kHz/V lowest frequency

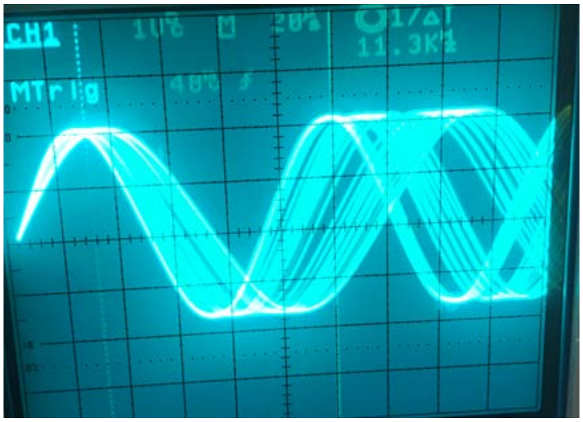

Figure 3: 3V pk-pk kf = 1KHz/V highest frequency

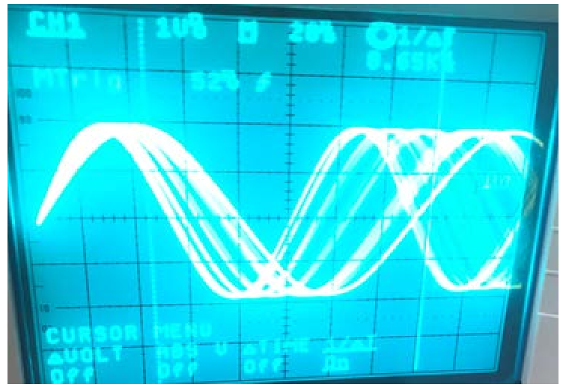

Figure 4: 3V pk-pk kf = 1KHz/V lowest frequency

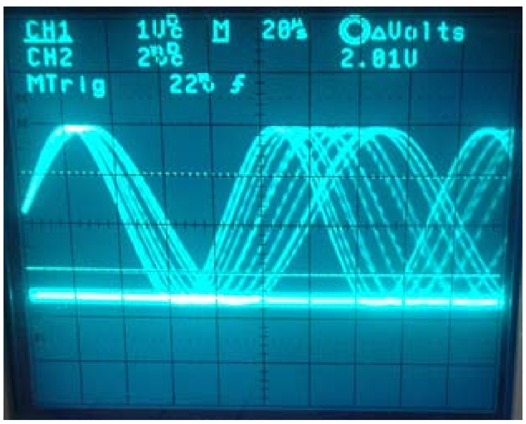

Figure 5: 2v pk-pk kf = 2kHz/V

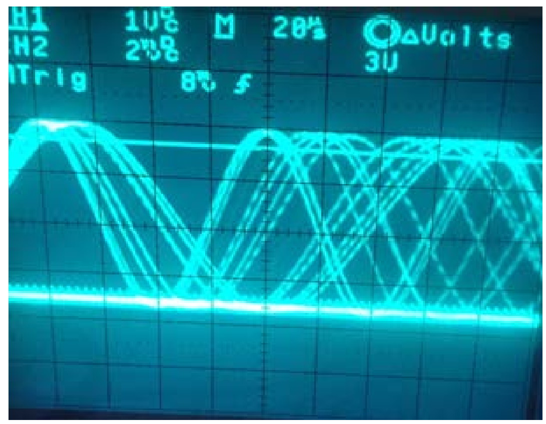

Figure 6: 3v pk-pk kf = 2kHz/V

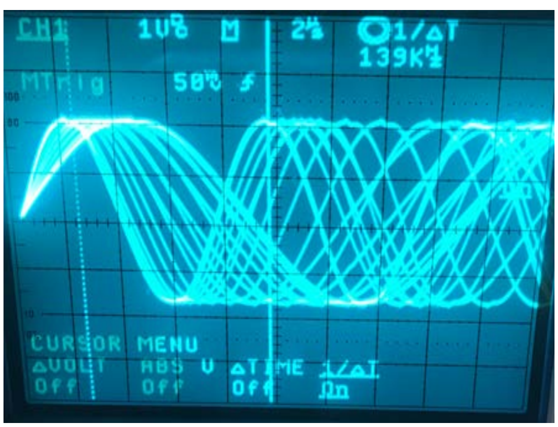

Figure 7: 3V pk-pk kf = 20 kHz /V highest frequency

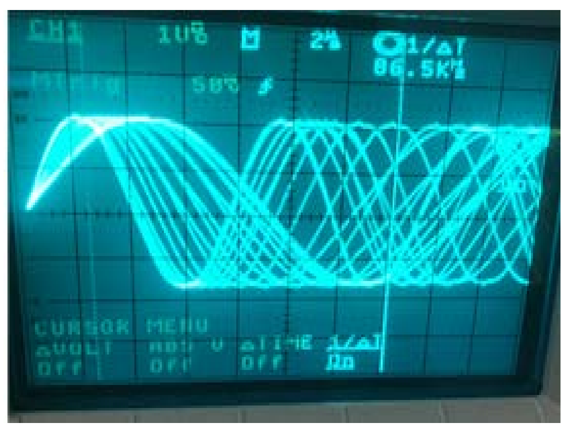

Figure 8: 3V pk-pk kf = 20 kHz/V lowest frequency

Figure 9: 2V pk-pk kf = 20 kHz/V highest frequency

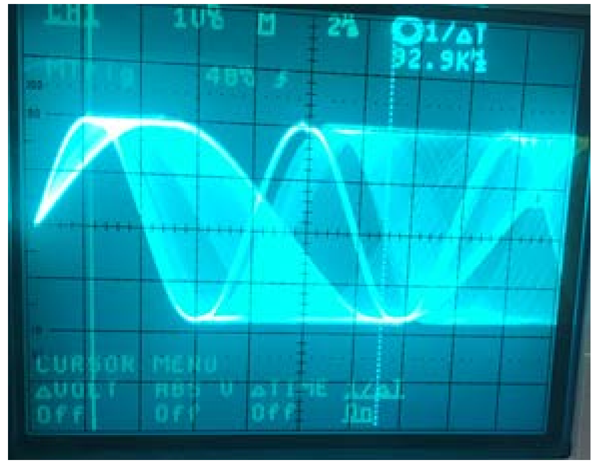

Figure 10: 2V pk-pk kf = 20 kHz/V lowest frequency

Figure 11: 1V pk-pk kf = 20 kHz/V highest frequency

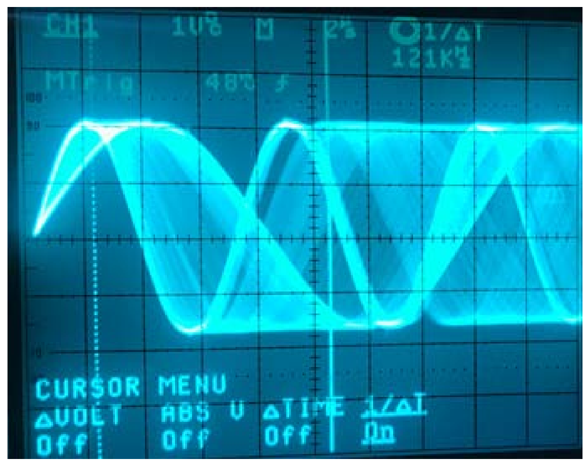

Figure 12: 1V pk-pk kf = 20 kHz/ V lowest frequency

Table 1: Measurements and calculations taken from oscilloscope

A_m (V)	K_f (kHz/V)	Max frequency (kHz)	Min Frequency (kHz)	Δf (kHz)*	Modulation Index , β
0.505	20	146	121	12.50	1.250
1.005	1	11.5	9.55	0.975	1.950
1.005	2	11.34	7.55	1.895	3.790
1.005	20	128	92.9	17.55	1.755
1.505	1	11.3	8.65	1.325	2.650
1.505	2	11.35	5.43	2.96	5.920
1.505	20	139	86.5	26.25	2.625

3.1.1 Time-Domain Discussion

The table values in table 1 above may not be as accurate because of not knowing where to accurately place the cursors for the high and low frequencies measurements. But the expected and calculated frequency deviations are roughly around the same.

3.2 Frequency Domain Measurements

In this part, we analyzed the behavior of the circuit behavior implemented in Section 3.1 in frequency domain with change in few parameters. The frequencies were changed to the maximum values in this part to get a better understanding and view on spectrum analyzer.

Bandwidth calculations for the FM signal,

Given,

Center Frequency of the VCO = 110 KHz and *CBR* = 20 kHz/volt

$$BW = 2(\Delta f + fm) = 2(40+10) = 100 \text{ kHz}$$

Where,

CBR = Bandwidth requirement

Δf = Peak frequency deviation

fm = Highest frequency in the modulating signal

From Figure 13, consider n0. 2 till 10 to be valid bandwidth

From Figure 14, consider n0. 1 till 10 to be valid bandwidth

From Figure 15, consider n0. 3 till 7 to be valid bandwidth

Table 2: FM frequency domain calculations

Δf	**BW cal= 2* (Δf+ f)**	**BW measured**
20K * 3	140 kHz	99.264 kHz
20K * 2	100 kHz	100.12 kHz
20K * 1	60 khz	41 kHz

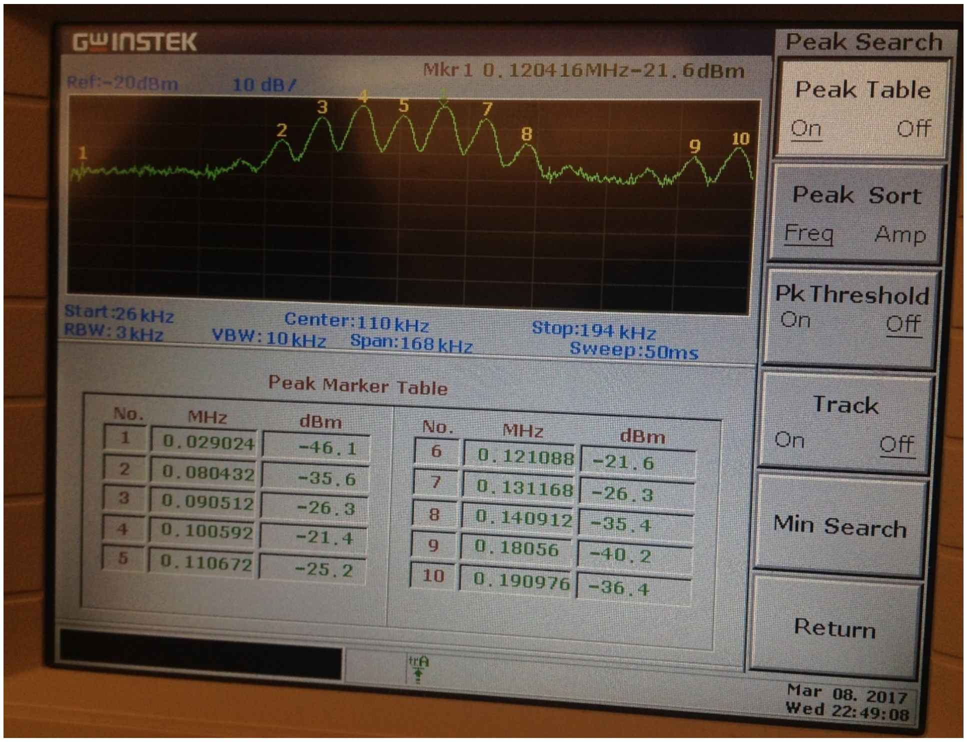

Figure 13: 2 volt pk-pk with 10 kHz frequency and kf = 20 khz/V

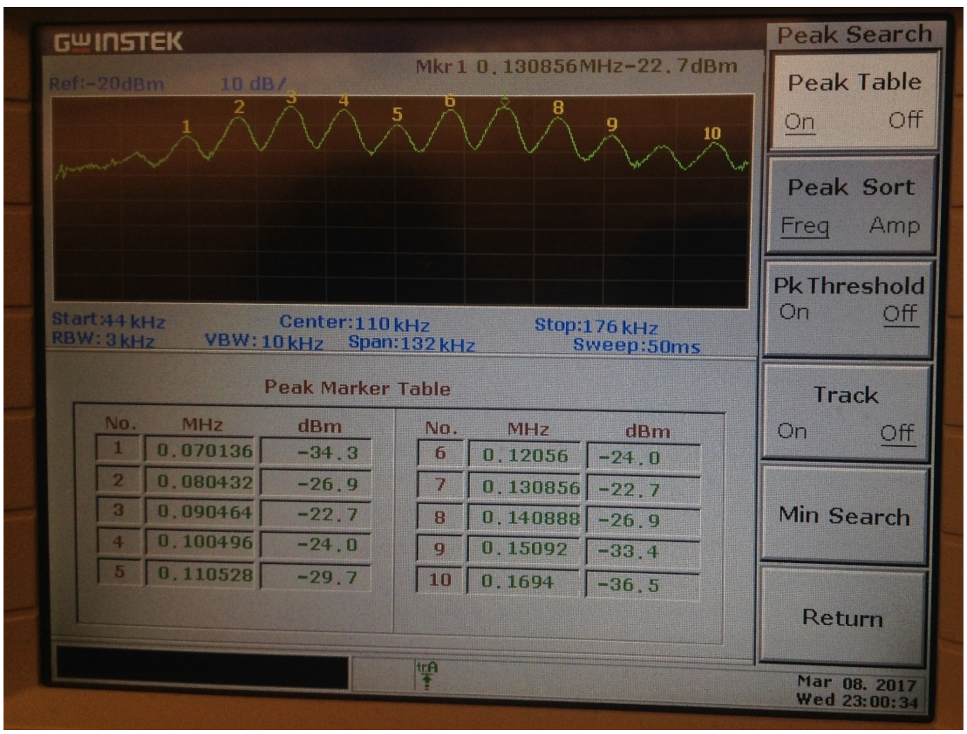

Figure 14: 3 volt pk-pk with 10 kHz frequency and kf = 20 khz/V

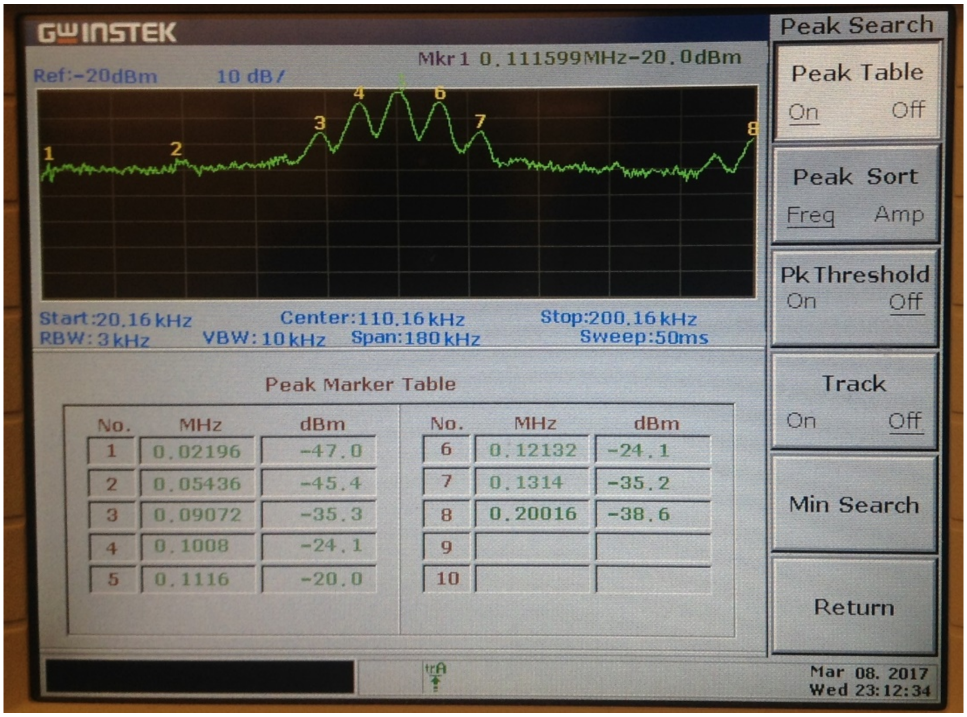

Figure 15: 1 volt pk-pk with 10 kHz frequency, kf = 20 khz/V before increasing amplitude

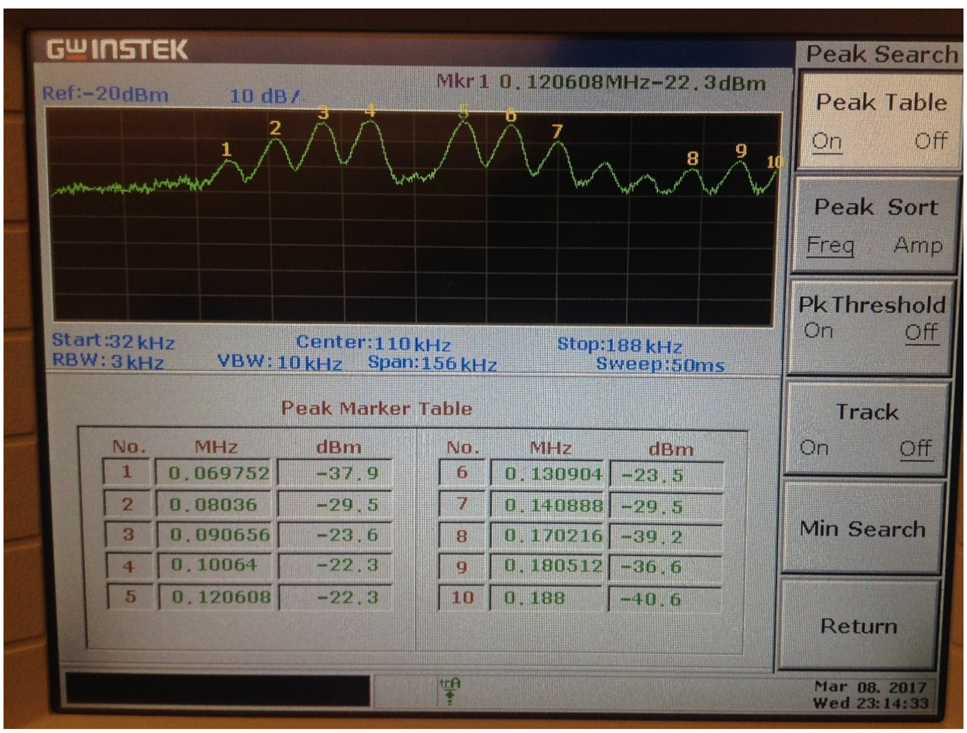

Figure 16: 1 volt pk-pk with 10 kHz frequency, kf = 20 khz/V after increasing amplitude

Based on these observations, we can calculate modulation index and frequency deviation.

β theoretical = $J_0(x)$ = 2.4

β calculated = delta f / fm = 4.6

Power calculations:

From Figure 13,

P1 = -21.4 dBm; P1/P2 measured = 1.2061 (converting from bBm 10^(p1/p2/10))

P2 = -26.3 dBm; P2/P3 measured = 4.7797 (converting from bBm 10^(p1/p2/10))

P3 = -35.6 dBm

Using the Bessel function,

J1 ^2 /J2 ^2 at beta 2.4, P1/P2(theoretical) = 1.46

J2 ^2 /J3 ^2 at beta 2.4, P1/P2(theoretical) = 4.6225

3.2.1 Frequency Domain Discussion

It can be analyzed that the bandwidth decreases if we reduce the amplitude of the source. The calculated power ratios almost match the theoretical power values. The calculated BW values do not match the theoretical values in couple of cases and it can be due to the less number of values recorded for the experiment or the other reason could be setting of the spectrum analyzer.

4. FM Demodulation Using PLL

Frequency demodulation is a process in which the original message signal is recovered from an incoming FM wave. This involves changing the frequency variations in a signal into amplitude variations at baseband. There are two techniques in accomplishing this and that is by frequency discriminator and phase-locked loop. In this lab, we've used the phase-locked loop technique.

Phase-locked loop is a feedback system that generates an output signal whose phase is related to the phase of an input. The direct FM modulated signal will be generated by using voltage controlled oscillator (VCO), where the output frequency is proportional to the voltage of the input signal. A block diagram of the Phase Locked Loop (PLL) is shown below:

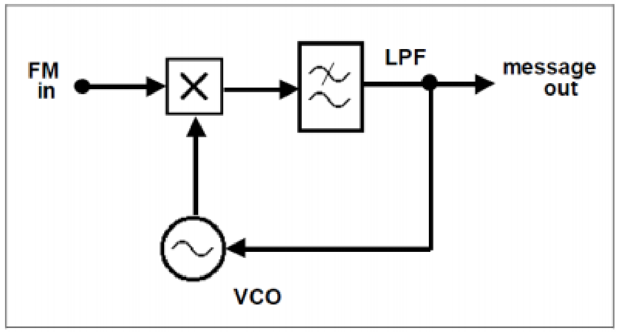

Figure 17: Phase Locked Loop (PLL)

From Figure 17, PLL has three major components: VCO, multiplier and a loop filter. VCO performs the frequency modulation on the control signal, the multiplier multiplies the incoming FM wave by the output of the VCO and the loop filter removes the high frequency components from the multiplier's output signal.

The following properties for our FM signal is given to the table below:

Table 3: FM signal properties for PLL

VCO Center Frequency	100 kHz
FM Frequency Sensitivity	2.5 kHz/volt
Message Signal	2 kHz sinusoidal signal

As a result of the circuit block in Figure 17 and the properties in Table 3, we have observed the message signal and the output of the PLL on the oscilloscope below:

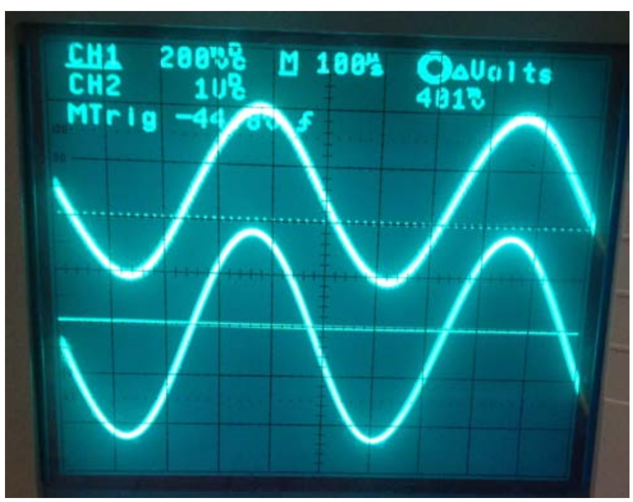

Figure 18: FM modulated signal channel 2 on the bottom and FM demodulated message out channel 1 on the top

4.1 FM Demodulation Using PLL Discussion

An error we did when we first assembled the PLL in the TIMs machine was that we created two FM signals. This was because we knew we were supposed to use two VCO modules and assumed this PLL is just two FM signals with one FM signal's input as a feedback loop output. We learned that this was a mistake and that only one FM signal was needed. The other VCO should only be a VCO. So, as Figure 17 shows, the PLL is an FM signal multiplied with a VCO whose input is the PLL output.

From Figure 18, our input signal is the bottom signal while our output signal is the top signal. Our input signal is 2V Pk-Pk with a center frequency of 2 kHZ. While our output signal is 400 mV Pk-pk. In comparing our input and our output signals, we can observe that there a slight phase shift to our output signal.   An important feature of the PPL where the bandwidth of the incoming FM wave can be much wider than that of the loop filter.

In addition, just by looking at Figure 18 we can see that the output signal is slightly shifted from our message signal. This is most likely because of the low pass filter in the PLL which introduced some phase shift. Aside from this, we were able to successfully demodulate an incoming FM signal and produce an output signal similar to our input signal.

Conclusion

We have successfully observed the FM modulated signal with different amplitude and frequency message signals. In the FM modulation section, we observed that as we decreased the frequency deviation the power peaks of the FM modulated output were more evenly spaced. Also, in the FM modulation section we found that our calculated values using Carson's rule matched that of the data from our experiment.

During the frequency domain section of the FM modulation we observed that the signal strength of the carrier frequency reaches a minimum at a certain message amplitude. We know that this changing of the amplitude also changes the bandwidth signal.

In the FM demodulation, we first had a non-sine wave looking output which would not be the expected output of a demodulated signal. Thus, we had to adjust our PLL by increasing the gain of the VCO. We increased the gain of the second VCO and not the VCO that the FM input used. We were then able to observe a demodulated FM signal at the expected 2 kHz frequency.