

# EE133 - Lab 4

## FM Demodulation using the PLL

### 1 Introduction

This should be an exciting lab (honest)! By the time you're done, you should be sending and receiving your very own FM broadcasts from within the confines of the lab. With that basic functionality under your belt, we'll then spend the next few weeks on improvements to increase performance in range and SNR.

First, we will need to get the Phase-Locked Loop up and running and characterize its limitations. This is particularly important because the rest of our system will need to accommodate the PLL specs if the whole radio is to function. In other words, it is worth your while to be diligent in your characterization. Then, we will practice some simple FM demodulation with the PLL (using signal generators as inputs). Finally, we will integrate the blocks of the transmitter and receiver so that you can broadcast your favorite music across the room (be sure to bring a CD!).

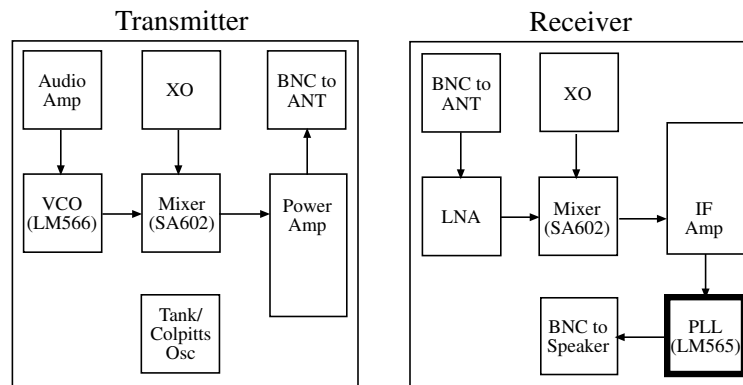


Figure 1: Roadmap for Lab 4

### 2 The Phase-Locked Loop - Signal Tracking

The first thing you will do with the PLL is get it working and use it to track an incoming signal. The circuit is (obviously) the one you designed (and hopefully built) during your lab preparations (It's included in Figure 2 just for your reference.)

1. Build and power up the LM565 with  $V_{cc} = 9V$ . Note the 4.5V DC biasing of pins 2 and 3. This is necessary for proper operation of the phase comparator (multiplier). **Before proceeding, be sure your LM565 is not on the same power and ground rails as your SA612 or crystal oscillator.**
2. View the VCO Output (pin 4) on the oscilloscope with no input connected. You should have a free-running frequency of around 300kHz (if not, tune it using the potentiometer with which you realized  $R_o$ ). What is the  $f_o$  of your PLL?
3. Connect a 1V sinusoid at your  $f_o$ . The PLL should now lock onto this incoming signal. The VCO output will be seen in the time domain as a steady square wave. The scope should be displaying both the input signal and the VCO output. Since the input signal is at the free running frequency of the VCO, the two signals should be 90 degrees out of phase with each other. Sketch or plot the two signals to verify this result.

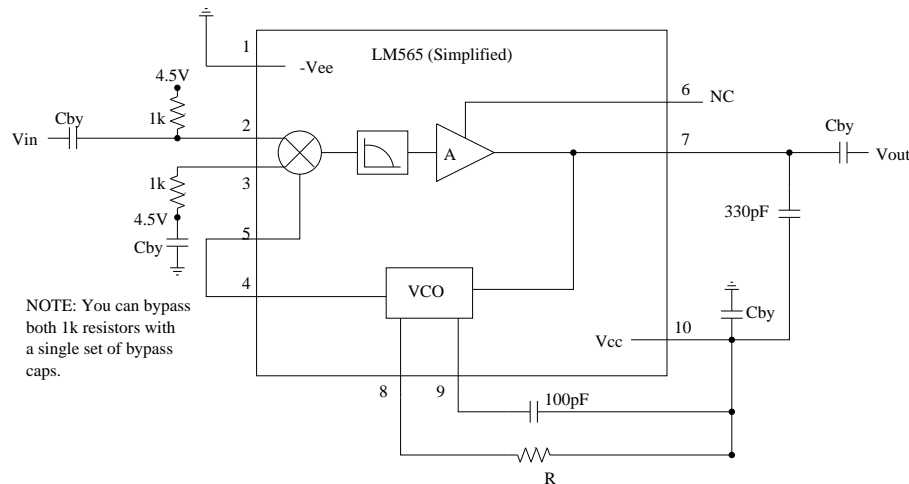


Figure 2: LM565 PLL

4. Measure the DC voltage on the output of the PLL. (If you have a DC blocking capacitor at the output, you should look at the inside of that cap, or directly at pin 7.) Does this agree with your prelab results for the free running frequency voltage?
5. Now, change the frequency of the input waveform to 350 kHz. Be sure the PLL is still locked at this frequency by examining the VCO output. Then, lower the input voltage until the PLL loses lock. What is the minimum detectable input signal of your PLL?  
*Note:* You can tell that lock has been lost when a large number of different signals suddenly appear in the frequency spectrum, and when the time domain trace is no longer clean and steady. This represents the fact that the PLL is now “searching” for an input signal it can lock to.
6. Please reset your signal generator to 1V at  $f_o$ . Then, vary the input signal frequency until the PLL loses lock. Plot or sketch the time domain signal just before it loses lock on either side.
7. Record the maximum and minimum “lockable” frequency and the respective phase differences observed. What is your lock range? Also, record the DC value of the output at the highest and lowest frequencies that lock. Do the lock range and observed phase differences agree with theory? Given your actual hold range, what equation for  $f_H$  would fit your data? (*Hint:* it’s probably not the equation in the data sheet, though it should depend on  $V_c$  and  $f_o$ )?
8. Record a few more corresponding pairs of input frequencies and DC output voltages within the lock range. Roughly sketch the graph of VCO frequency versus output DC voltage. Give an approximate value for  $\kappa(mV/kHz)$  - the ‘constant’ that relates a change in input frequency to a change in DC output voltage. Is  $\kappa$  constant across frequency? Why, or why not?
9. According to theory, why is there a difference between the output voltage when you apply a single-frequency signal and the output voltage in the free-running case? Is this consistent with your plot?
10. Reduce the power supply from 9V to 7.5V. What do you observe? What do you observe if you reduce the power supply to 6V?
11. Set the power supplies to 16V. (Be sure that doing this will not damage other chips connected to the power supply or the 4.5V reference - if it will, disconnect the power to those chips). Now re-check the lock range. Does it agree with theory?
12. Reset the power supplies to 9V.

### 3 FM Demodulation using the PLL

Now that you've seen how the PLL tracks a signal, we will explore one of its applications, FM demodulation. If we recall the original definition of FM, it is a signal whose frequency is proportional to a modulating voltage. We have just seen that a PLL produces an error voltage that is proportional to the frequency of the incoming signal. That's exactly what we need to demodulate an FM signal. In fact, it's as simple as setting the center frequency of the VCO in the PLL to the center frequency of the FM signal, and then taking the error voltage as the output. The only restriction is that the frequency deviation of the FM signal must be less than the hold range of the PLL, and that the frequency of the modulating signal be significantly less than the frequency of the carrier.

1. Set the input to the PLL to be a 1V, FM signal from the signal generator, with a center frequency equal to your  $f_o$  (hopefully, around 300kHz) and a 1kHz modulating signal with  $\Delta f = 30kHz$ .
2. Connect the scope and signal analyzer to the output (pin 7) of the PLL through the coupling capacitor.
3. At this point, the output should be a demodulated signal, at 1kHz, with a signal to noise ratio of at least 40 dB. If the low frequencies seem to be overpowered by feedthrough of the higher frequencies (i.e. if your output seems to be at  $f_o$  rather than at 1 kHz), build a low-pass filter and add it to the output (Be sure to add the LPF *after* the coupling capacitor at Pin 7). Don't spend too much time, we'll put in a more effective filter next week.
4. Plot or sketch this signal in the frequency and time domain. (Don't worry about how messy it might look in the time domain.)
5. Set the input FM signal to have a center frequency of  $f_o$ , and a deviation of 50kHz.
6. Record the S/N Ratio. At this point, you should have a signal with a good S/N ratio and THD (i.e. SNR near 40dB and THD from 1% - 5%).
7. Plot or sketch this signal in the frequency domain. As before, don't worry too much about its time domain appearance.
8. Attach the output of the PLL into a speaker and comment on the quality of the 1kHz tone.

### 4 Transmitting and Receiving

We are now going to hook up everything you've built up to this point, and get your first transmitter with super-heterodyned receiver system running. You have the option of proceeding through these steps with one of two different flavors of transmitter. The first is simply the Colpitts VCO. The second uses the SA612 (a.k.a. SA602, SA612, NE612 - they're equivalent), the fundamental-mode crystal oscillator, and the LM566. You are welcome to employ either one (or both) of these options - just follow the corresponding directions (denoted by *Colpitts VCO/LM566*).

1. Power up your transmitter from Lab 3 and view the 24.3MHz output signal on the spectrum analyzer. If you haven't built your audio amp yet, this is the time to do it.
2. For convenience, we will use music from the computer as the signal we are interested in transmitting. So, pop in your favorite CD or MP3 and hook up the audio output of the computer to the input of your audio amp (disconnect the microphone and use a big  $\geq 22\mu F$  coupling cap - if you'd prefer, you can just test with your voice) using a special BNC to stereo cable that will be provided by the TA's. Connect the output of the audio amp to the *base of the varactor/the RF port*. Turn up the volume until you get a  $\Delta f = 50kHz$  (but, turn down the computer speakers so that you do not damage them with the high volume).

3. *LM566 only*: Check that your SA612 transmit multiplier from Lab 2 is still operational. With the fundamental-mode crystal oscillator feeding the LO port at 24 MHz, connect the output of the LM566 VCO to the RF port. Depending on the size of your LM565 output and the maximum allowable input signal for the SA612, you may need to attenuate the signal coming from the VCO.
4. Then, connect *the node between the tapped inductors where the spectrum analyzer would otherwise be placed/the output of the SA612 on the transmitter* to the RF input of the SA612 on the receiver (the LO port of the receive SA612 should still be fed with the crystal oscillator). You might need to move some BNC's around to do this. If you have more than 2 BNC's left on your board, we highly recommend removing them and giving them back to the TA for reuse. View the output on the spectrum analyzer and make sure that you get a signal at 300kHz. What is the approximate signal power at 300kHz?
5. Now hook up the output of the receive multiplier into the PLL and hook the output of the PLL into a speaker. Comment on the relative quality of the music compared to what you got with the AM synchronous detector.
6. Disconnect the transmitter from the receive SA612 and now use 2 antennas to transmit and receive; one off the *tapped inductor/output of SA612* on the transmit board and one into the SA612 on the receive board (When you get to this step, be sure to let others in the lab know you are transmitting so that they are not surprised when their signals are jammed. Be sure to turn your circuit off when you are done!). Turn on the receiver and (hopefully) listen to the music. Comment on the sound quality now. If it doesn't work, look at the output power of the multiplier. Is this signal large enough for the PLL to lock onto?
7. Move your circuits further apart until the receiver stops operating and record this approximate distance.
8. For completeness, use a 1kHz modulating input into the *base of the varactor/VCO input* with the amplitude from Lab 3 needed to get a 50kHz deviation. Record the signal to noise ratio of the 1kHz output (from the PLL) first with antennas then with the transmitter and receiver directly connected.
9. Now that you've modulated a signal and demodulated again, try increasing the range by hooking up your LNA into the sequence. Find the minimum detectable signal via antenna then via direct connection. What effect does the LNA have?

Congratulations on getting the whole system working! The rest of the quarter should be easier, as you are now an expert RF engineer. From this point on, we will concentrate on the fun stuff: making the system work farther, be portable, and look pretty. Looking ahead we'll be working on the Intermediate Frequency(IF) Amplifier next week which will boost the distance at which your receiver can demodulate signals, and then we'll work on a power amplifier for your transmitter, so that you'll be able to transmit across campus.