EXPERIMENT #8
FREQUENCY MODULATION

INTRODUCTION:

Frequency modulation, or FM, is an important method of impressing information on a carrier. It has many advantages over AM. First, since FM only changes the frequency and not the amplitude of the carrier wave, FM receivers can be built to ignore amplitude (voltage) changes. This is important because most external noise is in the form of voltage variations that are "added" to the carrier wave as it makes its way from transmitter to receiver. An AM receiver directly responds to these with the familiar sounds of static interference; an FM receiver ignores these amplitude changes, almost eliminating the effect of the noise.

Second, it is much easier to design systems to reproduce high-fidelity sound using FM. "High-fidelity" means accurate signal reproduction with a minimum of distortion. The reproduced information signal is a very close replica of the original in an FM system. It's difficult to build hi-fi AM receivers, partly due to the inherent nonlinear distortion created in a conventional AM diode detector, and also partly due to the limited transmission bandwidth (8 kHz) allotted for AM broadcast.

These advantages do come at a price; that price is increased bandwidth. A typical FM broadcast station uses up to 75 kHz of signal deviation (the peak frequency change), which results in a typical bandwidth of 150 to 200 kHz. Because of the high bandwidth requirements, FM broadcasting is done in the VHF band between 88 and 108 MHz. FM receivers and detectors are slightly more complex than those for AM; and the higher frequencies used for FM (VHF) complicate overall transmitter and receiver design.

The circuitry in this lab operates on a carrier frequency of 100 kHz, which is in the VLF band. At such a low carrier frequency, the frequency deviation needs to be limited so that the available bandwidth is not used up. FM systems with limited deviation are very commonly used where the highest fidelity is not needed. Voice-only communication systems in the amateur, business, and government radio services are typical "narrowband" FM applications. Most narrowband FM communications occurs in the VHF and UHF bands, where the reduced bandwidth requirement allows more stations to share the available range of radio frequencies.

CIRCUIT ANALYSIS:

This experiment is in two parts, an FM modulator and an FM detector. The circuitry is designed to operate in the VLF band at a carrier frequency of 100 kHz. The VCO portion of an LM565 is used to create the FM waveform, and an LM565 phase-locked-loop (PLL) operates as the FM detector.

FM Modulator

Figure 1 illustrates the FM modulator circuit. It's quite similar to the VCO lab, with two minor additions.
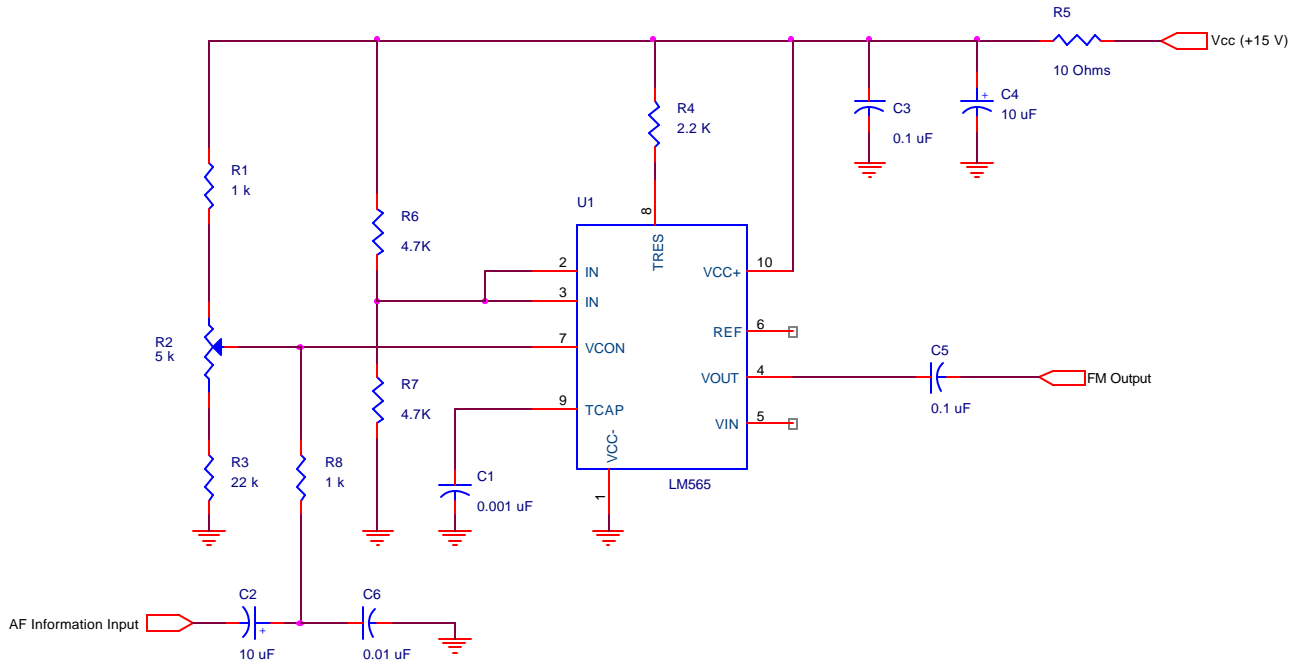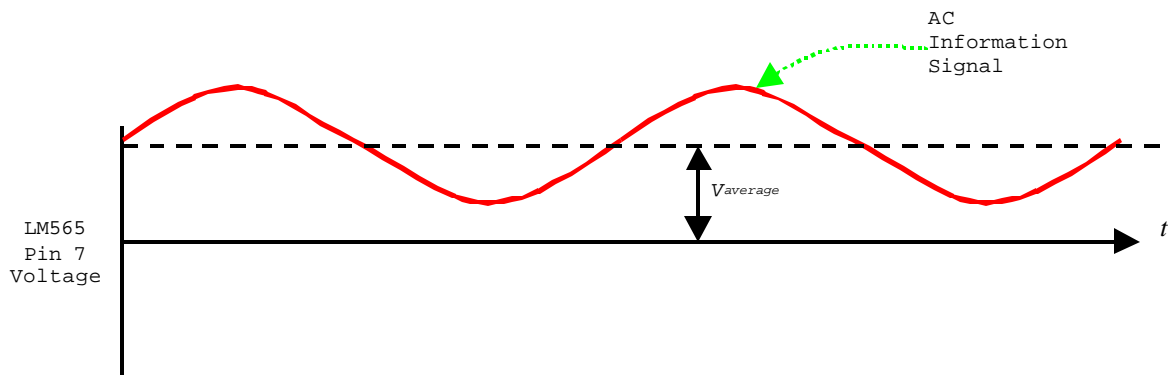
Figure 1: FM Modulator Employing the LM565

The first addition to the circuit is C2. C2 allows the information signal (an audio signal) to be AC-coupled into the control voltage input of the VCO (pin 7). The signal at pin 7 of the VCO looks like this:

Notice that the audio signal is now riding on top of a DC level, $V_{average}$. Potentiometer R2 sets this DC level, which controls the *carrier center frequency*. As the DC voltage rises, the VCO frequency decreases in direct proportion to the amount of rise. The voltage "rise" is actually the same thing as the amplitude of the information. Thus positive information causes negative carrier frequency change or deviation. The opposite effect happens on the negative peak of the intelligence; when the control voltage falls, the VCO frequency increases. In other words, *frequency modulation* occurs.

Modulator Sensitivity

The amount of frequency deviation produced in the VCO is directly proportional to the amplitude of the information signal. The amount of deviation can be predicted by using the following equation:

$$\boldsymbol{d} = V_m \times K_0$$

Where: K_0 is the modulator sensitivity, in Hz / Volt. (For this circuit, $K_0 = 72{,}727$ Hz/Volt.)
V_m = the *peak* information signal amplitude.
δ = the *deviation* or peak frequency swing, in Hz.

For example, if $V_m = 500$ mV peak, then the amount of deviation produced will be:

$$\boldsymbol{d} = V_m \times K_0 = (0.5 Vpk)(72.727\,KHz/V) = \underline{\underline{36.364\,kHz}}$$

This would probably be too much deviation, since the carrier frequency is only 100 kHz! *Therefore, the deviation in the experiment will be limited to 10 kHz.*

The FM output of the VCO could be directly transmitted over the air if two circuit additions were made. First, since the wave shape at the output pin is square it would need to be shaped into a clean sine wave using a low-pass filter; and second, some sort of power amplifier would be necessary since the signal output is quite small. Note that if you have access to a VLF receiver in your laboratory that can tune down to 100 kHz, you can monitor the output of this circuit.

FM Detector:

Figure 2 shows the FM detector. It's based on the LM565 phase-locked-loop. The loop is set to free-run at 100 kHz by C104 and the series combination of R107 and R106. Potentiometer R106 allows adjustment of the free-running frequency, which should be the same as the carrier or center frequency of the FM transmitter.
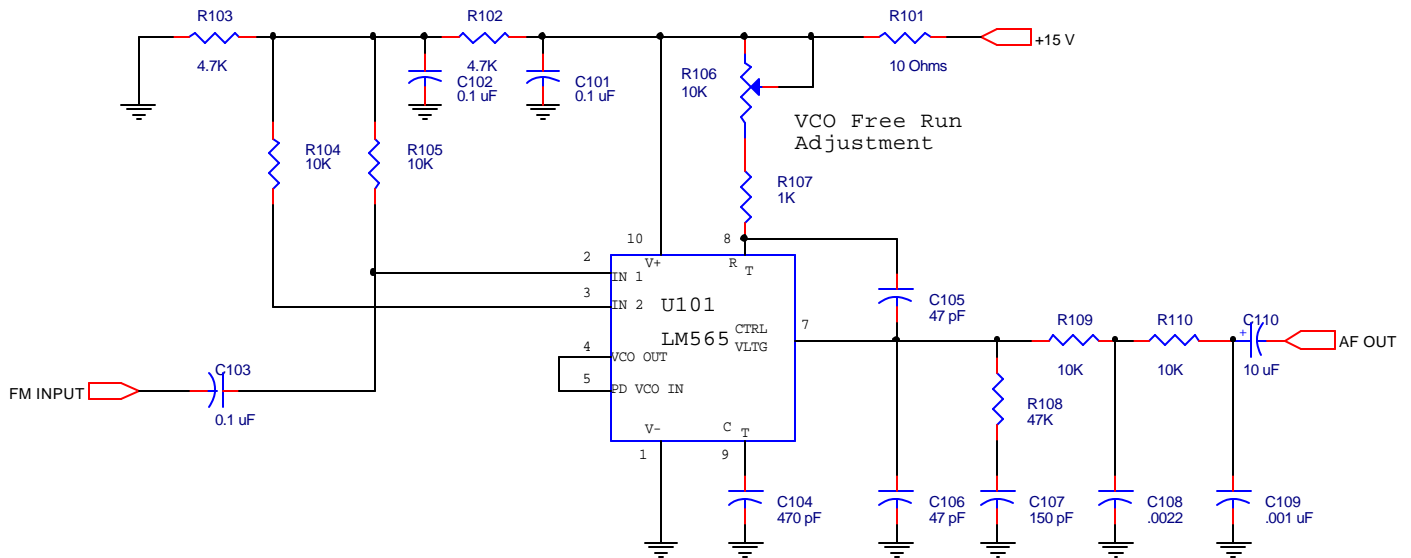

Figure 2: FM Demodulator Using the LM565

The FM signal is coupled into the number 1 reference input of the phase detector (pin 2) through C103. Since the PLL is operating from a single supply, resistors R102 and R103 are used as a voltage divider to split the power supply in half. Approximately 7.5 volts appears at the junction of R102 and R103 when the circuit is working properly. C102 is an RF bypass for the bias point, and R104 and R105 serve to isolate the two phase detector inputs (since signal should only be introduced into one input at a time.)

The VCO control voltage of the loop on pin 7 of the 565 contains two components. One is a DC level corresponding to the "average" frequency going into the PLL from the FM modulator, and the other is an AC level that is actually the detected information signal. This AC signal arises because of the PLL's self-correcting action; as the transmitter deviates up or down in frequency, the PLL attempts to force the VCO to follow this frequency *exactly* by varying its control voltage. Thus the control voltage is a copy of the original information signal.

Components C106, C107, and R108 form the loop filter which sets up the loop operating parameters (capture range, damping ratio, natural frequency) appropriately for demodulation of an FM signal.

The signal at pin 7 of the 565 contains some carrier frequency in addition to the AC and DC levels just discussed; components R109, C108, R110, and C109 form a low-pass filter to remove any traces of 100 KHz carrier signal. The final output is AC coupled by C110, leaving only demodulated information at the output.
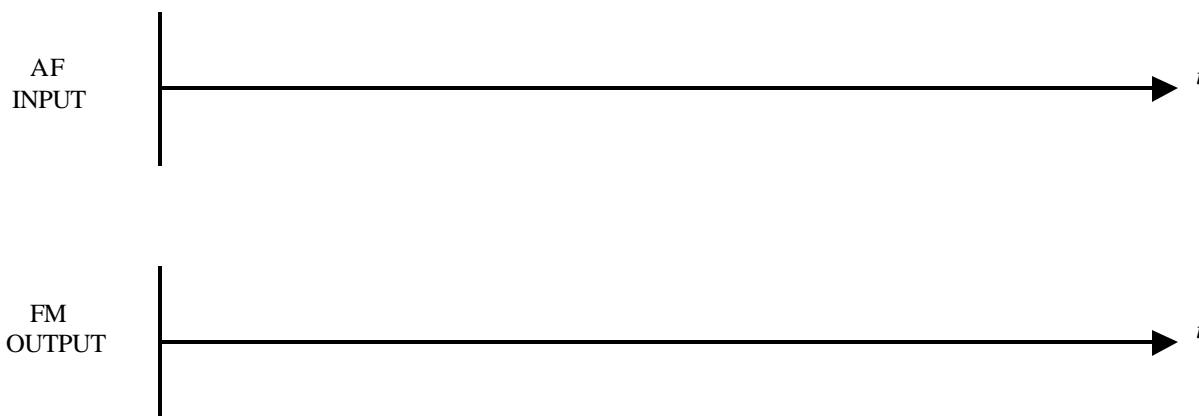
LABORATORY PROCEDURE:

Name _____ Sign-off _____

In this experiment you'll have two circuits to build. It is suggested that they be built on separate breadboards, if possible.

1. Build the circuit of figure 1. Don't connect anything to the *AF INPUT* yet.

2. Connect a frequency counter and scope to the *FM OUTPUT* of the circuit, and adjust R2 until a 100 KHz carrier wave frequency is obtained.

3. Now connect a signal generator to the *AF INPUT*. Adjust it for 1 kHz frequency, and correct peak voltage for 10 kHz deviation. (Remember that $K_0 = 72,727$ Hz/Volt.) Show your calculation below:

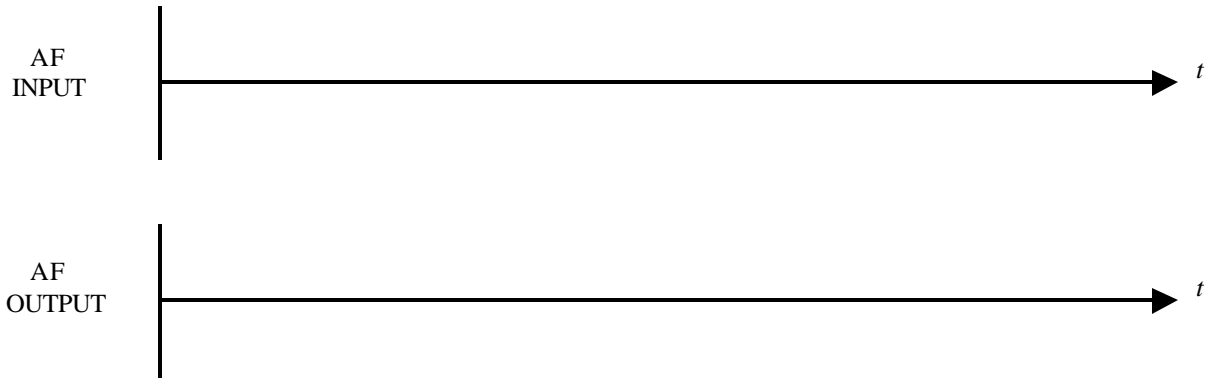   AF INPUT -- Peak voltage for 10 KHz deviation: _____ V pk

4. Connect scope channel 1 to the *AF INPUT*, and scope channel 2 to the *FM OUTPUT*. <u>Trigger off scope channel 1</u>. Adjust the controls appropriately, and draw what you see below:

AF
INPUT
⟶ t

FM
OUTPUT
⟶ t

5. How does the *FM OUTPUT* look with respect to the *AF INPUT* in question 4? Can you see the FM modulation taking place? Why or why not?

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6. Build the FM demodulator circuit of figure 2. Keep component lead lengths as short as possible.

7. Apply power to the demodulator circuit, but don't connect its FM INPUT to anything yet. First, adjust R106 so that the free-running VCO output on pin 4 of the LM565 PLL is <u>100 KHz</u>. Use a frequency counter for this measurement.

8. Now connect the transmitter and receiver circuits together. Don't forget to hook together the grounds! Connect the scope probes as follows: Channel 1 to the *AF INPUT* of the FM modulator, and Channel 2 to the *AF OUT* of the FM detector.

9. Make sure the signal generator is set the same as it was in step 3; then record the scope readings below:

AF
INPUT

t

AF
OUTPUT

t

10. How accurate is the reproduction of the information at the detector, when compared to the original information (scope channel 1?)

_____

11. Increase the deviation at the modulator (by adjusting the amplitude of the signal generator) until the detected output just begins to become distorted.

Remember, you can predict the deviation if you know the peak information signal voltage. Show your calculation below.

How much deviation could this system support? _____

Troubleshooting Hints

FM Modulator

1. Check the power supplies at the U1 IC pins ($Vcc = 15V$ at pin 8, $GND = 0$ V at pin 1).

2. Check the DC voltage at the following locations:

Circuit Location	DC voltage reading and tolerance	Comments
U1 Pin 2,3	7.5 V +/- 0.5 V	Supplied by divider R6 & R7. Circuit will not oscillate if this point is not properly biased.
U1 Pin 7	13.1 V +/- 1 V	Measured with R2 in center of rotation.

3. If the above checks are OK and the circuit oscillates at the wrong frequency (cannot adjust to 100 KHz), check the values of *C1* and *R4* (RC time-constant for VCO).

4. If you cannot get the circuit to oscillate and you've checked all of the above, try replacing the LM565. You may have a defective IC.

FM Detector

1. Check the power supplies at the U101 IC pins ($Vcc = 15V$ at pin 8, $GND = 0$ V at pin 1).

2. Check the DC voltage at the following locations:

Circuit Location	DC voltage reading and tolerance	Comments
U101 Pin 2,3	7.5 V +/- 0.5 V	Supplied by divider R102 & R103.
U101 Pin 7	8 V +/- 2 V	Measured with R106 at center of rotation, and no signal applied at the *FM INPUT*.

3. Check the free-run frequency of the VCO on pin 4; it should be 100 KHz +/- 5 KHz. If it is not so, check the values of *R106*, *R107*, and *C104*, which are the RC time-constant of the VCO.

4. Using the benchtop signal generator, apply a steady sine wave of 100 mV RMS over the frequency range of 90 KHz to 110 KHz to the *FM INPUT*. The frequency at the *VCO OUT* pin of U101 (pin 4) should *exactly* follow the applied frequency (PLL action). If this does not happen, then the PLL is not attaining lock and you should check:

* Is pin 4 connected to pin 5 (*VCO OUT* to *PD IN*)?
* Is the *FM INPUT* signal getting to pin 2? (Check with scope at U101 pin 2.)
* Is there anything miswired on pin 7 (possibly shorting the VCO control voltage to ground?)

QUESTIONS

1. What characteristic of the carrier is varied during Frequency Modulation?

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2. What controls the amount of deviation in an FM transmitter?

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3. What does R2 adjust in the modulator circuit? Why is this important?

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4. What causes the voltage at pin 7 of the FM demodulator (LM565) to follow the original information signal?

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5. What else have you learned in this experiment?

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