EXPERIMENT #7: 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 the 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 voltage-controlled-oscillator (VCO) section of an LM565 PLL is used to create the FM waveform, and a second LM565 phase-locked-loop (PLL) operates as the FM detector.

FM Modulator

Figure 1 illustrates the FM modulator circuit. It's based on the LM565 phase-locked loop (PLL). Only the VCO section of the IC is used.

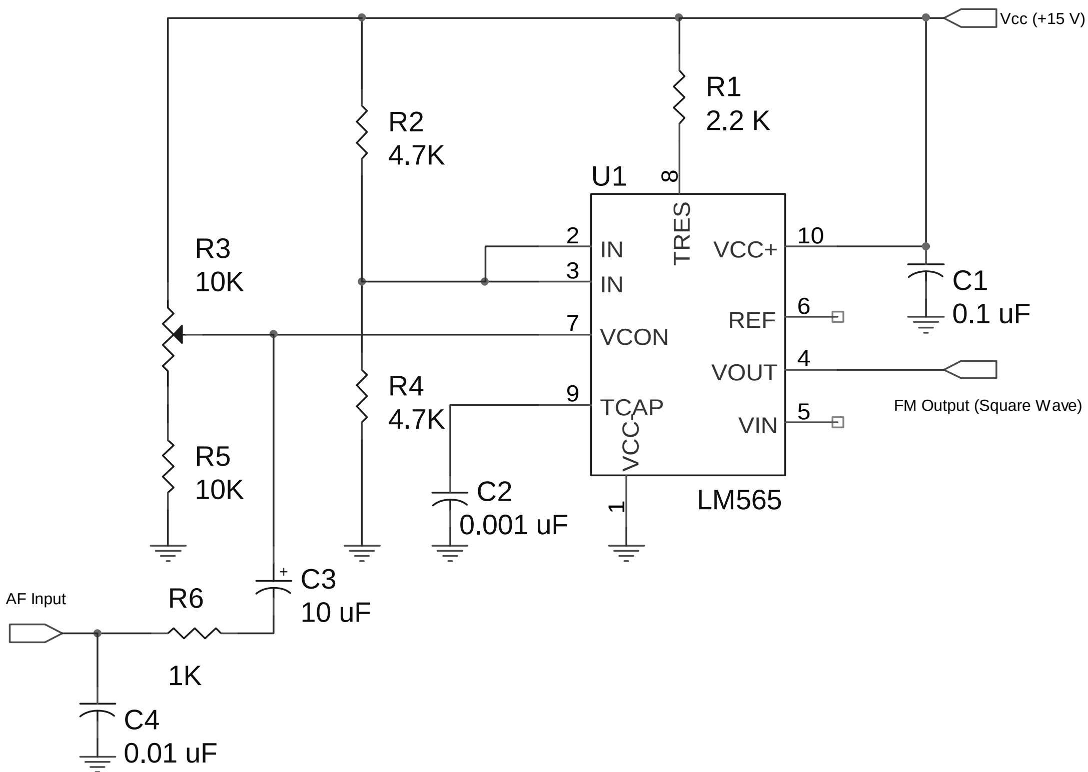


Figure 1: FM Modulator Employing the LM565

The frequency produced by the LM565 VCO is expressed by the following equation:

(1) $f = \dfrac{2.4(Vcc - Vc)}{RtCtVcc}$

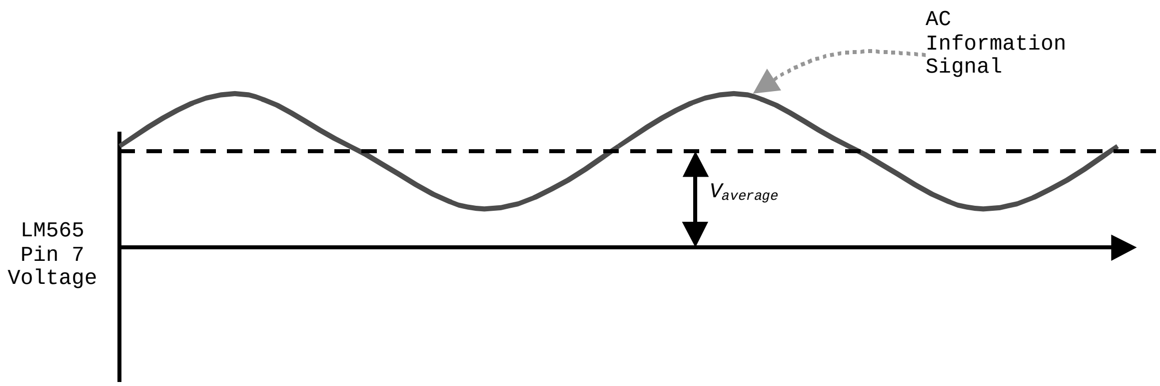
Where: Rt = The timing resistance on pin 8,

Ct = The timing capacitance on pin 9,

Vcc = The power supply voltage,

Vc = The control voltage on pin 7.

The intelligence enters the circuit through C3, a DC block, and is superimposed on the control voltage. This causes the DC control voltage at pin 7 of the VCO to rise and fall with the intelligence signal.



Notice that the audio signal is now riding on top of a DC level. Potentiometer R3 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.

Considerable amounts of RF signal from the VCO may "leak" out of pin 7 of the LM565. Components R6 and C4 form a low-pass filter to prevent this RF energy from passing back to the audio input.

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:

(2) $\delta = VmK_0$

Where: K_0 is the modulator sensitivity, in Hz/Volt.
Vm = the peak information signal amplitude.
δ = the deviation or peak frequency swing.

For example, if Vm=1/2 volt peak, and K_0 = 50 kHz / Volt, then the amount of deviation produced will be:

$$\delta = VmK_0 = (0.5V)(50KHz/V) = \underline{\underline{25KHz}}$$

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.*

Finding the Modulator Sensitivity

The constant of the modulator in the experiment can be easily derived by differentiating equation (1) with respect to Vc (recall that the control voltage Vc is the sum of the information signal, Vm(t) and the average DC control voltage):

$$(3)\ K_0 = \frac{dF}{dVc} = \frac{-2.4}{RtCtVcc}\ \text{(Hz/V)}$$

This derivative is negative, indicating that positive intelligence voltage decreases the oscillator frequency.

FM Detector:

Figure 2 shows the FM detector. It's based on the NE565 phase-locked-loop. The loop is set to free-run at 100 kHz by C104 and the series combination of R107 and R106. Pot R106 allows adjustment of the free-running frequency, which should be the same as the carrier or center frequency of the FM transmitter.

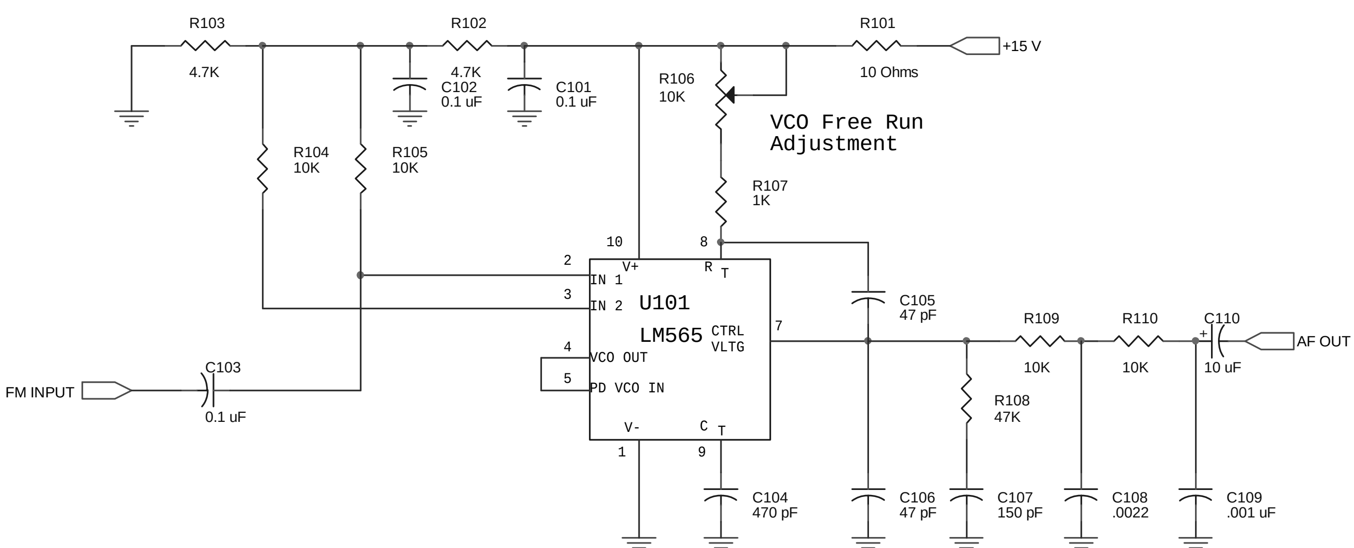


Figure 2: FM Detector using the LM565 PLL

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 componenents. 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:

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

Important: You must use proper RF grounding techniques for this experiment to work properly. Use only one bus for ground, and keep all wires and leads as short as 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 R3 until a 100 kHz carrier wave is obtained. The waveshape from the VCO circuit will be a square wave.

3. Calculate K_0, the modulator sensitivity, by using equation (3).

4. Now connect a signal generator to the AF INPUT. Adjust it for 5 kHz frequency, and correct peak voltage for 10 kHz deviation. (Use the result from step 3).

5. Connect scope channel 1 to the AF INPUT, and scope channel 2 to the FM OUTPUT. Trigger off scope channel 1. Adjust the controls appropriately. Record the oscilloscope graph: FM Output vs AF INPUT. Can you see the frequency deviation taking place? Why or why not?

6. Using the Agilent 54622D's spectrum analyzer feature, look at the spectrum being displayed on channel 1. Record this spectrum. Calculate the theoretical spectrum and compare the results.

TIP: To get the best picture of the FM signal on the '54622D, the following settings are suggested:

Timebase: 100 µS/div (or 2 MSample/s)	Center Frequency: 100 kHz
Span: 100 kHz	Window: HANNING

You'll also find it very helpful to take a spectral picture in the unmodulated condition in order to measure *Vc(unmodulated)*. You'll need this value to calculate the theoretical spectrum.

7. Build the circuit of Figure 2. Keep component lead lengths as short as possible.

8. 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 NE565 PLL is 100 kHz. Use a frequency counter for this measurement (the frequency counter function of the digital scope is sufficiently accurate for this adjustment.)

9. 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. Record the oscilloscope graph: Detected FM Output vs AF Input.

Note: Make sure the amplitude and frequency of the function generator are set correctly as in step 4.

10. How accurate is the reproduction of the information at the detector, when compared to the original information (scope channel 1)? Use the subtract feature of the oscilloscope to find out. Set up an oscilloscope trace that is the difference of channels 1 and 2 (use the *math* menu). You may need to scale the channels appropriately to get "null" on equal signals. *A system that isn't creating any distortion will have an input-output difference signal of zero.*

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

How much deviation could this system support? ___________________

QUESTIONS (ANSWER IN YOUR THEORY OF OPERATION SECTION)

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 did R3 adjust? Why was this important?

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4. What causes the voltage at pin 7 of the FM demodulator (NE565) to follow the original information signal?

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