University of Jordan
Electrical Engineering Department

EE 429
Communications Lab

EXPERIMENT 4
Frequency Modulation and PLL

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EXPERIMENT 4
FREQUENCY MODULATION AND PLL

OBJECTIVE

When you have completed this exercise, you will be able to describe FM modulation and demodulation along with their respective circuits including the VCO, quadrature detector and phase-locked loop (PLL).

DISCUSSION

The three *frequency modulation* (FM) concepts you need to remember are:
1. The carrier **frequency** deviates in proportion with the message signal amplitude.
2. The message signal's frequency does not affect the carrier frequency but does affect the rate of frequency deviation.
3. Amplitude variations of the FM carrier contain no message signal intelligence; only frequency deviations contain the intelligence.

As illustrated in Figure 6-5, the carrier frequency in the FM signal is at its greatest or smallest when the message signal's amplitude is at its maximum or minimum values. When the message signal is at its zero reference, the carrier frequency *deviation* is zero, because the carrier is at its center frequency.

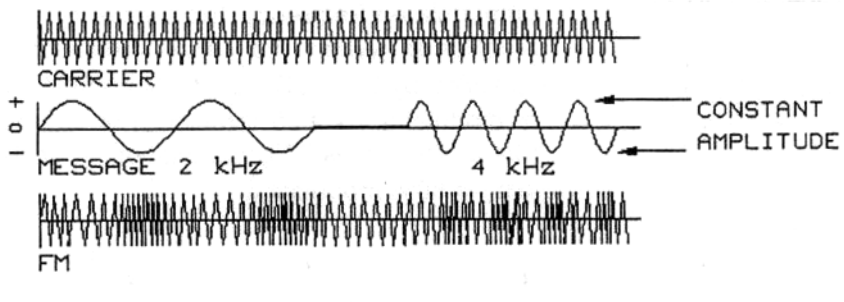

Figure 6-5.

If the peak amplitude of the message signal is constant but its frequency increases (for example, from 2 kHz to 4 kHz), the maximum frequency deviation of the carrier signal does not change. However, the same frequency deviation will occur 4000 times per second (4 kHz) instead of 2000 times per second (2 kHz).

Because amplitude variations of the FM signal do not contain any message signal intelligence, the FM carrier's amplitude can be limited within desired values (see Figure 6-6). Consequently, noise amplitude spikes can be reduced by limiter circuits. Efficient class C amplifiers, which may affect amplitude but not frequency, can also be used in FM equipment.

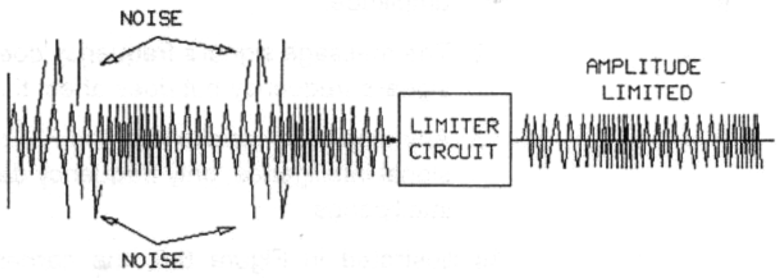

Figure 6-6.

The **bandwidth** required by an FM signal depends upon two factors: the peak frequency deviation of the carrier (Δf) and the frequency of the message signal itself (f_m). Figure 6-8 shows the FM spectrum of a 450 kHz carrier signal with a 5 kHz modulating sinusoidal message signal.

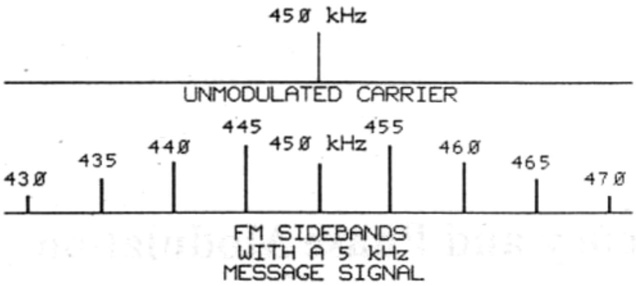

Figure 6-8.

In the FM spectrum, two sidebands that are spaced equally above and below the carrier's center frequency are called a **sideband pair**. The energy contained in each sideband pair decreases as the sideband pair get further from the center frequency. A point is reached at which a sideband pair contains so little energy that they can be disregarded. The point is determined by the modulation index.

The **FM modulation index (β)** is the ratio of carrier peak frequency deviation (Δf) to the maximum message signal frequency (f_m):

$$\boldsymbol{\beta = \Delta f / f_m}$$

For example, if a 5 kHz message signal (f_m) causing a carrier frequency deviation of ± 10 kHz (i.e., Δf = 10 kHz), the modulation index would be:

$$\beta = 10/5 = 2$$

The maximum number of **significant sideband pairs** (SSP) for FM signals is given by Carson’s rule which states that SSP = β + 1. The FM signal with a modulation index of 2, for example, would have 3 significant sideband pairs. If a 450 kHz FM carrier signal were modulated by a 5 kHz message signal, it would have the sidebands spaced 5 kHz apart for 15 kHz on each side of the 450 kHz center frequency. Even thought the frequency deviation is Δf = 10 kHz, the FM bandwidth would be 30 kHz (435 kHz to 465 kHz). In other words the bandwidth of an FM signal is BW = 2 (f_m) (β + 1) = 2 (f_m) (SSP).

Advantages of FM modulation include good signal-to-noise ratio (SNR) and the ability to use more efficient class C amplifiers because amplitude distortion does not affect the signal quality. The FM modulation disadvantage is the requirement of wider bandwidth than AM modulation.

One way to generate an FM signal is using a **Voltage-Controlled Oscillator (VCO)** circuit. In a previous experiment, you used the VCO-LO circuit block to generate a 452 kHz or a 1000 kHz sine wave, depending on the position of the two-post connector used. In this PROCEDURE section, you will use the VCO-LO block to generate an FM signal.

Remember that the potentiometer knob on the VCO-LO circuit block adjusts the output amplitude. To adjust the VCO-LO output frequency, you can adjust the NEGATIVE SUPPLY knob on the top left side of the base unit.

A simplified schematic of the VCO-LO circuit block is shown in Figure 6-12. The oscillator block consists of two transistors that are connected in a cross-coupled oscillator configuration. The oscillator's frequency is determined by the tuning of the LC network shown. You can tune the LC network by changing the value of the voltage applied at the anode of the varactor diode CR2. The voltage is applied by the NEGATIVE SUPPLY voltage source. The value of the NEGATIVE SUPPLY voltage affects the CR2 capacitance which, in turn, affects the tuning of the LC network. As the NEGATIVE SUPPLY voltage becomes more negative, VCO-LO's output frequency increases. At 0 V_{dc}, the output frequency is about 310 kHz. At -10 V_{dc}, the output frequency is about 510 kHz. The VCO-LO feeds its output through a buffer to the VCO-LO potentiometer, which acts as a simple voltage divider. You adjust the potentiometer to set the VCO-LO output amplitude.

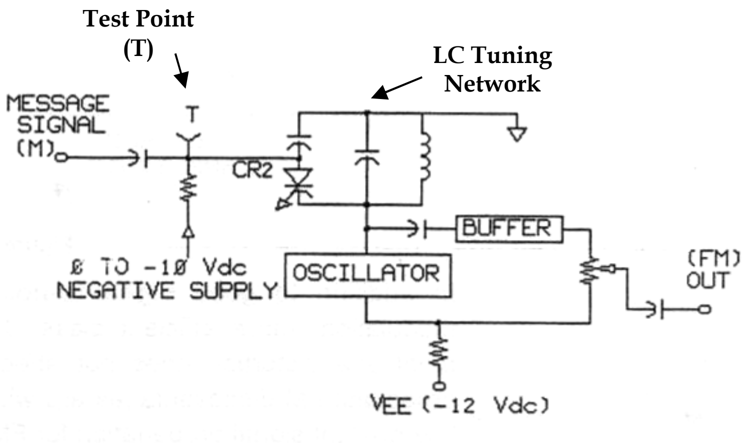

Figure 6-12. VCO-LO circuit block schematic.

At test point T, you can measure the DC voltage at CR2's anode. To use the VCO-LO as an FM modulator, the message signal is fed at terminal (M), and it causes the voltage at CR2 to vary. You can observe the FM signal at the (FM) OUT terminal.

FM demodulators are referred to as **discriminators** or **frequency detectors**. A **quadrature detector** is one of several circuits that can demodulate FM signals. Other FM demodulator circuits include the Foster-Seeley discriminator, the ratio detector, the pulse counting detector, and the phase-locked loop detector. All of these circuits convert FM frequency variations into the amplitude of the message signal.

The QUADRATURE DETECTOR circuit block on your kit includes a PHASE SHIFTER, a LIMITER, a PHASE DETECTOR (MIXER), and a FILTER. A simplified schematic of the quadrature detector is shown in Figure 6-24.

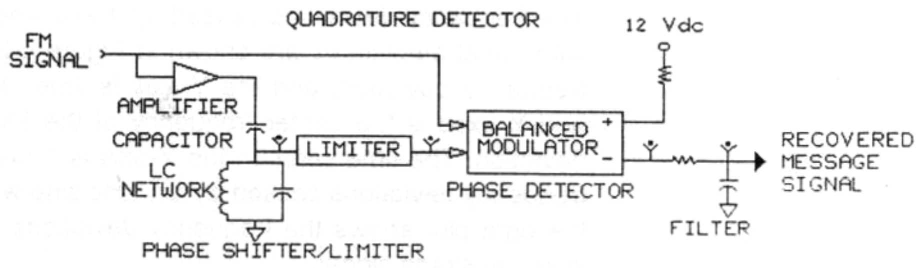

Figure 6-24.

At the quadrature detector's input, the FM signal takes two paths. In one path, the FM signal is input to a phase shifter (which is simply a resonant LC circuit). The phase shifter converts frequency deviations into phase deviations (slightly above and slightly below 90°). The phase shifter signal is then fed to a LIMITER.

The phase shifter circuit is composed of an amplifier, a capacitor and an LC network (see Figure 6-24). The FM signal goes first through an amplifier, which is a non inverting op amp with a gain of about 2. The capacitor shifts the FM signal by 90°. Because the resonant frequency (f_r) of the LC network equals the FM center frequency, it is a purely resistive impedance to the FM center frequency. Consequently, the 90° phase shift of the center frequency is not affected by the LC network.

However, frequencies greater or less than f_r are shifted less or more than 90°, respectively, from the original FM signal. In reference to the original FM signal, frequency deviations on each side of the FM center frequency will be greater than or less than 90° out of phase because the frequency deviations produce the phase deviations.

The original FM signal and the phase-shifted/limited FM signal are then fed to a phase detector, which is a balanced modulator. The balanced modulator combines the input frequencies to produce **sum** and **difference** frequencies. Because the FM inputs have equal frequencies, the sum frequency is twice the FM frequency. However, the difference frequency component becomes a DC voltage that varies with the phase difference between the two inputs (around 90°). Because FM frequency deviations are converted to phase differences at the output of the PHASE SHIFTER/LIMITER, the phase detector's difference dc voltage component varies directly with the message signal. Therefore, the output of the phase detector contains the sum frequency and the message signal.

A low pass filter (RC network) at the phase detector's output removes the high-frequency signal and passes the varying dc output voltage as the recovered message signal.

The phase-shifted FM signal is input to a LIMITER (shown in Figure 6-25). The limiter has two Zener diodes connected from the output to ground with their polarities reversed: anodes connect to cathodes. The reversed-polarity diodes limit the output amplitude and minimize any amplitude changes that the phase shifter may cause.

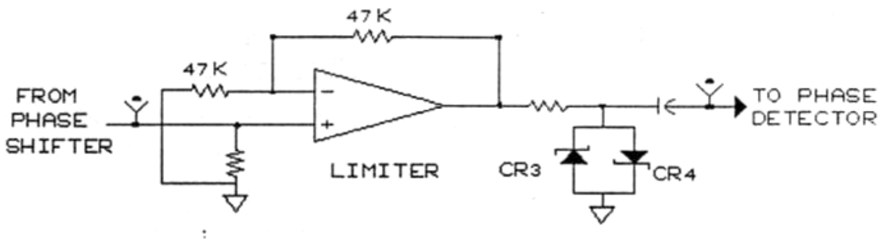

Figure 6-25.

The following components (see Figure 7-3) make up the PHASE-LOCKED LOOP circuit block on your kit:

- PHASE DETECTOR
- FILTER
- AMPLIFIER
- VCO

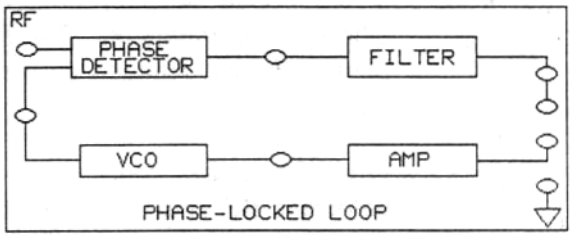

Figure 7-3. Block diagram of phase-locked loop circuit.

The PHASE DETECTOR, which is detailed in Figure 7-4, is an MC1496 balanced modulator whose function is similar to that of the phase detector on the QUADRATURE DETECTOR circuit block. It performs a full-wave multiplication of the RF and VCO input signals. When the RF input frequency (f_i) equals the VCO output frequency (f_{vco}), the phase detector's output includes the sum frequency of the inputs ($f_i + f_{vco}$) and a difference component, which is a dc voltage.

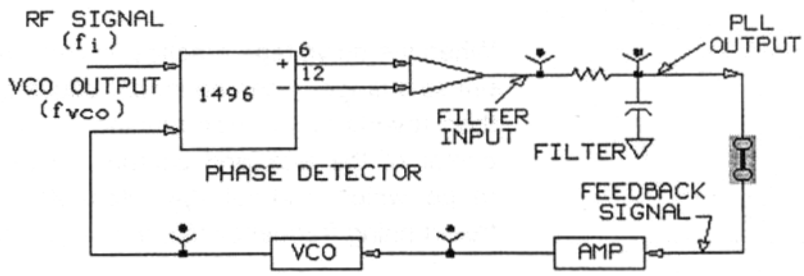

Figure 7-4. PLL circuit.

The low-pass RC filter removes the sum frequency and passes the dc voltage of the PLL's output signal, which is also the feedback signal. In order for the PLL to operate in a **closed loop**, you must insert a two-post connector on your circuit board to connect the filter and amplifier, as shown in Figure 7-4. The amplifier increases the feedback signal's voltage to the VCO. The DC voltage feedback signal controls f_{vco} to match f_i, by changing the capacitance of a **varactor diode** in the VCO circuit.

When f_i changes, there is an initial phase change between the PHASE DETECTOR'S RF and VCO input signals. The phase change causes the PHASE DETECTOR'S dc output voltage (difference component) to change. The amplified change in the dc output voltage that is fed back to the VCO causes f_{vco} to match the change in f_i.

Any PLL has three characteristics that you need to know about (see Figure 7-2):

- **Free-running frequency** f_o (about 456 kHz on your kit)
- **Capture range** (between 454 kHz and 458 kHz approximately on your kit)
- **Lock range** (between 400 kHz and 480 kHz approximately on your kit)

Usually the lock range of a PLL is greater than the capture range, and the free-running frequency is in the middle of both ranges. The PLL operates as follows: Once f_i goes within the ***capture range***, f_{vco} can track f_i for all values of f_i so long as it is within the ***lock range***. If f_i leaves the lock range f_{vco} reverts back to the free-running frequency.

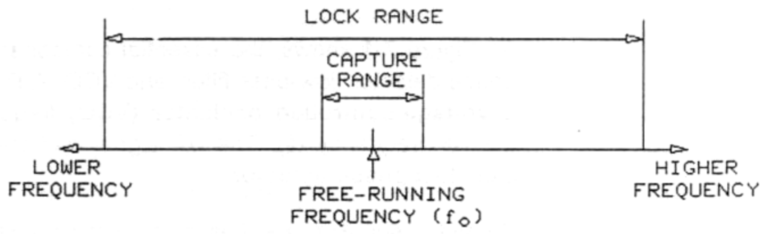

Figure 7-2.

The dynamic range of the PHASE DETECTOR'S difference component dc voltage *determines* the lock range. This is because when the dc voltage reaches its limit and does not change with an input phase change, it can no longer cause f_{vco} to match the change in f_i; f_{vco} then reverts to the free-running frequency f_o. And since the phase detector's difference component is a dc voltage, it is not affected by the cutoff frequency of the low-pass filter.

Notice, however, that if f_i doesn't go inside the capture range of the PLL in the first place, which is about ± 2 kHz around the VCO's free-running frequency (f_o), then f_{vco} will remain at f_o, and the PLL will not follow the input frequency.

The filter cut-off frequency *determines* the capture range. This is because when f_i and f_{vco} are not equal, the sum and difference frequencies are output from the phase detector. To capture f_{vco} the difference frequency ($f_i - f_{vco}$) has to be within the cutoff frequency of the low-pass filter. If the difference frequency is greater than the filter's cutoff frequency, the filter will remove the difference frequency and prevent a feedback signal to the VCO.

When the filter's output is not connected to the amplifier (open loop), there is no feedback signal to the VCO. With an open loop, f_{vco} is set by the dc bias voltage (about -4.8 V_{dc}) to the free-running frequency (f_o) of the VCO.

When a PLL is locked, the phase detector's input frequencies (f_i and f_{vco}) are equal but 90° out of phase. When f_i changes, the 90° phase difference between f_i and f_{vco} changes (see Figure 7-15). The initial phase change between f_i and f_{vco} causes the phase detector's dc voltage difference component to change. Every variation in f_i causes a phase change with f_{vco}, which then causes the dc voltage difference component to change. The dc voltage, or the feedback to the VCO, causes f_{vco} to change so that it equals f_i .

After capture, if the bandwidth of the FM signal stays within the PLL's lock range, the PLL recovers the message signal. However, if the bandwidth of the FM signal becomes greater than the PLL's lock range, f_{vco} returns to its free-running frequency (f_o).

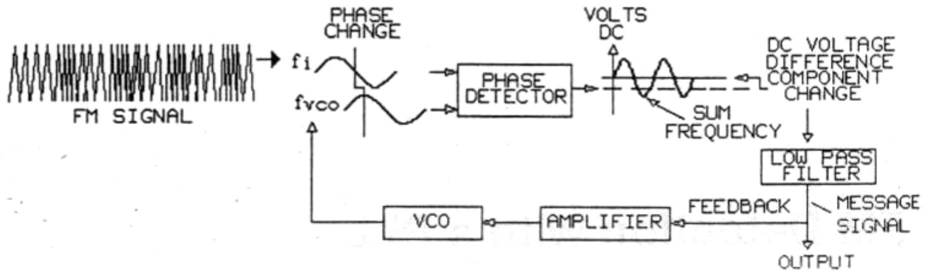

Figure 7-15.

PROCEDURE A - FREQUENCY MODULATION (FM)

In this PROCEDURE section, you will frequency modulate a carrier signal, measure its parameters, and observe its characteristics.

1. Locate the VCO-LO circuit block. Insert the two-post connector in the 452 kHz terminals (Figure 6-13). Set the VCO-LO amplitude potentiometer fully CW.

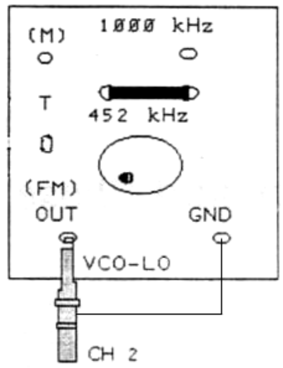

Figure 6-13.

2. Connect the oscilloscope CH2 probe to (FM) OUT on VCO-LO. Set CH2 for 200 mV/DIV and the sweep to 0.5 µs/DIV, and trigger on CH2.

3. Use a digital multimeter (DMM) to measure the voltage at the test point T. Adjust the NEGATIVE SUPPLY knob for (–4.0) V_{dc} at this test point T.

4. Accurately measure the period (T) between the peaks of the unmodulated FM carrier signal on CH2. From the period (T), calculate the center frequency (f) in kHz of the unmodulated FM carrier signal (f = 1/T).

. . . .

5. You will determine the frequency deviation of the FM carrier when the message signal amplitude changes by 1 V_{dc}. Adjust the NEGATIVE SUPPLY knob CW to change the voltage at test point T on the VCO-LO circuit block to (–5.0) V_{dc}.

6. Accurately measure the period (T) between the peaks of the modulated FM carrier signal on CH2. From T, calculate the frequency of the modulated FM carrier signal. Record f in kHz.

. . . .

7. Calculate the VCO sensitivity (k_f) which is the frequency deviation when the message signal's amplitude decreases by 1 V_{dc}. The FM center frequency is the value you calculated in step 5, and the frequency with a (–1) Vdc message signal is the value you just calculated in the previous step. Record your answer in kHz/Volt.

. . . .

8. Adjust the NEGATIVE SUPPLY knob to (–4.0) V_{dc} to return the carrier frequency to the center frequency.

9. You will now observe the effect of a 2.0 $V_{pk\text{-}pk}$, 5 kHz message signal on the FM carrier frequency. Connect the FUNCTION GENERATOR to (M) on the VCO-LO circuit block, as shown in Figure 6-15.

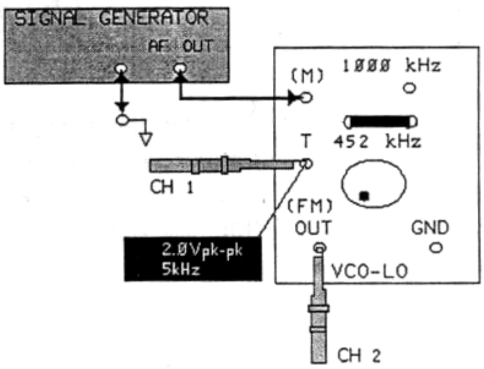

Figure 6-15.

10. Set the sweep to 50 μs/DIV, and trigger on CH1. Adjust the FUNCTION GENERATOR for a 2.0 $V_{pk\text{-}pk}$, 5 kHz sine wave at T. This adjustment is equivalent to varying the voltage at T by ± 1V. Now, set the sweep to 0.5 μs/DIV and trigger on CH2. Observe CH2, which shows an **FM signal** like the one in Figure 6-16.

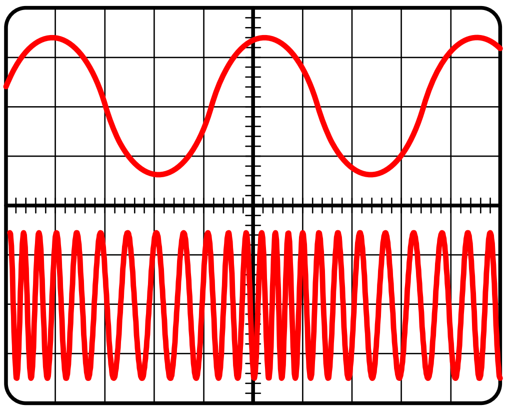

Figure 6-16.

11. Since the message signal is 2.0 V_{pk-pk} (i.e., its peak is 1 V), the frequency deviation (Δf) of the FM signal is equal to $k_f \times 1$ V = k_f. Calculate the modulation index (β) for the FM signal that has a sensitivity (k_f) of the amount you determined in step 8 and with a 5 kHz message signal (f_m).

. . . .

12. Using the β you calculated above, find the number of significant sideband pairs (SSP). If β is not a whole number, use the next highest β to find the number of SSP.

. . . .

13. Now calculate the bandwidth (BW) of your FM signal in kHz.

. . . .

PROCEDURE B – FM DETECTION USING QUADATURE DETECTOR

In this PROCEDURE section, you will study the FM quadrature detector by observing how a phase shifter changes the phase of an FM carrier signal and how the phase detector and filter recover the message signal.

1. On the VCO-LO circuit block, insert the two-post connector in the 452 kHz terminals, and **DISCONNECT** the FUNCTION GENERATOR from the message (M) input if it is already connected (see Figure 6-26).

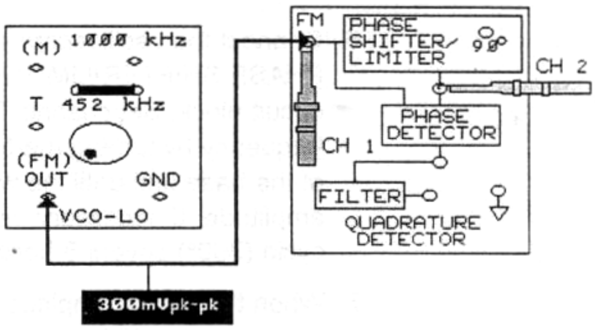

Figure 6-26.

2. Connect (FM) OUT on the VCO-LO circuit block to the FM input on the QUADRATURE DETECTOR circuit block.

3. Connect the oscilloscope CH1 probe to FM on the QUADRATURE DETECTOR circuit block, and trigger on CH1.

4. Set CH1 for 100 mV/DIV and the sweep to 0.5 µs/DIV. With the potentiometer knob on VCO-LO, adjust the unmodulated FM carrier signal at FM for 300 mV_{pk-pk}.

5. Connect the oscilloscope CH2 probe to the output of the PHASE SHIFTER/LIMITER on the QUADRATURE DETECTOR circuit block. Set CH2 for 200 mV/DIV. Adjust the FM frequency by turning the NEGATIVE SUPPLY knob on the left side of the base unit until the waveform on CH2 has a maximum amplitude.

6. Count how many horizontal divisions represent one cycle (360°) on CH1 signal.

. . . .

7. When the output amplitude of the PHASE SHIFTER/LIMITER is maximum, the FM center frequency is equal to what frequency?

. . . .

8. Measure the phase difference between the unmodulated FM carrier signal on CH1 and the PHASE SHIFTER/LIMITER output signal on CH2? **Note:** You know how many horizontal divisions represent 360° from step 6 above. Also be sure to center both signals at the zero level.

. . . .

9. In the PHASE SHIFTER/LIMITER circuit, what component causes a phase shift of 90° between the input and output signals?

. . . .

10. Adjust the NEGATIVE SUPPLY knob on the base unit CW and then CCW to vary the FM frequency. Why do you think the phase difference between the input and output signals increase and decrease?

. . . .

11. Why does the PHASE SHIFTER/LIMITER output signal on CH2 have flattened peaks and valleys?

. . . .

12. While observing the PHASE SHIFTER/LIMITER output signal (CH2), reduce the amplitude of the input signal (CH1) to about 100 mV_{pk-pk} and then back to 300 mV_{pk-pk} by turning the potentiometer on the VCO-LO circuit block CCW and then CW. When you reduced the input signal to 100 mV_{pk-pk}, did the PHASE SHIFTER/LIMITER output signal (CH2) become a sine wave or more flattened?

. . . .

13. The circuit is now connected as shown in Figure 6-29.

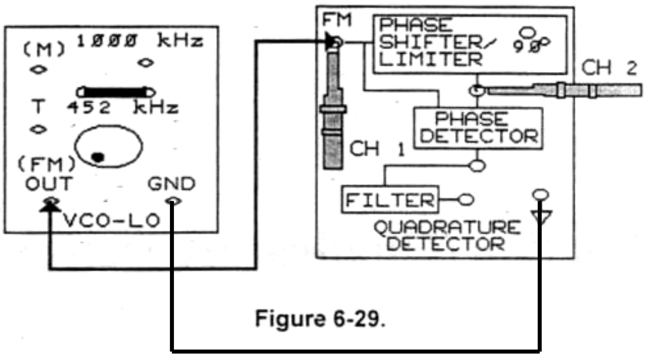

Figure 6-29.

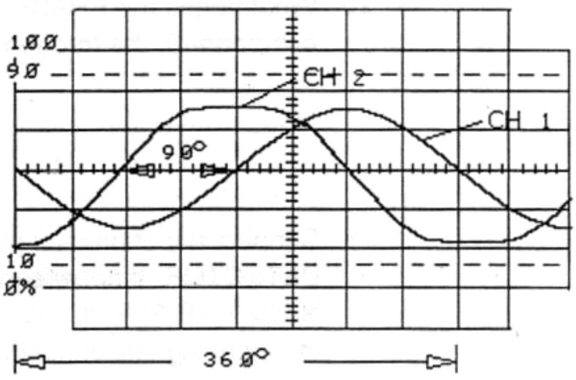

Figure 6-30.

14. Make sure that the CH1 signal is adjusted for 300 mV_{pk-pk}, and adjust the NEGATIVE SUPPLY knob on the BASE UNIT so that the CH2 waveform is 90° out-of- phase with the CH1 signal (see Figure 6-30).

15. What is the PHASE DETECTOR'S output signal on CH2?

. . . .

16. What is the PHASE DETECTOR output difference component (which is also the output of the FILTER)?

. . . .

17. Use a voltmeter to measure dc volts. Connect the voltmeter lead to the FILTER'S output, and connect the common lead to ground. With a 90° phase difference between the input signals, measure and record the dc voltage at the FILTER'S output ($V_{90°}$)

. . . .

18. Set the phase difference between the signals on CH1 and CH2 to 135° by adjusting the NEGATIVE SUPPLY voltage knob CCW. With a 135° phase difference between the input signals, measure and record the dc voltage at the FILTER'S output ($V_{135°}$).

. . . .

19. Set the phase difference between the signals on CH1 and CH2 to 45° by adjusting the NEGATIVE SUPPLY voltage knob CW. With a 45° phase difference between the input signals, measure and record the dc voltage at the FILTER'S output ($V_{45°}$).

. . . .

20. When the phase difference was increased or decreased from 90°, did the dc output voltage change?

. . . .

21. Set the phase difference between the signals on CH1 and CH2 back to 90° by adjusting the FM frequency with the NEGATIVE SUPPLY knob.

22. Now, you will modulate the FM carrier with a 300 mV_{pk-pk}, 3 kHz message signal. Connect the FUNCTION GENERATOR to (M) on the VCO-LO circuit block (Figure 6-32).

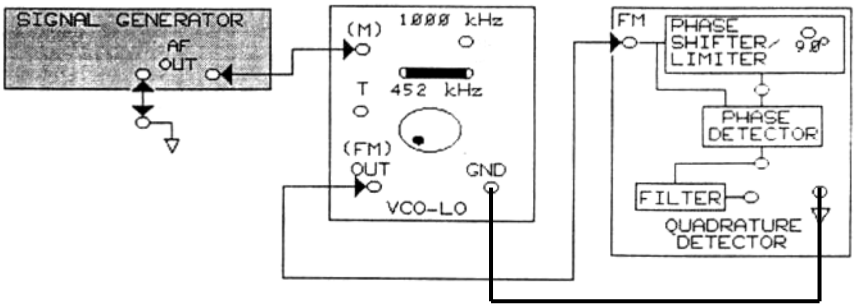

Figure 6-32.

23. Connect the CH1 probe to T on VCO-LO. Set CH1 for 100 mV/DIV, set the sweep to 0.1 ms/DIV, and trigger on CH1.

24. Adjust the FUNCTION GENERATOR (message signal) for a 300 mV_{pk-pk}, 3 kHz sine wave at T on VCO-LO (CH1).

25. Connect the CH2 probe to the PHASE DETECTOR'S output (just before the FILTER) to observe the sum and difference frequency signals. Set CH2 for 20 mV/DIV. Make sure that both signals (CH1 and CH2) are displayed on the oscilloscope simultaneously. Keep trigger on CH2. On CH2, is the DC level, which is the zero reference (midpoint) of the sum frequency signal changing?

. . . .

26. Compare the message signal on CH1 with the DC variations of the PHASE DETECTOR output on CH2. Is the frequency of the signal on CH2 the same as the message signal on CH1?

. . . .

27. Connect the CH2 probe to the output of the FILTER. Set CH2 to 50 mV/DIV. Observe the message signal on CH1 and the QUADRATURE DETECTOR output on CH2. Vary the message signal frequency and amplitude. Does the recovered message signal on CH2 vary with the message signal amplitude and frequency on CH1?

. . . .

<u>**PROCEDURE C - PHASE-LOCKED LOOP**</u>

In this PROCEDURE section, you will study the characteristics of the phase-locked loop on your Analog Communications Lab Kit.

1. You will first determine the VCO's free-running frequency. **Do not insert** a two-post connector between the FILTER and AMP in the PHASE-LOCKED LOOP circuit block just yet. Set oscilloscope CH2 to 200 mV/DIV, and set the sweep to 0.5 µS/DIV. Connect the CH2 probe to the VCO output, and trigger on CH2. Connect the voltmeter to the VCO input, and connect the voltmeter common lead to a ground terminal on the circuit board (See Figure 7-5.)

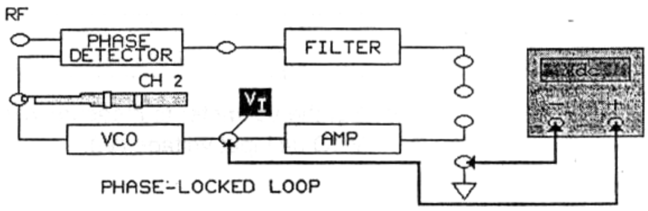

Figure 7-5.

2. Accurately measure the period (T) between the peaks of the waveform. Each horizontal division is 0.5 µs. Record your answer below.

. . . .

3. From the period (T) of the VCO output signal, calculate the free-running frequency ($f_o = 1/T$). Record your answer in kHz. Compare your answer to the frequency that the oscilloscope displays when you use its measure feature.

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4. Set the voltmeter to measure volts DC. Measure and record the VCO DC input voltage (V_i).

. . . .

5. Does V_I control the VCO output's amplitude or its frequency?

. . . .

6. On the VCO-LO circuit block, insert a two-post connector in the 452 kHz position. Connect the (FM) OUT terminal on VCO-LO to the RF terminal at the PHASE DETECTOR input on the PHASE-LOCKED LOOP circuit block, as illustrated in Figure 7-7.

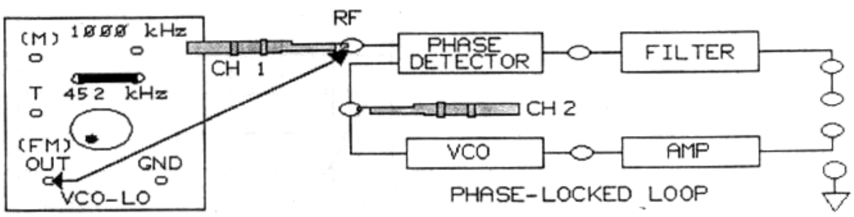

Figure 7-7.

7. Set oscilloscope CH1 to 50 mV/DIV. Connect the CH1 probe to the RF input of the PLL. Adjust the potentiometer knob on the VCO-LO circuit block for a 150 $mV_{pk\text{-}pk}$ signal at RF.

8. Use the oscilloscope to show the following two signals: The VCO-LO output and the output of the VCO inside the PLL circuit.

9. While observing the RF and VCO signals on the oscilloscope screen, slowly increase the RF frequency (the period decreases) by turning the NEGATIVE SUPPLY knob completely CW. Slowly decrease the RF frequency (the period increases) by turning the NEGATIVE SUPPLY knob completely CCW.

10. Did the change in the RF frequency (f_i) on CH1 affect the VCO frequency (f_{vco}) on CH2? Why or why not?

. . . .

11. **Place** a two-post connector in the terminals between the FILTER output and the AMP input to close the feedback loop.

12. Observe the RF and VCO signals on the oscilloscope. They will probably appear unstable on the oscilloscope screen. Turn the NEGATIVE SUPPLY knob **completely CCW**, then slowly increase f_i (CH1) by turning the NEGATIVE SUPPLY knob **CW** until the VCO signal **starts** to track (follow) the RF signal, at which time the signal will appear more stable on the screen. Now stop turning the NEGATIVE SUPPLY knob CW. The signals should appear as shown in Figure 7-9.

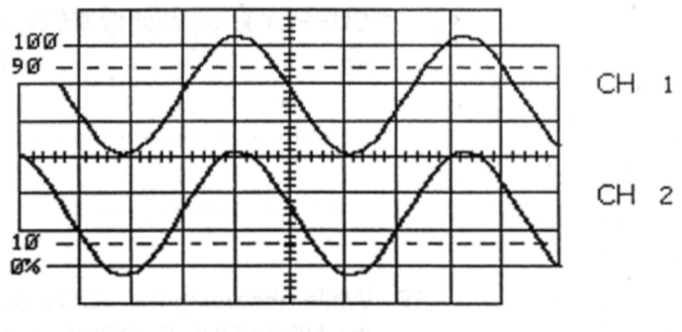

Figure 7-9.

13. On CH1, accurately measure the period (T) between peaks of the **RF input signal** waveform. Each horizontal division is 0.5 μs.

. . . .

14. From the period (T) above, calculate the frequency (f_i) in kHz of the RF input signal ($f_i = 1/T$).

. . . .

15. What is the name of the frequency range in which the VCO signal starts to track the RF input signal?

. . . .

16. What determines that range of the PLL?

. . . .

17. On the oscilloscope screen, compare f_{vco} and f_i when they start tracking by overlaying the signal traces. Are the frequencies about equal?

. . . .

18. While observing the oscilloscope screen, turn the NEGATIVE SUPPLY knob slightly CCW, and then slightly CW. Does f_{vco} track f_i? The oscilloscope will show stable traces when tracking occurs.

. . . .

19. While observing the VCO's dc input voltage (V_i), vary f_i by turning the NEGATIVE SUPPLY knob slightly CCW, and then slightly CW. When f_{vco} tracks f_i, does V_i change?

. . . .

20. What is the name of the frequency range over which f_{vco} tracks f_i?

. . . .

21. While observing the RF and VCO inputs to the PHASE DETECTOR, slowly increase f_i even more by turning the NEGATIVE SUPPLY knob CW. When f_{vco} **stops** tracking f_i (i.e., when the oscilloscope starts showing unstable traces), **stop** turning the NEGATIVE SUPPLY knob CW. This is the point at which the VCO signal snaps back to its free-running frequency. You may have to repeat this step to obtain the exact frequency at which tracking stops.

22. On the oscilloscope screen, compare f_{vco} to f_i by overlaying the signal trace. Are the frequencies equal?

. . . .

23. On CH1, accurately measure the period (T) between peaks of the **RF input signal** waveform. Each horizontal division is 0.5 µs.

. . . .

24. From the period (T) above, calculate the frequency (f_i) in kHz of the RF input signal ($f_i = 1/T$).

. . . .

25. Turn the NEGATIVE SUPPLY knob **completely CW**. While observing the inputs to the PHASE DETECTOR, slowly decrease f_i (CH1) by turning the NEGATIVE SUPPLY knob **CCW**, When the VCO signal **starts** to track (follow) the RF signal, **stop** turning the NEGATIVE SUPPLY knob CCW.

26. On CH1, accurately measure the period (T) between peaks of the **RF input signal** waveform. Each horizontal division is 0.5 μs.

. . . .

27. From the period (T) above, calculate the frequency (f_i) in kHz of the RF input signal ($f_i = 1/T$).

. . . .

28. While observing the RF and VCO inputs to the PHASE DETECTOR, slowly decrease f_i some more by turning the NEGATIVE SUPPLY knob **CCW**. When f_{vco} **stops** tracking f_i **stop** turning the NEGATIVE SUPPLY knob. This is the point at which the VCO signal snaps back to its free-running frequency. You may have to repeat this step to obtain the exact frequency at which tracking stops.

29. On CH1, accurately measure the period (T) between peaks of the RF input signal waveform. Each horizontal division is 0.5 μs.

. . . .

30. From the period (T) above, calculate the frequency (f_i) in kHz of the RF input signal ($f_i = 1/T$).

. . . .

31. You determined that when f_i is between the frequencies you calculated in steps 24 and 30, f_{vco} tracks f_i. What is the width of the lock range of the PLL?

. . . .

32. Now determine the width of the capture range of the PLL?

. . . .

33. On the PHASE-LOCKED LOOP circuit block, connect the CH1 probe to RF at the PHASE DETECTOR input, and connect the CH2 probe to the VCO output. Set CH1 to 500 mV/DIV, set CH2 to 2 V/DIV, and set the sweep to 0.5 μs/DIV. Trigger on CH1.

34. Adjust the NEGATIVE SUPPLY knob on the base unit completely CCW.

35. Slowly increase f_i (CH1) by turning the NEGATIVE SUPPLY knob CW. When the f_{vco} signal starts to track f_i and V_i is about -4.0 V_{dc}, stop turning the NEGATIVE SUPPLY knob CW. The signals should appear, as shown in Figure 7-23.

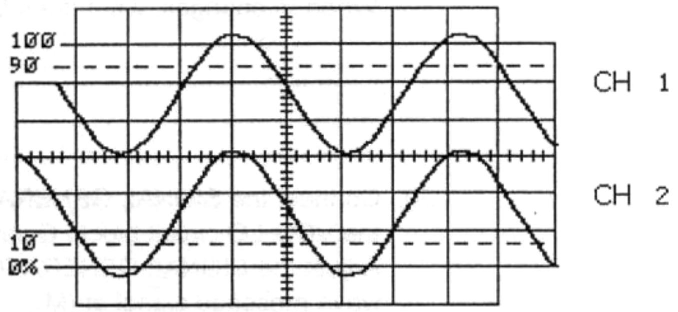

Figure 7-23.

36. Connect the FUNCTION GENERATOR'S output to the (M) terminal on the VCO-LO circuit block. Connect the CH1 probe to (M), Adjust the FUNCTION GENERATOR for a 100 mV_{pk-pk}, 3 kHz sine wave message signal at (M).

37. Connect the CH2 probe to the PHASE DETECTOR output. Set CH2 to 10 V/DIV and the oscilloscope sweep to 2 ms/DIV. The oscilloscope signals should appear, as shown in Figure 7-24.

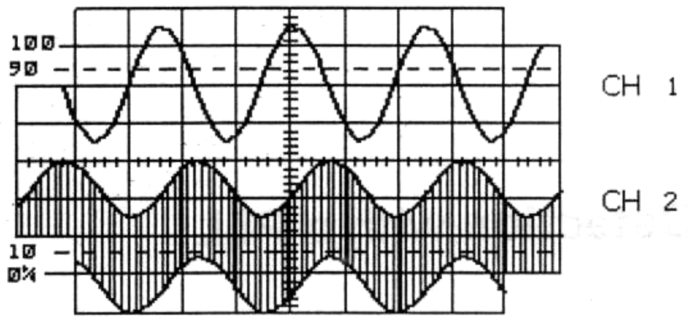

Figure 7-24.

38. What signals compose the PHASE DETECTOR output signal on CH2?

. . . .

39. What does the varying DC voltage represent?

. . . .

40. Connect the CH2 probe to the FILTER output on the PHASE-LOCKED LOOP circuit block. Set CH2 to 5 V/DIV.

41. Slightly vary the frequency and amplitude of the message signal from the FUNCTION GENERATOR. Do the frequency and amplitude of the recovered message signal vary with the message signal?

. . . .

42. Does the message signal feedback to VCO change f_{vco} or not?

. . . .

43. Now connect the CH2 oscilloscope probe back to the FILTER output. Set CH2 to 500 mV/DIV and CH1 to 100 mV/DIV. At the FUNCTION GENERATOR, increase the message signal amplitude on CH1 to 500 mV_{pk-pk}. Is the signal on CH2 the recovered message signal or not? Explain?

. . . .

44. Now slowly adjust the NEGATIVE SUPPLY voltage knob CW and CCW. Describe what happens to the recovered message signal at the FILTER output. Explain your observations.

. . . .