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Communication Circuits Design

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Lecture 3.5: FM Circuits and PLL

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Frequency Modulators

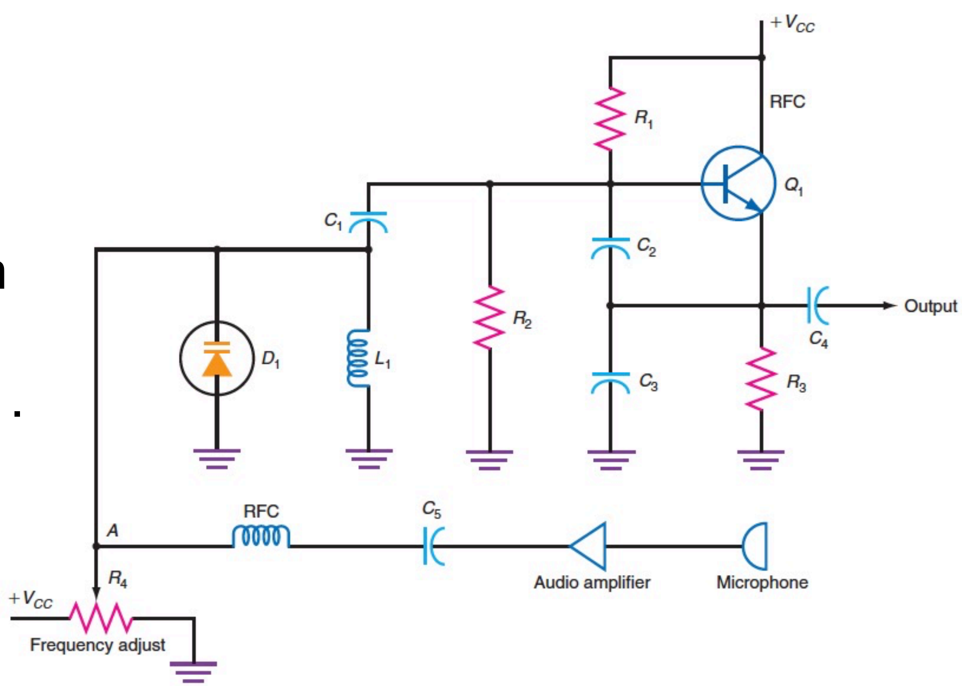
- A frequency modulator is a circuit that varies carrier frequency in accordance with the modulating signal.
- The carrier is generated by either an LC or a crystal oscillator circuit, and so a way must be found to change the frequency of oscillation.
- In an LC oscillator, the carrier frequency is fixed by the values of the inductance and capacitance in a tuned circuit, and the carrier frequency can therefore be changed by varying either inductance or capacitance.
- The idea is to find a circuit or component that converts a modulating voltage to a corresponding change in capacitance or inductance.

Frequency Modulators

- When the carrier is generated by a crystal oscillator, the frequency is fixed by the crystal.
- Again, the objective is to find a circuit or component whose capacitance will change in response to the modulating signal.
- The component most frequently used for this purpose is a varactor.
- Also known as a voltage variable capacitor, variable capacitance diode, or varicap, this device is basically a semiconductor junction diode operated in a reverse-bias mode.

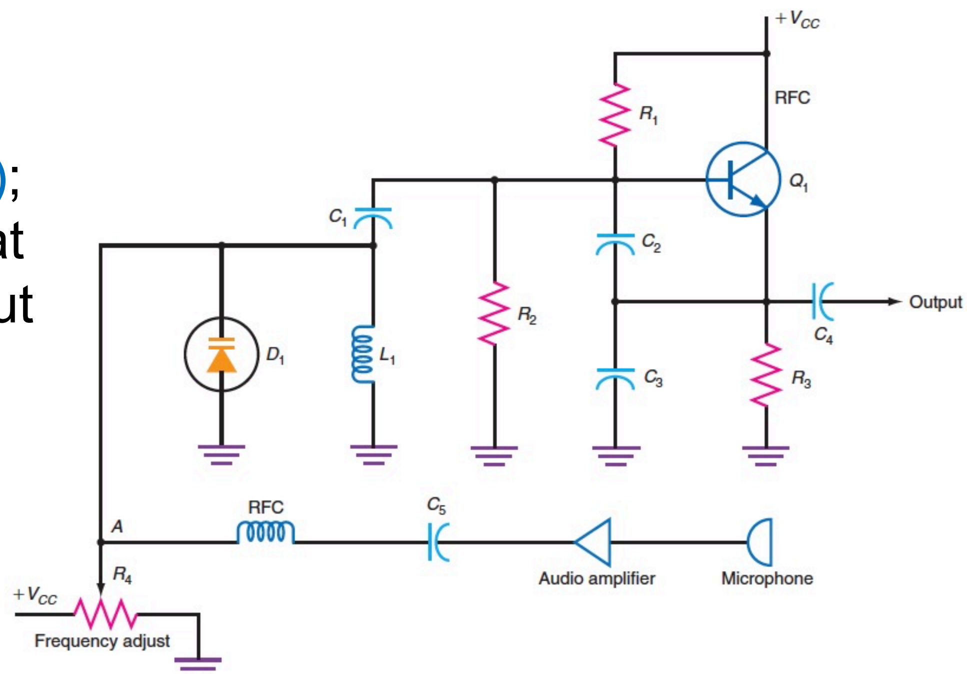
Varactor Modulators (1)

- Figure below, a carrier oscillator for a transmitter, shows the basic concept of a varactor frequency modulator.
- The capacitance of varactor diode D_1 and L_1 forms the parallel-tuned circuit of the oscillator.
- The value of C_1 is made very large at the operating frequency so that its reactance is very low.
- As a result, C_1 connects the tuned circuit to the oscillator circuit.
- Also C_1 blocks the dc bias on the base of Q_1 from being shorted to ground through L_1 .
- The values of L_1 and D_1 fix the center carrier frequency.



Varactor Modulators (2)

- The capacitance of D1 is controlled in two ways, through a fixed dc bias and by the modulating signal.
- In Figure, the bias on D1 is set by the voltage divider potentiometer R4 .
- Varying R4 allows the center carrier frequency to be adjusted over a narrow range.
- The modulating signal is applied through C_5 and the radio frequency choke (RFC); C_5 is a blocking capacitor that keeps the dc varactor bias out of the modulating-signal circuits.



Varactor Modulators (3)

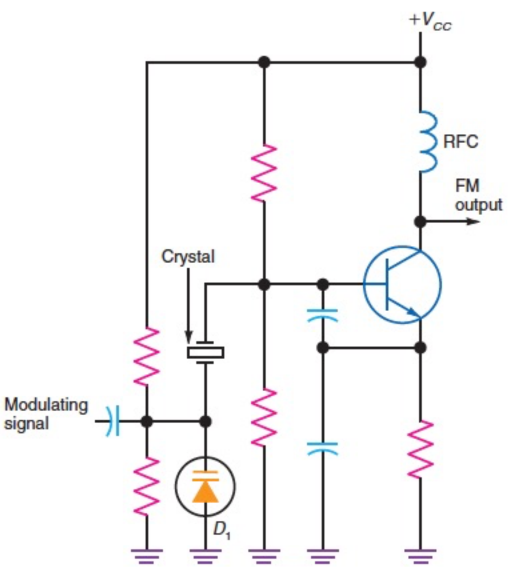
- The modulating signal derived from the microphone is amplified and applied to the modulator.
- As the modulating signal varies, it adds to and subtracts from the fixed-bias voltage.
- Thus, the effective voltage applied to D_1 causes its capacitance to vary.
- This, in turn, produces the desired deviation of the carrier frequency.
- A positive- going signal at point A adds to the reverse bias, decreasing the capacitance and increasing the carrier frequency.
- A negative-going signal at A subtracts from the bias, increasing the capacitance and decreasing the carrier frequency.

Problem with Varactor Modulators

- The main problem with the circuit in Figure is that most LC oscillators are simply not stable enough to provide a carrier signal.
- Even with high-quality components and optimal design, the frequency of LC oscillators will vary because of temperature changes, variations in circuit voltage, and other factors.
- Such instabilities cannot be tolerated in most modern electronic communication systems, where a transmitter must stay on frequency as precisely as possible.
- The LC oscillators simply are not stable enough to meet the stringent requirements imposed by the FCC.
- As a result, crystal oscillators are normally used to set carrier frequency. Not only do crystal oscillators provide a highly accurate carrier frequency, but also their frequency stability is superior over a wide temperature range.

FM using Crystal Oscillator (1)

- It is possible to vary the frequency of a crystal oscillator by changing the value of capacitance in series or in parallel with the crystal.
- Figure shows a typical crystal oscillator. When a small value of capacitance is connected in series with the crystal, the crystal frequency can be pulled slightly from its natural resonant frequency.
- By making the series capacitance a varactor diode, frequency modulation of the crystal oscillator can be achieved.
- The modulating signal is applied to the varactor diode D_1 , which changes the oscillator frequency.

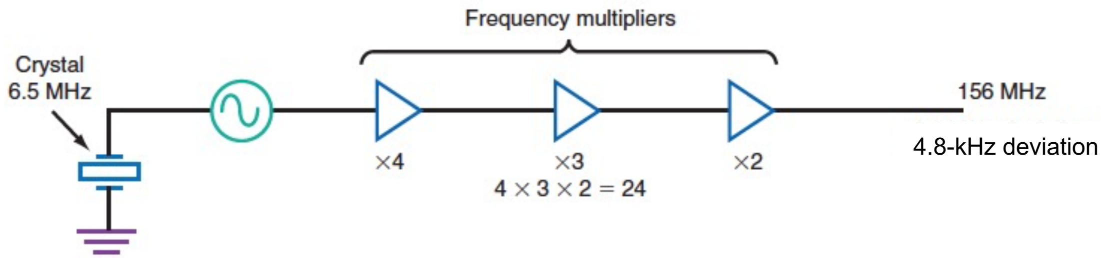


FM using Crystal Oscillator (2)

- It is important to note that only a very small frequency deviation is possible with frequency-modulated crystal oscillators.
- Rarely can the frequency of a crystal oscillator be changed more than several hundred hertz from the nominal crystal value. The resulting deviation may be less than the total deviation desired.
- The total deviation can be increased by using frequency multiplier circuits after the carrier oscillator.
- A frequency multiplier circuit is one whose output frequency is some integer multiple of the input frequency.
- When the FM signal is applied to a frequency multiplier, both the carrier frequency of operation and the amount of deviation are increased.

FM using Crystal Oscillator (3)

- Typical frequency multipliers can increase the carrier oscillator frequency by 24 to 32 times. Figure shows how frequency multipliers increase carrier frequency and deviation.
- The desired output frequency from the FM transmitter in the figure is 156 MHz, and the desired maximum frequency deviation is 5 kHz.
- Frequency modulation of the crystal oscillator by the varactor produces a maximum deviation of only 200 Hz.
- When multiplied by a factor of 24 in the frequency multiplier circuits, this deviation is increased to 200 x 24 = 4800 Hz, or 4.8 kHz, which is close to the desired deviation.

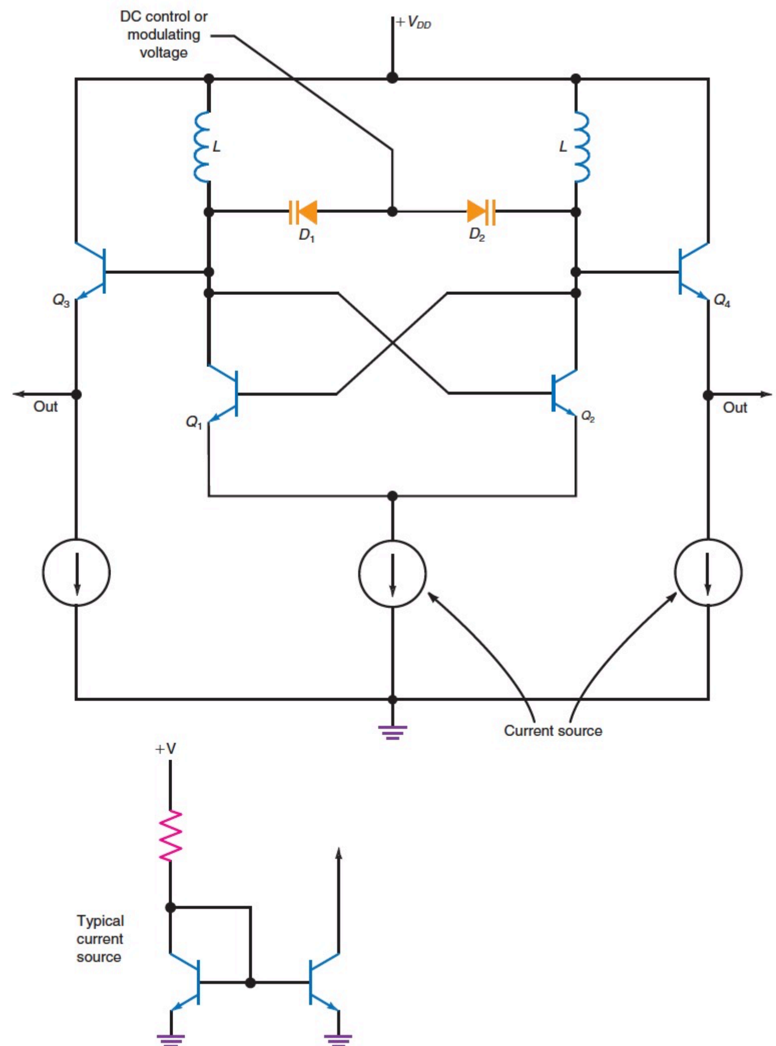


Voltage-Controlled Oscillators

- Oscillators whose frequencies are controlled by an external input voltage are generally referred to as voltage-controlled oscillators (VCOs) .
- Voltage-controlled crystal oscillators are generally referred to as VXOs.
- Although some VCOs are used primarily in FM, they are also used in other applications where voltage-to-frequency conversion is required. As you will see, their most common application is in phase-locked loops, discussed later in this chapter.
- Although VCOs for VHF, UHF, and microwaves are still implemented with discrete components, more and more they are being integrated on a single chip of silicon along with other transmitter or receiver circuits

10-GHz SiGe integrated VCO (1)

- An example of such a VCO is shown in Figure.
- This circuit uses silicon-germanium (SiGe) bipolar transistor to achieve an operating frequency centered near 10 GHz.
- The oscillator uses cross-coupled transistors Q_1 and Q_2 in a multivibrator or flip-flop type of design.
- The signal is a sine wave whose frequency is set by the collector inductances and varactor capacitances.

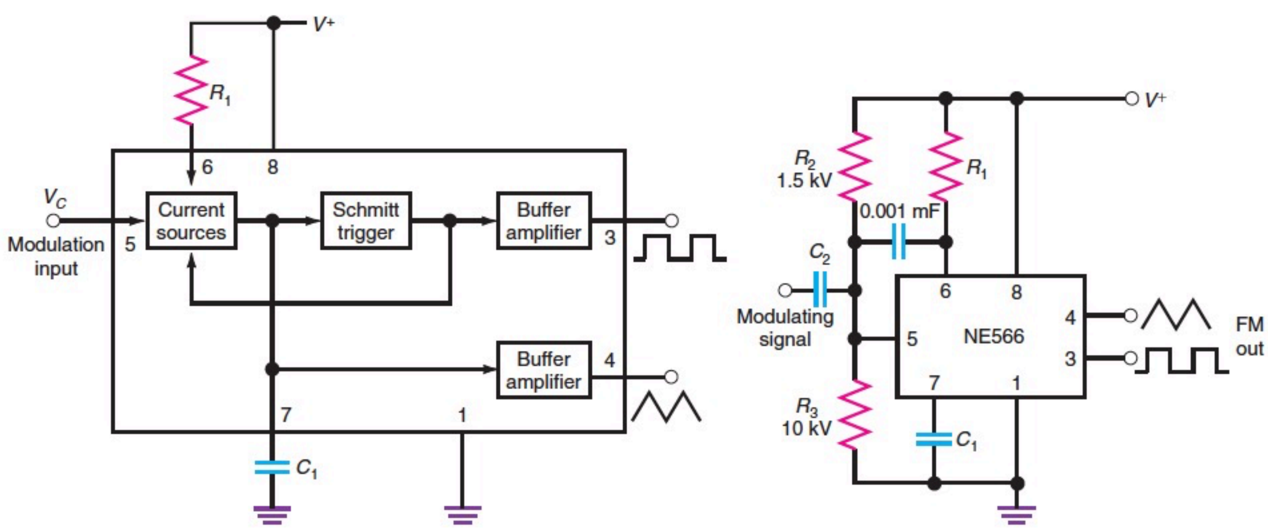


10-GHz SiGe integrated VCO (2)

- The modulating voltage is applied to the junction of D_1 and D_2 .
- Two complementary outputs are available from the emitter followers Q_3 and Q_4.
- In this circuit, the inductors are actually tiny spirals of aluminum (or copper) inside the chip, with inductance in the 500- to 900-pH range.
- The varactors are reverse-biased diodes that function as variable capacitors. The tuning range is from 9.953 to 10.66 GHz.

Frequency Modulation with an IC VCO (1)

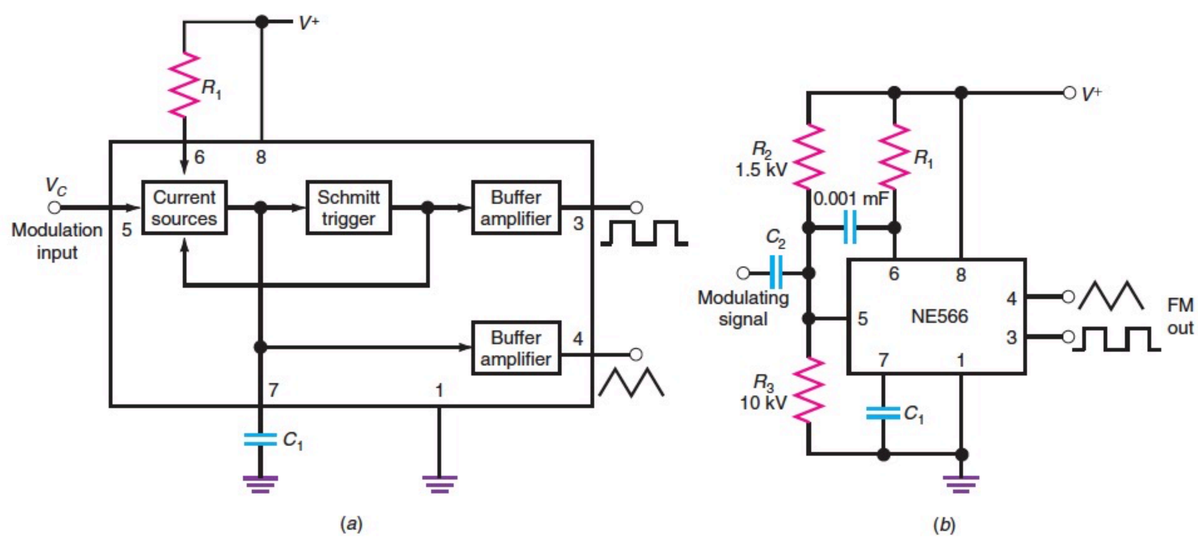
- Figure (a) is a block diagram of one widely used IC VCO, the popular NE566.
- External resistor R_1 at pin 6 sets the value of current produced by the internal current source.
- The current sources linearly charge and discharge external capacitor C_1 at pin 7.
- An external voltage V_C applied at pin 5 is used to vary the amount of current produced by the current sources.



(a) (b)

Frequency Modulation with an IC VCO (2)

- A complete frequency modulator circuit using the NE566 is shown in Figure (b). The current sources are biased with a voltage divider made up of R_2 and R_3 .
- The modulating signal is applied through C_2 to the voltage divider at pin 5.
- Carrier frequencies up to 1 MHz may be used with this IC. If higher frequencies and deviations are necessary, the outputs can be filtered or used to drive other circuits, such as a frequency multiplier.



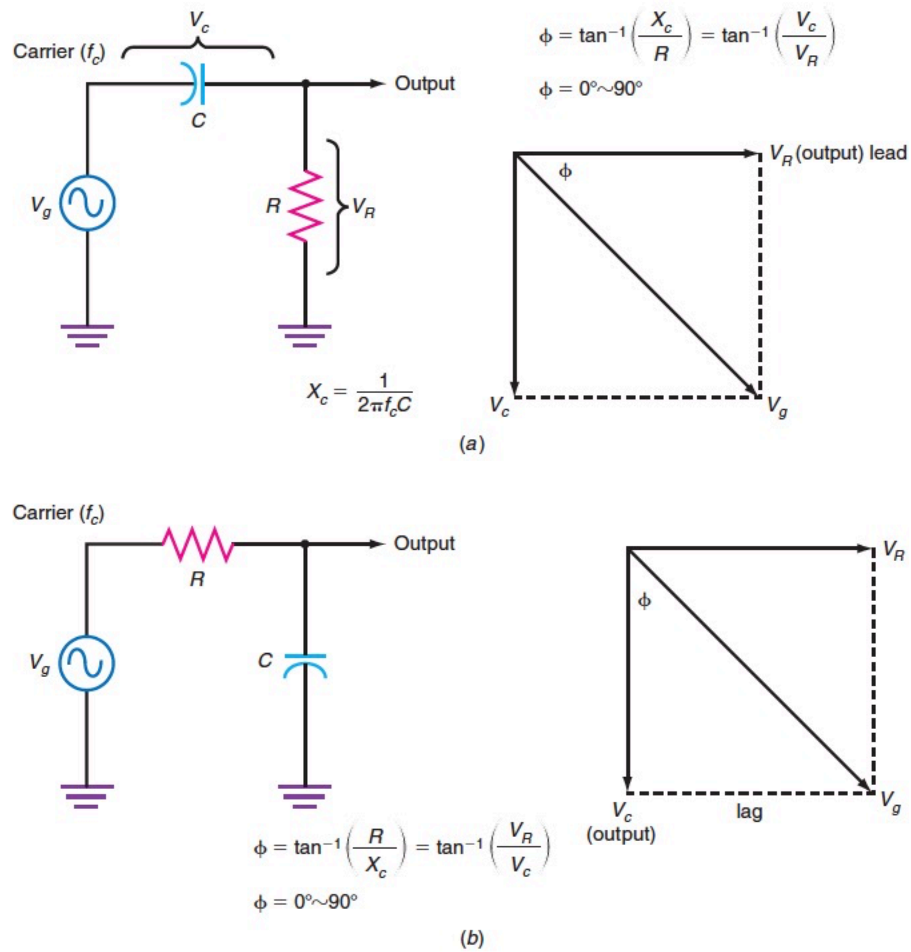
Phase Modulators

- Most modern FM transmitters use some form of phase modulation to produce indirect FM.
- The reason for using PM instead of direct FM is that the carrier oscillator can be optimized for frequency accuracy and stability.
- Crystal oscillators or crystal-controlled frequency synthesizers can be used to set the carrier frequency accurately and maintain solid stability.
- The output of the carrier oscillator is fed to a phase modulator where the phase shift is made to vary in accordance with the modulating signal.
- Since phase variations produce frequency variations, indirect FM is the result.

RC Phase-Shifter Basics (1)

- The simplest phase shifters are RC networks like those shown in Figure (a) and (b).
- Depending on the values of R and C, the output of the phase shifter can be set to any phase angle between 0 and 90°.
- In (a), the output leads the input by some angle between 0 and 90°. For example, when X_c equals R, the phase shift is 45°.
- The phase shift is computed by using the formula

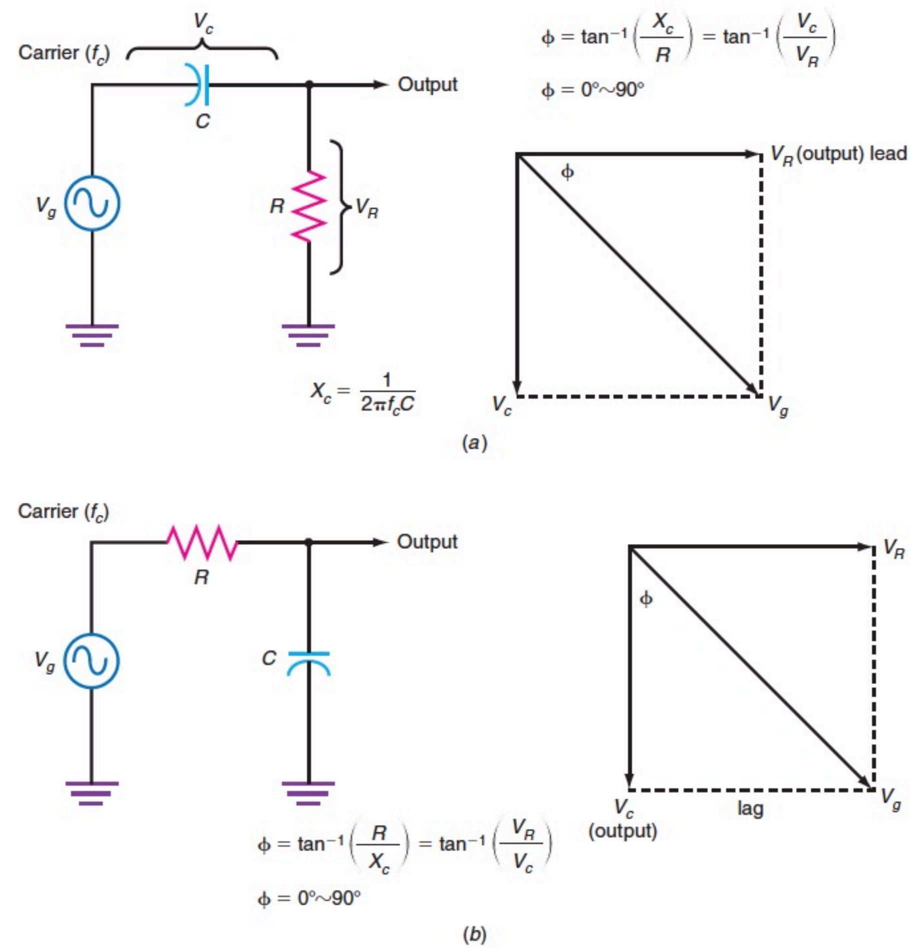
$$\phi = \tan^{-1}\frac{X_C}{R}$$



RC Phase-Shifter Basics (2)

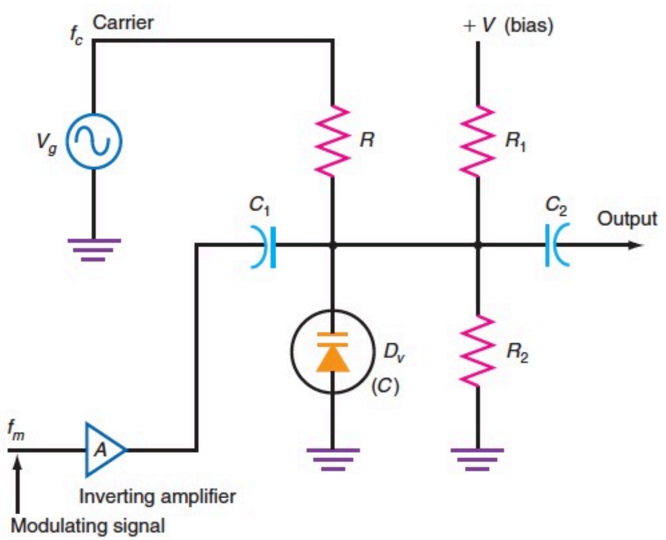
- A low-pass RC filter can also be used, as shown in Figure (b).
- Here the output is taken from across the capacitor, so it lags the input voltage by some angle between 0 and 90° .
- The phase angle is computed by using the formula:

$$\phi = \tan^{-1}\frac{X_C}{R}$$



A varactor phase modulator

- A simple phase-shift circuit can be used as a phase modulator if the resistance or capacitance can be made to vary with the modulating signal.
- One way to do this is to replace the capacitor shown in the circuit of Figure (b) with a varactor. The resulting phase-shift circuit is shown in this Figure.
- In this circuit, the modulating signal causes the capacitance of the varactor to change.



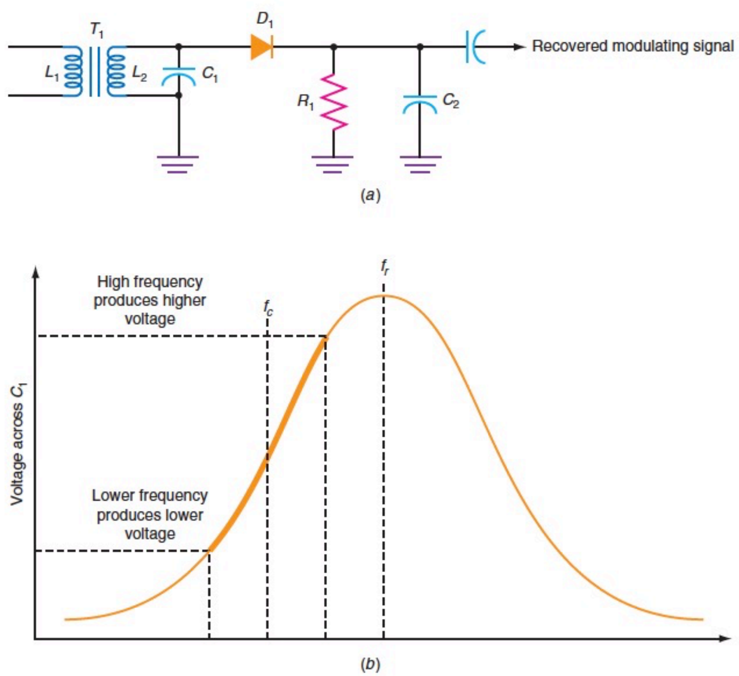
Frequency Demodulators

- Any circuit that will convert a frequency variation in the carrier back to a proportional voltage variation can be used to demodulate or detect FM signals.

- Circuits used to recover the original modulating signal from an FM transmission are called demodulators, detectors, or discriminators

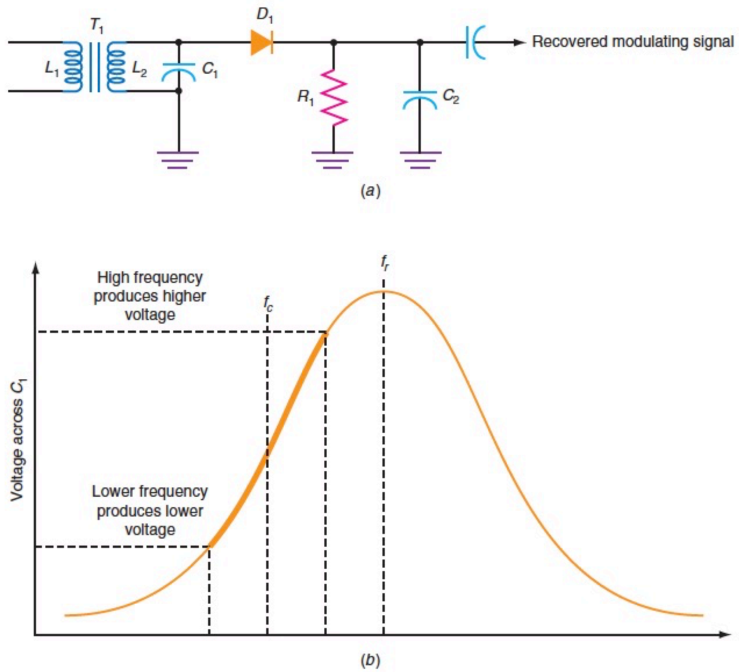
Slope Detectors

- The simplest frequency demodulator, the slope detector, makes use of a tuned circuit and a diode detector to convert frequency variations to voltage variations.
- The basic circuitis shown in Figure (a). This has the same configuration as the basic AM diode detector, although it is tuned differently.
- The FM signal is applied to transformer T1 made up of L1 and L2 .
- Together L2 and C1 form a series resonant circuit. Remember that the signal voltage induced into L2 appears in series with L2 and C1 and the output voltage is taken from across C1.



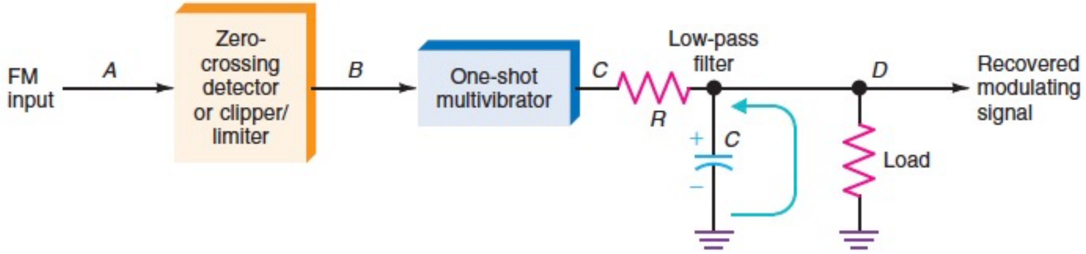
Slope Detectors

- The response curve of this tuned circuit is shown in Figure (b). Note that at the resonant frequency fr the voltage across C1 peaks.
- At lower or higher frequencies, the voltage falls off.
- To use the circuit to detect or recover FM, the circuit is tuned so that the center or carrier frequency of the FM signals is approximately centered on the leading edge of the response curve, as shown in Figure (b).
- As the carrier frequency varies above and below its center frequency, the tuned circuit responds as shown in the fi gure.



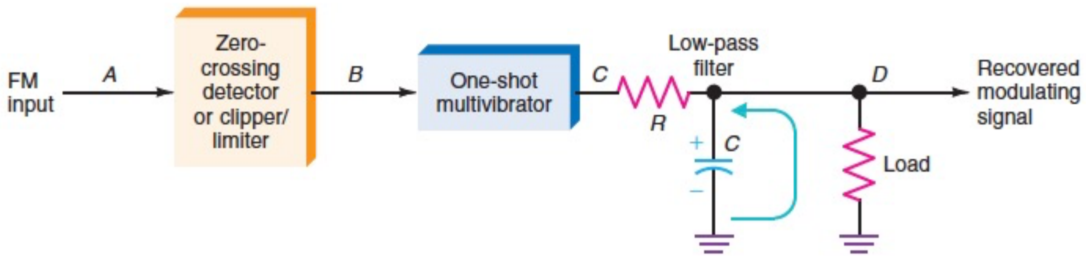
Pulse-Averaging Discriminators

- A simplifi ed block diagram of a pulse-averaging discriminator is illustrated in Figure.
- The FM signal is applied to a zero-crossing detector or a clipper-limiter that generates a binary voltage-level change each time the FM signal varies from minus to plus or from plus to minus
- The result is a rectangular wave containing all the frequency variations of the original signal but without amplitude variations.
- The FM square waveis then applied to a one-shot (monostable) multivibrator that generates a fixed-amplitude, fixed-width dc pulse on the leading edge of each FM cycle.



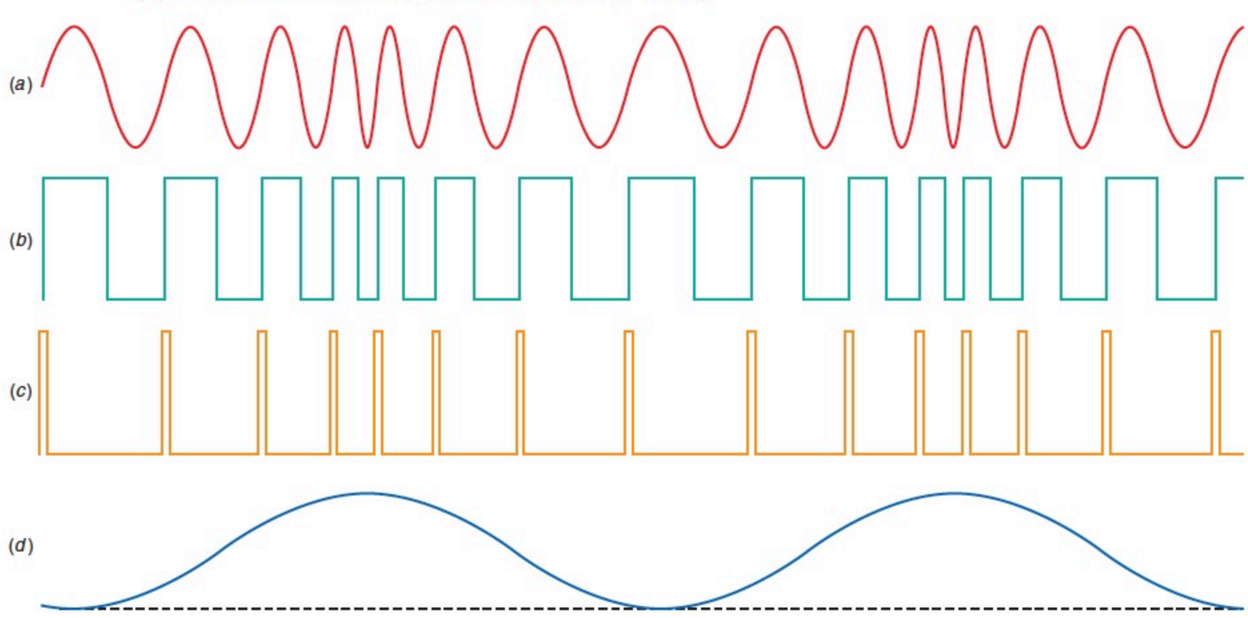
Pulse-Averaging Discriminators

- The duration of the one shot is set so it is less than one-half the period of the highest frequency expected during maximum deviation.
- The one-shot output pulses are then fed to a simple RC low-pass filter that averages the dc pulses to recover the original modulating signal.



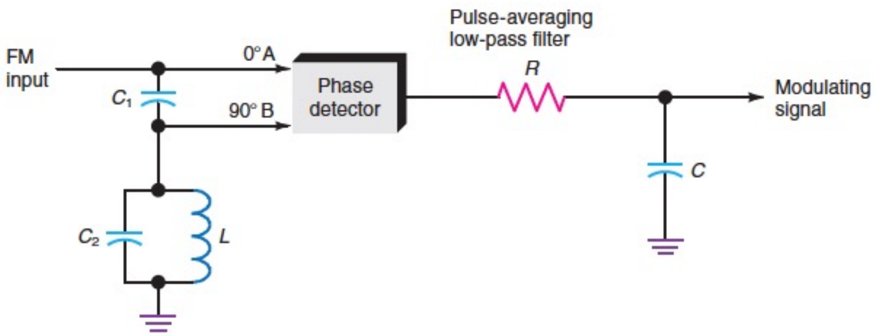
Pulse-Averaging Discriminators

- The waveforms for the pulse-averaging discriminator are illustrated in Figure.
- At low frequencies, the one-shot pulses are widely spaced; at higher frequencies, they occur very close together.
- When these pulses are applied to the averaging filter, a dc output voltage is developed, the amplitude of which is directly proportional to the frequency deviation.



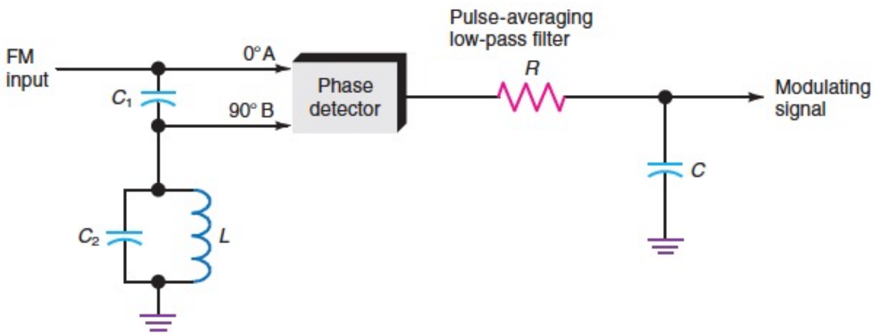
Quadrature Detectors

- The quadrature detector uses a phase-shift circuit to produce a phase shift of 90 at the unmodulated carrier frequency.
- The most commonly used phase-shift arrangement is shown in Figure. The frequency-modulated signal is applied through a very small capacitor (C1) to the parallel-tuned circuit, which is adjusted to resonate at the center carrier frequency.
- At resonance, the tuned circuit appears as a high value of pure resistance.
- The small capacitor has a very high reactance compared to the tuned circuit impedance.



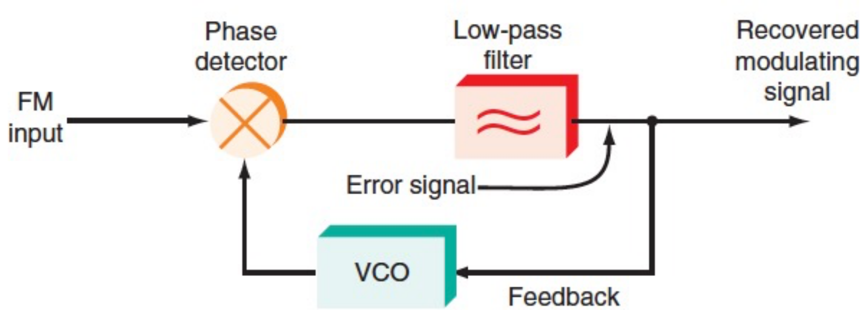
Quadrature Detectors

- Thus, the output across the tuned circuit at the carrier frequency is very close to 90° and leads the input.
- When frequency modulation occurs, the carrier frequency deviates above and below the resonant frequency of the tuned circuit, resulting in an increasing or a decreasing amount of phase shift between the input and the output.



Phase-Locked Loops (1)

- A phase-locked loop (PLL) is a frequency- or phase-sensitive feedback control circuit used in frequency demodulation, frequency synthesizers, and various filtering and signal detection applications.
- All phase-locked loops have the three basic elements, shown in Figure.
  1) A phase detector is used to compare the FM input, sometimes referred to as the reference signal, to the output of a VCO.
  2) The VCO frequency is varied by the dc output voltage from a low-pass filter.
  3) The low-pass filter smoothes the output of the phase detector into a control voltage that varies the frequency of the VCO.



Phase-Locked Loops (2)

- The primary job of the phase detector is to compare the two input signals and generate an output signal that, when filtered, will control the VCO.
- If there is a phase or frequency difference between the FM input and VCO signals, the phase detector output varies in proportion to the difference.
- The filtered output adjusts the VCO frequency in an attempt to correct for the original frequency or phase difference. This dc control voltage, called the error signal, is also the feedback in this circuit.
- When no input signal is applied, the phase detector and low-pass filter outputs are zero.

Phase-Locked Loops (3)

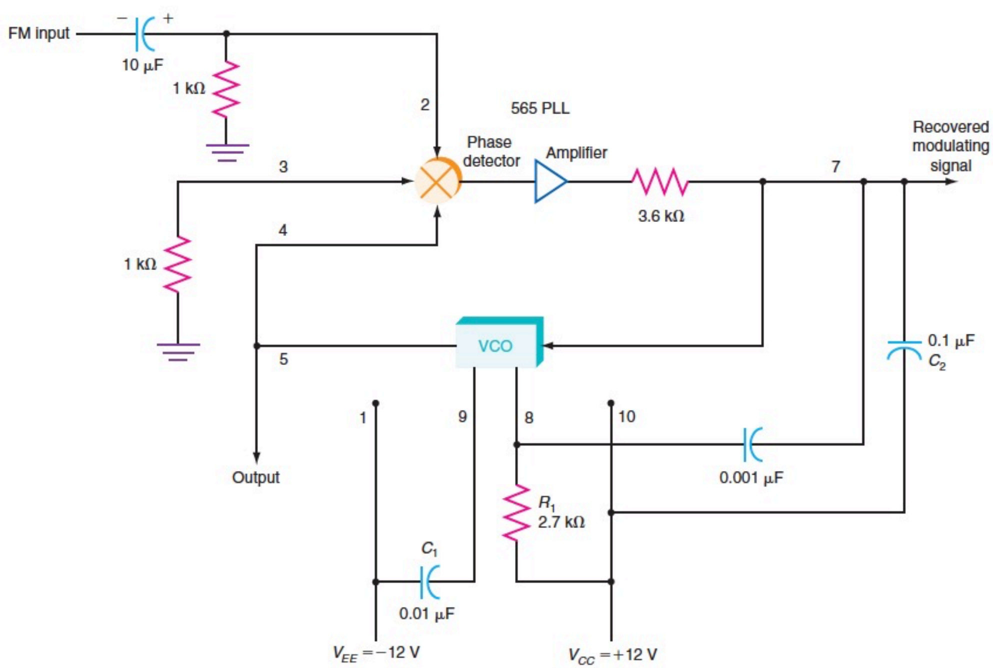
- The VCO then operates at what is called the free-running frequency, its normal operating frequency as determined by internal frequency-determining components.
- When an input signal close to the frequency of the VCO is applied, the phase detector compares the the VCO free-running frequency to the input frequency and produces an output voltage proportional to the frequency difference.
- The phase detector output is a series of pulses that vary in width in accordance with the amount of phase shift or frequency difference that exists between the two inputs.
- The output pulses are then filtered into a dc voltage that is applied to the VCO.
- This dc voltage is such that it forces the VCO frequency to move in a direction that reduces the dc error voltage.

Phase-Locked Loops (4)

- The error voltage forces the VCO frequency to change in the direction that reduces the amount of phase or frequency difference between the VCO and the input.
- At some point, the error voltage causes the VCO frequency to equal the input frequency; when this happens, the PLL is said to be in a locked condition.
- Although the input and VCO frequencies are equal, there is a phase difference between them, usually exactly 90^o, which produces the dc output voltage that will cause the VCO to produce the frequency that keeps the circuit locked

A PLL FM Demodulator Using the 565 IC

- Figure is a block diagram of an IC PLL, the 565. The 565 is connected as an FM demodulator.
- The numbers on the connections are the pin numbers on the 565 IC, which is housed in a standard 14-pin dual-in-line package (DIP).
- The circuit is powered by 6 12-V power supplies.



References

- Chapter 5 & 6, Beasley and Miller, Modern Electronic Communication, 9th Edition.