

# Chapter 7

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## FM MODULATORS

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## 7.1 OBJECTIVES

1. Studying the operation and characteristics of varactor diode.
2. Understanding the operation of voltage controlled oscillator.
3. Implementing a frequency modulator with voltage-controlled oscillator.

## 7.2 DISCUSSION OF FUNDAMENTALS

### Principle of Frequency Modulation Operation

Frequency modulation (FM) is a process in which the carrier frequency is varied by the amplitude of the modulating signal (i.e., intelligence signal). The FM signal can be expressed by the following equation:

$$x_{FM}(t) = A_c \cos \theta(t) = A_c \cos \left[ 2\pi f_c t + 2\pi f_\Delta \int x(\lambda) d\lambda \right] \quad (7-1)$$

If  $x(\lambda) = A_m \cos(2\pi f_m \lambda)$ , then

$$\begin{aligned} x_{FM}(t) &= A_c \cos \left[ 2\pi f_c t + \frac{f_\Delta A_m}{f_m} \sin(2\pi f_m t) \right] \\ &= A_c \cos \left[ 2\pi f_c t + \beta \sin(2\pi f_m t) \right] \end{aligned} \quad (7-2)$$

where

$\theta(t)$  = instantaneous modulated frequency

$f_c$  = carrier frequency

$f_m$  = modulating frequency

$\beta$  = modulation index =  $A_m(f_\Delta/f_m)$

The frequency of FM signal  $x_{FM}(t)$  may be expressed as

$$\begin{aligned} f &= \frac{1}{2\pi} \frac{d}{dt} \theta(t) = \frac{1}{2\pi} \frac{d}{dt} [2\pi f_c t + \beta \sin(2\pi f_m t)] \\ &= f_c - f_m \beta \cos(2\pi f_m t) \end{aligned} \quad (7-3)$$

From Eq. (7-3) we can find that the frequency of frequency modulated signal occurs frequency deviation from the center frequency of the carrier when the intelligence amplitude is variation.

### Varactor Diode

The varactor diode, sometimes called tuning diode, is the diode whose capacitance is proportional to the amount of the reverse bias voltage across p-n junction. Increasing the reverse bias voltage applied across the diode decreases the capacitance due to the depletion region width becomes wider. Conversely, when the reverse bias voltage decreased, the depletion region width becomes narrower and the capacitance increased. When an ac voltage is applied across the diode, the capacitance varies with the change of the amplitude.

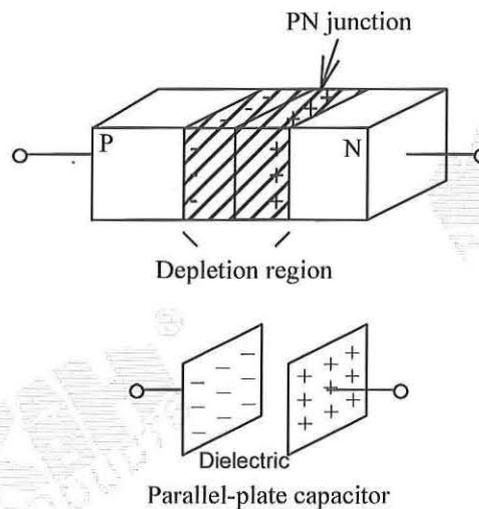


Fig. 7-1 Relationship between varactor diode and capacitor

A relationship between a varactor diode and a conventional capacitor is shown in Fig. 7-1. In fact, a reverse-biased varactor diode is similar to a capacitor. When a p and n semiconductors combined together, a small depletion region is formed because of the diffusion of minority carriers. The positive and negative charges occupy n and p sides of junction, respectively. This just likes a capacitor. The amount of internal junction capacitance can be calculated by the capacitance formula.

$$C = \frac{\epsilon A}{d} \quad (7-4)$$

where

$\epsilon = 11.8\epsilon_0 =$  dielectric constant

$\epsilon_0 = 8.85 \times 10^{-12}$

$A =$  cross area of capacitor

$d =$  width of depletion region

From the formula above, we know that the varactor capacitance is inversely proportional to the width of depletion region (or the distance between plates) if the area  $A$  is constant. Therefore, a small reverse voltage will produce a small depletion region and a large capacitance. In other words, an increase in reverse bias will result in a large depletion region and a small capacitance.



Fig.7-2 The equivalent circuit of varactor diode

A varactor diode can be considered as a capacitor and resistor connected in series as shown in Fig. 7-2. The  $C_j$  is the junction capacitance between p and n junctions. The  $R_s$  is the sum of bulk resistance and contact resistance,

approximately several ohms, and it is an important parameter determining the quality of varactor diode.

Tuning ratio (TR) is defined as the ratio of the capacitance of varactor diode at the reverse voltage  $V_2$  to that at another reverse voltage  $V_1$ , and can be expressed by

$$TR = \frac{C_{V2}}{C_{V1}} \quad (7-5)$$

where

$TR$  = tuning ratio

$C_{V1}$  = capacitance of varactor diode at  $V_1$

$C_{V2}$  = capacitance of varactor diode at  $V_2$

The 1SV55 varactor diode is used in our experiments and its major characteristics are

$C_{3V} = 42$  pF (capacitance of varactor diode at 3V)

$TR = 2.65$  (at 3V ~ 30V)

### Frequency Modulator Based on MC1648 VCO

In our experiments we will implement the frequency modulator with MC1648 VCO chip shown in Fig. 7-3. Basically, this circuit is an oscillator and the tuning circuit at input end determines its oscillating frequency. In this circuit, capacitors  $C_2$  and  $C_3$  are the bypass capacitors for filtering noise. When operating at a high frequency (for example 2.4 MHz), the capacitive reactance of these two capacitors are very small and can be neglected for practical purposes. Therefore, an ac equivalent circuit of tuning tank, shown in Fig. 7-4, is a parallel LC resonant circuit. The C can be considered as the capacitance of 1SV55 ( $C_d$ ) and the input capacitance of MC1648 ( $C_{in}$ ) connected in parallel. The value of

$C_{in}$  is approximately 6 pF. If we neglect the stray capacitance, the oscillating frequency can be calculated by the formula

$$f_o = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{L(C_d + 6 \times 10^{-12})}} \quad (\text{Hz}) \quad (7-6)$$

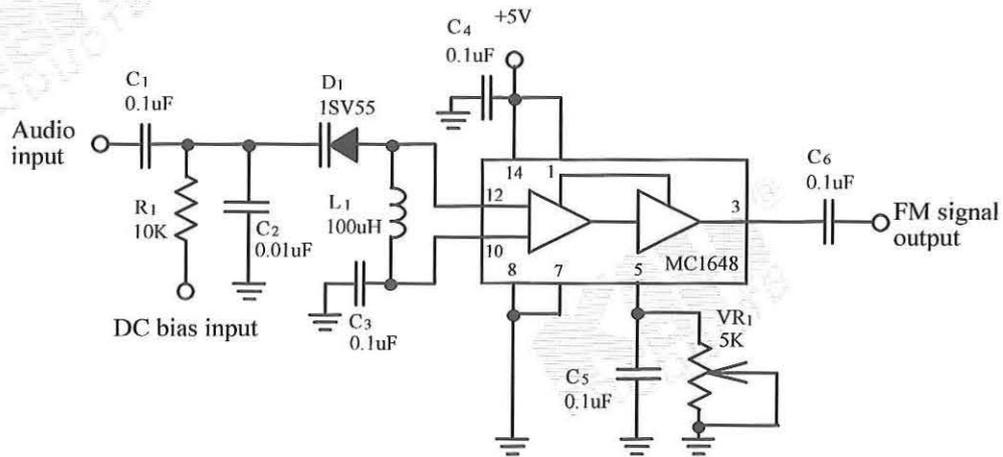


Fig.7-3 MC1648 FM modulator circuit

As mentioned above, the capacitance  $C_d$  of varactor diode  $D_1$  varies with the amount of its reverse bias voltage. According to Eq. (7-6), we know that the change of  $C_d$  value will cause the change of oscillating frequency. In the circuit of Fig. 7-3, a small dc bias will produce a large  $C_d$  value and a low frequency output. On the other hand, an increase in dc bias will result in a small  $C_d$  value and a high frequency output. Therefore, if the dc bias is fixed and an audio signal is applied to this input, the VCO output signal will be a frequency-modulated signal.

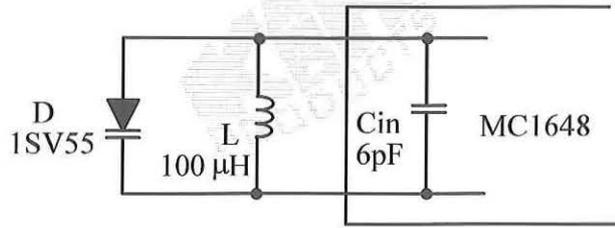


Fig.7-4 AC equivalent circuit of tuning tank

**Frequency Modulator Based on LM566 VCO**

The circuit of Fig. 7-5 is a frequency modulator based on voltage-controlled oscillator (VCO) IC, LM566. If the SW<sub>1</sub> is open, this circuit is a typical VCO whose output frequency is determined by the values of C<sub>3</sub> and VR<sub>1</sub>, and the audio input voltage. If the values of C<sub>3</sub> and VR<sub>1</sub> are fixed, the output frequency is directly proportional to the voltage difference between pins 8 and 5, (V<sub>8</sub>-V<sub>5</sub>). In other words, an increase in audio input voltage (V<sub>5</sub>) causes a decrease in the value of (V<sub>8</sub>-V<sub>5</sub>) and a decrease in the output frequency. Conversely, decreasing the audio input voltage (V<sub>5</sub>) will cause the output frequency to increase. As discussed above, the values of C<sub>3</sub> and VR<sub>1</sub> can also determine the output frequency, which is inversely proportional to the product of VR<sub>1</sub> and C<sub>3</sub>. That is, the greater the VR<sub>1</sub>×C<sub>3</sub> value the lower the output frequency.

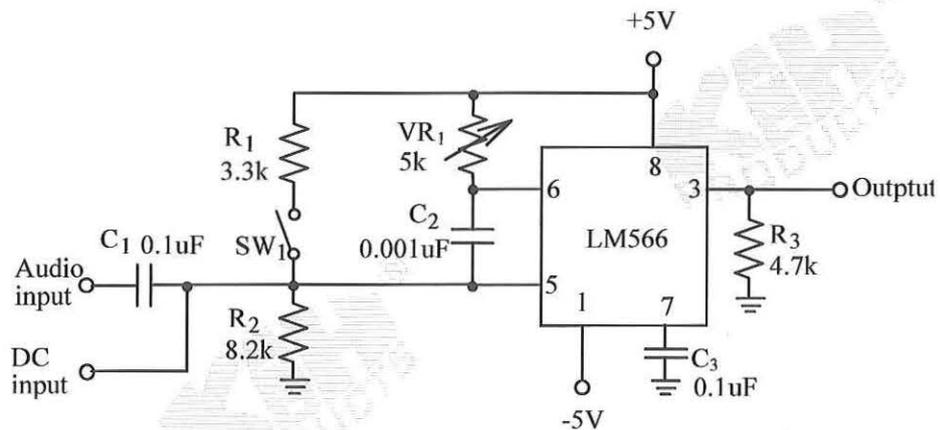


Fig.7-5 LM566 frequency modulator circuit

If the  $SW_1$  is closed, the voltage divider constructed by  $R_1$  and  $R_2$  provides a dc level to the audio input (pin 5). By adjusting the  $VR_1$ , we can easily tune the VCO center frequency  $f_o$ . When an audio signal is applied to the audio input, the output frequency will generate frequency deviations around  $f_o$  in the variations of audio amplitude. Thus, a frequency-modulated signal is obtained.

### 7.3 EQUIPMENT REQUIRED

- 1 - Module KL-92001
- 2 - Module KL-93004
- 3 - Oscilloscope
- 4 - Spectrum Analyzer

### 7.4 EXPERIMENTS AND RECORDS

#### **Experiment 7-1 MC1648 Characteristic Measurements**

- 1. Locate the MC1648 FM Modulator circuit on Module KL-93004. Insert the connect plug in J2 to set the inductor to  $L_1$  (100  $\mu$ H).
- 2. Connect a 3Vdc to dc bias input (I/P2) and observe the output waveform using the oscilloscope. Adjust the  $VR_1$  until a sine wave appears at the output and record the frequency in Table 7-1.
- 3. Repeat step 2 for other dc voltages listed in Table 7-1.
- 4. Using the results of Table 7-1, plot frequency vs. voltage curve in Fig. 7-6.

**Experiment 7-2 MC1648 Frequency Modulator**

- 1. Insert connect plugs in J1 and J2 to reverse-bias the varactor 1SV55 at 5 V and  $L_1=100\mu\text{H}$ . Under these conditions, the output frequency will be the center frequency  $f_o$ .
- 2. Connect a 2Vp-p, 3kHz sine wave of to the audio input (I/P1) and observe the output waveform using the oscilloscope. Adjust the VR<sub>1</sub> until a sine wave appears at the output.
- 3. Using the spectrum analyzer, observe and record the output spectrum in Table 7-2.
- 4. Repeat step 3 for audio frequencies of 5 kHz and 8 kHz.

Note: Since the frequency difference between the carrier and modulated signals is too large to observe an evident variation in time domain on the oscilloscope, therefore we recommend the use of the frequency analyzer in such a case.

**Experiment 7-3 LM566 Characteristic Measurements**

1. Locate the LM566 Modulator circuit on Module KL-93004. Insert the connect plug in J2 to set the capacitor to  $C_3$  ( $0.1 \mu\text{F}$ ).
2. Connect a 3.6Vdc to the dc voltage input (pin 5) and Adjust the  $VR_1$  to obtain an output frequency of 2 kHz. This frequency is the center frequency  $f_o$ .
3. Change the dc voltages at pin 5 to 2.7V, 3.0V, 3.3V, 3.9 V, 4.2 V and 4.5V sequentially. Observe the output frequencies corresponding to the dc voltage inputs and record the results in Table 7-3.
4. Using the results of Table 7-3, plot the frequency vs. voltage curve in Fig. 7-7.
5. Remove the connect plug from J2 and then insert it in J3. This changes the capacitor from  $C_3$  ( $0.1\mu\text{F}$ ) to  $C_4$  ( $0.01\mu\text{F}$ ).
6. Connect a 3.6Vdc to the dc voltage input (pin 5) and Adjust the  $VR_1$  to obtain an output frequency of 20 kHz. This frequency is the center frequency  $f_o$ .
7. Change the dc voltages at pin 5 to 2.7V, 3.0V, 3.3V, 3.9 V, 4.2 V and 4.5V sequentially. Observe the output frequencies corresponding to the dc voltage inputs and record the results in Table 7-4.
8. Using the results of Table 7-4, plot the frequency vs. voltage curve in Fig. 7-8.

**Experiment 7-4 LM566 Frequency Modulator**

1. Locate the LM566 FM Modulator circuit on Module KL-93004. Insert connect plugs in J1 and J3 to set the capacitor to  $C_4$  ( $0.01\mu\text{F}$ ). Turn the  $\text{VR}_1$  to get the output frequency of 20kHz.
2. Connect a 500mVp-p, 1kHz sine wave to the audio input (I/P1). Using the oscilloscope, observe the output waveform (O/P) and record the result in Table 7-5.
3. Change the audio frequencies to 3kHz and 5kHz sequentially. Observe the output waveforms corresponding to the audio inputs and record the results in Table 7-5.
4. Change the audio input to a 1Vp-p, 1kHz sine wave. Observe the output waveform and record the result in Table 7-6.
5. Change the audio frequencies to 3kHz and 5kHz sequentially. Observe the output waveforms corresponding to the audio inputs and record the results in Table 7-6.

Table 7-1

DC Bias Input (V)	3	4	5	6	7	8	9	10	11	12	13	14
Output Frequency (MHz)												

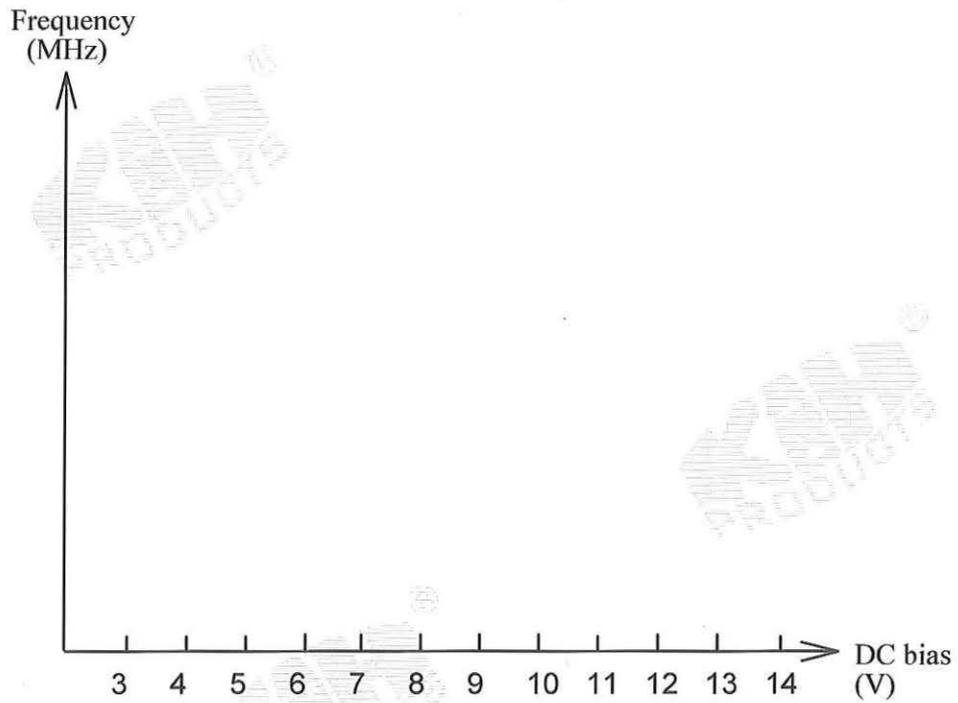


Fig.7-6

Table 7-2

 $(V_m = 2V)$ 

Input Frequency	Input Waveform	Output Spectrum
3 kHz		
5 kHz		
8 kHz		

Table 7-3

( $C_3 = 0.1\mu\text{F}, f_o = 2\text{kHz}$ )

Input Voltage (V)	2.7	3.0	3.3	3.6	3.9	4.2	4.5
Output Frequency (KHz)							

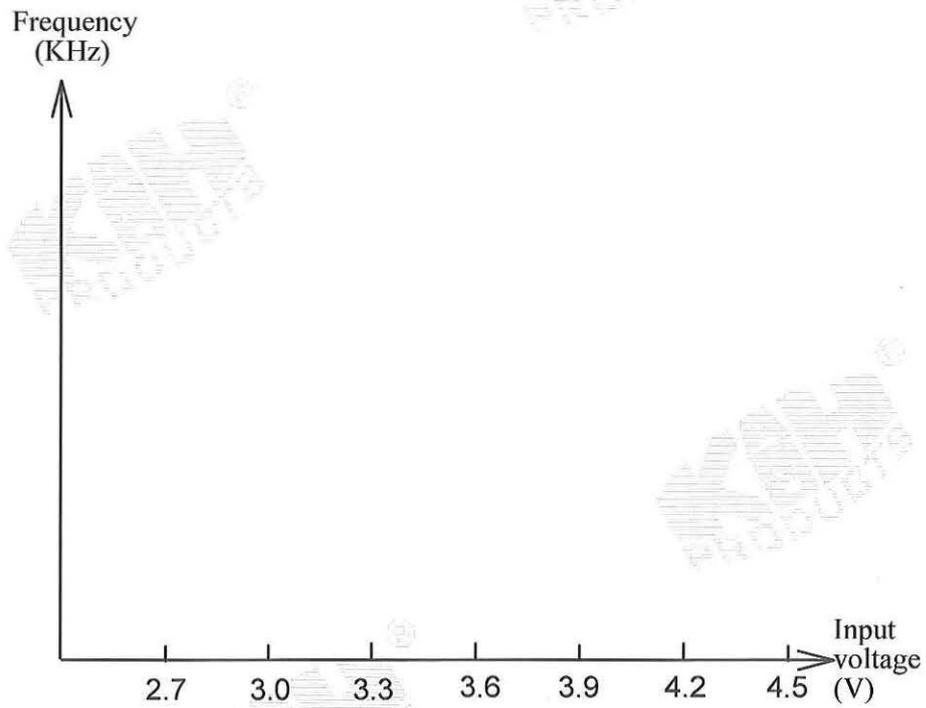


Fig.7-7

Table 7-4

( $C_3=0.01 \mu\text{F}$ ,  $f_o=20 \text{ kHz}$ )

Input Voltage (V)	2.7	3.0	3.3	3.6	3.9	4.2	4.5
Output Frequency (KHz)							

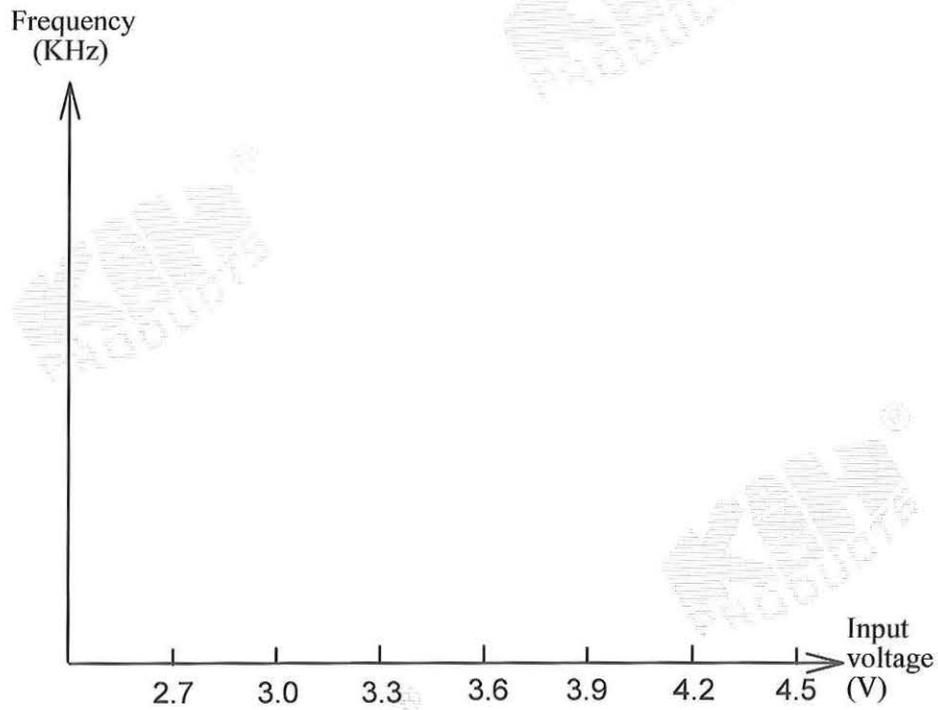


Fig.7-8

Table 7-5

( $V_m=500\text{mVp-p}$ ,  $C_3=0.01\mu\text{F}$ ,  $f_o=20\text{kHz}$ )

Input Frequency	Input Waveform	Output Waveform
1 kHz		
3 kHz		
5 kHz		

Table 7-6

 $(V_m=1V_{p-p}, C_3=0.01\mu F, f_o=20kHz)$ 

Input Frequency	Input Waveform	Output Waveform
1 kHz		
3 kHz		
5 kHz		

## 7.5 QUESTIONS

1. If the inductance in the tank circuit of Fig. 7-3 is 80nH and we wish to get a resonance frequency of 100MHz, what capacitance value of varactor diode should be?
2. Examining the Frequency vs. Voltage curve of Fig. 7-6, which portion on the curve is suitable for implementing a frequency modulator?
3. Reviewing the circuit of Fig.7-5, what is the function of R1 and R2 when the SW1 is closed?