Trainer Module: ETEK DCS-6000-07

Chapter Thirteen

FSK Modulator

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13-1: Curriculum Objectives

1. To understand the operation theory of FSK modulator.
2. To understand the FSK modulation by using the theory of mathematical.
3. To design and implement the FSK modulator by using VCO.

13-2: Curriculum Theory

In digital signal transmission, the repeater is used to recover the data signal, this will enhance the immunity to noise. So, the coding technique can be used to detect, correct and encrypt the signal. During long haul transmission, the high frequency part of the digital signal will easily attenuate and cause distortion. Therefore, the signal must be modulated before transmission, and one of the methods is the frequency-shift keying (FSK) modulation. FSK technique is to modulate the data signal to two different frequencies to achieve effective transmission. At the receiver, the data signal will be recovered based on the two different frequencies of the received signal.

The relation of FSK signal and data signal is shown in figure 13-1. When the data signal is 5 V, after the signal pass through the buffer, the switch S1 will OFF, then the frequency of FSK signal is f_1. When the data signal is 0 V, after the signal pass through the buffer, the switch S2 will OFF, the frequency of FSK signal is f_2. Normally, the difference between frequencies f_1 and f_2 must be as large as possible. This is because the correlation of both signals is low, therefore, the effect of transmitting and receiving will be better. However, the required bandwidth must be increased. Figure 13-2 is the signal waveforms of FSK modulation.

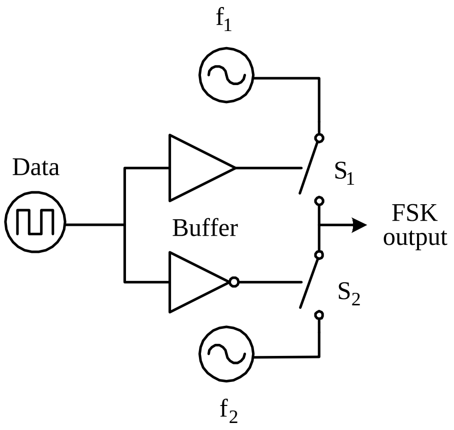


Figure 13-1 Structure diagram of FSK modulator.

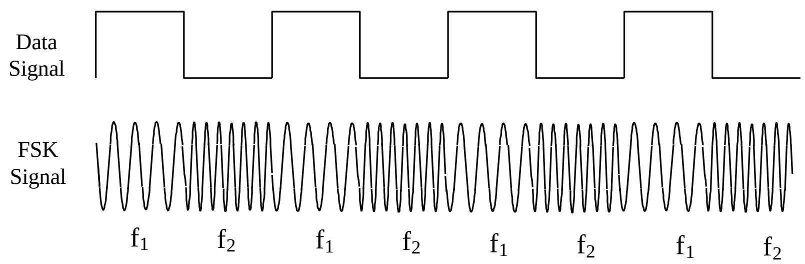


Figure 13-2 Relation diagram between data signal and FSK signal.

In this section, we utilize the theory of mathematic to solve the FSK modulation as shown in equation (13-1). The expression is shown as follow

$$\begin{aligned} V_{FSK} &= A\cos(\omega_C)t \times \cos(\omega_D)t \\ &= \tfrac{A}{2}\left[\cos(\omega_C + \omega_D)t + \cos(\omega_C - \omega_D)t\right] \end{aligned} \tag{13-1}$$

A: Magnitude of FSK signal.

$\cos(\omega_C)t$: Carrier Frequency.

$\cos(\omega_D)t$: Audio Frequency.

$\cos(\omega_C + \omega_D)t$: This frequency represents as “1”.

$\cos(\omega_C - \omega_D)t$: This frequency represents as “0”.

The technique of FSK is widely used in commercial and industrial wire transmission and wireless transmission. In the experiments, we will discuss how to produce FSK signal. In certain applications, the FSK signal is fixed. For example, for wireless transmission, the mark signal is 2124 Hz and space signal is 2975 Hz. For wire transmission such as telephone, the frequencies are as follow

Space = 1370 Hz

Mark = 870 Hz

or

Space = 2225 Hz

Mark = 2025 Hz

From the above mentioned, we notice that the frequency gap of FSK is 500 Hz.

In FSK modulator, we use data signal (square wave) as the signal source. The output signal frequency of modulator is based on the square wave levels of the data signal. In this chapter, the frequencies of the carriers are 870 Hz and 1370 Hz. These two frequencies can be produced by using a voltage-controlled oscillator, (VCO). The output signal frequencies are varied by the difference levels of the input pulse to produce two different frequencies. Each output signal frequency corresponds to an input voltage level (i.e. “0” or “1”).

In this chapter, we utilize 2206 IC waveform generator and SN74124 voltage-controlled oscillator to produce the modulated FSK signal. First of all, lets introduce the characteristics of 2206 IC. 2206 IC is a waveform generator, which is similar to 8038 IC. Figure 13-3 is the circuit diagram of the FSK modulator by using 2206 IC. In figure 13-3, resistors R_3, R_4 comprise a voltage divided circuit. The main function of the voltage divided circuit is to let the negative voltage waveform of the 2206 IC operates normally. The oscillation frequency of 2206 IC is determined by resistors R_1 and R_5. Its oscillation frequencies are $f_1 = 1/2\pi R_1 C$, $f_2 = 1/2\pi R_5 C$. There is an internal comparator in 2206 IC. Assume that when the input is 5 V, the output frequency is f_1, and when the input is 0 V, the output frequency is f_2. We can utilize the TTL signal at pin 9 to control the output frequency to be f_1 or f_2. This type of structure is similar to the structure in figure 13-1. Therefore, by using the characteristic of this structure, we can achieve FSK modulation easily.

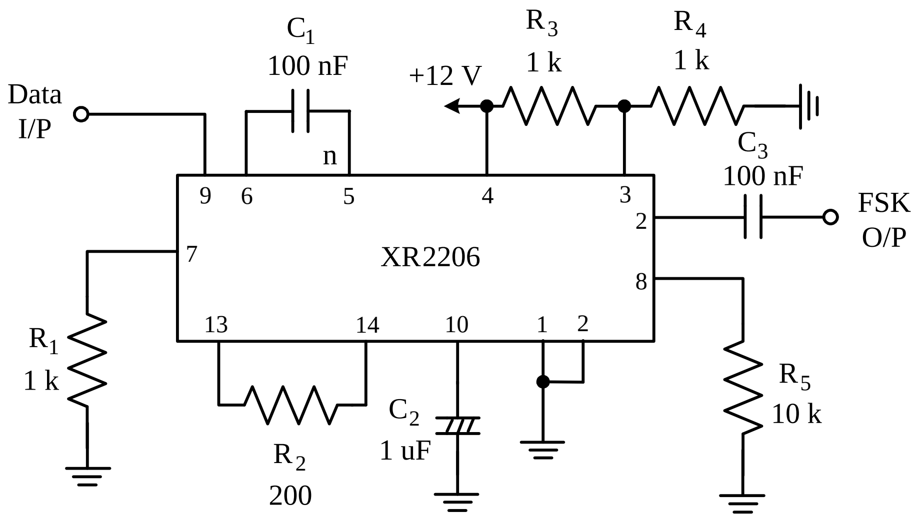


Figure 13-3 Circuit diagram of FSK modulator by using XR2206 IC.

Next, we use SN74124 voltage control oscillator to implement the FSK modulator. First of all, we will discuss the varactor diode. Varactor diode or tuning diode is mainly used for changing the capacitance value of oscillator. The objective is to let the output frequency of oscillator can be adjusted or tunable, therefore varactor diode dominates the tunable range of the whole voltage-controlled oscillator.

Varactor diode is a diode, which its capacitance can be varied by adding a reverse bias to pn junction. When reverse bias increases, the depletion region become wide, this will cause the capacitance value decreases; nevertheless, when reverse bias decreases, the depletion region will be reduced, this will cause the capacitance value increases. Varactor diode also can be varied from the amplitude of AC signal.

Figure 13-4 is the capacitance analog diagram of varactor diode. When a varactor diode without bias, the concentration will be differed from minor carriers at pn junction. Then these carriers will diffuse and become depletion region. The p type depletion region carries electron positive ions, then the n type depletion region carries negative ions. We can use parallel plate capacitor to obtain the expression as shown as follow:

$$C = \frac{\varepsilon A}{d} \tag{13-2}$$

where

$\varepsilon = 11.8\varepsilon_o$ (dielectric constant of Silicon)

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

A: the cross-section area of capacitor.

d: the width of depletion region.

When reverse bias increases, the width of depletion region *d* will increase but the cross-section area *A* remains, therefore the capacitance value would be reduced. On the other hand, the capacitance value will increase when reverse bias decreases.

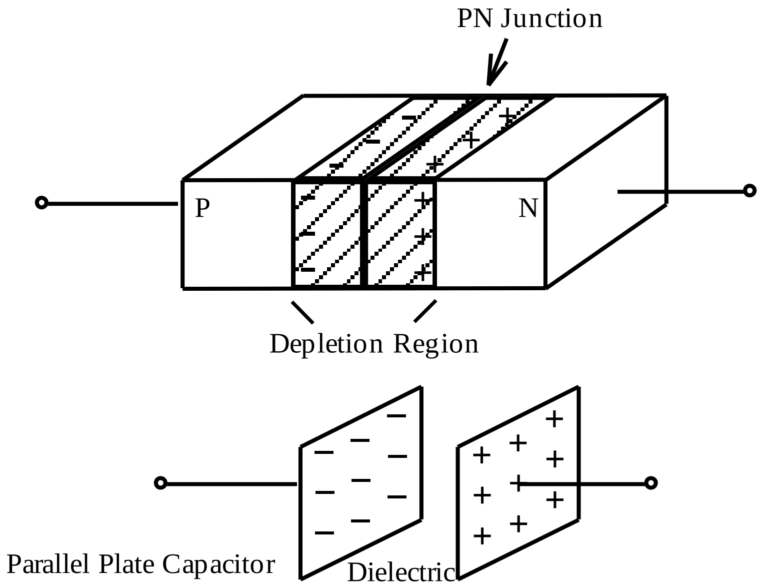


Figure 13-4 Capacitance analog diagram of varactor diode.

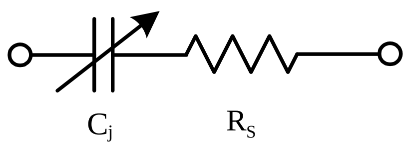


Figure 13-5 Equivalent circuit diagram varactor diode.

Varactor diode can be equivalent to a capacitor series a resistor as shown in figure 13-5. From figure 13-5, C_j is the junction capacitor of semiconductor, which only exits in pn junction. R_s is the sum of bulk resistance and contact resistance of semiconductor material, which is related to the quality of varactor diode (generally below a few ohm).

Tuning ratio, TR is the ratio of capacitance value under two different biases for varactor diode. The expression is shown as follow:

$$TR = \frac{C_{V2}}{C_{V1}} \tag{13-3}$$

where

TR: tuning ratio.

C_{V1} : capacitance value of varactor diode at V_1.

C_{V2} : capacitance value of varactor diode at V_2.

IC SN74124 is voltage-controlled oscillator integrated circuit. IC SN74124 Built-in 2 groups voltage-controlled oscillator. The output frequency range which can be controlled from several hundred Hz to several MHz, the output of the frequency can be decided by the external resistors and capacitors. Figure 13-6 is the functional description of the connection pins.

Figure 13-7 is the circuit diagram of FSK modulator. The frequency of the SN74124 output signal can be decided by the capacitors C_2, two variable resistors VR_1 and VR_2. Its operation circuit is as follows:

1. Let Data I/P connect to ground by using jump to make the voltage of the variable resistor VR_1 is equal to zero, that is the output frequency of the VCO will not be affected by the voltage of VR_1, but only the voltage of the variable resistor VR_2 can impact on the output frequency of the VCO. First of all, adjust VR_2 so that the frequency of the VCO is relatively low frequency f_1, that is 870 Hz.

2. Let Data I/P connect to $+5\ V$ by using jump and adjust VR_2 so that the frequency of the VCO is relatively high frequency f_2, that is $1370\ Hz$. At this time, the output frequency of the VCO will be affected by the sum of the voltages of the variable resistors VR_1 and VR_2.

3. By adjusting the variable resistor VR_1 to control the voltage, then, the VCO will produce two frequencies with respect to the input voltage levels (870 Hz and 1370 Hz), so we can achieve the purpose of FSK modulation.

In figure 13-7, the two μA741, R_5, R_6, R_7, R_8, R_9, R_{10}, C_3, C_4, C_5 and C_6 comprise a 4^{th} order low-pass filter. The objective is to remove the unwanted high-frequency harmonics signal from the SN74124 VCO output, so that we can obtain the sinusoidal waveform signal.

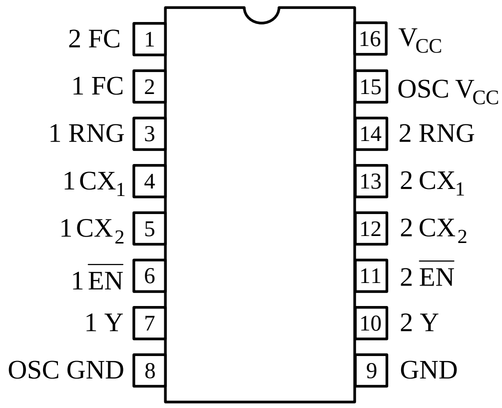


Figure 13-6 The functional description of the SN74124 connection pins.

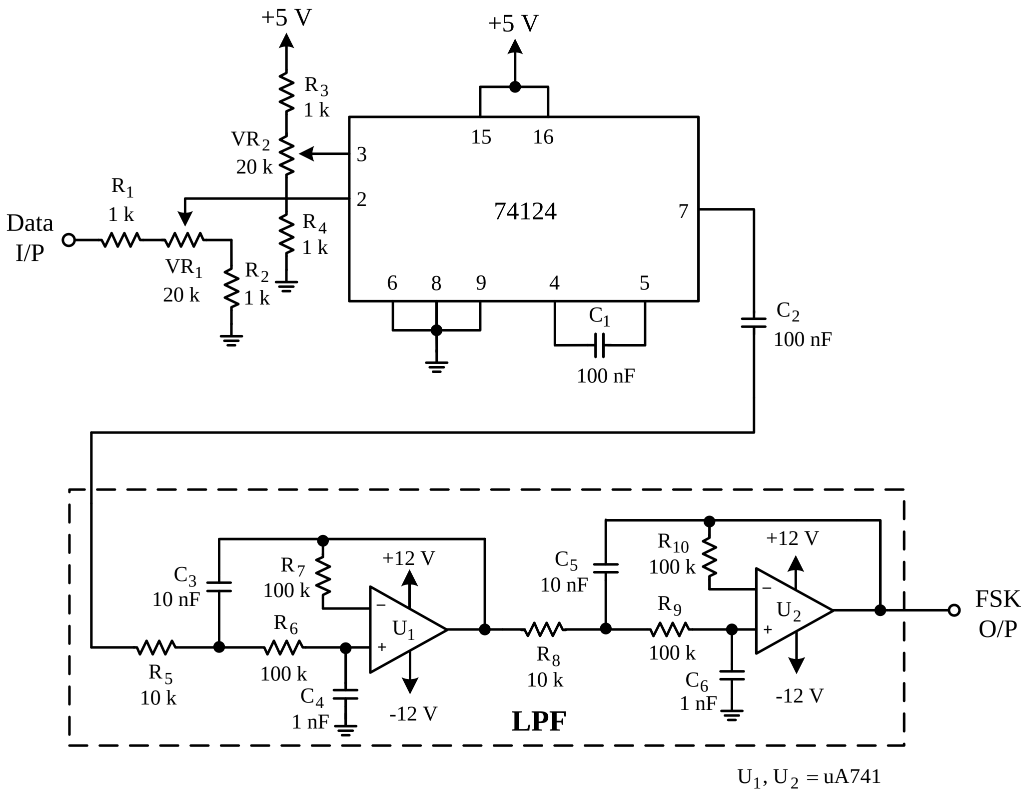


Figure 13-7 Circuit diagram of SN74124 FSK modulator.

13-3: Experiment Items

Experiment 1: XR2206 FSK modulator

1. Refer to figure 13-3 with R_1 = 1 kΩ and R_5 = 10 kΩ or refer to figure DCS13-1 on ETEK DCS-6000-07 module. Let J2 and J4 be short circuit, J3 and J5 be open circuit.

2. From figure DCS13-1, let the two terminals of Data I/P be short circuit and JP1 be open circuit, i.e. at the data signal input terminal (Data I/P), input 0 V DC voltage. By using oscilloscope, observe on the output signal waveform of FSK signal (FSK O/P), then record the measured results in table 13-1.

3. From figure DCS13-1, let the two terminals of Data I/P be open circuit and JP1 be short circuit, i.e. at the data signal input terminal (Data I/P), input 5 V DC voltage. By using oscilloscope, observe on the output signal waveform of FSK signal (FSK O/P), then record the measured results in table 13-1.

4. At the data signal input terminal (Data I/P), input 5 V amplitude, 100 Hz TTL signal. By using oscilloscope, observe on the output signal waveform of FSK signal (FSK O/P), then record the measured results in table 13-1.

5. According to the input signal in table 13-1, repeat step 4 and record the measured results in table 13-1.

6. Refer to figure 13-3 with R_1 = 7.5 kΩ and R_5 = 15 kΩ or refer to figure DCS13-1 on ETEK DCS-6000-07 module. Let J2 and J4 be open circuit, J3 and J5 be short circuit.

7. According to the input signal in table 13-2, repeat step 2 to step 4 and record the measured results in table 13-2.

Experiment 2: SN74124 FSK modulator

1. Refer to the circuit diagram in figure 13-6 or figure DCS13-2 on ETEK DCS-6000-07 module.

2. From figure DCS13-2, let the two terminals of Data I/P be short circuit and JP1 be open circuit, i.e. at the data signal input terminal (Data I/P), input 0 V DC voltage. By using oscilloscope, observe on the output signal waveform of the VCO output port (TP1) of SN74124. Slightly adjust VR_2 so that the frequency of TP1 is 870 Hz. Again, observe on the test point (TP2) of second order low-pass filter and FSK signal output port (FSK O/P). Finally, record the measured results in table 13-3.

3. From figure DCS13-2, let the two terminals of Data I/P be open circuit and JP1 be short circuit, i.e. at the data signal input terminal (Data I/P), input 5 V DC voltage. By using oscilloscope, observe on the output signal waveform of the VCO output port (TP1) of SN74124. Slightly adjust VR_1 so that the frequency of TP1 is 1370 Hz. Again, observe on TP2 and FSK O/P. Finally, record the measured results in table 13-3.

4. At the data signal input terminal (Data I/P), input 5V amplitude and

100 Hz TTL signal. By using oscilloscope, observe on the output signal waveforms of Data I/P, TP1, TP2, and FSK O/P. Finally, record the measured results in table 13-4.

5. According to the input signal in table 13-4, repeat step 4 and record the measured results in table 13-4.

13-4: Experimental Results

Experiment 1: XR2206 FSK Modulator

Table 13-1 Measured results of FSK modulator by using XR2206 IC.

Input Signal	0 V	5 V
J2, J4 SC J3, J5 OC		
Input Signal	TTL Signal with $V_P = 5\,V, f = 100\,Hz$	TTL Signal with $V_P = 5\,V, f = 200\,Hz$
J2, J4 SC J3, J5 OC		

Table 13-2 Measured results of FSK modulator by using XR2206 IC.

Input Signal	0 V	5 V
J3, J5 SC J2, J4 OC		
Input Signal	TTL signal with $V_P = 5\ V, f = 100\ Hz$	TTL Signal with $V_P = 5\ V, f = 200\ Hz$
J3, J5 SC J2, J4 OC		

Experiment 2: SN74124 FSK Modulator

Table 13-3 Measured results of FSK modulator by using SN74124.

<table>
<tr><th>Input Signal</th><th>TP1</th><th>TP2</th></tr>
<tr><td rowspan="3">0 V</td><td></td><td></td></tr>
<tr><td colspan="2">FSK O/P</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Table 13-3 Measured results of FSK modulator by using SN74124. (Continue)

<table>
<tr><th>Input Signal</th><th>TP1</th><th>TP2</th></tr>
<tr><td rowspan="4">5 V</td><td></td><td></td></tr>
<tr><td colspan="2">FSK O/P</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Table 13-4 Measured results of FSK modulator by using SN74124.

Input Signal Frequencies	Data I/P	TP1
TTL Signal with $V_P = 5$ V $f = 100$ Hz		
	TP2	FSK O/P

Table 13-4 Measured results of FSK modulator by using SN74124. (Continue)

Input Signal Frequencies	Data I/P	TP1
TTL Signal with $V_P = 5$ V $f = 150$ Hz		
	TP2	FSK O/P

13-5: Problems Discussion

1. In figure 13-7, what are the functions of R_1 and R_5?

2. In figure 13-7, what are the functions of variable resistors VR_1 and VR_2?

3. In figure 13-7, what are the functions of low-pass filter?

Appendix

Expected Experimental Results

Chapter 13: Expected Experimental Results

Experiment 1: XR2206 FSK Modulator

Table 13-1 Measured results of FSK modulator by using XR2206 IC.

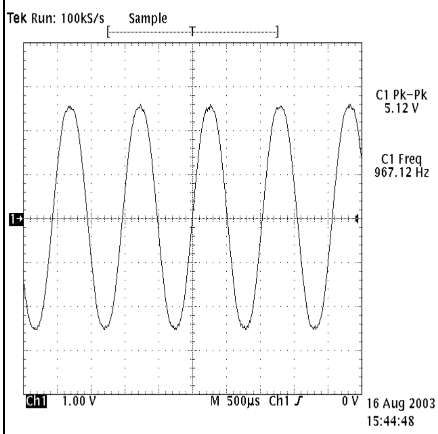
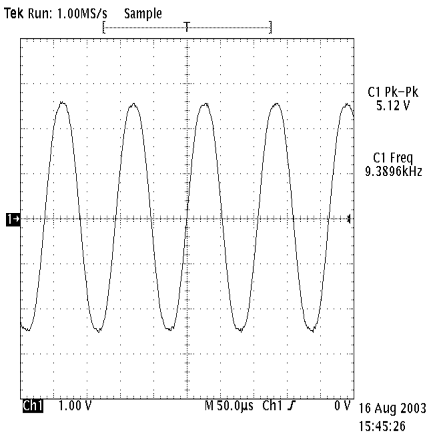
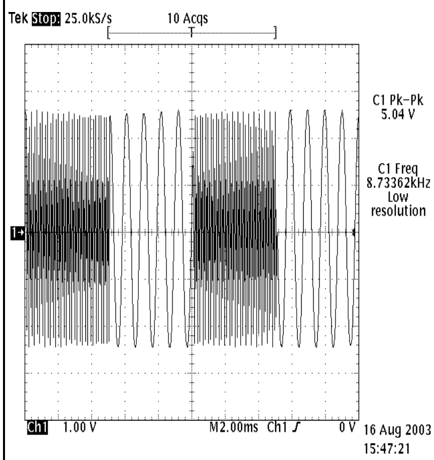
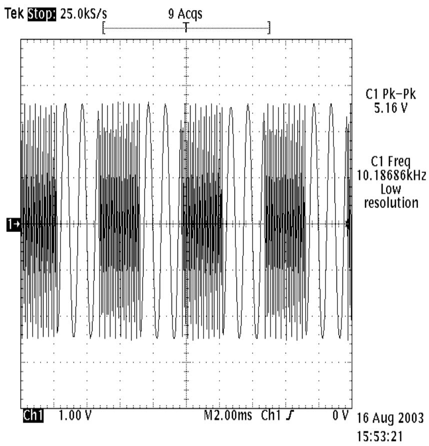
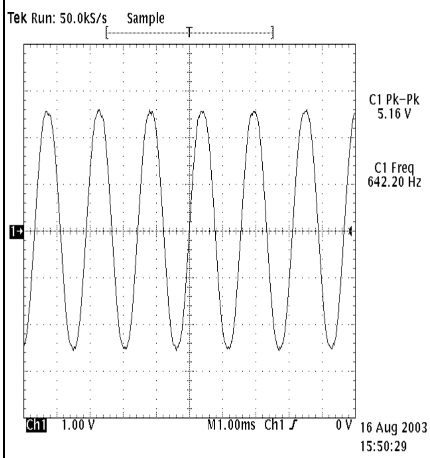
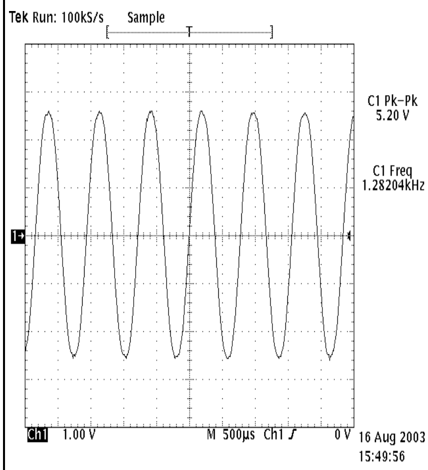
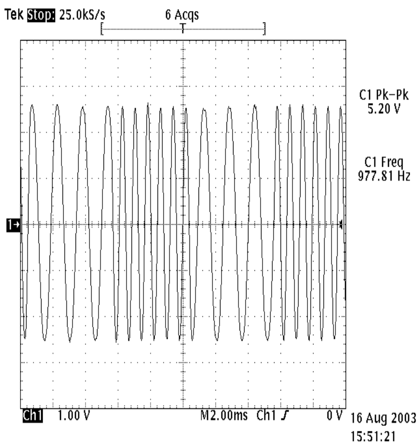
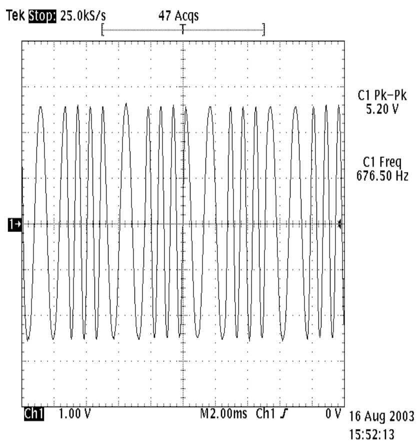
Input Signal	0 V	5 V
J2, J4 SC J3, J5 OC		
Input Signal	100 Hz	200 Hz
J2, J4 SC J3, J5 OC		

Table 13-2 Measured results of FSK modulator by using XR2206 IC.

Input Signal	0 V	5 V
J3, J5 SC J2, J4 OC		
Input Signal	100 Hz	200 Hz
J3, J5 SC J2, J4 OC		

Experiment 2: SN74124 FSK Modulator

Table 13-3 Measured results of FSK modulator by using SN74124.

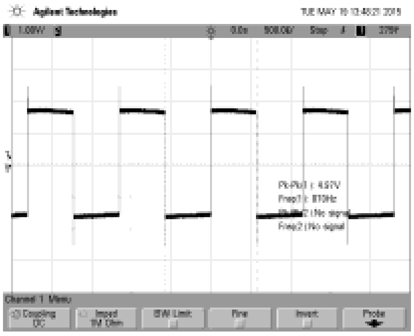
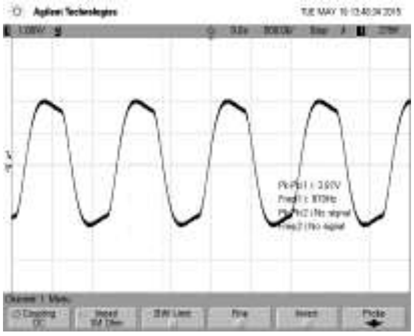
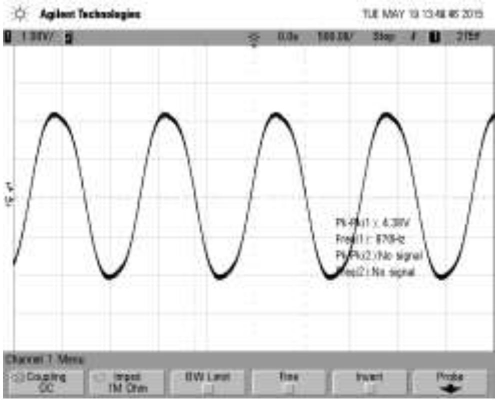
<table>
<tr><th>Input Signal</th><th>TP1</th><th>TP2</th></tr>
<tr><td rowspan="4">0 V</td><td>
</td><td>
</td></tr>
<tr><td colspan="2">FSK O/P</td></tr>
<tr><td colspan="2">
</td></tr>
</table>

Table 13-3 Measured results of FSK modulator by using SN74124. (Continue)

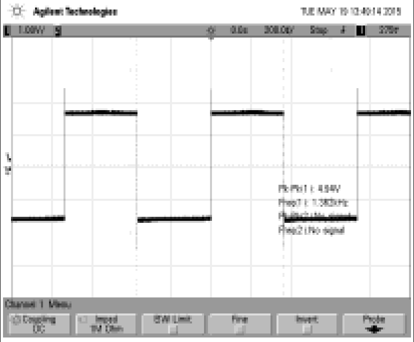
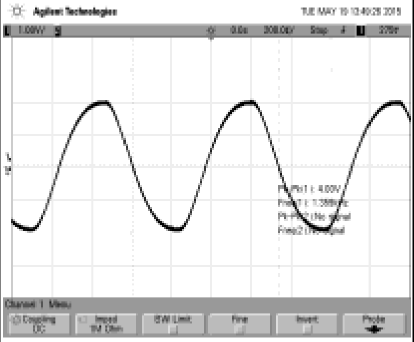
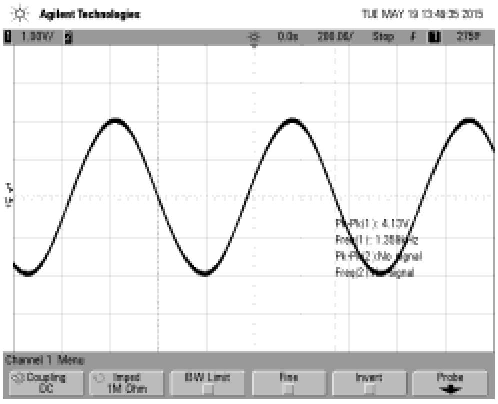
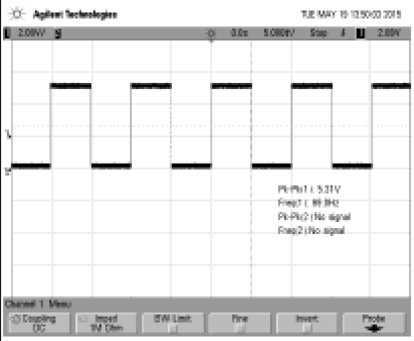
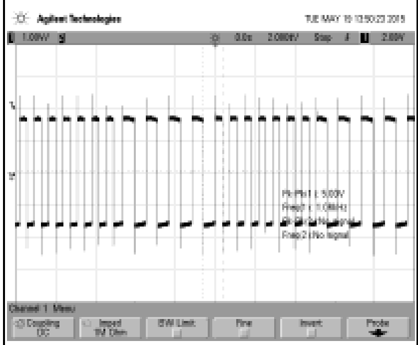
<table>
<tr><th>Input Signal</th><th>TP1</th><th>TP2</th></tr>
<tr><td rowspan="3">5 V</td><td></td><td></td></tr>
<tr><td colspan="2">FSK O/P</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Table 13-4 Measured results of FSK modulator by using SN74124.

Input Signal	Data I/P	TP1
TTL Signal with $V_P = 5$ V $f = 100$ Hz		
	TP2	FSK O/P