8 PWM Modulators

8.1 *Objectives*

- Implementing a pulse-width modulator with μA741.
- Studying the characteristics and basic circuits of LM555.
- Implementing a pulse-width modulator with LM555.
- Measuring and evaluating a pulse-width modulator circuit.

8.2 Discussion

Pulse-width modulation (PWM) is a modulation technique, which converts an analog signal into a digital signal for transmission. The PWM converts an audio signal (the amplitude-varying signal) into a sequence of pulses having a constant frequency and amplitude, but the width of each pulse is proportional to the amplitude of the audio signal. The relationship between audio and PWM signals is illustrated in Fig. 8.1.

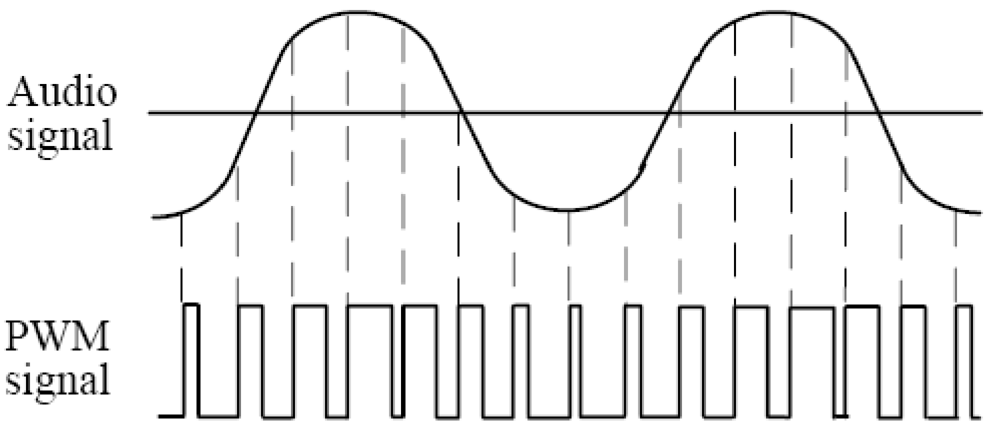

Fig. 8-1 Relationship between audio and PWM signals.

A square-wave generator or a monostable multivibrator can be used to generate the PWM signal. Fig. 8.2 shows a square generator whose output pulse width is determined by the values of R_2, C_2, and $V_{in}(+)$. The μA741 operational amplifier acts as a voltage comparator. The reference voltage at $V_{in}(+)$ input (pin 3) is determined by the resistor values of R_1 and VR_1. The combination of R_2 and C_2 provides the path for charging and discharging. When no audio signal is applied, the dc reference voltage at $V_{in}(+)$ input can be changed by adjusting the VR_1 value. If dc level of VR_1 is fixed and an audio signal is applied to the audio input, the audio signal is added to the fixed dc level and the reference voltage will be changed with the change of audio amplitude. The resulting PWM signal presents at the output of the comparator.

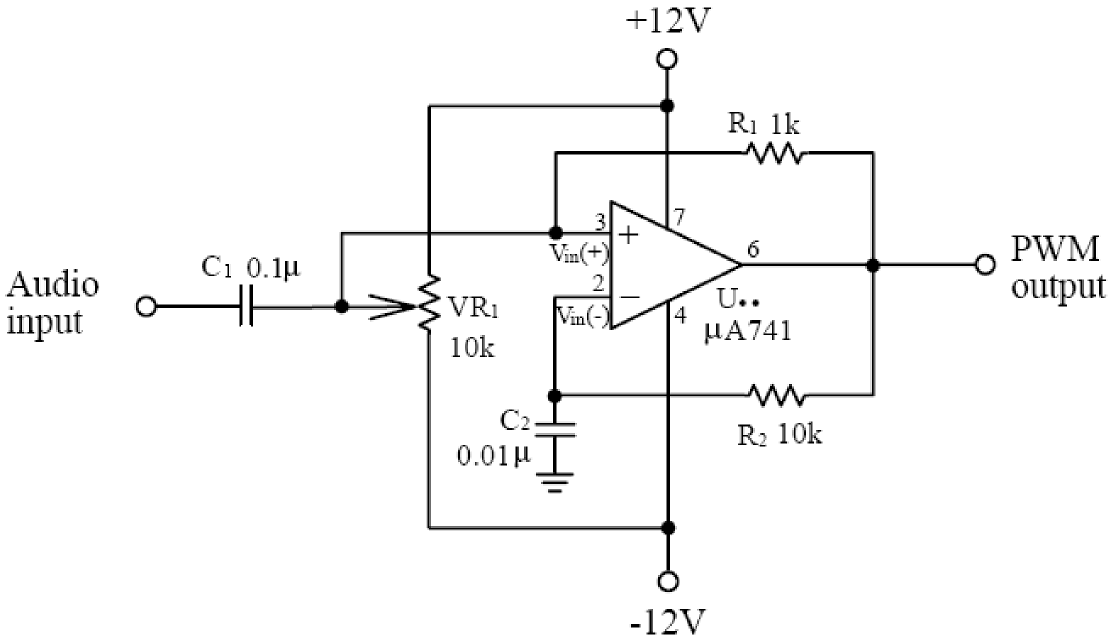

Fig. 8-2 The pulse width modulator based *μA741*.

The connection diagram and equivalent circuit of LM555 timer are illustrated in Figs 8.3 and 8.4 respectively. It comprises five major sections: (1) the lower comparator or trigger comparator; (2) the upper comparator or critical comparator; (3) flip-flop (FF); (4) discharge transistor; and (5) output driver.

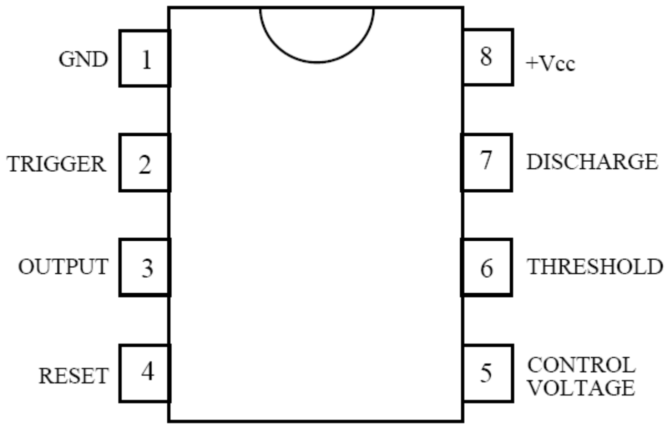

Fig. 8-3 LM555 pin configuration

If no signal is applied to the control voltage terminal (pin 5), the reference voltages of the upper and lower comparators are of $2V_{cc}/3$ and $V_{cc}/3$, respectively. These reference voltages can be externally applied to the control voltage pin. In practice, the control voltage pin should be grounded through a 0.01 *μ*F bypass capacitor if it is not available.

An astable multivibrator with the LM555 timer is shown in Fig. 8.4. The output waveform is a square wave and the frequency is determined by the values of R_1, R_2, and C_1. According to time constant formula, the charging time t_1 is $0.693\times(R_1+R_2)\times C_1$ and the discharging time t_2 is $0.693\times R_2\times C_1$, and the period is $T=t_1+t_2=0.693\times(R_1+2\times R_2)\times C_2$. The waveforms at major test points are illustrated in Fig. 8.5.

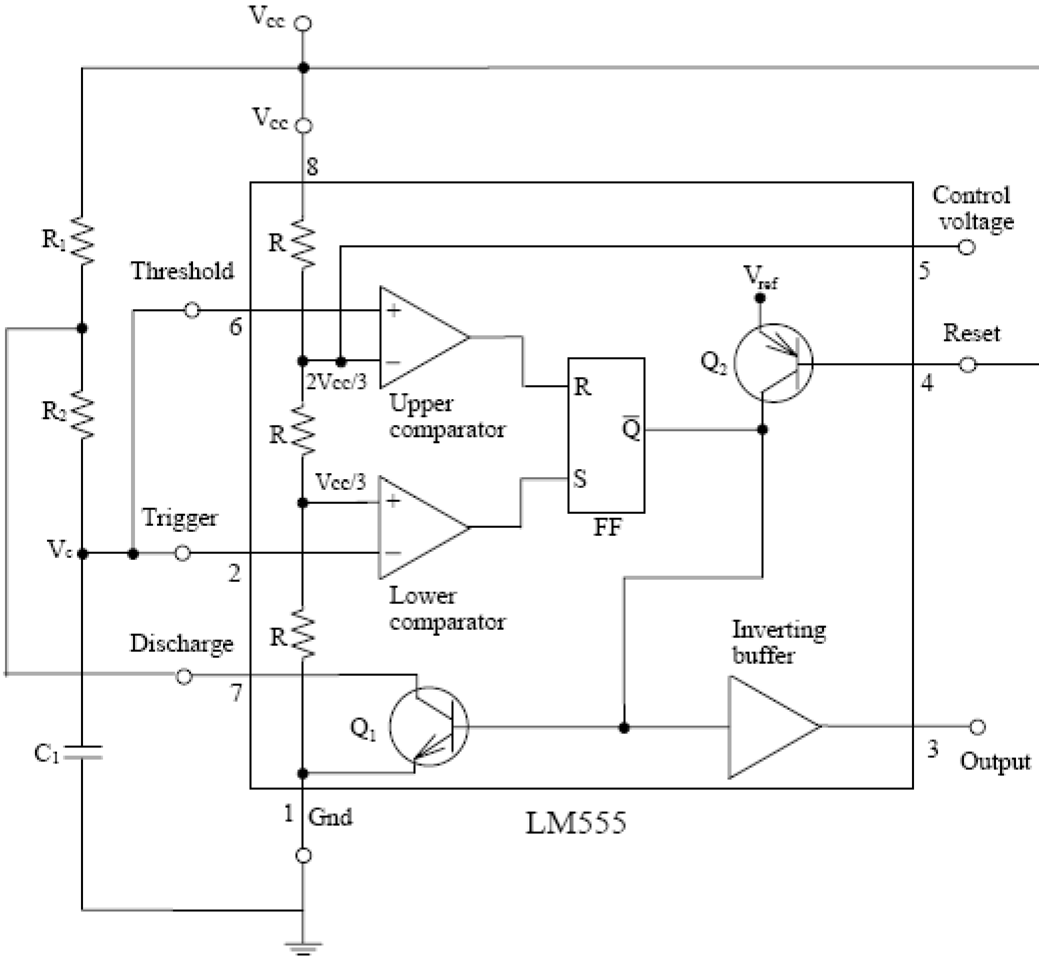

Fig. 8-4 LM555 astable multivibrator

The circuit of Fig. 8.6 is a monostable multivibrator implemented by LM555 timer IC. When the trigger level changes from high (+12V) to low (0V), a pulse will be occurred at output terminal and its pulse width T is determined by $R_1\times C_1$ and approximately $1.1\times R_1\times C_1$. For example, suppose R_1 = 10kΩ and C_1 = 0.01μF, then T is about 110μs. If the trigger input (pin 2) is triggered by a less than 9.1kHz clock signal (the output of the circuit in Fig. 8.5 is available), the output will be positive pulse. Connecting an audio signal to the control voltage pin, the PWM signal should appear at the output.

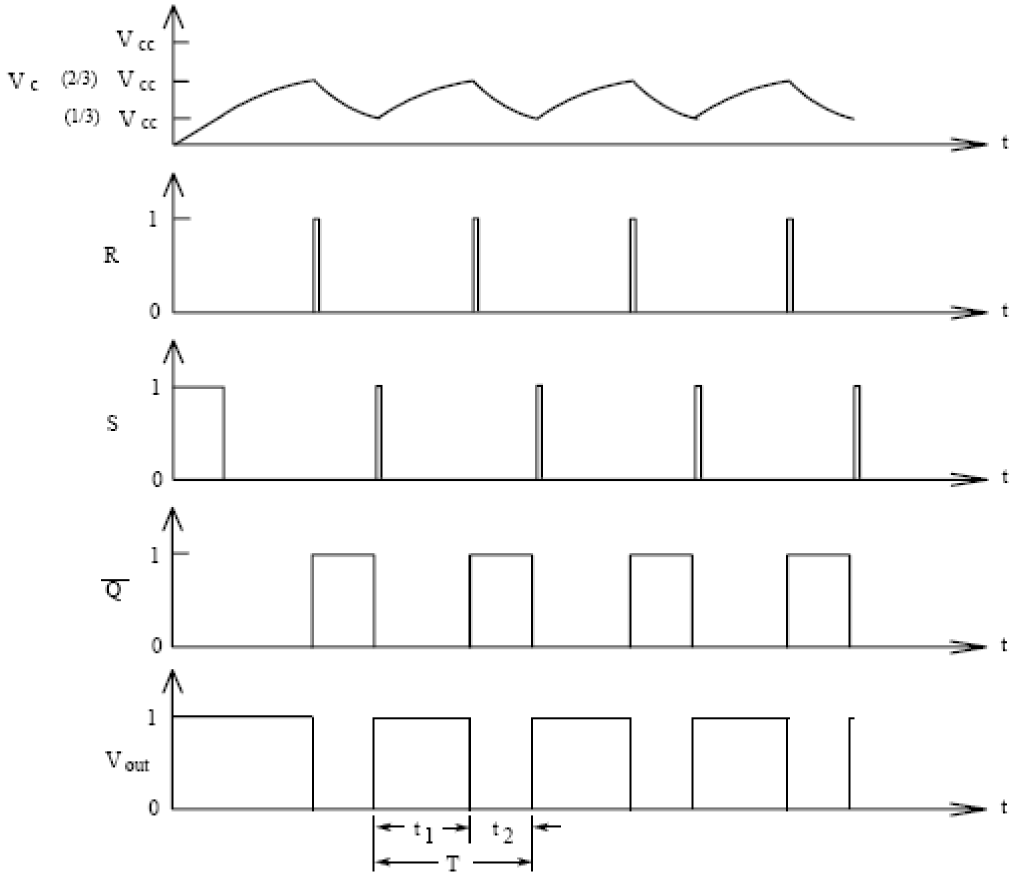

Fig. 8-5 Waveforms of LM555 astable multivibrator

Fig. 8.7 shows a pulse-width modulator using two LM555 timers. In this circuit the U_1 and U_2 perform the astable and monostable multivibrators, respectively. Combining these two sections, the pulse width modulator is completed. The trigger clock of monostable multivibrator (U_2) comes from the output (pin 3) of astable multivibrator (U_1). The audio signal is connected to the U_2 control voltage input (pin 5) and the PWM signal appears at the output (pin 3).

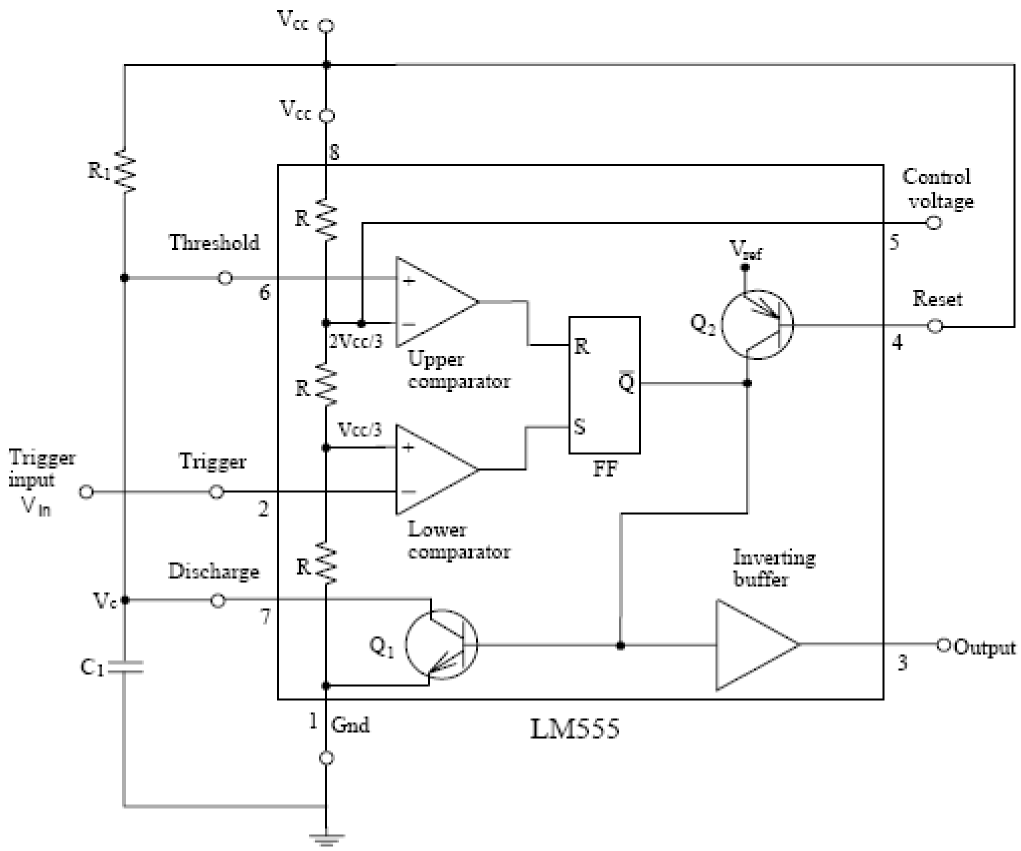

Fig. 8-6 LM555 monostable multivibrator

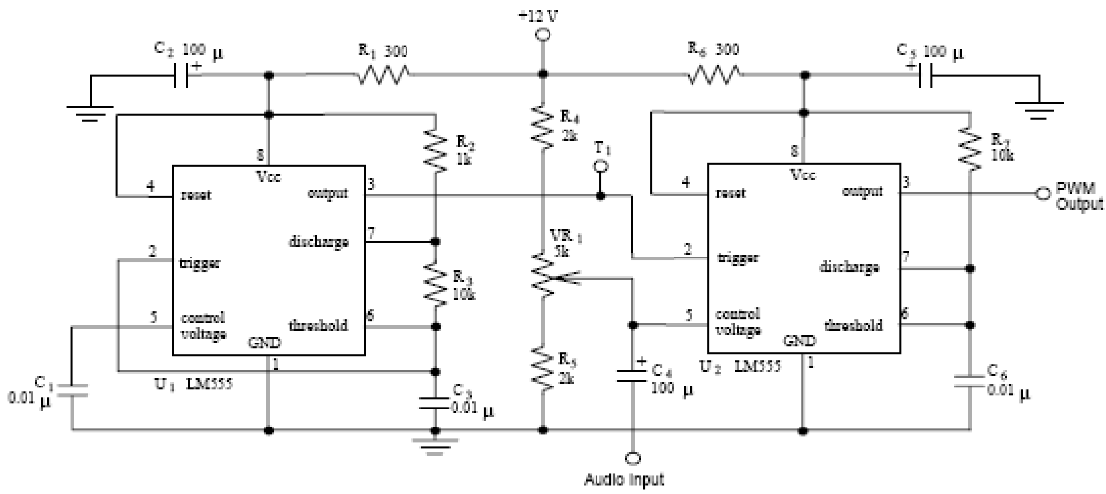

Fig. 8-7 Pulse width modulator

8.3 Experiment Equipments

- Module KL-92001
- Module KL-93002
- Oscilloscope

8.4 Procedures

Procedure 1- Pulse Width Modulator using μA741

1. Locate the LM741 PWM modulator circuit on Module KL-94002.
2. Adjust the VR_1 to get the voltage of 0V at the V_{in}(+) input terminal.
3. Insert the connect plug to J1.
4. Connect a 4Vp-p, 500Hz sine wave to the audio input.
5. Using the oscilloscope, observe the audio input and output (pin 6) waveforms and record the results in Table 8.1.
6. Remove the connector plug from J1 and the audio signal. Adjust the VR_1 to get the voltage 6V at V_{in}(+) and repeat steps 4,5.
7. Remove the connector plug from J1 and the audio signal. Adjust the VR_1 to get the voltage -6V at V_{in}(+) and repeat steps 4,5.

Procedure 2- Pulse Width Modulator using LM555

1. Locate the PWM modulator circuit on Module KL-94002.
2. Connect a 5Vp-p, 1kHz square wave to the audio signal input.
3. Using the oscilloscope, observe the T1 test point and the output waveforms and adjust the VR_1 to get a rectangular wave (duty cycle is not equal to 50%) at T1.
4. Switch the coupling mode of oscilloscope to DC position. Observe and record the output waveform in Table 8.2.
5. Changed the input signal to triangle wave and repeat step 4.
6. Changed the input signal to sine wave and repeat step 4.

Before you leave the lab;

- **Turn off the power to all the equipment.**
- **Disassemble the circuit and place the Small components in the plastic tray.**
- **Straighten up your lab station.**
- **Report any problems or suggest improvements to your TA.**

8.5 Results

Table 8-1

(V_m=6Vp-p, f_m=500Hz)

DC Bias at $V_{in}(+)$	Input Waveform	Output Waveform
0 V		
6 V		
- 6 V		

Table 8-2

(V_m=5Vp-p, f_m=1kHz)

Input Signal	Input Waveform	Output Waveform
Square Wave		
Triangle Wave		
Sine Wave		

8.6 Questions

1. What is the function of VR_1 in Figs 8.2 and 8.7?
2. If the C_6 value in Fig 8.7 is changed to 0.1 μF, is the output still a PWM waveform? Explain.
3. In a point of view a voltage polarity, what is the difference between the output PWM signals in the experiments?

9 PWM Demodulators

9.1 *Objectives*

- Understanding the operation of pulse-width demodulator.
- Implementing a pulse-width demodulator using a product detector.

9.2 Discussion

The square generator and the monostable multivibrator circuits were used to generate the PWM signal. To recover the original audio signal from a PWM signal, a decoder or demodulator is need in the receiver circuit.

There are two common techniques used for pulse-width demodulation. One method is that the PWM signal must first be converted to a pulse-amplitude modulation (PAM) signal and then passed through a low-pass filter. Consider that the PWM signal shown in Fig 9.1(a) is applied to an integrator and hold circuit. When the positive edge of pulse appears, the integrator generates ramp output whose magnitude is proportional to the pulse width. After the negative edge, the hold circuit maintains the peak ramp voltage for a given period and then forces the output voltage to zero, as shown in Fig 9.1(b). The waveform V_c, shown in Fig. 9.1(c), is the sum of V_b and a sequence of constant-amplitude and constant-width pulse generated by demodulator. This signal is then applied to the input of clipping circuit, which cuts off the portion of signal below the threshold voltage V_{th} and outputs the reminder. Therefore the output of clipping circuit is a PAM signal whose amplitude is proportional to the width of PWM signal, as shown in Fig. 9.1(d). Finally, the PAM signal passes through a simple low-pass filter and the original audio signal is obtained.

The other technique for demodulating a PWM signal is illustrated in Fig. 9.2. It consists of a product detector and a low-pass filter. The PWM and the carrier signals are connected to the inputs of a product detector, and then a sequence of pulses having the width inversely proportional to the width of PWM pulse presents at output. When the V_a signal passes through the low-pass filter, a demodulated signal is obtained.

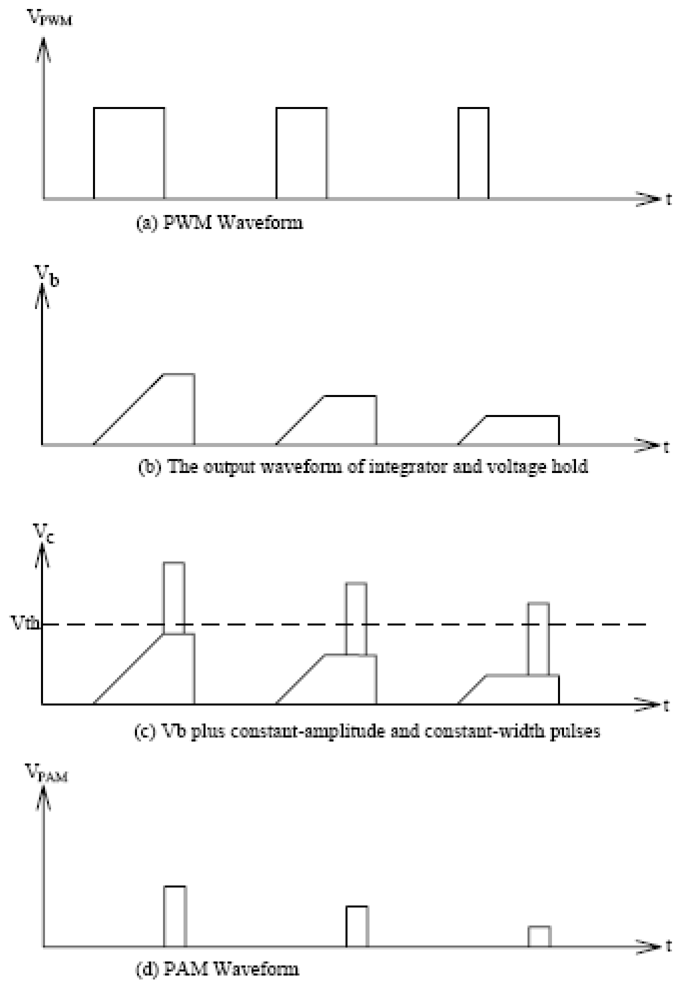

Fig. 9-1 PWM to PAM

Fig. 9.3 shows the internal configuration of MC1496. The differential amplifier (Q_5 and Q_6) is used to drive the differential amplifiers Q_1Q_2 and Q_3Q_4. The constant-current source generator (Q_7 and Q_8) provides the differential amplifier Q_5 and Q_6 with a constant current. Overall gain of MC1496 can be controlled by externally connecting a resistor between pins 2 and 3. For PWM demodulation, the PWM signal should be applied to pins 1 and 4, and the carrier to pins 8 and 10. The bias current to pin 5 is commonly provided by connecting a series resistor from this pin to the power supply. Since the detector has two outputs (pins 6 and 12), one of the outputs can be used as the detector output and the other used for the use of automatic gain control (*AGC*).

The PWM demodulator circuit using the MC1496 product detector is shown in Fig. 9.4. This circuit is similar to the AM, SSB and DSB-SC detectors introduced before. The U_1 and U_2 amplifiers control the input amplitudes of PWM and carrier signals within the range of 300mVp to 1400mVp-pi so that the detector operates in linear region. The resistor R_7 connected between pins 2 and 3 determines the voltage gain of MC1498. The coupling capacitors C_1, C_2, C_4, C_4, and C_9 are used to block dc signals while passing ac signals. The VR_1 and VR_2 control the gains of U_1 and U_2 respectively. The value of VR_3 determines the magnitude of PWM signal to the input of the detector. The U_4 operates as a second-order low-pass filter.

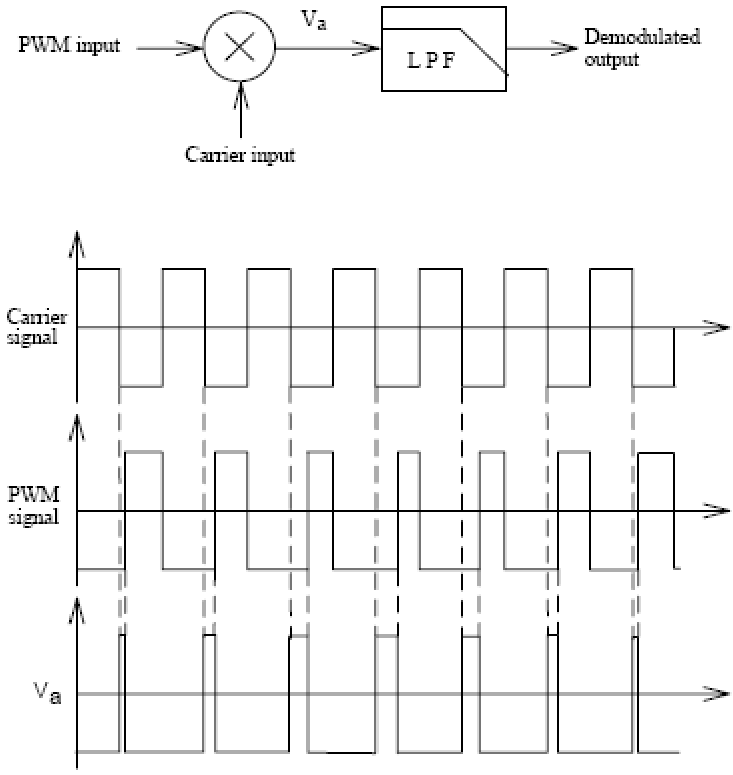

Fig. 9-2 Illustration of PWM demodulation with product detector.

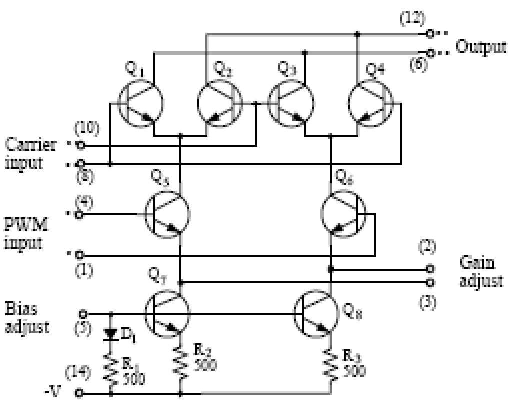

Fig. 9-3 MC1496 internal circuit

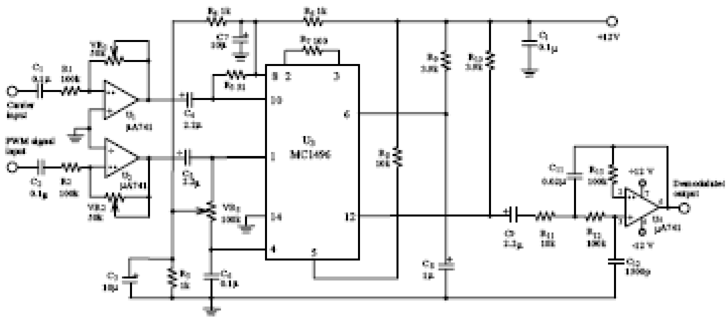

Fig. 9-4 PWM demodulator

9.3 Experiment Equipments

- Module KL-92001
- Module KL-93002
- Oscilloscope

9.4 Procedures

Procedure 1- Pulse Width Modulator using μA741

1. Locate the PWM demodulator circuit on Module KL-94002.
2. Complete the PWM modulator circuit and connect a 3Vp-p, 700Hz sine wave to the audio input.
3. Connect the test point T1 of the PWM modulator circuit to the carrier input (I/P1) of the PWM demodulator circuit.
4. Connect the PWM modulated output of the PWM modulator circuit to the PWM input (I/P2) of the PWM demodulator circuit.
5. Vary the VR_1 to get an output signal with minimum distortion at U1 μA741 output.
6. Carefully adjust VR_2 and VR_3 until getting a proper demodulated signal.
7. Using the oscilloscope, observe the signals of PWM input signal, carrier signal, U_1 output signal, U_2 output signal, MC1496 output signal (pin 12) and PWM demodulated signal. Record the results in Table 9.1.

9.5 Results

Table 9-1

(V_m=3Vp-p, f_m=700Hz)

Test Point	Output Waveform
Carrier Input Terminal	
PWM Input Terminal	
U_1 Output Terminal	
U_2 Output Terminal	
MC1496 (pin 12) Output Terminal	
PWM Demodulated Signal Output	

9.6 Questions

1. In Fig. 9.4, what are the functions of the VR_1 and VR_2?
2. In Fig. 9.4, what is the function of the VR_3?
3. As the audio frequency of Fig 9.7 goes down, what components of Fig 9.4 must be modified for normal operation?

Before you leave the lab;

- **Turn off the power to all the equipment.**
- **Disassemble the circuit and place the Small components in the plastic tray.**
- **Straighten up your lab station.**