PHOTOPLETHYSMOGRAM MEASUREMENT 6

EXPERIMENT NO 6 PHOTOPLETHYSMOGRAM MEASUREMENT

6.0 PURPOSE

The purpose of the experiment is to help students learn how to measure small changes in the diameter of a finger artery using an infrared photocoupler. Furthermore, after this exercise, students will be able to easily understand changes in the volume of a peripheral blood vessel.

6.1 PHYSIOLOGICAL PRINCIPLES

The heart, composed of the left and right ventricles, is the primary organ of the circulatory system. Blood in the superior and inferior vena cava is low in oxygen and flows to the right atrium. The right ventricle pumps blood from the atrium to the lungs. In the lung alveoli, oxygen and carbon dioxide exchange. The cleansed, highly oxygenated blood returns to the left atrium, where it is pumped by the left ventricle into the aorta and distributed throughout the body via the arterial system. The smallest blood vessels in the tissues are called capillaries.

Capillaries are very small vessels that normally contain 5% of circulating blood. Oxygen and nutrients, which make up 5% of the blood, must pass through the capillary walls to reach the cells. Carbon dioxide and waste products, however, must pass from the cells to the capillaries. This low-oxygen blood formed in the capillaries flows into the veins. As a result of these processes, the blood returns to the right ventricle via the inferior and superior vena cava. This system is called the circulatory system. The arterial system is capable of maintaining blood pressure. Blood pumped from the heart enters the arteries and flows into the small capillaries. Signals from the autonomic nervous system control the sphincters of the small vessels. This allows the body to regulate blood distribution. Similarly, the amount of blood flowing to an organ varies depending on certain conditions in that region. For example, when the pH value in the cells decreases, or the oxygen concentration decreases, or the carbon dioxide concentration increases, more blood is pumped to these cells. The sphincter muscles in the veins relax, allowing more blood to flow into the capillaries.

Blood distribution is completely different between an organ's activity and its rest. During exercise, blood flow to the skin and gastrointestinal organs decreases, while blood flow to skeletal muscles increases. Meanwhile, cardiac output increases.

The amount of blood in the capillaries changes with the contraction and relaxation of the heart. Changes in capillary blood volume can be easily measured using a photoplethysmogram. The signal detected by the photoplethysmogram indicates changes in vascular volume. The derivative of the signal is related to blood flow.

6.2 CIRCUIT DESCRIPTIONS

1. Vascular Volume Measurement Circuit Block Diagram

Figure 6.1 shows how an infrared photocoupler is used to measure changes in blood vessel volume and obtain blood flow patterns. Photoresistors or visible-light photocouplers can be affected by ambient light interference. Using an infrared photocoupler eliminates these interferences. The signal detected by the infrared photocoupler is filtered with a second-order high-pass filter. This eliminates drift voltages that could result from finger movements and ensures that the next circuit stage will not operate in the saturation region. The amplifier circuit is used to amplify the signal and protect it from distortion in the subsequent detection circuit, but it often causes phase shift. After amplification, a fourth-order low-pass filter is used to eliminate 60 Hz noise, as well as high-frequency noise. The signal passes through the differential receiver and is amplified again. The resulting signal passes through the comparator circuit and is converted into a square wave signal. Changes in blood pressure affect the measurement. When the patient's blood pressure reaches the threshold value, the peripheral capillaries are fully open. Therefore, there are very small or no changes in vascular volume.

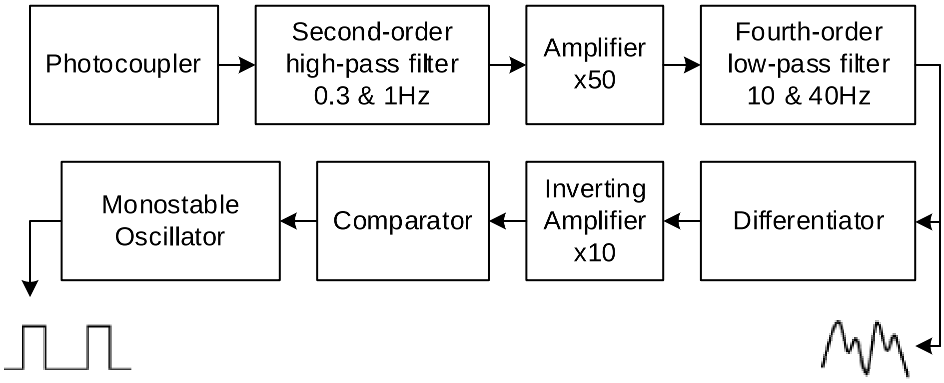


Figure 6.1 Measurement of vascular volume and heart rate using a photocoupler

2. Infrared Photocoupler

The PN junction of a semiconductor consists of a P-type doped semiconductor and an N-type doped semiconductor. When the P-type semiconductor is biased positively and the N-type semiconductor is biased negatively, hole and electron carriers move toward the junction, thus creating a hole-electron combination. However, when the PN junction is reverse-biased, electric charges repel the junction. Because there are no free electric charges in the junction region, a depletion region is formed. Meanwhile, minority carriers in the P- and N-type semiconductors migrate into the depletion region, causing a leakage current. In a PN junction semiconductor, the N-type semiconductor layer is thin enough to allow light to pass through. Therefore, some electrons are excited by light, creating a leakage current. The leakage current is directly proportional to the light intensity. The same principle can be applied to NPN-type transistors, also known as phototransistors. In a phototransistor, the base acts like a light mask and can receive external light. Thus, when light waves reach the base, a collector-emitter current is allowed.

An infrared photocoupler consists of an infrared diode and a phototransistor. Tissue structure changes in response to changes in blood flow in the capillaries. Therefore, when a subject's skin comes into contact with the photocoupler, the intensity of the reflected infrared light changes with blood flow. Although weak, the light signal reflected from the skin can be detected by a photocoupler. To avoid visible light interference, a maximum intensity infrared light with a wavelength of 880nm is selected for the emitter diode and receiver transistor.

A light emitting diode (LED), CL-1CL3, and a phototransistor, ST-1CL3H, produced by Kodenshi company, are used in the experimental module. Figure 6.2 shows the wavelength range, light emitting angle, and pin configuration of the CL-1CL3. Figure 6.3 shows the wavelength range, light receiving angle, and pin configuration of the ST-1CL3H. The light-emitting diode operates at forward bias, as shown in Figure 6.5. The CL-1CL3 technical specifications are known as V_F = 1.5 (max) and I_F = 40mA (max). For safety reasons, a current value of one-tenth of the maximum value was selected. The Z_1 value to be used for this current value is calculated as follows:

$$Z_1 = \frac{(5-1.5)V}{4mA} = 1.1k\Omega$$

The phototransistor operates in a common-collector configuration, as shown in Figure 6.4. According to the ST-1CL3H technical specifications, for the operating point to be V_{CE} = 2.5V and I_C = 2mA, the Z_3+Z_2 value must be as follows:

$$Z_3 + Z_2 = \frac{(5-2.5)V}{2mA} = 1.25k\Omega$$

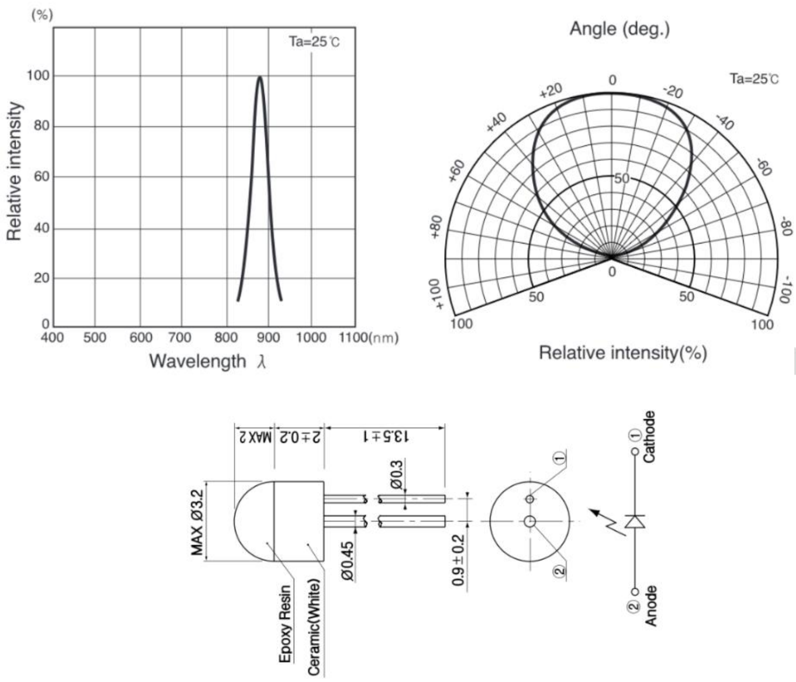


Figure 6.2 CL-1CL3 Wavelength range, emitting angle and pin configuration

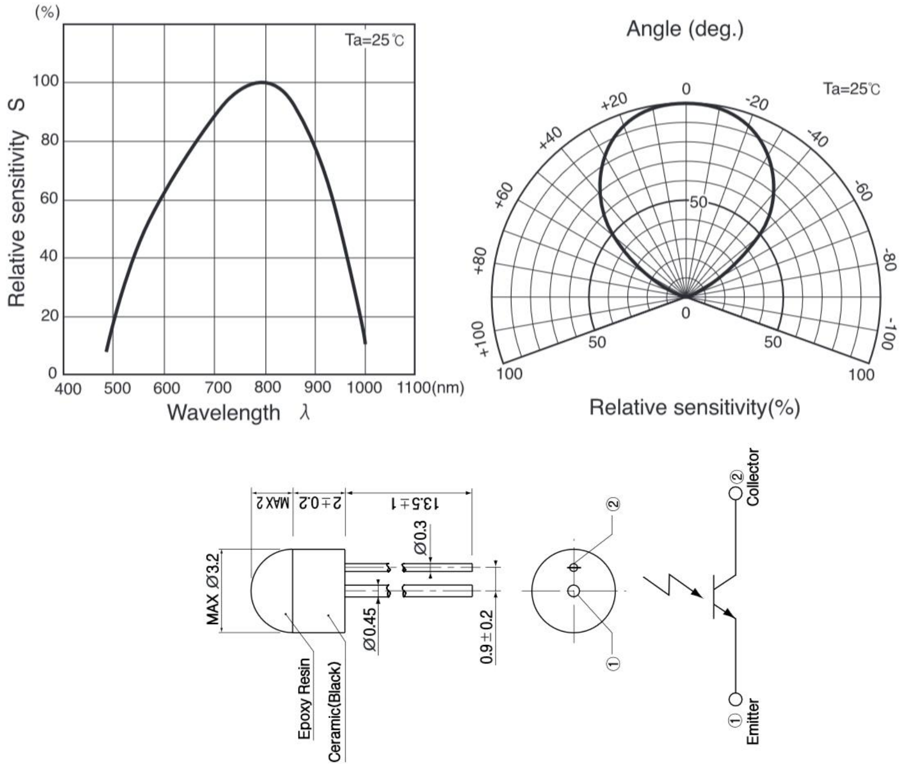


Figure 6.3 ST-1CL3H Wavelength range, receive angle and pin configuration

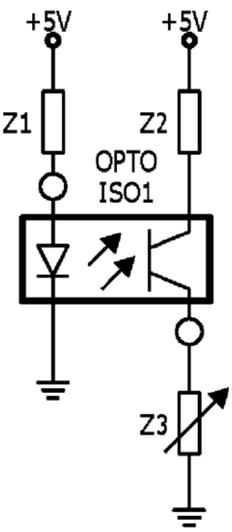


Figure 6.4 Photocoupler wiring diagram

3. High-Pass Filter

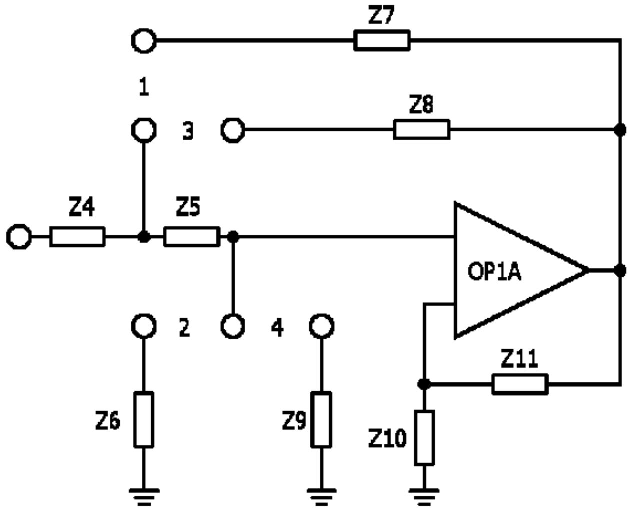


Figure 6.5 High-pass filter biasing circuit

The purpose of the high-pass filter (Figure 6.5) is to eliminate the drift voltage that might result from finger movements and to ensure that the next circuit stage operates in the normal region, not in the saturation region. The high-pass filter used is of the Butterworth type, with gain A_v and 3dB frequency as shown in Equations 6.1 and 6.2.

$$A_v = \frac{(Z_{10}+Z_{11})}{Z_{10}} = 1.51 \quad (6.1)$$

$$f_H = \frac{1}{2\pi\sqrt{Z_4 Z_5 Z_6 Z_7}} \quad or \quad f_H = \frac{1}{2\pi\sqrt{Z_4 Z_5 Z_8 Z_9}} \quad (6.2)$$

4. Amplifier

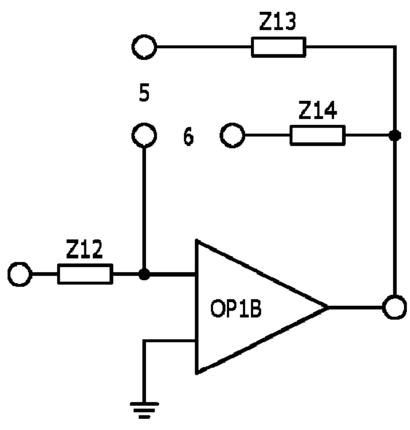


Figure 6.6 Amplifier circuit

Figure 6.6 shows an amplifier circuit used to amplify the signal for the next circuit stage. The gain equation for the inverting amplifier, which has a gain of about 50, is expressed in Equation 6.3.

$$A_v = \frac{-Z_{13}}{Z_{12}} \;\; or \;\; A_v = \frac{-Z_{14}}{Z_{12}} \quad (6.3)$$

5. Low-Pass Filter

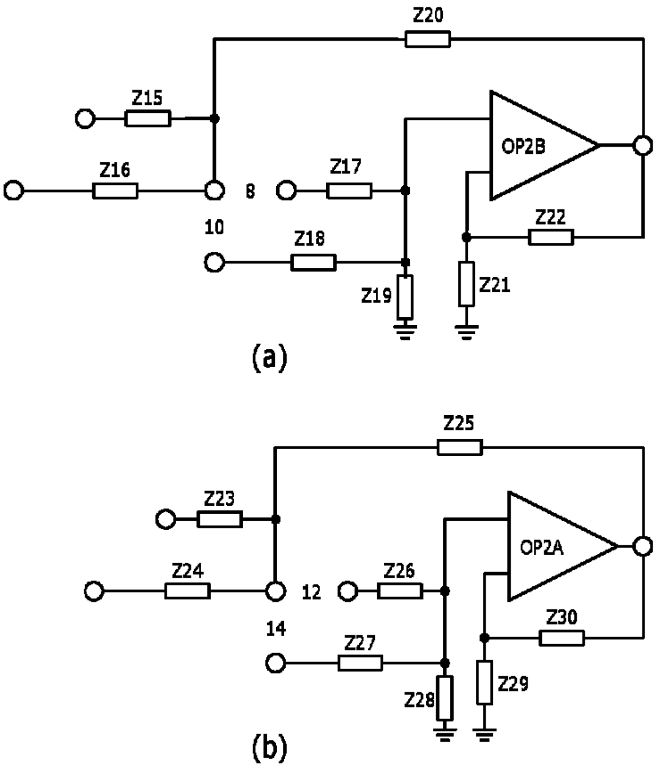


Figure 6.7 Low-pass filter circuit

The purpose of the low-pass filter (Figure 6.7) is to eliminate high-frequency noise from the power supply, fluorescent lamps, and visible lights. The low-pass filter here is of the Butterworth type, with gains Av1 and Av2 and the 3dB frequency given in Equations 6.4, 6.5, 6.6, and 6.7, respectively.

$$A_{v1} = \frac{(Z_{21}+Z_{22})}{Z_{21}} = 1.15 \quad (6.4)$$

$$A_{v2} = \frac{(Z_{29}+Z_{30})}{Z_{29}} = 2.21 \quad (6.5)$$

$$f_{L1} = \frac{1}{2\pi\sqrt{Z_{15}Z_{17}Z_{19}Z_{20}}} \ \ veya \ \ f_{L1} = \frac{1}{2\pi\sqrt{Z_{16}Z_{18}Z_{19}Z_{20}}} \tag{6.6}$$

$$f_{L2} = \frac{1}{2\pi\sqrt{Z_{23}Z_{25}Z_{26}Z_{28}}} \ \ veya \ \ f_{L2} = \frac{1}{2\pi\sqrt{Z_{24}Z_{25}Z_{27}Z_{28}}} \tag{6.7}$$

6. Differentiator

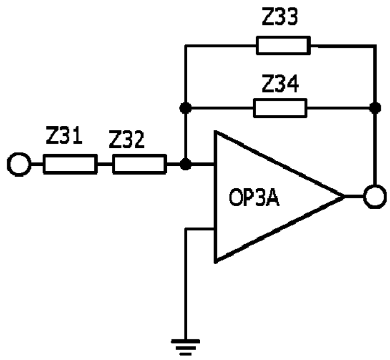


Figure 6.8 Differentiator circuit

The differentiator circuit (Figure 6.8) can amplify the amount of change in the signal, making it easier to analyze small changes in the signal. DC effects can push operational amplifiers into the saturation region and cause abnormal operation of the differentiator circuit. For this reason, a high-pass filter is used before the differential receiver in this system.

7. Inverting Amplifier

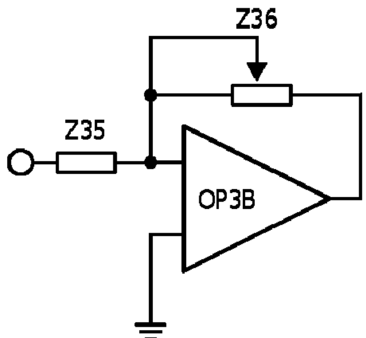


Figure 6.9 Inverting amplifier

The differentiator circuit causes a 180 degrees signal phase shift. To resolve this issue, the signal is returned to its phase using an inverting amplifier.

8. Comparator

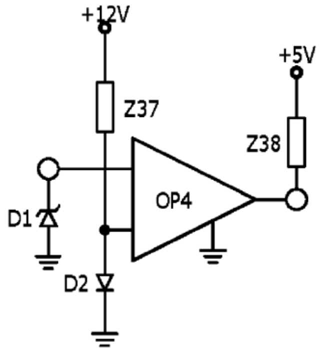


Figure 6.10 Comparator circuit

D2 is used as the on-state voltage reference. This eliminates the initial blood pressure reflection caused by the closure of the aortic valve to avoid generating a false trigger pulse. The voltage drop across D1 is used as the comparator input. Thus, the zener diode prevents excessive voltage from negatively impacting the comparator circuit. With each heartbeat, the comparator generates only one pulse to trigger the monostable multivibrator.

9. Monostable Multivibrator

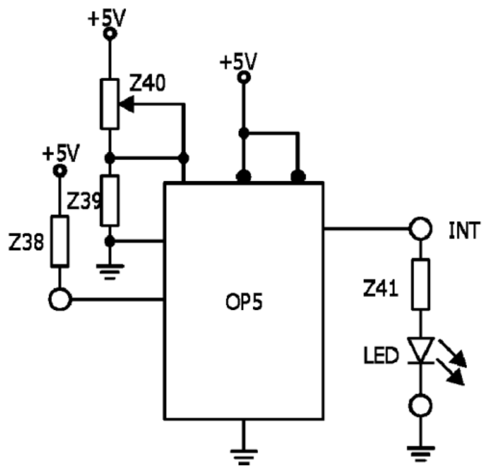


Figure 6.11 Monostable multivibrator circuit

Figure 6.11 shows a monostable multivibrator circuit that generates a pulse with a positive trigger signal. The pulse width is controlled by Z_{39} and Z_{40}. If an LED is attached to the multivibrator output, this LED will be seen to flash with each heartbeat.

6.3 REQUIRED EQUIPMENTS

1. KL-71001 Main Controller
2. KL-73006 Experiment Module
3. Infrared Photocoupler (KL-73006A)
4. Digital Storage Oscilloscope (extra hardware)
5. 10mm Connectors
6. D-sub 9-9 Cable

6.4 EXPERIMENT PROCEDURE

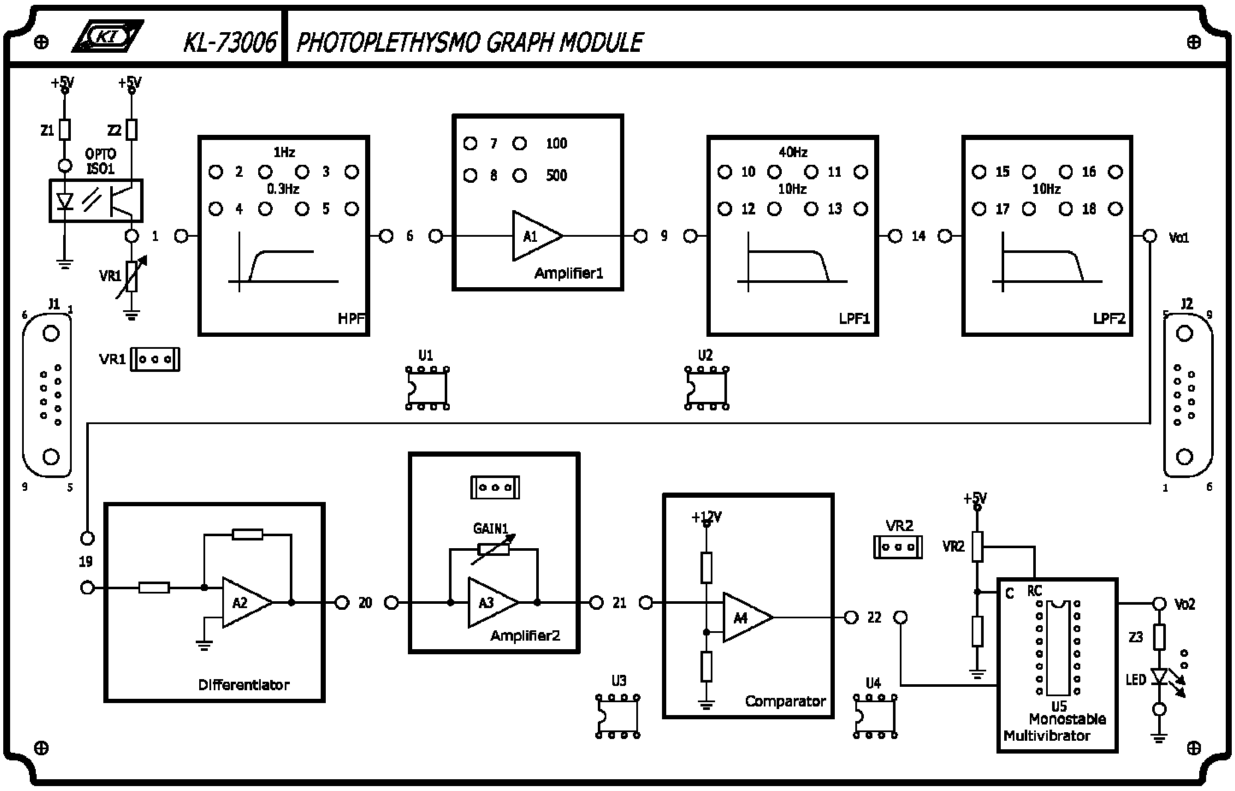


Figure 6.12 Vascular volume measurement module

1. High-Pass Filter Characteristics Experiment

(1) Connect the J2 connector of the KL-73006 to the MODULE OUTPUT terminal of the KL-71001. There is no need for a connector plug between any two circuit blocks.

(2) Connect the function generator output of the KL-71001 to terminal '1' of the KL-73006, and the GND terminal of the KL-71001 to the ground terminal of the KL-73006. Connect the terminals marked 2 and 3 with the connectors.

Set the sinusoidal frequency of the function generator to its maximum value and its amplitude to 1Vpp. Connect the function generator output to the CH1 channel of the oscilloscope, and the HPF output terminal to the CH2 channel of the oscilloscope.

(3) Adjust the frequency to various values and record the output amplitude of the high-pass filter to Table 6.1 at Results section.

(4) Using the results in Table 6.1, plot the characteristic curve of the low-pass filter to Table 6.2 at Results section.

(5) Disconnect the connectors from the terminals marked 2 and 3 and connect to the terminals marked 4 and 5.

(6) Since the minimum frequency that can be generated by the function generator is 1Hz, the 0.1Hz pole of the high-pass filter cannot be measured. To perform a 0.1Hz measurement, a function generator capable of generating a frequency of 0.1Hz is required. To perform this measurement, repeat steps 3 and 4 and record the results in Table 6.1.

2. Amplifier (1) Experiment

(1) Connect the J2 connector of the KL-73006 to the MODULE OUTPUT terminal of the KL-71001. There is no need for a connector plug between any two circuit blocks.

(2) Connect the function generator output of the KL-71001 to terminal 6 of the KL-73006, and the GND terminal of the KL-71001 to the ground terminal of the KL-73006. Connect the terminal marked "7" with the jumper plug. Connect the function generator output to the CH1 channel of the oscilloscope, and the "Amplifier 1" output terminal to the CH2 channel of the oscilloscope.

(3) Set the function generator sinusoidal frequency to 100Hz and the amplitude to 50mVpp. Record the amplifier output amplitude to Table 6.3 at Results section.

(4) Remove the jumper plug from the terminal marked "7" and connect it to the terminal marked "8." Record the amplifier output amplitude to Table 6.3 at Results section.

(5) If the amplifier output is at the saturation region, reduce the output amplitude of the function generator to avoid distortion.

3. Low-Pass Filter (1) Characteristics Experiment

(1) Connect the J2 connector of the KL-73006 to the MODULE OUTPUT terminal of the KL-71001. There is no need for a connector plug between any two circuit blocks.

(2) Connect the function generator output of the KL-71001 to terminal '9' of the KL-73006, and the GND terminal of the KL-71001 to the ground terminal of the KL-73006. Set the sinusoidal frequency of the function generator to its minimum value and its amplitude to 1Vpp. Connect the function generator output to the CH1 channel of the oscilloscope, and the LPF1 output terminal to the CH2 channel of the oscilloscope.

(3) Adjust the frequency to various values and record the output amplitude of the low-pass filter to Table 6.4 at Results section.

(4) Disconnect the terminals marked 10 and 11 and connect them to the terminals marked 12 and 13. Record the amplifier output amplitude to Table 6.4 at Results section.

(5) Referring to the results in Table 6.4, plot the characteristic curve of the low-pass filter to Table 6.5 at Results section.

4. Low-Pass Filter (2) Characteristics Experiment

(1) Connect the J2 connector of the KL-73006 to the MODULE OUTPUT terminal of the KL-71001. There is no need for a connector plug between any two circuit blocks.

(2) Connect the function generator output of the KL-71001 to terminal '14' of the KL-73006, and the GND terminal of the KL-71001 to the ground terminal of the KL-73006. Connect the terminals marked 15 and 16 with the connection plug. Set the sinusoidal frequency of the function generator to its minimum value and its amplitude to 1Vpp. Connect the function generator output to the CH1 channel of the oscilloscope, and the LPF2 output terminal to the CH2 channel of the oscilloscope.

(3) Adjust the frequency to various values and record the output amplitude of the low-pass filter to Table 6.6 at Results section.

(4) Disconnect the terminals marked 15 and 16 and connect them to the terminals marked 17 and 18. Record the amplifier output amplitude to Table 6.6 at Results section.

(5) Referring to the results in Table 6.6, plot the characteristic curve of the low-pass filter to Table 6.7 at Results section.

5. Comparator Experiment

(1) Connect the J2 connector of the KL-73006 to the MODULE OUTPUT terminal of the KL-71001. There is no need for a connector plug between any two circuit blocks.

(2) Connect the function generator output of the KL-71001 to terminal '19' of the KL-73006, and the GND terminal of the KL-71001 to the ground terminal of the KL-73006. Set the sinusoidal frequency of the function generator to its minimum value and its amplitude to 1Vpp. Connect the function generator output to the CH1 channel of the oscilloscope, and the 'Differentiator' output terminal to the CH2 channel of the oscilloscope.

(3) Set the frequency to various values and record the differentiator output amplitude to Table 6.8 at Results section.

6. Amplifier (2) Experiment

(1) Connect the J2 connector of the KL-73006 to the MODULE OUTPUT terminal of the KL-71001. There is no need for a connector plug between any two circuit blocks.

(2) Connect the function generator output of the KL-71001 to terminal 20 of the KL-73006, and the GND terminal of the KL-71001 to the ground terminal of the KL-73006. Connect the function generator output to the CH1 channel of the oscilloscope, and the "Amplifier 2" output terminal to the CH2 channel of the oscilloscope.

(3) Set the function generator sinusoidal frequency to 1kHz and the amplitude to 100mVpp. Set the GAIN 1 SVR value and record the amplifier output amplitude to Table 6.9 at Results section.

(4) If the amplifier output is at the saturation region, reduce the output amplitude of the function generator to avoid distortion.

7. Comparator Experiment

(1) Connect the J2 connector of the KL-73002 to the MODULE OUTPUT terminal of the KL-71001. There is no need for a connector plug between any two circuit blocks.

(2) Connect the function generator output of the KL-71001 to terminal '20' of the KL-73006, and the GND terminal of the KL-71001 to the ground terminal of the KL-73006. Connect the terminals marked 21 and 22 with the connector plug. Connect the function generator output to the CH1 channel of the oscilloscope, and the 'Comparator' output terminal to the CH2 channel of the oscilloscope.

(3) Set the sinusoidal frequency of the function generator to 100Hz and its amplitude to 200mVpp. Adjust the GAIN 1 SVR value until you get an output from the comparator. Record the comparator output waveform to Table 6.10 at Results section.

8. Monostable Multivibrator Experiment

(1) Connect the J2 connector of the KL-73002 to the MODULE OUTPUT terminal of the KL-71001. There is no need for a connector plug between any two circuit blocks.

(2) Connect the function generator output of the KL-71001 to terminal '20' of the KL-73006, and the GND terminal of the KL-71001 to the ground terminal of the KL-73006. Connect the terminals marked 21 and 22 with the connector plug. Connect the function generator output to the CH1 channel of the oscilloscope, and the ' Monostable Multivibrator ' output terminal to the CH2 channel of the oscilloscope.

(3) Set the sinusoidal frequency of the function generator to 1Hz and its amplitude to 100mVpp. Record the circuit output waveform to Table 6.11 at Results section.

9. Vascular Volume Experiment (Results should be stored using digital storage oscilloscope)

(1) Connect terminals J1 and J2 of the KL-73006 to the MODULE INPUT and MODULE OUTPUT terminals of the KL-71001, respectively. Use the connectors to connect terminals 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 14, 15, 16, 19, 20, 21, and 22. Connect the Vo1 output terminal to the CH1 channel of the oscilloscope, and the Vo2 output terminal to the CH2 channel of the oscilloscope.

(2) Select the KL-73006 module using the INPUT SELECT button on the KL-71001 (see LCD display). The IN7 LED on the KL-71001 panel should light up. This indicates that the input signal should be connected to this input. Therefore, connect the vascular volume sensor KL-73006A to this input terminal.

(3) Set the oscilloscope input coupling setting for both channels to DC. Set the CH1 voltage scale to 1V/div and the CH2 voltage scale to 2V/div. Set the time scale setting to 500ms/div.

(4) Adjust VR1 so that the V_E voltage is 1Vdc when the vascular volume sensor is exposed to normal light and not contacting the finger. Use a digital multimeter to measure the V_E voltage.

(5) Place your index finger on the KL-73006A sensor window as shown in Figure 6.13. Be careful not to move your hand.

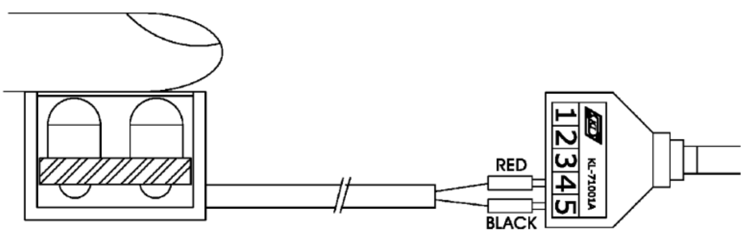


Figure 6.13 Finger position

(6) Record the vascular volume waveform in Table 6.12 at Results section. Observe the changes in the LED.

(7) If Vo2 waveform cannot be generated, adjust GAIN1 and VR2.

(8) During the test, no hand movement should be made while the finger is on the sensor. Otherwise, the output waveform may not be measured accurately.

10. Vascular Volume Experiment (Results are recorded to the computer via the RS232 interface)

(1) Connect terminals J1 and J2 of the KL-73006 to the MODULE INPUT and MODULE OUTPUT terminals of the KL-71001, respectively. Use the connectors to connect terminals 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 14, 15, 16, 19, 20, 21, and 22. Connect the Vo1 output terminal to the CH1 channel of the oscilloscope, and the Vo2 output terminal to the CH2 channel of the oscilloscope.

(2) Select the KL-73006 module using the INPUT SELECT button on the KL-71001 (see LCD display). The IN7 LED on the KL-71001 panel should light up. This indicates that the input signal should be connected to this input. Therefore, connect the vascular volume sensor KL-73006A to this input terminal.

(3) Set the oscilloscope input coupling setting for both channels to DC. Set the CH1 voltage scale to 1V/div and the CH2 voltage scale to 2V/div. Set the time scale setting to 500ms/div.

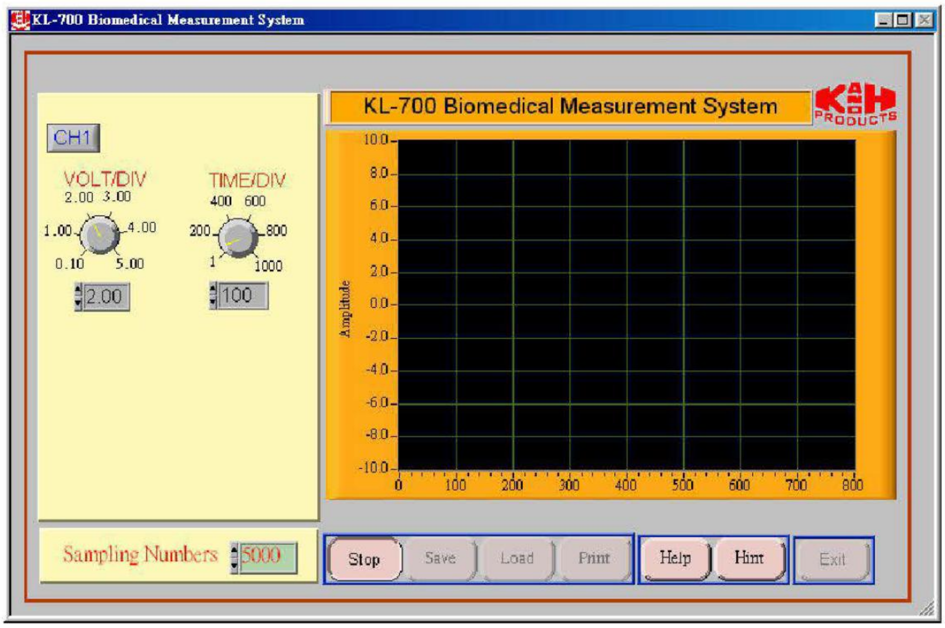
(4) Adjust VR1 so that the V_E voltage is 1Vdc when the vascular volume sensor is exposed to normal light and not contacting the finger. Use a digital multimeter to measure the V_E voltage.

(5) Place your index finger on the KL-73006A sensor window as shown in Figure 6.13. Be careful not to move your hand.

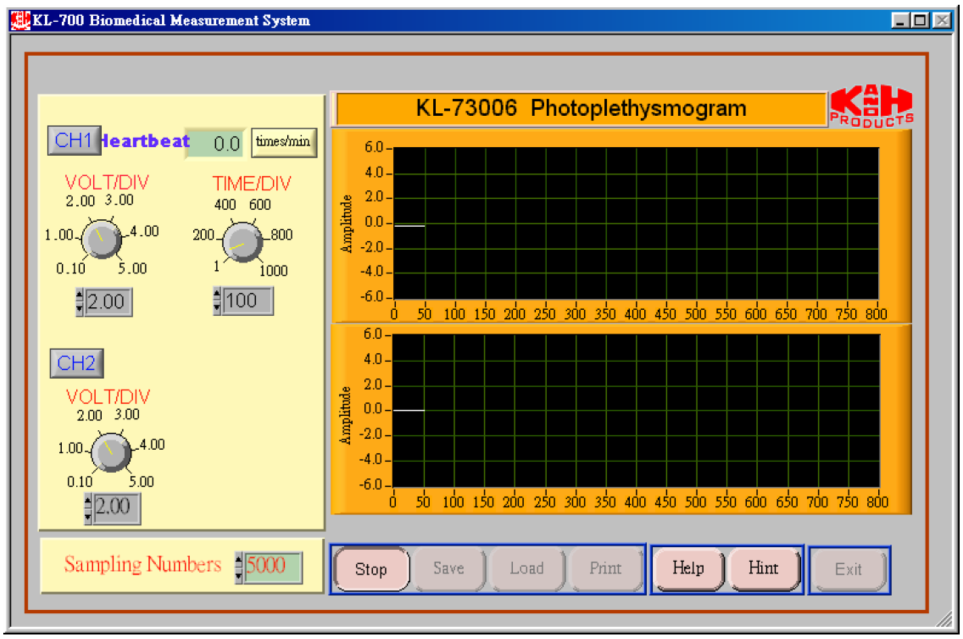
(6) Connect the 9-pin RS232 cable to COM Port on the computer.

(7) Run the KL-700 Biomedical Measurement System software. For instructions and installation information, see Chapter 0.

(8) When the system is loaded, the image below will appear on the screen.



(9) Press the 'Acqu' button to display the image below. The KL-73006 Photoplethysmogram recording screen will appear.



(10) Adjust the VOLT/DIV and TIME/DIV settings so that the signal waveform appears in the center of the graph area.

(11) Record the vascular volume waveform to the computer and observe the changes on the LED.

(12) If Vo2 waveform cannot be generated, adjust GAIN1 and VR2.

(13) No hand movement should be made while the finger is on the sensor. Otherwise, the output waveform may not be measured accurately.

6.5 RESULTS

Table 6.1 High-Pass Filter Characteristics Experiment

Connectors 2-3 Wired (1Hz)

Frequency	1kHz	500Hz	100Hz	10Hz	5Hz	4Hz	3Hz	2Hz	1Hz
HPF Output (Vpp)									

Connectors 4-5 Wired (0.3Hz)

Frequency	1kHz	500Hz	100Hz	10Hz	5Hz	4Hz	3Hz	2Hz	1Hz
HPF Output (Vpp)									

Table 6.2 High-Pass Filter Characteristic Curve

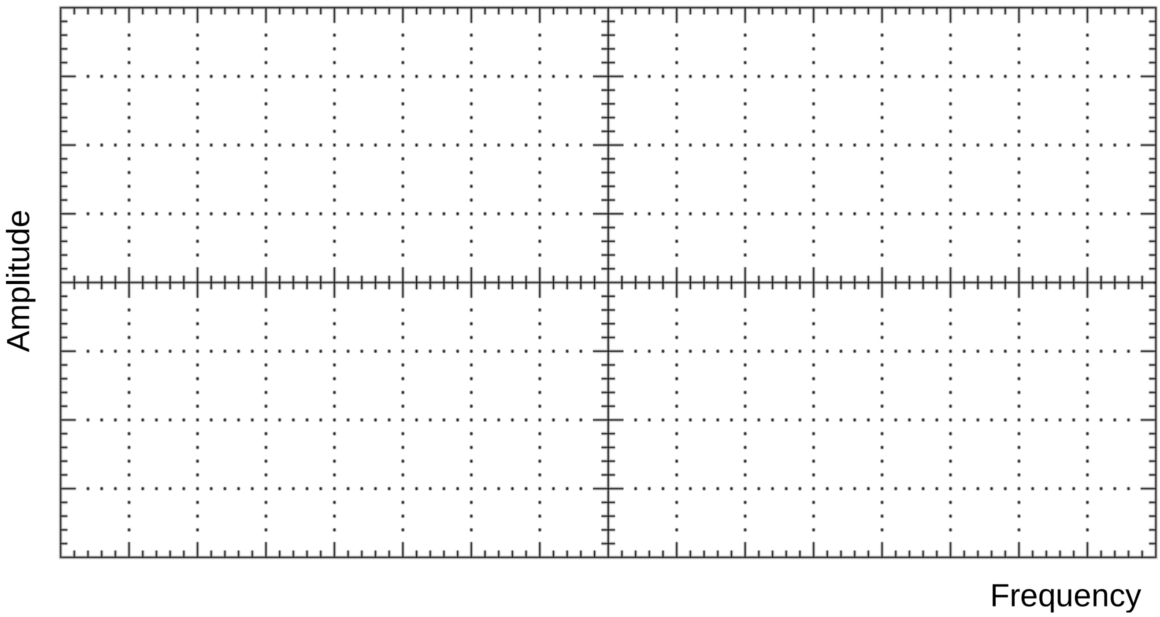


Table 6.3 Amplifier (1) Experiment

Amplifier Gain	Amplifier Output
8➔x50	
7➔ x100	

Table 6.4 Low-Pass Filter (1) Characteristics Experiment

Connectors 10-11 Wired (40Hz)

Frequency	1Hz	2Hz	3Hz	4Hz	5Hz	10Hz	100Hz	500Hz	1kHz
LPF Ouput (Vpp)									

Connectors 12-13 Wired (10Hz)

Frequency	1Hz	2Hz	3Hz	4Hz	5Hz	10Hz	100Hz	500Hz	1kHz
LPF Ouput (Vpp)									

Table 6.5 Low-Pass Filter (1) Characteristic Curve

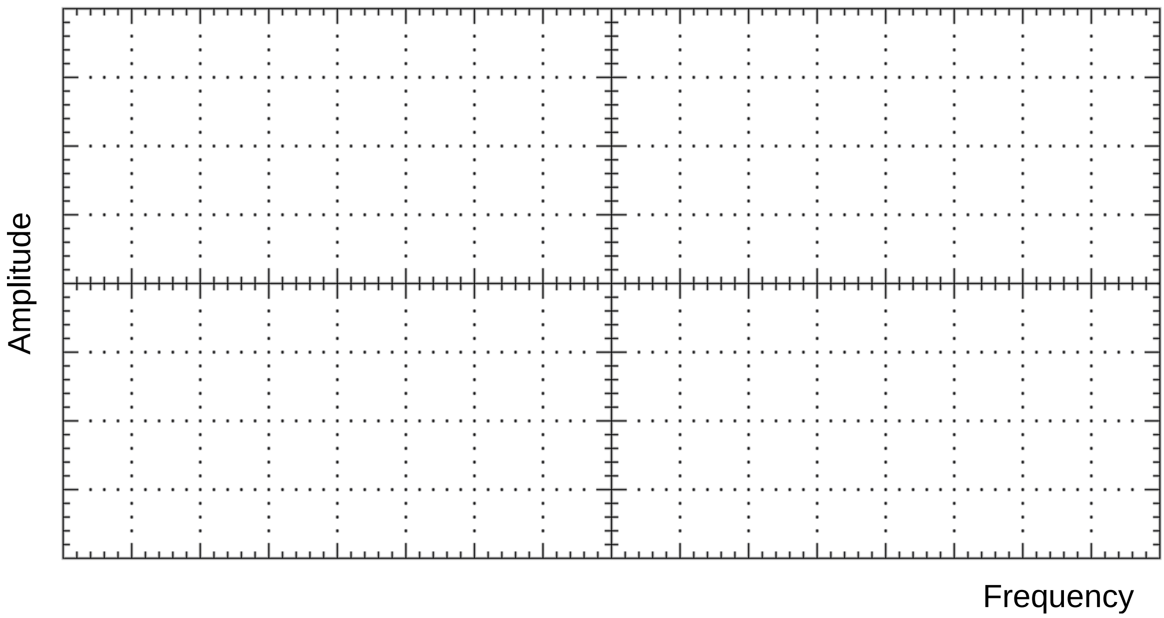


Table 6.6 Low-Pass Filter (2) Characteristics Experiment

Connectors 15-16 Wired (40Hz)

Frequency	1Hz	2Hz	3Hz	4Hz	5Hz	10Hz	100Hz	500Hz	1kHz
LPF Ouput (Vpp)									

Connectors 17-18 Wired (10Hz)

Frequency	1Hz	2Hz	3Hz	4Hz	5Hz	10Hz	100Hz	500Hz	1kHz
LPF Ouput (Vpp)									

Table 6.7 Low-Pass Filter (2) Characteristic Curve

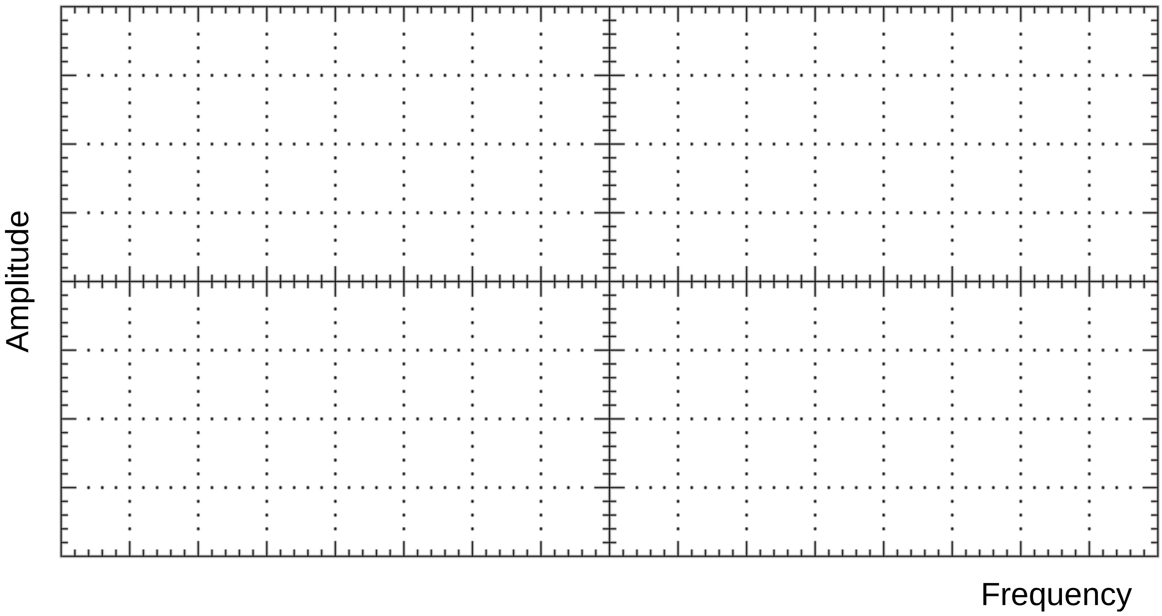


Table 6.8 Differentiator Experiment

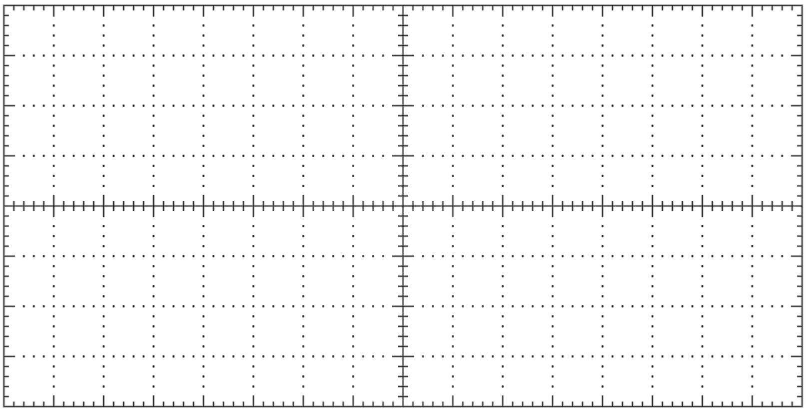
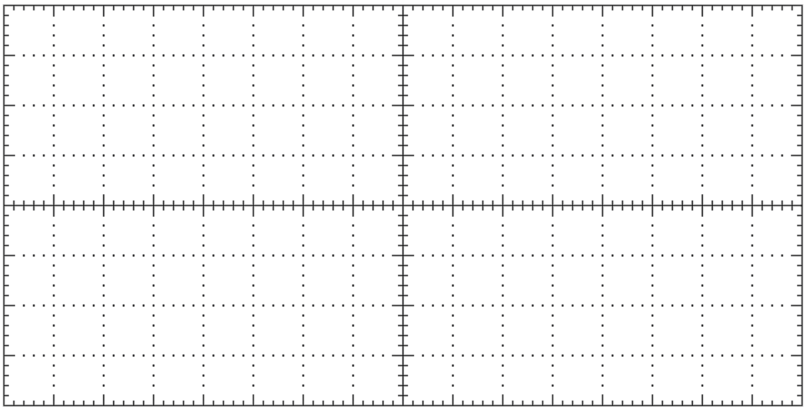
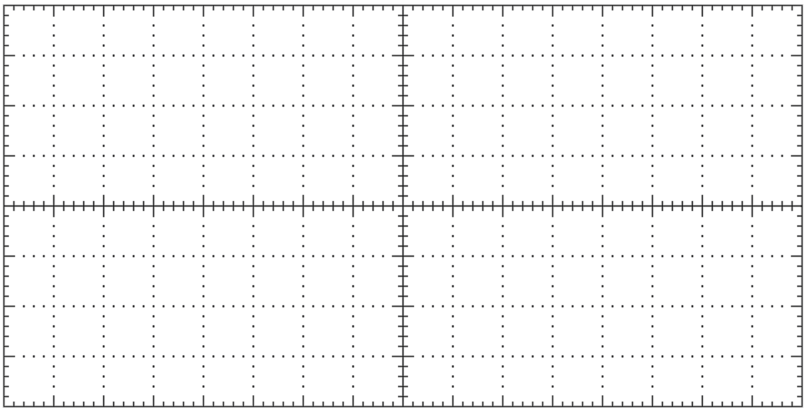
Input Frequency	Input / Output
50Hz	
100Hz	
150Hz	

Table 6.9 Amplifier (2) Experiment

GAIN1 Position	Amplifier Output
Minimum	
Center	
Maximum	

Table 6.10 Differentiator Experiment

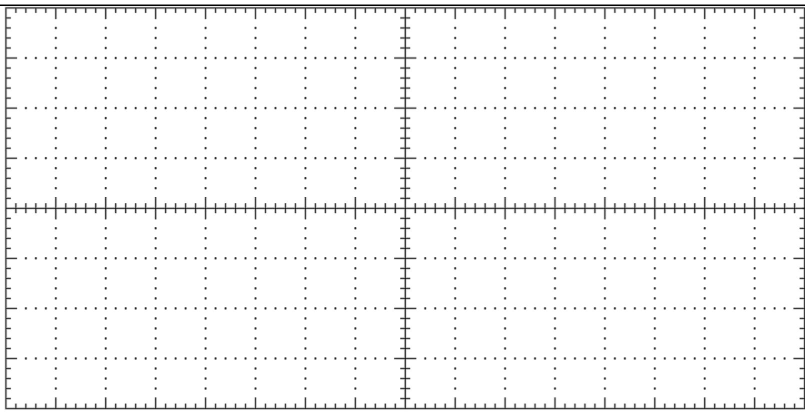
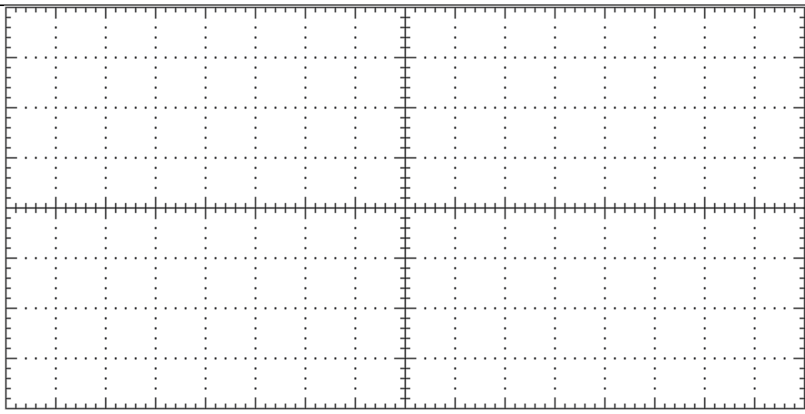
Frequency	Input (CH1) / Output (CH2)
100Hz	
1Hz	

Table 6.11 Monostable Multivibrator Experiment

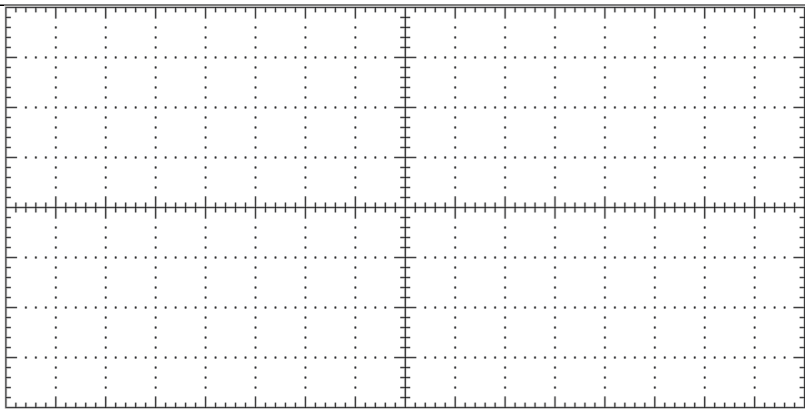
Frequency	Input (CH1) / Output (CH2)
1Hz	

Table 6.12 Vascular Volume Experiment

Amplifier 1	HPF	LPF 1,2	Vo1 (CH1) / Vo2 (CH2)
x50 8	1Hz 2 3	40Hz 10, 11 15, 16	
x50 8	1Hz 2 3	10Hz 12, 13 17, 18	
x50 8	0.3Hz 4 5	40Hz 10, 11 15, 16	
x50 8	0.3Hz 4 5	10Hz 12, 13 17, 18	

Table 6.12 (continuing)

Amplifier 1	HPF	LPF 1,2	Vo1 (CH1) / Vo2 (CH2)
x100 7	1Hz 2 3	40Hz 10, 11 15, 16	
x100 7	1Hz 2 3	10Hz 12, 13 17, 18	
x100 7	0.3Hz 4 5	40Hz 10, 11 15, 16	
x100 7	0.3Hz 4 5	10Hz 12, 13 17, 18	

6.6 QUESTIONS

1. Where is the -3dB frequency of the high-pass filter?
2. Where is the -3dB frequency of the low-pass filter?
3. Explain the effect of VR1.
4. Does the plethysmogram waveform change when you change the -3dB frequencies of the high-pass and low-pass filters?
5. In this experiment, does the pressure of the finger on the sensor affect the plethysmogram waveform?
6. In the monostable multivibrator experiment, is the output waveform affected by changes in VR2 and Vo2?
7. Compare the difference between the input and output signals of the differentiator circuit. If the input signal corresponds to volume, what physical signal does the output signal represent?
8. Can the plethysmogram waveform be measured after a strenuous exercise?