EXPERIMENT 5 OSCILLOMETRIC BLOOD PRESSURE MEASUREMENT

5.0 OBJECTIVE

The purpose of this experiment is to help students to understand the noninvasive method of blood pressure measurement. A traditional stethoscope measurement is compared with the measurement by a modern oscillometric meter. Through the exercise, students realize not only the piezoelectric property of pressure sensor, but also the direct and indirect calibration methods for blood pressure registration.

5.1 PHYSIOLOGICAL PRINCIPLE

What is the pressure? In physics, the pressure is defined as the force divided by per unit of surface. There are several expressions for the pressure unit. Usually, 1 Pascals (Pa)＝ 1 N/m^2. The atmospheric pressure on the earth's surface is 1 atm, and its corresponding unit is 14.7psi, 760 mm Hg, or 1.013×10^5 Pa. When a force exerts on a system, a pressure is generated. If the force is static, its corresponding pressure is hydrostatic; oppositely, if the force is dynamic, its corresponding pressure is hydrodynamic. In physiology, the blood pressure is hydrodynamic, and the pressure in a closed system must follow Pascals theorem. In other words, the pressure values of any parts of the inner tube or wall are all the same. A pressure measured in vacuum is called 'absolute pressure,' a pressure measured under 1 atm is called 'Gauge pressure,' and a pressure resulting from the comparison between two standard pressures is called 'difference pressure.'

In clinic, blood pressure (BP) is the pressure which presents in the artery during the left ventricular contraction and dilation. In most cases, BP is measured from the radial artery of the wrist, and systolic blood pressure and diastolic blood pressure are obtained by using a sphygmomanometer. Systolic blood pressure is the blood force acting on the arterial wall as the left ventricle contracts, and diastolic blood pressure is the blood force acting on the arterial as the left ventricle dilates. The difference between systolic and diastolic blood pressures is called pulse pressure. Figure 5.1 shows the relationship between the left atrium pressure (short-dash line), the left ventricular pressure (solid line), the arterial blood pressure (long-dash line), and the heart sound. The peak of arterial blood pressure is systolic blood pressure, and the valley is diastolic blood pressure. It is obvious that the left ventricular systolic blood pressure is almost the same as the arterial systolic blood pressure. When the ventricles contract, the artriovenricular valve closes, the first heart sound is generated. As the aortic valve opens, the blood is pumped into the arteries. Note that the left ventricular diastolic blood pressure is different from the arterial diastolic blood pressure. The arterial valve will be closed once the ventricular pressure is lower than the arterial pressure to avoid the blood return back to the ventricles. This will generate the second heart sound. Since the arterial valves impede the blood return and cause the reflection effect, a second peak in the blood pressure waveform occurs. A healthy young man has, in average, a systolic blood pressure of 120 mmHg and a diastolic blood pressure of 80 mmHg. What we call hypertension is when the systolic blood pressure higher than 140 mmHg or the diastolic blood pressure higher than 90 mmHg.

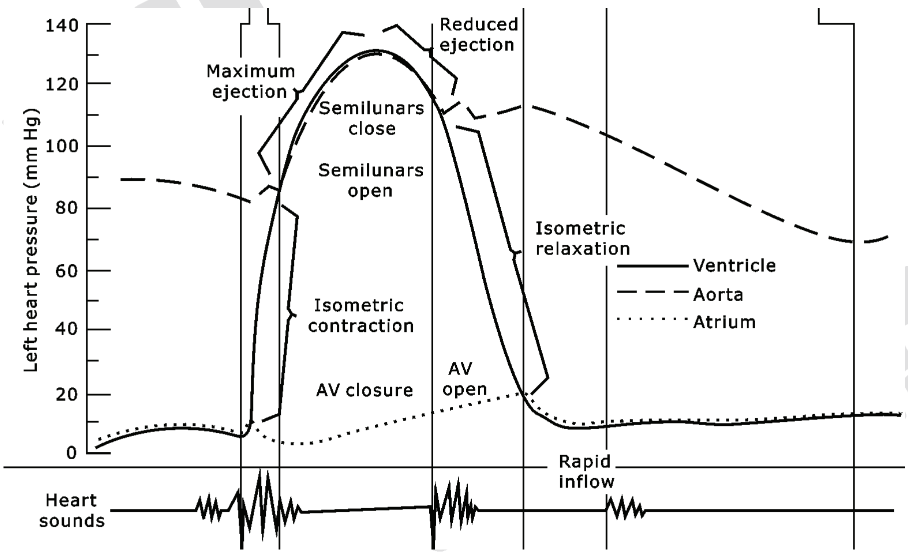


Figure 5.1 Relationship between the pressure of the left atrium (short-dash line), pressure of left ventricle (solid line), arterial blood pressure (long-dash line) and heart sound.

5.2 METHODS OF MEASUREMENT

There are two methods to measure blood pressure: direct and indirect. The direct blood pressure measurement is usually used in surgery; the pressure in circulatory organs can be detected. The method of indirect blood pressure measurement is the most used nowadays. Two available techniques will be introduced in the following text including the stethoscope method and the oscillometry.

1. Principle of Stethoscope Method for Blood Pressure Measurement

The method requires a stethoscope, an air cuff, a user-pump and a mercury meter. Figure 5.2 shows the method for blood pressure measurement. In this method, an air cuff is wrapped around the upper arm, a stethoscope is placed on the brachial artery, and the user-pump is used to inflate the cuff up to above the subject's systolic blood pressure and then to slowly deflate. The mercury meter is applied to read the cuff pressure. When the cuff pressure is higher than the arterial pressure, the artery is pressed and collapsed. This will stop the blood flow. As the arterial pressure is instantly higher than the cuff pressure, the blood flow through the artery will bring about a turbulent phenomenon due to a vacuum in the upstream. Thus, a so-called Korotkoff sound in clinic will result from the turbulence. And the sound can be heard with a stethoscope. As shown in Figure 5.2, the first sound can be heard when the cuff pressure is lower for first time than the arterial systolic pressure. In the meantime, the cuff pressure indicates the systolic blood pressure. The last sound is heard when the cuff is lower at last than the arterial diastolic pressure. At that time, the cuff pressure corresponds just to the diastolic blood pressure. The disadvantage of this method is the difficulty to hear the sound precisely. Thus, more practice is needed. The advantage is that the measurement is less affected by cardiovascular disease or human interference, so it's able to provide a more accurate result.

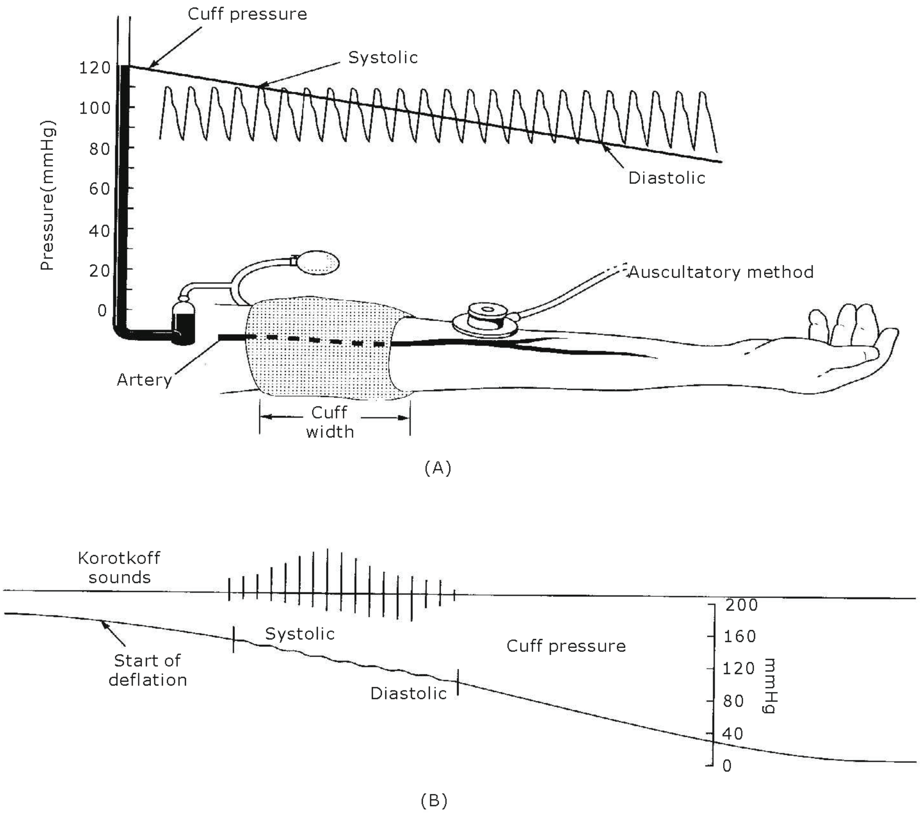


Figure 5.2 Method for blood pressure measurement using a stethoscope.

2. Principle of Oscillometry for Blood Pressure Measurement

Figure 5.3 shows the oscillometic principle for the blood pressure measurement. When the pressure waveform passes through the arterial vessel, a vessel volume pulse will be produced. Then the vessel volume pulse affects the alteration of pressure in the cuff, which is the oscillometric pulse needed to measure. Compared with the invasive blood pressure measurement, the maximum oscillation amplitude occurs when the cuff pressure is equal to the mean arterial pressure. The findings of the systolic and diastolic pressures are based on statistic investigation. They will occur at the place beside the maximum oscillation. Once the relative ratios of the systolic and diastolic pressures are known, the corresponding cuff pressures are the systolic and diastolic pressures, respectively. The oscillometric technique requires an arm cuff, a user-held pump, and a mercury meter. Its disadvantage is the vulnerability to cardiovascular disease and human interference which leads to a less accuracy. But it’s a convenient way to measure blood pressure.

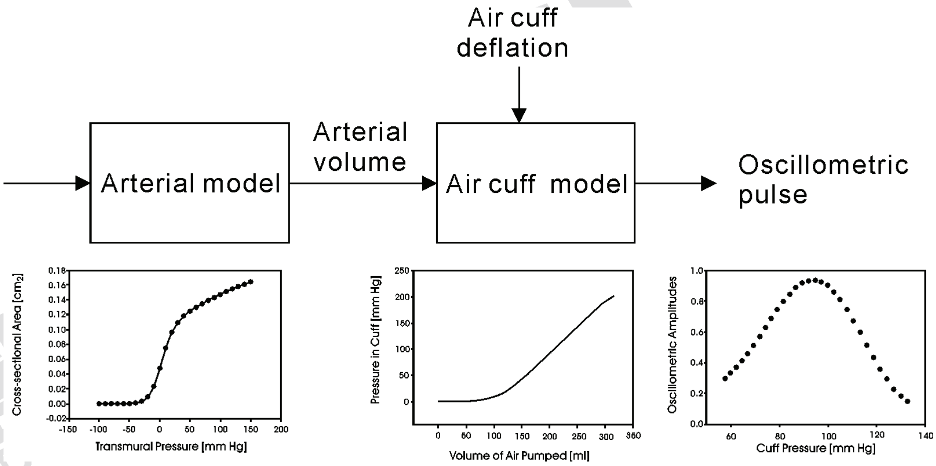


Figure 5.3 Model of oscillometric blood pressure measurement.

Figure 5.4 shows the relationship between the cuff pressure and oscillation pulse. Once the maximum amplitude, Amax, is obtained, its corresponding cuff pressure is then the mean arterial pressure. The oscillation amplitude, 0.5 times of Amax, showing up before the Amax is used to find out the corresponding cuff pressure which is the systolic blood pressure. Similarly, the oscillation amplitude, 0.75 times of Amax, showing up after the Amax is used to find out the corresponding cuff pressure which is the diastolic blood pressure.

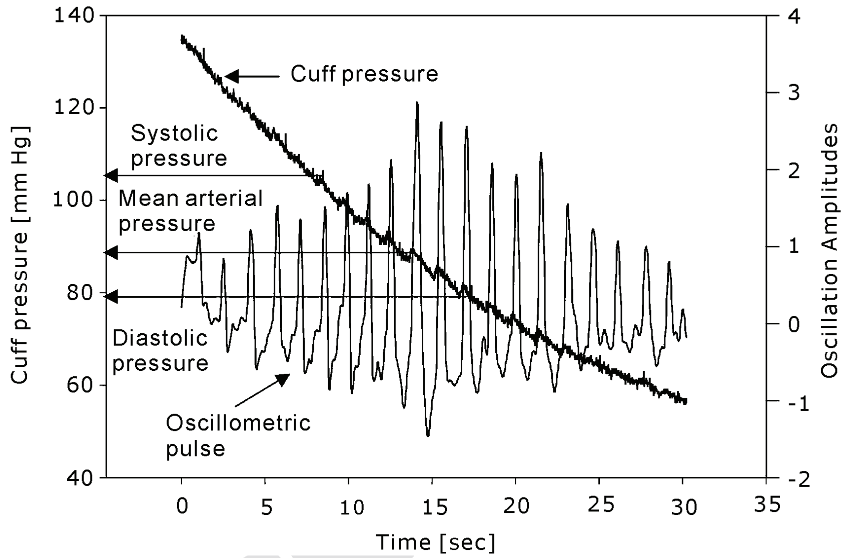


Figure 5.4 Relationship between cuff pressure and oscillometric amplitude.

5.3 PRINCIPLE OF CIRCUIT DESIGN

1. Block Diagram of Blood Pressure Measurement

As described in the previous section related to the oscillometric method, two kinds of parameters are the most important, including the peak-to-peak amplitude of the oscillation pulse, and its corresponding cuff pressure. Thus, the interrupted sampling method is adopted in the circuit design rather than the continuous sampling method. Figure 5.5 shows the block diagram of the oscillometric blood pressure measurement. The cuff pressure is converted to an electric voltage by a pressure sensor. This conversion is performed through the pressure-sensor driving circuit. The band-pass filter with a bandwidth of 0.3~3 Hz can be used to pick up the oscillometric pulse signal. After the pulse amplified by 500 times, the comparator circuit generates a sample-triggering signal out of phase with the pulse. Meanwhile, the sample and hold circuit will remain the peak of the oscillometric pulse wave in order to wait for sampling.

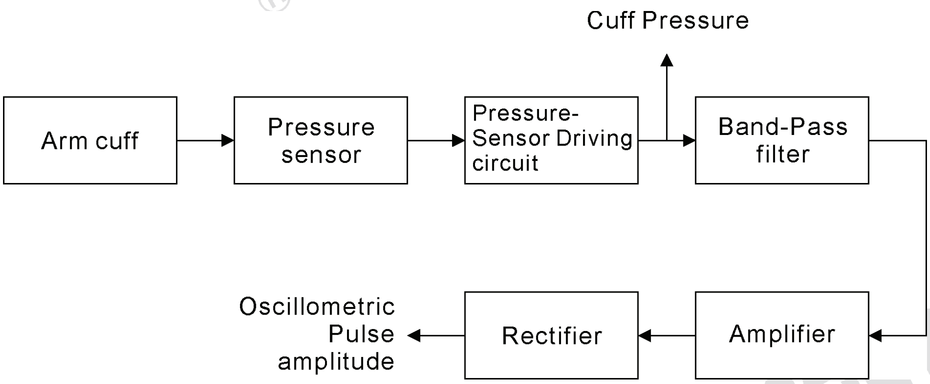


Figure 5.5 Block diagram of oscillometric blood pressure measurement

2. Pressure Sensor

In the experiment, a pressure sensor is used, as shown in Figure 5.6. In absolute pressure measurement, a vacuum chamber in the sensor can be used as a pressure reference. So, the output voltage is absolutely proportional to the measured pressure. In differential pressure measurement, the pressure measured enters the sensor through the terminal P1. A vibrating thin diaphragm inside the sensor chamber separates the measured pressure and the reference pressure which goes through the terminal P2. The output voltage is proportional to the pressure difference between the terminals P1 and P2. Figure 5.6 shows the dimensional views of the pressure sensor, and Table 5.0 lists the function of each pin.

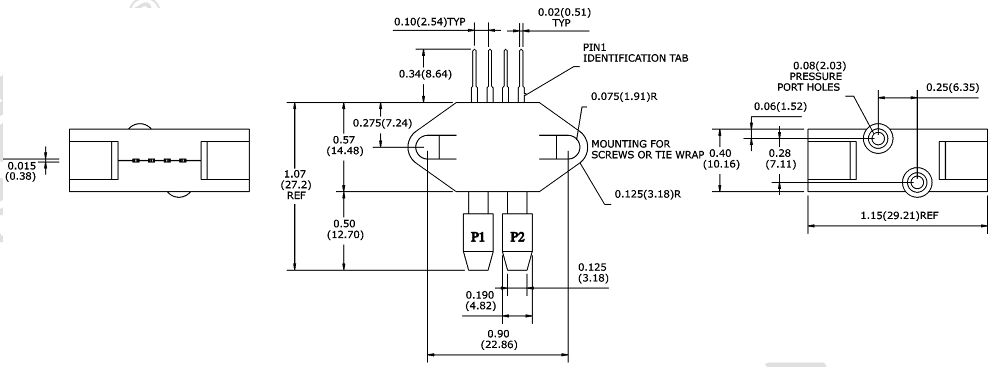


Figure 5.6 Different dimension views of pressure sensor.

Table 5.0 Pin function of pressure sensor.

Pin No.	Function
Pin 1	Ground
Pin 2	Negative output terminal in pressure change
Pin 3	Voltage value
Pin 4	Positive output terminal in pressure change

3. Pressure-Sensor Driver Circuit

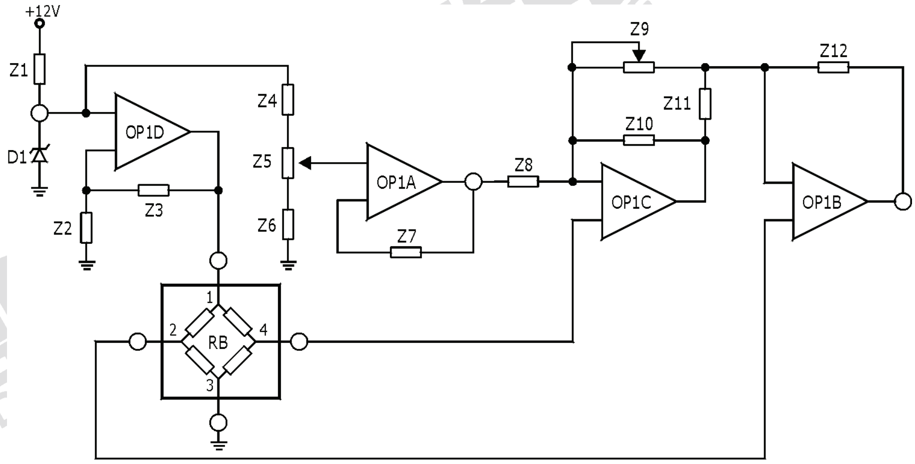


Figure 5.7 Driving circuit for the pressure sensor.

Figure 5.7 shows the pressure-sensor driver circuit which is composed of OP1 IC. This experiment is designed for practical application. A voltage output of the circuit is between 1 ~ 5 V in response to an input pressure from 0 to 200 mmHg. OP1D is a voltage-stabilizing circuit in which V_{D1} is always kept at 5.1 V by the Zener diode D1. The voltage will not alter even in the presence of fluctuation of power source. The instrumentation amplifier is constructed by OP1B and OP1C which can amplify the potential difference resulting from the differential pressure, as determined by Equation (5.1).

$$V_{out} = V_{in}(2\frac{Z_9 + Z_{10}}{Z_9}) + V_R \tag{5.1}$$

V_{in} is the output voltage of the pressure sensor, and V_R, the output voltage of OP1A. The output voltage of the OP1B may be 5 V, by adjusting Z_9, when the input pressure is 200 mmHg. As a potentiometer, OP1C can be sent out, by adjusting Z_5, an output voltage of 1 V (V_{out}) when the input pressure is 0 mmHg.

4. Oscillometric Pulse Measuring Circuit

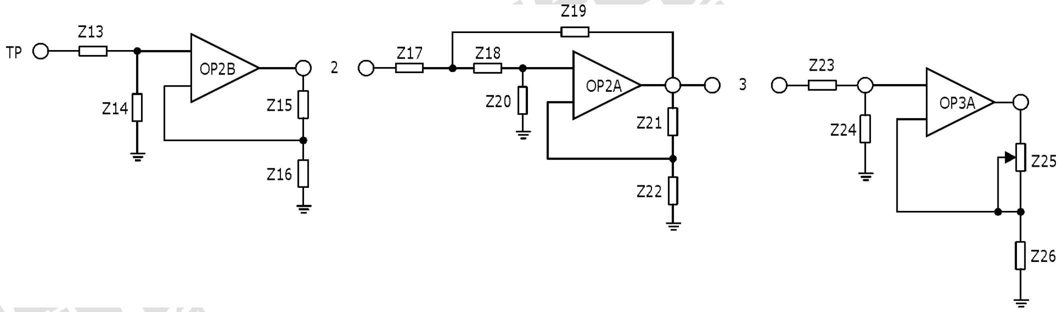


Figure 5.8 Oscillometric pulse measuring circuit.

In designing the oscillometric pulse measuring circuit, a 1-order high-pass filter is constructed by Z_{13}, Z_{14}, Z_{23} and Z_{24}, in order to decrease DC offset due to a high amplifying gain, as shown in Figure 5.8. The cutoff frequency (f_L) of the filter is set at 0.3 Hz, and can be calculated with Equation (5.2).

$$f_L = \frac{1}{2\pi\sqrt{Z_{13}Z_{14}Z_{23}Z_{24}}} \tag{5.2}$$

OP2A is used to construct an active 2nd-order low-pass filter. The cutoff frequency (f_H) of the filter is set at 3 Hz, and can be calculated by Z_{17}, Z_{18}, Z_{19} and Z_{20}, as expressed in Equation (5.3),

$$f_H = \frac{1}{2\pi\sqrt{Z_{17}Z_{18}Z_{19}Z_{20}}} \tag{5.3}$$

And, its passband gain is explained in Equation (5.4).

$$\frac{Z_{21}+Z_{22}}{Z_{22}} = 1.56 \tag{5.4}$$

Both OP2B and OP3A are non-inverting amplifiers. In the OP3A amplifier, Z_{25} is used for the gain adjustment as expressed in Equation (5.5).

$$A_V = \frac{Z_{25}+Z_{26}}{Z_{26}} \tag{5.5}$$

5. Rectifier Circuit

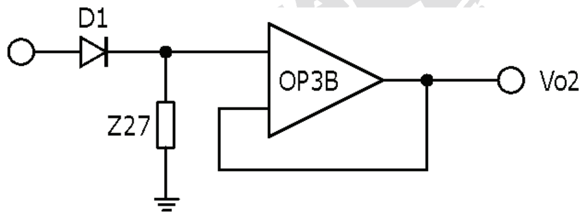


Figure 5.9 Half-wave rectifier.

The half-wave rectifier shown in Figure 5.9 is used to pass only the positive half cycles of oscillometric pulse signal. During the positive half cycles, the diode D1 conducts and delivers the signal to the output Vo2 through the voltage follower OP3B.

5.4 EQUIPMENT REQUIRED

1. KL-72001 Main Unit
2. KL-75005 Blood Pressure Measurement Module
3. Digital Storage Oscilloscope
4. Digital Voltmeter (DVM)
5. Y Tube
6. Tube Connector
7. Stethoscope
8. Arm Cuff
9. Hand-operated Pump
10. Mechanical Sphygmomanometer
11. PET blow bottle filled with water up to 80% of height
12. DB9 Cable
13. BNC Cables
14. RS-232 Cable
15. Connecting Wires
16. 10-mm Bridging Plugs
17. Trimmer

5.5 PROCEDURE

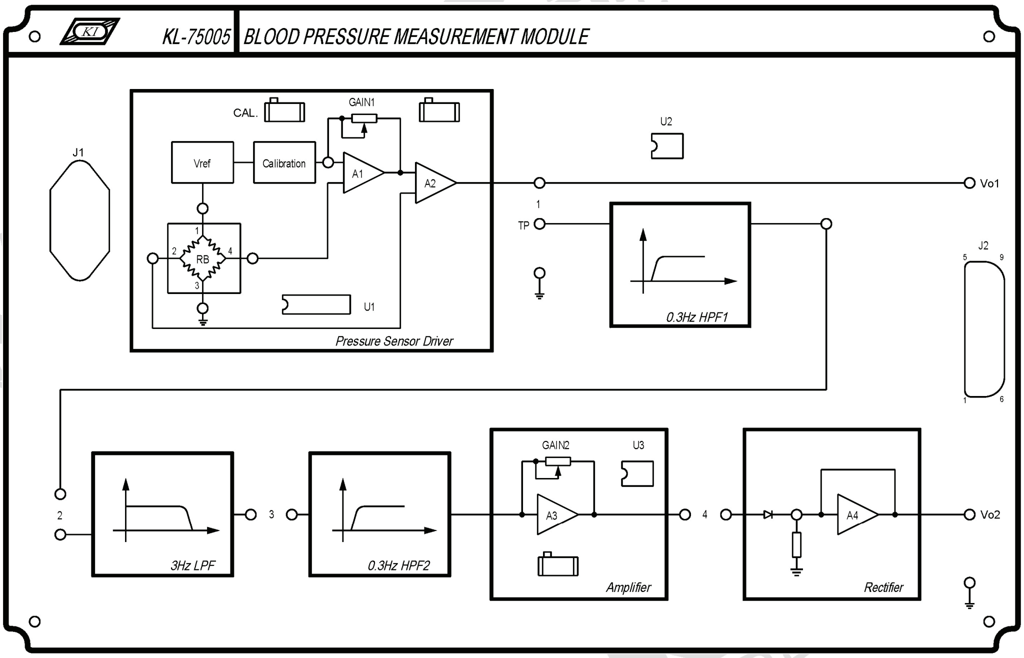


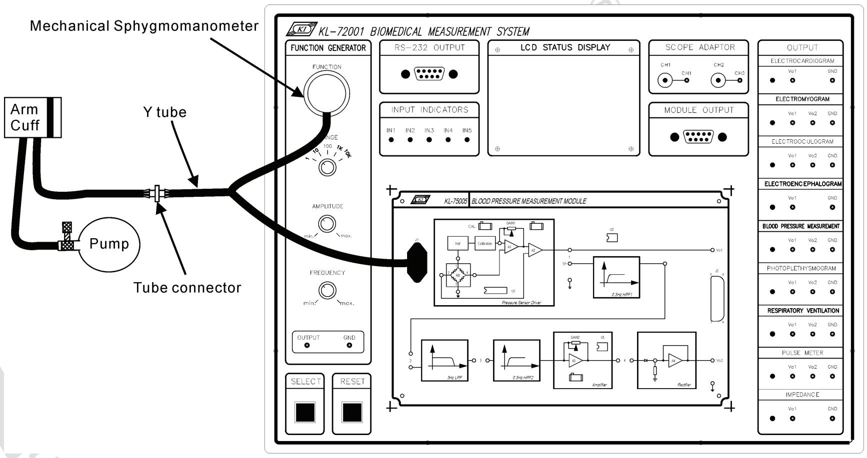
Figure 5.10 Front panel of KL-75005 Blood Pressure Measurement Module.

A. Calibrating the Pressure Sensor Driver

1. Set KL-75005 Blood Pressure Measurement Module on KL-72001 Main Unit. Then, complete the following connection.

KL-72001 Main Unit				KL-75005 Blood Pressure Measurement Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2

2. Using Y tube, connect the Mechanical sphygmomanometer and the pressure sensor installed in J1 on the KL-75005 Blood Pressure Measurement Module, as show below.
3. Connect the hand-operated pump to arm cuff, and connect Y tube to arm cuff using a tube connector.



4. Turn power on.
5. Connect the positive probe of the DVM to the Vo1 terminal, and the negative probe to the ground located at the bottom-right of KL-75005 Blood Pressure Measurement Module.
6. Wrap the arm cuff around the PET blow bottle. Tightly close (CW) the deflation valve of the pump.
7. Observe the indications of DVM and sphygmomanometer. When the pressure indicated by the sphygmomanometer is zero, adjust the CAL potentiometer in the Pressure Sensor Driver block, so the Vo1 indicated by the DVM is equal to 3 Vdc.
8. Apply pressure to the arm cuff until the pressure indicated by the sphygmomanometer equals to 100mmHg. Adjust the GAIN1 potentiometer in the Pressure Sensor Driver block, so the Vo1 indicated by DVM is equal to 4 Vdc.
9. Apply pressure to the arm cuff until the pressure indicated by the sphygmomanometer equals to 200mmHg. Adjust the GAIN1 potentiometer in the Pressure Sensor Driver block, so the Vo1 indicated by DVM is equal to 5 Vdc.
10. Therefore, the relationship between Vo1 and pressure can be expressed by:

$$P = 100\ Vo1 - 300$$

11. Repeat step 7 to 9, till you find the output voltage of Vo1 complied with the equitation of step 10.
12. Apply each of the cuff pressures listed in Table 5.1, observe and record the output dc voltage indicated by the DVM in Table 5.1.

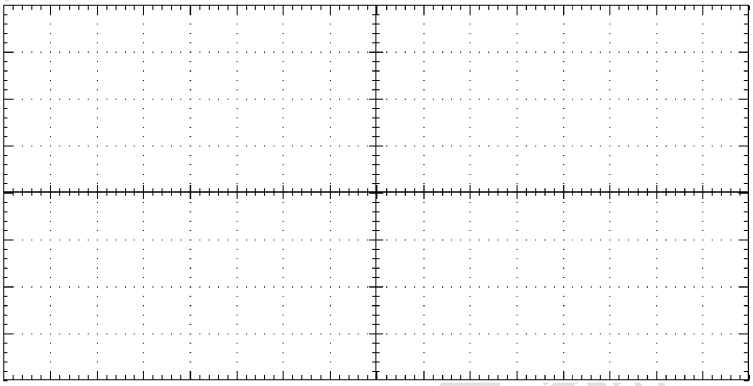
Table 5.1 Measured output dc voltage of the pressure sensor driver.

Pressure (mmHg)	0	20	50	80	100	120	150	180	200
Vo1									

13. According to the recorded data in Table 5.1, plot the relationship of pressure to Vo1 in Table 5.2.

Table 5.2 Characteristic curve of the pressure sensor.

Vo1



mmHg

14. Turn power off and disconnect circuit.

B. Measuring the Characteristics of High-Pass Filter 1 (HPF1)

1. Set KL-75005 Blood Pressure Measurement Module on KL-72001 Main Unit. Complete the following connections:

KL-72001 Main Unit				KL-72001 Main Unit		
Section	Area	Terminal	To	Section	Area	Terminal
FUNCTION GENERATOR	--	OUTPUT	→	SCOPE ADAPTOR	--	CH1
SCOPE ADAPTOR	--	CH1 (BNC)	→	CH1 input of the oscilloscope		
SCOPE ADAPTOR	--	CH2 (BNC)	→	CH2 input of the oscilloscope		

KL-72001 Main Unit				KL-75005 Blood Pressure Measurement Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2
FUNCTION GENERATOR	--	OUTPUT	→	0.3Hz HPF1	Input (TP)
FUNCTION GENERATOR	--	GND	→	--	Ground (in the bottom right corner)
SCOPE ADAPTOR	--	CH2	→	0.3Hz HPF1	Output

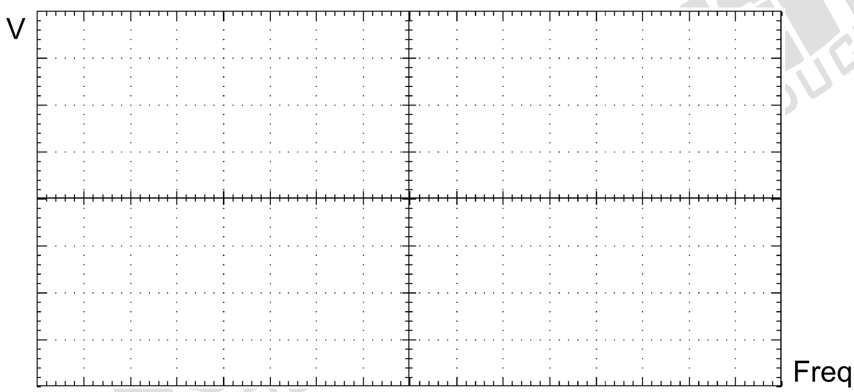
2. Turn power on.
3. Apply a 1 KHz, 100 mVpp sine signal to HPF1 input by adjusting the FREQUENCY and AMPLITUDE knobs of the FUNCTION GENERATOR and observing CH1 trace on the oscilloscope screen.
4. Observe HPF1 output signal displayed on the CH2 trace and record the amplitude in Table 5.3.
5. Without changing the amplitude of input sine signal, repeat Steps 3 and 4 for other frequency values listed in Table 5.3.

Table 5.3 Measured output amplitude of HPF1.

Input Freq	1KHz	10Hz	1Hz	0.6Hz	0.5Hz	0.4Hz	0.3Hz	0.2Hz	0.1Hz
HPF1 Output (Vpp)									

6. According to the recorded data in Table 5.3, plot the characteristic curve of HPF1 in Table 5.4.

Table 5.4 Characteristic curve of HPF1.



7. Turn power off and disconnect circuit.

C. Measuring the Characteristics of Low-Pass Filter (LPF)

1. Set KL-75005 Blood Pressure Measurement Module on KL-72001 Main Unit. Complete the following connections:

KL-72001 Main Unit				KL-72001 Main Unit		
Section	Area	Terminal	To	Section	Area	Terminal
FUNCTION GENERATOR	--	OUTPUT	→	SCOPE ADAPTOR	--	CH1
SCOPE ADAPTOR	--	CH1 (BNC)	→	CH1 input of the oscilloscope		
SCOPE ADAPTOR	--	CH2 (BNC)	→	CH2 input of the oscilloscope		

KL-72001 Main Unit				KL-75005 Blood Pressure Measurement Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2
FUNCTION GENERATOR	--	OUTPUT	→	3Hz LPF	Input
FUNCTION GENERATOR	--	GND	→	--	Ground (in the bottom right corner)
SCOPE ADAPTOR	--	CH2	→	3Hz LPF	Output

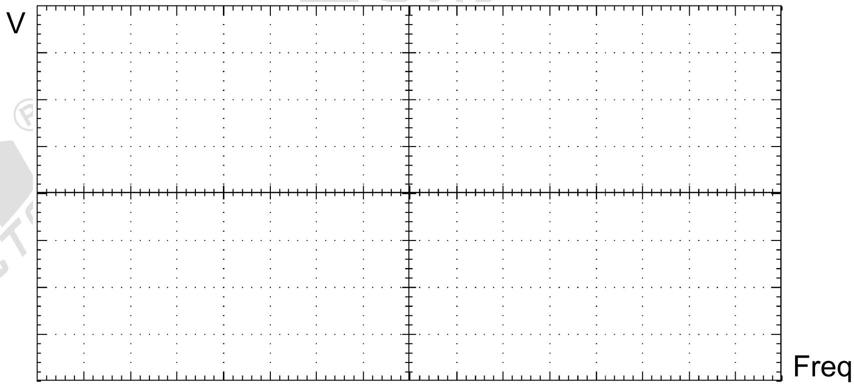
2. Turn power on.
3. Apply a 0.1 Hz, 1 Vpp sine signal to LPF input by adjusting the FREQUENCY and AMPLITUDE knobs of the FUNCTION GENERATOR and observing CH1 trace on the oscilloscope screen.
4. Observe LPF output signal displayed on the CH2 trace and record the amplitude in Table 5.5.
5. Without changing the amplitude of input sine signal, repeat Steps 3 and 4 for other frequency values listed in Table 5.5.

Table 5.5 Measured output amplitude of LPF.

Input Freq	0.1Hz	0.5Hz	1Hz	2Hz	3Hz	4Hz	5Hz	10Hz	20Hz
LPF Output (Vpp)									

6. According to the recorded data in Table 5.5, plot the characteristic curve of the LPF in Table 5.6.

Table 5.6 Characteristic curve of LPF.



7. Turn power off and disconnect circuit.

D. Measuring the Characteristics of HPF2 and Amplifier

1. Set KL-75005 Blood Pressure Measurement Module on KL-72001 Main Unit. Complete the following connections:

KL-72001 Main Unit				KL-72001 Main Unit		
Section	Area	Terminal	To	Section	Area	Terminal
FUNCTION GENERATOR	--	OUTPUT	→	SCOPE ADAPTOR	--	CH1
SCOPE ADAPTOR	--	CH1 (BNC)	→	CH1 input of the oscilloscope		
SCOPE ADAPTOR	--	CH2 (BNC)	→	CH2 input of the oscilloscope		

KL-72001 Main Unit				KL-75005 Blood Pressure Measurement Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2
FUNCTION GENERATOR	--	OUTPUT	→	0.3Hz HPF2	Input
FUNCTION GENERATOR	--	GND	→	--	Ground (in the bottom right corner)
SCOPE ADAPTOR	--	CH2	→	Amplifier	Output

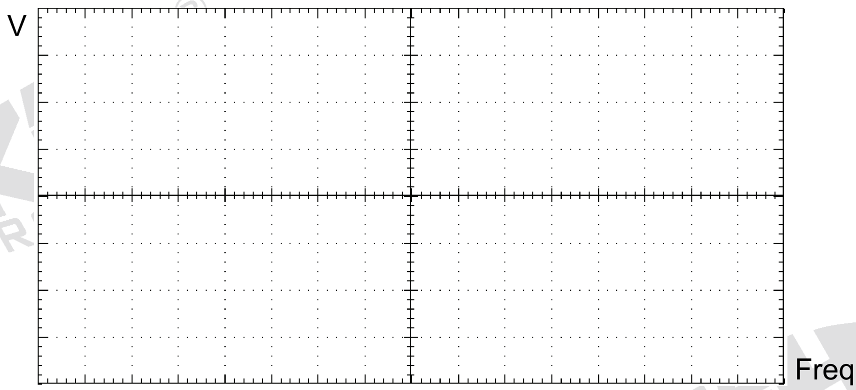
2. Turn power on.
3. Apply a 1 KHz, 200 mVpp sine signal to HPF2 input by adjusting the FREQUENCY and AMPLITUDE knobs of the FUNCTION GENERATOR section and observing CH1 trace on the oscilloscope screen.
4. Observe the Amplifier output signal displayed on the CH2 trace, adjust the Amplifier GAIN2 potentiometer so that the amplitude of the output signal is equal to 5 Vpp. Record the amplitude in Table 5.7.
5. Without changing the amplitude of input sine signal and GAIN2 setting, repeat Steps 3 and 4 for other frequency values listed in Table 5.7.

Table 5.7 Measured output amplitude of HPF2.

Input Freq	1KHz	10Hz	1Hz	0.6Hz	0.5Hz	0.4Hz	0.3Hz	0.2Hz	0.1Hz
HPF2 Output (Vpp)									

6. According to the recorded data in Table 5.7, plot the characteristic curve of the HPF2 in Table 5.8.

Table 5.8 Characteristic curve of HPF2.



7. Turn power off and disconnect circuit.

E. Measuring the Characteristics of Rectifier

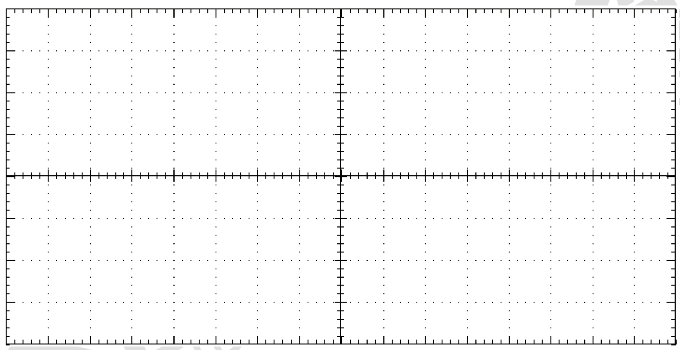
1. Set KL-75005 Blood Pressure Measurement Module on KL-72001 Main Unit. Then, complete the following connections:

KL-72001 Main Unit				KL-72001 Main Unit		
Section	Area	Terminal	To	Section	Area	Terminal
FUNCTION GENERATOR	—	OUTPUT	→	SCOPE ADAPTOR	—	CH1
SCOPE ADAPTOR	—	CH1 (BNC)	→	CH1 input of the oscilloscope		
SCOPE ADAPTOR	—	CH2 (BNC)	→	CH2 input of the oscilloscope		

KL-72001 Main Unit				KL-75005 Blood Pressure Measurement Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	—	9-Pin	→	—	J2
FUNCTION GENERATOR	—	OUTPUT	→	Rectifier	Input
FUNCTION GENERATOR	—	GND	→	—	Ground (in the bottom right corner)
SCOPE ADAPTOR	—	CH2	→	Rectifier	Output

2. Turn power on.
3. Apply a 1 KHz, 1 Vpp sine signal to Rectifier input by adjusting the FREQUENCY and AMPLITUDE knobs of the FUNCTION GENERATOR section and observing CH1 trace on the oscilloscope screen.
4. Observe the Rectifier output signal displayed on the CH2 trace. Record the waveform in Table 5.9.

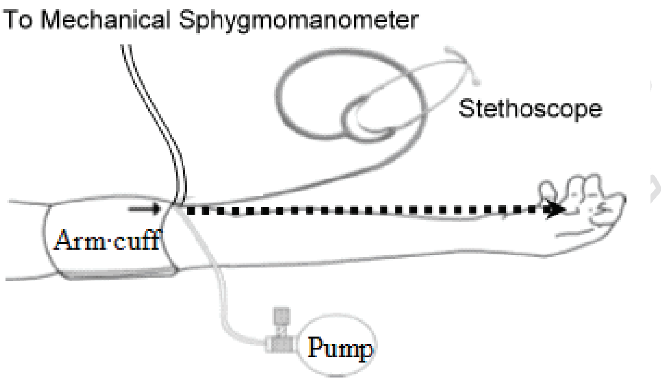
Table 5.9 Measured input and output waveforms of rectifier.

CH1 (Input Waveform) / CH2 (Output Waveform)


5. Turn power off and disconnect circuit.

F. Blood Pressure Measurement using Stethoscope

1. Ask the subject to put his/her hand on the table.
2. Connect mechanical sphygmomanometer, stethoscope, arm cuff and hand-operated pump as shown below.
3. Tightly close (CW) the deflation valve of the pump.
4. Wrap the arm cuff around the subject upper arm by keeping 2 - 3 cm apart from the elbow and aligning the arrowhead on the arm cuff with the middle finger.
5. Tighten the arm cuff securely.



Notes:

a. In the experiment, it is better to keep a constant deflation rate of 2 – 3 mmHg. And, the cuff pressure will never be allowed to be higher than 200 mmHg, avoiding the subject's discomfort.
b. Let the subject take a rest at least 3 minutes after every measurement. Continuous measurement is not allowed.

6. Put on the stethoscope.
7. Press the pump to inflate the arm cuff at about 10 mmHg per inflation and up to 180 mmHg approximately.
8. Adjust the deflation valve counterclockwise to deflate the arm cuff at the deflation rate of 2 - 3 mmHg/sec.
9. When the first sound is heard, record the cuff pressure (the systolic pressure) indicated by the sphygmomanometer in Table 5.10. When the last sound is heard, record the cuff pressure (the diastolic pressure) in Table 5.10.

Table 5.10 Measured systolic pressure and diastolic pressure.

Systolic Pressure (mmHg)	Diastolic Pressure (mmHg)

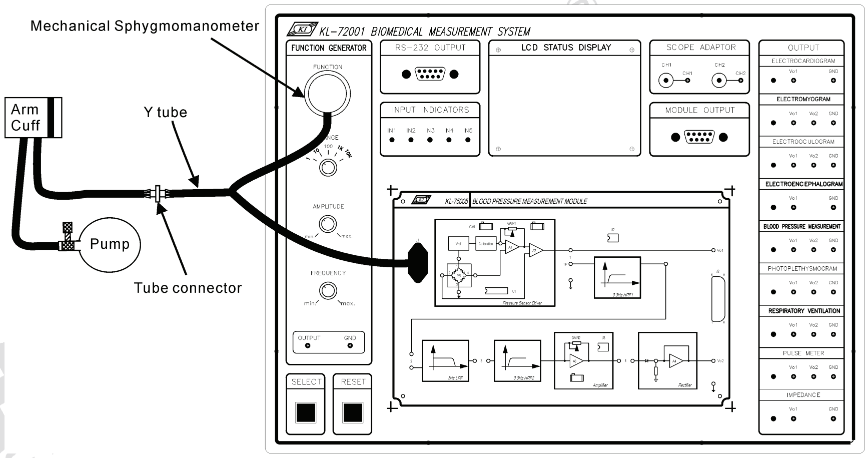
G. Blood Pressure Measurement using Oscillometric Sensor and Oscilloscope

1. Set KL-75005 Blood Pressure Measurement Module on KL-72001 Main Unit. Then, complete the following connections:

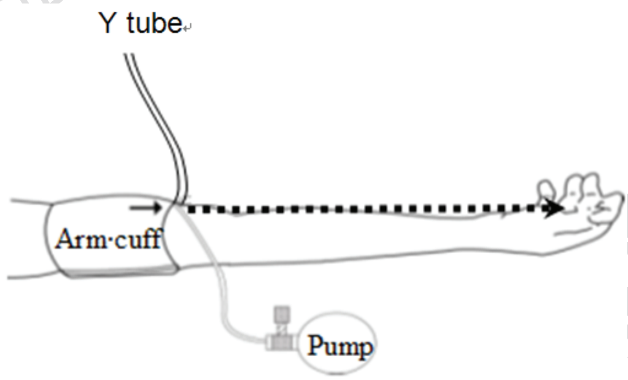
KL-72001 Main Unit				KL-72001 Main Unit		
Section	Area	Terminal	To	Section	Area	Terminal
SCOPE ADAPTOR	–	CH1	→	OUTPUT	BLOOD PRESSURE MEASUREMENT	Vo1
SCOPE ADAPTOR	–	CH2	→	OUTPUT	BLOOD PRESSURE MEASUREMENT	Vo2
SCOPE ADAPTOR	--	CH1 (BNC)	→	CH1 input of the oscilloscope		
SCOPE ADAPTOR	--	CH2 (BNC)	→	CH2 input of the oscilloscope		

KL-72001 Main Unit				KL-75005 Blood Pressure Measurement Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2

2. On KL-75005 Blood Pressure Measurement Module, insert bridging plugs in positions 1, 2, 3, and 4.
3. Using Y tube, connect the Mechanical sphygmomanometer and the pressure sensor installed in J1 on the KL-75005 Blood Pressure Measurement Module, as show below.
4. Connect the hand-operated pump to arm cuff, and connect Y tube to arm cuff using a tube connector.



5. Turn power on. Select the MODULE:KL-75005 (BPM) from the LCD display by pressing SELECT button of KL-72001 Main Unit.
6. Make sure the Pressure Sensor Driver and Amplifier circuits have been calibrated. (Refer to Procedures A and D)
7. Ask the subject to put his/her hand on the table.
8. Tightly close (CW) the deflation valve of the pump.
9. Wrap the arm cuff around the subject upper arm by keeping 2 - 3 cm apart from the elbow and aligning the arrowhead on the arm cuff with the middle finger. See the figure below.
10. Tighten the arm cuff securely.

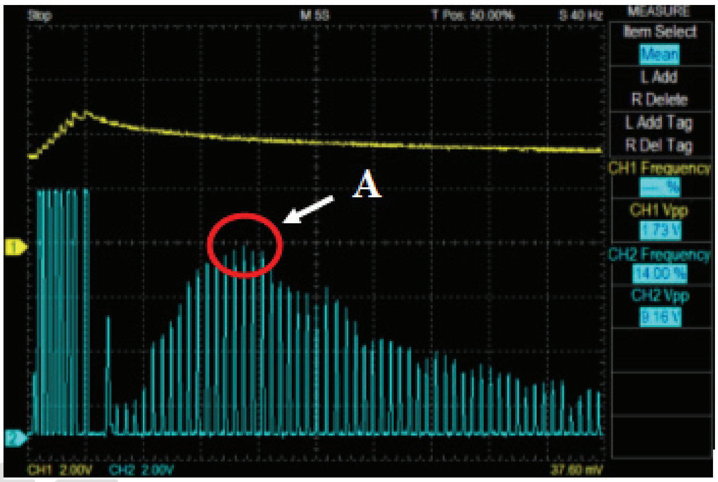


Notes:

a. In the experiment, it is better to keep a constant deflation rate of 2 - 3 mmHg. And, the cuff pressure will never be allowed to be higher than 200 mmHg, avoiding the subject's discomfort.

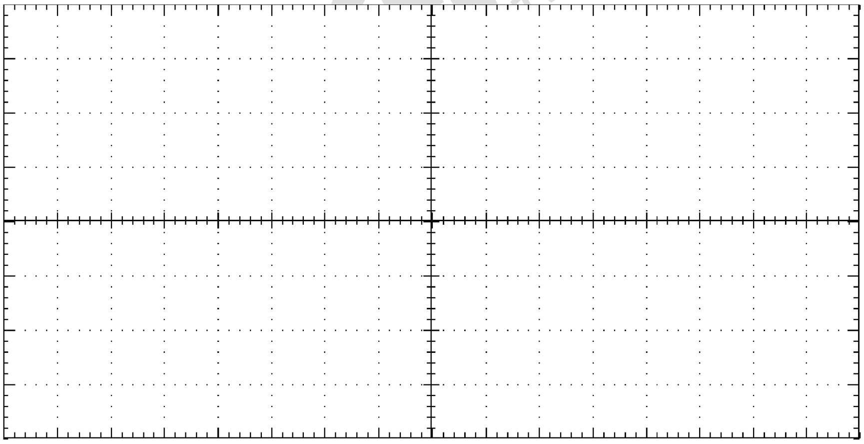
b. Let the subject take a rest at least 3 minutes after every measurement. Continuous measurement is not allowed.

11. Set the VOLT/DIV controls of CH1 and CH2 to 2 V/div, and set the TIME/DIV control to 5 S/div.
12. Press the pump to inflate the arm cuff at about 10 mmHg per inflation and up to 180 mmHg approximately.
13. Adjust the deflation valve counterclockwise to deflate the arm cuff at the deflation rate of 2 - 3 mmHg/sec.
14. Repeat Steps 12 and 13. Observe the Vo2 signal displayed on the CH2 trace. Adjust the Amplifier GAIN2 potentiometer to obtain a maximum unclipped pulse like A in the figure below.

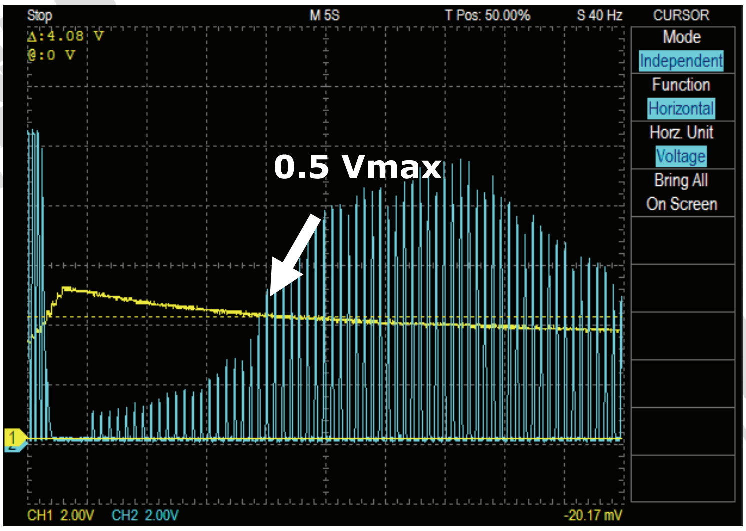


15. Repeat Steps 12 and 13. Observe the oscilloscope screen. After the occurrence of the maximum oscillometric pulse (Vmax), see if the present of oscillometric pulse is lower than a half of the maximum oscillometric pulse (0.5Vmax). If it does, halt the recording of oscilloscope, and record the waveforms in Table 5.11.

Table 5.11 Measured waveforms of blood pressure measurement.

Vo1 (CH1) / Vo2 (CH2)


16. According to the result in Table 5.11, find out the maximum amplitude (Vmax). Search backward for the amplitude most approximating 0.5Vmax and find out its corresponding voltage of CH1 (Vo1). Convert the voltage into pressure using the equation P = 100 Vo1 - 300. The pressure calculated is the systolic pressure. Record the systolic pressure in Table 5.12.



17. According to the result in Table 5.11, find out the maximum amplitude (Vmax). Search forward for the amplitude most approximating 0.75Vmax and find out its corresponding voltage of CH1 (Vo1). Convert the voltage into pressure using the equation P = 100 Vo1 - 300. The pressure calculated is the diastolic pressure. Record the diastolic pressure in Table 5.12.

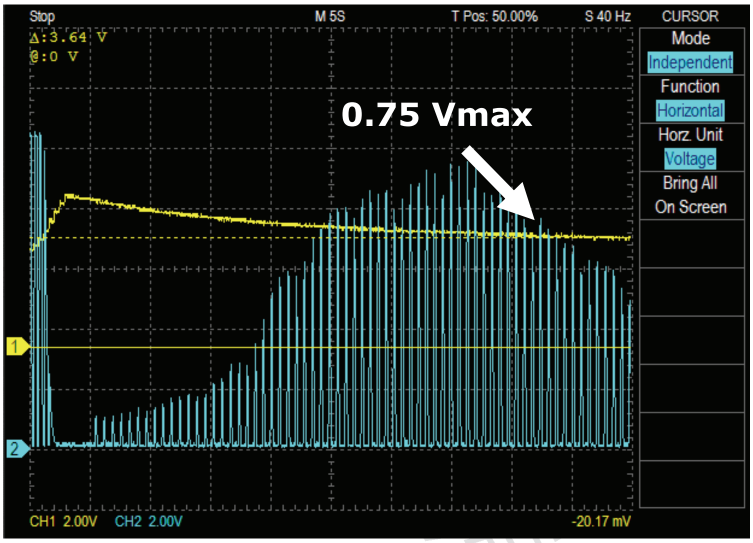


Table 5.12 Calculated diastolic pressure and systolic pressure.

Systolic Pressure (mmHg)	Diastolic Pressure (mmHg)

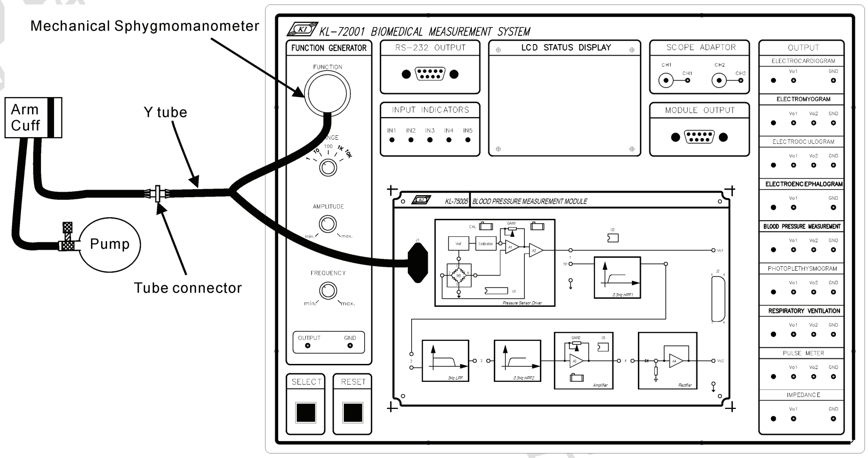
18. Turn power off and disconnect circuit.

H. Blood Pressure Measurement using Oscillometric Sensor and KL-720 Software

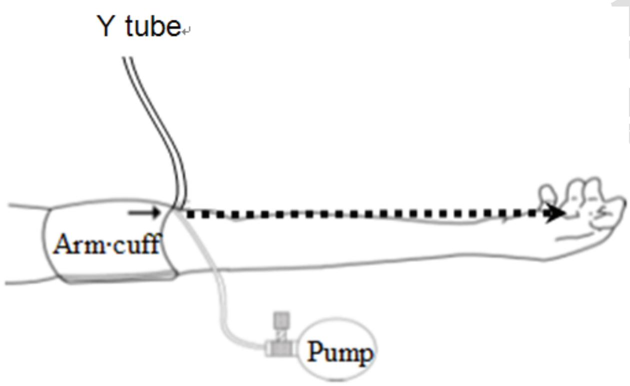
1. Set KL-75005 Blood Pressure Measurement Module on KL-72001 Main Unit. Complete the following connection.

KL-72001 Main Unit				KL-75005 Blood Pressure Measurement Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	–	9-Pin	→	--	J2

2. On KL-75005 Blood Pressure Measurement Module, insert bridging plugs in positions 1, 2, 3, and 4.
3. Using Y tube, connect the Mechanical sphygmomanometer and the pressure sensor installed in J1 on the KL-75005 Blood Pressure Measurement Module, as show below.
4. Connect the hand-operated pump to arm cuff, and connect Y tube to arm cuff using a tube connector.



5. Ask the subject to put his/her hand on the table.
6. Tightly close (CW) the deflation valve of the pump.
7. Wrap the arm cuff around the subject upper arm by keeping 2 - 3 cm apart from the elbow and aligning the arrowhead on the arm cuff with the middle finger. See the figure below.
8. Tighten the arm cuff securely.

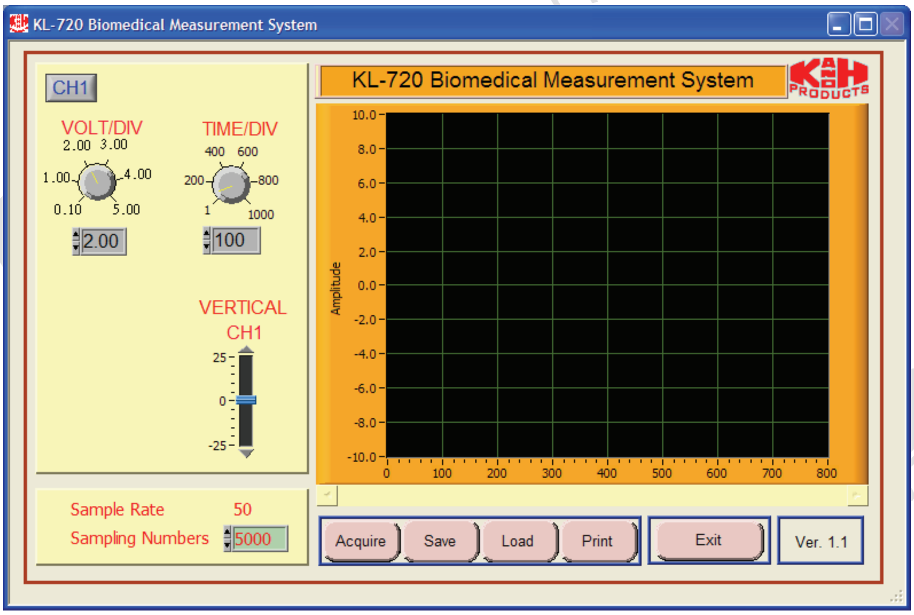


Notes:

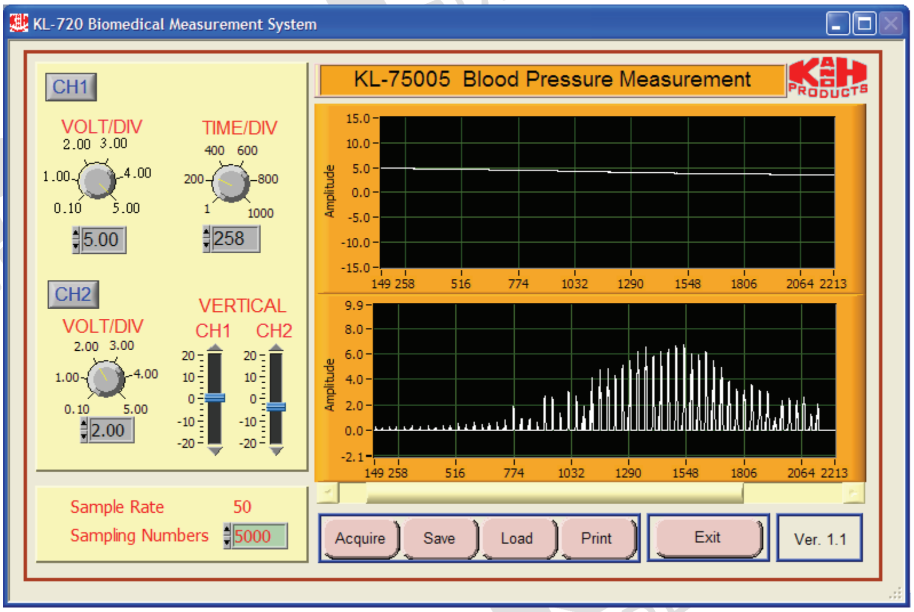
a. In the experiment, it is better to keep a constant deflation rate of 2 - 3 mmHg. And, the cuff pressure will never be allowed to be higher than 200 mmHg, avoiding the subject's discomfort.

b. Let the subject take a rest at least 3 minutes after every measurement. Continuous measurement is not allowed.

9. Connect the RS-232 OUTPUT connector on the KL-72001 Main Unit to the RS-232 port on the computer by RS-232 cable.
10. Turn power on. Select MODULE:KL-75005 (BPM) from the LCD display by pressing the SELECT button of KL-72001 Main Unit.
11. Make sure the Pressure Sensor Driver and Amplifier circuits have been calibrated. (Refer to Procedures A and D)
12. Boot the computer.
13. Execute KL-720 program. KL-720 Biomedical Measurement System window appears as shown below.

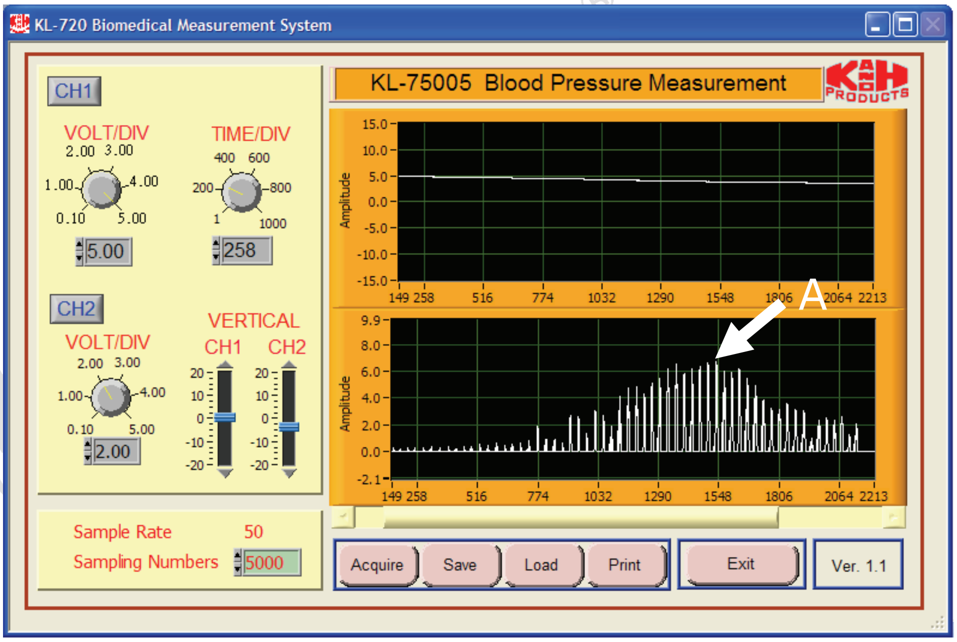


14. Click the Acquire button. The system begins to acquire the measured data via RS-232 port and shows the waveforms in KL-75005 Blood Pressure Measurement window. It should look like this:



Note: If the message “time out, please check the COM port was connected the device” appears, check the connection and setup of the RS-232 port.

15. Press the pump to inflate the arm cuff at about 10 mmHg per inflation and up to 180 mmHg approximately.
16. Adjust the deflation valve counterclockwise to deflate the arm cuff at the deflation rate of 2 - 3 mmHg/sec.
17. Adjust the VOLT/DIV and TIME/DIV knobs, so the signals can be read accurately.
18. Repeat Steps 15 and 16. Observe the Vo2 signal displayed on the CH2 trace. Adjust the Amplifier GAIN2 potentiometer to obtain a maximum unclipped pulse like A in the figure below.



19. Repeat Steps 15 and 16. Save the waveform data on disk after the oscillometric pulse terminates.
20. Exit KL-720 Biomedical Measurement System, turn power off and disconnect circuit.