EXPERIMENT 1 ELECTROCARDIOGRAM (ECG) MEASUREMENT

1.0 OBJECTIVE

The purpose of this experiment is to help students to learn the phenomenon of electrical activity which occurs during the cardiac pumping cycle. The waveform of periodical changing potential related to electrical activity is called electrocardiogram (ECG). The ECG measurement module is designed to detect ECG signals from six different leads of human body. Students can understand the theory of Wilson network through this exercise. And they will be more capable of designing isolation circuits.

1.1 PHYSIOLOGICAL PRINCIPLE

Human heart is composed of myocardium. When action potential occurs, it will lead to a myocardial contraction. Then heart pumps blood to whole body. In the meantime, the current resulting from action potential will spread from heart to whole body unequally. It explains why we can catch the signal from the different parts of human body by surface electrodes. The measured waveform is called electrocardiogram (ECG). And a lead is composed by potential waveforms recorded from the electrodes placed on different parts of body. Based on cardiac potential axis, there are six standard leads, including Lead Ⅰ, Lead Ⅱ, Lead Ⅲ, aV_R, aV_L and aV_F. The right foot is usually considered as a reference ground. His potential amplitude changes less than all other reference points because it's farthest from heart. In fact, the systole of heart is not completely controlled by automatic nervous system, but originally by the specialized cells in Sinoatrial node which works like a pacemaker. The regular potential from Sinoatrial node will spread to all atria and make it contracted. Then, when contracted, atria pumps the blood into the ventricles. In the meantime, passing through the atrioventricular node between the ventricle and atrium, action potential will enter to all areas of the ventricles via Purkinje fibers, then makes the it contracted. Finally, ventricle pumps the blood to the arteries.

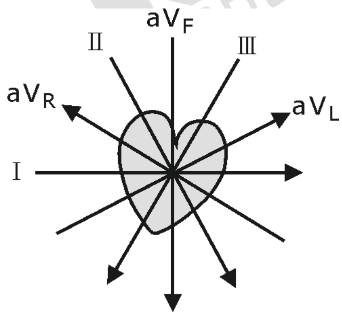


Figure 1.1 Cardiac potential axes corresponding to different ECG leads.

When the nervous impulses pass through the atrium and ventricle, the electrical current will spread to the cardiac tissue and induces the generation of the myocardial action potential. Some parts of action potential can be detected on the surface of skin. That's why it's possible to measure the change of action potential when we put electrodes on the surface of body. Of course, those electrodes should be placed on the area corresponding to heart. The time-varying potential recorded is ECG. Figure 1.1 shows the cardiac potential axes used to measure different ECG lead signals. And a cardiac vector is a kind of projection of potential on the front plane surface of body. There is 60 degrees between each two axes formed by projected vectors. Each axe represents a lead which has no relationship with the position of electrodes. The phenomenon is discovered by a Holland physiologist Willen Einthoven. We also call it Einthoven's triangle. Please refer to Figure 1.2 for cardiac vector.

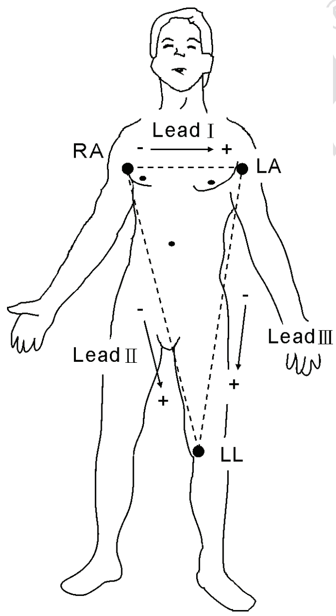


Figure 1.2 Einthoven's triangle.

Figure 1.3 shows a normal ECG which consists of a P wave, QRS wave and T wave. P wave is a current caused by the depolarization of atria contraction. QRS is the current caused by the depolarization before ventricular contraction. And at last, T wave, by ventricular repolarization.

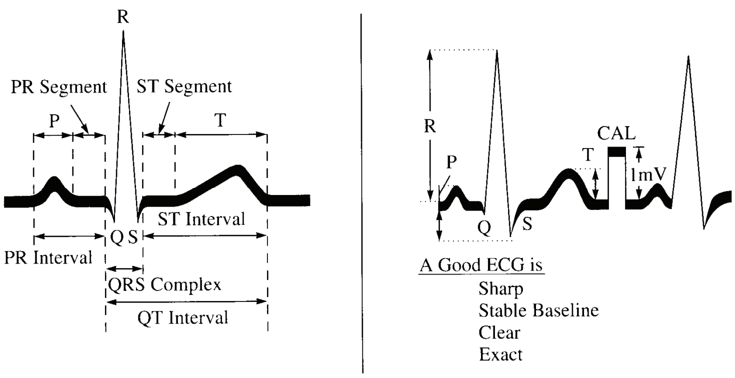


Figure 1.3 Timing and wave amplitudes of ECG.

Figure 1.4 shows the bipolar lead measurements in the different vector directions including Lead I, Lead II and Lead III. In unipolar lead measurement, the average of two potentials detected from extremities is a reference of signal ground, as shown in Figure 1.5. The unipolar lead measurement includes an increasing voltage right arm (aV_R), an increasing voltage left arm (aV_L), and an increasing voltage foot (aV_F).

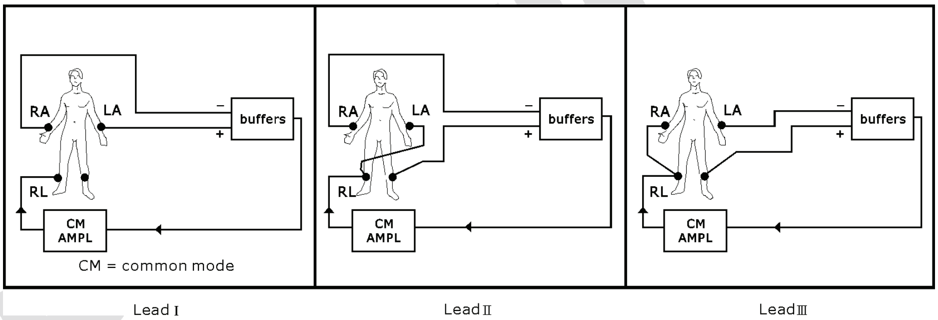


Figure 1.4 Bipolar lead measurements.

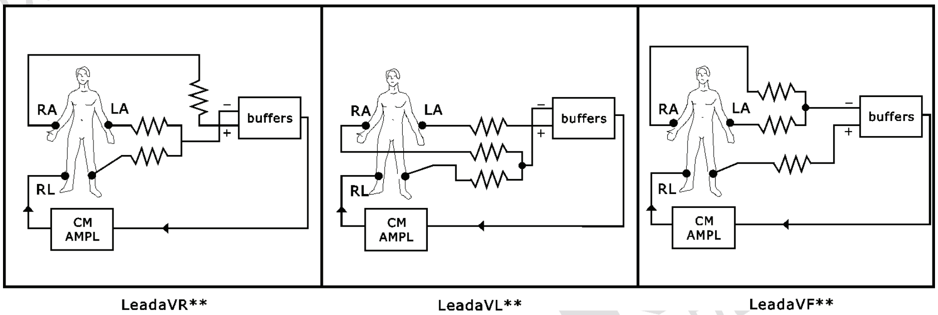


Figure 1.5 Unipolar lead measurements.

1.2 PRINCIPLE OF CIRCUIT DESIGN

1. Block Diagram of ECG Measurement Circuit

In the extremity lead measurements as described above, the right foot is always used as a reference ground. Through the testing points on right arm, left arm and left foot, six ECG lead signals including Lead I, Lead II, Lead III, aV_R, aV_L and aV_F can be realized. For the consideration of hardware cost, the circuit is one channel with the possibility of multiple-lead. In general, the frequency range is from 0.1 to 100 Hz and the maximum amplitude is 1 mV in a normal ECG signal. Further, to avoid the electrical shock caused by leakage of the power supply or testing instrument, the isolation circuit must be considered for ECG detection.

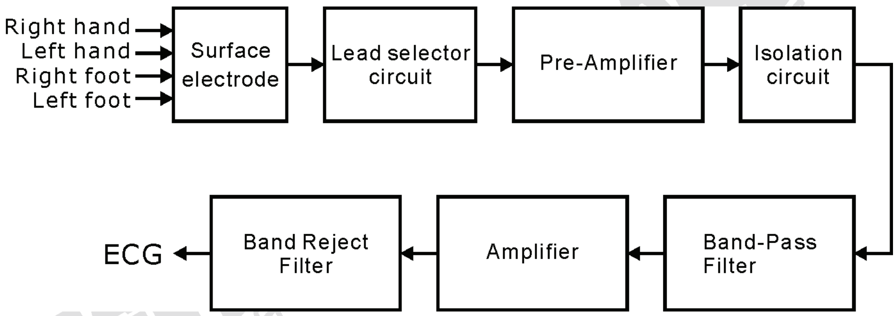


Figure 1.6 Block diagram of ECG measurement circuit.

Figure 1.6 shows the block diagram of ECG measurement circuit. In ECG measurement, the surface electrodes (or electrode clamps) placed on four extremities are used to catch very weak and time-varying potentials. The lead selector circuit contains a voltage follower circuit to match impedance between the electrode and skin, this design can augment the sensitivity of measurement. The triangle selection network of the selector circuit is constructed by the various measuring modes shown in Figures 1.4 and 1.5. An instrumentation amplifier with a gain of 100 is applied as the preamplifier to catch the unipolar signal from the ECG vectors. The isolation circuit is designed to isolate signal and line power source by using an optical method. The bandwidth of the band-pass filer is from 0.1 to 100 Hz, and the amplifier possesses an amplification factor of 10. After the signal goes through 50 or 60Hz band-reject filter, the final signal can be displayed on the oscilloscope screen.

2. Lead Selector Circuit

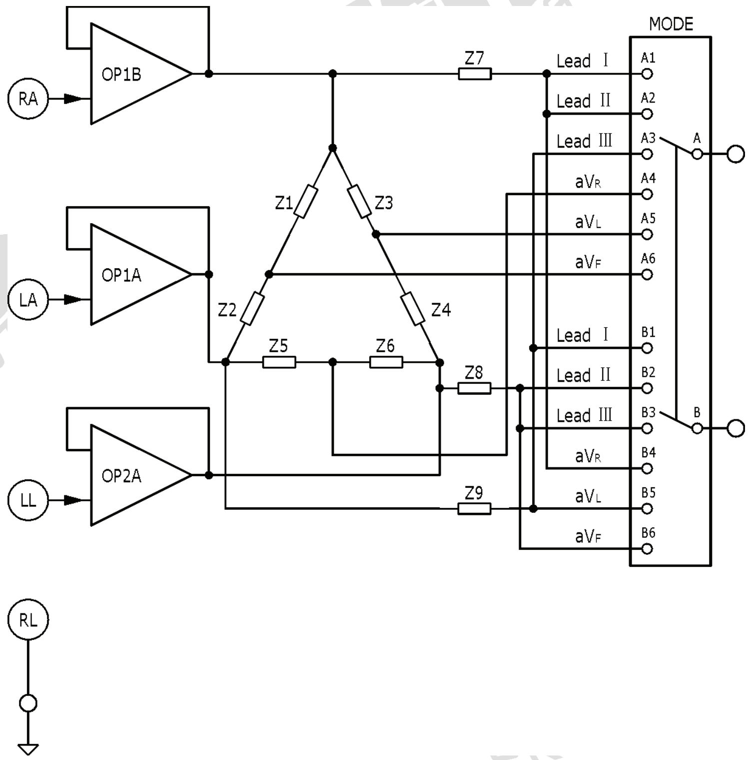


Figure 1.7 Lead selection circuit of ECG.

In the ECG lead selector circuit as shown in Figure 1.7, both OP1 and OP2 are the voltage followers. In order to increase input impedance of the selector circuit, OP1 and OP2 are designed with JFET-input operational amplifiers. Z_1~Z_9 are the equivalent resistors for the triangle network circuit. To the bipolar leads, OP1B~Z_7 and OP1A~Z_9 are for Lead I, OP1B~Z_7 and OP2A~Z_8 for Lead II, OP1A~Z_9 and OP2A~Z_8 for Lead III, and the terminal RL for the right leg as a reference ground. To the unipolar leads, OP1A~Z_5 plus OP2~Z_6 and OP1B~Z_7 are for aV_R, OP1B~Z_3 plus OP2A~Z_4 and OP1A~Z_9 for aV_L, and OP1B~Z_1 plus OP1A~Z_2 and OP2A~Z_8 for aV_F.

3. Preamplifier Circuit

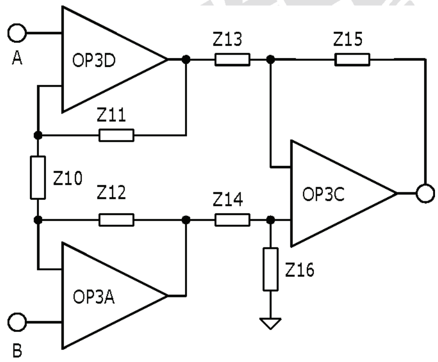


Figure 1.8 Preamplifier circuit.

Figure 1.8 shows the preamplifier circuit which is composed of an instrumentation amplifier with OP3. If $Z_{11} = Z_{12}$, $Z_{13} = Z_{14}$ and $Z_{15}=Z_{16}$, then the voltage gain can be determined by Equation (1.1):

$$Av = \frac{Z_{15}}{Z_{13}}\left(1+\frac{2Z_{11}}{Z_{10}}\right) \tag{1.1}$$

4. Isolation Circuit

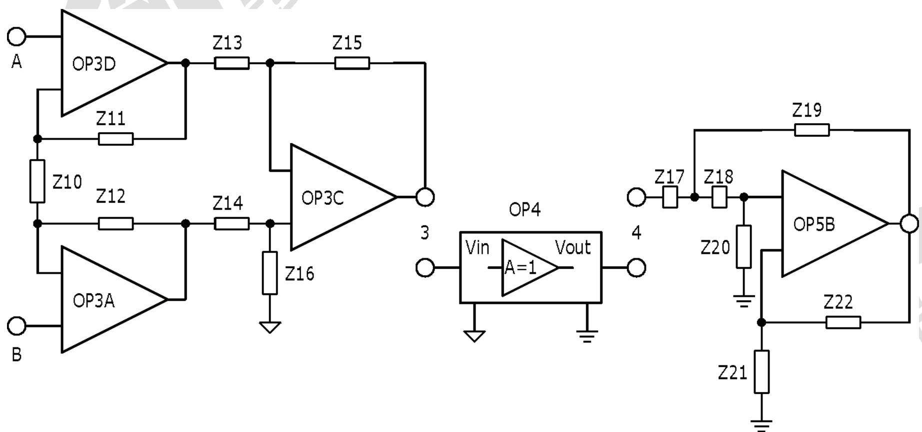
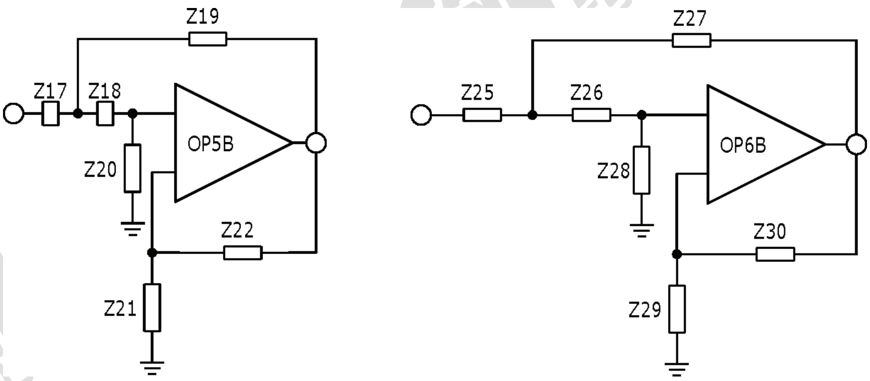


Figure 1.9 Isolation circuit.

As shown in Figure 1.9, the isolation circuit is constructed by OP4. Here, the isolation of the signal is achieved by an optical approach.

5. Band-Pass Filter Circuit



(a) 2nd-order high-pass filter (b) 2nd-order low-pass filter

Figure 1.10 Filter circuits.

In the design of circuits, OP5B is used to create an active 2nd-order high-pass filter, as shown in Figure 1.10(a). The cutoff frequency (f_L) of the filter is set at 0.1 or 1 Hz, and can be calculated using Z_{17}, Z_{18}, Z_{19} and Z_{20}, as expressed in Equation (1.2),

$$f_L = \frac{1}{2\pi\sqrt{Z_{17}Z_{18}Z_{19}Z_{20}}} \quad (1.2)$$

And the passband gain is explained in Equation (1.3).

$$\frac{(Z_{21} + Z_{22})}{Z_{21}} = 1.56 \quad (1.3)$$

OP6B is used to construct an active 2nd-order low-pass filter, as shown in Figure 1.10(b). The cutoff frequency (f_H) of the filter is set at 100 Hz, and can be calculated using Z_{25}, Z_{26}, Z_{27} and Z_{28}, as expressed in Equation (1.4),

$$f_H = \frac{1}{2\pi\sqrt{Z_{25}Z_{26}Z_{27}Z_{28}}} \quad (1.4)$$

And the passband gain is described in Equation (1.5).

$$\frac{(Z_{29} + Z_{30})}{Z_{29}} = 1.56 \quad (1.5)$$

6. Amplifier Circuit

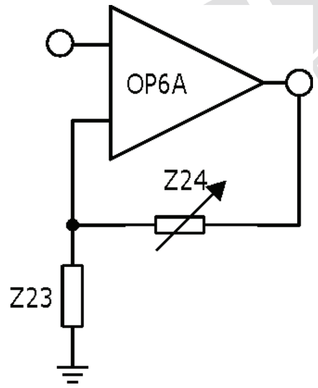


Figure 1.11 Non-inverting amplifier.

Figure 1.11 shows a non-inverting amplifier constructed by OP6A. In the amplifier, Z_{24} is for the gain adjustment, as expressed in Equation (1.6).

$$A_V = \frac{Z_{23} + Z_{24}}{Z_{23}} \tag{1.6}$$

7. Band-Reject Filter Circuit

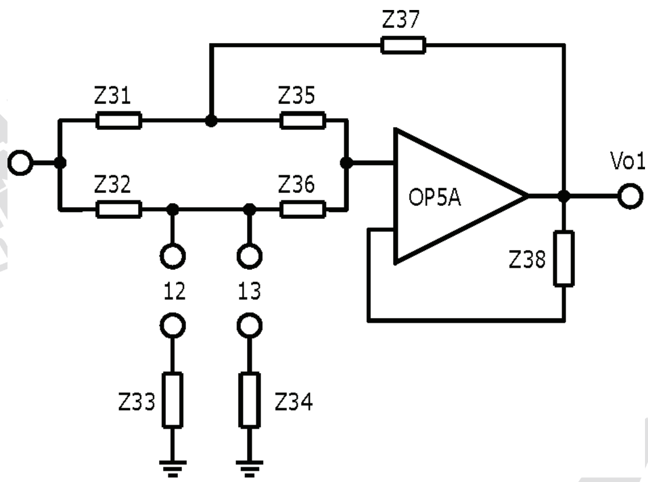


Figure 1.12 Band-reject filter.

Figure 1.12 shows a twin-T band-reject filer composed by RC networks, including OP5A, Z_{31}, Z_{32}, Z_{33} (or Z_{34}), Z_{35}, Z_{36} and Z_{37}. If $Z_{31} = Z_{35}$, $Z_{32} = Z_{36}$, $Z_{33} = 0.5Z_{31}$ (or $Z_{34} = 0.5Z_{31}$) and $Z_{37} = 2Z_{32}$, the center frequency can be calculated by Equation (1.7).

$$f = \frac{1}{2\pi Z_{31} Z_{32}} \tag{1.7}$$

1.3 EQUIPMENT REQUIRED

1. KL-72001 Main Unit
2. KL-75001 Electrocardiogram ECG Module
3. Digital Storage Oscilloscope
4. ECG Simulator
5. KL-79101 5-Conductor Electrode Cable
6. Alcohol Prep Pads
7. Lead Clamps
8. Electrode Leads
9. DB9 Cable
10. BNC Cables
11. RS-232 Cable
12. Connecting Wires
13. 10-mm Bridging Plugs
14. Trimmer

1.4 PROCEDURE

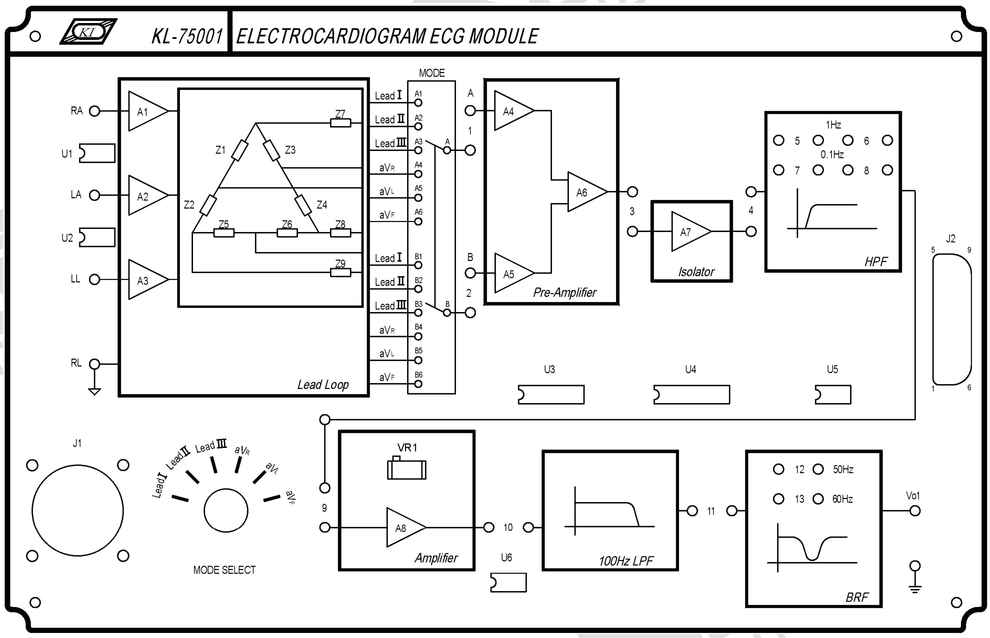


Figure 1.13 Front panel of KL-75001 ECG Module

A. Measuring the Characteristics of High-Pass Filter (HPF)

1. Set KL-75001 ECG 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-75001 ECG Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2
FUNCTION GENERATOR	--	OUTPUT	→	HPF	Input
FUNCTION GENERATOR	--	GND	→	--	Ground (in the bottom right corner)
SCOPE ADAPTOR	--	CH2	→	HPF	Output

2. On KL-75001 ECG Module, insert bridging plugs in positions 5 and 6 in the HPF block. This sets the cutoff frequency of HPF to 1 Hz.
3. Turn power on.
4. Apply a 1 KHz, 1 Vpp sine signal to the HPF input by adjusting the FREQUENCY and AMPLITUDE knobs of the FUNCTION GENERATOR, and observe the CH1 trace on oscilloscope screen.
5. Observe HPF output signal displayed on the CH2 trace and record the amplitude in Table 1.1.
6. Without changing the amplitude of input sine signal, repeat Steps 4 and 5.

Table 1.1 Measured output amplitude of HPF.

(a) Cutoff frequency = 1 Hz

Input Freq	1KHz	10Hz	3Hz	2Hz	1Hz	0.9Hz	0.8Hz	0.5Hz	0.1Hz
HPF Output (Vpp)									

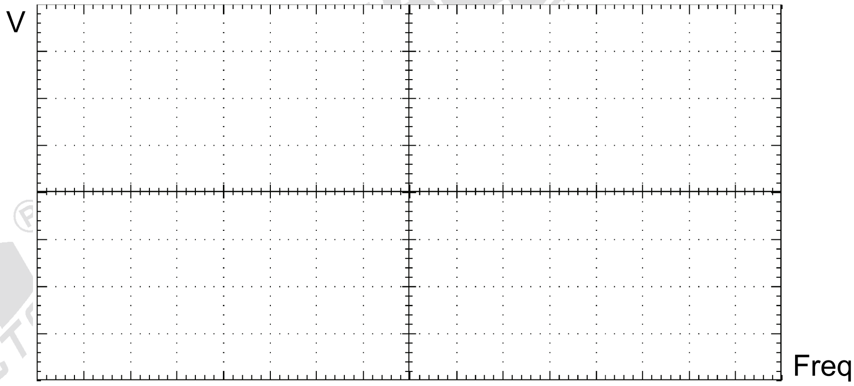
(b) Cutoff frequency = 0.1 Hz

Input Freq	1KHz	100Hz	10Hz	5Hz	3Hz	1Hz	0.3Hz	0.2Hz	0.1Hz
HPF Output (Vpp)									

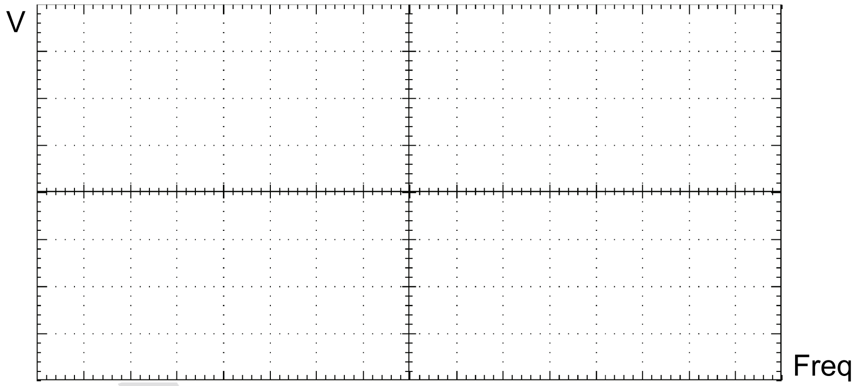
7. According to the recorded data in Table 1.1, plot the characteristic curve of HPF in Table 1.2.

Table 1.2 Characteristic curve of HPF.

(a) Cutoff frequency = 1 Hz



(b) Cutoff frequency = 0.1 Hz



8. Remove bridging plugs from positions 5 and 6 to positions 7 and 8 in HPF block. This changes the cutoff frequency of HPF from 1 Hz to 0.1 Hz.
9. Repeat Steps 4 to 7 for the HPF cutoff frequency of 0.1 Hz.
10. Turn power off and disconnect circuit.

B. Measuring the Characteristics of Amplifier

1. Set KL-75001 ECG Module on KL-72001 Main Unit. Then, complete the following connections:

KL-72001 Main Unit				KL-75001 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-75001 ECG Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2
FUNCTION GENERATOR	--	OUTPUT	→	Amplifier	Input
FUNCTION GENERATOR	--	GND	→	--	Ground (in the bottom right corner)
SCOPE ADAPTOR	--	CH2	→	Amplifier	Output

2. Turn power on.
3. Apply a 100 Hz, 100 mVpp sine signal to the Amplifier input by adjusting the FREQUENCY and AMPLITUDE knobs of the FUNCTION GENERATOR, and observe CH1 trace on oscilloscope screen.
4. Turn the potentiometer VR1 to the minimum counterclockwise position (with clicks at the end). Record the amplitude of the Amplifier output signal displayed on CH2 trace in Table 1.3.
5. Turn the potentiometer VR1 clockwise to obtain a maximum undistorted output signal. Record the output peak-to-peak voltage in Table 1.3.

Table 1.3 Measured output amplitude of Amplifier.

VR1 Position	Amplifier Output Voltage (Vpp)
Minimum counterclockwise	
Maximum undistorted output	

6. Turn power off and disconnect circuit.

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

1. Set KL-75001 ECG 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-75001 ECG Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2
FUNCTION GENERATOR	--	OUTPUT	→	100Hz LPF	Input
FUNCTION GENERATOR	--	GND	→	--	Ground (in the bottom right corner)
SCOPE ADAPTOR	--	CH2	→	100Hz LPF	Output

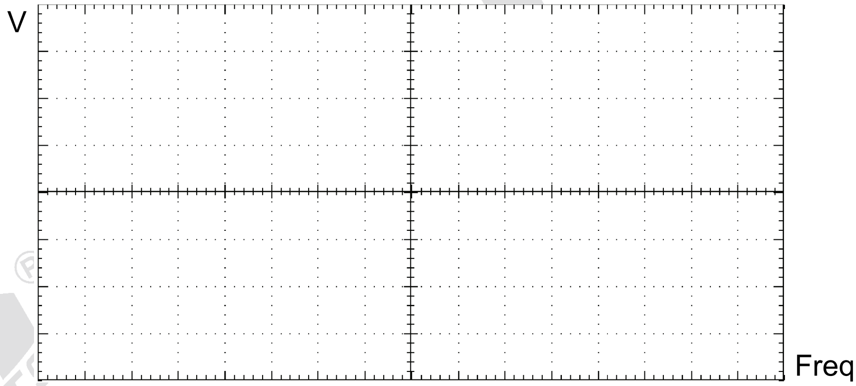
2. Turn power on.
3. Apply a 1 Hz, 1 Vpp sine signal to the LPF input by adjusting the FREQUENCY and AMPLITUDE knobs of the FUNCTION GENERATOR, and observe CH1 trace on oscilloscope screen.
4. Observe the LPF output signal displayed on CH2 trace and record the amplitude in Table 1.4.
5. Without changing the amplitude of input sine signal, repeat Steps 3 and 4 for different frequency values listed in Table 1.4.

Table 1.4 Measured output amplitude of LPF.

Input Freq	1Hz	10Hz	50Hz	80Hz	100Hz	120Hz	150Hz	250Hz	500Hz
LPF Output (Vpp)									

6. According to the recorded data in Table 1.4, plot the characteristic curve of the low-pass filter in Table 1.5.

Table 1.5 Characteristic curve of LPF.



7. Turn power off and disconnect circuit.

D. Measuring the Characteristics of Band-Reject Filter (BRF)

1. Set the KL-75001 ECG Module on the 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-75001 ECG Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2
FUNCTION GENERATOR	--	OUTPUT	→	BRF	Input
FUNCTION GENERATOR	--	GND	→	--	Ground (in the bottom right corner)
SCOPE ADAPTOR	--	CH2	→	BRF	Output (Vo1)

2. Insert a bridging plug into position 12 or 13 to set the center frequency of BRF to 50 or 60 Hz (according to local line frequency).
3. Turn power on.

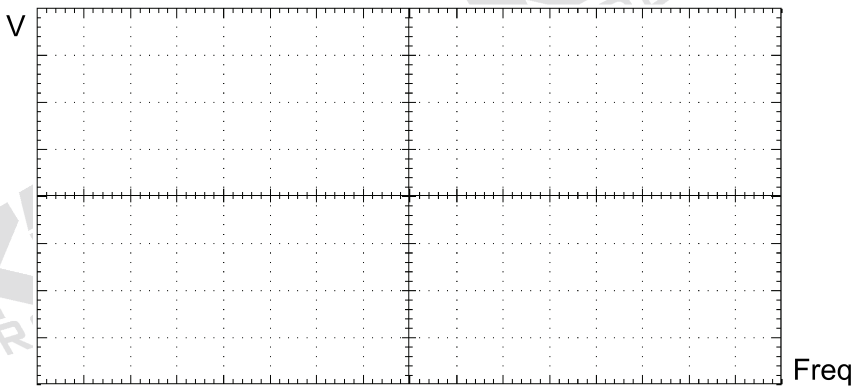
4. Apply a 5 Hz, 1 Vpp sine signal to BRF input by adjusting FREQUENCY and AMPLITUDE of FUNCTION GENERATOR, then observe CH1 trace from the oscilloscope screen.
5. Observe the BRF output signal displayed on CH2 trace and record the amplitude in Table 1.6.
6. Without changing the amplitude of input sine signal, repeat Steps 4 and 5 for different frequency values listed in Table 1.6.

Table 1.6 Measured output amplitude of BRF.

Input Freq	5Hz	10Hz	20Hz	30Hz	50 or 60Hz	100Hz	200Hz	500Hz	1KHz
BRF Output (Vpp)									

7. According to the recorded data in Table 1.6, plot the characteristic curve of the band-reject filter in Table 1.7.

Table 1.7 Characteristic curve of BRF.



8. Turn power off and disconnect circuit.

E. ECG Measurement using ECG Simulator

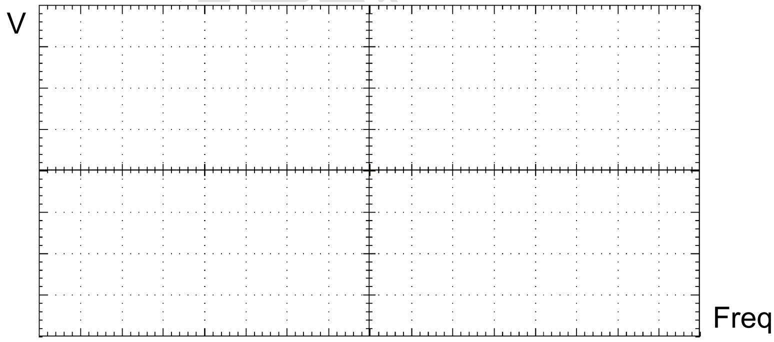
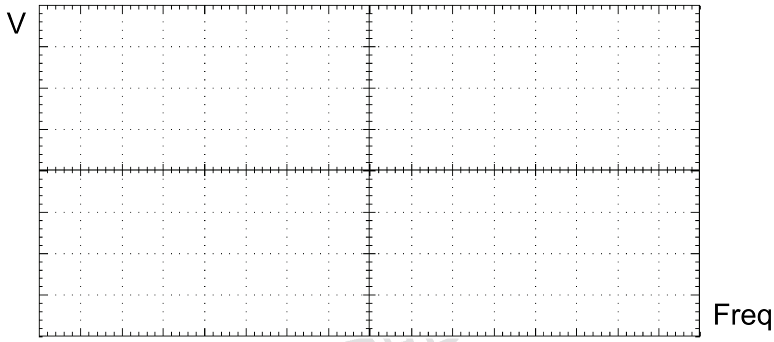
1. Set the KL-75001 ECG Module on the KL-72001 Main Unit. Then, complete the following connections:

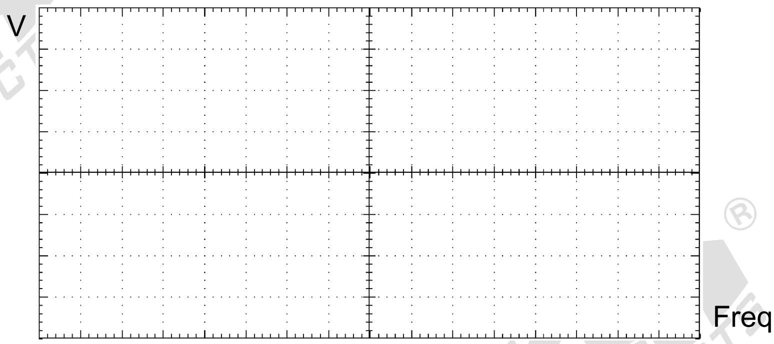
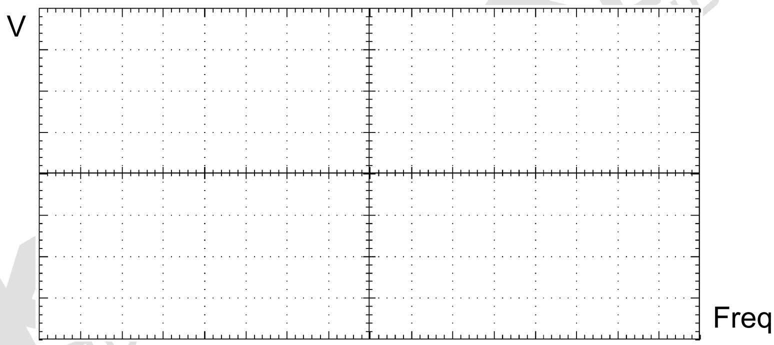
KL-72001 Main Unit				KL-72001 Main Unit		
Section	Area	Terminal	To	Section	Area	Terminal
SCOPE ADAPTOR	-	CH1	→	OUTPUT	ELECTRO-CARDIOGRAM	Vo1
SCOPE ADAPTOR	-	CH1 (BNC)	→	CH1 input of the oscilloscope		

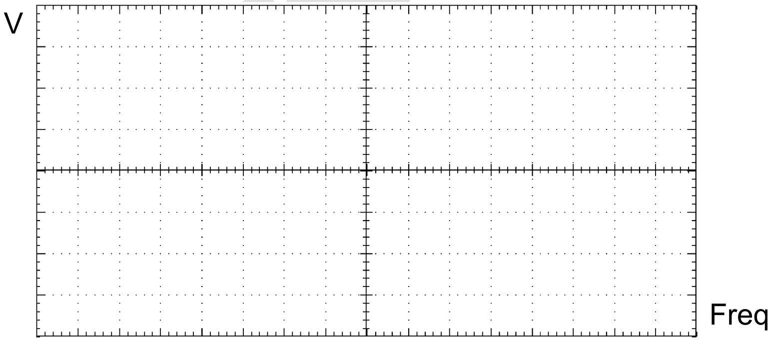
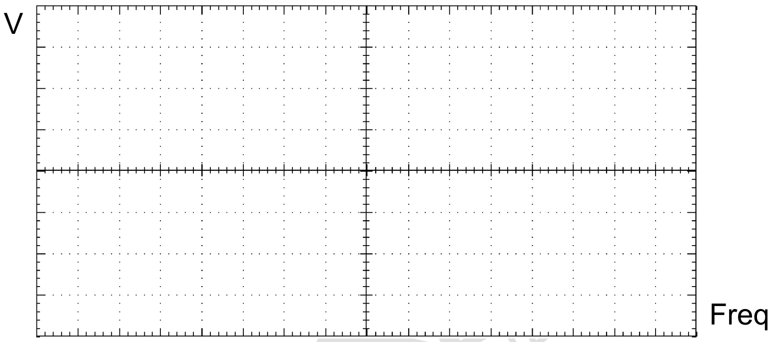
KL-72001 Main Unit				KL-75001 ECG Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2

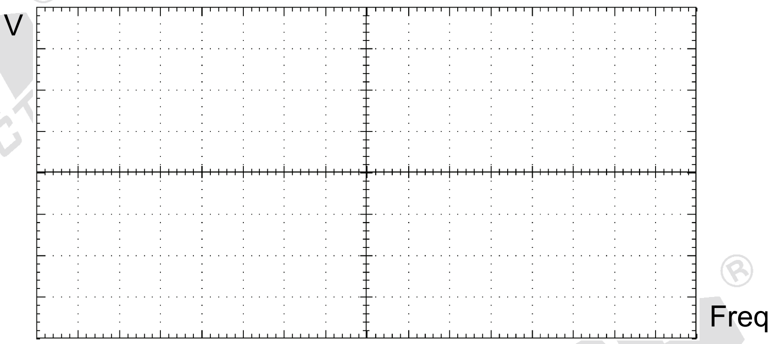
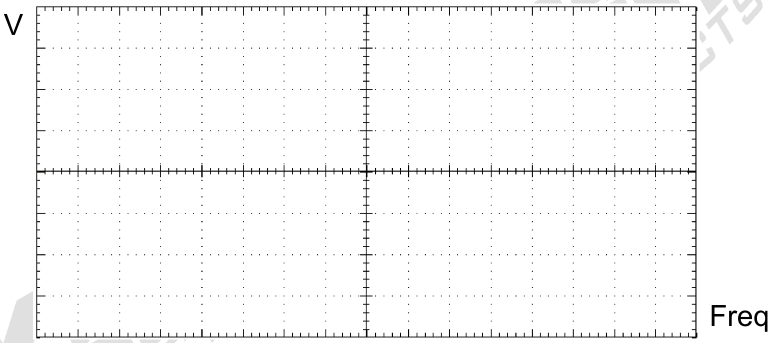
2. On KL-75001 ECG Module, insert bridging plugs in positions 1, 2, 3, 4, 5 and 6 (HPF cutoff frequency=1Hz), 9, 10, 11, and 12 or 13 (BRF center frequency 50 or 60Hz in accordance with local line frequency).
3. Connect the outputs of ECG Simulator to the lead side of KL-79101 5-Conductor Electrode Cable as follows: RA→1, LA→2, LL→3, RL→5. Connect the module side of KL-79101 5-Conductor Electrode Cable to J1 connector on KL-75001 ECG Module. Choose an output of 60 beats per minute. Then, ECG Simulator produces standard ECG signals.
4. Turn power on. Select MODULE:KL-75001 (ECG) item from the LCD display by pressing the SELECT button of KL-72001 Main Unit.
5. Set MODE SELECT switch to the Lead I position. Record the Vo1 waveform displayed on CH1 trace in Table 1.8.
6. Make sure that the Amplifier VR1 has been adjusted for maximum undistorted output amplitude. (Refer to Procedure B)
7. Repeat Step 5 for the signals of Lead II, Lead III, aV_R, aV_L, and aV_F by switching MODE SELECT to the corresponding position and recording the waveform in Table 1.8.
8. Remove bridging plugs from positions 5 and 6 to positions 7 and 8. This changes the cutoff frequency of HPF from 1 Hz to 0.1 Hz.
9. Repeat Steps 5 to 7.
10. Turn power off and disconnect circuit.

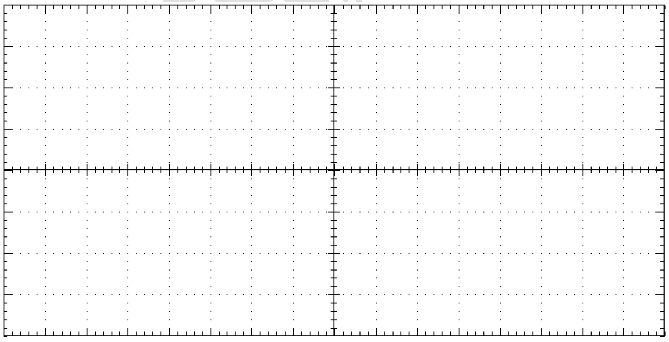
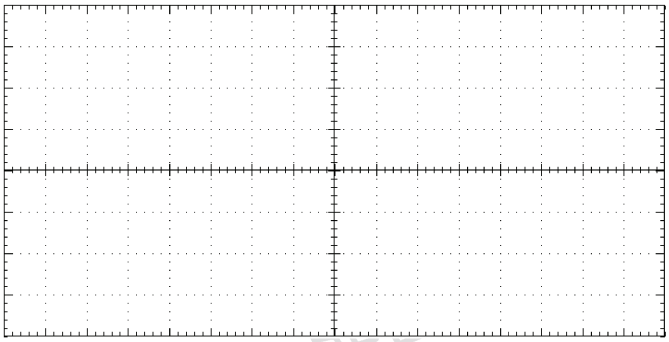
Table 1.8 Measured ECG signals generated by ECG Simulator.

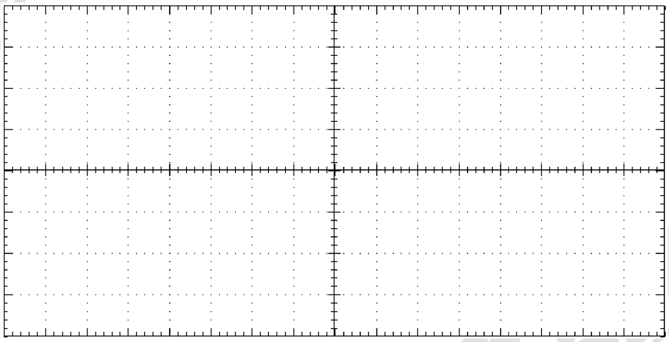
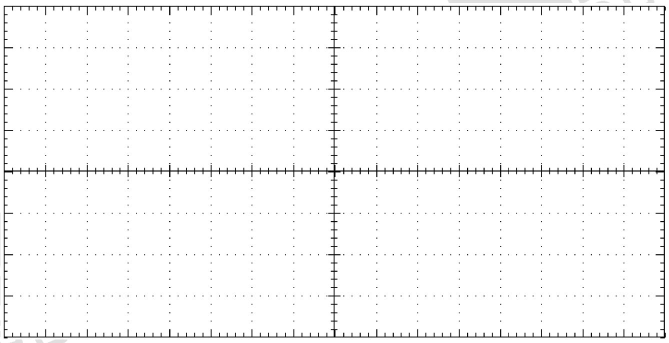
HPF Cutoff Frequency	Lead I Waveform
1 Hz	
0.1 Hz	

HPF Cutoff Frequency	Lead II Waveform
1 Hz	
0.1 Hz	

HPF Cutoff Frequency	Lead III Waveform
1 Hz	
0.1 Hz	

HPF Cutoff Frequency	aV_R Waveform
1 Hz	
0.1 Hz	

HPF Cutoff Frequency	aV_L Waveform
1 Hz	V  Freq
0.1 Hz	V  Freq

HPF Cutoff Frequency	aV_F Waveform
1 Hz	V  Freq
0.1 Hz	V  Freq

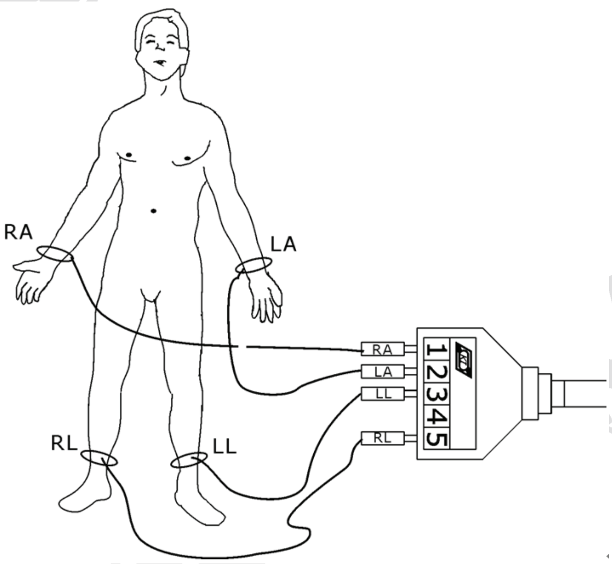
F. Human ECG Measurement using Oscilloscope

1. Set KL-75001 ECG 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
SCOPE ADAPTOR	--	CH1	→	OUTPUT	ELECTRO-CARDIOGRAM	Vo1
SCOPE ADAPTOR	--	CH1 (BNC)	→	CH1 input of the oscilloscope		

KL-72001 Main Unit				KL-75001 ECG Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2

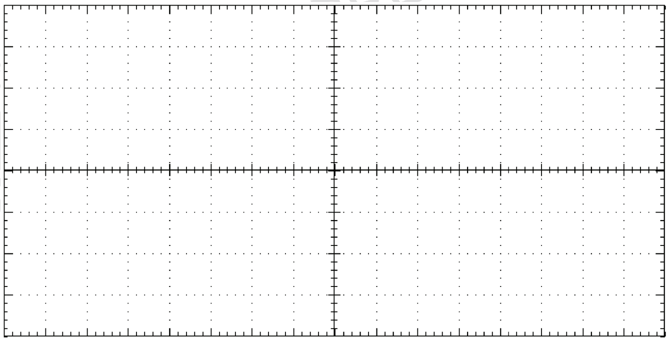
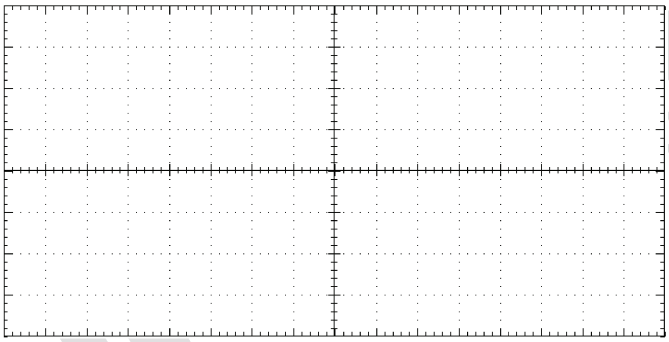
2. Insert bridging plugs in positions 1, 2, 3, 4, 5 and 6 (HPF cutoff frequency=1Hz), 9, 10, 11, and 12 or 13 (BRF center frequency 50 or 60Hz in accordance with local line frequency).
3. Wet the lead clamps and put them on the subject's forearms and lower legs as shown below. It is usually necessary to clean the clamping regions with alcohol prep pads.

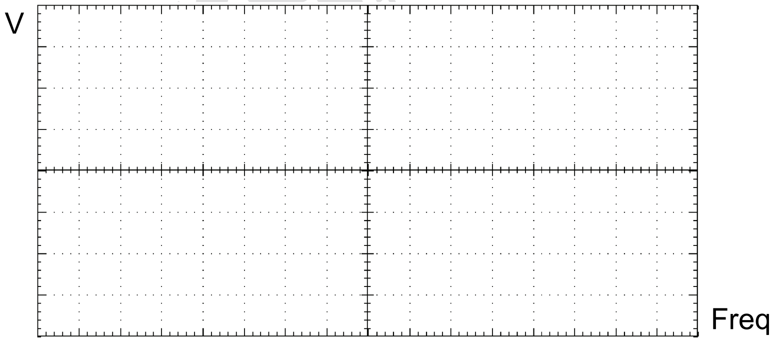
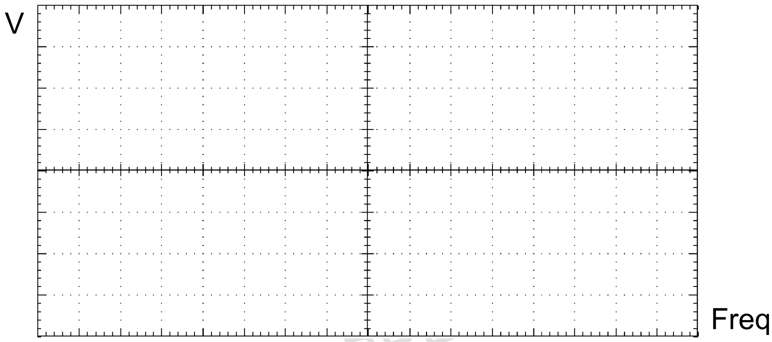


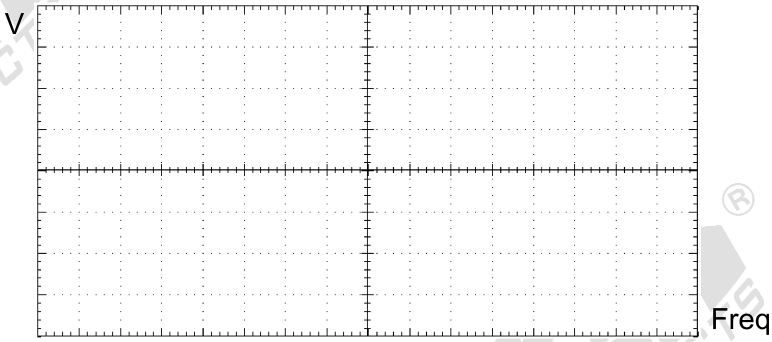
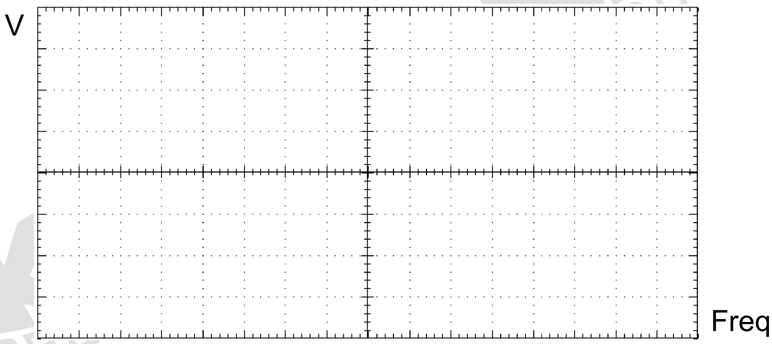
4. Connect the lead clamps to the lead side of KL-79101 5-Conductor Electrode Cable as follows: RA →1, LA→2, LL→3, and RL→5. Connect the module side of KL-79101 5-Conductor Electrode Cable to J1 connector on KL-75001 ECG Module.

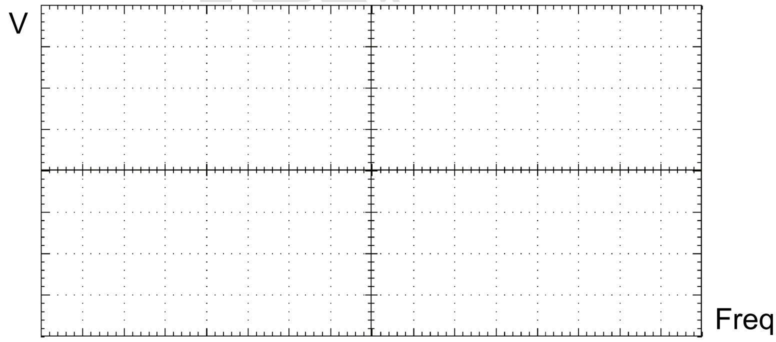
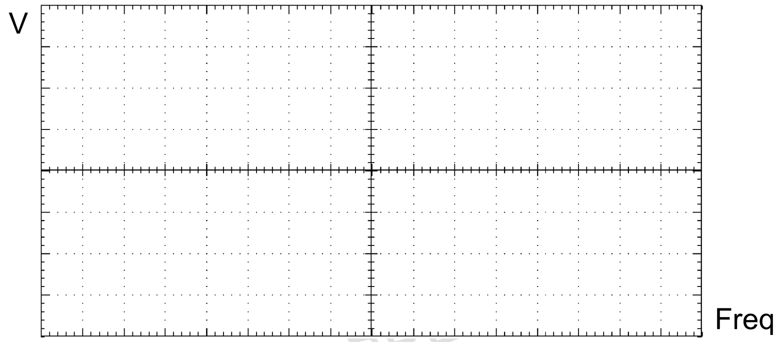
5. Turn power on. Select MODULE:KL-75001 (ECG) item from LCD display by pressing the SELECT button of KL-72001 Main Unit.
6. Set MODE SELECT switch to the Lead I position. Record the Vo1 waveform displayed on CH1 trace in Table 1.9.
7. Make sure that the Amplifier VR1 has been adjusted for maximum undistorted output amplitude. (Refer to Procedure B)
8. Repeat Step 6 for the signals Lead II, Lead III, aV_R, aV_L, and aV_F by switching MODE SELECT to the corresponding position and recording the waveform in Table 1.9.
9. Remove bridging plugs from positions 5 and 6 to positions 7 and 8. This changes the cutoff frequency of HPF from 1 Hz to 0.1 Hz.
10. Repeat Steps 6 to 8.
11. Turn power off and disconnect circuit.

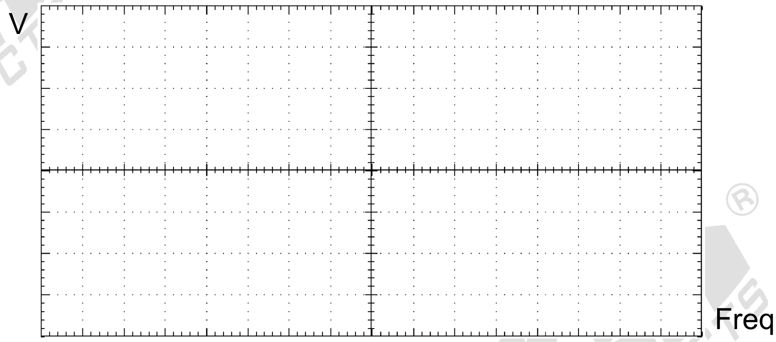
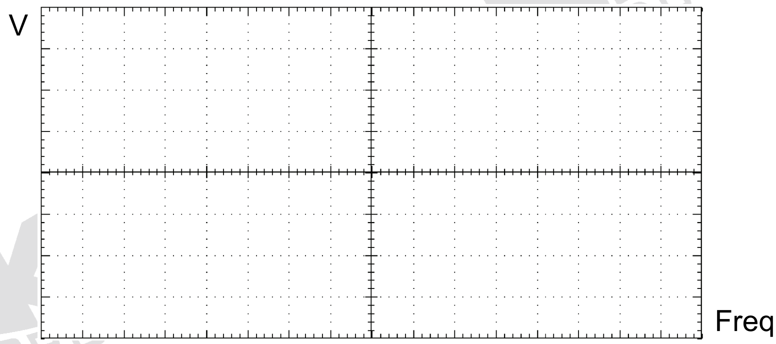
Table 1.9 Measured human ECG signals

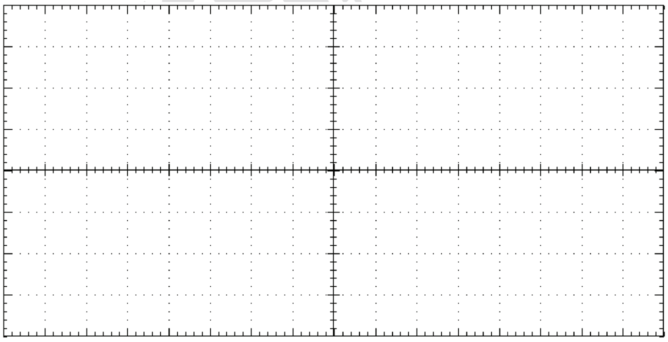
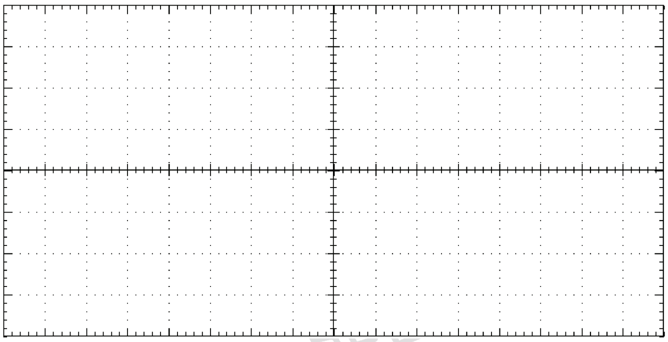
HPF Cutoff Frequency	Lead I Waveform
1 Hz	
0.1 Hz	

HPF Cutoff Frequency	Lead II Waveform
1 Hz	
0.1 Hz	

HPF Cutoff Frequency	Lead III Waveform
1 Hz	
0.1 Hz	

HPF Cutoff Frequency	aV_R Waveform
1 Hz	
0.1 Hz	

HPF Cutoff Frequency	aV_L Waveform
1 Hz	
0.1 Hz	

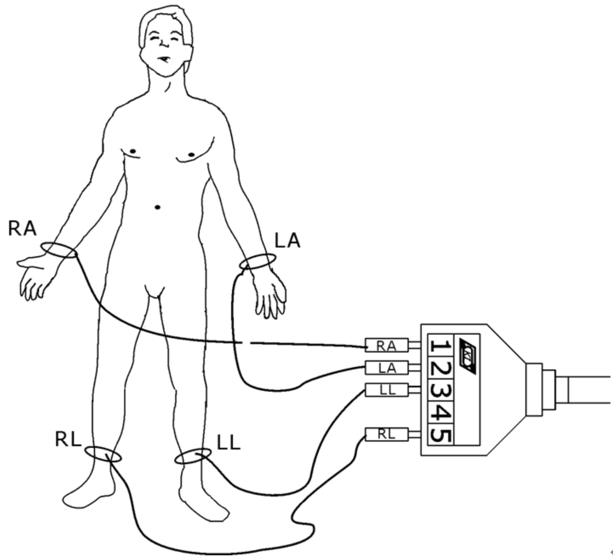
HPF Cutoff Frequency	aV_F Waveform
1 Hz	
0.1 Hz	

G. Human ECG Measurement using KL-720 Software

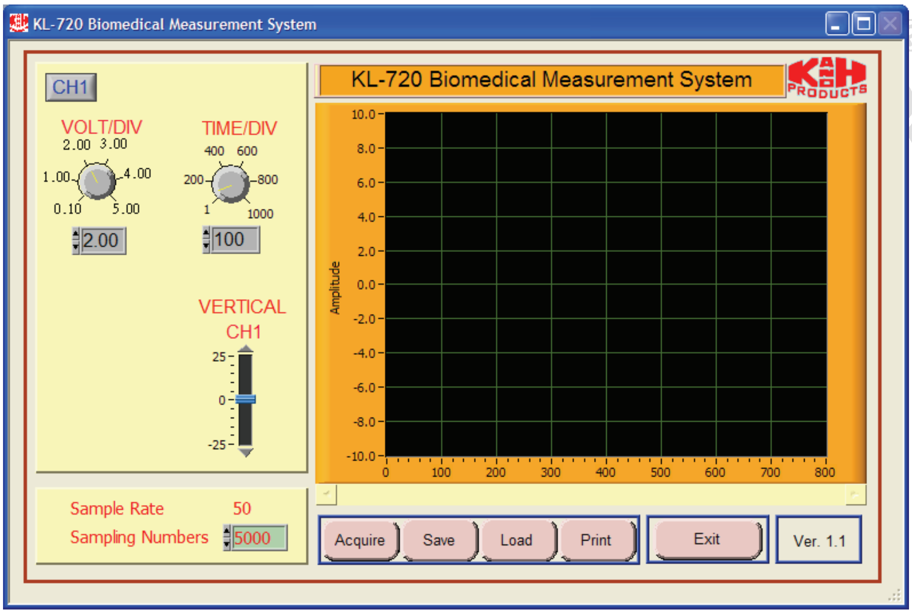
1. Set KL-75001 ECG Module on KL-72001 Main Unit. Complete the following connection:

KL-72001 Main Unit				KL-75001 ECG Module	
Section	Area	Terminal	To	Block	Terminal
MODULE OUTPUT	--	9-Pin	→	--	J2

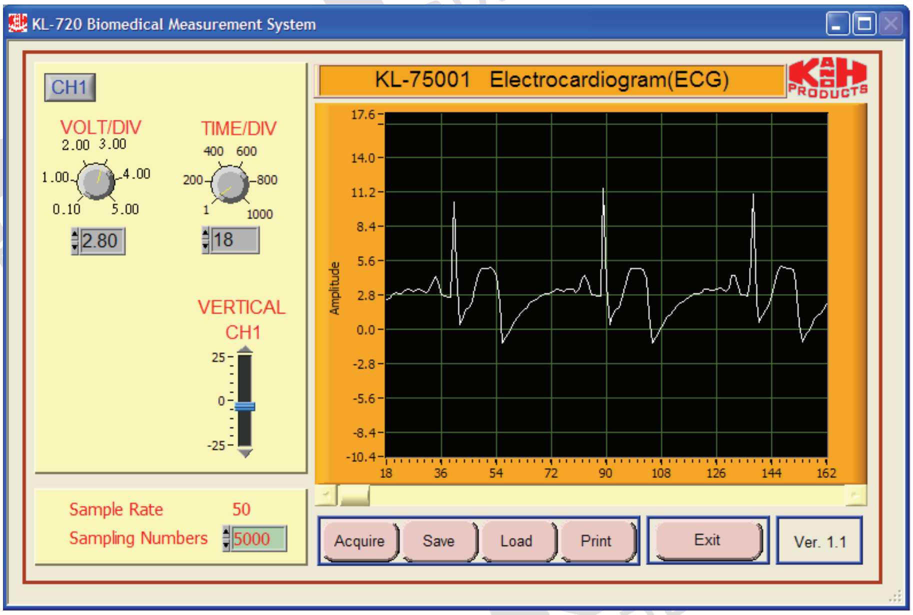
2. Insert bridging plugs in positions 1, 2, 3, 4, 5 and 6 (HPF cutoff frequency=1Hz), 9, 10, 11, and 12 or 13 (BRF center frequency 50 or 60Hz in accordance with local line frequency).
3. Wet the lead clamps and put them on the subject's forearms and lower legs as shown below. It is usually necessary to clean the clamping regions with alcohol prep pads.



4. Connect the lead clamps to the lead side of KL-79101 5-Conductor Electrode Cable as follows: RA →1, LA→2, LL→3, and RL→5. Connect the module side of KL-79101 5-Conductor Electrode Cable to J1 connector on KL-75001 ECG Module.
5. Connect RS-232 OUTPUT connector on KL-72001 Main Unit to RS-232 port on computer using RS-232 cable.
6. Turn power on. Select MODULE:KL-75001 (ECG) item from LCD display by pressing the SELECT button located at bottom-left of KL-72001 Main Unit.
7. Set the MODE SELECT switch to the Lead I position.
8. Boot the computer.
9. Execute KL-720 program, the window appears as shown below.



10. Click the Acquire button. The system begins to acquire the measured data via RS-232 port and shows the waveform (Lead I) on KL-75001 Electrocardiogram (ECG) waveform window as below:



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

11. Adjust the VOLT/DIV and TIME/DIV knobs, so the signal can be read accurately.
12. Save the Lead I signal on disk.
13. Switch MODE SELECT to the corresponding position and repeat Steps 10 through 12 for the Lead II, Lead III, aV_R, aV_L, and aV_F signals.
14. Remove bridging plugs from positions 5 and 6 to positions 7 and 8. This changes the cutoff frequency of HPF from 1 Hz to 0.1 Hz.
15. Repeat Steps 10 through 13.
16. Exit KL-720 Biomedical Measurement System, turn power off and disconnect circuit.