ELECTROMYOGRAM (EMG) MEASUREMENT 2

EXPERIMENT NO 2 ELECTROMYOGRAM (EMG) MEASUREMENT

2.0 PURPOSE

The purpose of this experiment is to help students understand the electrical potential changes during various muscle activities, including conscious control and muscle triggering events. Furthermore, this experiment helps students understand the changes in muscle force produced during isotonic and isometric contractions.

2.1 PHYSIOLOGICAL PRINCIPLES

Skeletal muscles allow us to support our body weight. Skeletal muscles can rotate through joints, and these muscles can be attached to bones directly or via tendons. Two or more skeletal muscle groups trigger each other. That is, when one contracts, the other(s) lengthens. Skeletal muscle consists of multinucleated cells, and the muscle fiber bundles are organized. The action potential propagates from the motor nerve to the muscle fiber innervated by the nerve. This propagation produces a sudden increase in calcium ion concentration within the muscle cell, activating the molecular mechanisms responsible for contraction.

The fundamental element of skeletal muscles is the motor unit, which can be voluntarily activated. A number of motor units constitute a muscle fiber. When a single motor unit (SMU) is activated by stimulation, a potential waveform with an amplitude of 20-2000μV, a discharge frequency of 6-30Hz, and a time interval of 3-1μs is observed. Thus, contraction of muscle fibers produces a higher-amplitude and higher-frequency potential signal, called an electromyogram (EMG). The motor unit regulates the skeletal muscle fiber. Therefore, when a motor neuron is stimulated, all the fibers controlled by the motor unit are activated. This process involves the generation of action potentials and the contraction of muscle fibers. A muscle segment is controlled by perhaps hundreds of motor units. The nervous system attempts to control muscle movements to varying degrees by stimulating various numbers of excitatory motor units. The more motor units stimulated, the more muscle fibers are activated. Therefore, the number of motor units stimulated determines the extent of muscle movement. Similar to an ECG, an EMG can be measured and recorded using electrodes on the body surface. Voluntary muscle movement often causes large variations in the EMG signal. The EMG signal contains various irregular waveforms that differ slightly from the ECG signal.

When a muscle is in isotonic contraction, it must maintain a constant tone and consume energy. Simultaneously, muscle length changes. As muscle length changes, the load on the muscle and the distance moved through the muscle effectively create work. When a muscle is in isometric contraction, the muscle length shortens slightly or not at all, but a significant tone is produced. While isometric contraction does not cause body movement, it certainly consumes energy, and ultimately, the energy is transferred into heat or tone. Since no movement occurs in isometric muscle contraction, no actual work is performed at the end of the process.

2.2 CIRCUIT DESCRIPTIONS

1. EMG Measurement Circuit Block Diagram

As explained in the previous section, EMG signals consist of the variable potential generated by activated muscle fibers. To reduce interference from other muscle fibers, it is important in the experimental design to measure the EMG signal emitted from only one muscle fiber as a result of a specific movement. This experiment examines the biceps, the skeletal muscle that controls elbow movement of the upper arm. One electrode is placed on the biceps muscle to measure the EMG signal; the other electrode is used for the reference potential and is placed on the opposite hand, which is not being tested. When designing a circuit for EMG measurement, an isolation system must be installed to prevent electrical shock during use due to leakage from the power supply or measuring devices. Figure 2.1 shows the block diagram of the circuit used to measure EMG signals. A surface electrode is placed on the upper arm to detect very small potential changes in the biceps muscle. An instrumentation amplifier with a gain of 100 was used as a preamplifier to detect the unipolar component of the EMG signals. A JFET operational amplifier is used to match the impedance between the skin electrode and the circuit.

An isolation circuit is used to isolate the signal from the power supply line, which can be implemented by optical or voltage conversion. The band-pass filter has a bandwidth of 90~1000Hz, and the gain amplifier amplifies the signal from the filter by a factor of 10. The amplified EMG signal can be sent to an oscilloscope for display. The amplified EMG signal passes through a half-wave rectifier, and the output of the integrator circuit is used to calculate the amplitude of the force generated by the muscle.

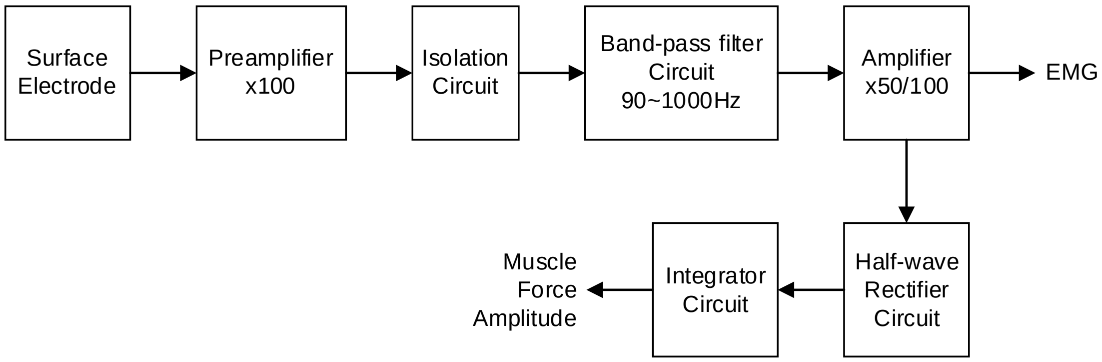


Figure 2.1 EMG Measurment block diagram

2. Surface Electrodes

The human body consists of numerous fluid cells containing different electrolyte ions. The intracellular fluid contains potassium, sodium, and chloride ions. Action potentials arise from changes in ion concentrations. The electrode used to detect an action potential generates an interfacial potential. When a metal electrode is immersed in an electrolyte solution, two types of chemical reactions occur. The first is an oxidation reaction, in which metal atoms release electrons and become metal ions. The second is a reduction reaction, in which electrons and metal ions combine to form metal atoms. At the interface between the metal and the electrolyte liquid, positively and negatively charged ions move in opposite directions, thus forming two ion layers with opposite electric charges. The resulting ion potential is called the interface potential. Therefore, metals with low interface potential should be selected as electrodes for measuring biological signals. This way, excessive interface potentials can be avoided during measurement. The general range of biological signals is 50μV~1mV, and the interface potential of metals is 0.1V~1V. In addition, the interface potentials of the electrodes change over time. The most readily available electrode material is silver-silver chloride (Ag/AgCl). These electrodes are made primarily of silver, with a thin layer of AgCl where the electrodes contact the electrolyte solution. AgCl provides unidirectional exchange of silver (Ag+) and chlorine (Cl) ions, without forming a compound layer and with a very low interfacial potential. The gel-surface electrodes shown in Figure 2.2 are used in the KL-700. The electrode has a silver-silver chloride electrode at the top, a hollow chamber filled with gel in the center, and a rubber disc with an adhesive surface at the bottom for attaching the electrode to the skin.

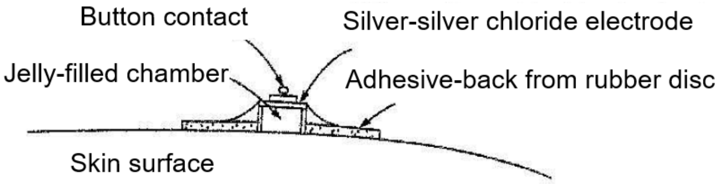


Figure 2.2 Surface electrode

3. Preamplifier Circuit

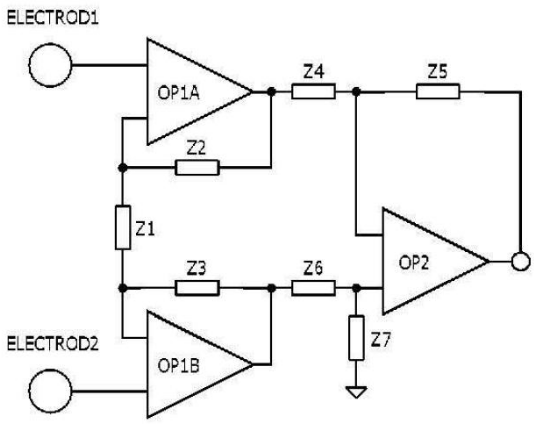


Figure 2.3 Preamplifier circuit

Figure 2.3 shows a preamplifier circuit consisting of an instrumentation amplifier consisting of OP1 and OP2. When Z2=Z3, Z4=Z6, and Z5=Z7, the gain can be calculated as in Equation 2.1:

$$A_v = \frac{Z_5}{Z_4}\left(1 + \frac{2Z_2}{Z_1}\right) \tag{2.1}$$

4. Isolation Circuit

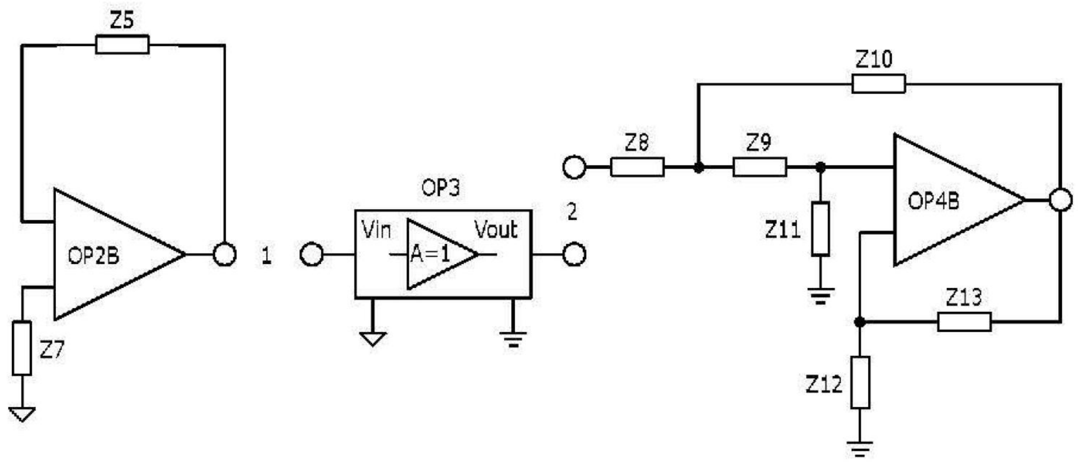


Figure 2.4 Isolation circuit

Figure 2.4 shows the isolation circuit consisting of OP3. Here, signal isolation is achieved through optical method.

5. Bandpass Filter Circuit

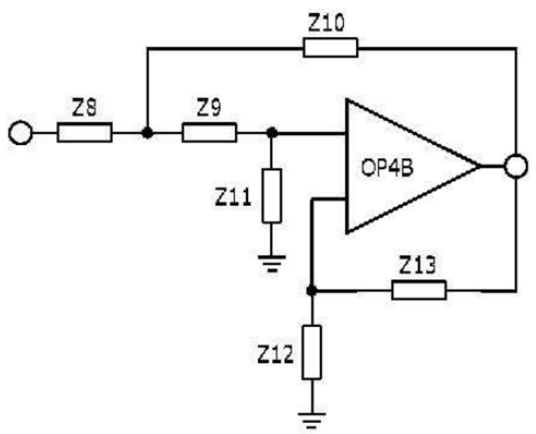


Figure 2.5 Second-order low-pass filter

In the EMG measurement circuit design, OP4B is used to form an active second-order low-pass filter, as shown in Figure 2.5. The corner frequency (fL) of the filter is set to 1000 Hz, and this value can be calculated using Z8, Z9, Z10, and Z11, as shown in Equation 2.2.

$$f_L = \frac{1}{2\pi\sqrt{Z_8 Z_9 Z_{10} Z_{11}}} \tag{2.2}$$

The pole design is described in Equation 2.3,

$$\frac{(Z_{12}+Z_{13})}{Z_{12}} = 1.51 \tag{2.3}$$

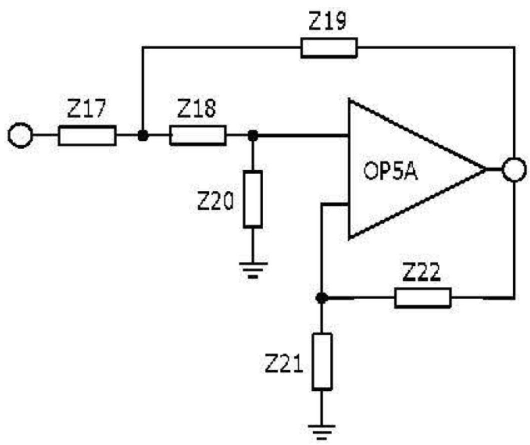


Figure 2.6 Second-order high-pass filter

An active second-order high-pass filter implemented using OP5Z is shown in Figure 2.6. The corner frequency (fH) of the filter is set to 90 Hz, and this value can be calculated using Z17, Z18, Z19, and Z20 as shown in Equation 2.4.

$$f_H = \frac{1}{2\pi\sqrt{Z_{17} Z_{18} Z_{19} Z_{20}}} \tag{2.4}$$

The pole design is described in Equation 2.5,

$$\frac{(Z_{21}+Z_{22})}{Z_{21}} = 1.56 \tag{2.5}$$

This high-pass filter is used to eliminate the drift effect created by the low-frequency components of the noise, so that the signals in the next circuit stage become more uniform.

6. Gain Amplifier

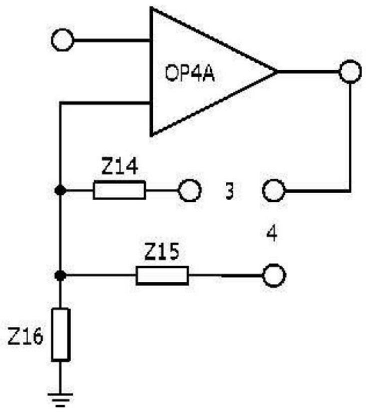


Figure 2.7 Gain amplifier circuit

Figure 2.7 shows a non-inverting amplifier implemented using OP4A. In the amplifier, Z14 or Z15 is used for gain adjustment. The gain expression is given in Equation 2.6:

$$A_v = \frac{(Z_{16}+Z_{14})}{Z_{16}} \;\&\; A_v = \frac{(Z_{16}+Z_{15})}{Z_{16}} \tag{2.6}$$

7. Precision Half-Wave Rectifier Circuit

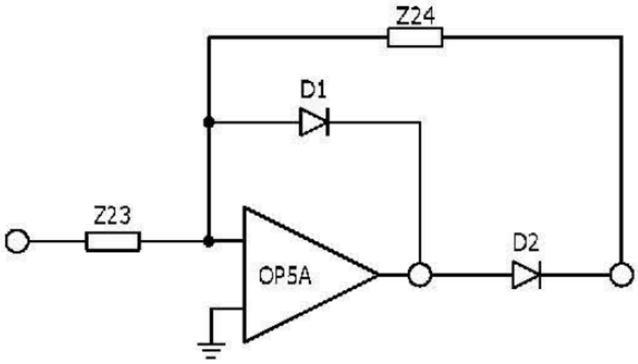


Figure 2.8 Precision half-wave rectifier circuit

To measure muscle strength, the signal from the gain amplifier must be rectified and integrated. Figure 2.8 shows a precision half-wave rectifier circuit implemented using OP5A, D1, D2, Z23, and Z24. The rectifier's function is different from other two-diode rectifiers. In a diode rectifier, there is a voltage drop of 0.7V across each diode. In other words, when the diodes are biased in the forward direction, the rectified signal is 0.7V less than the original signal. In contrast, a precision half-wave rectifier uses the internal current of the op-amp component to prevent conduction between the diode's ON and OFF states. Thus, in this rectifier circuit, no voltage drop occurs during conduction.

8. Integrator Circuit

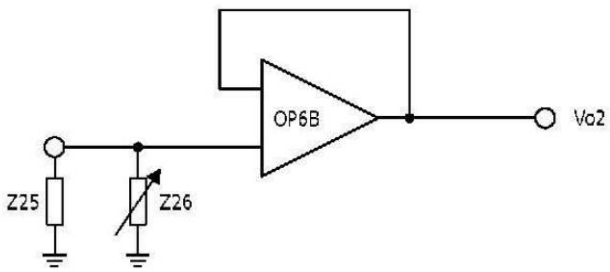


Figure 2.9 Integrator circuit

Figure 2.9 shows an integrator circuit implemented using OP6B, Z25, and Z26. Here, OP6B operates as a voltage follower and its function is to prevent discharge. Additionally, the integrator effect can be modified by adjusting the resistor Z26.

2.3 REQUIRED EQUIPMENTS

1. KL-71001 Main Controller
2. KL-73002 Experiment Module
3. Surface Electrodes for Measurements
4. Digital Storage Oscilloscope (extra hardware)
5. Swab
6. Weight (5 kg)
7. 10mm Connectors
8. Electrode Cable
9. HUB
10. D-sub 9-9 Cable

2.4 EXPERIMENT PROCEDURE

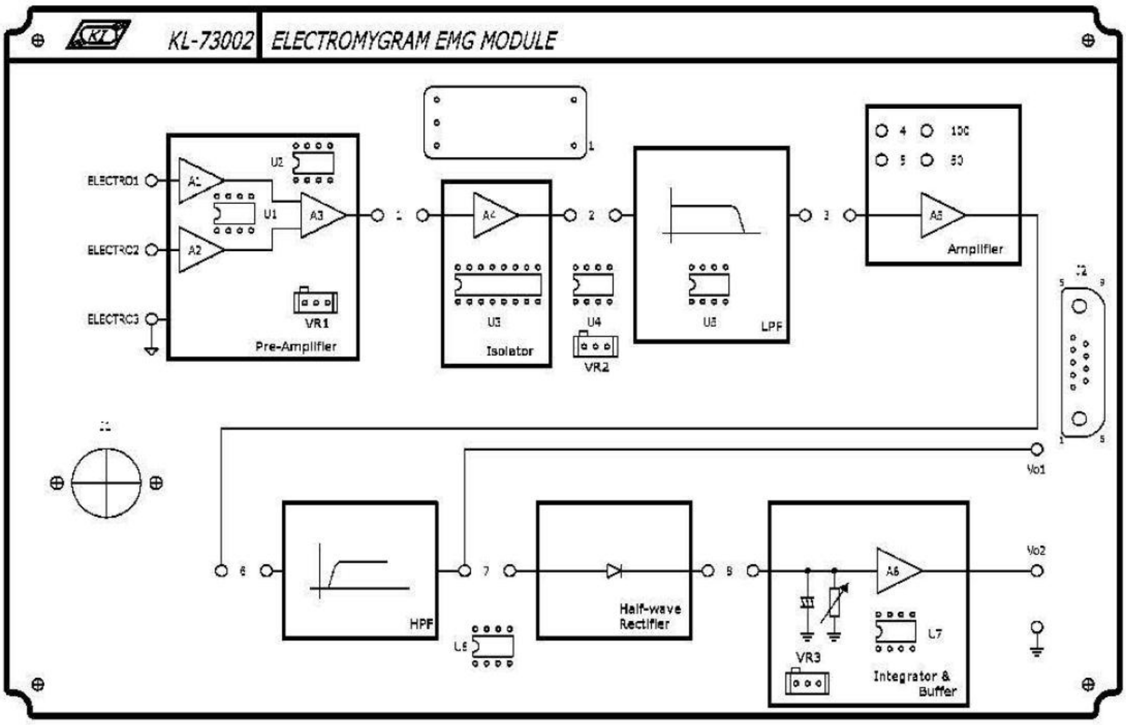


Figure 2.10 EMG measurement module

1. Low-Pass Filter Characteristics 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 2 of the KL-73002, and the GND terminal of the KL-71001 to the right-side ground terminal of the KL-73002. 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 LPF 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 2.1 in the Results section.

(4) Referring to the results in Table 2.1, plot the characteristic curve of the low-pass filter to Table 2.2 at Results section

2. Amplifier 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 '3' of the KL-73002, and the GND terminal of the KL-71001 to the right-side ground terminal of the KL-73002. Use the jumper plugs to connect the terminals marked 5. Connect the function generator output to the CH1 channel of the oscilloscope, and the "Amplifier" 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 2.3 at Results section.

(4) Remove the connection plug from the terminal marked 5 and insert into the terminal marked 4.

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

3. High-Pass Filter Characteristics 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 '6' of the KL-73002, and the GND terminal of the KL-71001 to the right ground terminal of the KL-73002. 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 2.4 at Results section.

(4) Referring to the results in Table 2.4, plot the characteristic curve of the high-pass filter to Table 2.5 at Results section.

4. Half-Wave Rectifier Characteristics 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 '7' of the KL-73002, and the GND terminal of the KL-71001 to the right-side ground terminal of the KL-73002. Set the sinusoidal frequency of the function generator to 1kHz and its amplitude to 1Vpp. Connect the function generator output to the CH1 channel of the oscilloscope, and the Half Wave Rectifier output terminal to the CH2 channel of the oscilloscope.

(3) Plot the input and output waveforms to Table 2.6 at Results section.

5. Integrator Circuit Characteristics 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 the terminal '7' of the KL-73002, and the GND terminal of the KL-71001 to the right-side ground terminal of the KL-73002. Use the connector plugs to connect the points marked as 8. Connect the function generator output to the CH1 channel of the oscilloscope and the Vo2

output terminal to the CH2 channel of the oscilloscope.

(3) Set the output amplitude of the function generator to 1Vpp. Adjust the frequency to various values and record the observed results to Table 2.7 at Results section.

(4) Set the function generator frequency to 500 Hz. Adjust the output amplitude to various values and record the observed results to Table 2.8 at Results section.

6. EMG Experiment (Signals should be measured using digital storage oscilloscope)

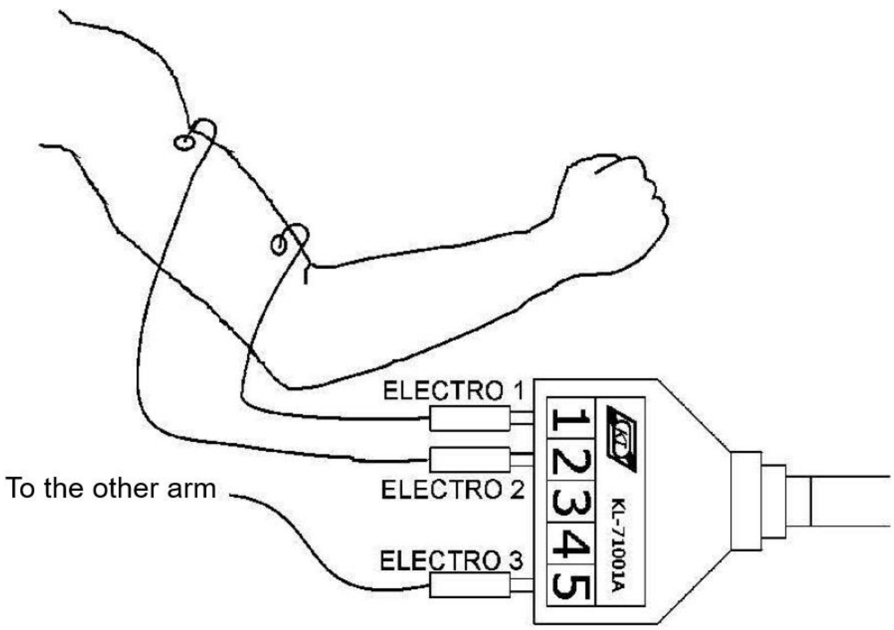


Figure 2.10 Electrode positions

(1) The person being tested on must first remove any watch or other ornaments from his/her wrist.

(2) Use a swab to clean the areas where the electrodes will be placed to reduce resistance. Place the electrodes on the upper right arm, 6-8 cm apart from each. The line connecting the two electrodes should be parallel to the arm axis.

(3) Mark any location on the left arm with a marker. This point will be used for the reference electrode.

**** According to personal habits in force generation**

(4) Connect the J1 connector of the KL-73002 to the hub; connect the J2 connector to the MODULE OUTPUT terminal of the KL-71001. Use the connectors to connect the terminals marked 1, 2, 3, 4, 6, 7, and 8. Connect the Vo1 output terminal to the CH1 channel of the oscilloscope, and the Vo2 output terminal to the CH2 channel of the oscilloscope.

(5) Use the INPUT SELECT button of the KL-71001 to select the KL-73002 module (see the LCD screen). The IN1, IN2, and IN5 LEDs on the KL-71001 front panel will light. This indicates that input signals should be connected to these input terminals.

(6) Set the oscilloscope input coupling to DC. Set the CH1 and CH2 voltage scales to 5V/div, and the time scale to 500ms/div.

Note:

A. Errors that may occur during waveform recording may be due to various reasons: (a) During isotonic contraction, the electrode should be wrapped with a bandage to prevent it from shifting due to arm movement. (b) The impedance between the body skin and the electrode may be high. Clean the area thoroughly or apply gel to reduce the resistance.

B. It is not easy to distinguish momentarily fluctuations caused by electrode movement from the EMG signal. Therefore, an isometric test should be performed first, followed by an isotonic test.

C. In the muscle fatigue experiment, the muscle must be clearly sore to see a fatigue-related change in the EMG signal.

D. If the signal noise is too high, adjust VR1 and VR2 to appropriate positions.

7. Isometric Contraction Experiment

(1) The subject should assume a comfortable sitting position with the right arm relaxed (fingers pointing down) and the palm facing the face.

(2) Observe whether the CH2 signal is stable and whether the signal noise level is below 100mVpp. If the values are undesirable, there is high impedance between the electrode and the skin. Therefore, the surface electrodes should be repositioned. It is more appropriate to reposition the reference electrode first. Minimize the signal noise by adjusting VR1

and VR2.

(3) Consciously contract the biceps muscle and observe whether the waveform amplitude on the oscilloscope increases. Release the biceps muscle and observe whether the waveform appears on the oscilloscope; the signal noise should be less than 10mVpp. Record the waveform in the location indicated in the Results section.

(4) Hold the 5kg weight or the edge of a table.

(5) After recording the oscilloscope screen for 2 seconds, lift the weight for 2 seconds, with the elbow at 90 degrees and the arm at 45 degrees. Release the weight and rest for 2 seconds. Record the waveform to Table 2.10 at Results section.

8. Isotonic Contraction Experiment

(1) The subject should assume a comfortable sitting position with the right arm relaxed (fingers pointing down) and the palm facing the face.

(2) Hold the 5kg weight or the edge of a table.

(3) After recording the oscilloscope image for 2 seconds, lift and lower the weight within 1 second. Repeat this movement 3 times and rest for 2 seconds. Record the waveform to Table 2.11 at Results section.

9. Muscle Fatigue Experiment

(1) The subject should assume a comfortable sitting position with the right arm relaxed (fingers pointing down) and the palm facing the face.

(2) Hold the 5kg weight or the edge of a table.

(3) Lift the weight and hold it until there is a significant change in the EMG signals. Record the waveform to Table 2.12 at Results section.

10. Real EMG Experiment (experimented on the human body)

(EMG signals are recorded to the computer via RS232 interface)

(1) Place the electrodes on the arm according to Figure 2.10.

(2) The person being tested on must first remove any watch or other ornaments from his/her wrist.

(3) Use a swab to clean the areas where the electrodes will be placed to reduce resistance. Place the electrodes on the upper right arm, 6-8 cm apart from each. The line connecting the two electrodes should be parallel to the arm axis.

(4) Mark any location on the left arm with a marker. This point will be used for the reference electrode.

**** According to personal habits in force generation**

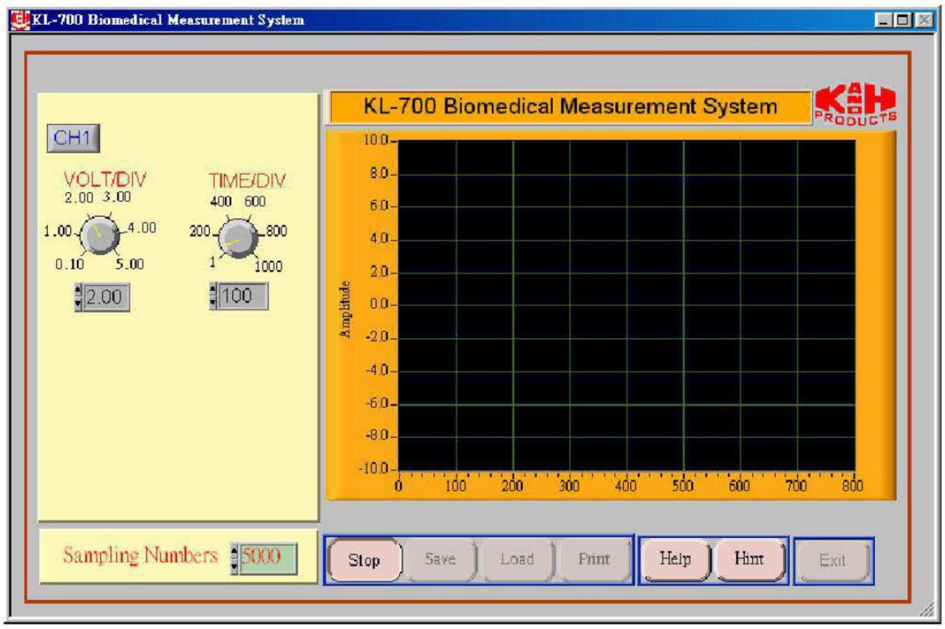
(5) Connect the J1 connector of the KL-73002 to the hub; connect the J2 connector to the MODULE OUTPUT terminal of the KL-71001. Use the connectors to connect the terminals marked 1, 2, 3, 4, 6, 7, and 8. Connect the Vo1 output terminal to the CH1 channel of the oscilloscope, and the Vo2 output terminal to the CH2 channel of the oscilloscope.

(6) Use the INPUT SELECT button of the KL-71001 to select the KL-73002 module (see the LCD screen). The IN1, IN2, and IN5 LEDs on the KL-71001 front panel will light. This indicates that input signals should be connected to these input terminals.

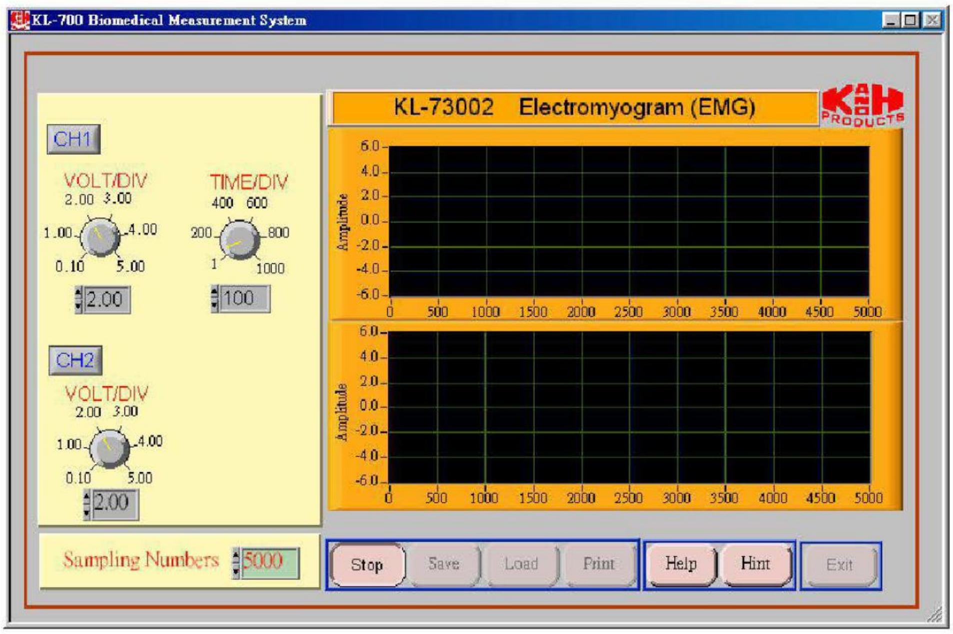
(7) Connect the 9-pin RS232 cable to COM Port on the computer.

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

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



(10) Press the 'Acqu' button to display the image below. The KL-73002 EMG recording screem will appear.



(11) Adjust the VOL T/DIV and TIME/DIV settings so that the signal waveforms appear in the center of the screen. Repeat steps 7, 8 and 9, and save the signal waveforms to the computer.

2.5 RESULTS

Table 2.1 Low-Pass Filter Characteristics Experiment

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

Table 2.2 Low-Pass Filter Characteristic Curve

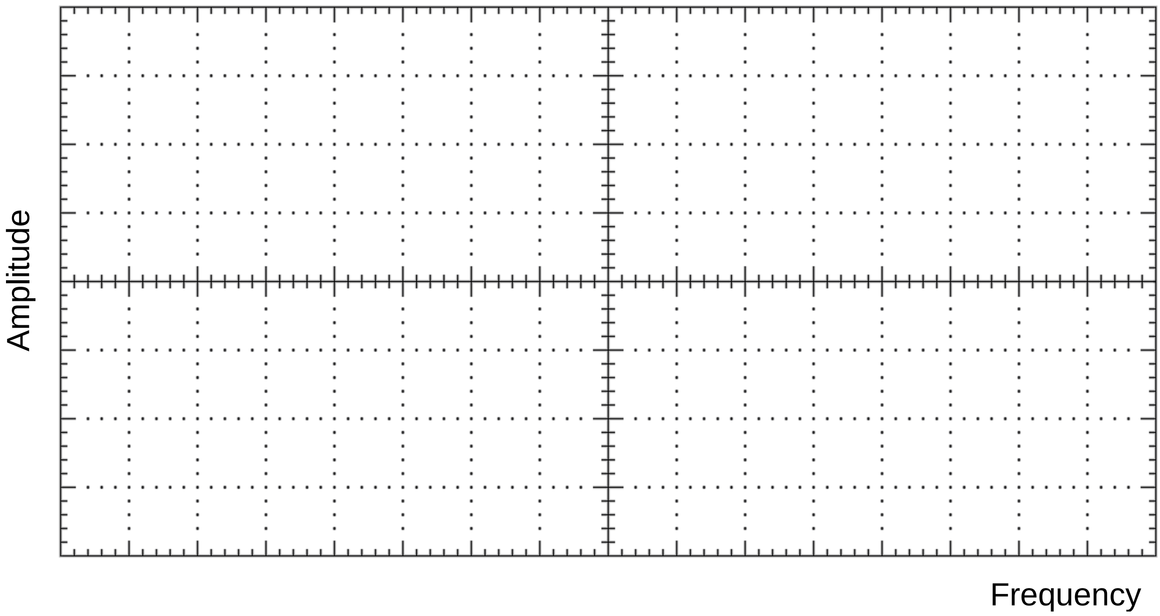


Table 2.3 Amplifier Experiment

Amplifier Gain	Amplifier Output
5➔x50	
4➔ x100	

Table 2.4 High-Pass Filter Characteristics Experiment

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

Table 2.5 High-Pass Filter Characteristic Curve

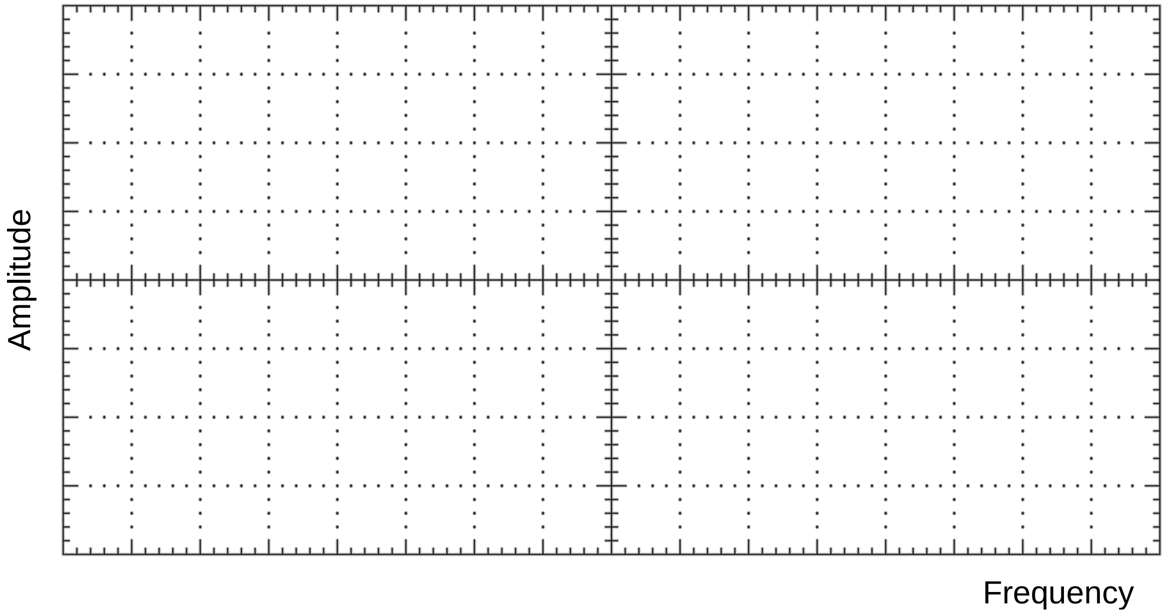


Table 2.6 Half-Wave Rectifier Characteristics Experiment

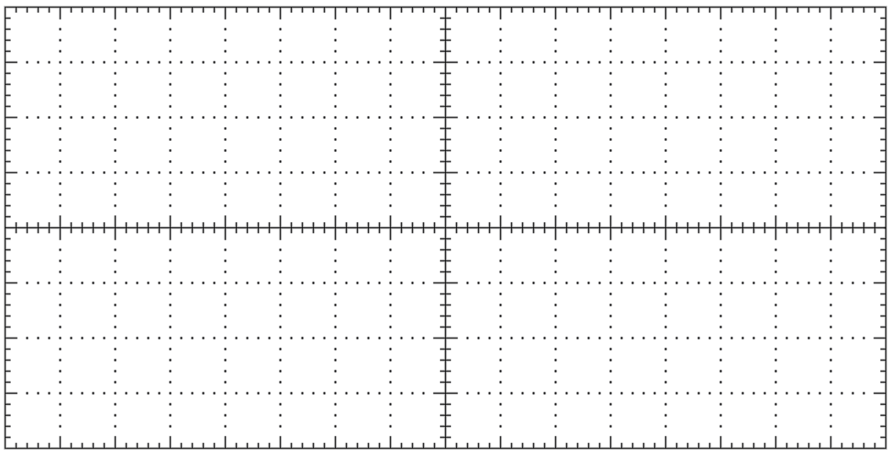
	Waveform
CH1 Input CH2 Output	

Table 2.7 Integrator Characteristics Experiment

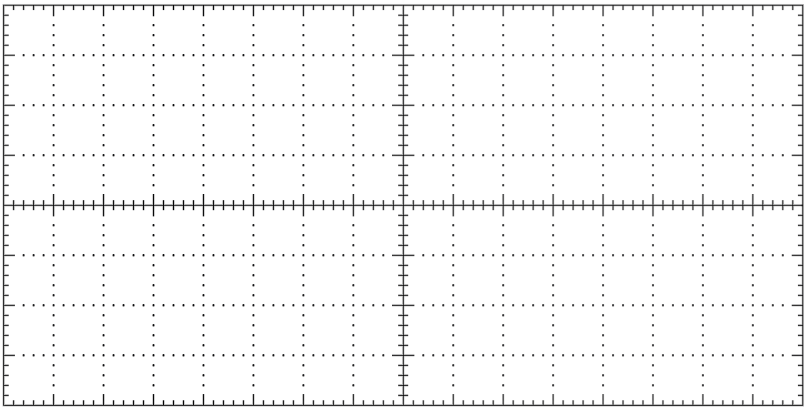
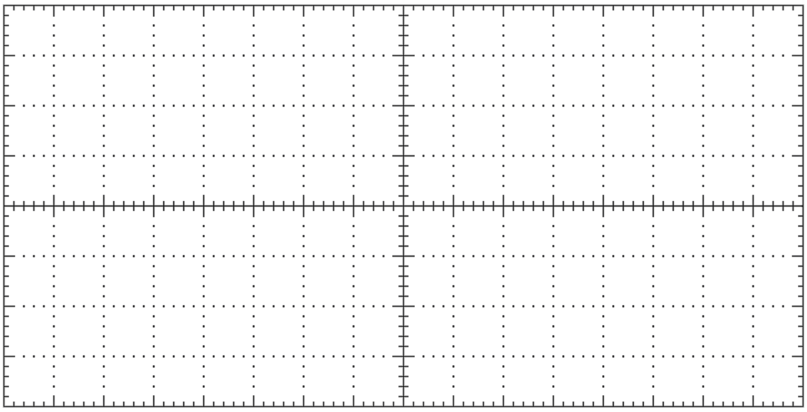
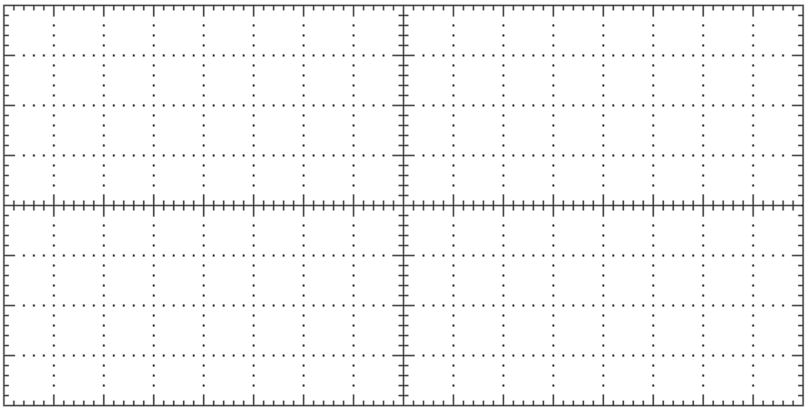
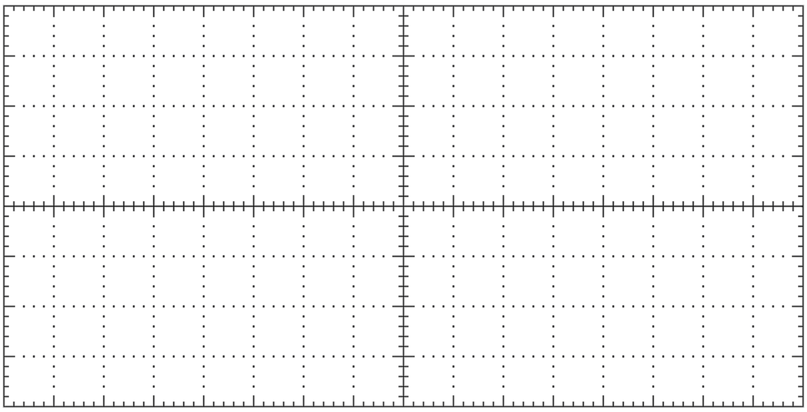
	Frequency	Output
Function Generator Output Amplitude = 1Vpp	5Hz	
	50Hz	
	500Hz	
	1kHz	

Table 2.8 Effect of Different Output Amplitude Values on Output When Function Generator Output Frequency is Set to 500Hz

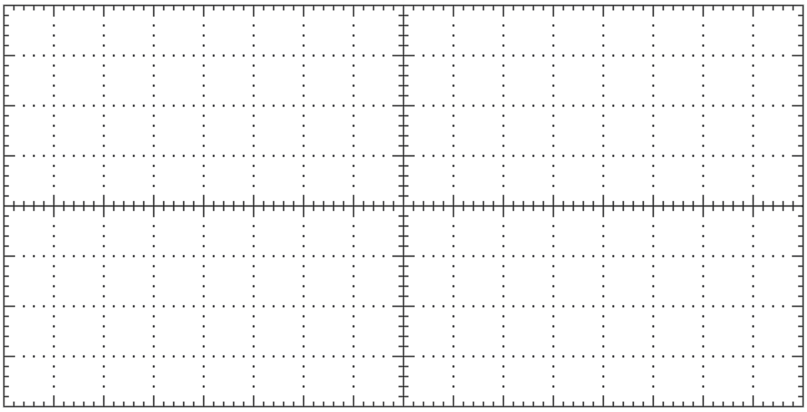
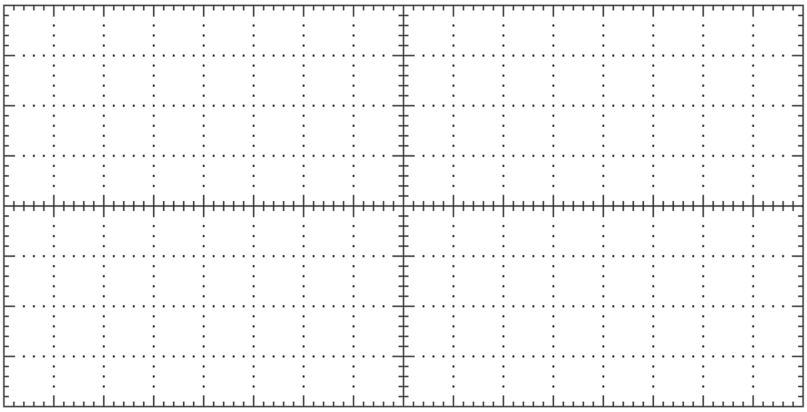
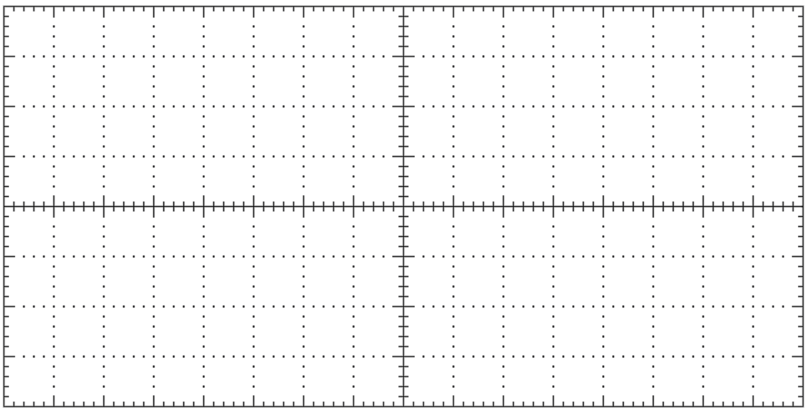
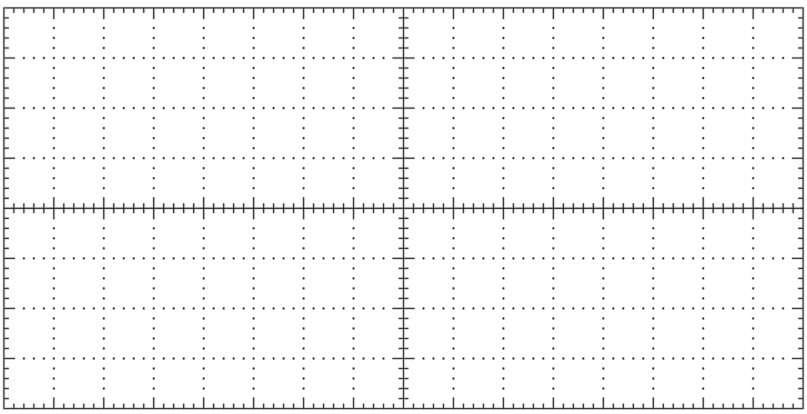
	Amplitude	Output
Function Generator Output Amplitude = 1Vpp	50mVpp	
	1Vpp	
	5Vpp	
	10Vpp	

Table 2.9 EMG Isometric Contraction Experiment

Condition	Output
After placing the electrodes, apply force and release the arm.	

Table 2.10

Condition	Output
Lift the weight for 2 sec., keeping the elbow at 90 degrees and the arm at 45 degrees. Release the weight and rest for 2 seconds	

Condition	(CH1 EMG signal and CH2 muscle force)
Isometric Contraction Experiment Results	

Table 2.11 EMG Isotonic Contraction Experiment

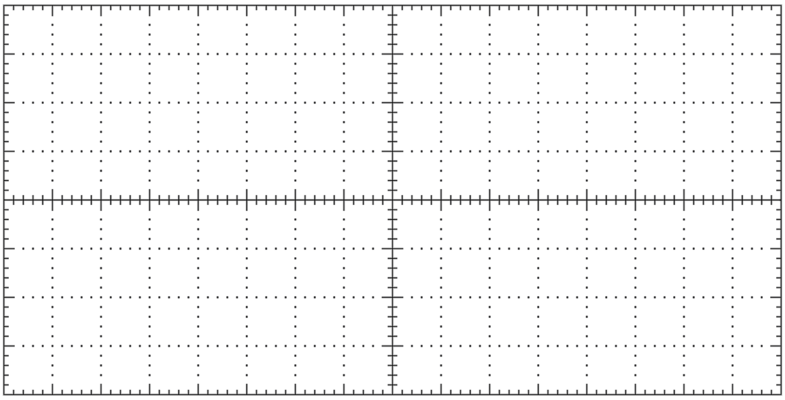
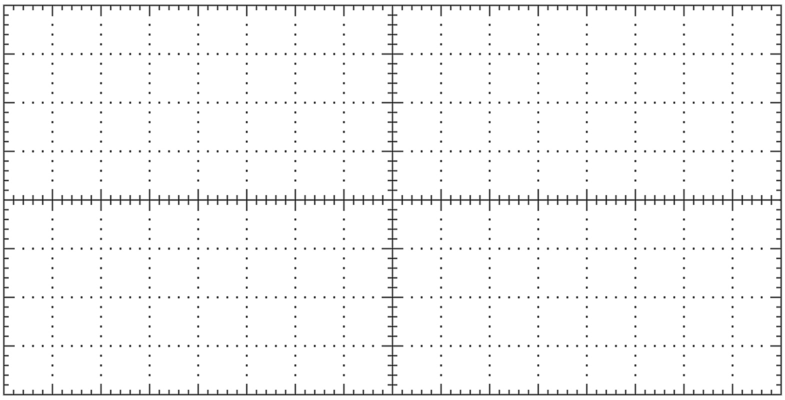
Condition	(CH1 EMG signal and CH2 muscle force)
Isotonic Contraction Experiment Results	

Table 2.12 EMG Muscle Fatigue Experiment

Condition	(CH1 EMG signal and CH2 muscle force)
Muscle Fatigue Experiment Results	

2.6 QUESTIONS

1. Where is the -3dB frequency in the low-pass filter experiment?
2. Where is the -3dB frequency in the high-pass filter experiment?
3. How does the output signal change when VR3 is changed in the integrator experiment?
4. If the forearm is moved continuously in the isotonic contraction experiment, are the recorded EMG signals real EMG signals?
5. Compare the EMG results from the fatigue experiment with the normal EMG results.
6. When the subject exerts sufficient force to lift the forearm, the EMG signal cannot be measured, or the measured EMG signal is very small. Explain why.
7. When the arm is in a relaxed position, there is a lot of noise in the output. Explain why.