

BE 3600 BIOMEDICAL INSTRUMENTATION (LAB) - WEEK 2

Principles of Biosensors

OBJECTIVE: Learn the various modalities for construction of sensors utilizing electrical and optical measurement techniques.

EXPERIMENT 1: ELECTRICAL IMPEDANCE BACKGROUND:

Many of the biomedical measurements are done by measuring "secondary" quantities instead of measuring the actual biological quantity of interest. For example, direct measurement of the left ventricular (LV) volume requires the removal and isolation of the heart, which is usually not possible. Measurement of electrical impedance of the blood volume contained within the heart can be done using a catheter with minimal disturbance to the cardiovascular function. This impedance is related to the ventricular volume and can be used to estimate the LV volume as well as other cardiovascular parameters such as ejection fraction. Impedance Plethysmography is one of the commonly used procedures for the measurement of the LV volume. The principle is explained below:

Electrical resistance of a conductor is given by the following equation:

$$\text{[Equation 2.1]} \quad R = \frac{\rho L}{A}$$

where R is the resistance in Ω (ohms)

ρ is the unit resistance in Ω -meters,

L is the length of the conductor,

A is the cross sectional area of the conductor.

One can place two electrodes in tissue at a distance L from each other. Experimenter applies a small amount of current to these electrodes, represented as I . Since the tissue acts as a resistor; a voltage drop of V can be measured between the electrodes. Resistance of the tissue between the electrodes can be calculated using the Ohm's Law:

$$\text{[Equation 2.2]} \quad R = \frac{V}{I}$$

Since we know ρ and L , we can calculate the cross sectional area, A , and the tissue volume = $A L$. Although this method is applicable to cylindrical shaped tissue, if the organ being measured does not conform to cylindrical shape, then some modifications to the method is needed. In the case of the left ventricle, we will measure the volume by approximating as multiple disks stacked on top of each other. Figure 2.1 below shows

the concept drawing.

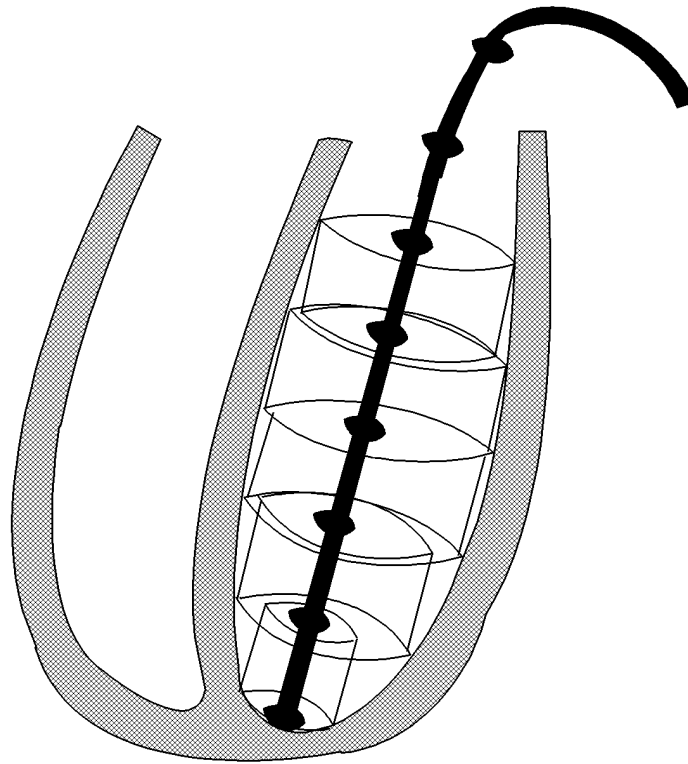


Figure 2.1. Measurement of Left Ventricular volume using impedance plethysmography

Electrical current is applied between the most distal and the most proximal electrodes, i.e. one in the apex and the one in the aorta. Resistance of the disk between the electrodes i and j can be found as

$$\text{[Equation 2.3]} \quad R_{i,j} = \frac{V_i - V_j}{I}$$

which can be used to calculate the area of the disks as

$$\text{[Equation 2.4]} \quad A_i = \frac{\rho L}{R_{i,j}}$$

Volume of the individual disks can be calculated as

$$\text{[Equation 2.5]} \quad \text{Volume}_i = A_i L_i$$

And the total volume of the left ventricle can be calculated as

$$\text{[Equation 2.6] } \text{Volume}_{LV} = \sum \text{Volume}_i$$

PROCEDURE 1: You will be provided with a resistor pack to simulate the LV intracardiac impedance.

1. Connect the 9 volt battery to its outer terminals and measure the intra-electrode voltages.
2. Next, measure the current stimulating the entire resistor pack.

REPORT SECTION 1:

- a. Describe the theory of intracardiac impedance plethysmography.
- b. What assumptions are being made?
- c. What are the advantages and disadvantages of impedance plethysmography for measurement of organ volume?
- d. What pit-falls one must avoid when measuring LV volume with intracardiac impedance plethysmography?
- e. Using the theory of intracardiac impedance plethysmography, calculate the shape of the left ventricle using the data you collected. You can assume that the electrodes are spaced 1 cm apart and $\rho = 150 \Omega$ -meter.
- f. Sketch the LV, label electrode positions and numerical values of the radii of the cross sectional planes intersecting the electrodes on the catheter.

EXPERIMENT 2: BACKGROUND ON ELECTRICAL CAPACITANCE:

Capacitive sensors are also used for biomedical measurements. In one application, engineers use a capacitive sensor to measure force. Electrical capacitance between two parallel plates is a function of the distance between the plates. If a compliant material is placed between these metal plates, application of a vertical force compresses the material and reduces the distance between the plates, increasing the capacitance. Parallel plate capacitor is a simple electrical device that is based on the physical principle as explained below:

Two conductive plates are placed in parallel to each other as shown in Figure 2.2 below.

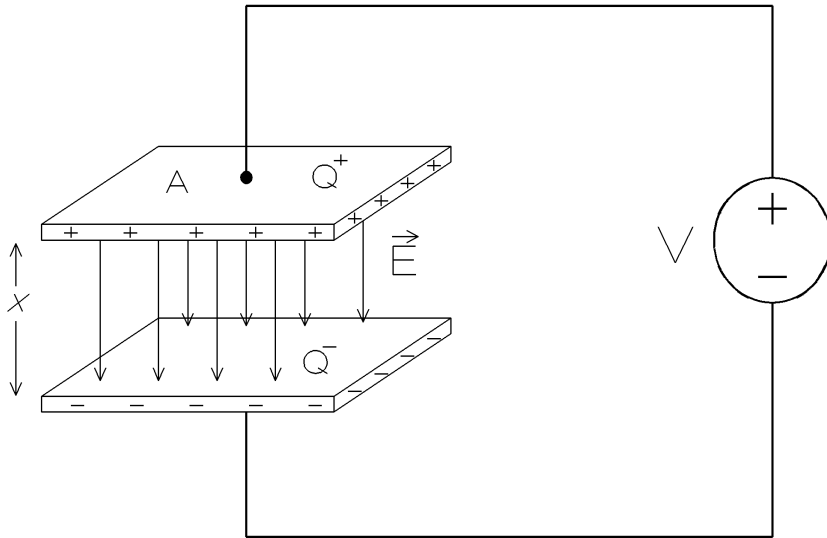


Figure 2.2. Parallel plate capacitor

Electric field vector E is defined as the electrostatic force seen by a unit charge, and given by the following equation:

$$[\text{Equation 2.7}] \quad \vec{E} = \frac{\vec{F}}{q}$$

where E is the electric field vector,

F is the force seen by the charge q within the electric field.

Electrical flux, Φ_E is defined as the "flow" of electric field across a surface and is given by the following equation:

$$\text{[Equation 2.8]} \quad \Phi_E = \oint \vec{E} \cdot \vec{d}s$$

where Φ_E is the electrical flux,

E is the electric field vector,

ds is the vector normal to the surface.

Gauss' Law gives the relationship between Φ_E over a surface enclosing a charge Q , and is given as stated below:

$$\text{[Equation 2.9]} \quad \epsilon_0 \Phi_E = Q$$

where ϵ_0 is the permittivity constant and given as $\epsilon_0 = 8.85 \times 10^{-12}$ Farads/meter,

Φ_E is the electrical flux as given by the equation 2.8,

Q is the electrical charge enclosed by the surface that forms the base of the integration in equation 2.8.

Substituting equations 2.8 in equation 2.9,

$$\text{[Equation 2.10]} \quad \epsilon_0 \Phi_E = \epsilon_0 \oint \vec{E} \cdot \vec{d}s = Q$$

If a closed surface was placed over the top plate shown in Figure 2.2, we can calculate the electric field between the two plates as follows:

$$\text{[Equation 2.11]} \quad \epsilon_0 \oint \vec{E} \cdot \vec{d}s = \epsilon_0 EA = Q$$

where A is the surface area of the parallel plate

Solving for the scalar electric field, E ,

$$\text{[Equation 2.12]} \quad E = \frac{Q}{\epsilon_0 A}$$

Electrical voltage, V , is defined as the line integral of the electrical field, so,

$$\text{[Equation 2.13]} \quad V = \vec{E} \cdot \vec{dx} = Ex = \frac{Q}{\epsilon_0 A} x$$

where V is the voltage between the two plates,

Q is the electrical charge on the plate,

x is the distance between the plates,

A is the surface area of the parallel plate,

ϵ_0 is the permittivity constant and given as $\epsilon_0 = 8.85 \times 10^{-12}$ Farads/meter.

Electrical capacitance is defined as electrical charge which can be stored for a given voltage. Then the capacitance, C , of the parallel plate capacitor can be found as follows:

$$\text{[Equation 2.14]} \quad C = \frac{Q}{V} = \frac{\epsilon_0 A}{x}$$

Note that the equation 2.14 for electrical capacitance is independent of the electrical charge on the plates as well as the voltage between the plates. It is very similar to the equation 2.1 where the electrical resistance does not depend on the voltage or the current.

When a force is applied to the parallel plate capacitor, the distance between the plates changes, hence changing the capacitance.

PROCEDURE 2: You will build a capacitor and vary the distance between the plates to simulate application of pressure.

1. Connect a pulse generator to a 10 cm x 10 cm parallel plate capacitor formed by two metal sheets and a series resistor. Sandwich two sheets of paper between the plates.
2. Record on the oscilloscope the voltage across the capacitor as well as the voltage on the resistor (how would you do that simultaneously with one oscilloscope?).
3. Remove one of the sheets and repeat step 2.

REPORT SECTION 2:

- a. Describe the theory of capacitive force sensor.
- b. What assumptions are being made?
- c. What are its advantages and disadvantages?
- d. What pit-falls one must avoid when measuring force with a capacitive force sensor?
- e. Draw the circuit diagram of your experimental setup. Label all components.
- f. Calculate the capacitance for the two cases studied.
- g. Why did we measure the voltage across the capacitor and the resistor?
- h. What is the purpose of the measurement of the voltage drop across the resistor?
- i. Derive the relationship between the measured capacitance and the applied force (hint: what is the equation for the Young's Modulus?).
- j. Does the capacitance go up or down when a force is applied? Explain.
- k. If there was a fixed charge on a capacitor and the force is increased, would the voltage seen across the parallel plate capacitive force sensor increase or decrease? Explain.

Appendix

Background information on the function generator

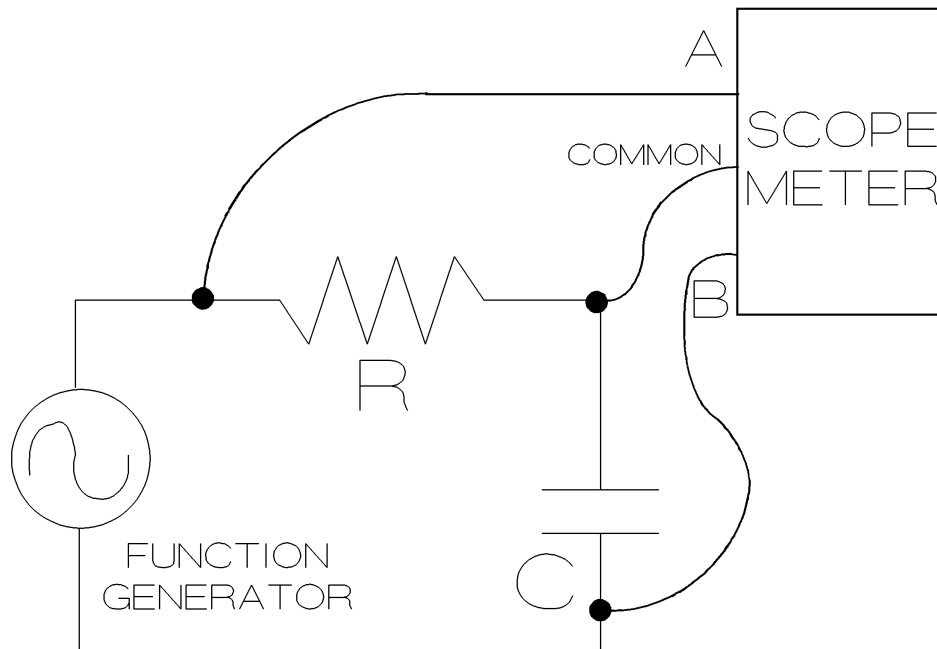
Introduction:

The DIGITAL FUNCTION GENERATOR provides square, triangle, sine, ramp and pulse waveforms over a frequency range from 0.2Hz to 2MHz, plus a VCF input, variable DC offset and TTL or CMOS pulse output.

The main output and all controls are located on the front panel.

- ◆ To turn function generator on or off, push button POWER switch.
- ◆ There are seven frequency RANGE push button switches -
Seven fixed decades of frequency are provided by the RANGE pushbutton switch. Each of the seven pushbutton RANGE switches is interlocked. Pressing one pushbutton will release all others.
- ◆ There are three push button FUNCTION switches -
Three interlocking pushbutton switches provide selection of the desired output waveform. Pressing one switch will release the switch previously pressed. Square, triangle, and sine waveforms are provided.
- ◆ The frequency MULTIPLIERS (variable) -
The MULTIPLIERS are variable potentiometers allowing frequency settings between a fixed ranged. They are controlled by the coarse and fine adjusts knobs.
- ◆ DUTY potentiometer with invert switch, DC OFFSET control with level control, OUTPUT, VCF(voltage controlled frequency) input, TTL/CMOS pulse output, CMOS level control with CMOS/TTL selector SW
--- These knobs are normally turned to the left.
- ◆ output AMPLITUDE control with output attenuation
--- This knob should be turned to extreme right.

Connect scopemeter to the resistive circuit shown below :



How to use a scopemeter to make measurements -

- ◆ Single (First) Connection -
 - Use the red input A for all single input measurements possible with the test tool.
 - Use the black COM as single ground for low frequency measurements, and for Continuity, Ohm(Ω), Diode, and Capacitance measurements.
- ◆ Measurement Selection -
 - (1) Open the INPUT A menu by pressing the left yellow button which has V Hz A on it.
 - (2) Use the blue arrow keys to highlight the desired measurement.
 - (3) Press the blue "ENTER" function key "F4" to confirm selection.
- ◆ Now desired measurement will be displayed on the screen as well as the waveform (if measuring voltage, current, frequency, or anything else that would have a waveform associated with it).
- ◆ Second Connection -
 - Use the gray input (B) for a second connection when two measurements are to be made at once.

- The black COM connection must be located between the red (A) and gray (B) connections. The waveform shown for one of the inputs will be upside down when compared to the other, unless the input is inverted. One or both waveforms may be inverted by adjusting the input settings.
- ◆ Measurement Selection -
 - (1) Open the INPUT B menu by pressing the right yellow button which has V Hz A on it.
 - (2) Use the blue arrow keys to highlight "ON."
 - (3) Press the "ENTER" key (F4).
 - (4) Use blue arrow keys again to highlight desired measurement.
 - (5) Press the blue "ENTER" key (F4) again.