Department of Biomedical Engineering

Biomedical Sensors I

Lecture 6:- Biopotential Electrodes

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Lecture Outline

- Introduction of Biopotential Electrodes
- Half Cell Potential
- Electrode Circuit Model
- Electrode Skin Interface
- Skin-Electrode Electric Model
- Motion Artifacts
- Body Surface Electrodes
- Needle or Internal Electrodes
- Micro Electrodes

Biopotential Electrodes

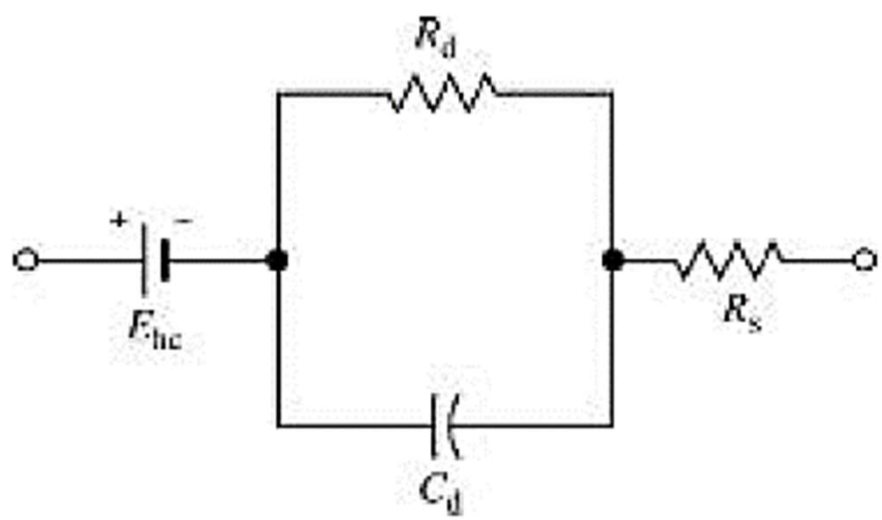
- Electrical conduction in medical instrument circuits is electronic.
- Electrical conduction in the body is ionic.
- Electrodes provide transduction between ionic and electronic conduction.
- Biopotential electrodes function as sensor that couple the ionic potentials generated inside the body to an electronic instrument.

Electrode or Half Cell Potential

- Skin and other body tissues act as electrolytic solutions.
- When a metal is placed in an electrolyte solution, the metal slightly dissolve into solution.
- This slight dissolution of metal is accompanied by a loss of electrons to the atoms that remain with the parent metal.
- It leaves the parent metal with a net negative charge and the dissolved metal ions with a positive charge.
- The created electric field tends to draw the ions back to the vicinity of the metal surface; however, energy is required for their recombination, so the ions are just held close to the metal surface and form the region called the *electrode double layer* and its ionic difference form the potential called *Half cell potential*.

Electrode Circuit Model

- Equivalent circuit for a Biopotential electrode in contact with an electrolyte.
- E_{hc} is the half-cell potential,
- R_d and C_d make up the impedance associated with the electrode–electrolyte interface and polarization effects,
- R_s is the series resistance associated with interface effects and is due to resistance in the electrolyte.



Electrode Skin Interface

The skin consists of three layers,

I. Epidermis,

II. Dermis and

III. Subcutaneous or Fatty tissue layer.

The main contact of the electrode with the skin is the Epidermis layer.

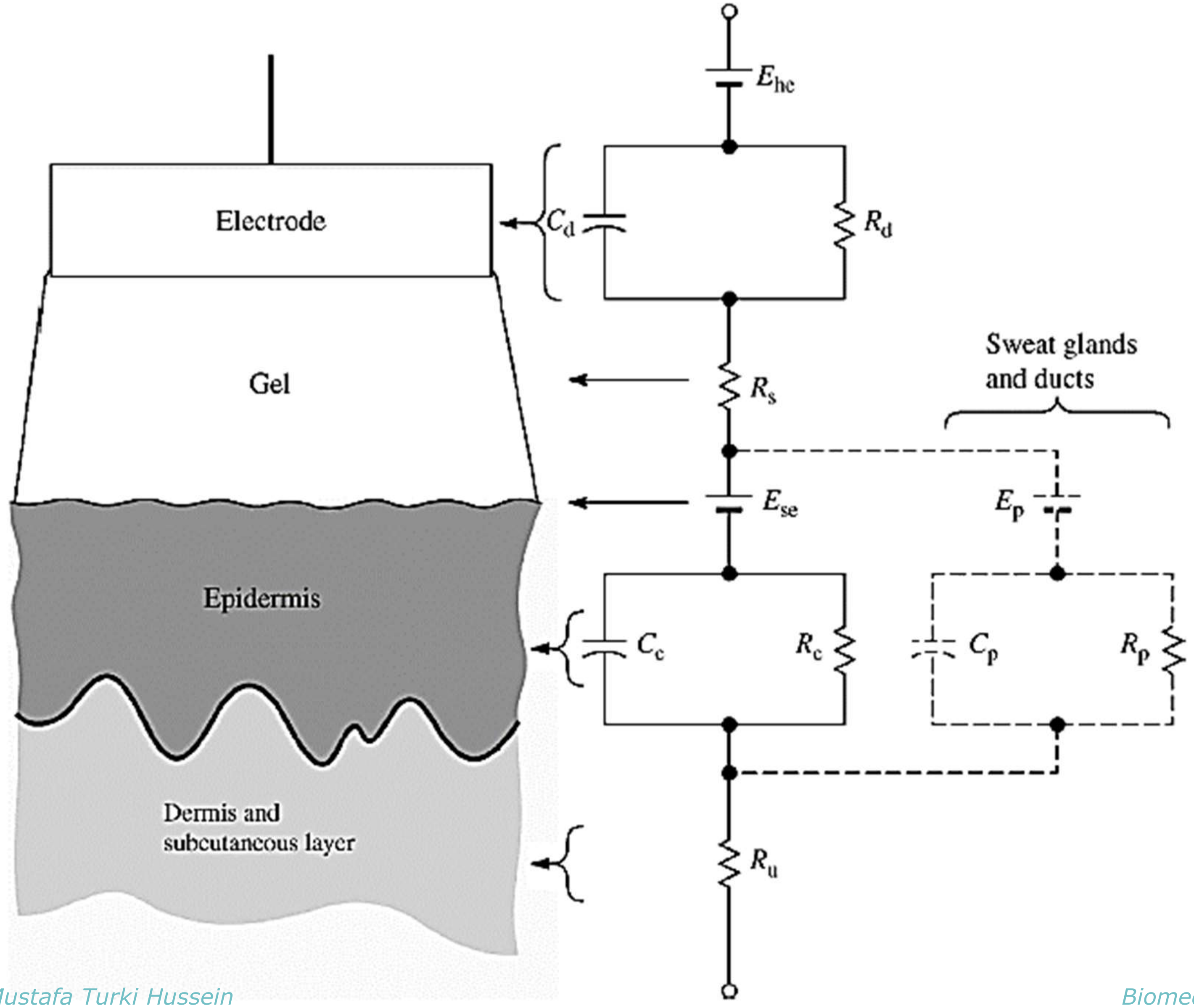
The Epidermis consists of following layers,

- Stratum corneum (dead cells)
- Stratum lucidum
- Stratum granulosum
- Stratum spinsum
- Stratum (basale) germinativum (where new skin cells form)

Deep layers of skin consist of vascular and nervous components, as well as sweat glands, sweat ducts and hair follicles.

With the exception of sweat glands, no particular characteristics affecting the electrode performance

The Skin-Electrode Electric Model



Motion Artifacts

- The main issue in biopotential measurements is the motion artifact.
- When electrode moves it disturb the charge distribution which can affect the acquired signal during measurement.
- The use of non-polarizable electrodes such as silver-silver chloride (Ag/AgCl) reduce the low frequency noise created by the motion artifact.
- The gel-skin contact also creates motion artifacts, which can also affect the performance of Ag/AgCl electrodes.

Types of Biopotential Electrodes

Bioelectrical signals are acquired from one of three forms of electrode:

- Body Surface Electrodes,
- Needle Electrodes
- Micro Electrodes

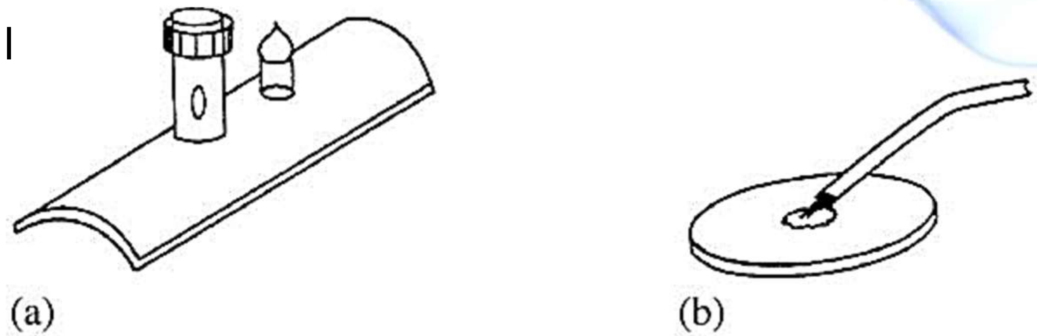
Body Surface Electrodes

There are **four** different types of body surface recording electrodes;

1. Metal Plate Electrodes
2. Suction Electrodes
3. Floating Electrodes
4. Flexible Electrodes

Metal Plate Electrodes

- Large surface: Earliest, and still used for ECG.
- Smaller diameters.
- Metal disk with stainless steel, platinum or gold coated.
- Also used for EMG and EEG.
- Susceptible to Motion artifacts.
- Disposable foam-pad.
- Very Cheap.



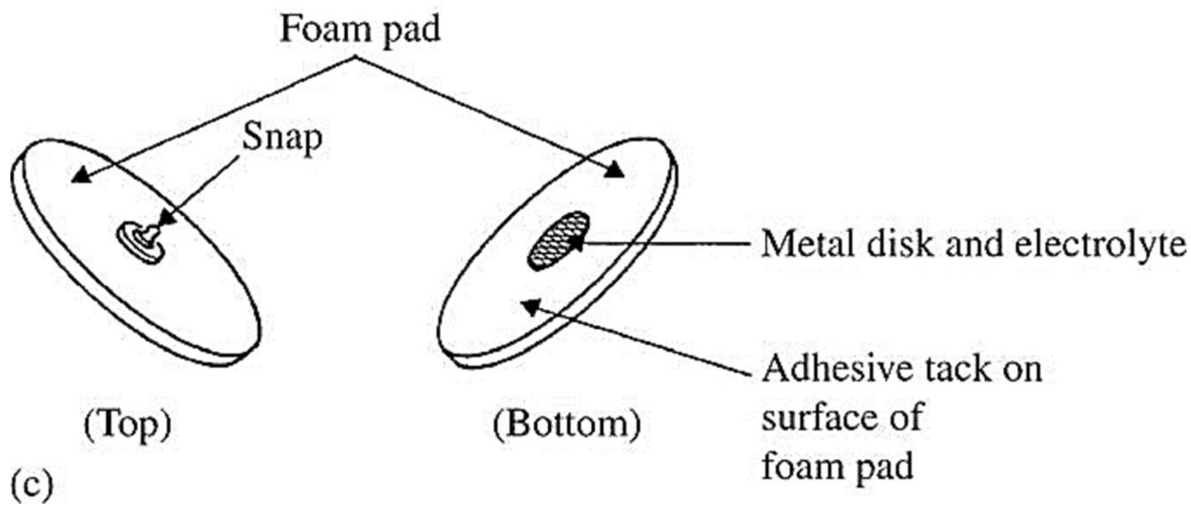
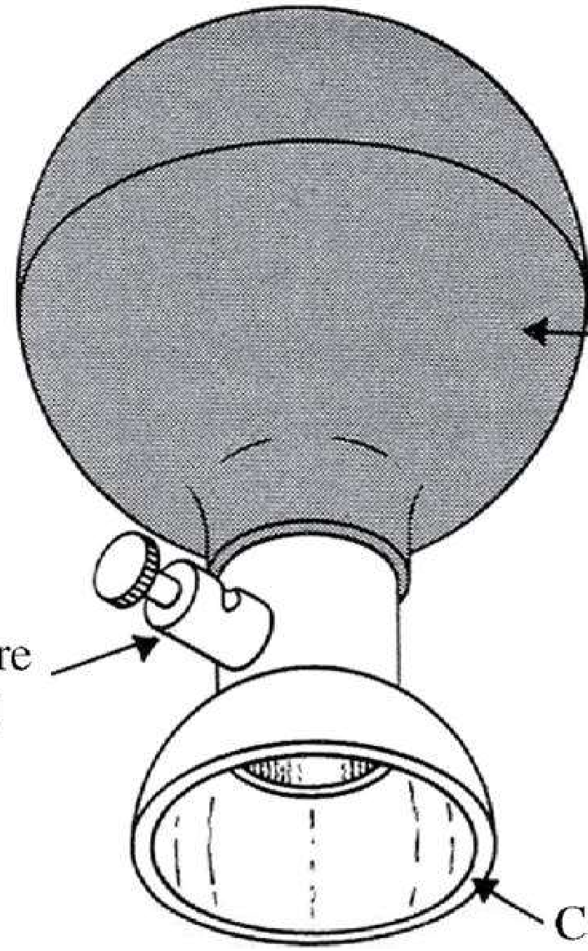


Figure (a): Metal-plate electrode used for application to limbs.
Figure (b): Metal-disk electrode applied with surgical tape.
Figure (c): Disposable foam-pad electrodes, often used with ECG.

Suction Electrodes

- Straps or adhesives not required.
- Often used for precordial (chest) ECG.
- For short periods only.



Floating Electrodes

- Metal disk is recessed.
- Floating in the electrolyte gel.
- Not directly contact with the skin.
- Reduces motion artifacts.

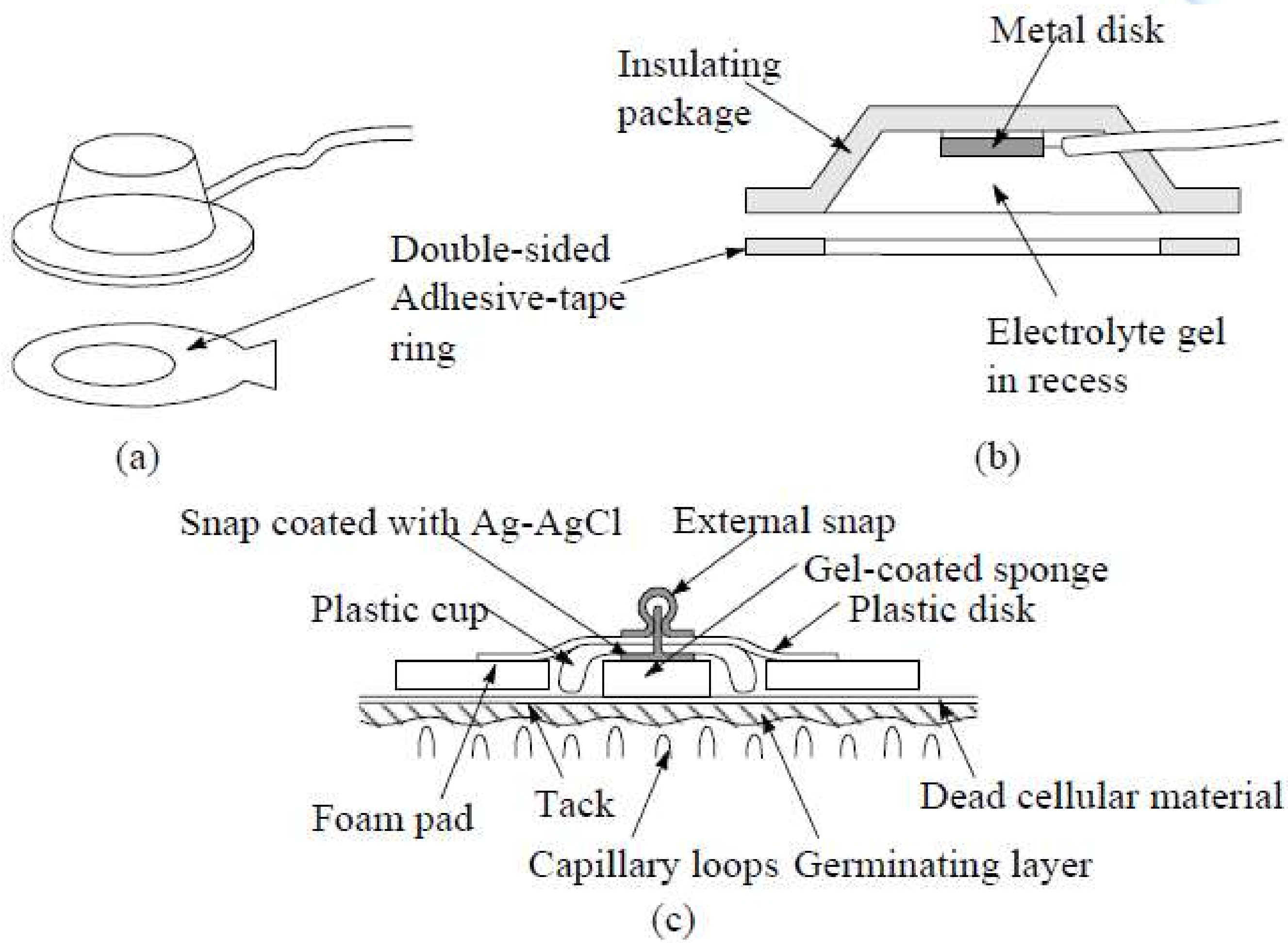
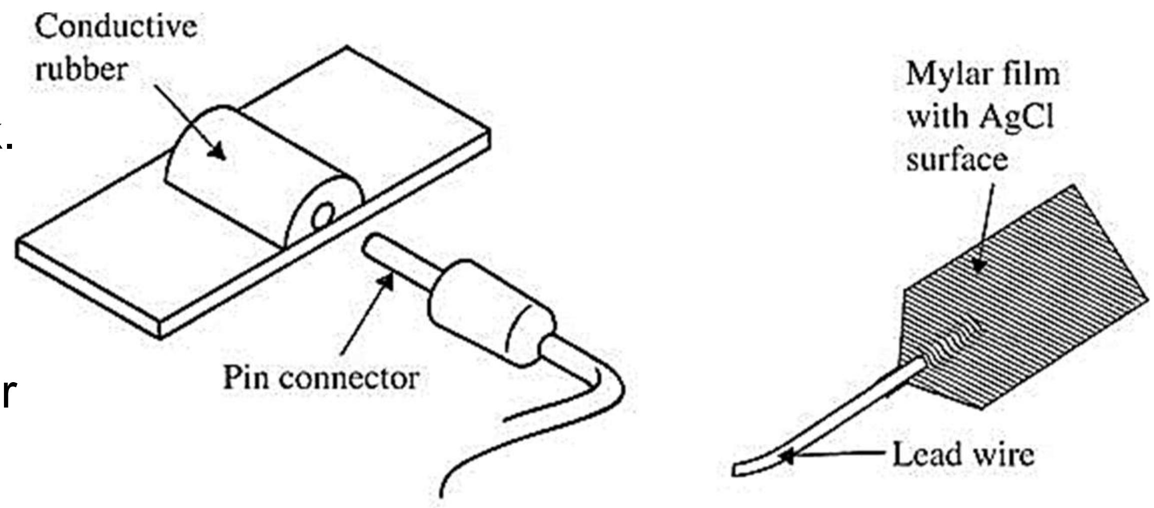


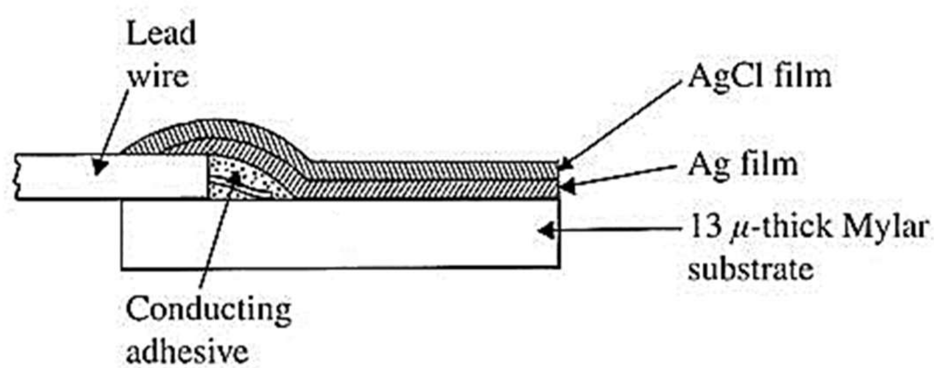
Figure (a): Recessed electrode with top-hat structure.
Figure (b): Cross-sectional view of the reusable electrode in (a).
Figure (c): Cross-sectional view of a disposable recessed electrode.

Flexible Electrodes

- Body surface are often irregular.
- Regularly shaped rigid electrodes may not always work.
- Special case : infants.
- Material: polymer or nylon with silver, carbon filled silicon rubber (Mylar film).



(a) (b)



(c)

Figure (a): Carbon-filled silicone rubber electrode, **Figure (b):** Flexible thin-film neonatal electrode. **Figure (c):** Cross-sectional view of the thin-film electrode in (b).

Needle or Internal Electrodes

Needle and wire electrodes for percutaneous measurement of Biopotentials.

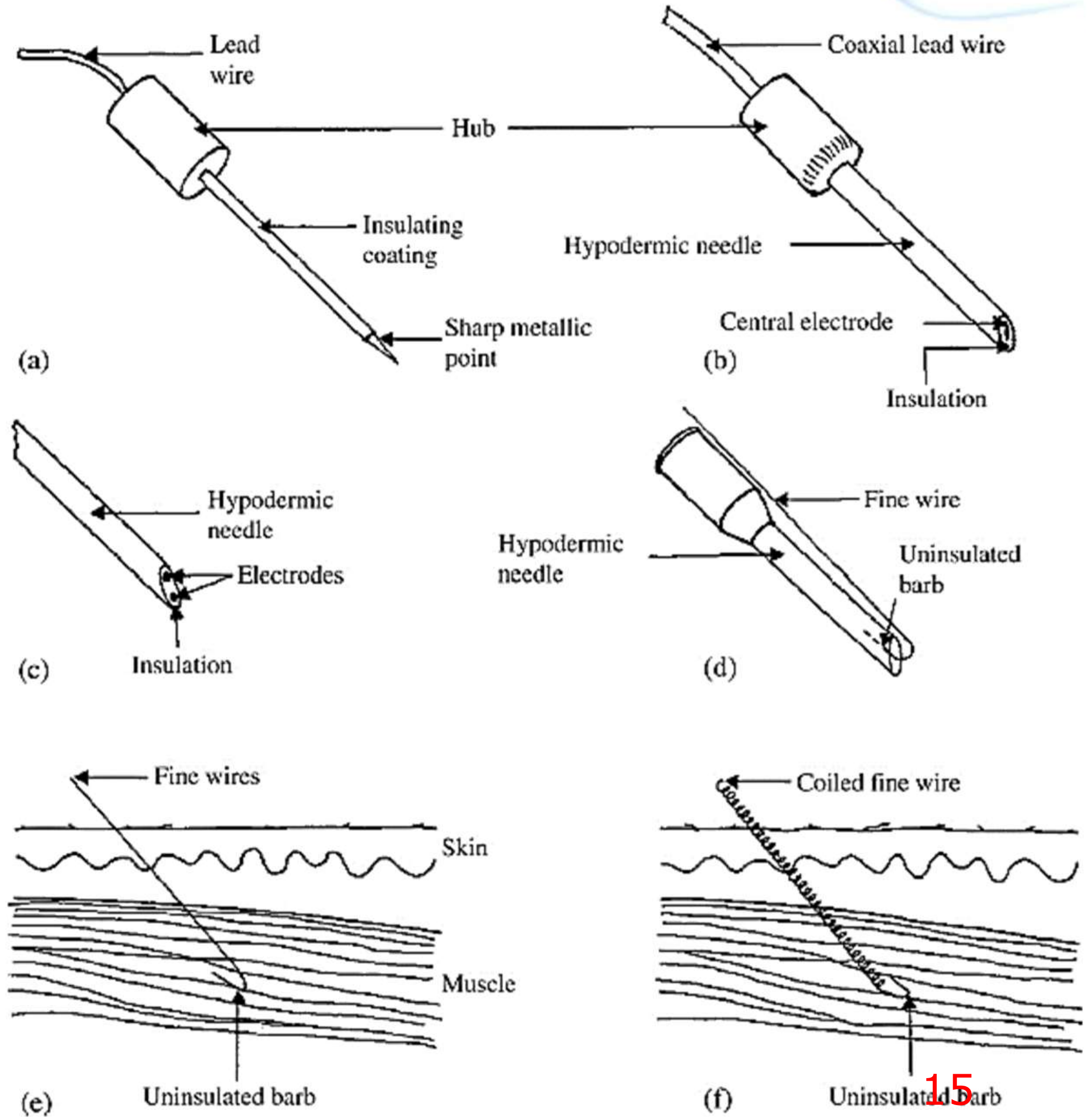
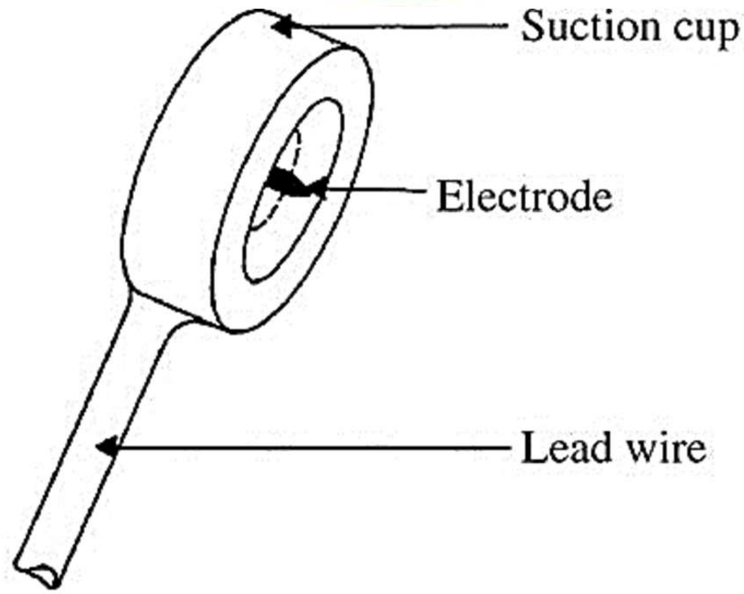


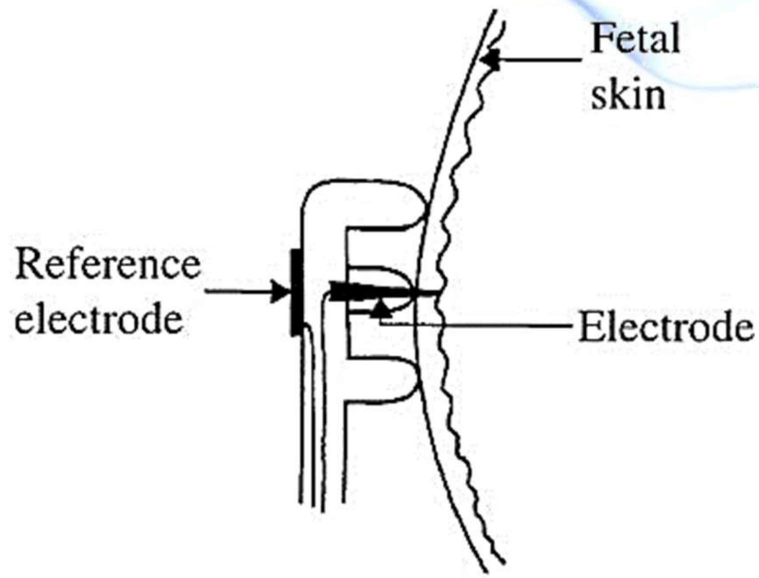
Figure:

(a) Insulated needle electrode,
(b) Coaxial needle electrode,
(c) Bipolar coaxial electrode,
(d) Fine-wire electrode connected to hypodermic needle, before being inserted,
(e) Cross-sectional view of skin and muscle, showing fine-wire electrode in place,
(f) Cross-sectional view of skin and muscle, showing coiled fine-wire electrode in place.

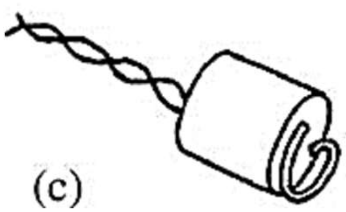
Fetal ECG Electrodes



(a)



(b)



(c)

- Electrodes for detecting fetal electrocardiogram during labor, by means of intracutaneous needles.

Figure (a): Suction electrode,
Figure (b): Cross-sectional view of suction electrode in place, showing penetration of probe through epidermis,
Figure (c): Helical electrode, that is attached to fetal skin by corkscrew-type action.

Electrode Arrays

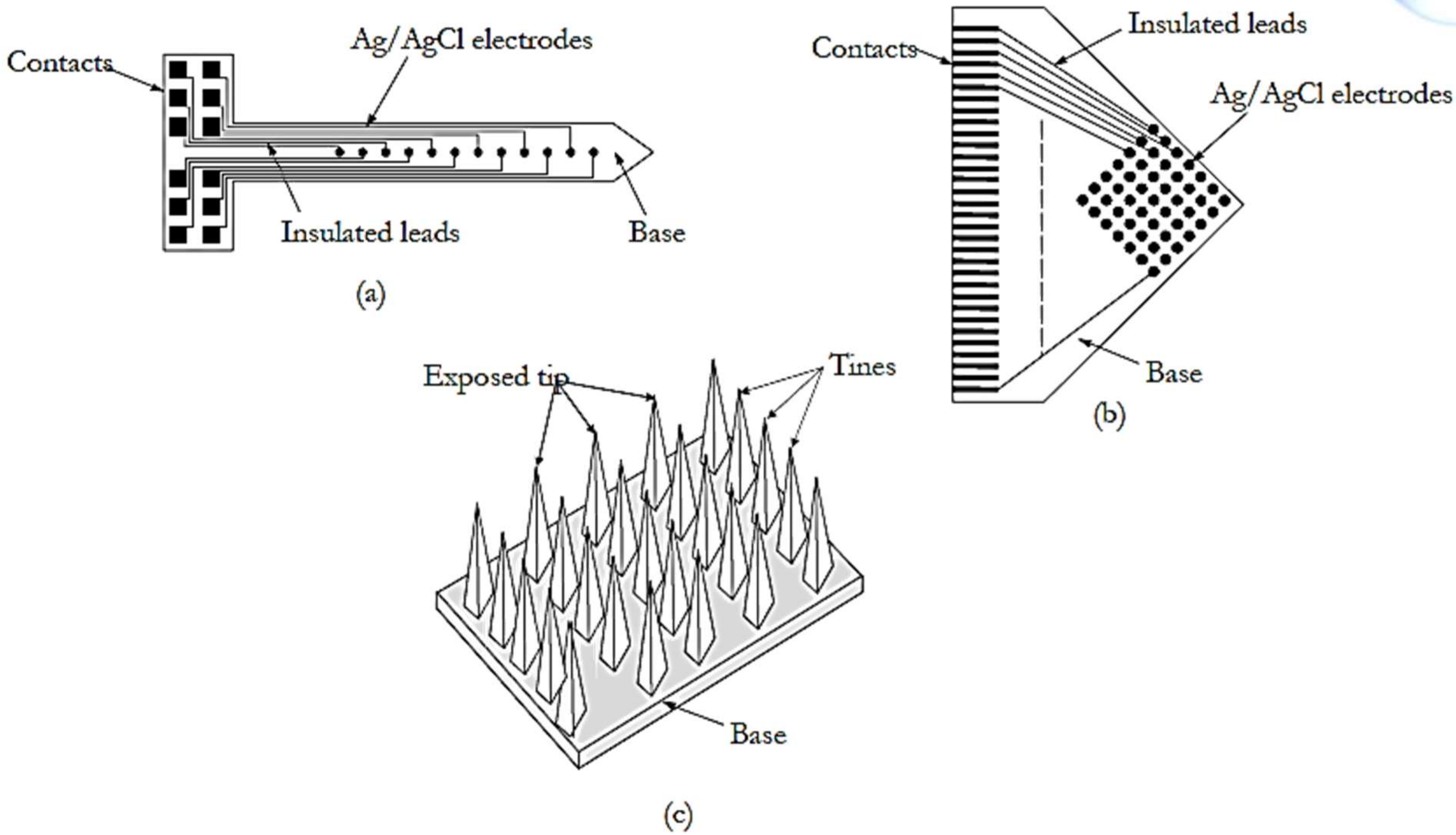


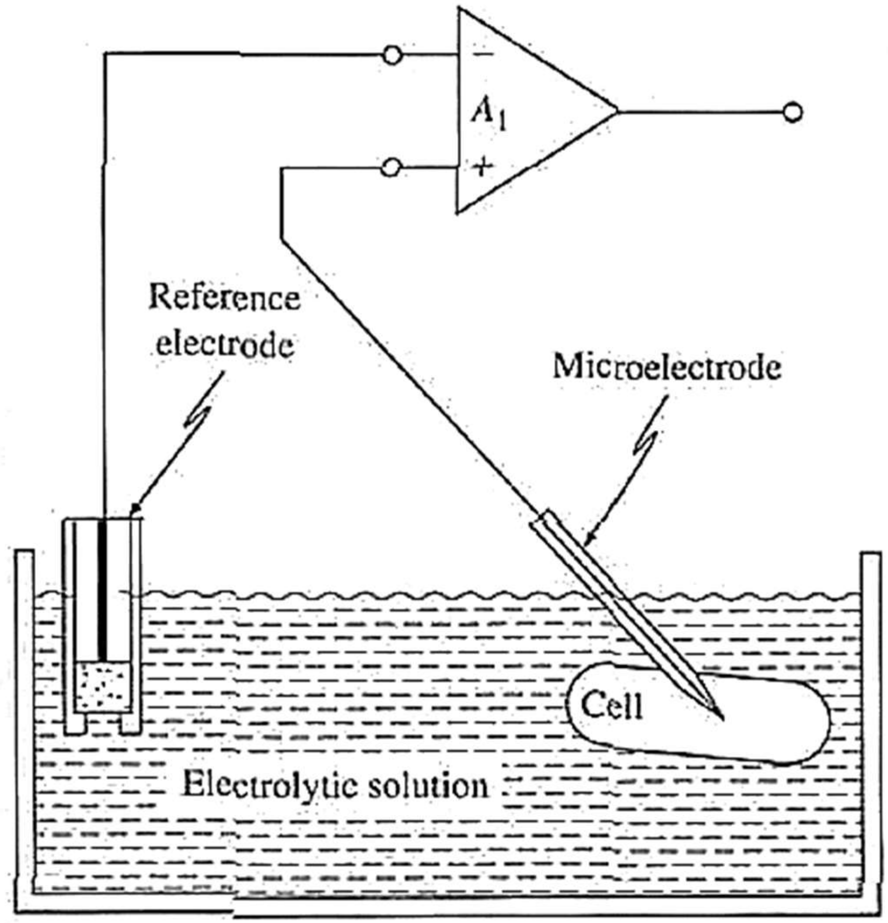
Figure (a): One-dimensional plunge electrode array,
Figure (b): Two-dimensional array,
Figure (c): Three-dimensional array

Microelectrodes *I*

The microelectrode is an ultrafine device that can measure the potential difference across cell membrane which is immersed in the physiological solution such as saline.

Some properties of microelectrode are;

- Small enough to be placed into cell
- Strong enough to penetrate cell membrane
- Tip diameter: 0.05 –10 micrometers



Microelectrodes *II*

There are Three major types of microelectrode.

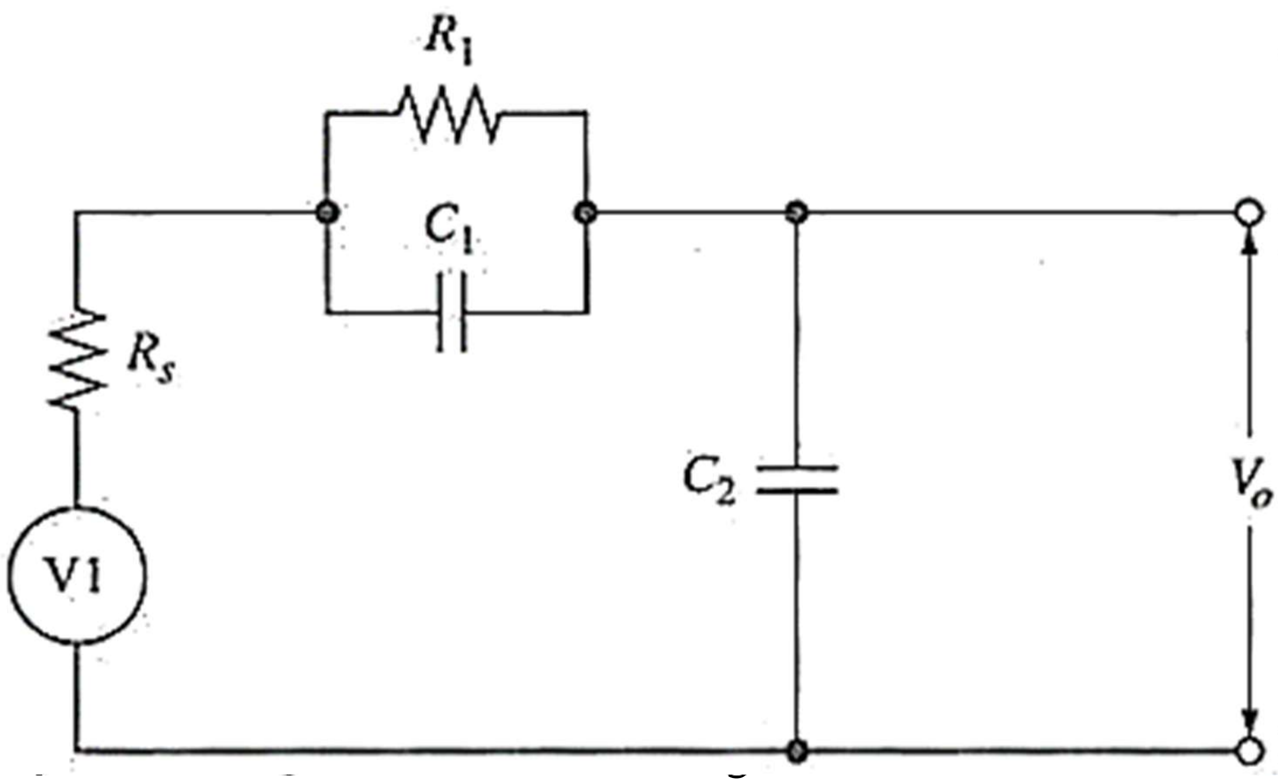
- Solid Metal Electrodes (Tungsten Microelectrodes)
- Glass-Metal or Supported Metal Electrodes (metal contained within/outside glass needle)
- Fluid-Filled Glass Micropipette Electrodes (with Ag-AgCl electrode metal)

Microelectrodes *III*

- Microelectrode equivalent circuit is shown in the figure.
- The RC components may caused the problem in signal acquisition.
- The R_1 and C_1 are the result of the effects at the electrode/cell interface.
- The R_1 and C_1 are frequency-dependent and their values fall off at $1/(2\pi F)^2$.
- The values of R_1 and C_1 are generally lower than R_s and C_2.
- The spreading resistance R_s is a function of the electrode tip diameter.

Microelectrodes *III*

- Microelectrode equivalent circuit is shown in the figure.



- The ... n in sign...
- The ... t the elec...
- The ... their valu...
- The ... than R_s and
- The ... the electrode tip diameter.

Further Info. and discussion on

Google Classroom

Microelectrodes *IV*

The value of tip spreading resistance R_s, in metallic micro-electrodes without the glass coating is approximated by

$$R_s = \frac{P}{4\pi r}$$

where

R_s is the resistance in ohms (Ω)

P is the resistivity of the infinite solution outside of the electrode (e.g., 70 Ω-cm for physiological saline)

r is the tip radius (typically 0.5 μm for a 1-μm electrode)

Microelectrodes *V*

Example: Calculate the tip-spreading resistance R_s of a 1μm metallic microelectrode, where the resistivity P of the solution is 70 Ω-cm.

Solution

The tip spreading resistance R_s can be calculated as;

$$R_x = \frac{P}{4\pi r}$$

$$R_x = \frac{70\ \Omega\text{-cm}}{(4\pi)\left(0.5\ \mu\text{m} \times \left(\frac{10^{-4}\ \text{cm}}{1\ \mu\text{m}}\right)\right)}$$

$$R_s = \mathbf{111.4\ k\Omega}$$

Note that the impedance of glass-coated metallic microelectrodes is at least one or two orders of magnitude higher than this value.

Microelectrodes *VI*

For fluid-filled potassium chloride (KCl) microelectrodes with small taper angles (π/180 radians), the series resistance R_s is approximated by;

$$R_s = \frac{2P}{\pi r \alpha}$$

where

- R_s is the resistance in ohms (Ω)
- P is the resistivity (typically 3.7 Ω-cm for 3M KCl)
- r is the tip radius (typically 0.1 μm)
- α is the taper angle (typically π/180)

Microelectrodes *VII*

Example: Find the series impedance R_s of a potassium chloride (KCl) micro-electrodes, where the resistivity P of the 3M solution of KCl is 70 Ω-cm.

Solution

$$R_s = \frac{2P}{\pi r \alpha}$$

$$R_s = \frac{(2)(3.7\ \Omega\text{-cm})}{(3.14)\left(0.1\mu\text{m} \times \left(\frac{10^{-4}\ \text{cm}}{1\ \mu\text{m}}\right)\right)\left(\frac{3.14}{180}\right)}$$

$$R_s = \mathbf{13.5\ M\Omega}$$

Microelectrodes *VIII*

The capacitance C_2 of microelectrodes is given by

$$C_2 = \frac{0.55e}{\ln\left(\frac{R}{r}\right)} \frac{\text{pF}}{\text{cm}}$$

where

e is the dielectric constant of glass (typically 4)
R is the outside tip radius
r is the inside tip radius

Microelectrodes *IX*

Find the capacitance of a microelectrode if the pipette radius is 0.2 μm, the inside tip radius is 0.15 μm and the typical value of dielectric constant of glass is 4. Assume platinum wire is used inside a glass pipette.

Solution

The capacitance of the microelectrode is given by

$$C_2 = \frac{0.55e}{\ln\left(\frac{R}{r}\right)} \frac{\text{pF}}{\text{cm}}$$

$$C_2 = \frac{(0.55)(4)}{\ln\left(\frac{0.2\ \mu\text{m}}{0.15\ \mu\text{m}}\right)} \frac{\text{pF}}{\text{cm}}$$

$$C_2 = \mathbf{7.7}\ \frac{\mathbf{pF}}{\mathbf{cm}}$$

Microelectrodes *X*

- Resistance R_s and capacitor C_2 of the microelectrode act together as a RC low-pass filter.
- The frequency response of the low-pass filter at -3 dB can be calculated as

$$F = \frac{1}{2\pi RC}$$

Where

F is the frequency at -3 dB point in hertz (Hz)

R is the resistance in ohms (Ω)

C is the capacitance in Pico farads (pF)

Microelectrodes *XI*

Example: A potassium chloride (KCl) microelectrode immersed in 3 cm of physiological saline has a capacitance of approximately 23 pF. Suppose it is connected to the amplifier input (15 pF) through 3 ft of small-diameter coaxial cable (27 pF/ft, or 81 pF). The total capacitance is (23 + 15 + 81) pF = 119 pF. Given a resistance of 13.5 MΩ, find the frequency response of the electrode at -3dB point.

Solution

$$F = \frac{1}{2\pi RC}$$

$$F = \frac{1}{(2)(3.14)(1.35) \times 10^7\ \Omega)(1.19 \times 10^{-10}\ \text{f})}$$

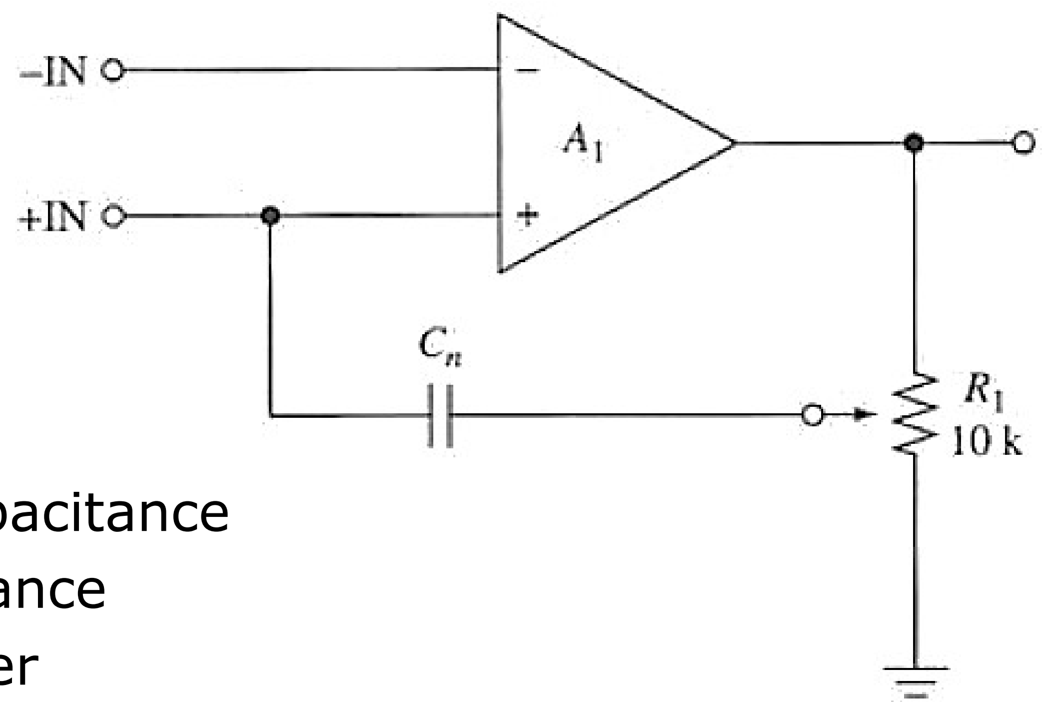
$$F = 99\ \text{Hz} \approx \mathbf{100\ Hz}$$

Microelectrodes *XII*

Capacitance nulling circuit for neutralizing the microelectrode capacitance.

- A neutralizing capacitance C_n, is in the positive feedback path along with a potentiometer voltage divider.
- The value of the capacitance C_n is

$$C_n = \frac{C}{A - 1}$$



where

Cn is the neutralization capacitance

C is the total input capacitance

A is the gain of the amplifier

Microelectrodes *XIII*

A microelectrode and its cabling exhibit a total capacitance of 100 pF. Find the value of neutralization capacitor required for a gain of 10 amplifier.

Solution

The value of neutralization capacitance is given by

$$C_n = \frac{C}{A - 1}$$

$$C_n = \frac{100\ \text{pF}}{10 - 1}$$

$$C_n = \frac{100\ \text{pF}}{9} = \mathbf{11\ pF}$$