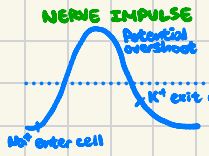
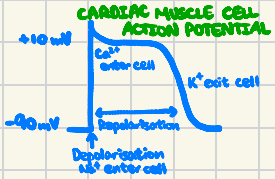
Electrochemical impulses → Contraction of cell

Resting membrane potential (-40 ~ -90 mV)

outside: Na^+ Cl^- → Slightly permeable
inside: K^+ → Fully permeable



ELECTRO-CONDUCTION PATHWAY
- Sinoatrial node
- Right atrium
- Left atrium
- Atrioventricular node
- Bundle of His
- Right bundle branches
- Left bundle branches
- Purkinje network / fibres



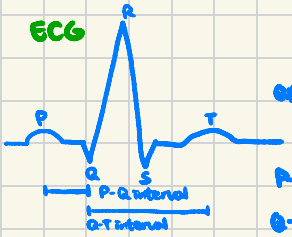
① Depolarisation
② Plateau Phase
③ Repolarisation & Contraction

EINTHOVEN TRIANGLE

Lead I: $V_I = \phi_L - \phi_R$
Lead II: $V_{II} = \phi_F - \phi_R$
Lead III: $V_{III} = \phi_F - \phi_L$

12 LEAD CLINICAL ECG
- Bipolar limb leads
- Augmented unipolar limb leads
- Unipolar (+) chest leads
  - Posterior anterior: V_1, V_2, V_3
  - Lateral: V_4, V_5, V_6

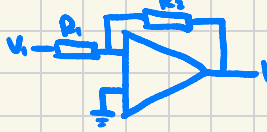
ECG



P: Atrial depolarisation → Atrial systole
QRS: Ventricular depolarisation → Ventricular systole
T: Ventricular repolarisation → Ventricular diastole
P-Q: Atrial systole & diastole
Q-T: Ventricular systole & diastole

- ECG measures electric currents produced during the cardiac cycle from AP's
- Electrodes detect voltage from AP's and muscular events

INVERTING AMPLIFIER

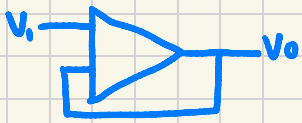


$\frac{V_o}{V_i} = -\frac{R_2}{R_1}$

NON-INVERTING AMPLIFIER

$\frac{V_o}{V_i} = \frac{R_1+R_2}{R_1}$

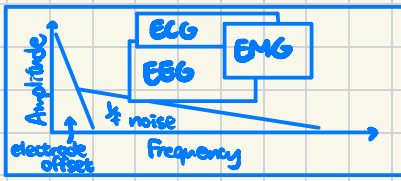
BUFFER / FOLLOWER



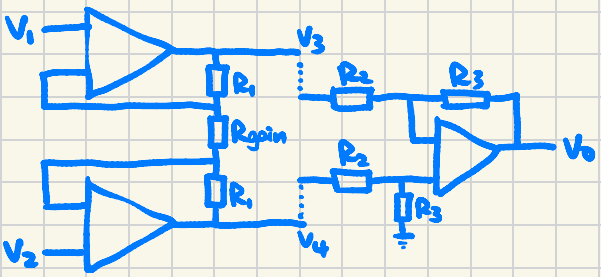
∵ No current
∴ No voltage loss
∴ No input impedance

$V = \frac{Q}{d}$
$C = \frac{\Phi}{V} = \frac{\varepsilon A}{d}$

- Put in-between skin & ECG to prevent loading error (voltage drop) due to skin impedance
~ Get voltage without current / load



INSTRUMENTAL AMPLIFIER



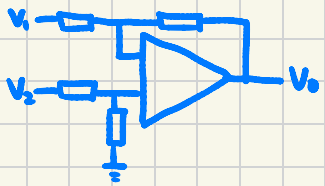
$G_c = 1$

$V_o = (V_2 - V_1)\left(1 + \frac{2R_1}{R_{gain}}\right)\left(\frac{R_3}{R_2}\right)$

For balanced design: $R_2 = R_3$ → Stage 2 = Differential Amplifier

Let V_3/V_4 for calculations!
Otherwise shit gets weird ¯_(ツ)_/¯

DIFFERENTIAL AMPLIFIER



Common mode
$V_1 = V_2 = V_i$, $G_c = \frac{V_o}{V_i}$

Differential mode
$G_d = \frac{V_o}{V_2 - V_1}$

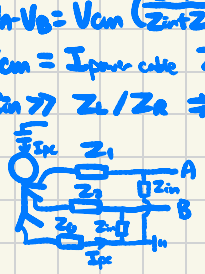
$CMRR = \frac{G_d}{G_c}$
≥ 100/10000 practically
= ∞ Ideally ($G_c = 0$)

INTERFERENCE
- Shield wires
- Coil wires
- ↓ Skin-electrode impedance
- ↑ Amplifier input impedance

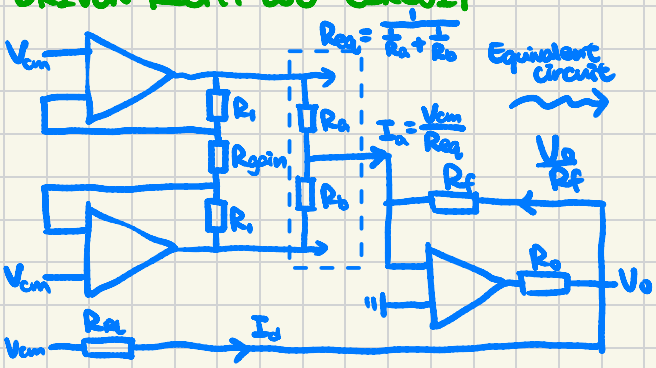
$V_A - V_B = V_{cm}\left(\frac{Z_{in}}{Z_{in}+Z_a} - \frac{Z_{in}}{Z_{in}+Z_b}\right)$

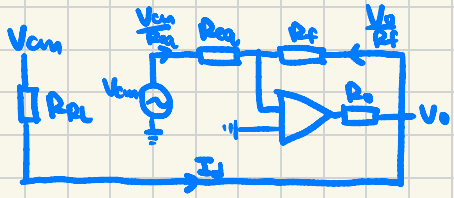
$V_{cm} = I_{power\ cable} Z_{ground}$

$Z_{in} \gg Z_L / Z_a \Rightarrow V_A - V_B = 0$



DRIVEN-RIGHT-LEG CIRCUIT





$\frac{V_{cm}}{R_{eq}} + \frac{V_o}{R_f} = 0$

$\begin{cases} V_o = -\frac{R_f}{R_{eq}} V_{cm} \\ V_{cm} = I_d R_{PL} + V_o \end{cases}$

$V_{cm} = \frac{R_{PL} I_d}{1 + \frac{R_f}{R_{eq}}}$

← $R_f \gg R_a / R_b / R_{eq}$
⇒ $V_{cm} \to 0$
⇒ ↑R_f ↑R_o ↓I_d

Motor unit AP
- Triphasic form
- 3~15 ms
- 20~2000 μV

Surface vs Needle electrode
S: Cross-talk from adj muscles
⇒ Poor selectivity
N: Small pickup area ⇒ Individual MU

Neuropathy:
- Difficulty in initiating nerve impulse
- Takes long time to transmit to muscle
⇒ EMG scatter & desynchronisation

Test EMG:
① At needle insertion
② At rest
③ Min contraction
④ Max contraction

TRANSDUCER

Case: Prevent electric shock
Damping material: Reduce vibration
Improve axial resolution

Piezoelectric crystal: Piezoelectric effect
Matching layer: Acoustic impedance between crystal & skin
Transmit more ultrasound into tissue

ATTENUATION

① ABSORPTION (friction)
- High viscosity
- Long relaxation time
- High frequency

② REFRACTION
$\frac{\sin\theta_1}{\sin\theta_2} = \frac{V_1}{V_2}$

③ SCATTERING
④ DIFFRACTION
⑤ INTERFERENCE
⑥ REFLECTION

$V_{air} = 330\ ms^{-1}$
$V_{water} = 1400\ ms^{-1}$
$V_{soft\ tissue} = 1540\ ms^{-1}$
$V_{bone} = 3400\ ms^{-1}$

Continuous:
- Doppler flow measurement
- Therapy

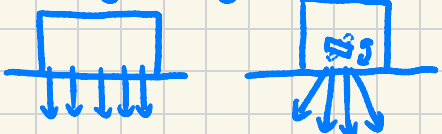
Pulse echo:
- Imaging

AMPLITUDE MODE (A-MODE)

1D

BRIGHTNESS MODE (B-MODE)

2D image of bright dots



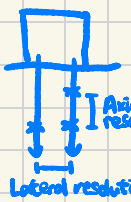
MOTION MODE (M-MODE)

Detailed visualisation of long axis

DOPPLER

$f_D = f_R - f_T$

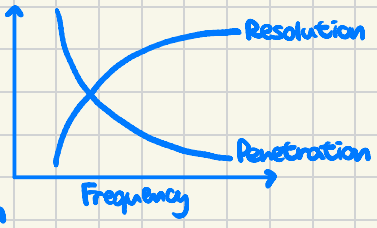
$f' = \frac{V \pm V_o}{V - V_s} f \cos\theta$



Axial resolution:
- Spatial pulse length
- Ultrasound frequency

Lateral resolution: (Limiting factor)
- Transducer size
- Beam width

∵ $V_{bone} \gg V_{soft\ tissue}$
∴ Image of bone is axially compressed
⇒ Bone distortion



- Lab-on-a-chip (MEMs / Microfluidics)
- Fluorescence-based DNA Biosensor
- Label-free sensors
  - Field effect (charge → current) → Protein
  - Electrochemical (chemical → current) → Glucose
  - Cantilever (mass → frequency) → Protein

BINDING AFFINITY

$\frac{d[AB]}{dt} = k_1[A]_s([B]_{max} - [AB]) - k_{-1}[AB]$

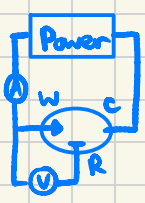
$k_1[A][B] = k_{-1}[AB]$

$K_d = \frac{k_{-1}}{k_1} = \frac{[A][B]}{[AB]}$ (50% bound)

k_1 : association rate const
k_{-1} : dissociation rate const

ELECTROCHEMICAL SENSOR

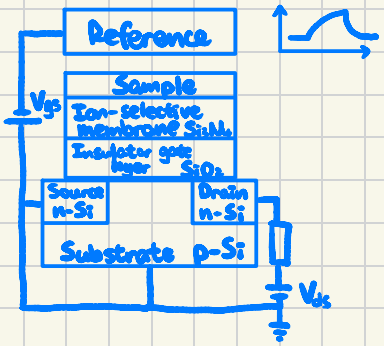
Enzyme → Redox → Current
Concentration ∝ Rate of reaction ∝ Current
- Accurate & Reliable (~ppm)
- Power-efficient
- Portable & Easily integrated
- Limited lifespan (2-3 yrs)
- Require calibration against reference
- Sensitive to temperature

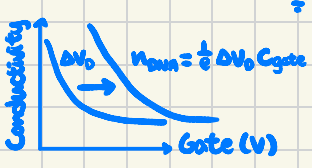


Ag/AgCl:
Working electrode
Counter electrode
Reference electrode

FIELD EFFECT SENSOR

Charge ↝ MOSFET → Conductivity

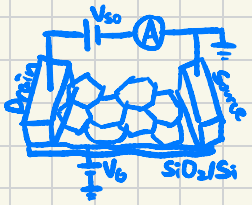


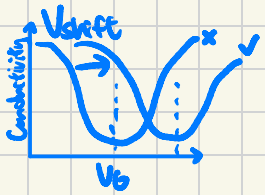


GRAPHENE FIELD EFFECT DNA SENSOR

$\Delta V_D' = A\frac{c}{K_d + c}$

$\Delta V_D^{rel}(c) = \frac{c}{K_d + c}A$





CANTILEVER SENSOR