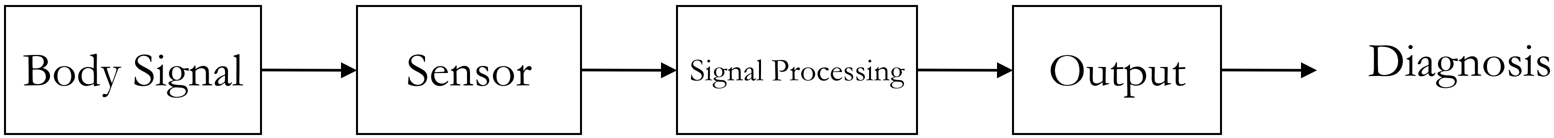
Bio-Potential Amplifiers

Biomedical Models for Diagnosis



- Body signals and sensors were covered in EE470
- The signal processing part is in EE471
- Bio-Potential Amplifier ➔ Biological Potential difference
- Signal processing includes amplification and filtering
- Why Amplification?
- Why filtering?

Basic Requirements for Amplifiers

- Type of amplification:
  - Voltage Amplification
  - Current Amplification
- High input impedance (≥10 MW) …why?
- Isolation and protection circuits … why?
- Low output impedance …why?
- High common mode rejection ration … why?
- The appropriate frequency spectrum, SNR, gain,
- Calibration input to calibrate the amplifier

Example of Bio-Potential Amplifier
ECG Amplifier

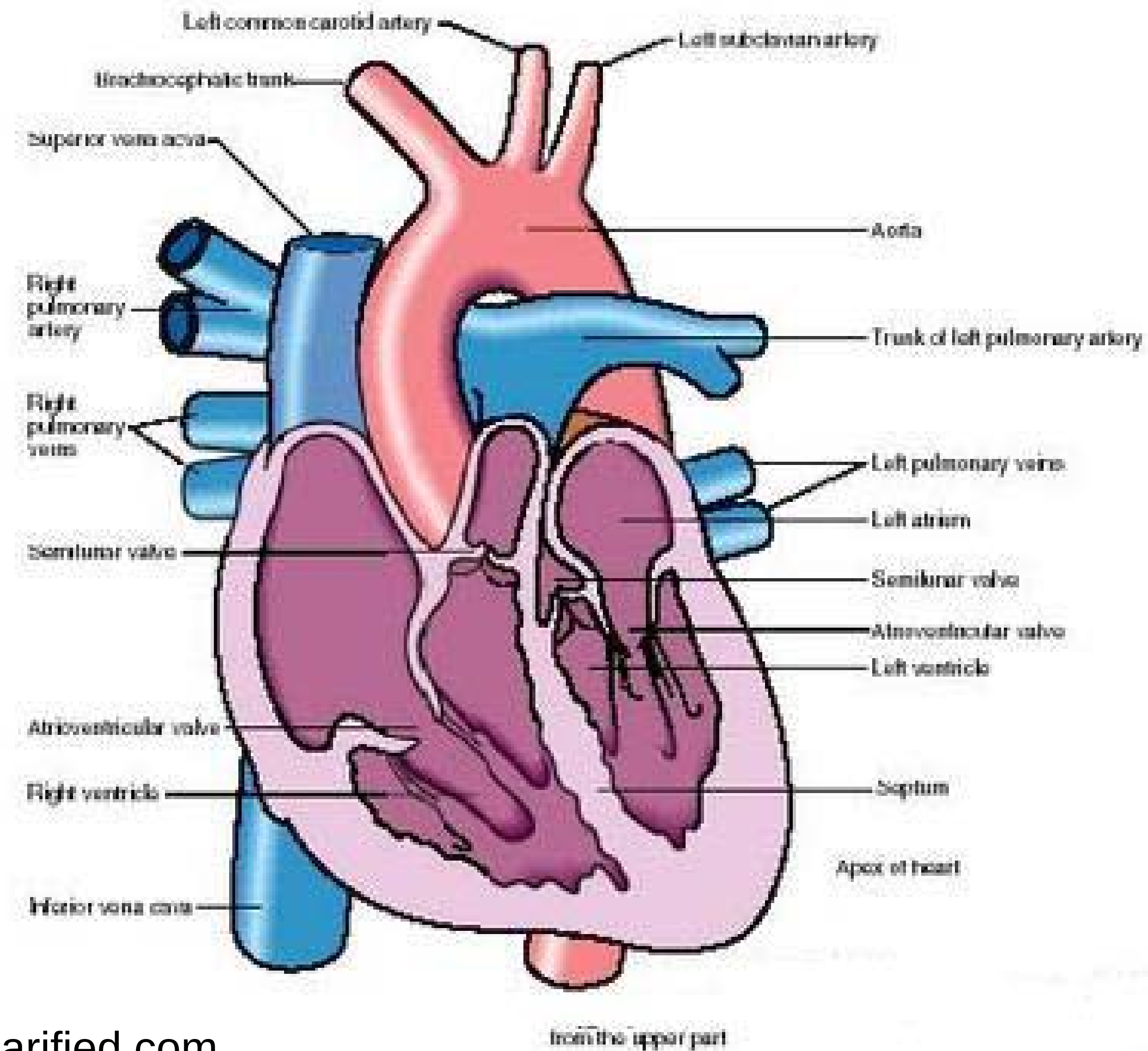
Origins of the electrocardiogram

- Blood Cycle
- The cardiac vector
- The ECG waveform
- Indicator of a good ECG
- 12-lead electrocardiography

Blood Cycle of the Heart

- Objectives of the cycle:
  - Provide Oxygenated blood to all body cells
  - Remove Carbon-Dioxide accumulating in cells
- Two Blood Cycles simultaneously
  - Pulmonary cycle ➔ add oxygen and remove Co_2
  - Blood Cycle ➔ carry oxygen to body cells

Normal heart as a pump and muscular structure

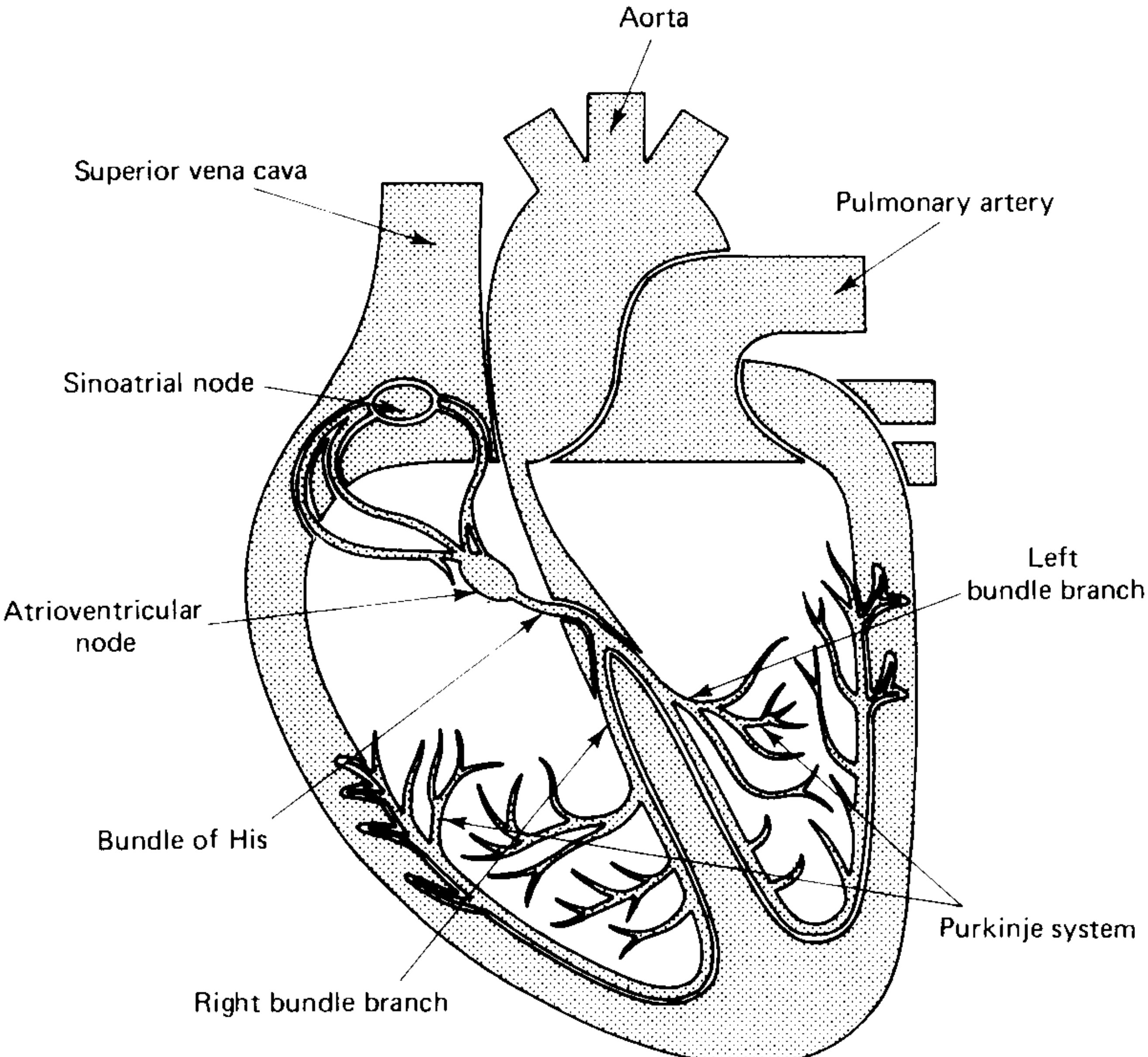


From scienceclarified.com

The Heart Beat (Cardiac cycle)

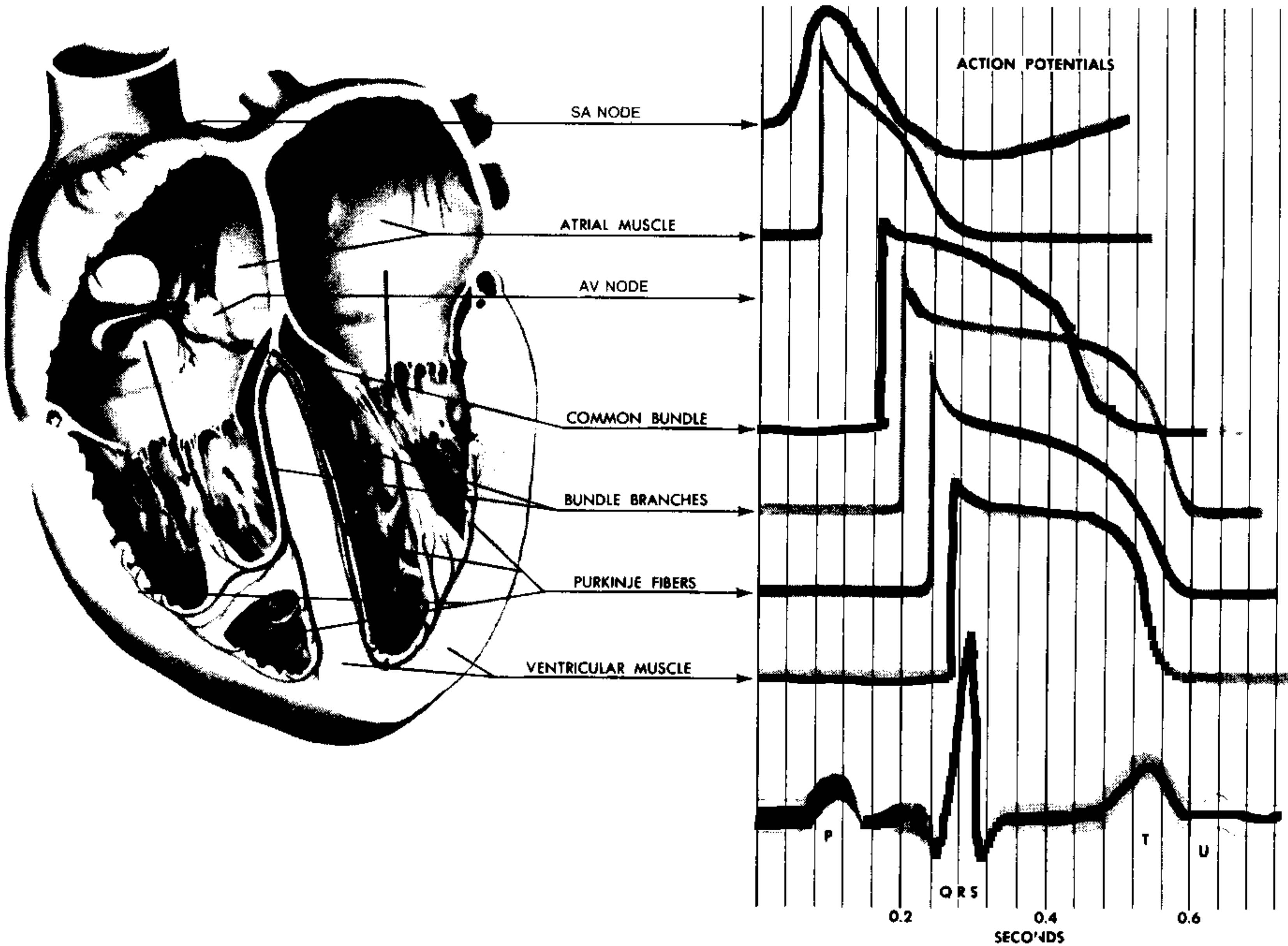
- Two Phases
  1. Two atriums contract and two ventricles relax
  2. Two ventricles contract and two atriums relax
  3. Four chambers relax
- Terminology:
  – Systolic phase ➔ contraction
  – Diastolic phase ➔ relaxation
- Control is done via an independent nervous system in the heart though electrical signals

Conduction mechanism of the heart



Sequence of Control Signals

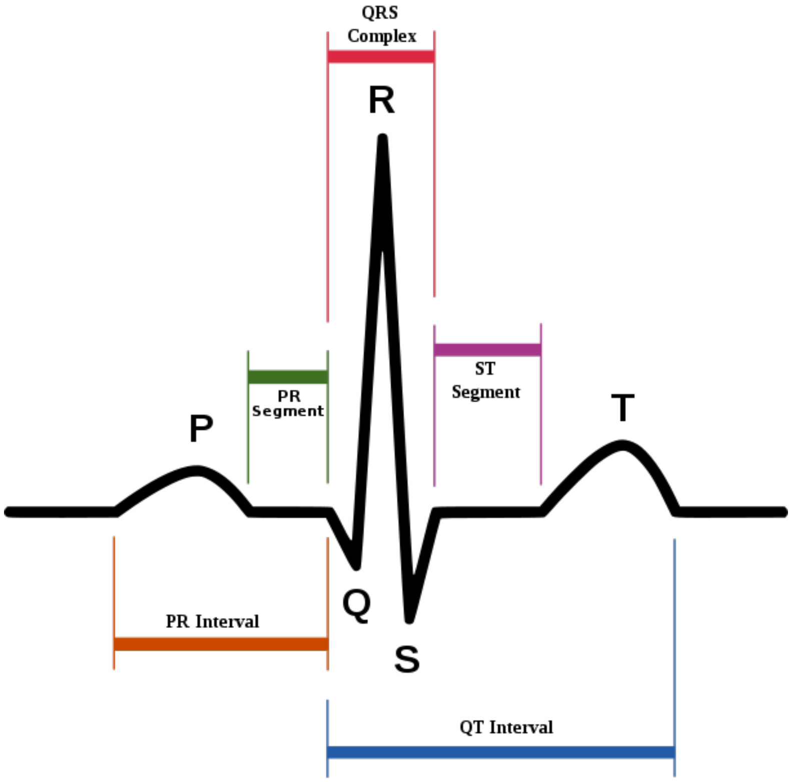
- SA node (heart pace maker) initiate signal to atriums causing it to contract ➔ blood flows through valves to ventricles
- Impulse flows till it reaches AV node
- AV node fires a signal along the bundle of his and ventricles contract in top to bottom fashion to push the blood out of the heart
- http://en.wikipedia.org/wiki/File:ECG_principle_slow.gif#file



Origin and propagation of the action potential in the cardiac muscles

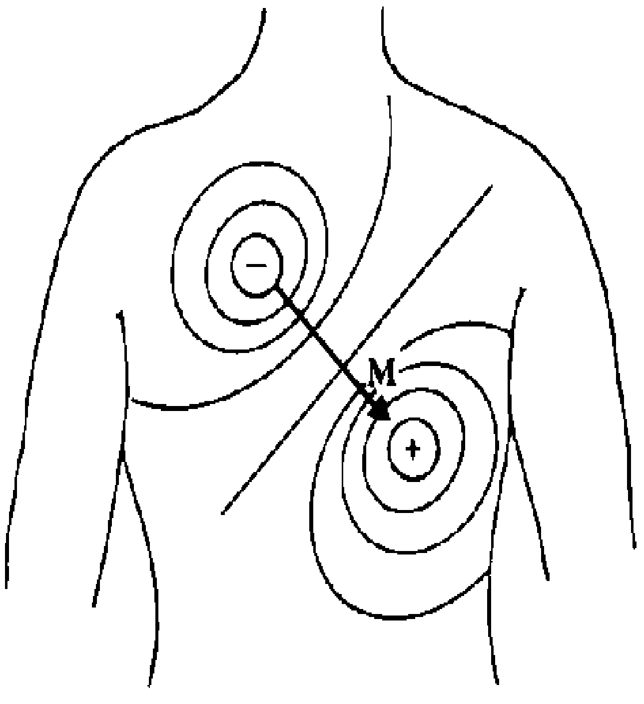
Components of ECG

- The ECG is drawn against time.
- It contains elements indicating the temporal relationship between different actions taking place during a cardiac cycle.
- The respective amplitudes of these elements and their respective positions are studied



Picture from wikipedia.com

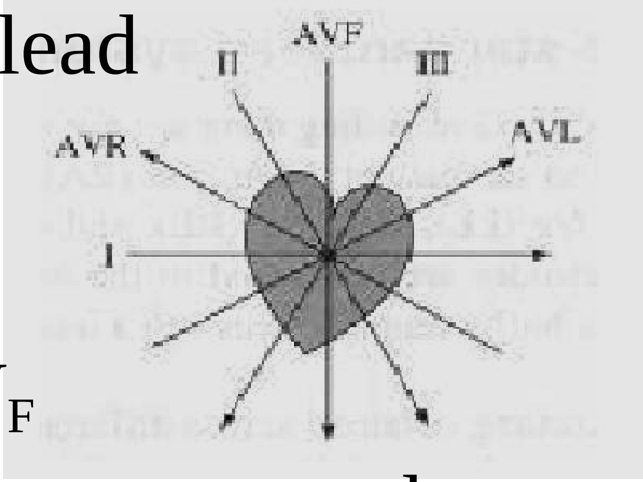
ECG Amplifiers

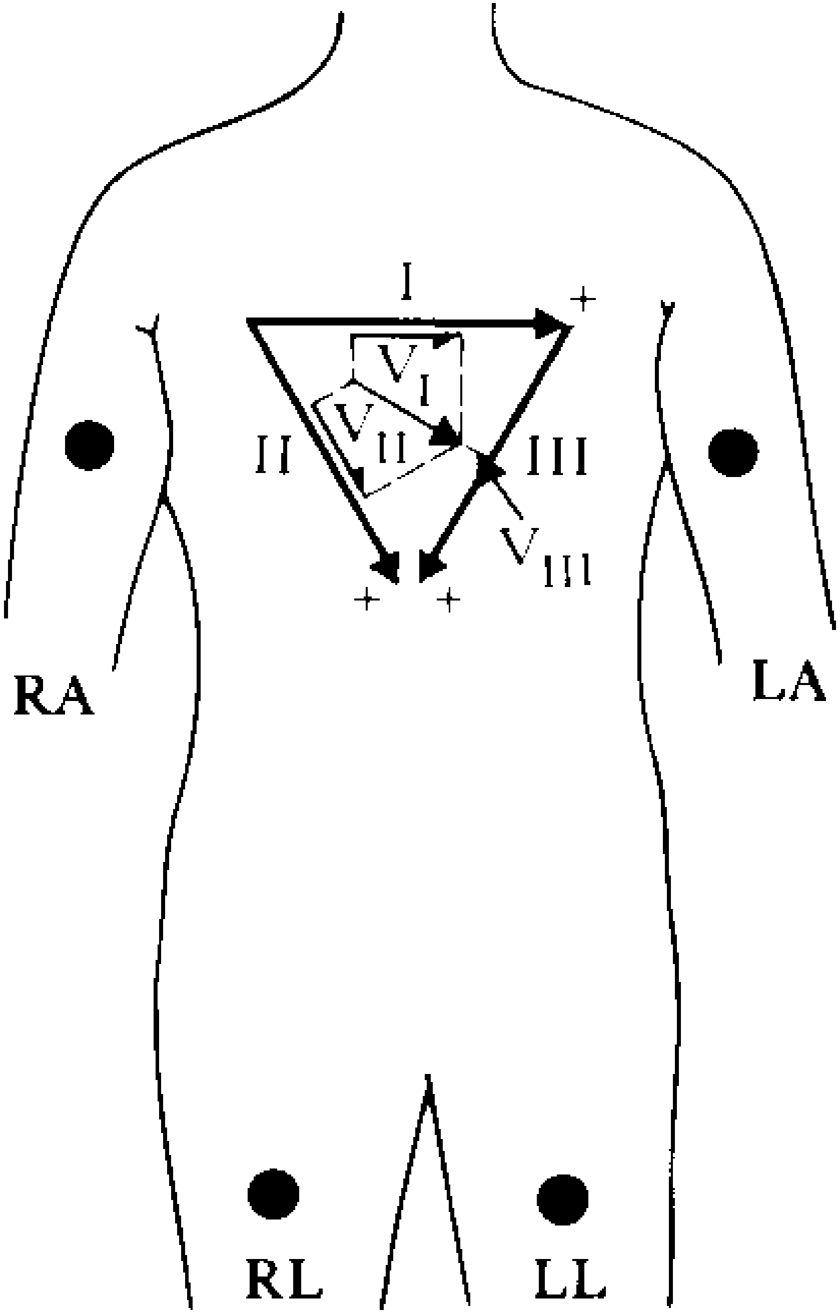


- The electrical activity of the heart can be modeled as an Electric dipole in the thorax
- This dipole is represented with a vector that varies in amplitude and direction (cardiac vector)
- Defined lead vectors: unit vectors with fixed orientation
- Vector can be observed from different directions and angles

12-Lead Electrocardiography

- The electrocardiogram is measured by putting electrodes on specific locations on the body.
- The electrodes used, their respective wires and resistors for measuring the ECG from a particular direction is called the lead
- Measurement in Frontal Plane
  - – Bipolar limb leads, I, II, III
  - – Unipolar limb leads, aV_R, aV_L, aV_F
- Precordial (chest) leads for transverse plane (V1-V6)



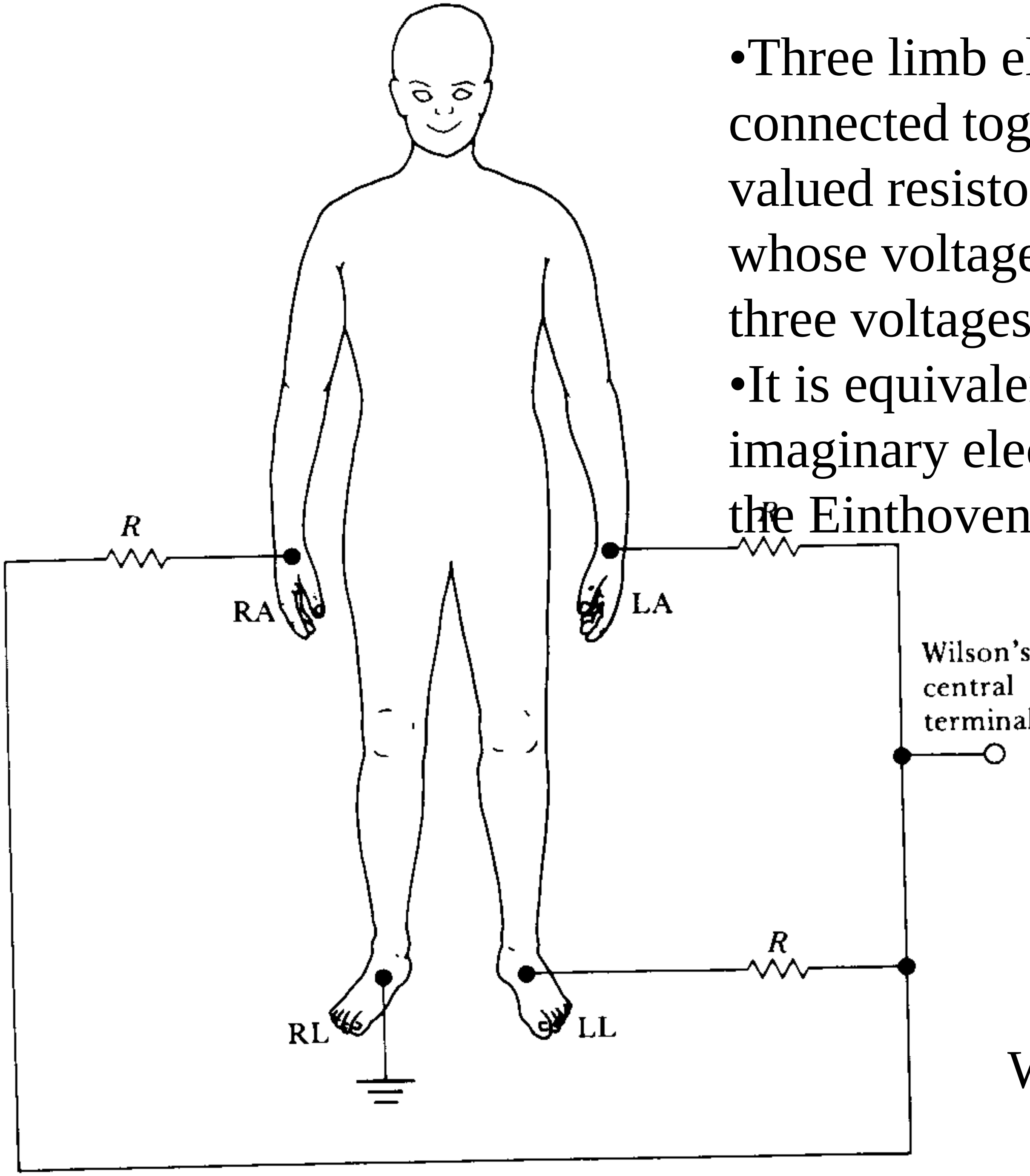


Bipolar limb leads

- Projection of the cardiac vector in the frontal plane is obtained and the projection vector is studied in three directions that are 60 degrees apart.
- The directional components are called lead I, II and III as they are measured between LA and RA, LL and RA, and LL and LA resp.
- In all measurements the right leg (RA) is used as the reference ground for the differential amp.
- Lead vectors I, II and III form an equilateral triangle.
- At any given time **I – II + III** = 0

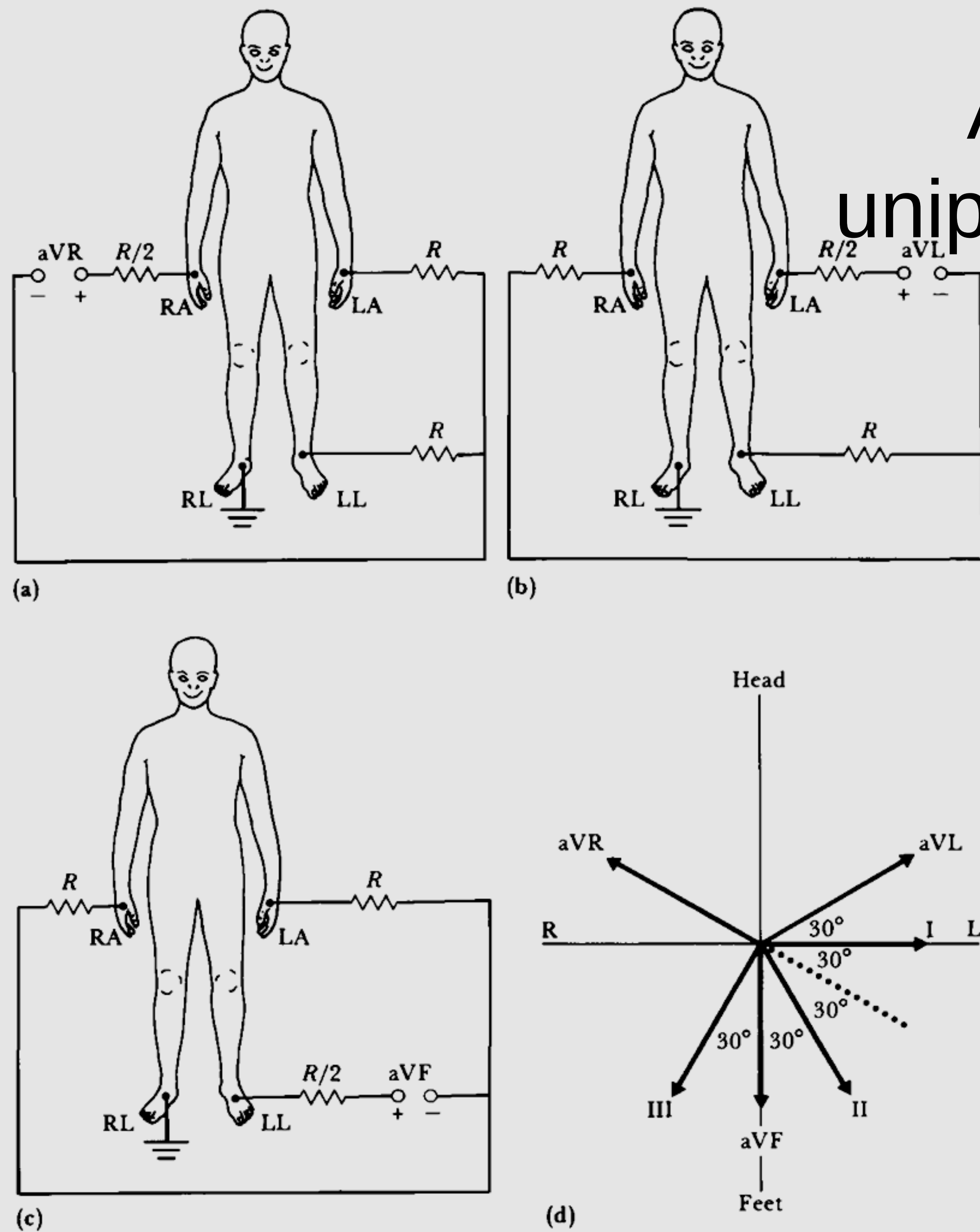
•Three limb electrodes are connected together through equal valued resistors to obtain a terminal whose voltage is the average of three voltages.

•It is equivalent to placing an imaginary electrode to the centre of the Einthoven’s triangle.



Uni-Polar limp leads
Wilson’s central terminal

Augmented unipolar limb leads



- 33% increase in voltage measured by disconnecting the measuring electrode from the Wilson’s terminal without affecting the direction of the lead vector.
- Three new configurations thus obtained as aVR, aVL and aVF. “a” stands for “augmented”.
- A resistance of R/2 is added to balance the input impedances seen by both inputs of the diff. amplifier.

Homework 1
Bio-Potential Amplifiers and ECG leads

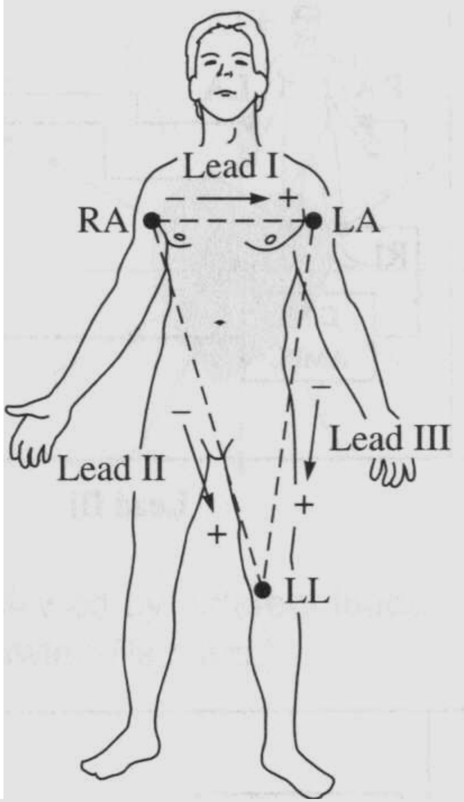
1. Explain why Bio-Potential Amplifiers need to have the following requirements:
   - High Input Impedance
   - Low output impedance
   - Frequency response appropriate to the signal
   - Isolation Circuit
2. Show that the voltage at wilson central point (figure 6.4) is the average of the voltages at each node
3. Show that voltage at the augmented lead shown in figure 6.5 increases the output voltage and calculate this increase

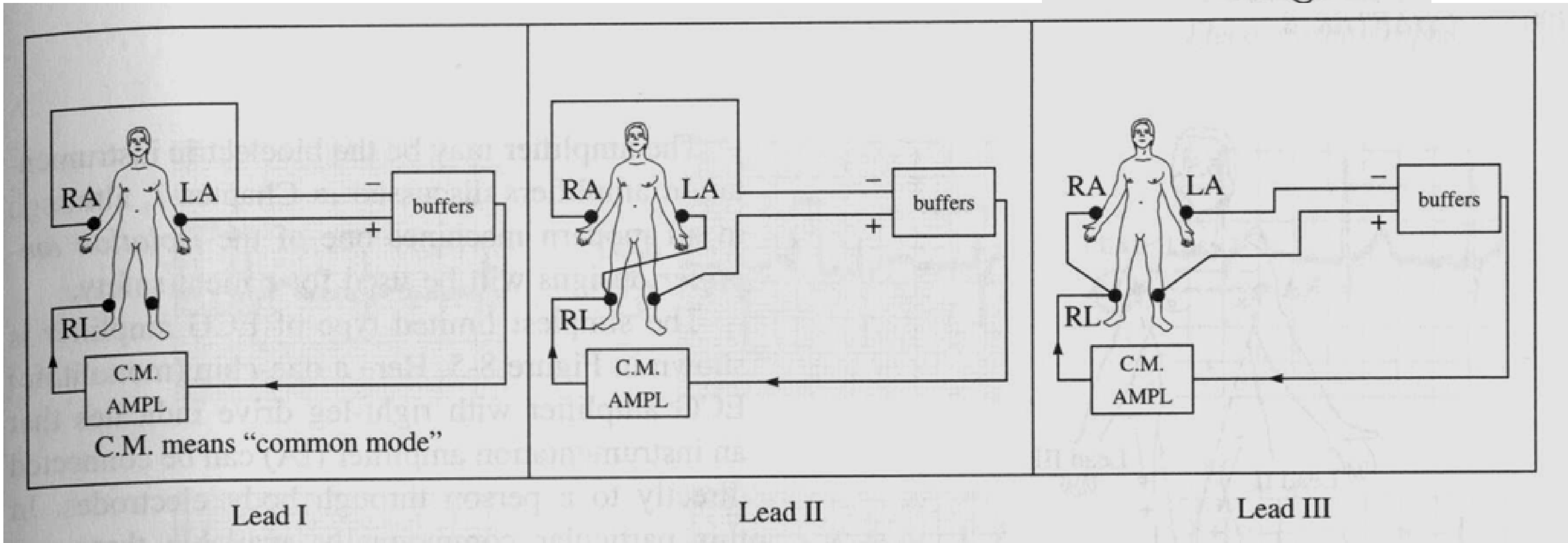
Notes:

- Homework due at beginning of Tue Oct 20th class
- Late submission are subject to 10% decrease for everyday after the class
- No late submissions would be accepted after Sun Oct 24th class

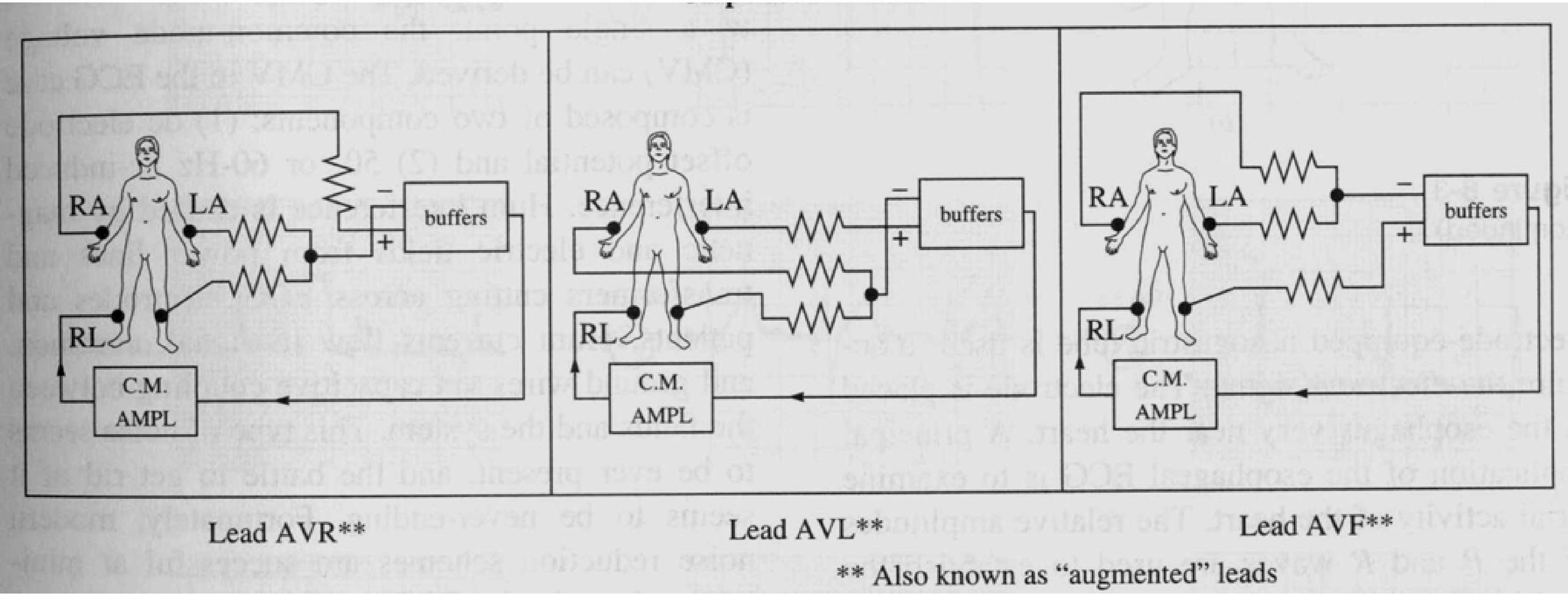
Bio-Potential Amplifier II

Electrode connections in bipolar limb leads



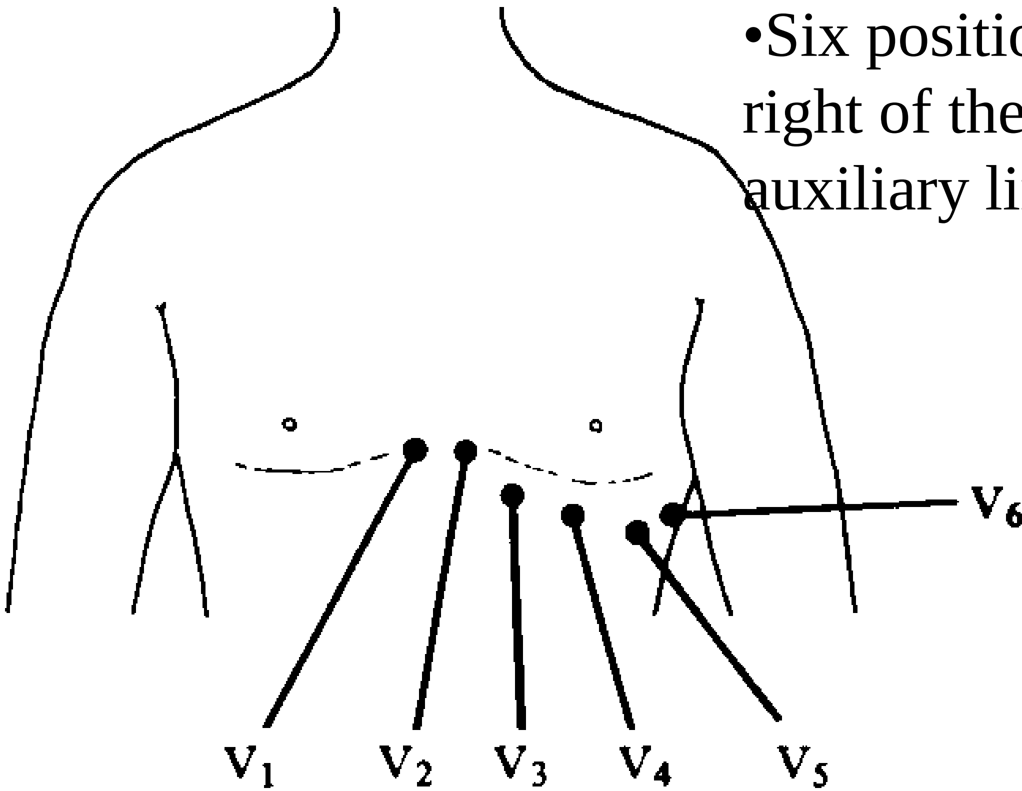


Electrode connections in uni-polar limb leads

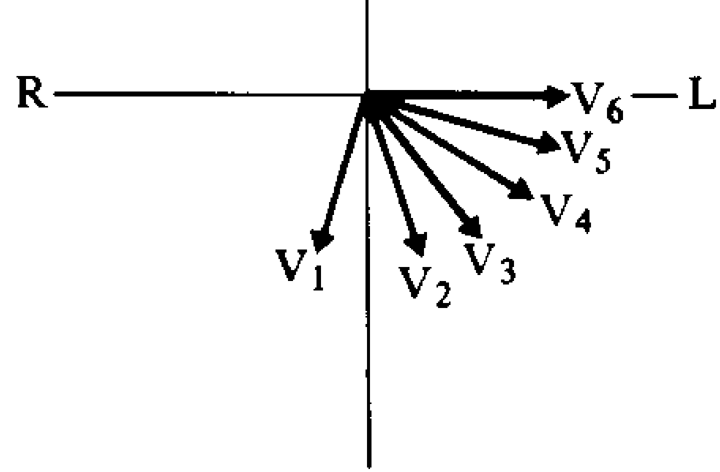


Measurement in transverse plane (top view)

•Six positions are selected from the right of the manibrium to the mid auxiliary line



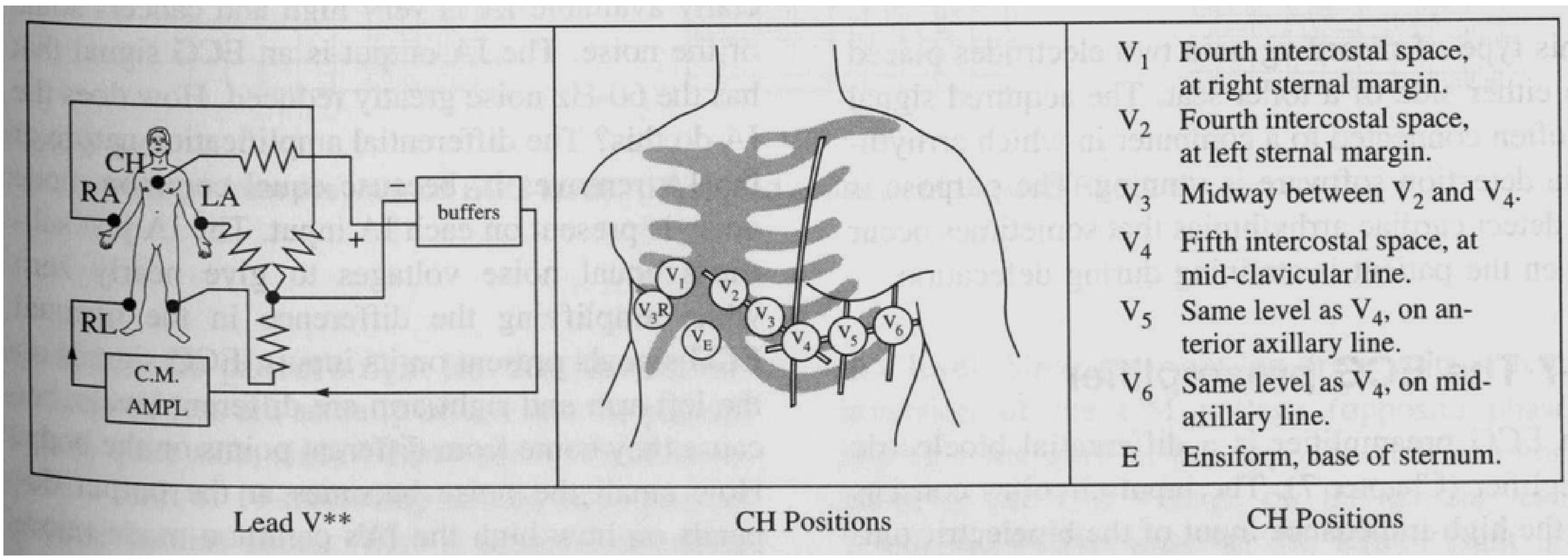
(a)



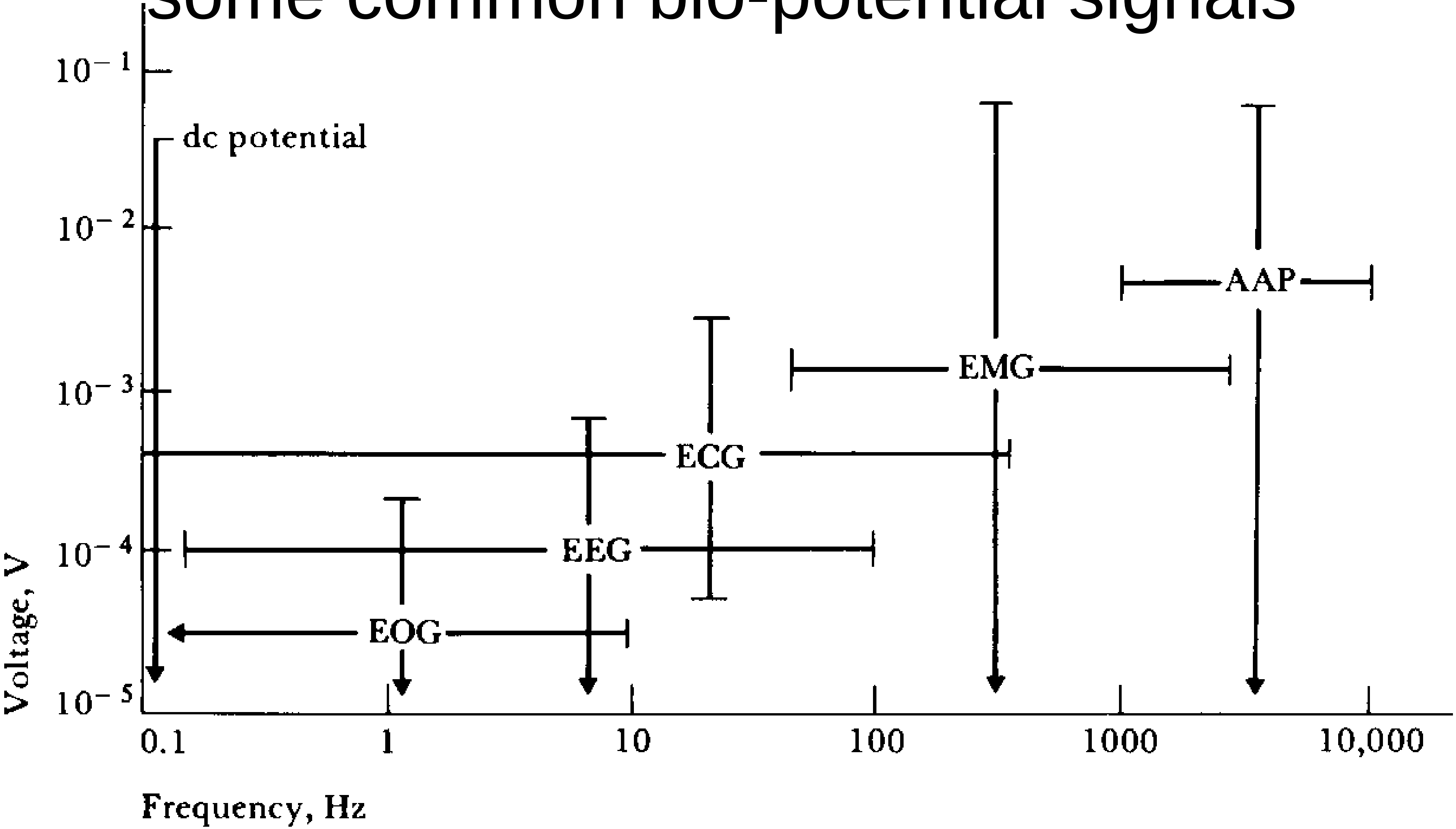
(b)

•Electrodes are placed over the chest and voltages are measured with respect to the Wilson’s central terminal

Electrode connections in unipolar chest leads



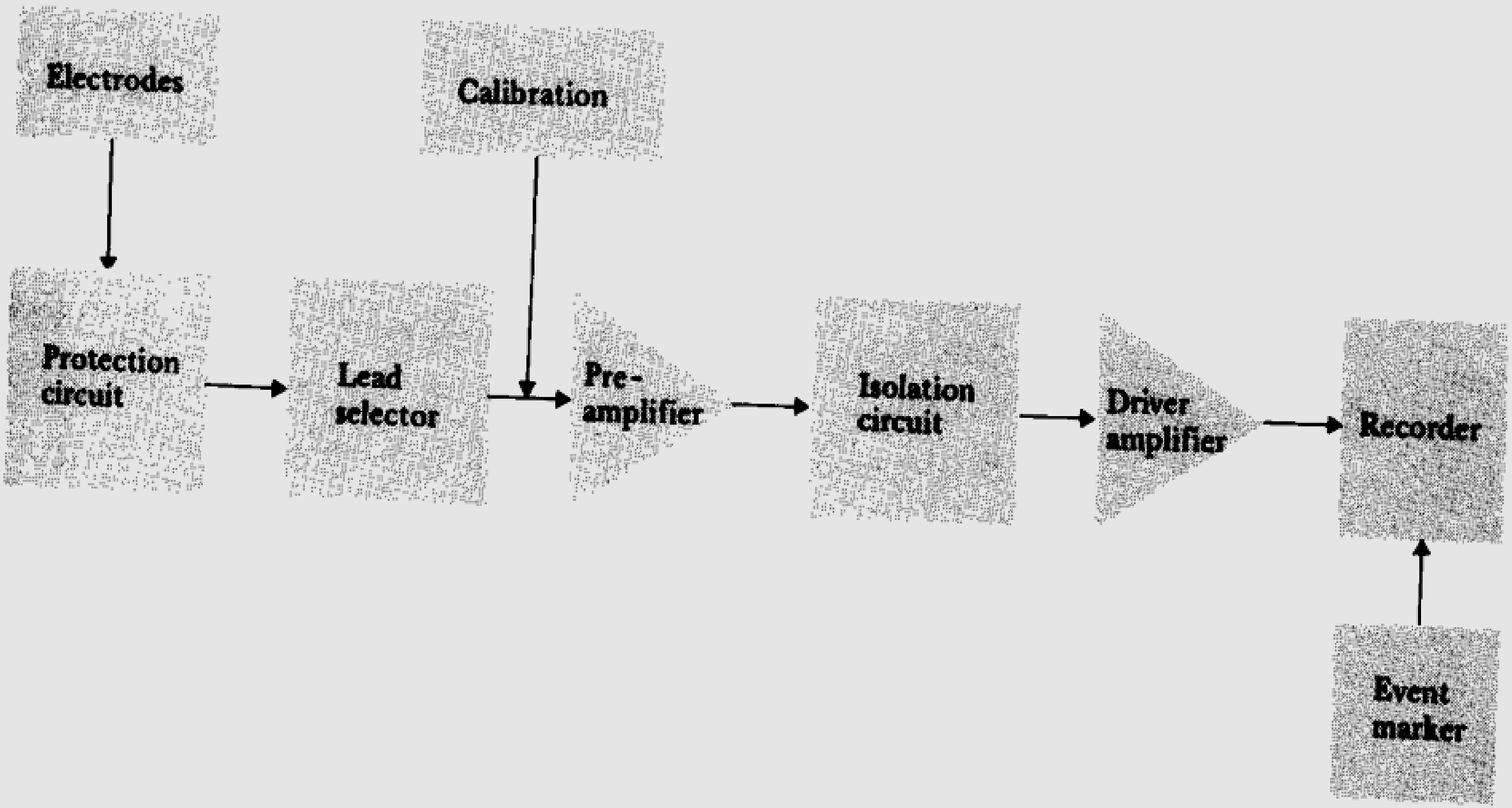
Voltage and frequency ranges of some common bio-potential signals



ECG Amplifier requirements

- Protection circuit (zener diodes, gas-discharge tube)
- Lead selector switch (can be controlled by a microprocessor)
- Calibration signal (1mV)
- Preamplifier: high input impedance, high CMRR, gain selector.
- Isolation circuit: protect subjects from 50-60 Hz current
- Driven right leg circuit
- Driver amplifier: contains BPF to remove dc offset, amplifies signal to appropriate level.
- Memory system: samples of each lead are stored
- Microcomputer
- Recorder-printer: provides hard copy of the signal

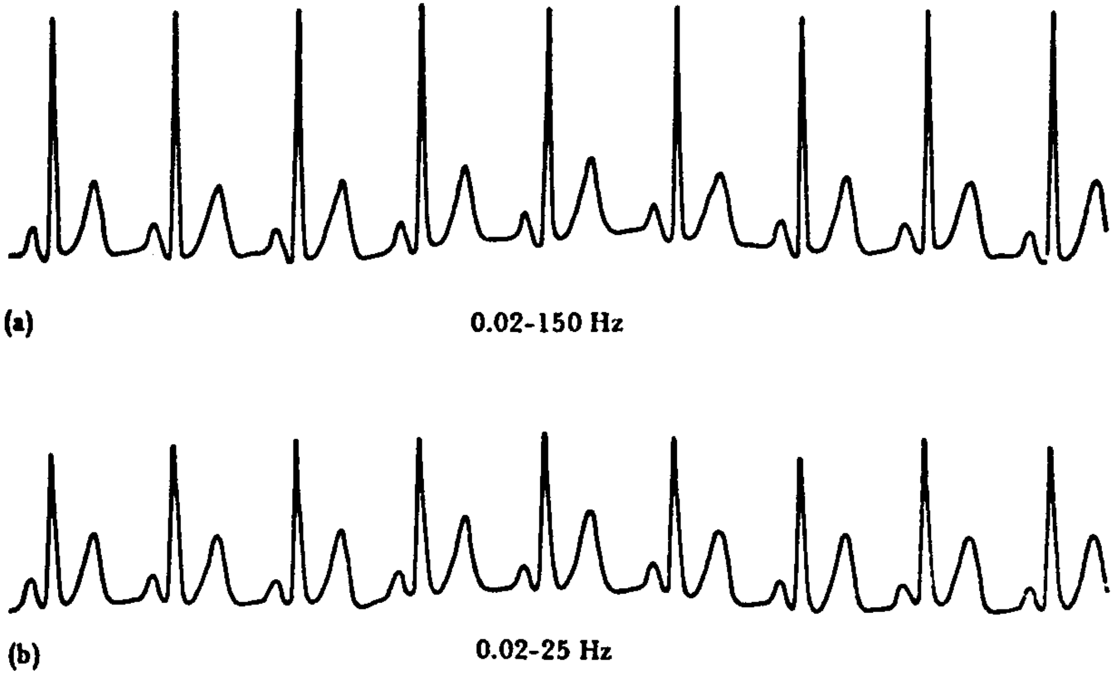
Block diagram of an earlier version of an electrocardiograph



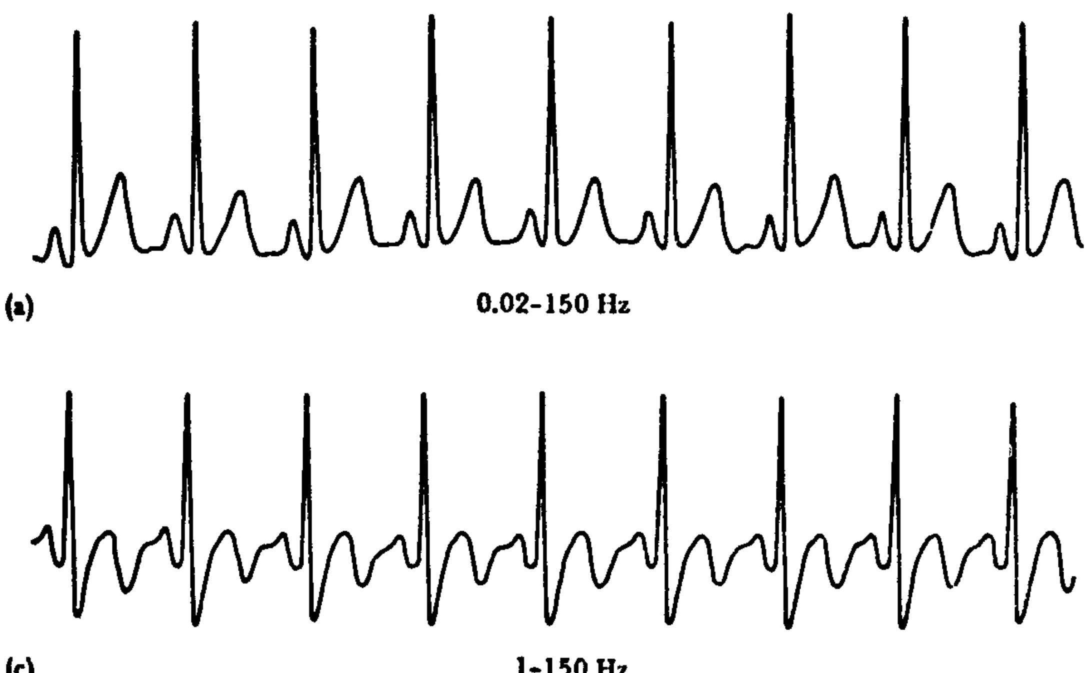
Problems frequently encountered in electrocardiography

- Distortion in the Signal
  - Frequency distortion
  - Saturation or cut-off distortion
- Ground loops
- Open lead wires
- Artifacts from large electrical transients
- Interference on signal
  - Interference from electrical devices
  - Electromagnetic interference
  - Interference from other biological signals

Frequency distortion



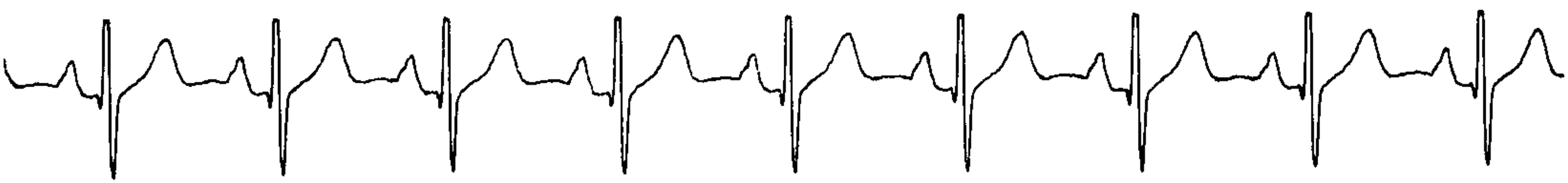
The high f components of the signal are attenuated yielding a rounding of sharp edges and dropping in the R-wave magnitude. This is a distortion in the signal due to high f limitation.



A distortion due to low f limitation. The signal looks like a differentiated one and the stable baseline needed for the clinical ECG is lost

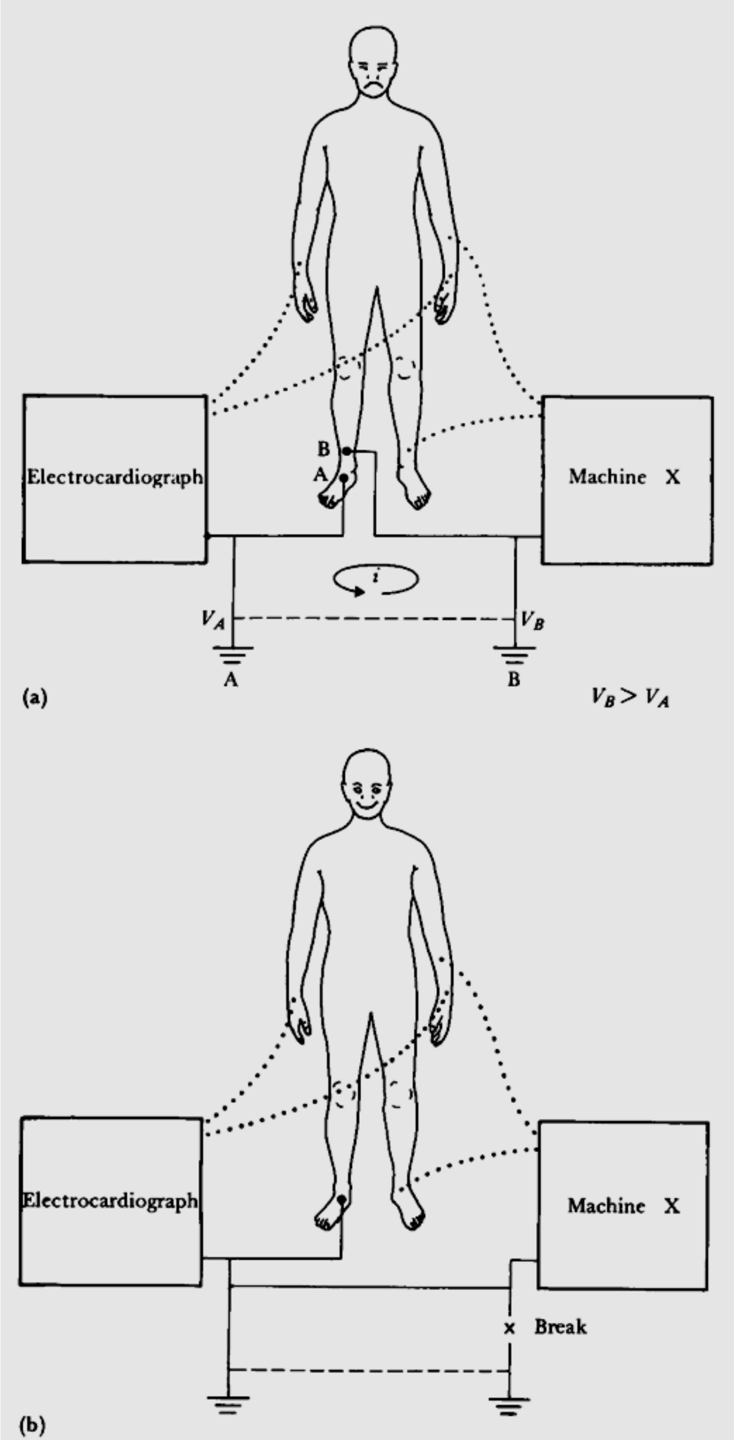
Saturation or cut-off distortion

(a)



(b)

(c)

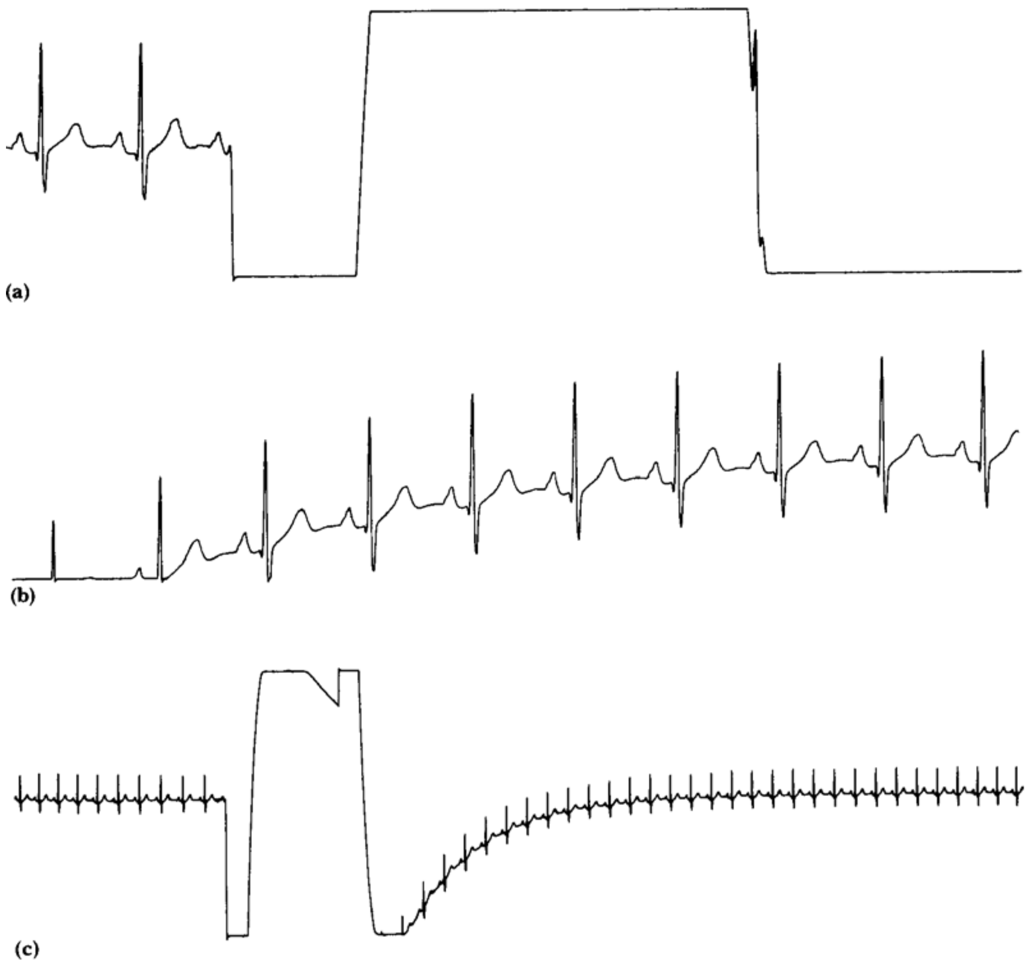


Ground loops and their elimination

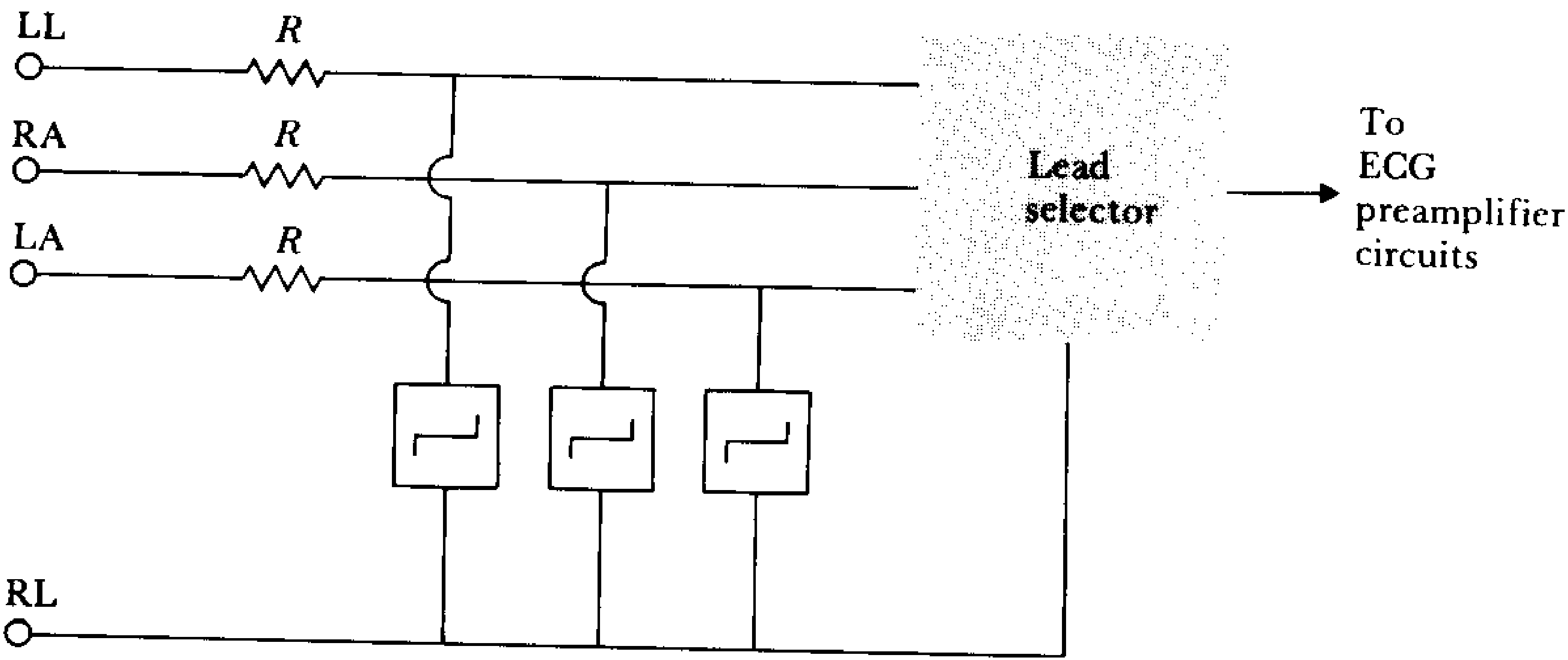
Solution
Connect the grounds for both machines together

Artifacts from large electrical transients

Example: Defibrillator

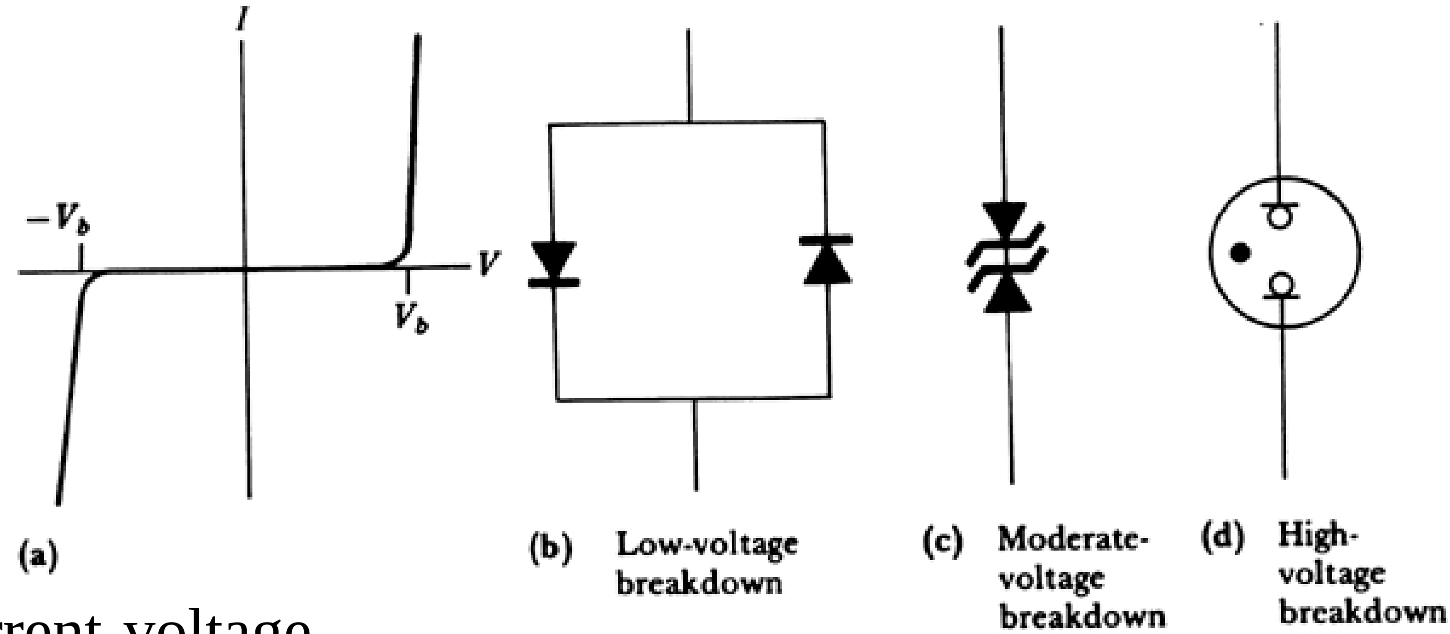


Solution: Transient protection



A voltage protection scheme at the input of an ECG amplifier

Solution
Voltage-limiting devices used for input protection



2-20 V

50-90 V

Current-voltage characteristic

Parallel silicon diodes

Back-to-back silicon zener diodes

Gas discharge tube (neon light)

How do voltage limiting devices protect the input of the amplifier?

60-Hz power line and electromyography interference

(a)

60-Hz power-line interference on the ECG

(b)

Electromyography interference on the ECG

Solution: Proper filter design

Lead Dropping

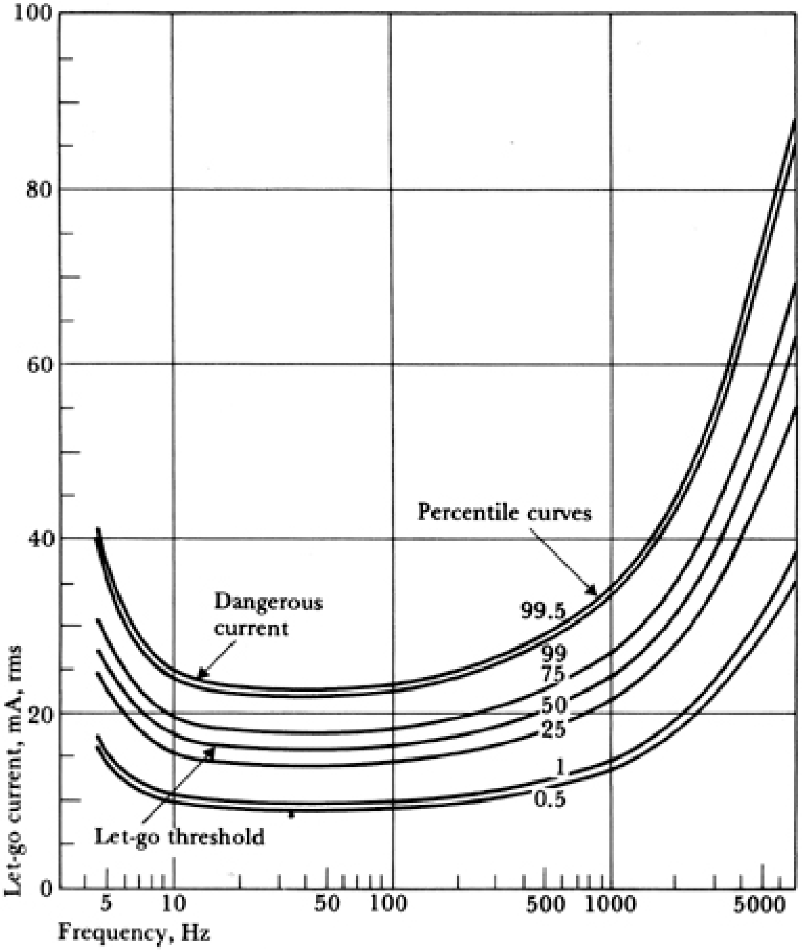
- Lead drop = No ECG = Patient is Dead !!
- Medical staff not EE specialists
- Training example

Solution

- Lead drop detector circuit

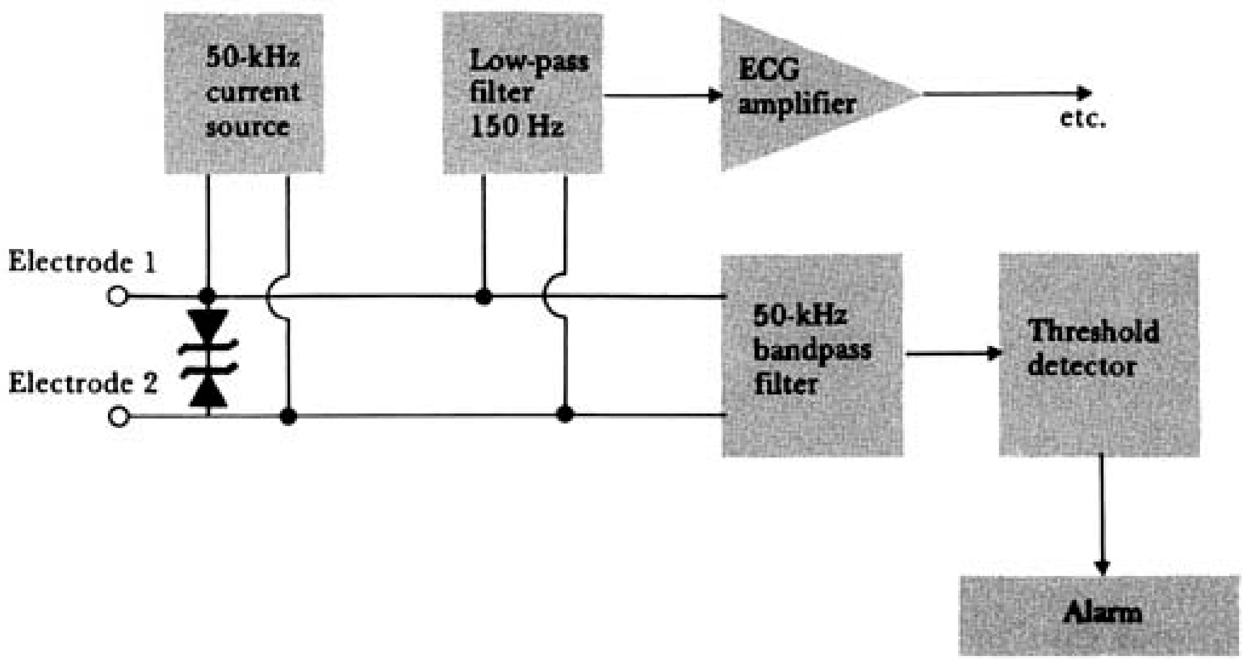
Effect of Frequency

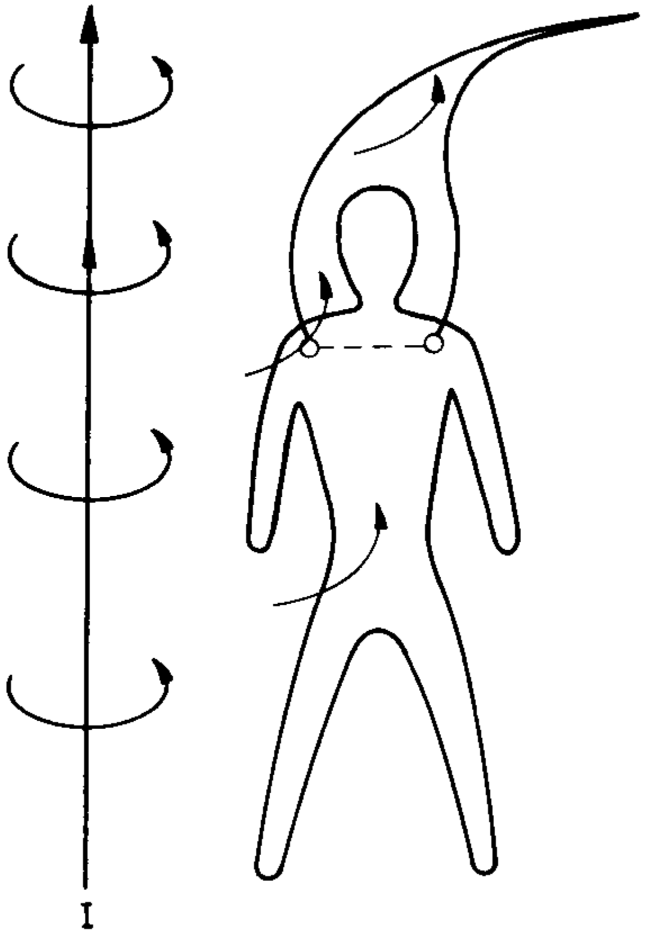
- Let go current
- Higher frequency, less dangerous
- Why don't we generate electricity at high frequencies?



Open lead wire detector

- Lead wire breaks or poorly contacting the body

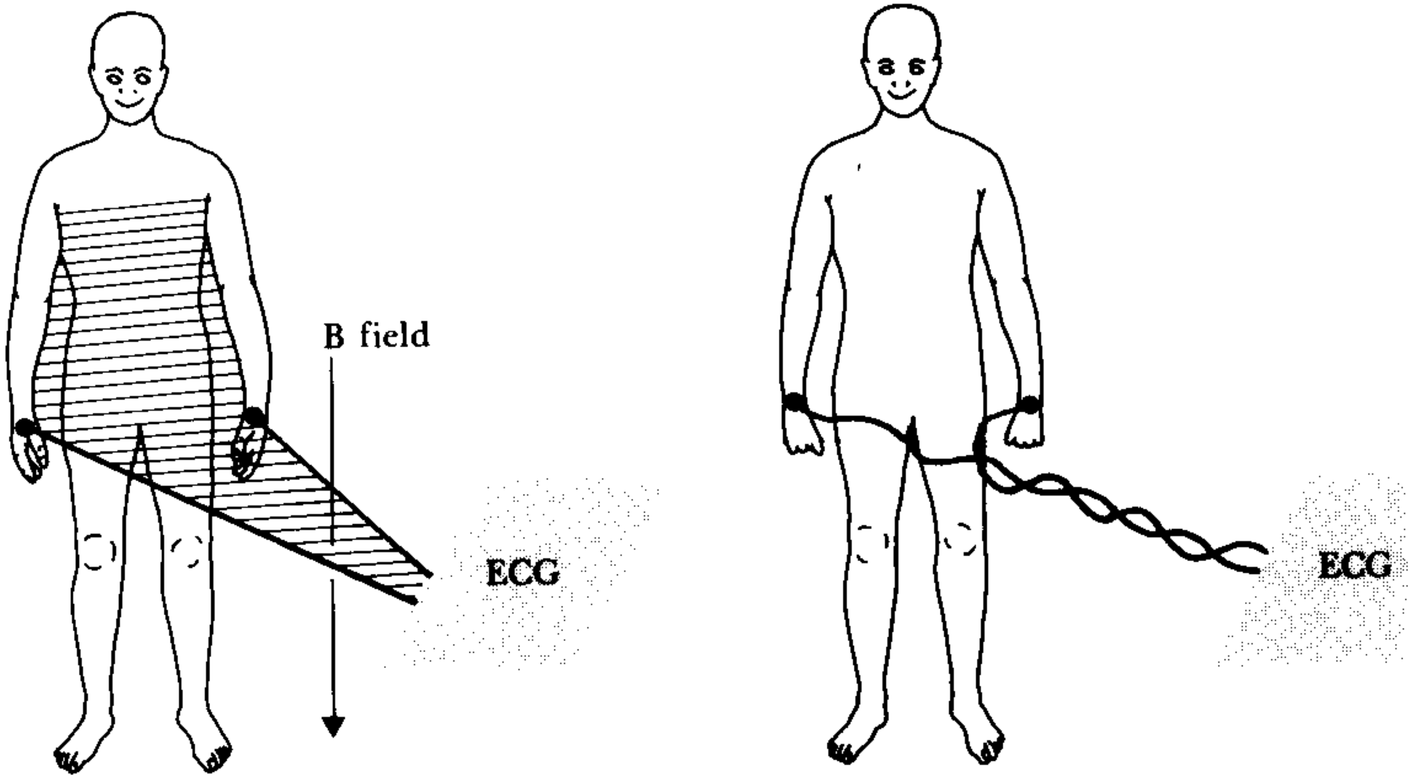




2-Generation and effects of magnetic field

- Protection through alternative path for the current

Currents Picked up in the Body
1-Magnetic field pickup



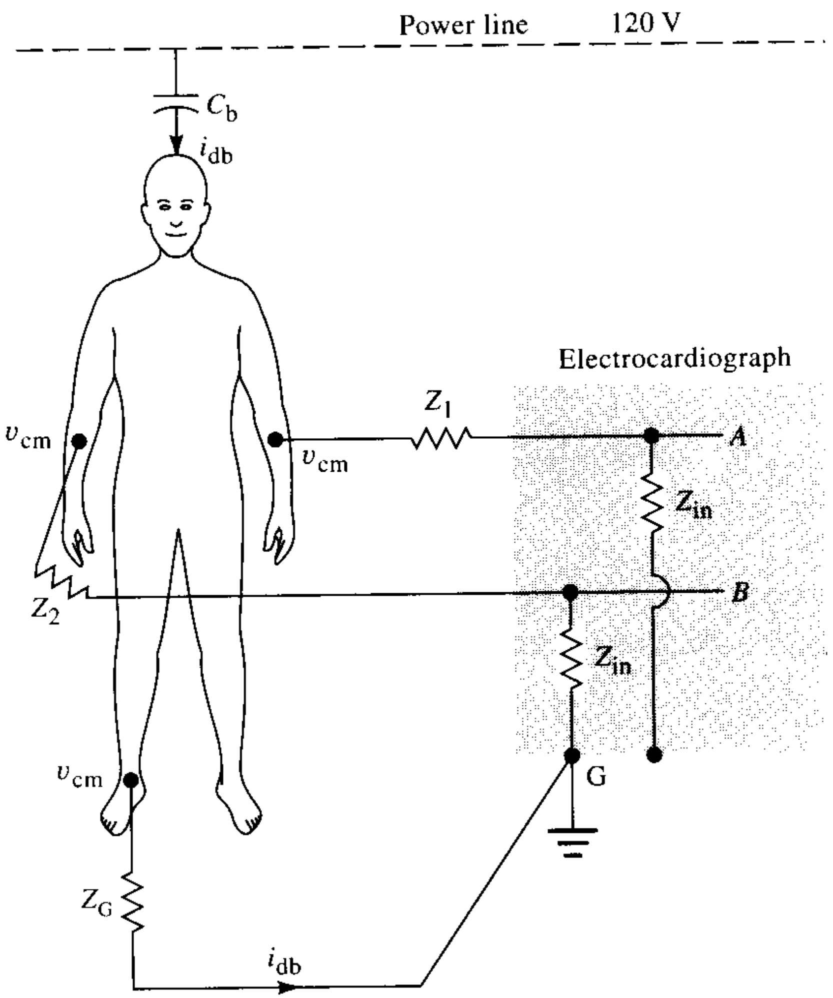
(a) (b)

Lead wires for lead I making a closed loop with patient and ECG machine

Solution

Twisting lead wires together and keeping them close to body minimizes interference

Currents Picked up in the Body
2-Pickup due to displacement current flowing through the patient



$$v_A - v_B = v_{cm}\left(\frac{Z_{in}}{Z_{in}+Z_1} - \frac{Z_{in}}{Z_{in}+Z_2}\right)$$

$$Z_1 \text{ and } Z_2 << Z_{in}$$

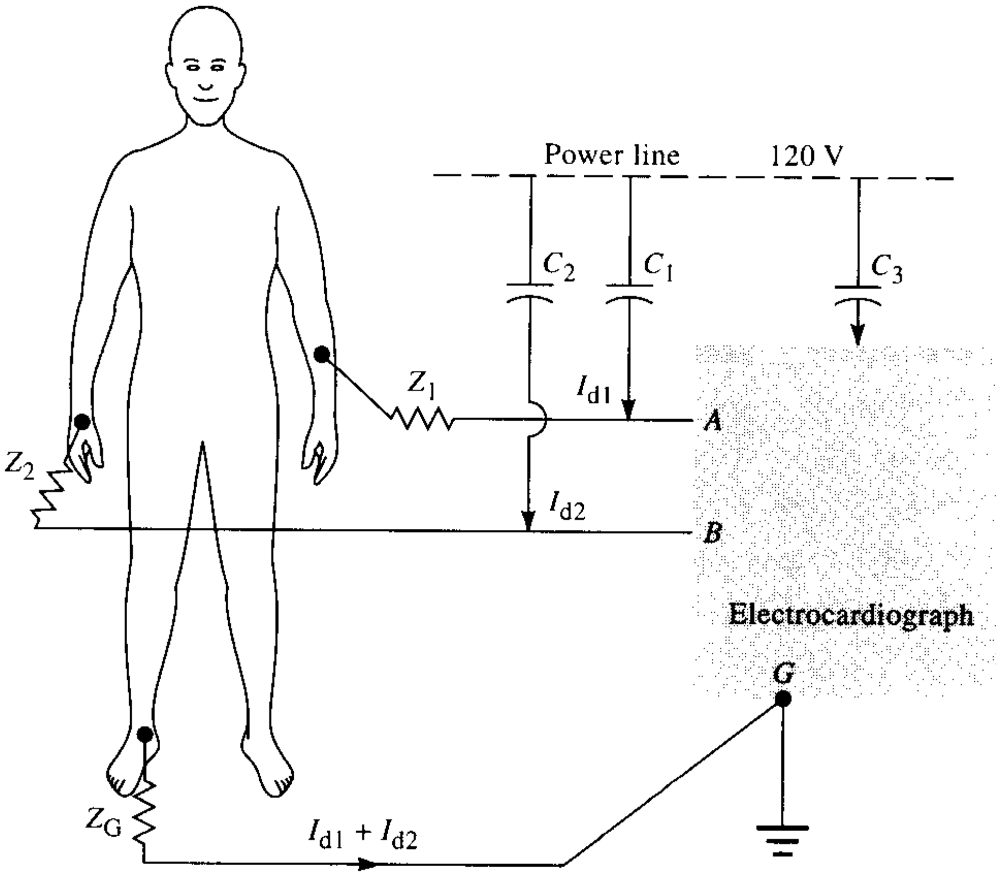
$$v_A - v_B = v_{cm}\left(\frac{Z_2 - Z_1}{Z_{in}}\right)$$

$$v_{cm} = i_{db} Z_G$$

Solution

Choose High input impedance Amplifier

Currents Picked up in the Body
3-Electrical field pickup by connecting wires and instrument



- What is a Capacitor?
- Coupling between hot side of the power line and lead wires

$$v_A - v_B = i_{d1}Z_1 - i_{d2}Z_2$$

With $i_{d1} \approx i_{d2}$

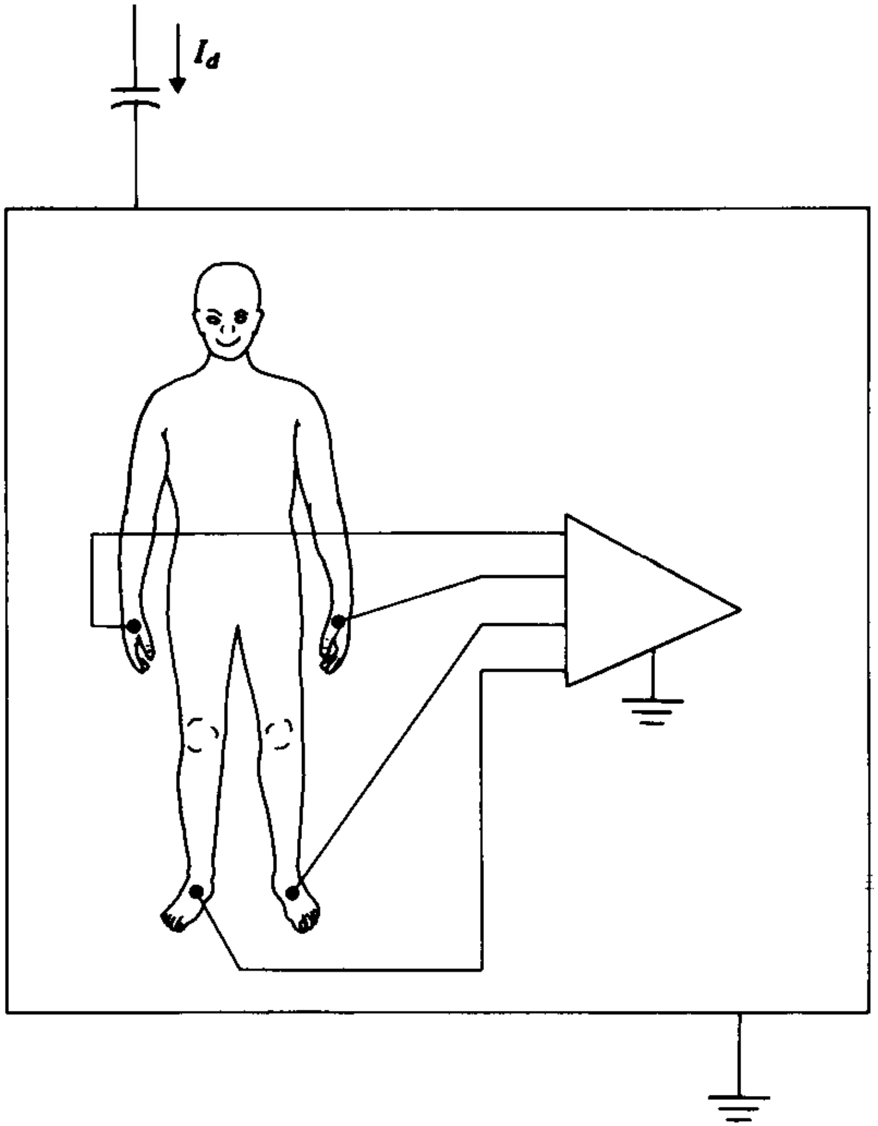
$$v_A - v_B = i_{d1}(Z_1 - Z_2)$$

How to minimize the current picked up by lead wires and instrument?

Currents Picked up in the Body
4-Electromagnetic interference

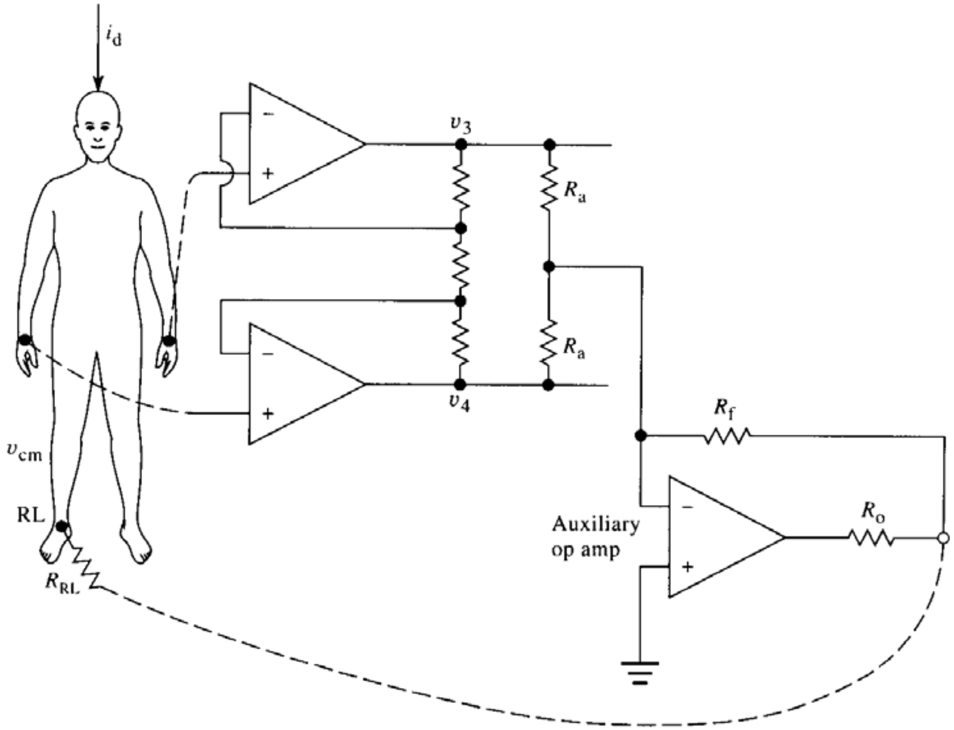
- EM waves generated by
  - Radar facilities
  - X-ray machines
  - Nearby transformers
  - Radio waves
- EM waves picked-up by patient and lead wires
- Demodulated by p-n junctions of transistors and/or electrode-electrolyte interfaces
- Modulating audio signal appears as interference on top of the ECG signal
- Solution: Can be eliminated by shunting the input terminals of the ECG amplifier with a small capacitor (around 200pF)

Solution: Electrostatic shielding

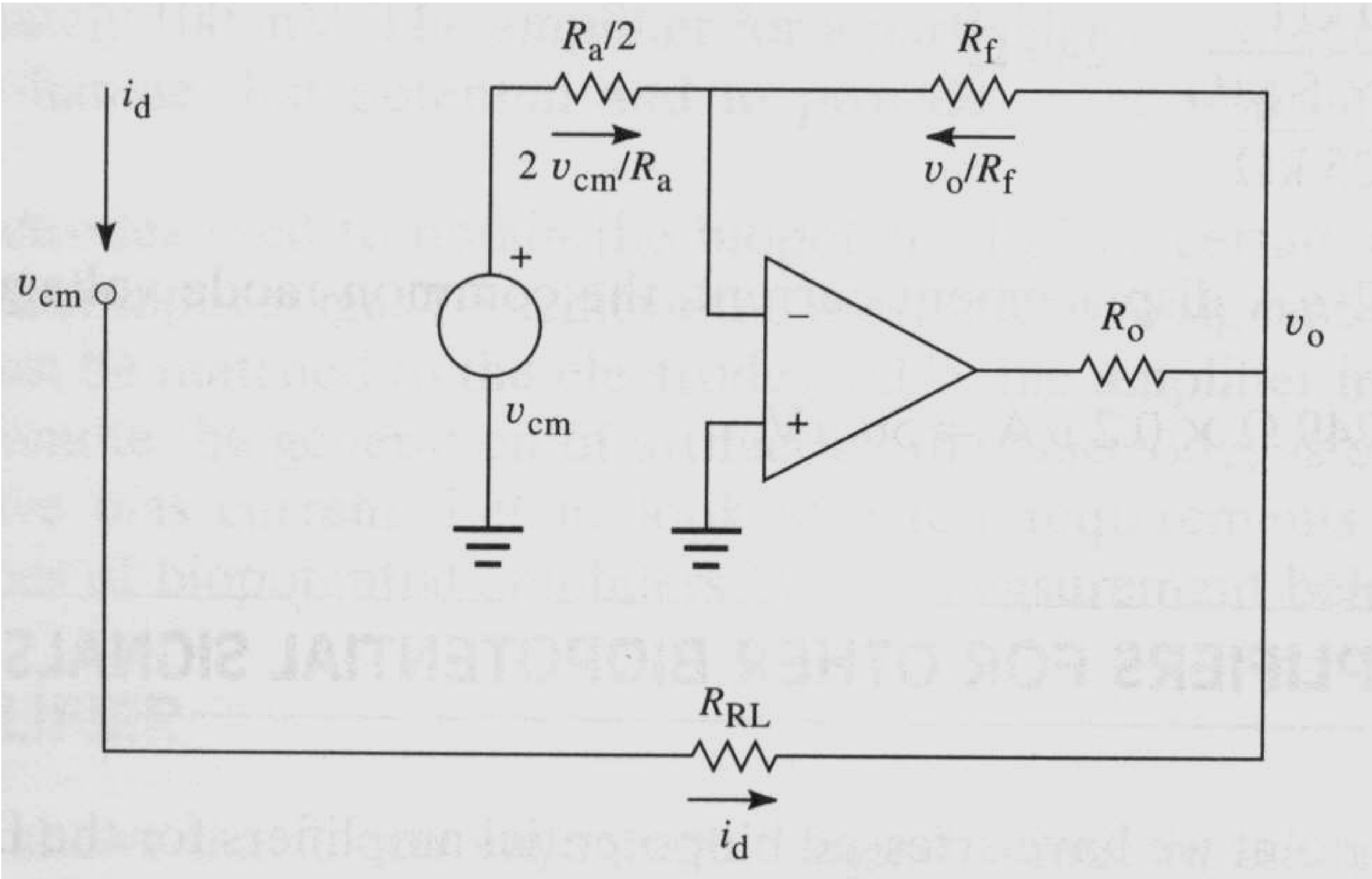


Driven-right-leg circuit

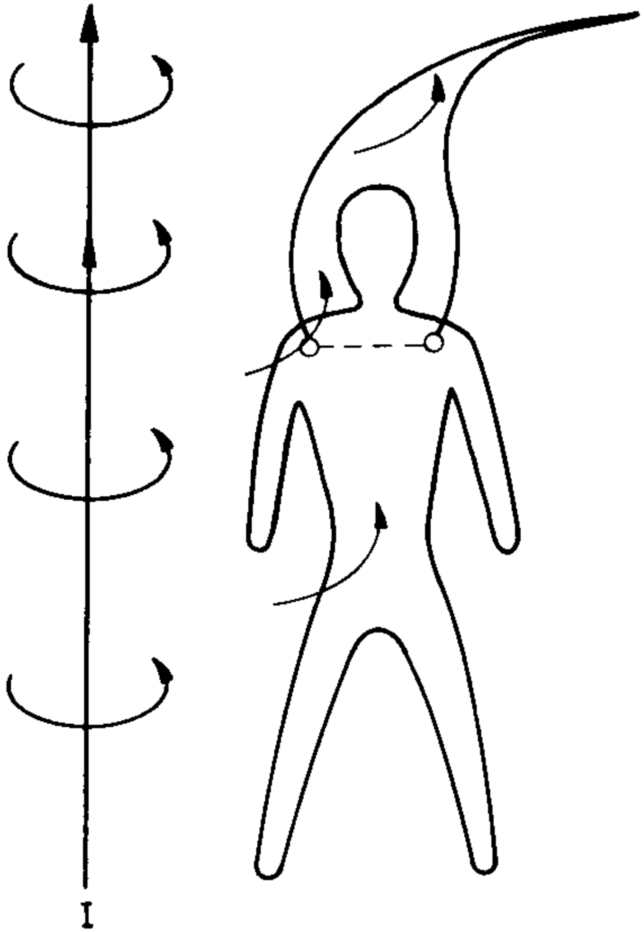
- Right leg connected to the output of an OPAMP instead of ground
- Why?
  1. Displacement current flows through output resistance instead of body
  2. Patient un-grounded when high voltage appears between patient and ground (R_f and R_o large values)



Analysis of the driven-right-leg circuit



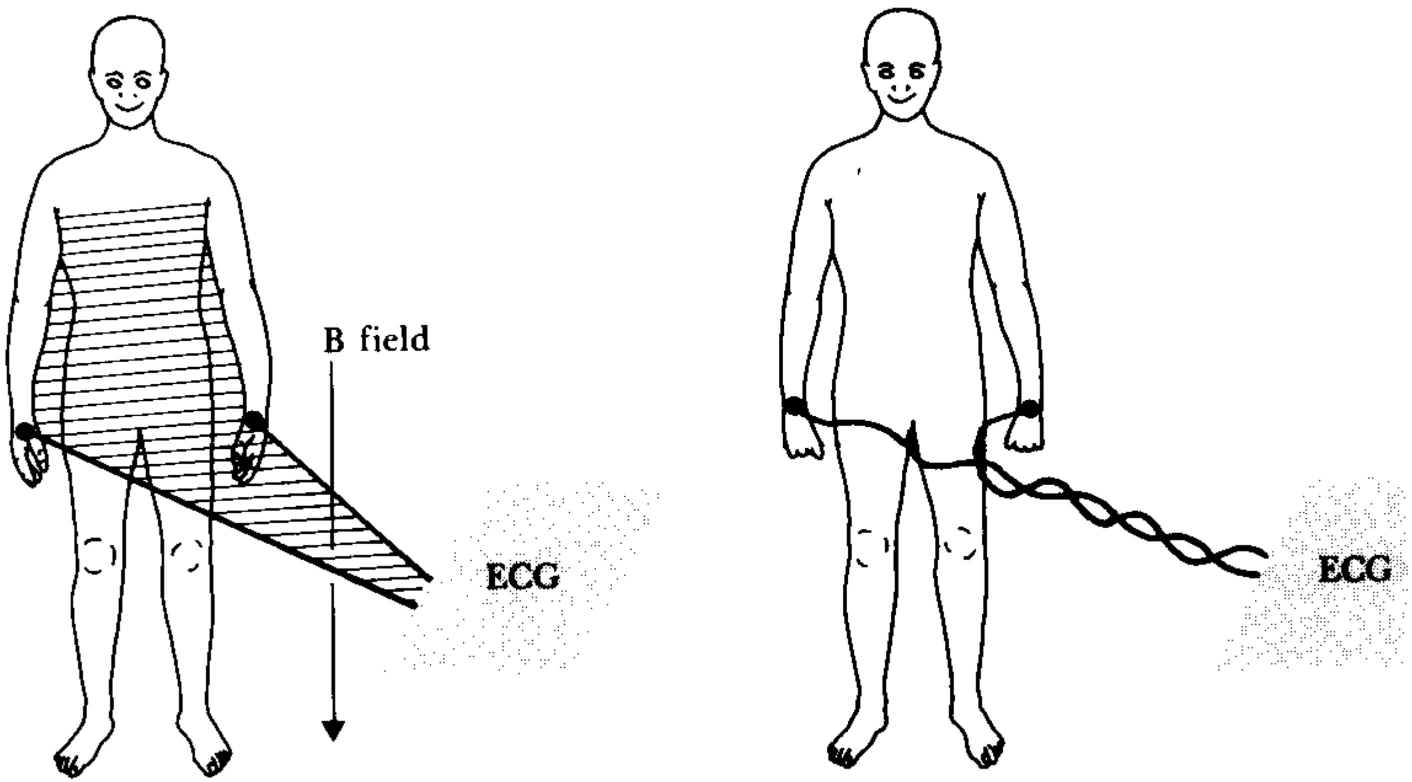
Bio-Potential Amplifiers 3



2-Generation and effects of magnetic field

- Protection achieved through alternative low resistance paths for the current

Currents Picked up in the Body
1-Magnetic field pickup



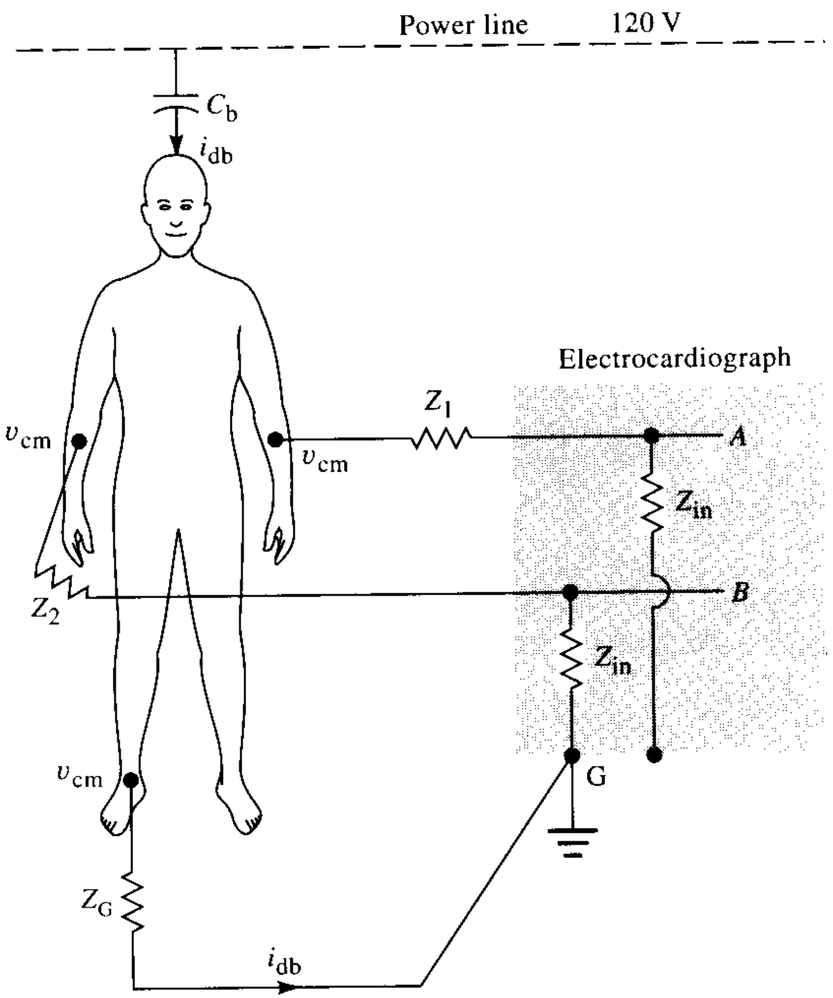
(a) (b)

Lead wires for lead I making a closed loop with patient and ECG machine

Solution

Twisting lead wires together and keeping them close to body minimizes interference

Currents Picked up in the Body
2-Pickup due to displacement current flowing through the patient



$$v_A - v_B = v_{cm}\left(\frac{Z_{in}}{Z_{in}+Z_1} - \frac{Z_{in}}{Z_{in}+Z_2}\right)$$

$$Z_1 \text{ and } Z_2 << Z_{in}$$

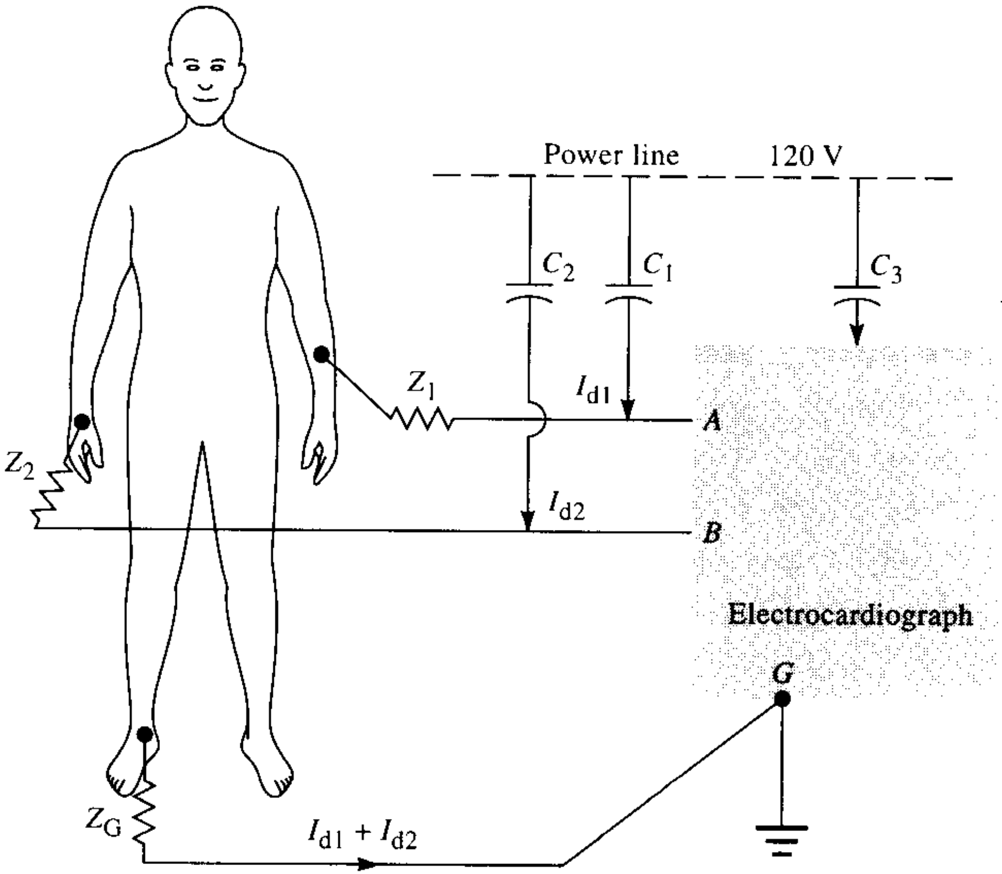
$$v_A - v_B = v_{cm}\left(\frac{Z_2 - Z_1}{Z_{in}}\right)$$

$$v_{cm} = i_{db} Z_G$$

Solution

Choose High input impedance Amplifier

Currents Picked up in the Body
3-Electrical field pickup by connecting wires and instrument



- What is a Capacitor?
- Coupling between hot side of the power line and lead wires

$$v_A - v_B = i_{d1} Z_1 - i_{d2} Z_2$$

With $i_{d1} \approx i_{d2}$

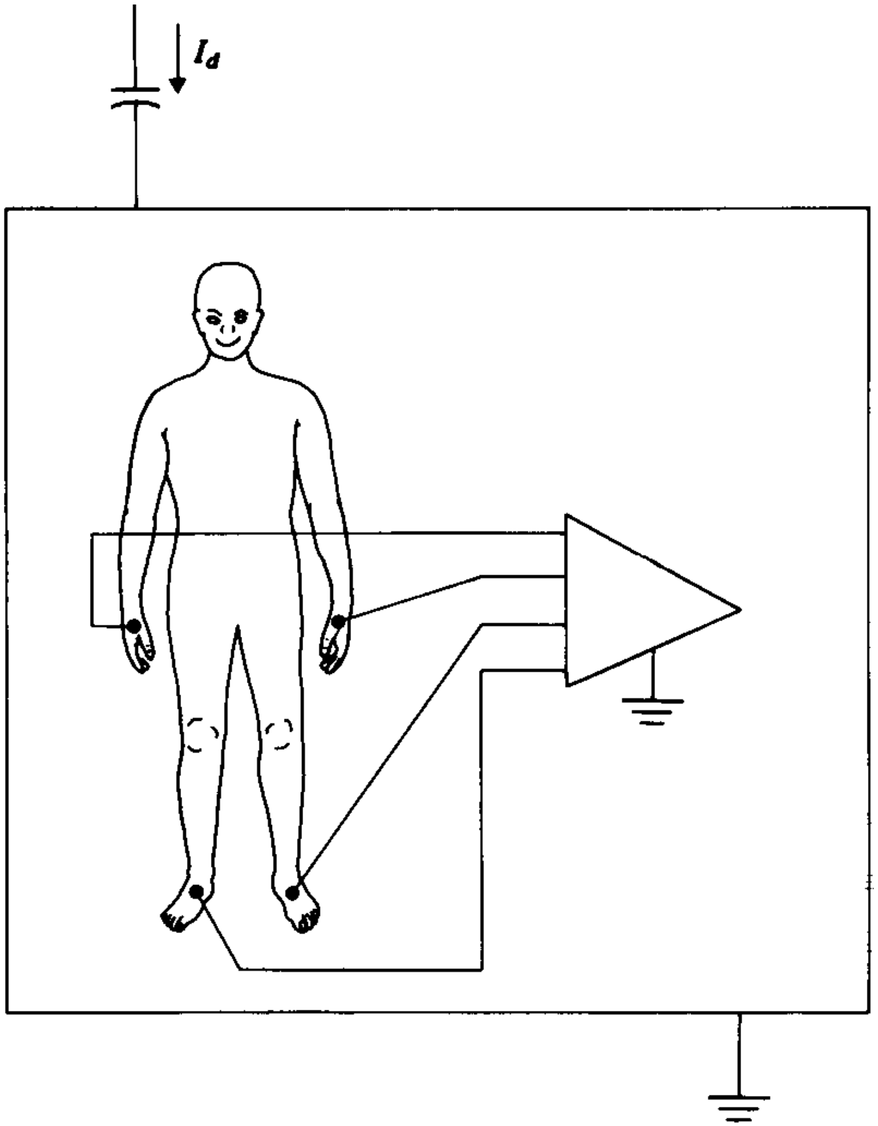
$$v_A - v_B = i_{d1}(Z_1 - Z_2)$$

How to minimize the current picked up by lead wires and instrument?

Currents Picked up in the Body
4-Electromagnetic interference

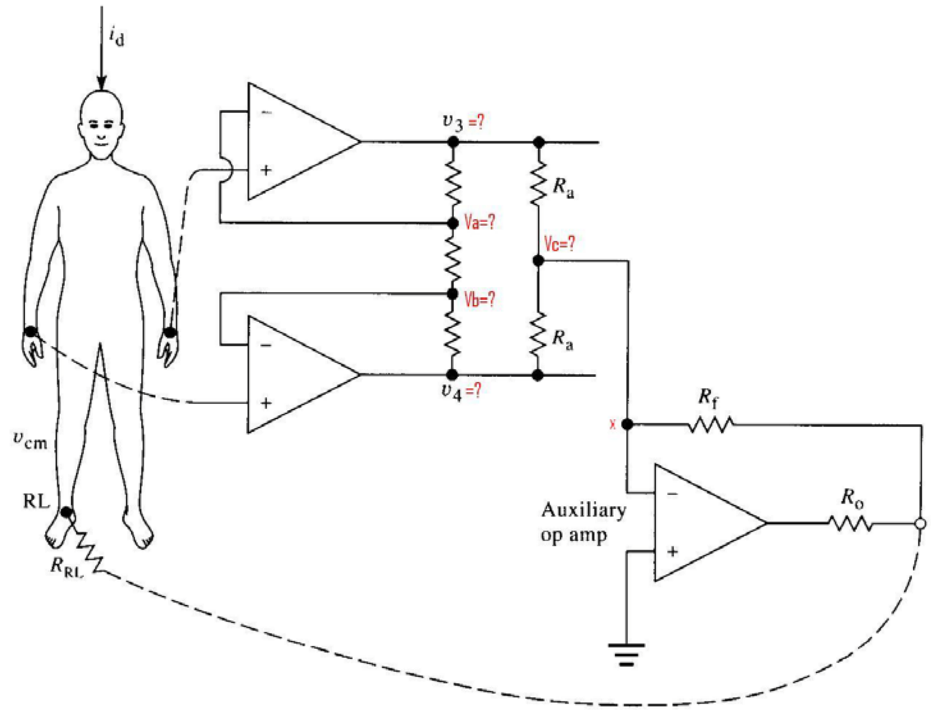
- EM waves generated by
  - Radar facilities
  - X-ray machines
  - Nearby transformers
  - Radio waves
- EM waves picked-up by patient and lead wires
- Demodulated by p-n junctions of transistors and/or electrode-electrolyte interfaces
- Modulating audio signal appears as interference on top of the ECG signal
- Solution: Can be eliminated by shunting the input terminals of the ECG amplifier with a small capacitor (around 200pF)

Solution: Electrostatic shielding

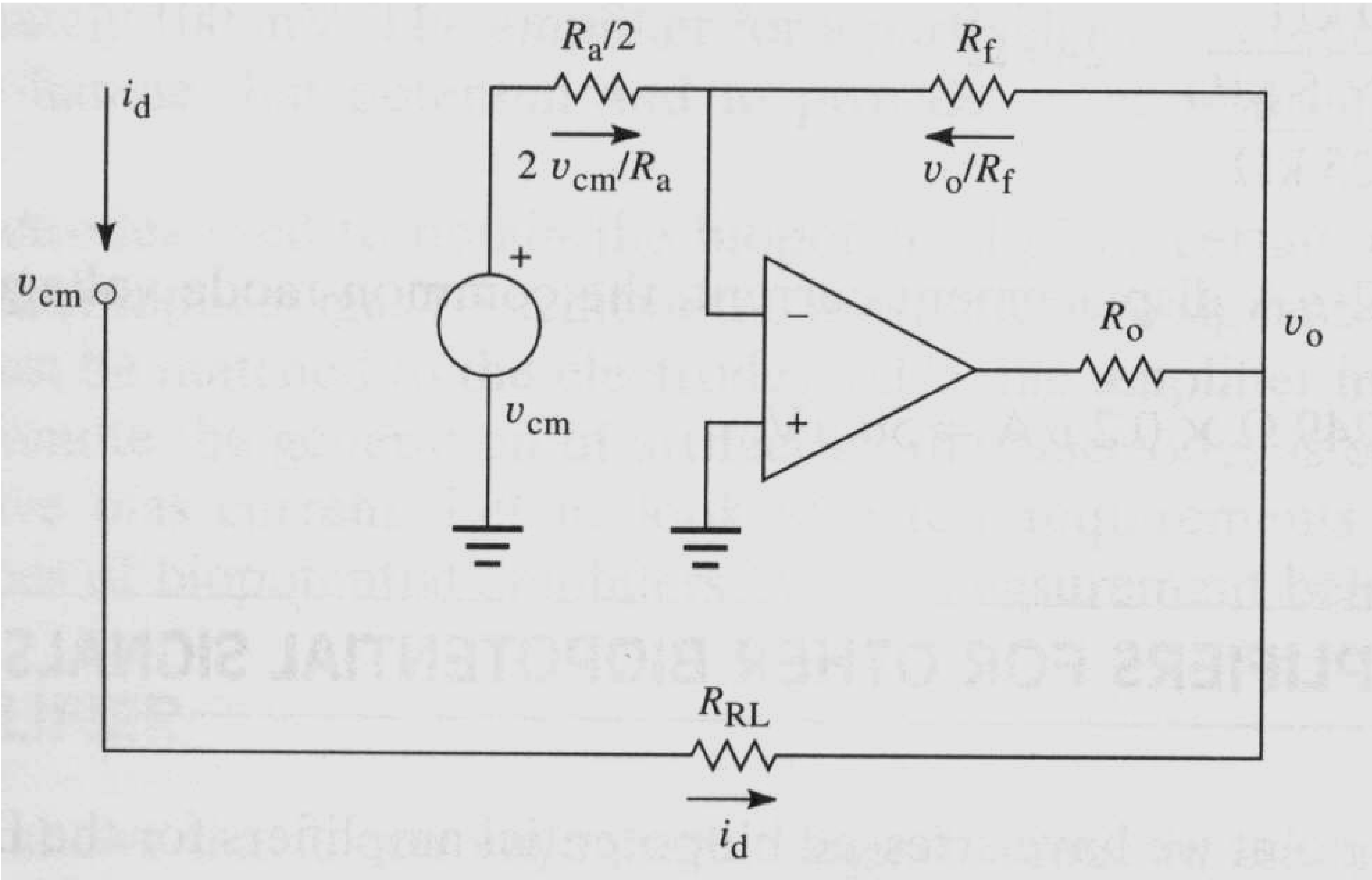


Driven-right-leg circuit

- Right leg connected to the output of an OPAMP instead of ground
- Why?
  1. Displacement current flows through output resistance instead of body
  2. Patient un-grounded when high voltage appears between patient and ground (R_f and R_o large values)



Analysis of the driven-right-leg circuit



Driven Right Leg Circuit

KCL at point x

$$\frac{2v_{cm}}{R_a} + \frac{v_o}{R_f} = 0$$

i.e.

$$v_o = -\frac{2R_f}{R_a} v_{cm}$$

But

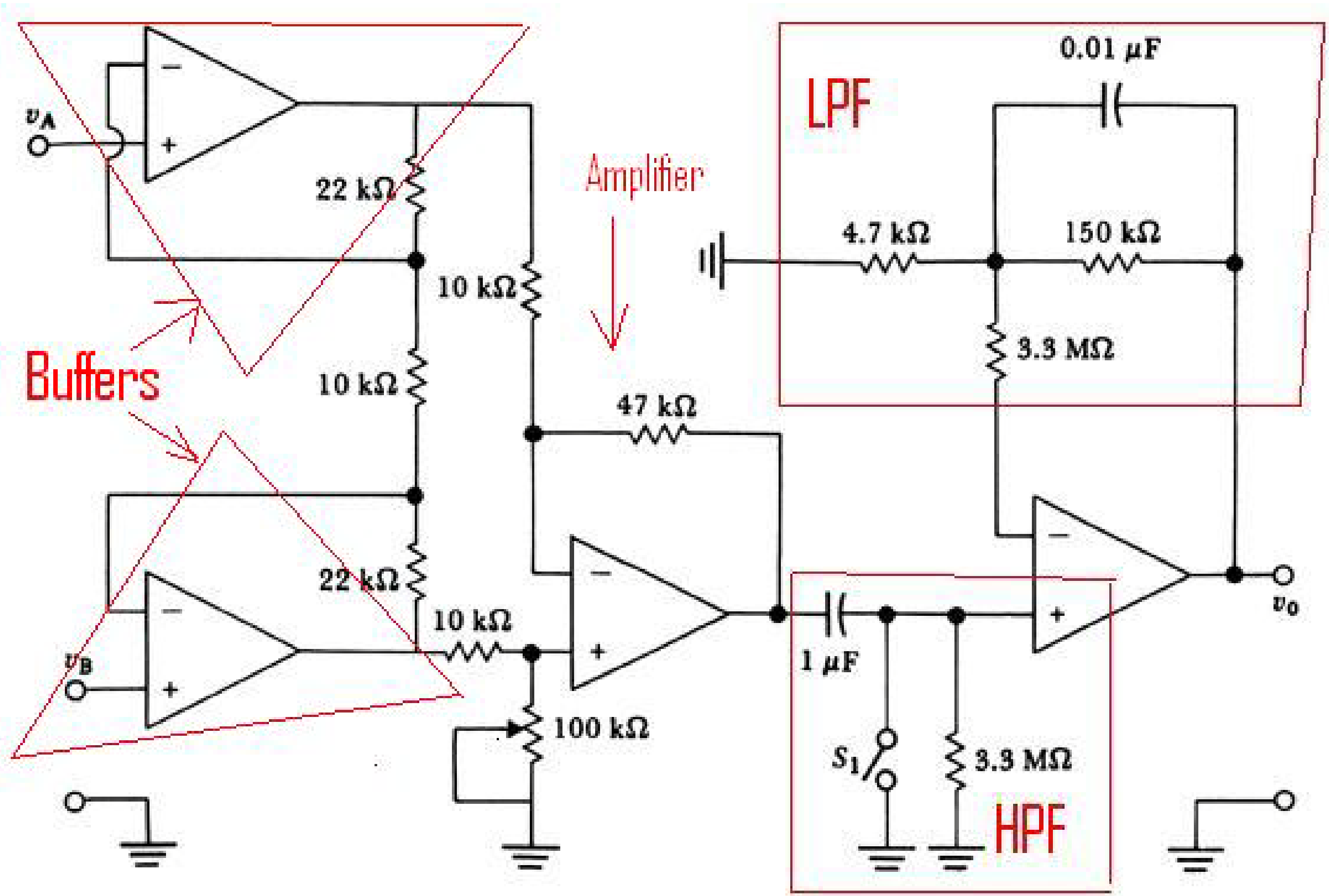
$$v_{cm} = R_{RL} i_d + v_o$$

Therefore

$$v_{cm} = \frac{R_{RL}}{1 + 2 \frac{R_f}{R_a}} i_d$$

- What is the effective resistance between right leg and ground?
- Large transients ➔ Saturation➔ chose large R_f and R_o =~ 5 MΩ
- Regular operation ➔ want v_{cm} as small as possible➔ large R_f and small R_a

Bio-Potential Amplifiers -4



Example of a simple ECG amplifier

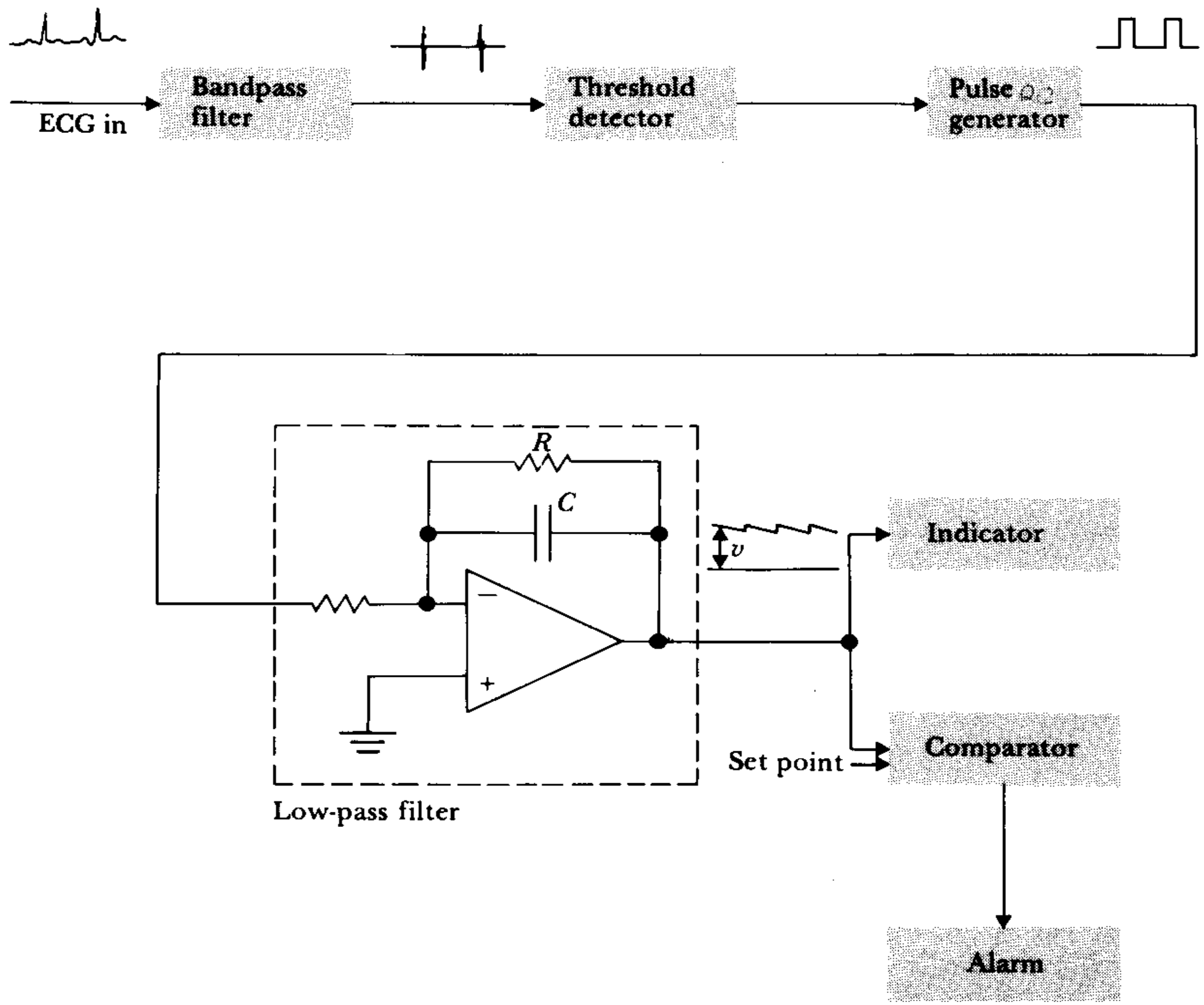
Examples of Bio-Potential Amlifiers

Biomedical Signal Processor Examples

- Cardiac Tachometers
- Electromyogram integrators
- Fetal electrocardiography
- Cardiac monitors
- Biotelemetry

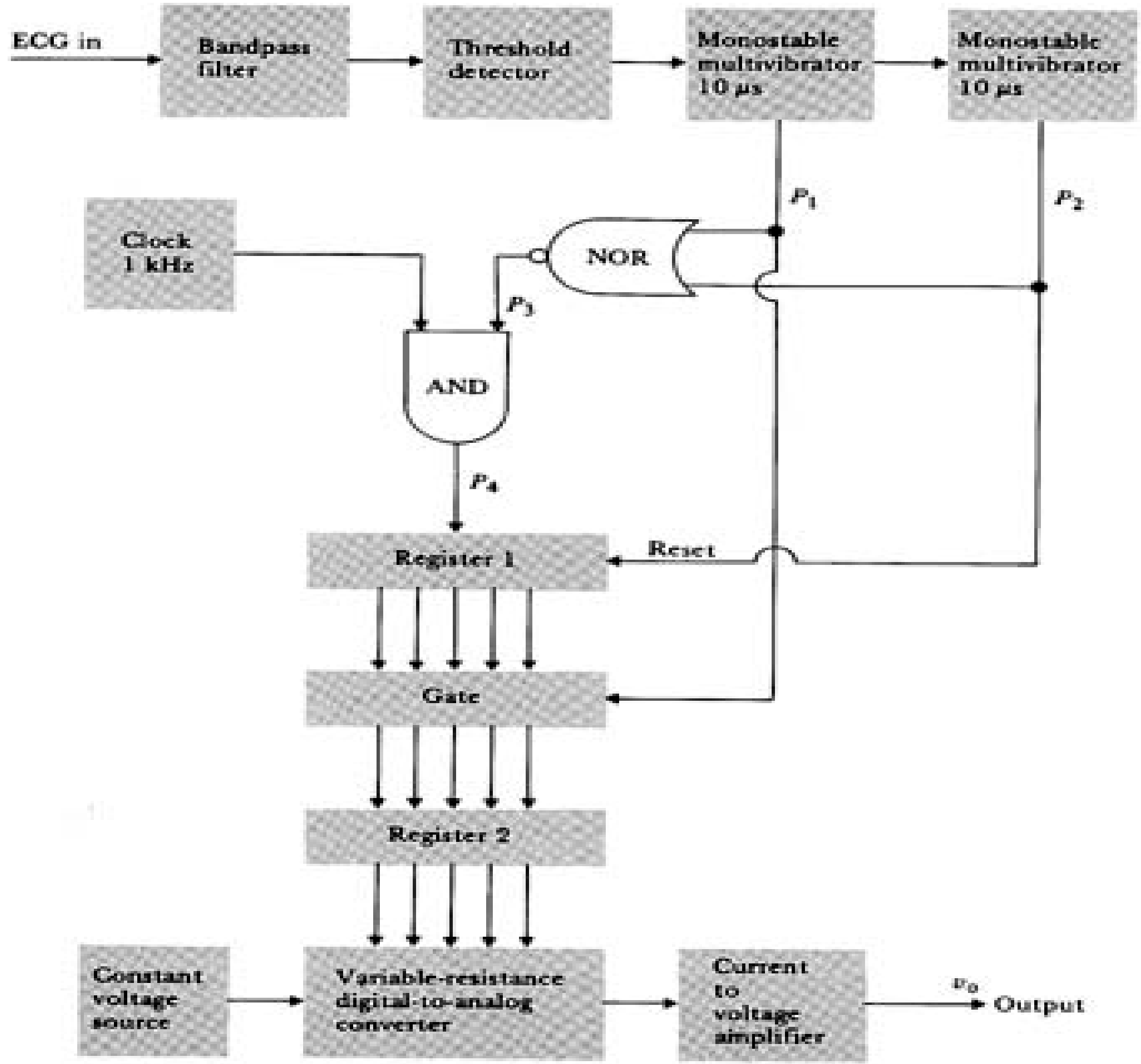
Tachometers

Averaging type

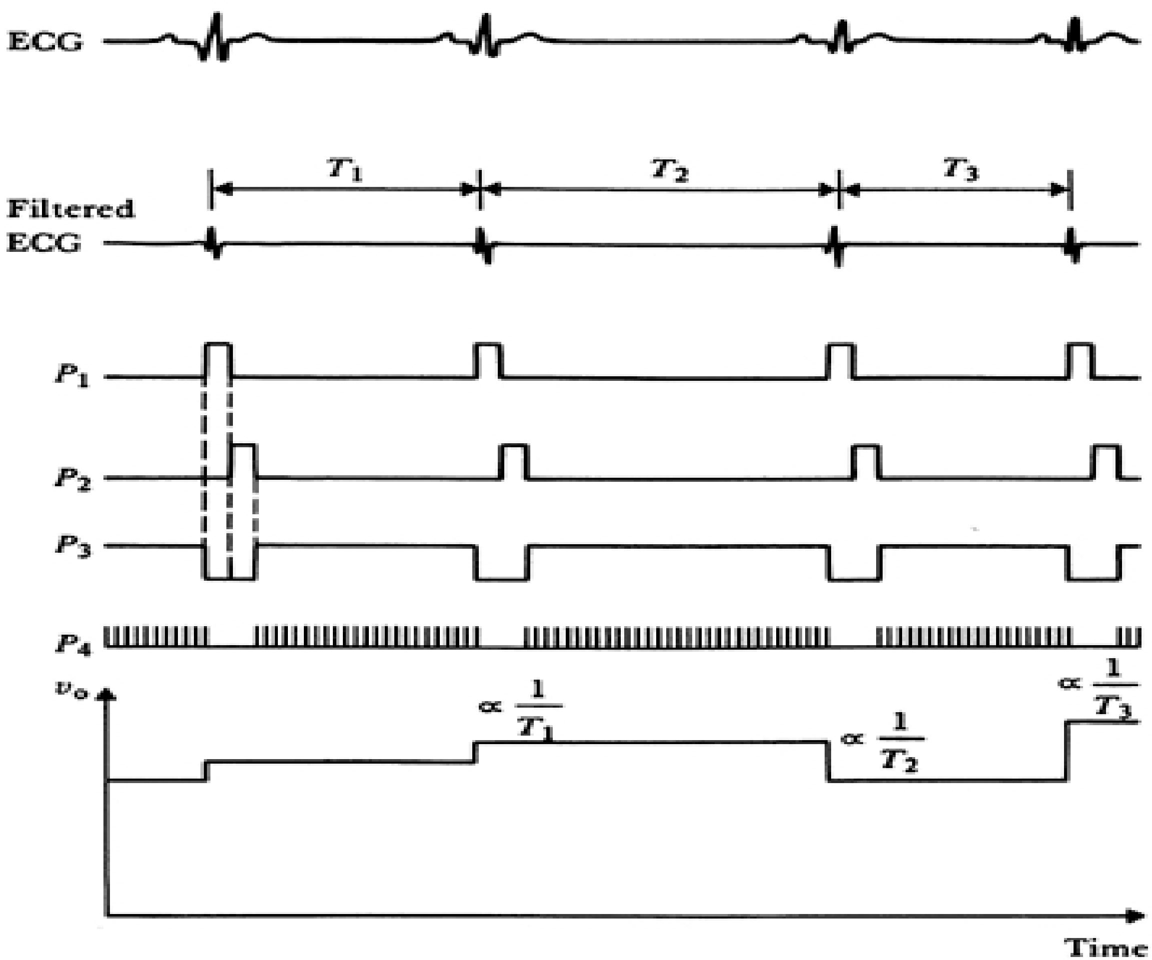


Tachometers

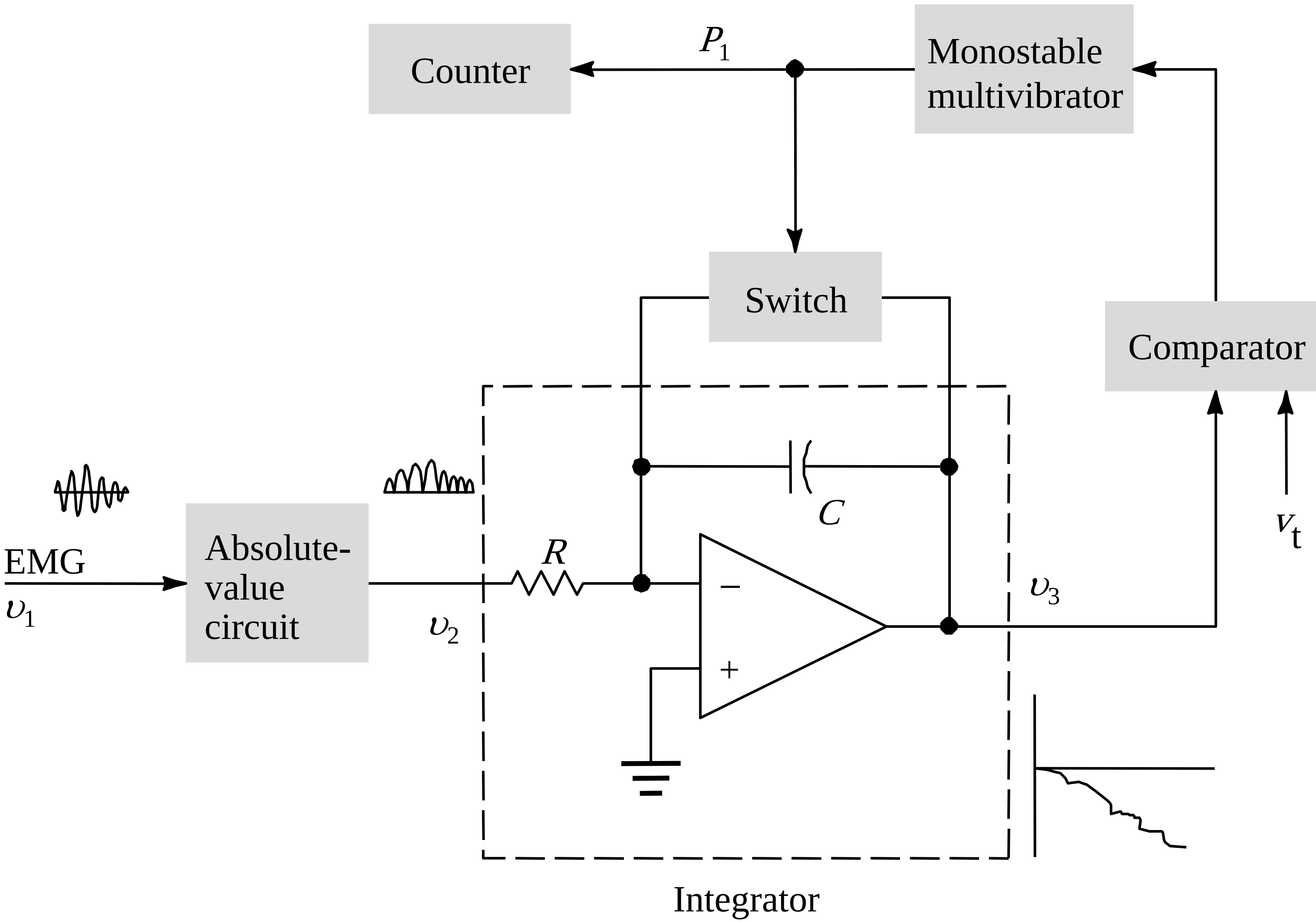
Beat-to-beat



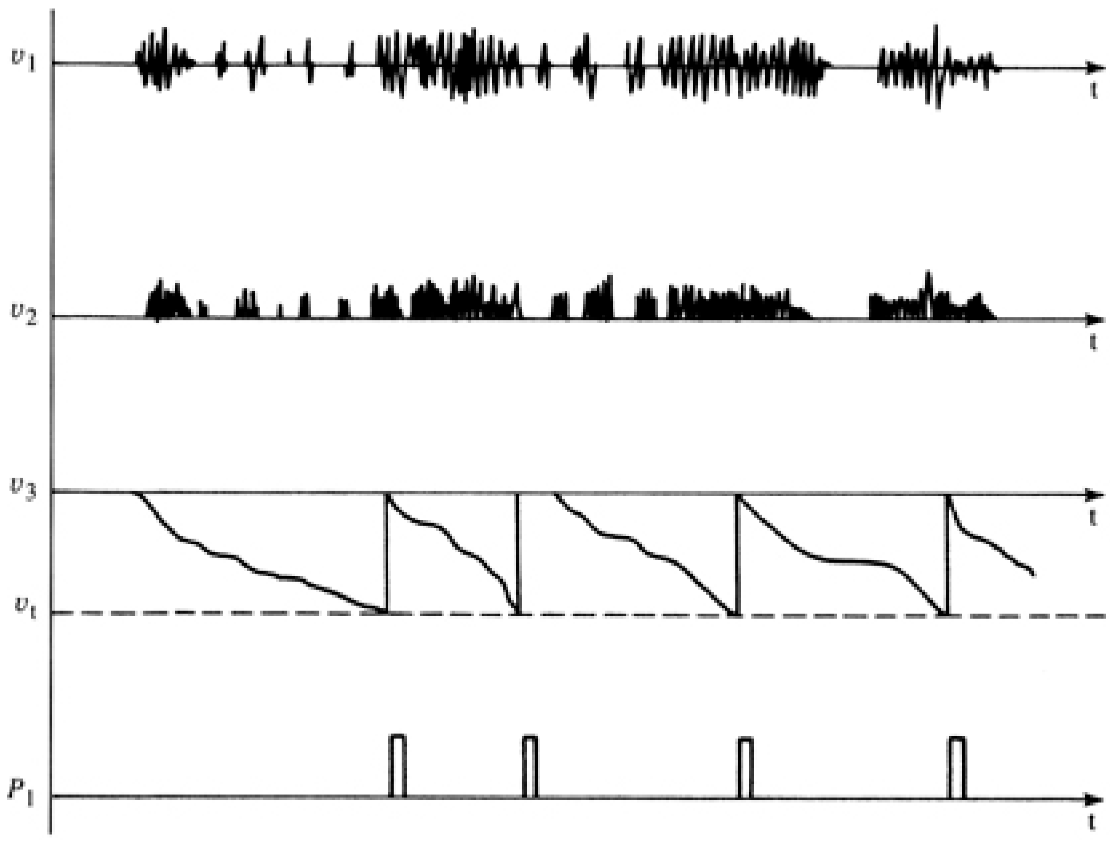
Tachometers



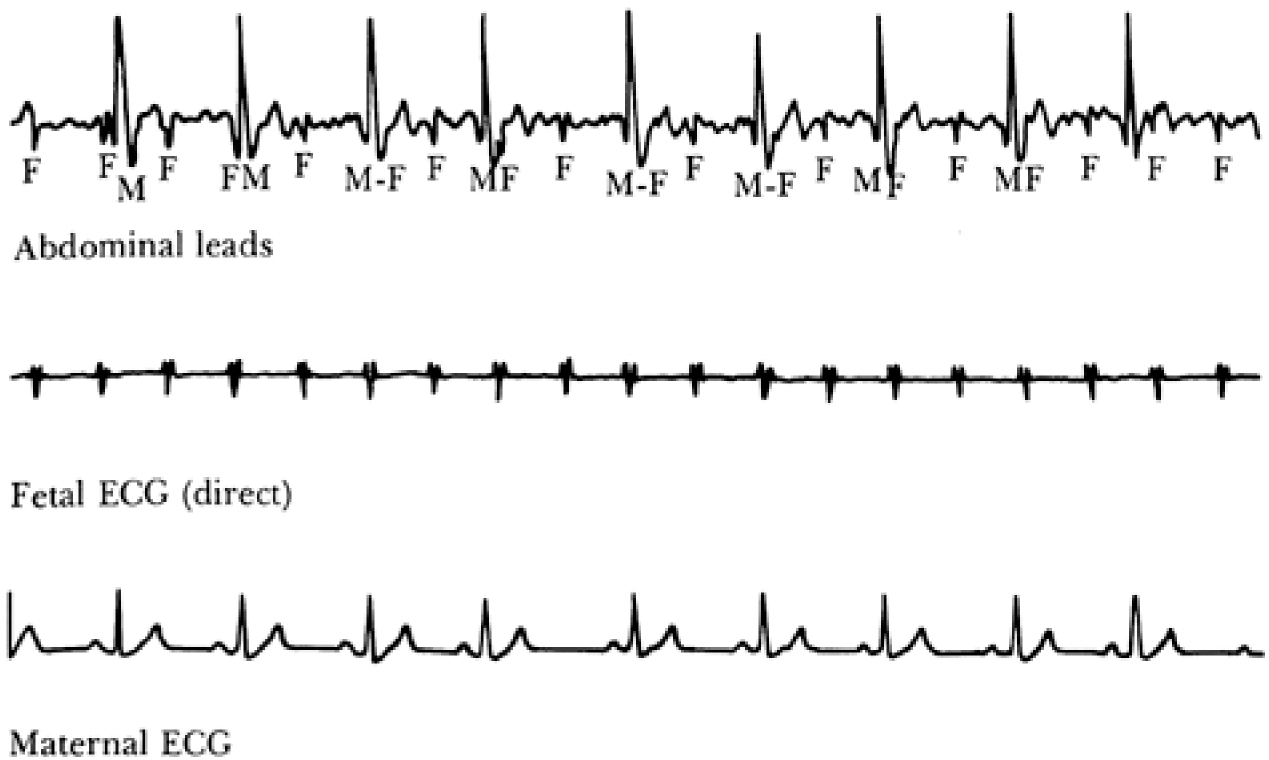
EMG integrators



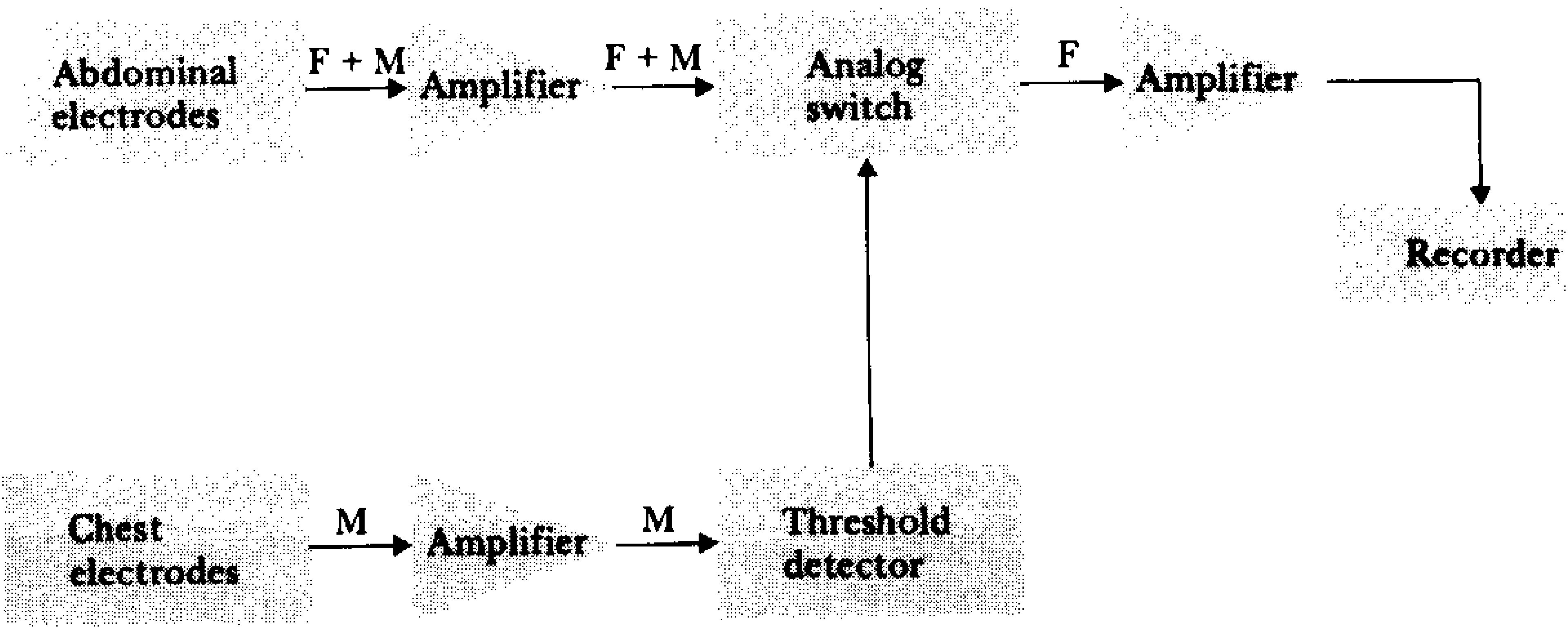
EMG integrators



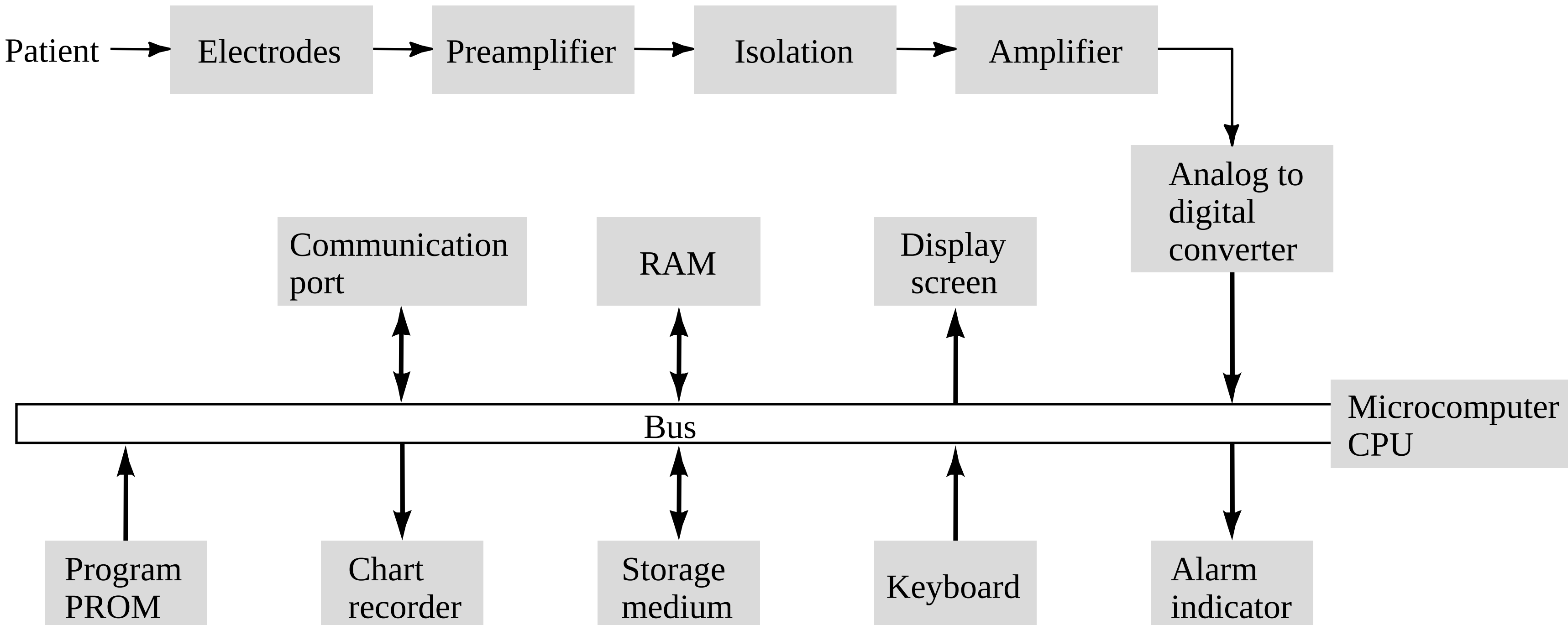
Fetal electrocardiology



A technique for isolating fetal ECG from maternal

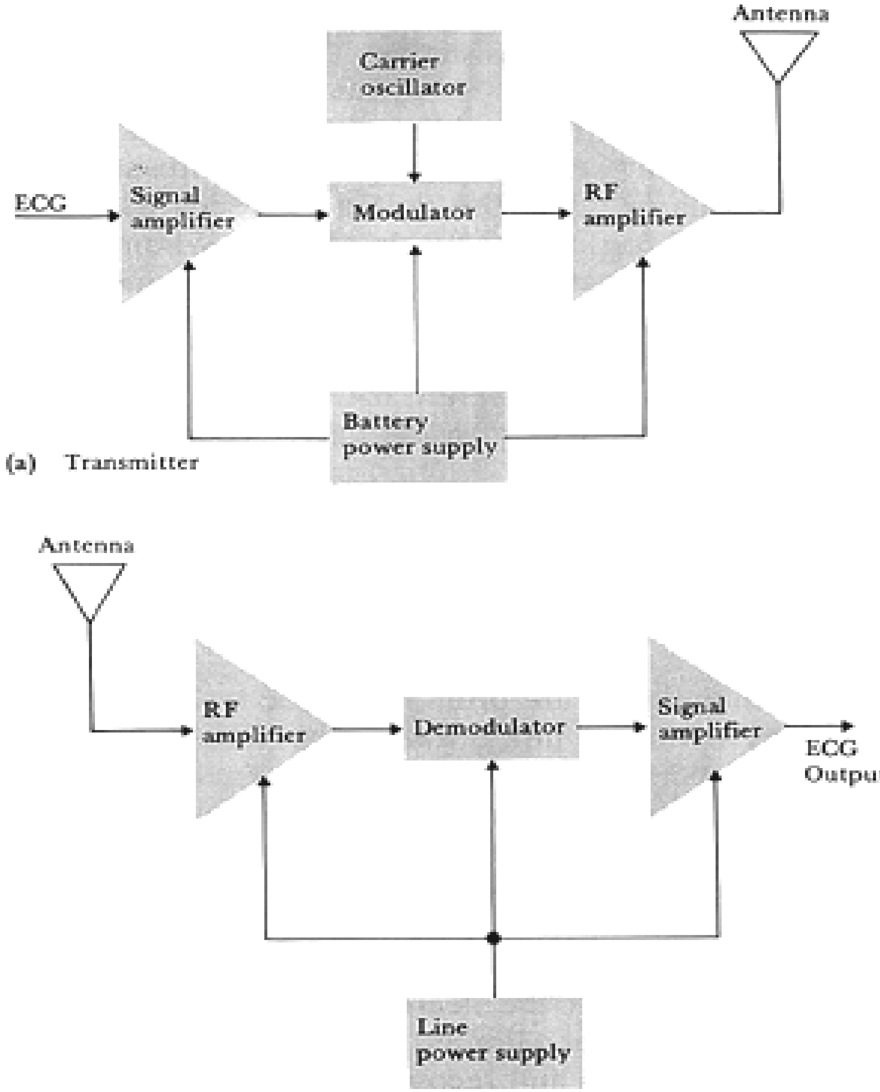


Cardiac monitors



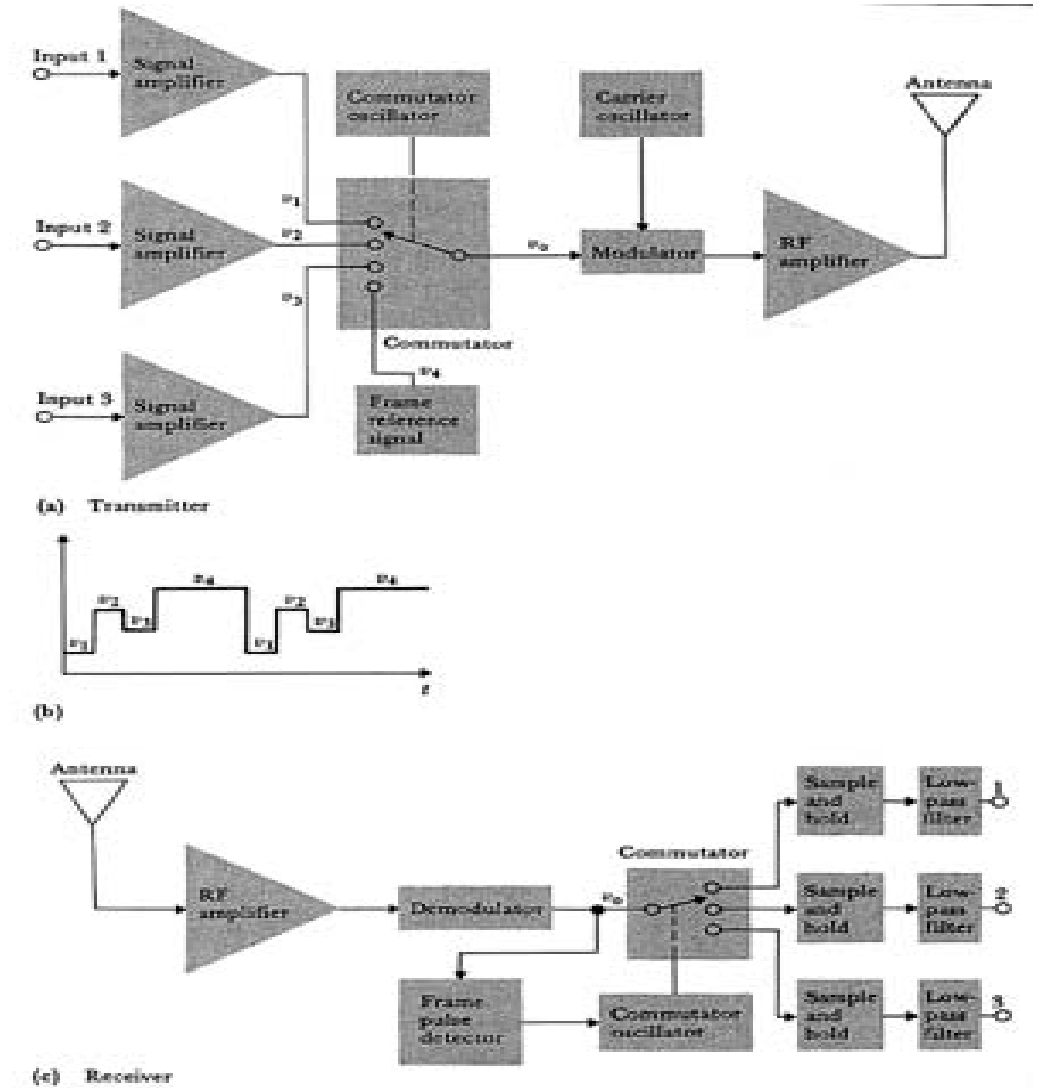
Telemetry

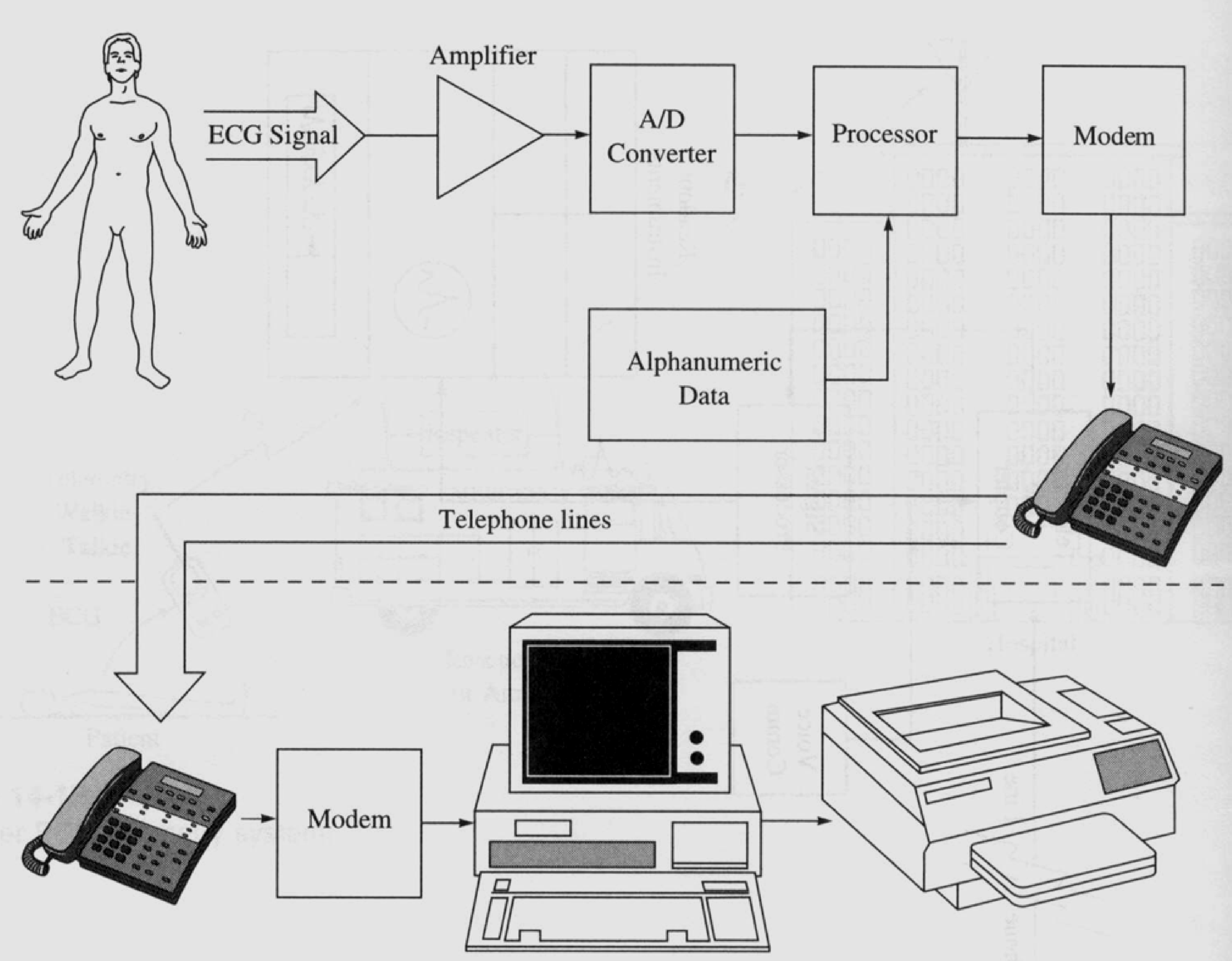
Frequency modulation



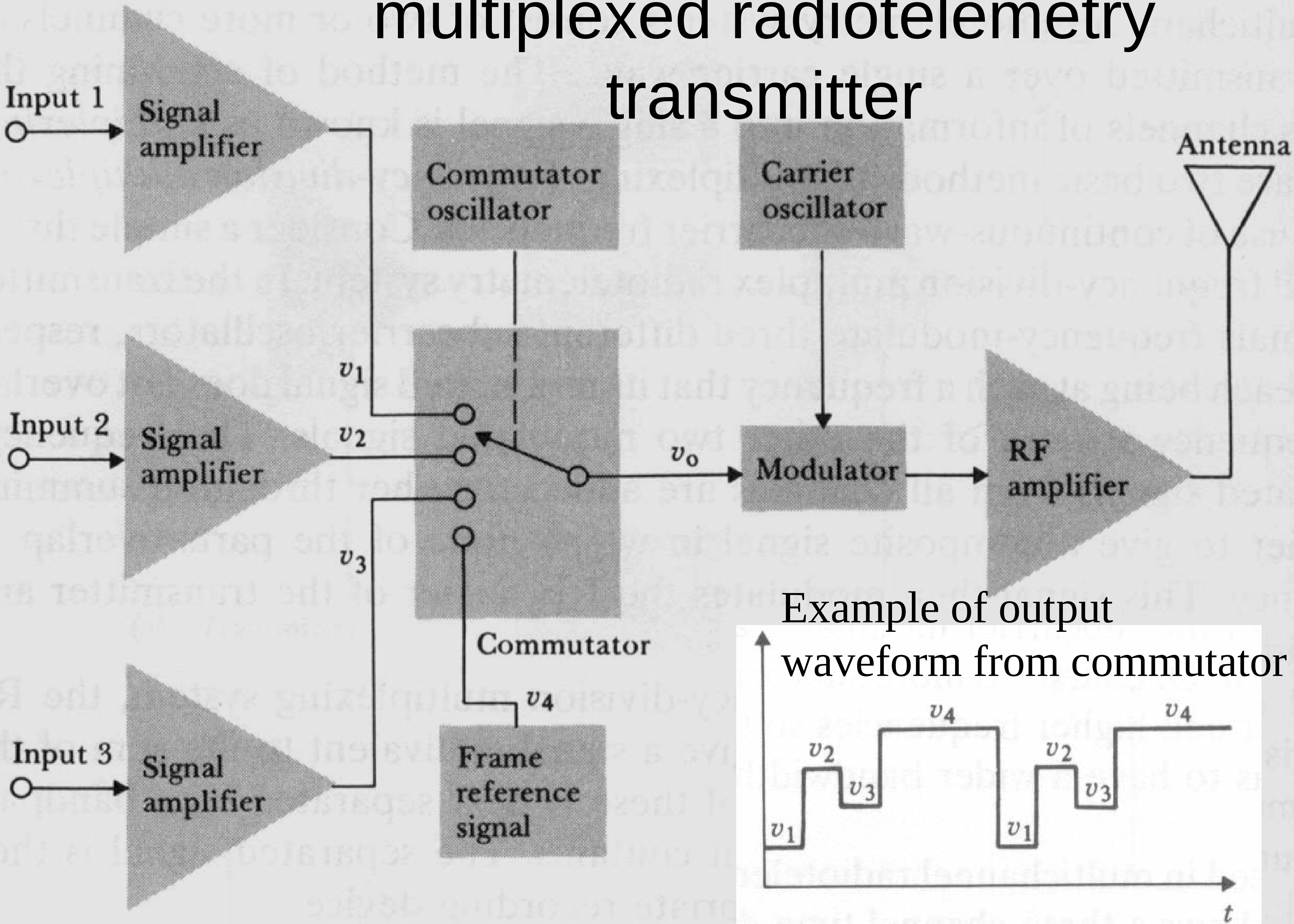
Telemetry

Time division multiplexing

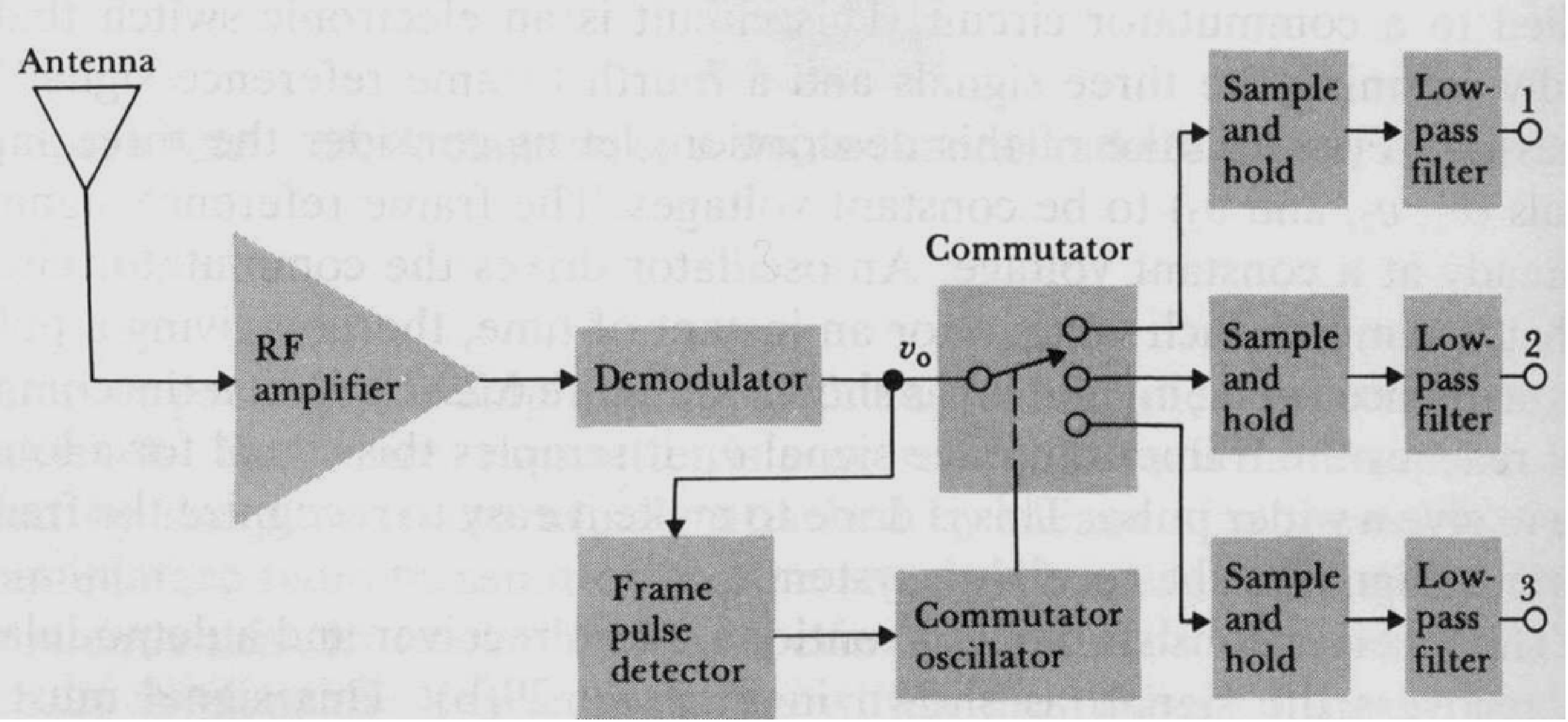


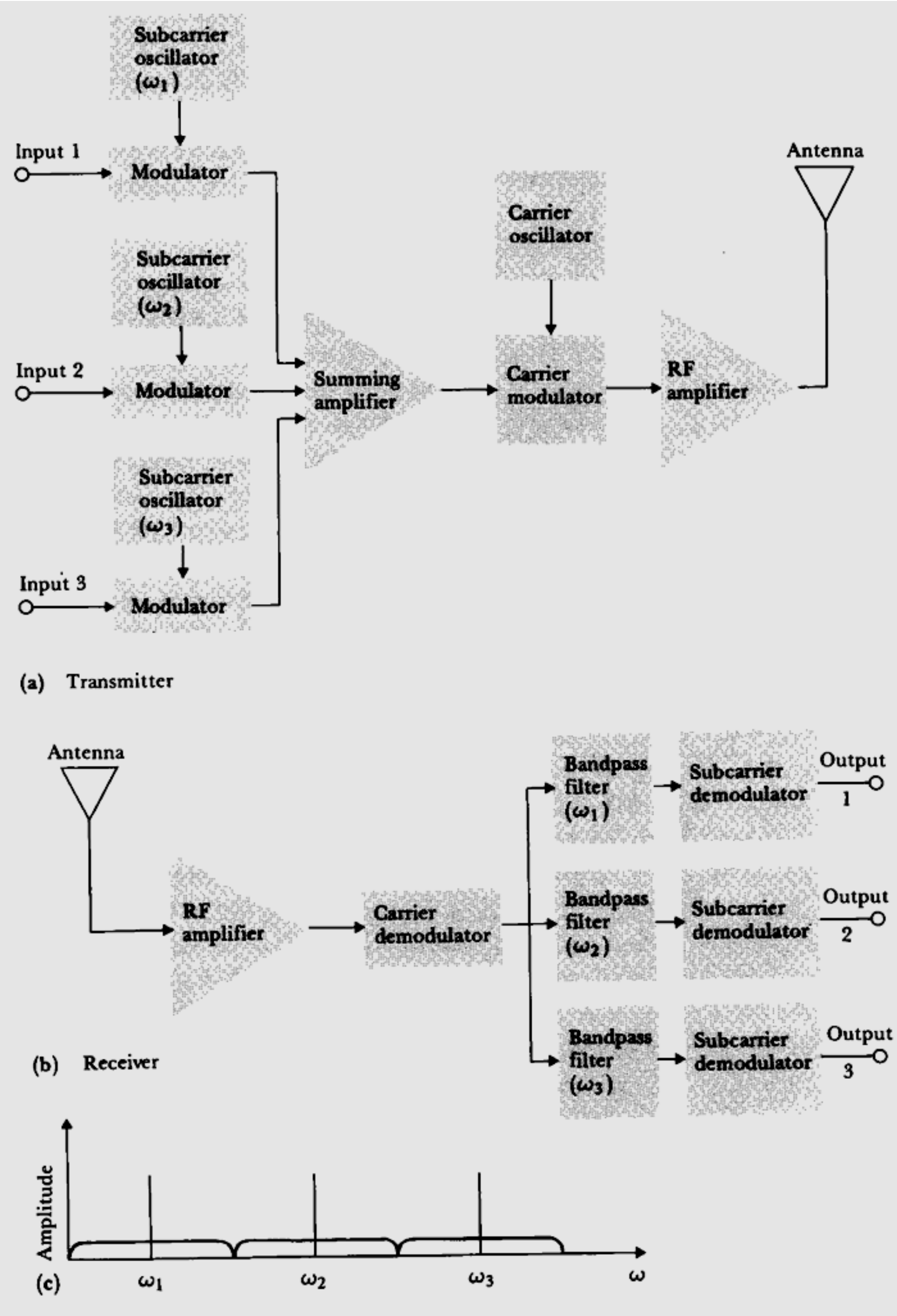

Amplifier
ECG Signal
A/D Converter
Processor
Modem
Alphanumeric Data
Telephone lines
Modem

Three-channel time-division multiplexed radiotelemetry transmitter



Three-channel time-division multiplexed radiotelemetry receiver





Three-channel frequency-division multiplexed radiotelemetry system