Sahand University of Technology

Lecture 4
Biopotential Amplifiers

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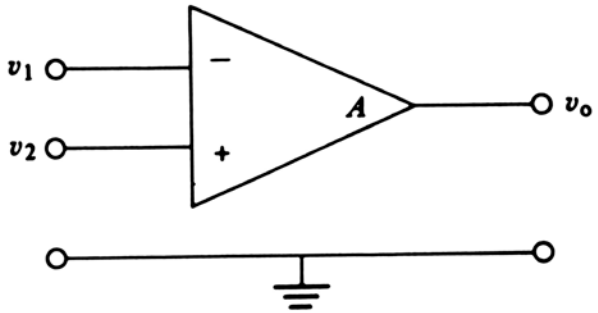
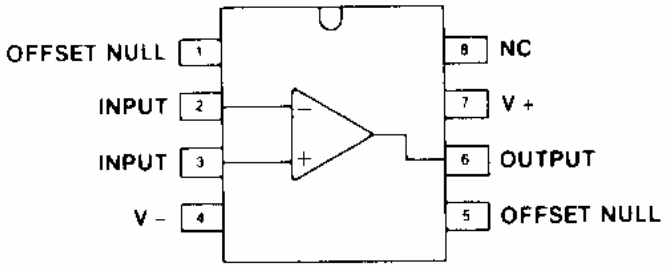
Summer 2016

OpAmp and Rules





741 op amp

1- A = ∞ (gain is infinity)
2- Vo = 0, when v1 = v2 (no offset voltage)
3- Rd = ∞ (input impedance is infinity)
4- R0 = 0 (output impedance is zero)
5- Bandwidth = ∞ (no frequency response limitations) and no phase shift

Rule 1
When the op-amp output is in its linear range, the two input terminals are at the same voltage.
Rule 2
No current flows into or out of either input terminal of the op amp.

OpAmp and Applications

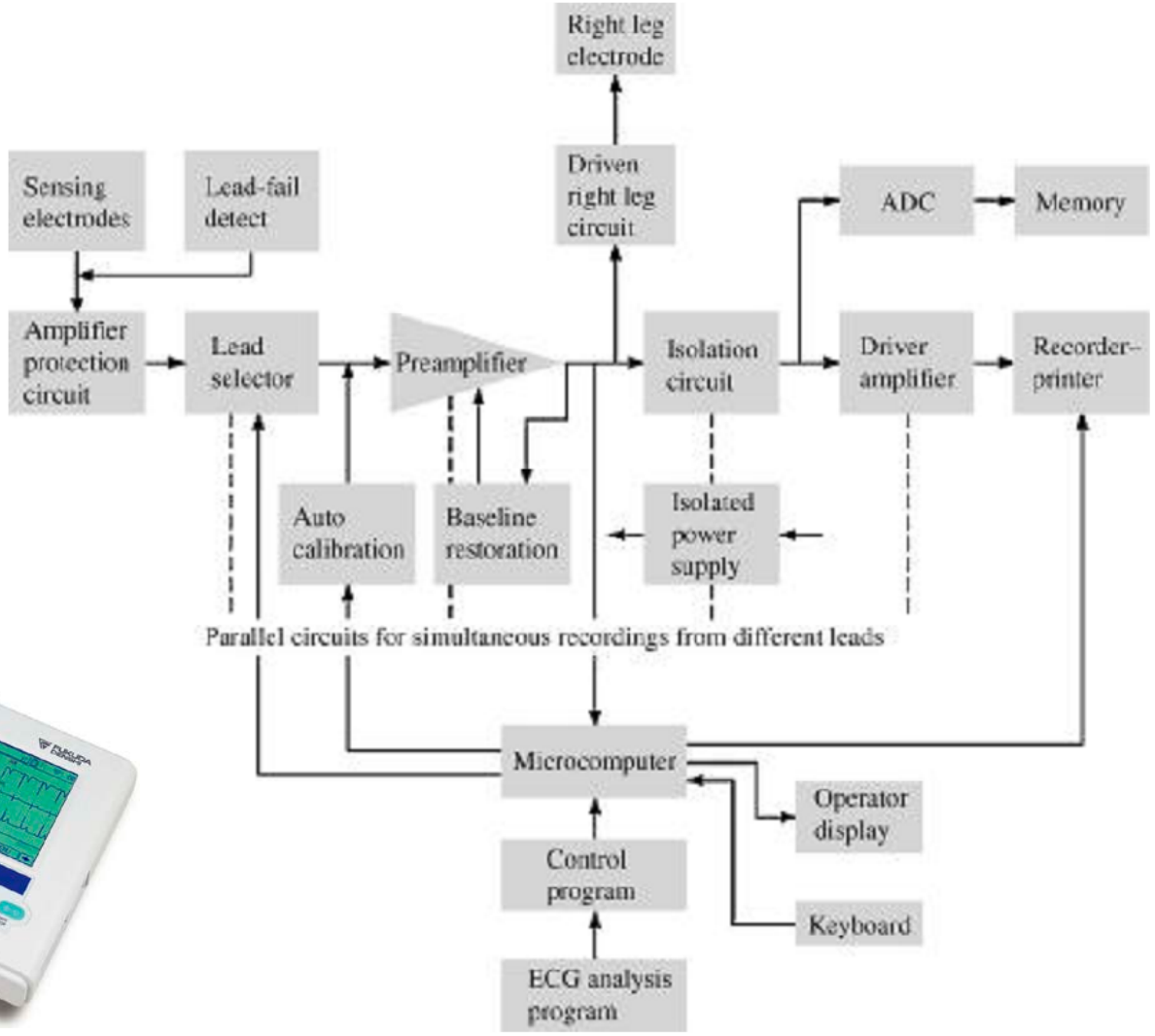
- Types and review:
  - Inverting Amplifier
    - Summing Amp.
  - Non-inverting Amplifier
    - Buffer
    - Non-inverting Amplifier
  - Differential Amplifier
  - Instrumentation Amplifier
  - Isolated Amplifier
  - Comparator
  - Rectifier
  - Logarithmic and Anti-Logarithmic Amps
  - Integrator and Differentiator Amps

Biopotential Amplifier

- Amplifiers are an important part of modern instrumentation system for measuring biopotentials.
- Such measurements involve voltages that often are at low levels, have high source impedances, or both.
- These Amplifiers that have been designed specifically for this type of processing of biopotentials are know as biopotential amplifiers.
- Basic Requirements for biological usage:
  - Voltage amplifiers
  - High Impedance (at Least 10 MΩ)
  - Minimum Loading Effects
  - Protection input circuit (against micro or macroshocks)
  - Recording and Display
  - Biopotential frequency spectrum (Bandwidth)
  - SNR issues
  - High gain
  - Electrode common mode problem
  - Calibration possiblity

ECG (Electrocardiogram)

- **Read The review if the ECG First**



Problems Frequently Encountered

- Frequency Distortion
- Saturated of Cutoff Distortion
- Ground Loop and Patient Safety
- Open Lead Wires
- Artifact from Large Electric Transients (Defibrillation)

  Example 6.2
- Interference From Electric Devices

ECG and Power Line

Id1 and id2 do not flow through amplifier because of its high impedance. Current through C3 flows to ground and cause not interference.

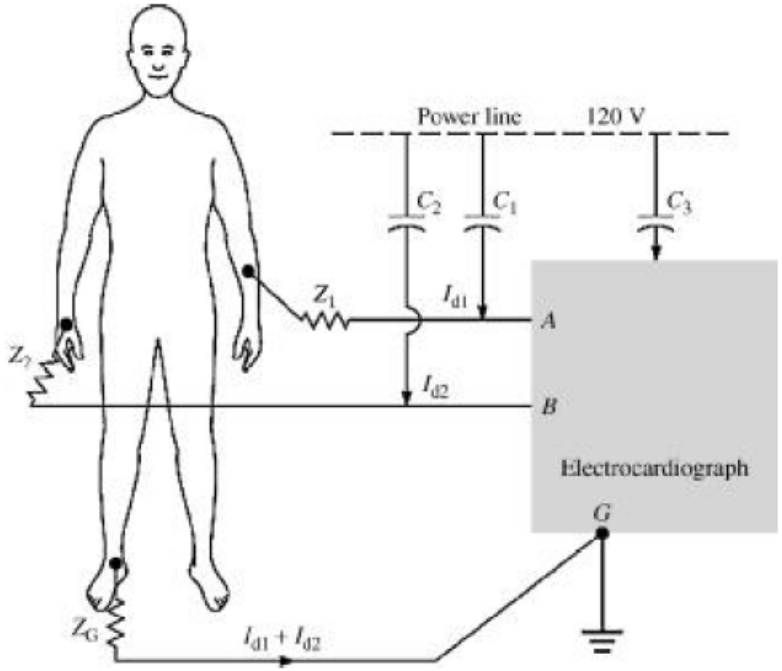
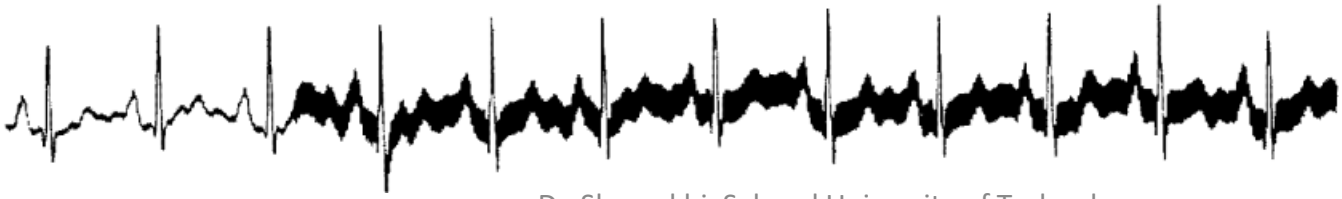


Figure 6.10 A mechanism of electric-field pickup of an electrocardiograph resulting from the power line. Coupling capacitance between the hot side of the power line and lead wires causes current to flow through skin–electrode impedances on its way to ground.

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

$$i_{d1} \cong i_{d2}$$ Huhta and Webster (1973)

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



Body-Ground impedance

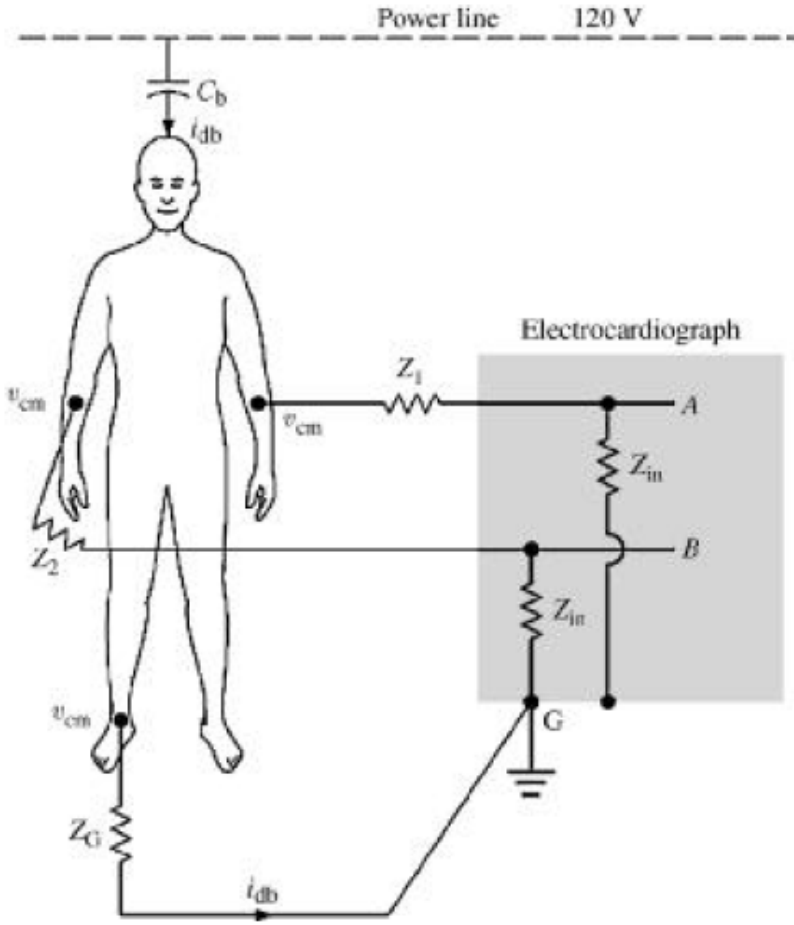


Figure 6.11 Current flows from the power line through the body and ground impedance, thus creating a common-mode voltage everywhere on the body. Z_{in} is not only resistive but, as a result of RF bypass capacitors at the amplifier input, has a reactive component as well.

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

For perfect amplifier this would cause no problem because of CMRR.
Because of real amplifiers finite input impedance.

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

Because Z1 and Z2 are much less than Zin:

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

ECG and Magnetic field

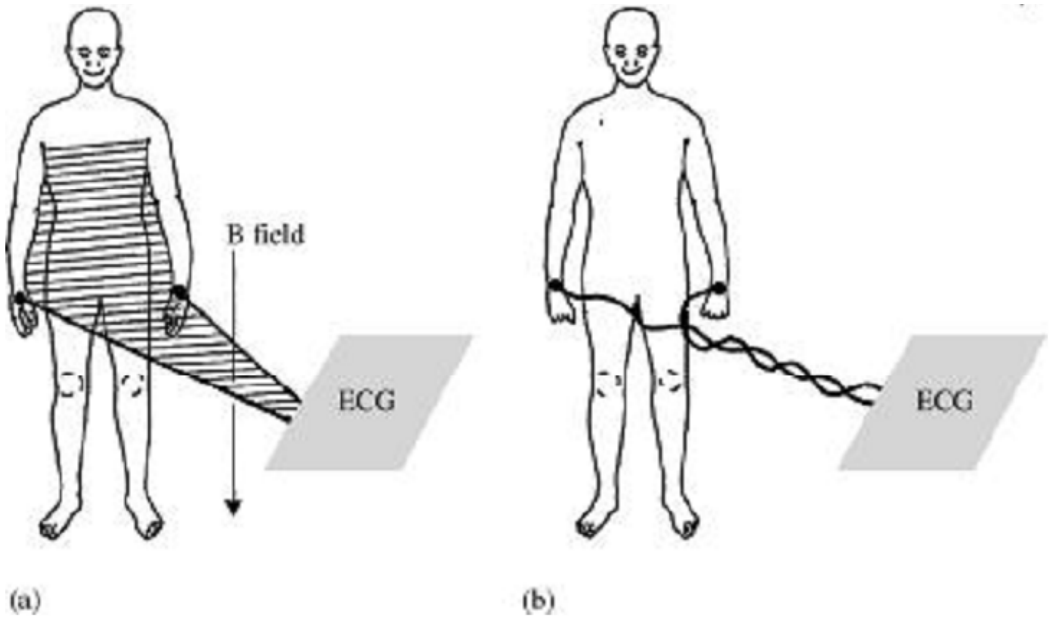


Figure 6.12 Magnetic-field pickup by the electrocardiograph (a) Lead wires for lead I make a closed loop (shaded area) when patient and electrocardiograph are considered in the circuit. The change in magnetic field passing through this area induces a current in the loop. (b) This effect can be minimized by twisting the lead wires together and keeping them close to the body in order to subtend a much smaller area.

It can be reduced:

1- by reducing the magnetic field through the use of magnetic shielding

2- by keeping the electrocardiograph and leads away from potential magnetic-field regions

3- by reducing the effective area of the single-turn coil

Transient Protection

The **isolation circuits** are primarily for the protection of the patient in that they eliminate the hazard of electric shock resulting from interacting among the patient, the electrocardiograph and other electric devises in the patient's environment.

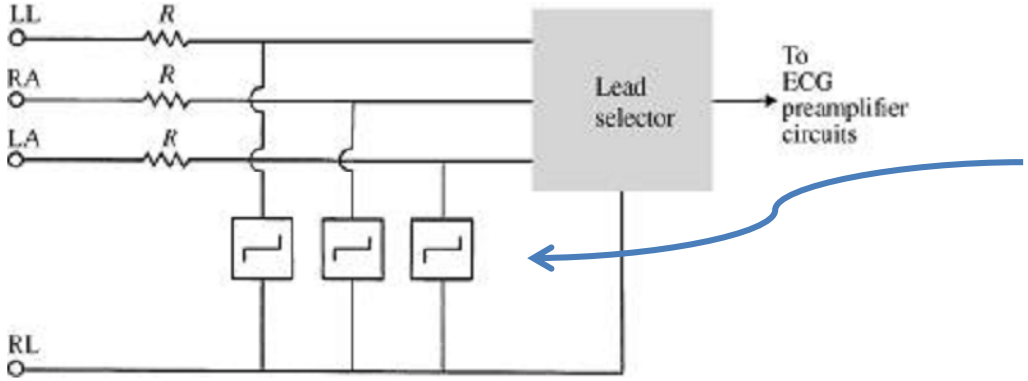
Example: In the operation suite,

ECG monitoring

Electrosurgical unit (ESU) using

If the **ground connection to the ESU is faulty** or if **higher-than-normal resistance** is present, the patient's voltage with respect to ground can become quite high during coagulation or cutting. These high potentials enter the electrocardiograph or cardiac monitor and can be large enough **to damage the electronic circuitry**.

To reduce this effect:

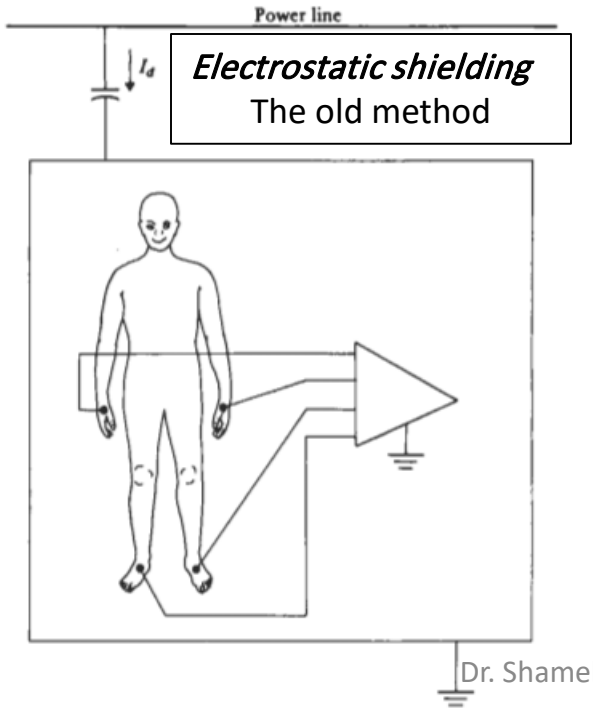


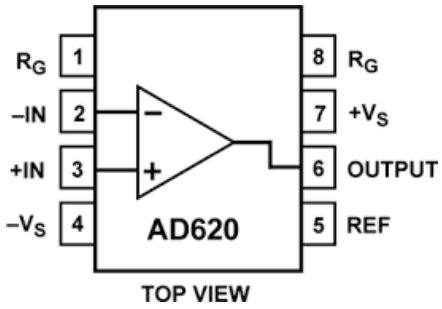
- Parallel silicon diodes,
-Zener diodes
- gas discharge tubes

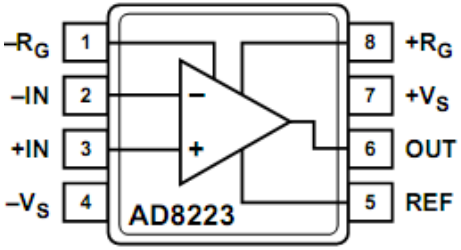
Figure 6.13 A voltage-protection scheme at the input of an electrocardiograph to protect the machine from high-voltage transients. Circuit elements connected across limb leads on left-hand side are voltage-limiting devices.

ELECTRIC- AND MAGNETIC-FIELD PICKUP

- We can minimize these interfering signals by trying to eliminate the sources of the signals via shielding techniques.
- This type of shielding is ineffective for magnetic fields unless the metal panels have a high permeability. (good magnetic and electric conduction are needed)
- Today, High-quality differential instrumentation amplifiers with high CMRR make such shielding unnecessary.







DRIVEN-RIGHT-LEG SYSTE

- In most modern electrocardiographic systems, the patient is not grounded at all. Instead, the right-leg electrode is connected.
- The common-mode voltage on the body is sensed by the two averaging resistors Ra inverted, amplified, and fed back to the right leg. This negative feedback drives the common-mode voltage to a low value

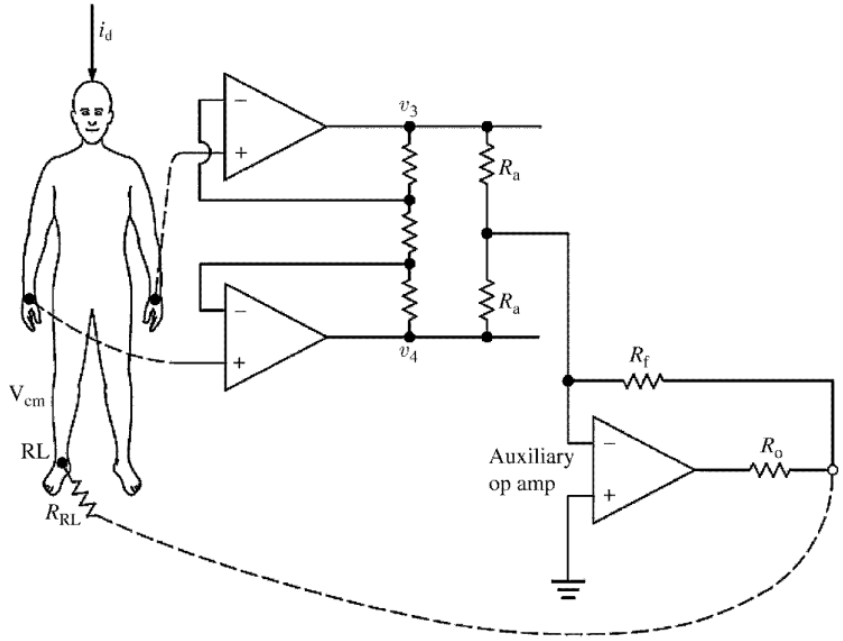
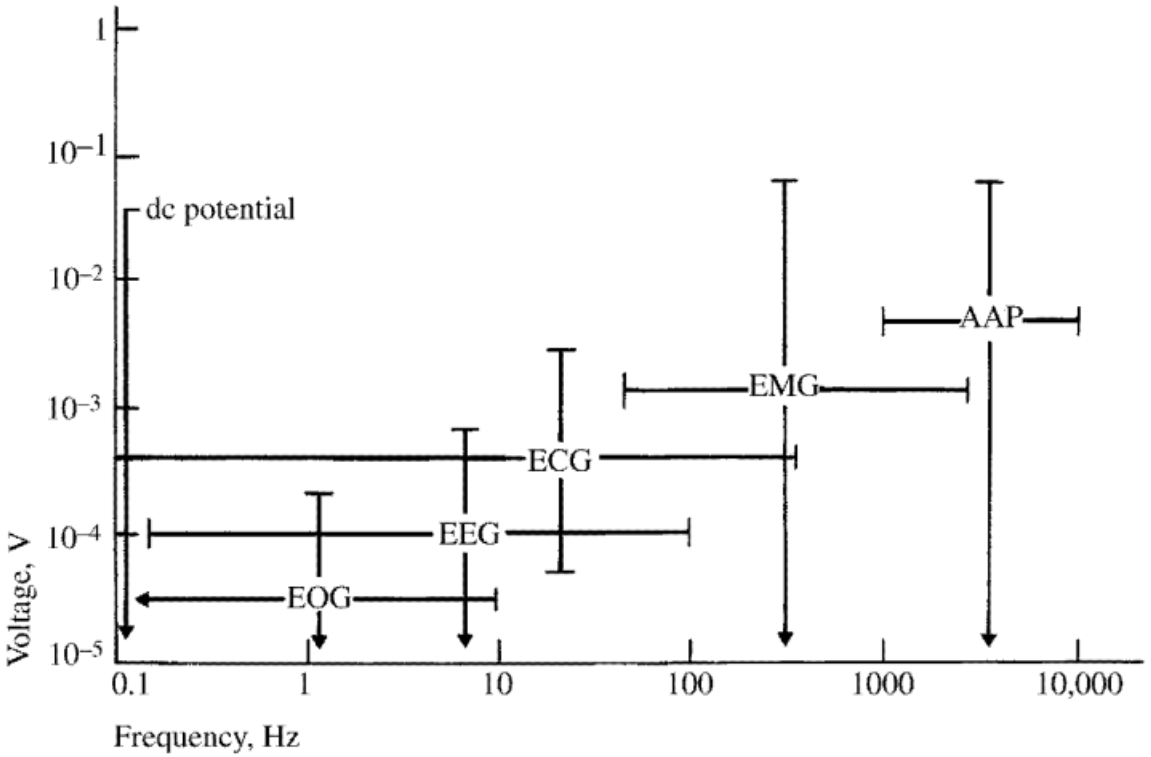


Figure 6.15 Driven-right-leg circuit for minimizing common-mode interference The circuit derives common-mode voltage from a pair of averaging resistors connected to v_3 and v_4 in Figure 3.5. The right leg is not grounded but is connected to output of the auxiliary op amp.

AMPLIFIERS FOR OTHER BIOPOTENTIAL SIGNALS

- Main differences between Biopotential amplifiers:
  - Signal spectrum (bandwidth)
  - Signal Amplitude



Electromyography Amps.

- frequency from 25 Hz to several kilohertz. Signal amplitudes range from 100 μV to 90 mV
- wider frequency response than ECG amplifiers,
- do not have to cover so low a frequency range as the ECGs.
- motion artifact
- In Skin-surface electrode recording
  - The levels of signals are generally low (0.1 to 1 mv) .this, **higher** gain needed
  - Electrode impedance is relatively low, ranging from about 200 to 5000 Ω
- In needle electrode recording
  - the EMG signals can be an order of magnitude stronger, thus requiring an order of magnitude **less gain**.
  - Furthermore, the surface area of the EMG needle electrode is much less than that of the surface electrode, so its source impedance is higher. Therefore, a higher amplifier input impedance is desirable for quality signal reproduction

AMPLIFIERS FOR USE WITH GLASS MICROPIPET INTRACELLULAR ELECTRODES

- Intracellular electrodes or microelectrodes that can measure the potential across the cell membrane generally detect potentials on the order of 50 to 100 mV.
- Their **small size and small effective surface-contact** area give them a **very high source impedance**. These features place on the **amplifier** the constraint of requiring an **extremely high input impedance**.
- Furthermore, the **high shunting capacitance** of the electrode itself affects the frequency- response characteristics of the system.
- Often **positive-feedback schemes are used** in the biopotential amplifier to provide an effective negative capacitance that can compensate for the high shunt capacitance of the source.
- DC to 10kHz
- A preamplifier circuit that is especially useful with microelectrodes is the **negative-input-capacitance** amplifier

- **Read The equations**

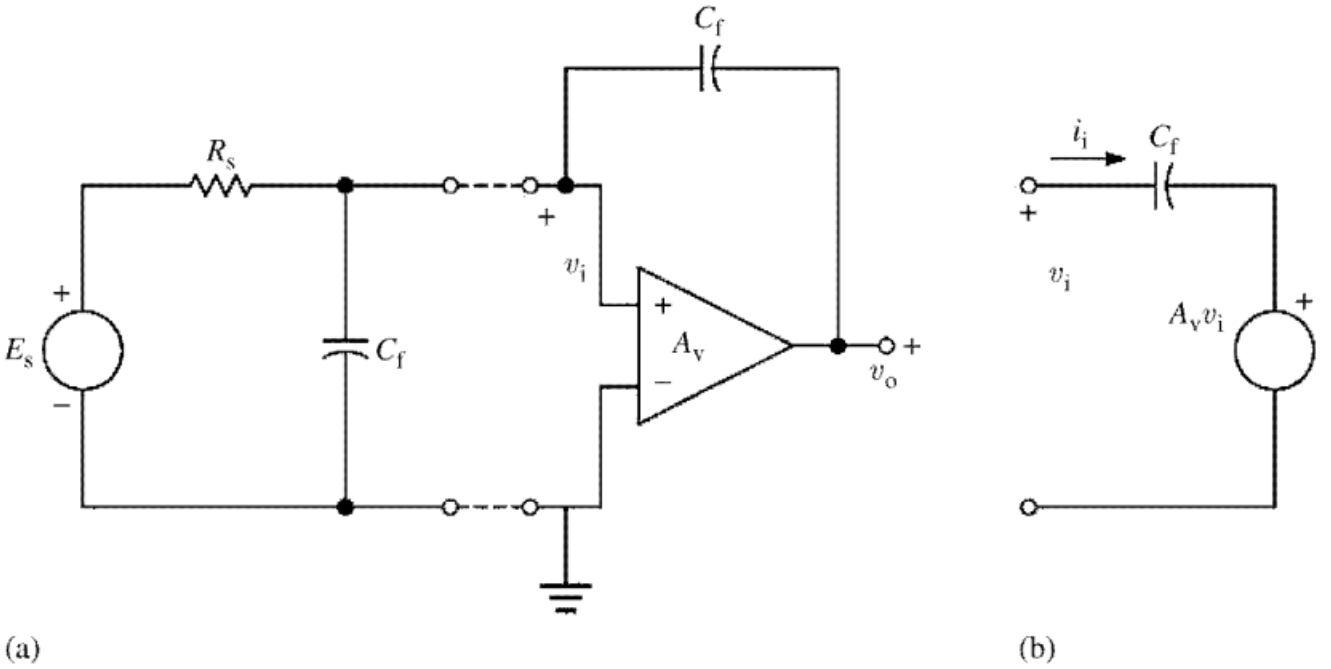


Figure 6.17 (a) Basic arrangement for negative-input-capacitance amplifier. Basic amplifier is on the right-hand side; equivalent source with lumped series resistance R_s and shunt capacitance C_s is on the left. (b) Equivalent circuit of basic negative-input-capacitance amplifier.

EEG AMPLIFIERS

- The EEG requires an amplifier with a frequency response of from 0.1 to 100 Hz.
- Surface electrode, as in clinical EEG,
  - amplitudes of signals range from 25 to 100 μV.
  - Thus amplifiers with relatively high gain are required.
  - These electrodes are smaller than those used for the ECG, so they have somewhat higher source impedances, and a high input impedance is essential in the EEG amplifier.
  - Because the signal levels are so small, common-mode voltages can have more serious effects.
  - Therefore more stringent efforts must be made to reduce common-mode interference, as well as to use amplifiers with higher CMRR and low noise.

EXAMPLE OF A BIOPOTENTIAL AMPLIFIER

- Preamplifiers must:
  - have low noise
  - have high input impedance
  - coupled directly with electrodes
  - minimize charging effects on coupling capacitors
  - deal with offset voltage
- Thus it must have low gain,
- For safety reasons, the preamplifier is electrically isolated from the remaining amplifier stage.

ECG Amplifier

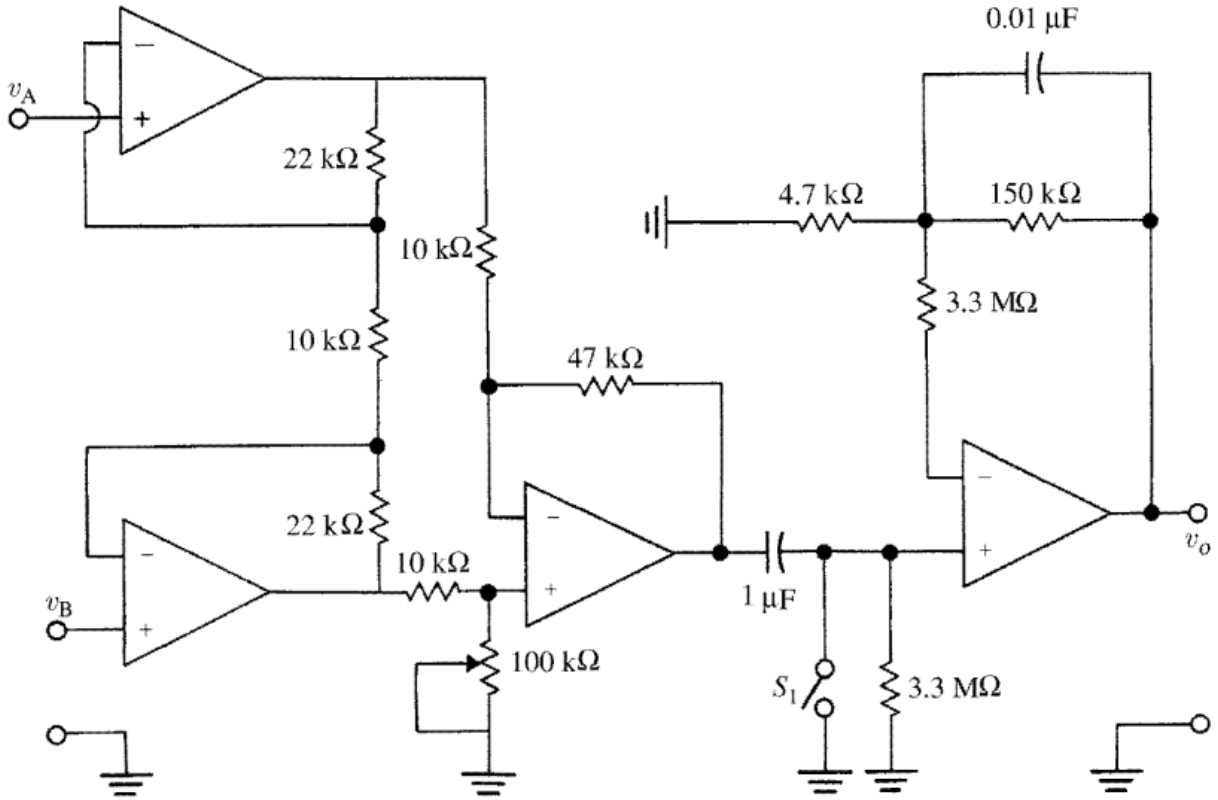


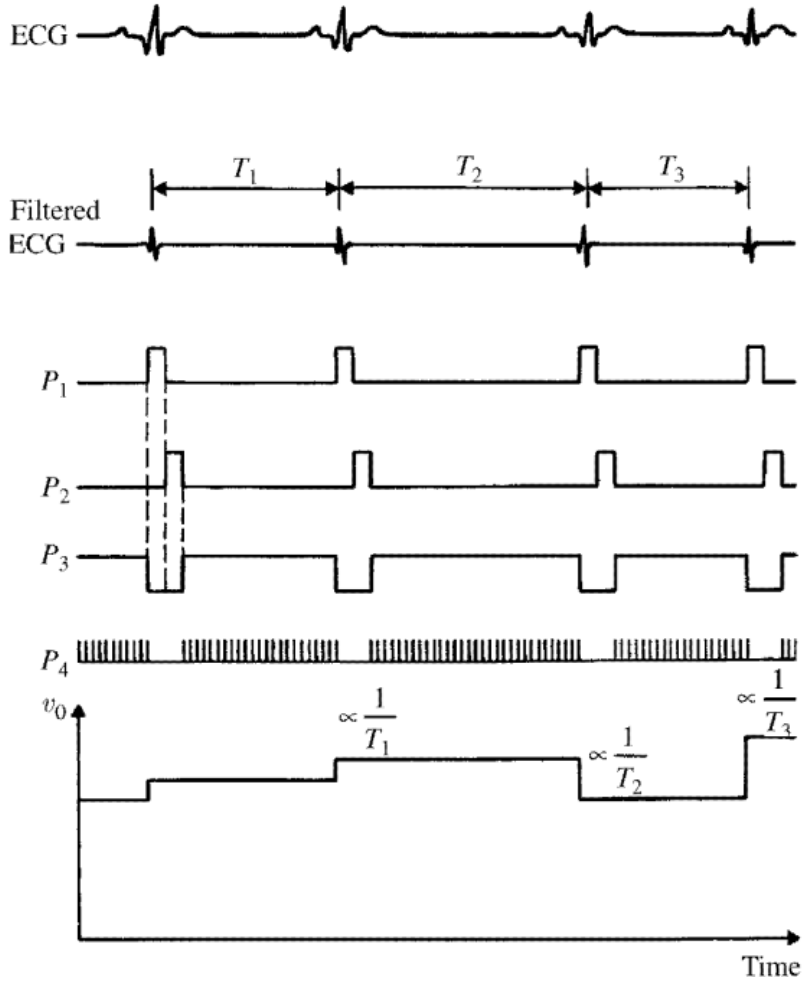
Figure 6.18 This ECG amplifier has a gain of 25 in the dc-coupled stages. The high-pass filter feeds a noninverting-amplifier stage that has a gain of 32. The total gain is $25 \times 32 = 800$. When μA 776 op amps were used, the circuit was found to have a CMRR of 86 dB at 100 Hz and a noise level of 40 mV peak to peak at the output. The frequency response was 0.05 to 106 Hz for ±3 dB and was flat over 4 to 40 Hz. A single op-amp chip, the LM 324, that contains four individual op amps could also be used in this circuit reducing the total parts count.

ECG Amplifier

- High CMR is achieved by adjusting the pot. to about 47 kΩ.
- Electrodes may produce an offset potential of up to 0.3 V. Thus, to prevent saturation, the dc-coupled stages have a gain of only 25.
- Coupling capacitors are not placed at the input because this would block the op-amp bias current.
- Coupling capacitors placed after the first op-amps would have to be impractically large. Therefore, the single 1μF coupling capacitor and the 3.3-MΩ resistor form a high-pass filter.
- The resulting 3.3s time constant passes all frequencies above 0.05 Hz.
- The output stage is a non-inverting amplifier that has a gain of 32
- A second 3.3MΩ resistor is added to balance bias-current source impedances.
- The 150kΩ and 0.01-pF low-pass filter attenuates frequencies above 100 Hz.
- Switch S1 may be closed to decrease the discharge time constant when the output saturates.
- We want the right end to be at 0 V when the left end is at the dc voltage determined by the electrode offset voltage.

OTHER BIOPOTENTIAL SIGNAL PROCESSORS

- Cardiotachometers
  - A cardiotachometer is a device for determining heart rate.
  - Types:
    - The averaging cardiotachometer
    - Beat to beat cardiotachometer



OTHER BIOPOTENTIAL SIGNAL PROCESSORS

- Electromyogram integrators
  - It is frequently of interest to quantify the amount of EMG activity measured by a particular system of electrodes. Such quantification often assumes the form of taking the absolute value of the EMG and integrating it.

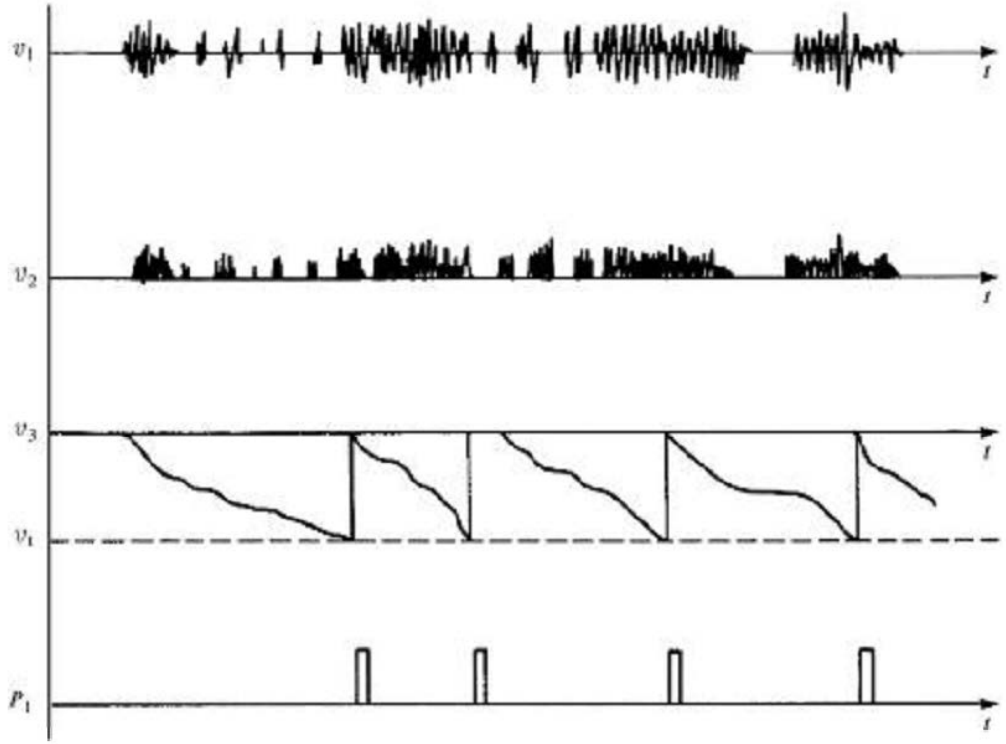


Figure 6.20 The various waveforms for the EMG integrator

OTHER BIOPOTENTIAL SIGNAL PROCESSORS

- Evoked potentials and signal averaging
  - EP signals are electric in nature, and frequently represent very weak signals with a very poor signal-to-noise ratio (SNR).
  - When the stimulus is repeated, the same or a very similar response is repeatedly elicited. This is the basis for biopotential signal processors that can obtain an enhanced response by means of repeated application of the stimulus (Childers, 1988).

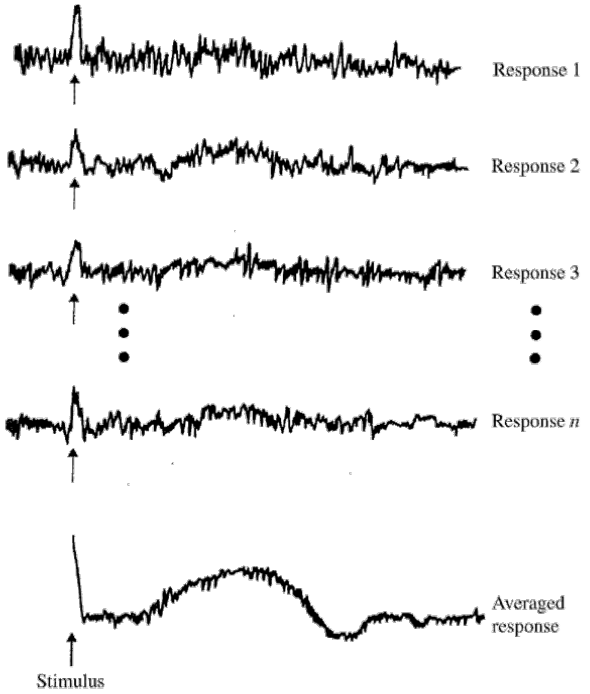


Figure 6.21 Signal-averaging technique for improving the SNR in signals that are repetitive or respond to a known stimulus.

OTHER BIOPOTENTIAL SIGNAL PROCESSORS

- Fetal ECG
  - The signal-averaging technique
  - Anticoincidence detectors
  - uses at least three electrodes:
    - on the mother's chest,
    - at the upper part or fundus of the uterus,
    - over the lower part of the uterus
- Vectorcardiograph
  - A VCG shows a 3-D at or least a 2D-picture of the orientation and magnitude of the cardiac vector throughout the cardiac cycle.

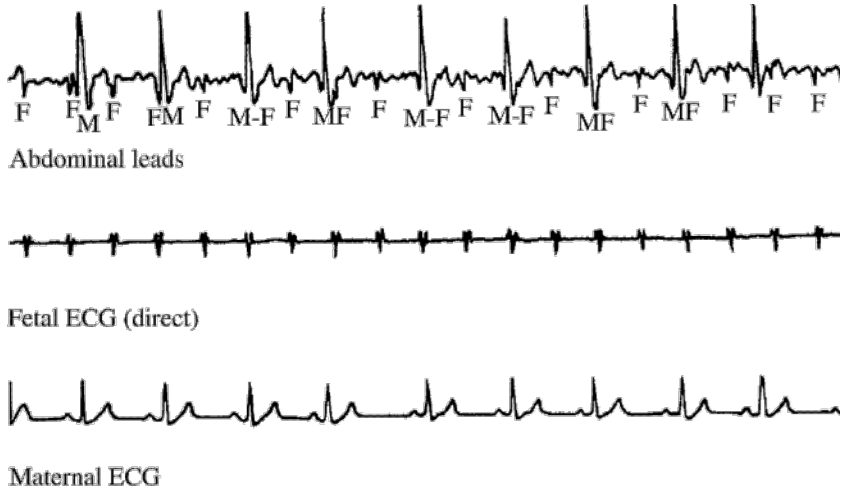


Figure 6.22 Typical fetal ECG obtained from the maternal abdomen

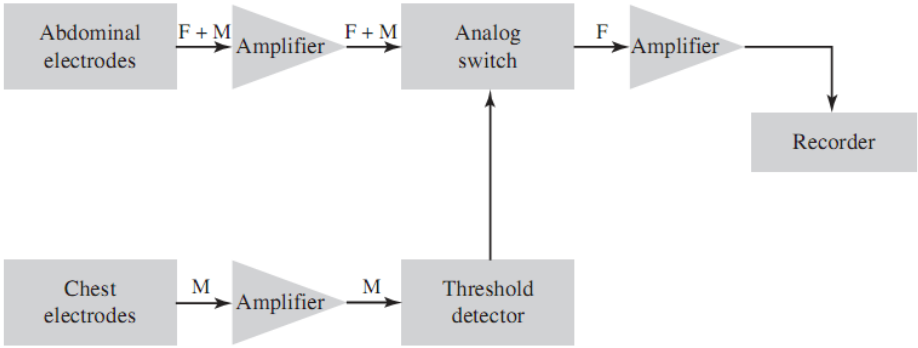


Figure 6.23 Block diagram of a scheme for isolating fetal ECG from an abdominal signal that contains both fetal and maternal ECGs. (From J. F. Roux, M. R. Neuman, and R. C. Goodlin, "Monitoring of intrapartum phenomena." In *CRC Critical Reviews in Bioengineering*, 2, January 1975, pp. 119–158 Copyright CRC Press. Used by permission of CRC Press, Inc.)

OTHER BIOPOTENTIAL SIGNAL PROCESSORS

- Cardiac monitors
  - Clinical applications of continuous monitoring of the ECG and heart rate are made possible by *cardiac monitor*.

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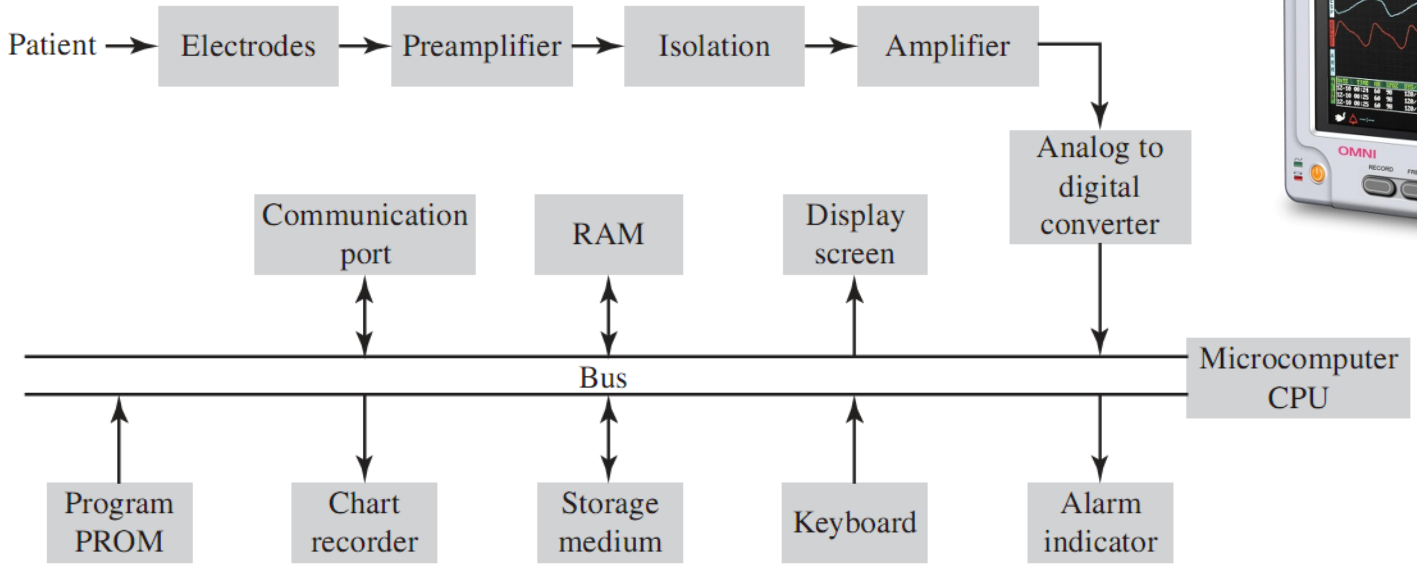
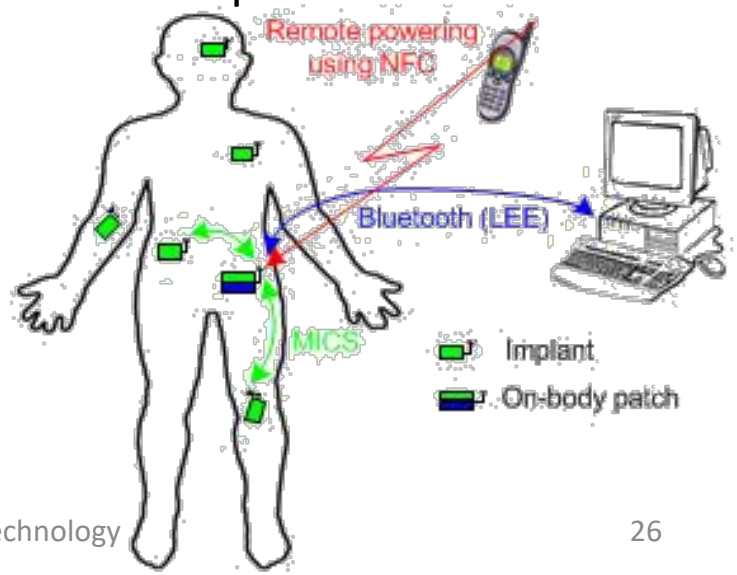


Figure 6.24 The cardiac monitor displays a continuous electrocardiogram and heart rate and also identifies alarm conditions.

OTHER BIOPOTENTIAL SIGNAL PROCESSORS

- Biotelemetry
  - Biopotential and other signals are often processed by radiotelemetry, a technique that provides a wireless link between the patient and the majority of signal-processing components.
  - Exp. By using a miniature radio transmitter
  - Provides the best method of isolating the patient from recording equipments and power line.
  - Low voltage with negligible risk to the patient
  - Utilize the standard wireless computer connection protocols:
    - WiFi
    - Bluetooth
    - ZigBee