Biopotential Amplifiers

- Amplifiers are an important part of modern instrumentation systems for measuring biopotentials.

- They are required to increase signal strength while maintaining high fidelity.

- Amplifiers that have been designed specifically for the processing of biopotentials are known as **biopotential amplifiers** .

BASIC REQUIREMENTS of BIOPOTENTIAL AMPLIFIERS

- All biopotential amplifiers must meet certain basic requirements.

  - **They must have high input impedance**, so that they provide minimal loading of the signal being measured. Loading effects are minimized by making the amplifier input impedance as high as possible, thereby reducing this distortion. Modern biopotential amplifiers have input impedances of at least 10 MΩ .

  - **The input circuit of a biopotential amplifier must provide protection to the organism being studied**. Any current or potential appearing across the amplifier input terminals that is produced by the amplifier is capable of affecting the biological potential being measured. In clinical systems, electric currents from the input terminals of a biopotential amplifier can result in microshocks or macroshocks in the patient being studied— a situation that can have grave consequences. To avoid these problems, the amplifier should have isolation and protection circuitry, so that the current through the electrode circuit can be kept at safe levels and any artifact generated by such current can be minimized.

  - **the output impedance of the amplifier must be low with respect to the load impedance**, and the amplifier must be capable of supplying the power required by the load.

- **Biopotential amplifiers must operate in that portion of the frequency spectrum in which the biopotentials that they amplify exist**. Biopotential signals usually have amplitudes of the order of a few millivolts or less. Such signals must be amplified to levels compatible with recording and display devices.

- **Biopotential differential amplifiers must have high common mode-rejection ratios** to minimize interference due to the common-mode signal.

- **Gain of the amplifier must be well calibrated**. Frequently biopotential amplifiers have a standard signal source that can be momentarily connected to the input, automatically at the start of a measurement or manually at the push of a button, to check the calibration.

- **Biopotential amplifiers have additional requirements that are application-specific and that can be ascertained from an examination of each application.**

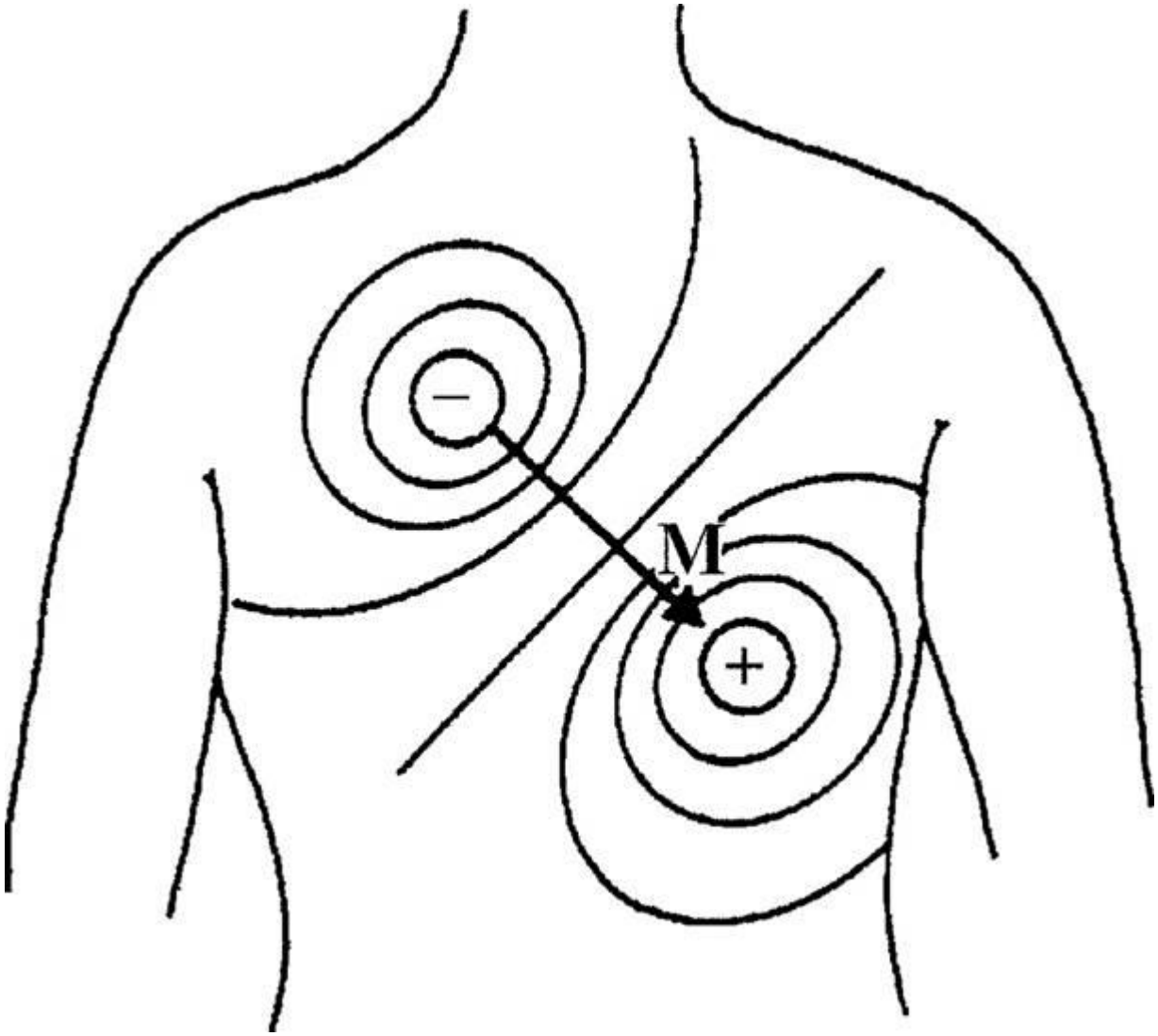


Figure 6.1 Rough sketch of the dipole field of the heart when the R wave is maximal. The dipole consists of the points of equal positive and negative charge separated from one another and denoted by the dipole moment vector M.

- Moving Dipole

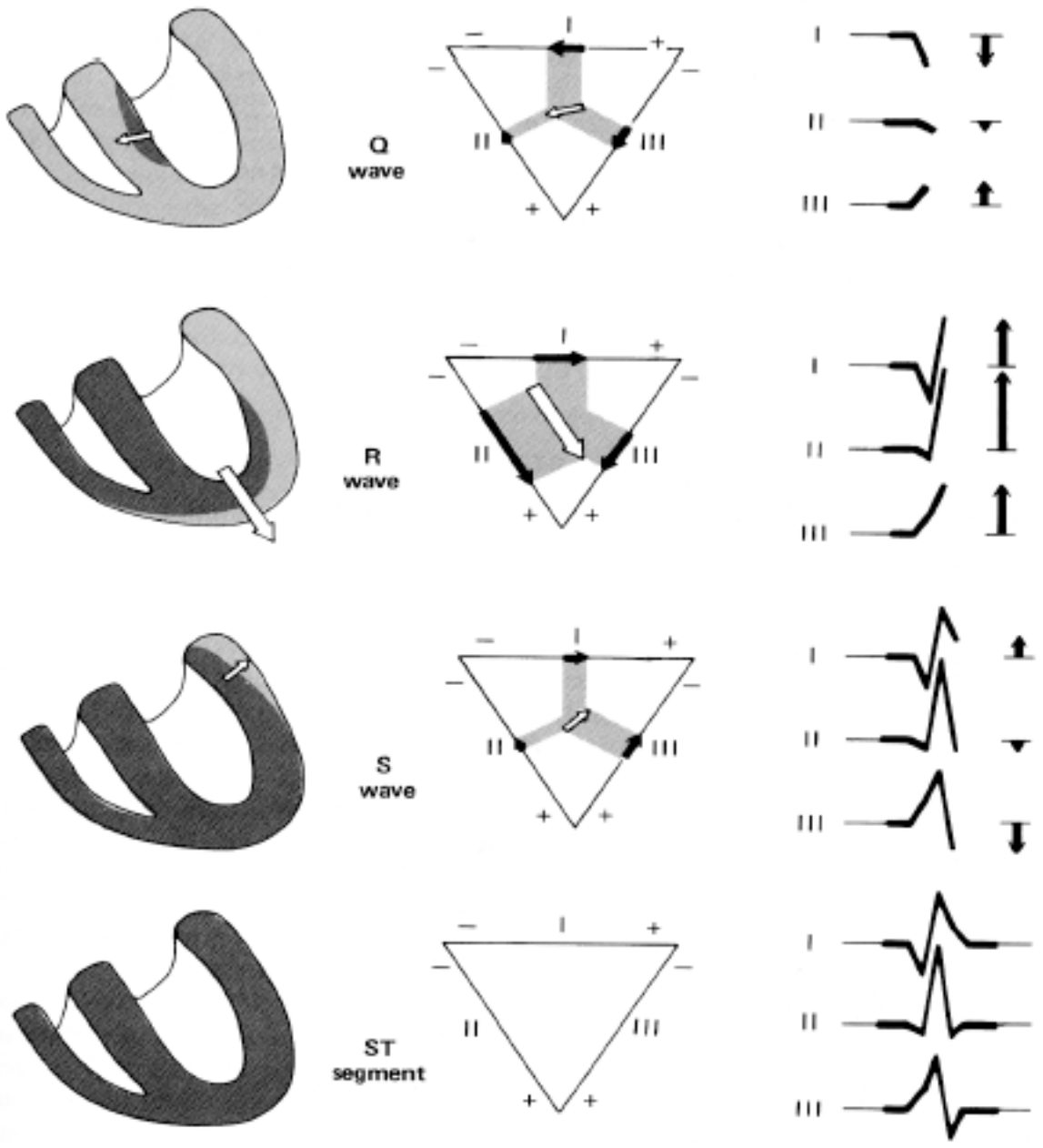
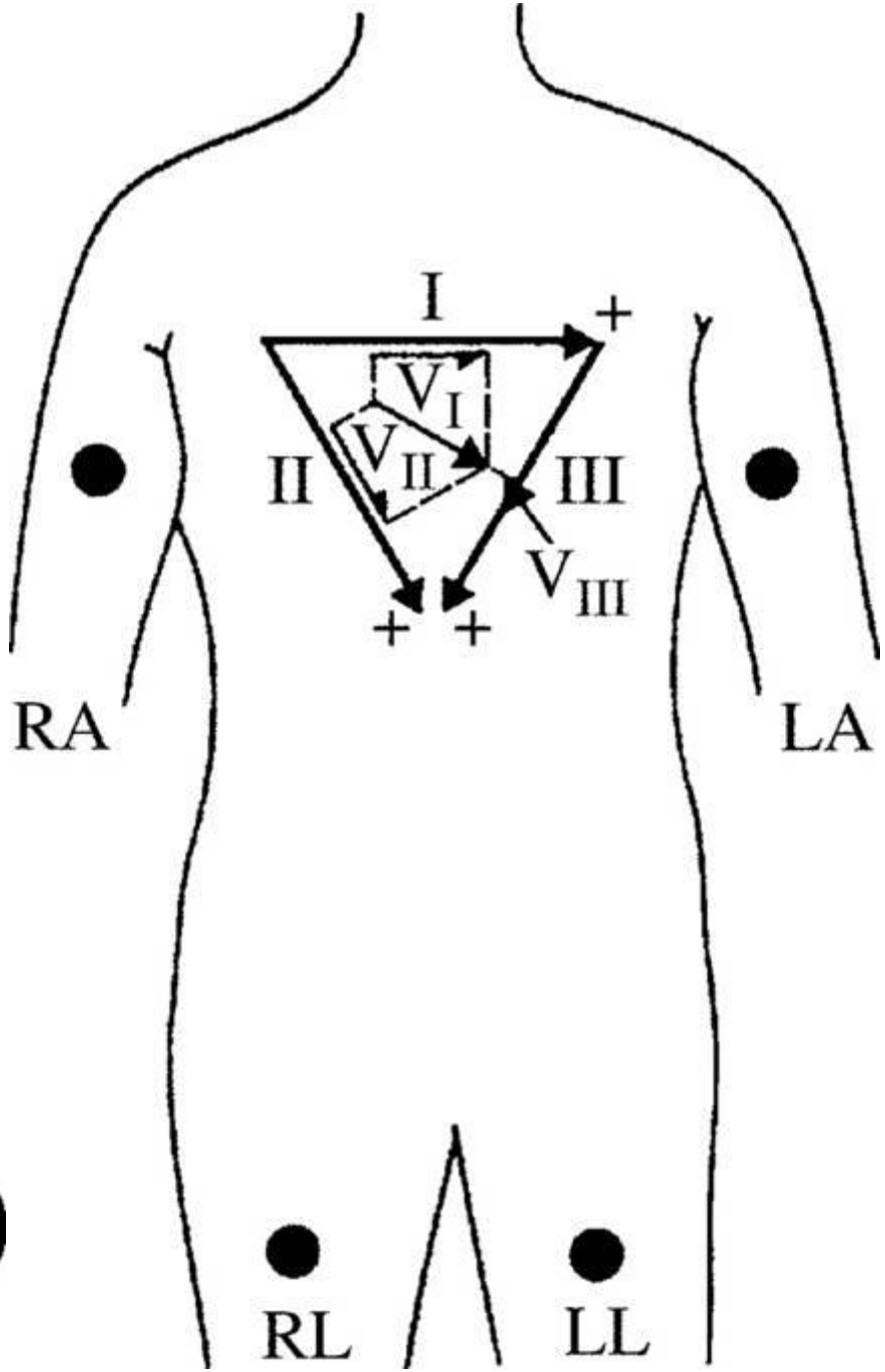


Figure 6.3 Cardiologists use a standard notation such that the direction of the lead vector for lead I is 0°, that of lead II is 60°, and that of lead III is 120°. An example of a cardiac vector at 30° with its scalar components seen for each lead is shown.



$$I - II + III = 0$$

Figure 6.4
Connection of electrodes to the body to obtain Wilson's central terminal

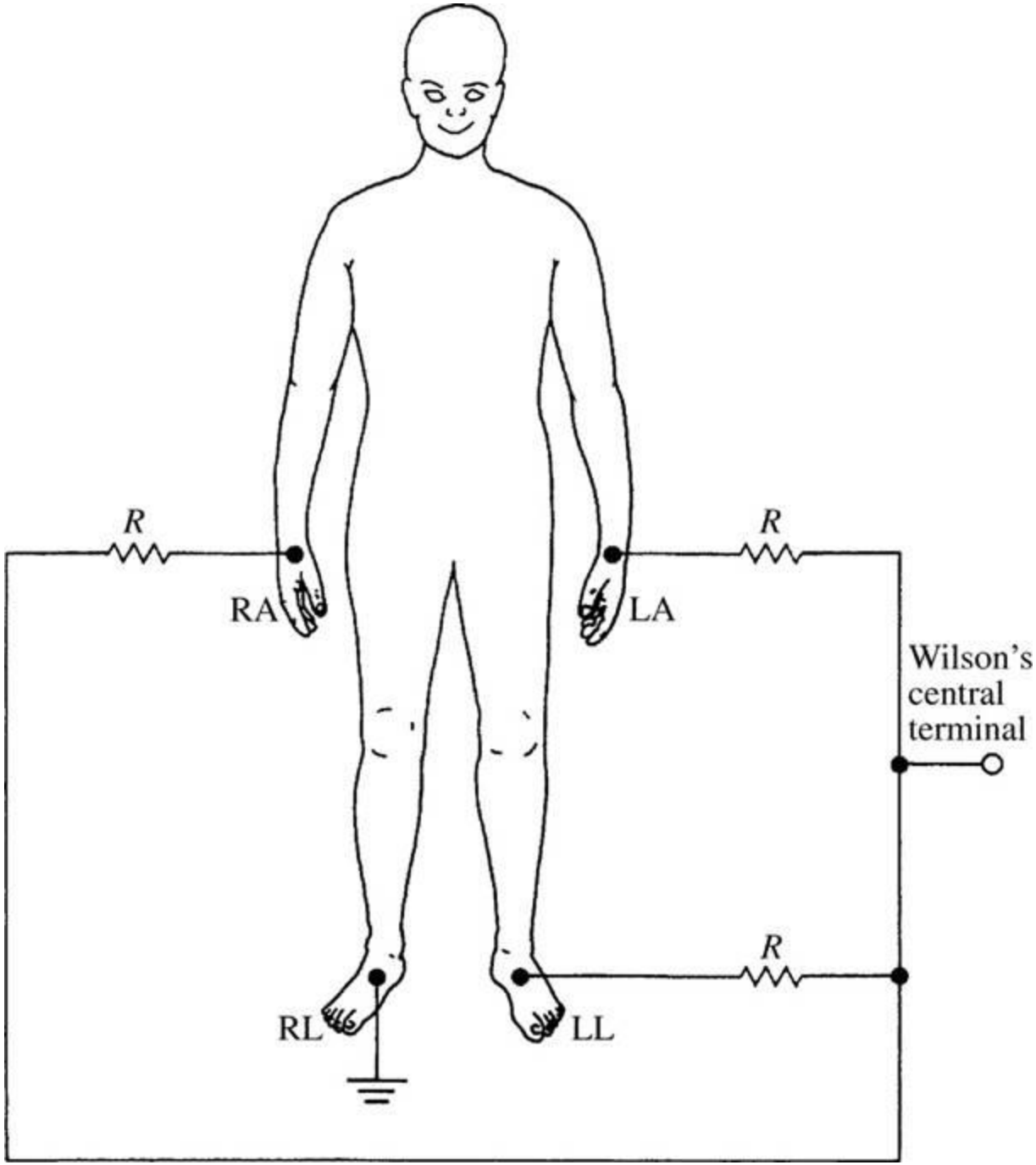
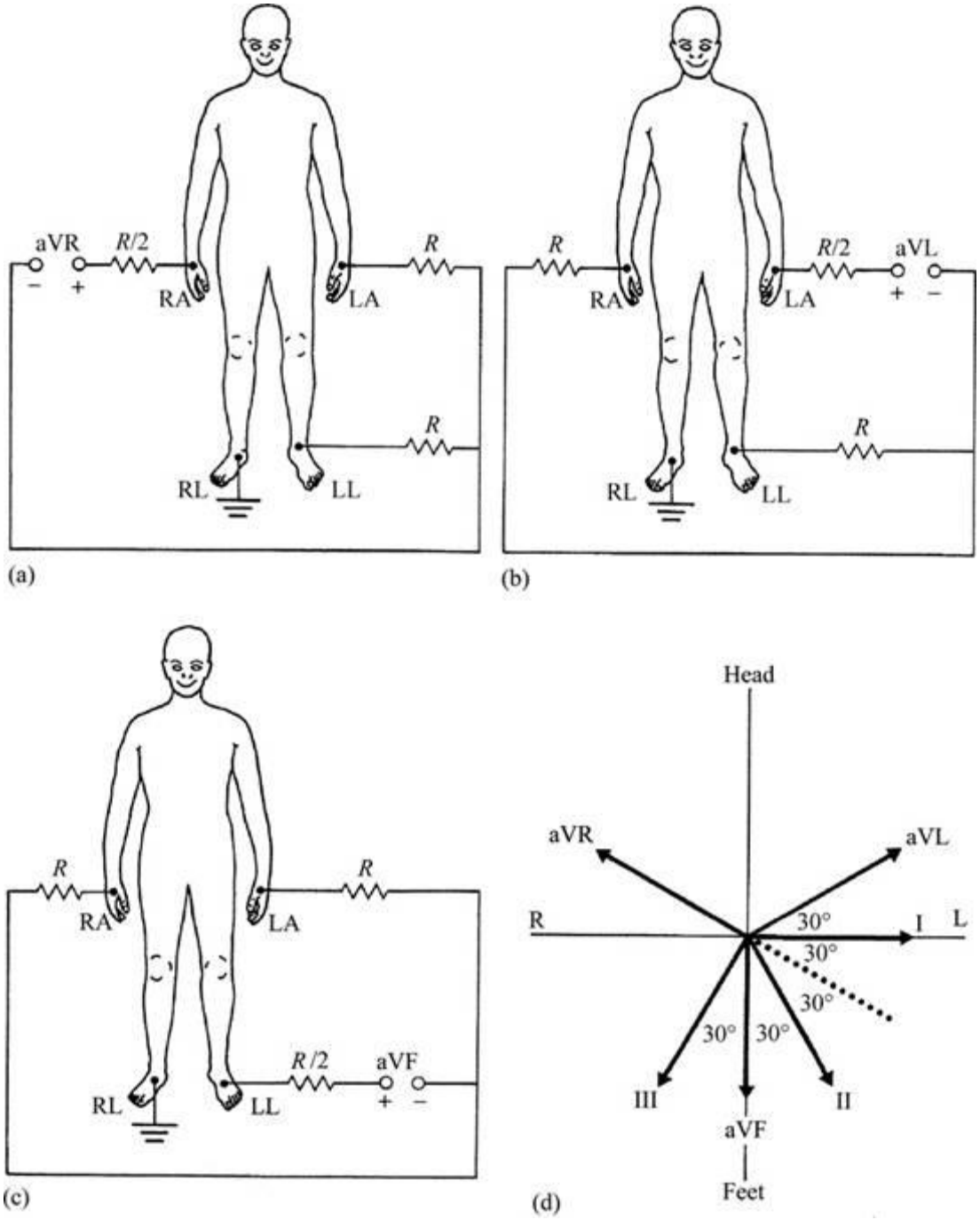


Figure 6.5 (a), (b), (c) Connections of electrodes for the three augmented limb leads, (d) Vector diagram showing standard and augmented lead-vector directions in the frontal plane.



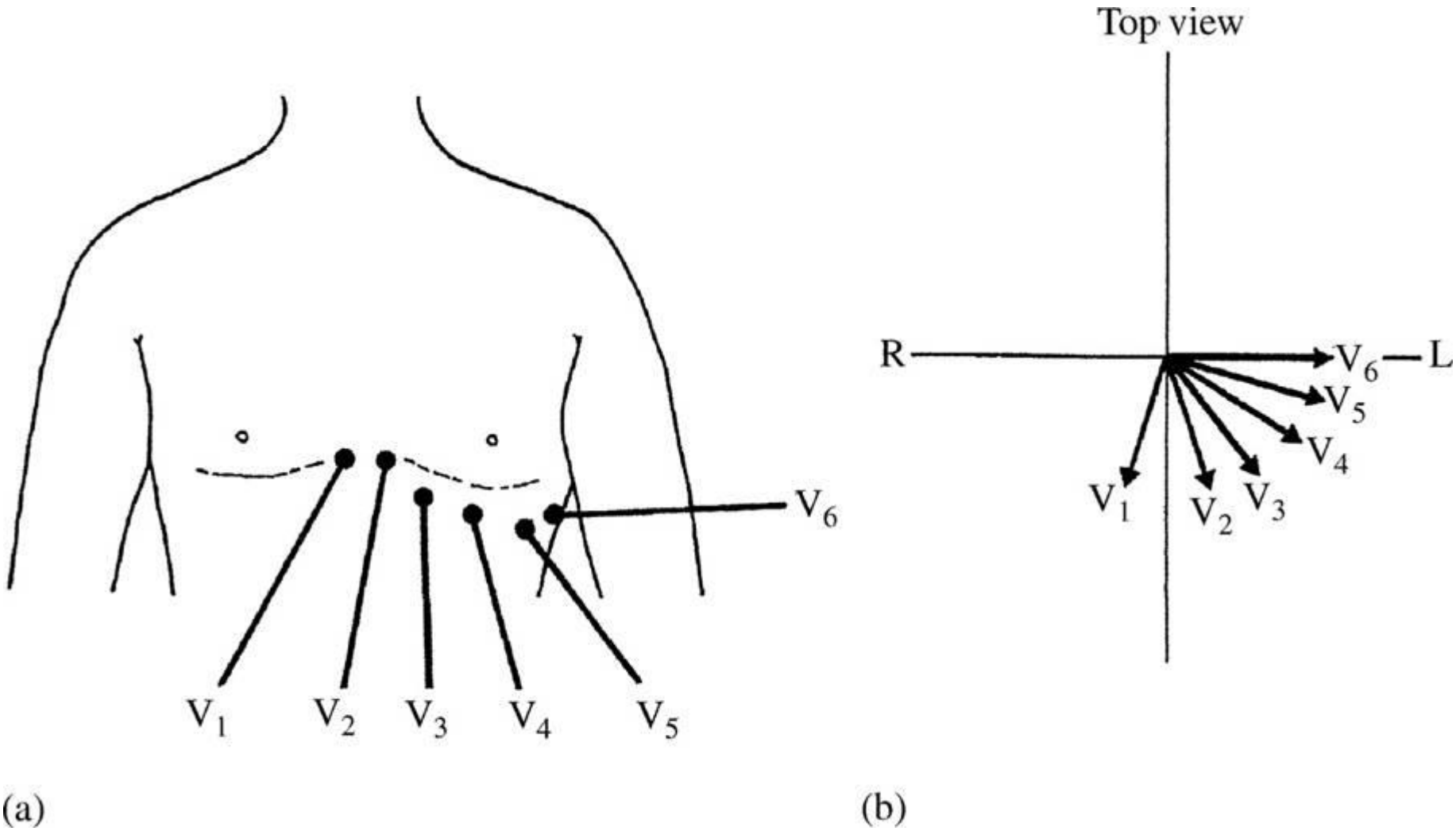
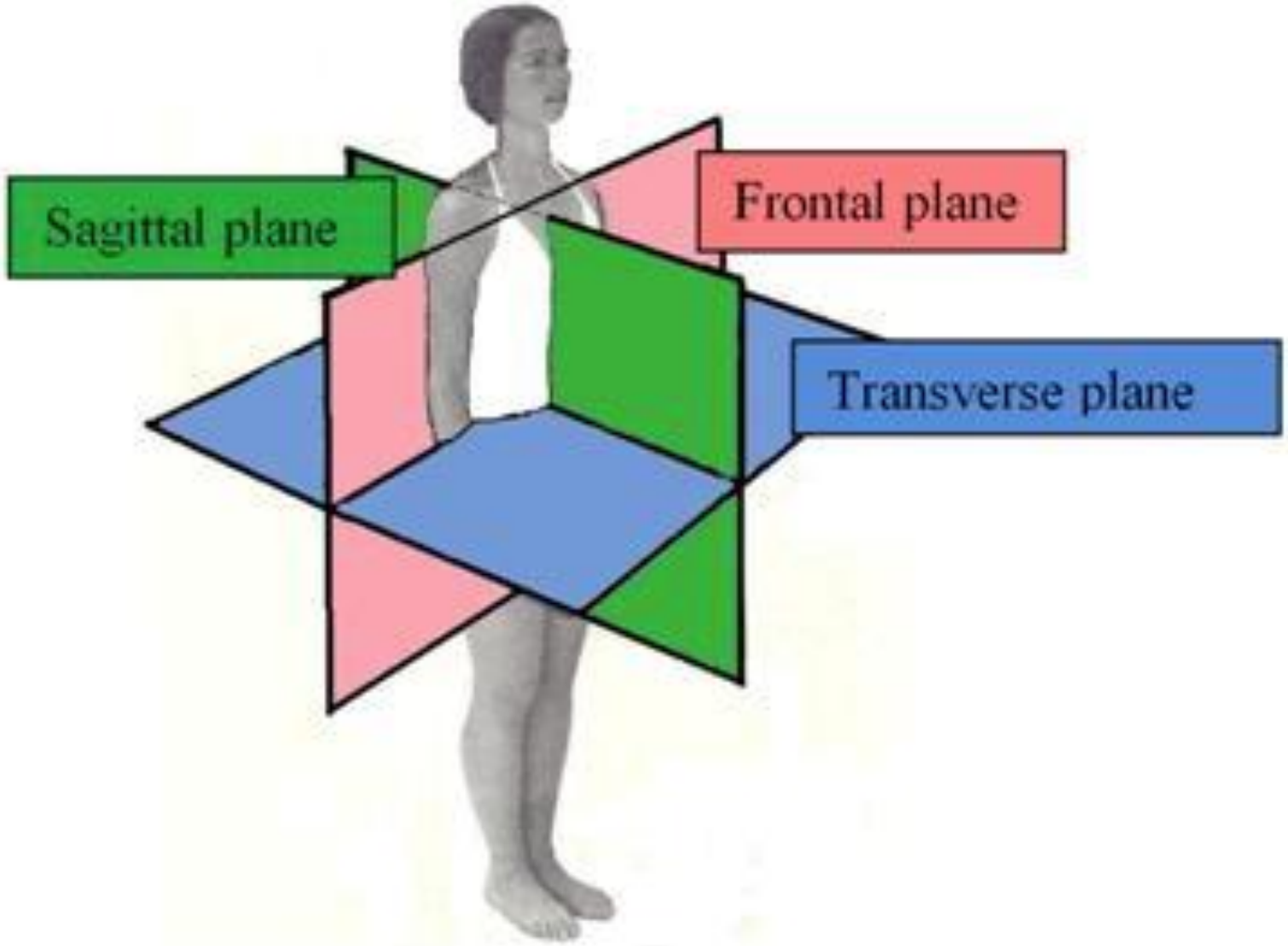
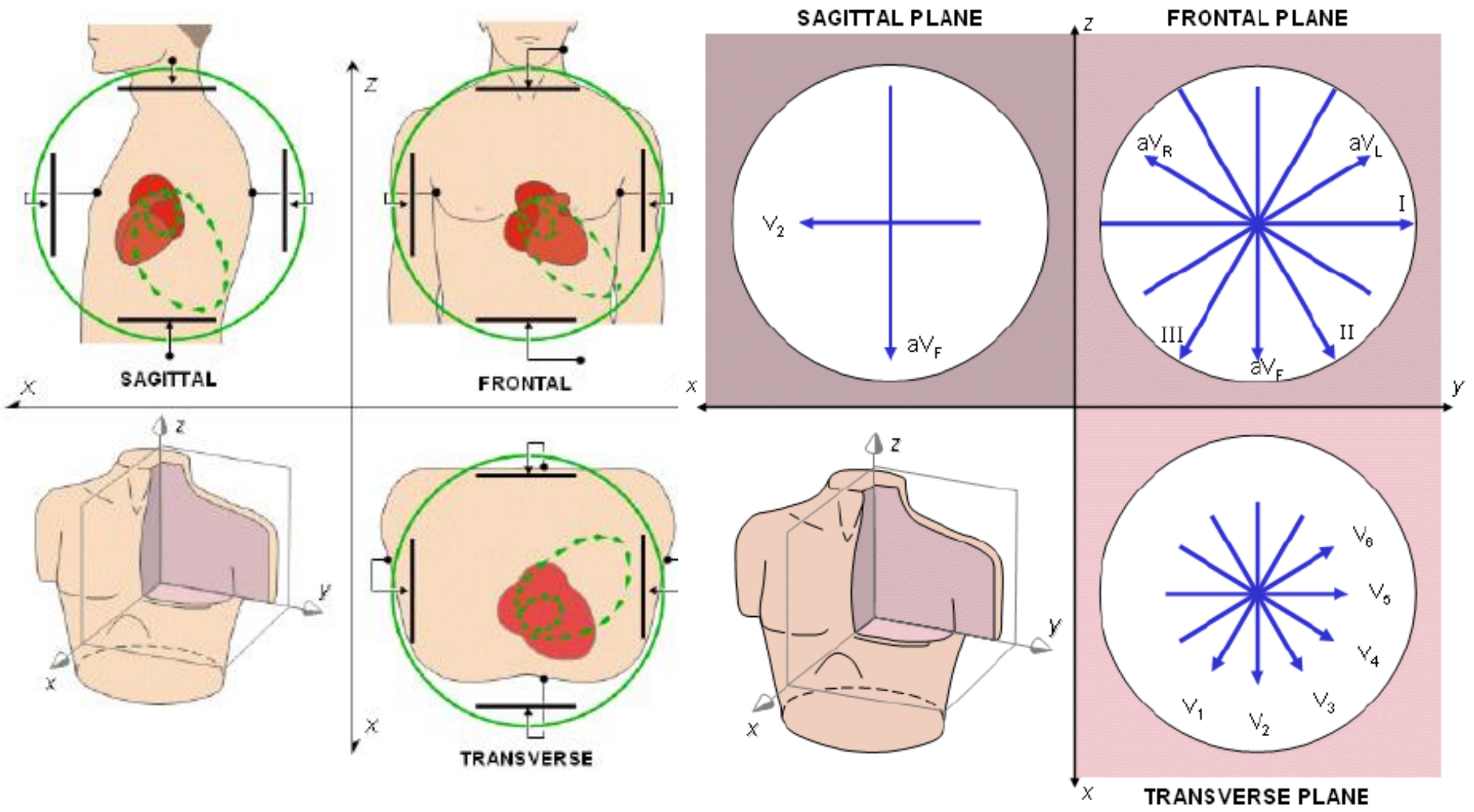


Figure 6.6 (a) Positions of precordial leads on the chest wall, (b) Directions of precordial lead vectors in the transverse plane.


Sagittal plane
Frontal plane
Transverse plane


SAGITTAL
FRONTAL
TRANSVERSE
SAGITTAL PLANE
FRONTAL PLANE
TRANSVERSE PLANE
V_2
aV_F
aV_R
aV_L
I
III
II
aV_F
V_6
V_5
V_4
V_1
V_2
V_3
x
y
z
X
Z

- Because the electrocardiograph is widely used as a diagnostic tool and there are several manufacturers of this instrument, standardization is necessary.

Table 6.1 Summary of Performance Requirements for Electrocardiographs (Anonymous, 1991)

Section	Requirement Description	Min/max	Units	Min/Max Value
3.2.1	Operating conditions:			
	Line voltage	Range	V rms	104 to 1127
	Frequency	Range	Hz	60 ± 1
	Temperature	Range	°C	25 ± 10
	Relative humidity	Range	%	50 ± 20
	Atmospheric pressure	Range	Pa	7×10^4 to 10.6×10^4
3.2.2	Lead definition (number of leads):	NA	NA	Table 3
	Single-channel	Min	NA	7
	Three-channel	Min	NA	12
3.2.3	Input Dynamic Range:			
	Range of linear operations of input signal	Min	mV	±5
	Slew rate change	Max	mV/s	320
	DC offset voltage range	Min	mV	±300
	Allowed variation of amplitude with dc offset	Max	%	±5
3.2.4	Gain control, accuracy, and stability:			
	Gain selections	Min	mm/mV	20, 10, 5
	Gain error	Max	%	5
	Manual override of automatic gain control	NA	NA	NA
	Gain change rate/min	Max	%/min	±0.33
	Total gain change/h	Max	%	±3
3.2.5	Time base selection and accuracy:			
	Time base selections	Min	mm/s	25, 50
	Time base error	Max	%	±5
3.2.6	Output display:			
	General	NA	NA	per 3.2.3
	Width of display	Min	mm	40
	Trace visibility (writing rates)	Max	mm/s	1600
	Trace width (permanent record only)	Max	mm	1
	Departure from time axis alignment	Max	mm	0.5
		Max	ms	10
	Preruled paper division	Min	div/cm	10
	Error of rulings	Max	%	±2
	Time marker error	Max	%	±2
3.2.7	Accuracy of input signal reproduction:			
	Overall error for signals	Max	%	±5
	Up to ±5 mV and 125 mV/s	Max	μV	±40

Table 6.1 *(Continued)*

Section	Requirement Description	Min/max	Units	Min/Max Value
	Upper cut-off frequency (3 dB)	Min	Hz	150
	Response to 20 ms, 1.5 mV triangular input	Min	mm	13.5
	Response after 3 mV, 100 ms impulse	Max	mV	0.1
		Max	mV/s	0.30
	Error in lead weighting factors	Max	%	5
	Hysteresis after 15 mm deflection from baseline	Max	mm	0.5
3.2.8	Standardizing voltage:			
	Nominal value	NA	mV	1.0
	Rise time	Max	ms	1
	Decay time	Min	s	100
	Amplitude error	Max	%	±5
3.2.9	Input impedance at 10 Hz (each lead)	Min	megohms	2.5
3.2.10	DC current (any input lead)	Max	μA	0.1
	DC current (any patient electrode)	Max	μA	1.0
3.2.11	Common-Mode Rejection:			
	Allowable noise with 20 V, 60 Hz and ±300 mV dc and 51 kΩ	Max	mm	10
	Imbalance	Max	mV	1
3.2.12	System noise:			
	RTI, *p-p*	Max	μV	30
	Multichannel crosstalk	Max	%	2
3.2.13	Baseline control and stability:			
	Return time after reset	Max	s	3
	Return time after lead switch	Max	s	1
	Baseline stability:			
	Baseline drift rate RTI	Max	μV/s	10
	Total baseline drift RTI (2 min period)	Max	μV	500
3.2.14	Overload protection:			
	No damage from differential voltage, 60 Hz, 1 Vp-p, 10 s application	Min	V	1
	No damage from simulated defibrillator discharges:			
	Overvoltage	N/A	V	5000
	Energy	N/A	J	360
	Recovery time	Max	s	8
	Energy reduction by defibrillator shunting	Max	%	10
	Transfer of charge through defibrillator chassis	Max	μC	100

(Continued)

Table 6.1 *(Continued)*

Section	Requirement Description	Min/max	Units	Min/Max Value
	ECG display in presence of pacemaker pulses:			
	Amplitude	Range	mV	2 to 250
	Pulse duration	Range	ms	0.1 to 2.0
	Rise time	Max	μs	100
	Frequency	Max	pulses/min	100
3.2.15	Risk current (isolated patient connection)	Max	μA	10
		As per applicable document 2.11		
3.2.16	Auxiliary output (if provided):			
	No damage from short circuit risk	Max	μA	10
	Current (isolated patient connection)	As per applicable document 2.1.1		

FUNCTIONAL BLOCKS OF THE ELECTROCARDIOGRAPH

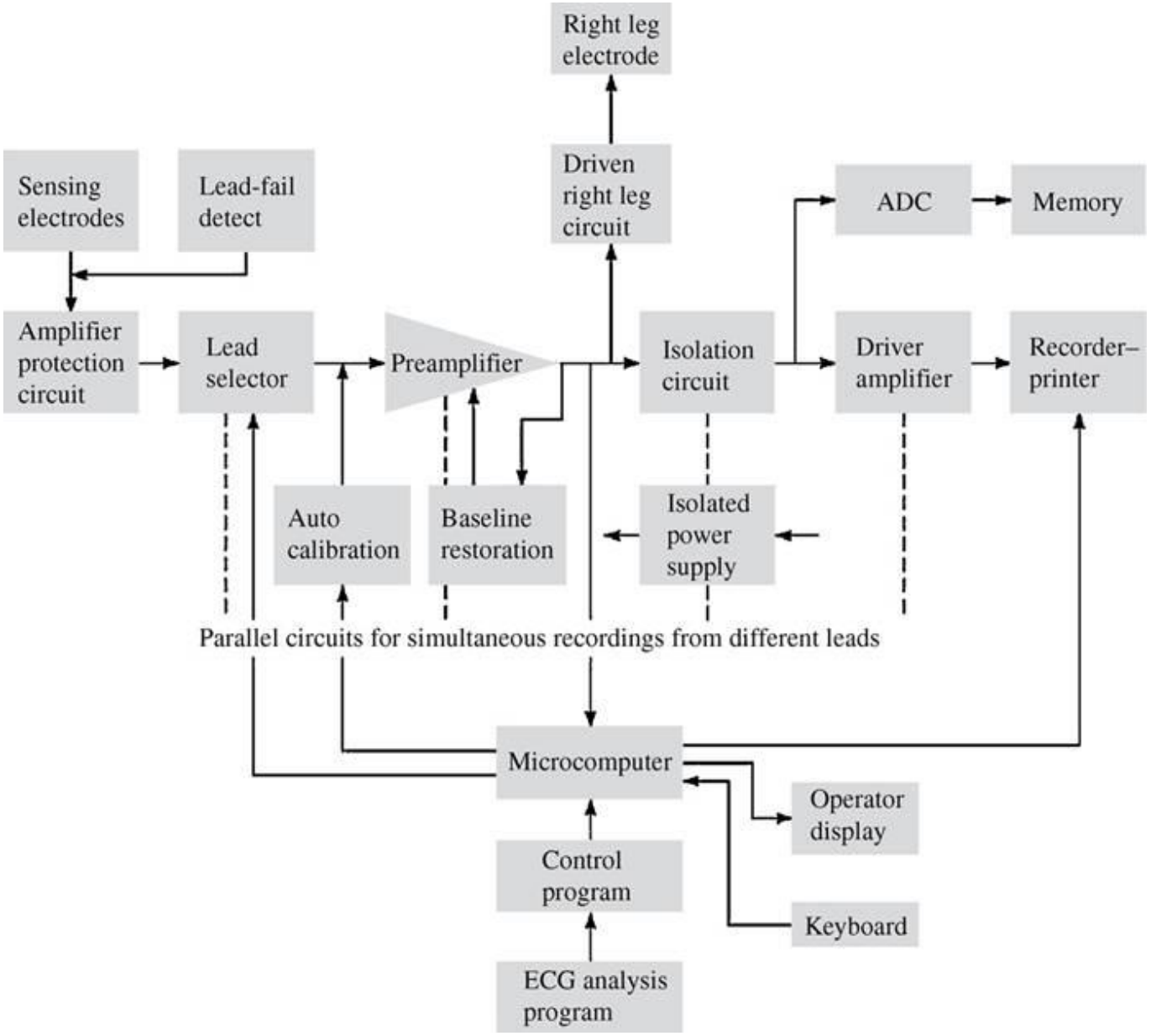
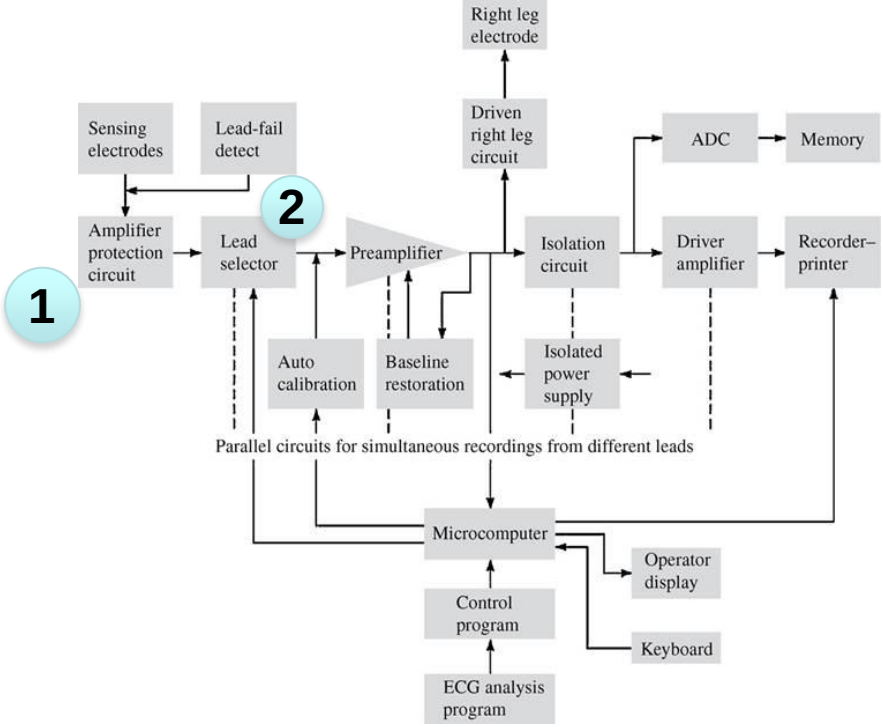


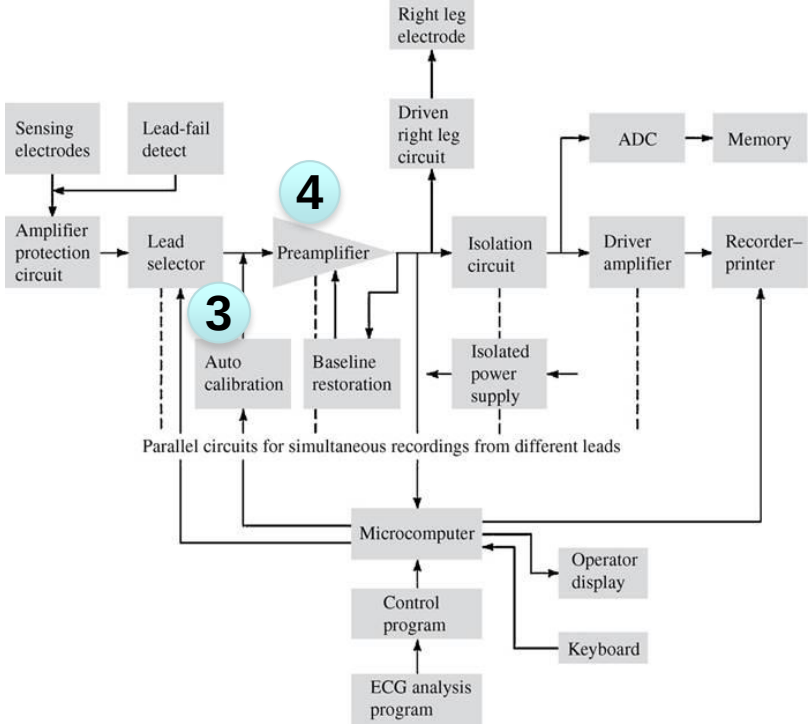
Figure 6.7 Block diagram of an electrocardiograph



①**Protection circuit:** This circuit includes protection devices so that the high voltages that may appear across the input to the electrocardiograph under certain conditions do not damage it.

② **Lead selector:** Each electrode connected to the patient is attached to the lead selector of the electrocardiograph. The function of this block is to determine which electrodes are necessary for a particular lead and to connect them to the remainder of the circuit.

- This block can be controlled by the operator or by the microcomputer of the electrocardiograph when it is operated in automatic mode. It selects one or more leads to be recorded. In automatic mode, each of the 12 standard leads is recorded for a short duration such as 10 s.



③Calibration signal: A 1 mV calibration signal is momentarily introduced into the electrocardiograph for each channel that is recorded.

④Preamplifier: The input preamplifier stage carries out the initial amplification of the ECG. This stage should have very high input impedance and a high common-mode-rejection ratio (CMRR). A typical pre-amplifier stage is the differential amplifier that consists of three operational amplifiers (op amps) (Figure 3.5). A gain-control switch is often included as a part of this stage.

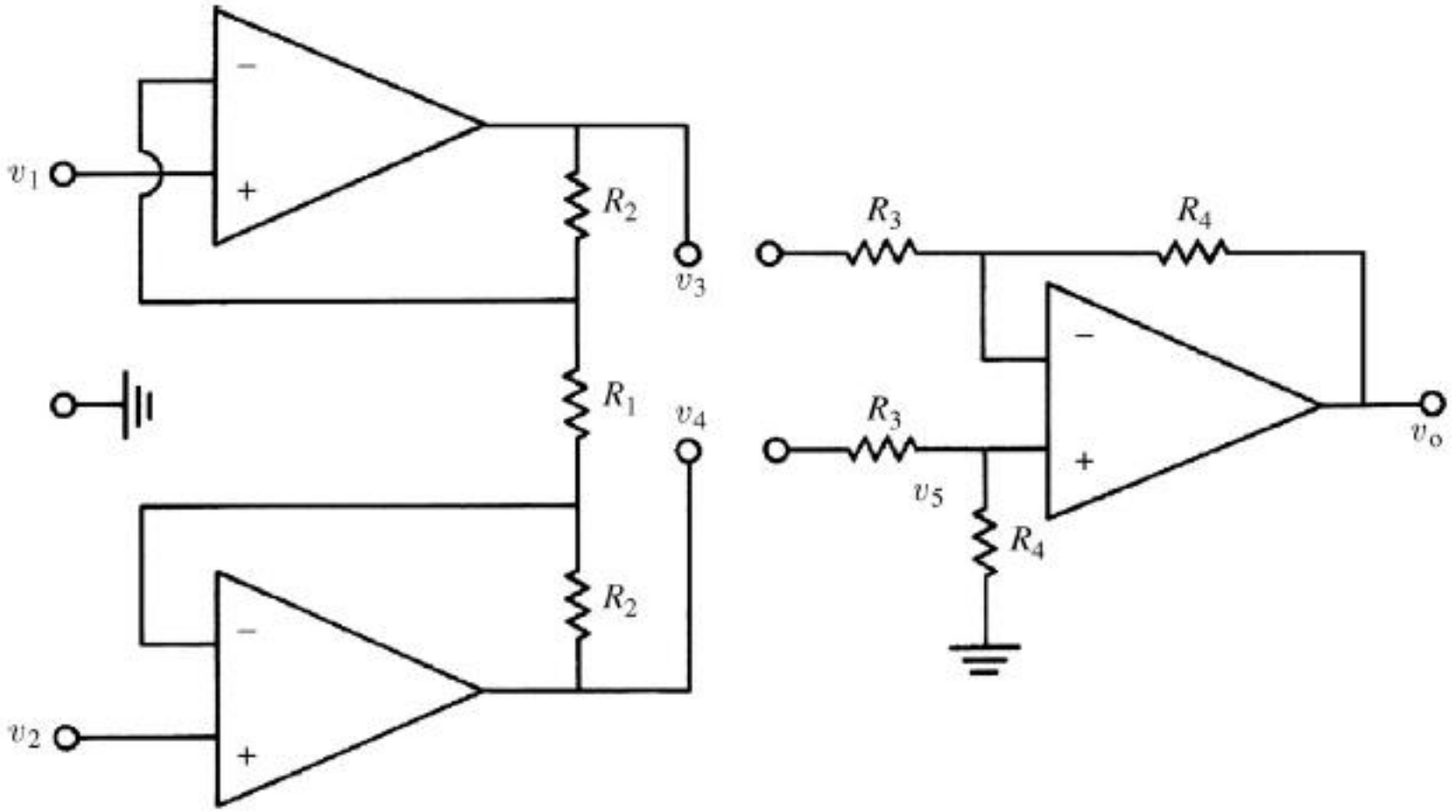
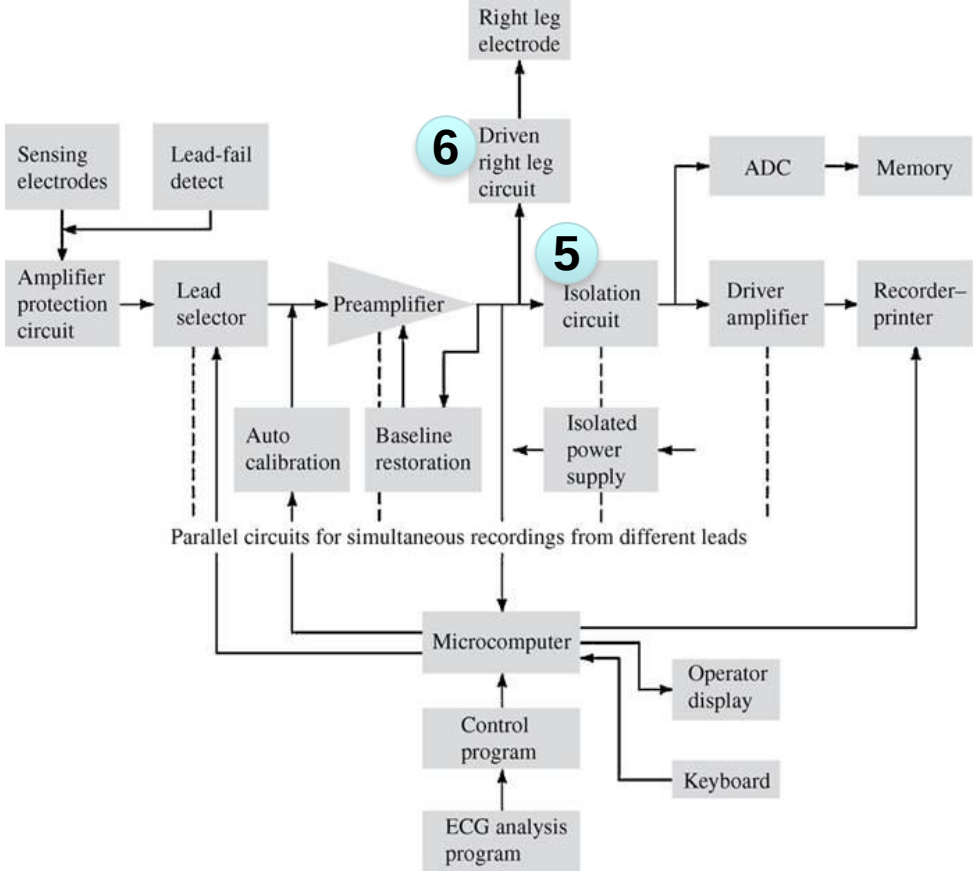
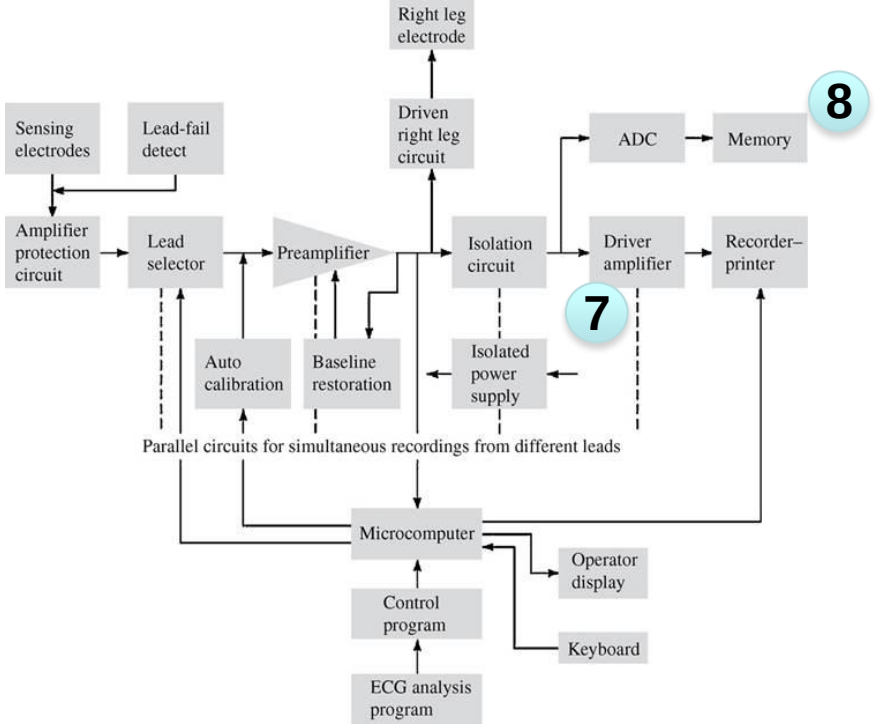


Figure 3.5 (a) The right side shows a one-op-amp differential amplifier, but it has low input impedance. The left side shows how two additional op amps can provide high input impedance and gain.



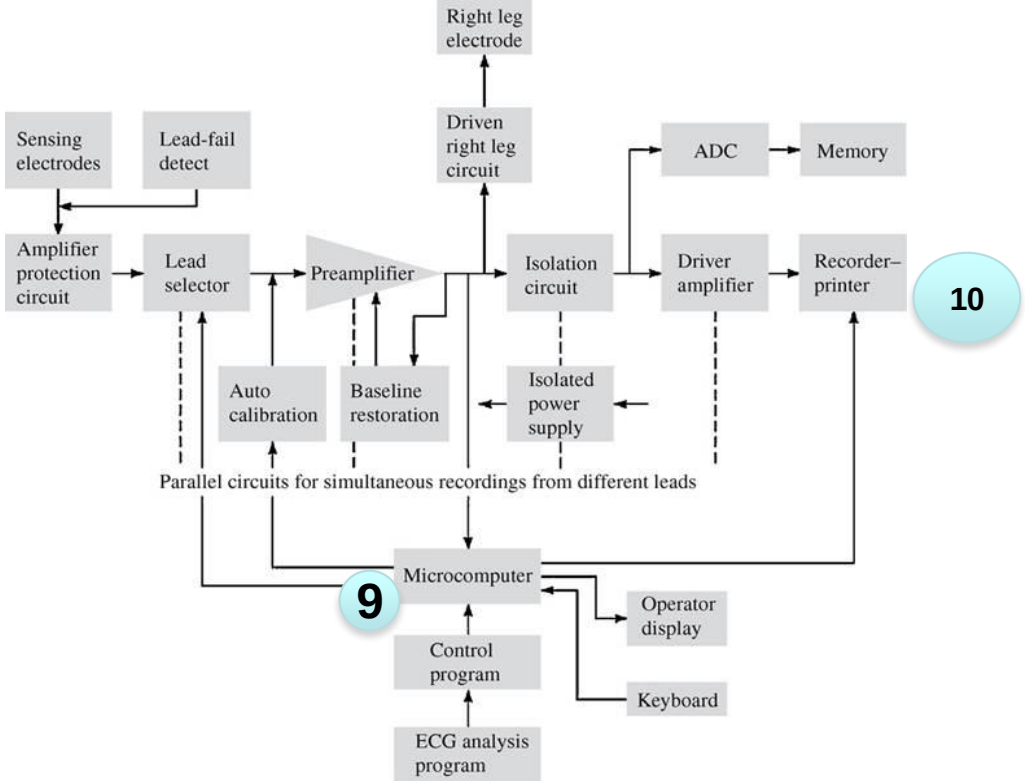
⑤ **Isolation circuit:** The circuitry of this block contains a barrier to the passage of current from the power line (50 or 60 Hz). For example, if the patient came in contact with a 120 V line, this barrier would prevent dangerous currents from flowing from the patient through the amplifier to the ground of the recorder or microcomputer.

⑥ **Driven-right-leg circuit:** This circuit provides a reference point on the patient that normally is at ground potential. This connection is made to an electrode on the patient's right leg.



⑦**Driver amplifier:** Circuitry in this block amplifies the ECG to a level at which it can appropriately record the signal on the recorder. Its input should be ac coupled so that offset voltages amplified by the preamplifier are not seen at its input. These dc voltages, when amplified by this stage, might cause it to saturate. This stage also carries out the bandpass filtering of the electrocardiograph to give the frequency characteristics described in Table 6.1.

⑧**Memory system:** Many modern electrocardiographs store electrocardiograms in memory as well as printing them out on a recorder. The signal is first digitized by an analog-to-digital converter (ADC), and then samples from each lead are stored in memory. Patient information entered via the keyboard is also stored. The microcomputer controls this storage activity.



⑨ **Microcomputer:** The microcomputer controls the overall operation of the electrocardiograph. The operator can select several modes of operation by invoking a particular program. For example, she or he can ask the microcomputer to generate the standard 12-lead electrocardiogram by selecting three simultaneous 10 s segments of the six frontal plane leads followed by three 10 s segments of the six transverse plane leads. The microcomputer in some machines can also perform a preliminary analysis of the electrocardiogram to determine the heart rate, recognize some types of arrhythmia, calculate the axes of various features of the electrocardiogram, and determine intervals between these features.

⑩ **Recorder–printer:** This block provides a hard copy of the recorded ECG signal. It also prints out patient identification, clinical information entered by the operator, and the results of the automatic analysis of the electrocardiogram.

➢ Frequency Distortion

- High-frequency distortion rounds off the sharp corners of the waveforms and diminishes the amplitude of the QRS complex.
- The baseline is no longer horizontal.
- Monophasic waves in the ECG appear to be more biphasic.

➢ Saturation Or Cut off Distortion

- High offset voltages at the electrodes or improperly adjusted amplifiers in the electrocardiograph can produce saturation or cutoff distortion that can greatly modify the appearance of the ECG.
- The combination of input-signal amplitude and offset voltage drives the amplifier into saturation during a portion of the QRS complex. The peaks of the QRS complex are cut off because the output of the amplifier cannot exceed the saturation voltage.
- In a similar occurrence, the lower portions of the ECG are cut off. This can result from negative saturation of the amplifier. In this case only a portion of the S wave may be cut off.

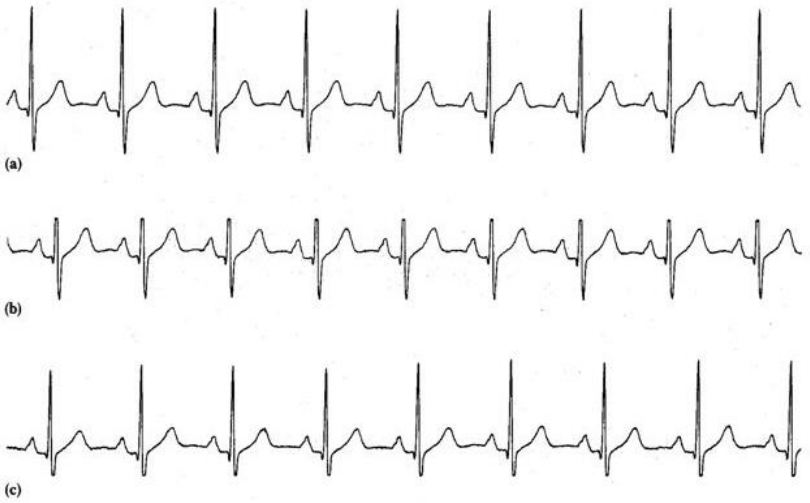


Figure 6.9 **Effects of saturation or cutoff distortion on ECG** (a) Undistorted ECG. (b) Clipping of peak of the ECG in (a) due to positive-saturation effects in the amplifier. (c) Clipping of lower voltages in the ECG of (a) due to negative saturation or cutoff effects in amplifier.

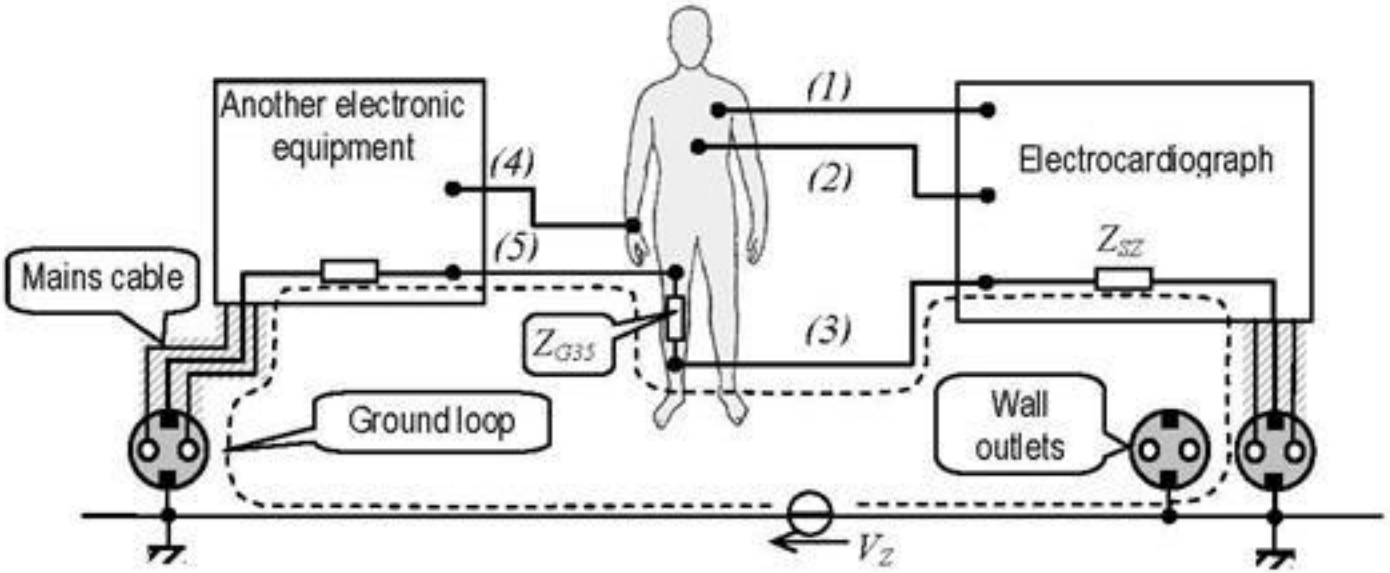
➢ Ground Loops

- A ground loop can exist when two machines are connected to the patient. Both the electrocardiograph and a second machine have a ground electrode attached to the patient.

- The electrocardiograph is grounded through the power line at a particular socket. The second machine is also grounded through the power line, but it is plugged into an entirely different outlet across the room, which has a different ground. If one ground is at a slightly higher potential than the other ground, a current from one ground flows through the patient to the ground electrode of the electrocardiograph and along its lead wire to the other ground.

- In addition to this current's presenting a safety problem, it can elevate the patient's body potential to some voltage above the lowest ground to which the instrumentation is attached.

- This produces common-mode voltages on the electrocardiograph that, if it has a poor CMRR, can increase the amount of interference seen.



➢ Open Lead Wires

- Frequently one of the wires connecting a biopotential electrode to the electrocardiograph becomes disconnected from its electrode or breaks as a result of excessively rough handling, in which case the electrode is no longer connected to the electrocardiograph.

- Relatively high potentials can often be induced in the open wire as a result of electric fields emanating from the power lines or other sources in the vicinity of the machine. This causes a wide, peak-to-peak deflection of the trace on the recorder at the power-line frequency, as well as, of course, signal loss.

➢ Artifact From Large Electric Transients

Reasons:

•situations in which a patient is having an ECG taken, cardiac defibrillation may be required. In such a case, a high-voltage high-current electric pulse is applied to the chest of the patient so that transient potentials can be observed across the electrodes. Other electric sources can cause similar transients.
• motion of the electrodes can produce variations in potential greater than ECG potentials
•static electric charge that can be partially discharged through the body

Solutions:
•electronic protection circuitry
•the use of conductive clothing, shoes.

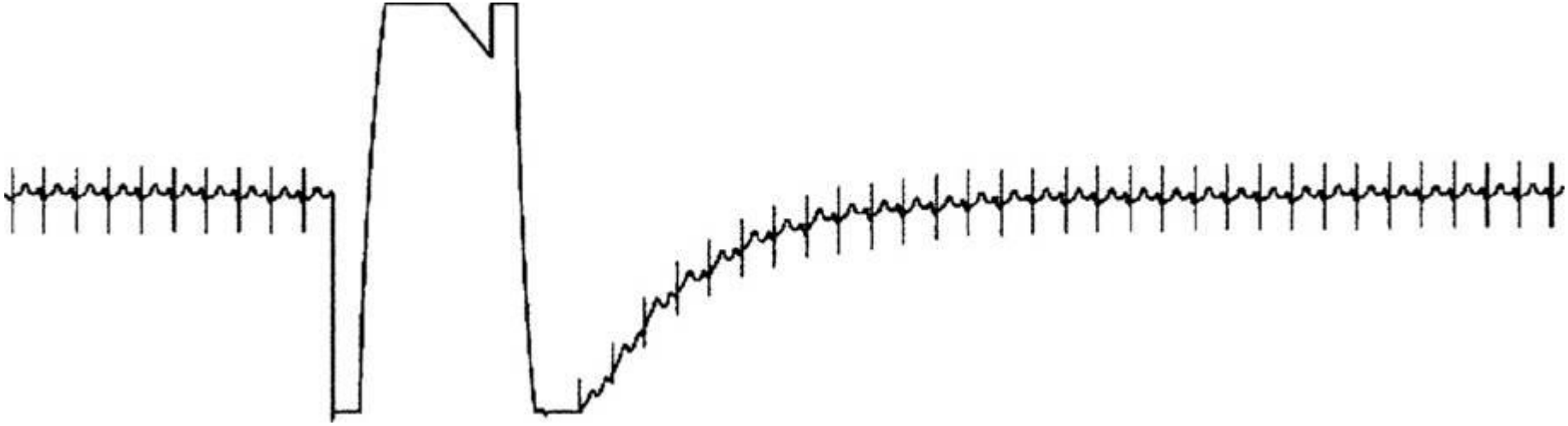


Figure 6.8 Effect of a voltage transient on an ECG recorded on an electrocardiograph in which the transient causes the amplifier to saturate, and a finite period of time is required for the charge to bleed off enough to bring the ECG back into the amplifier's active region of operation. This is followed by a first-order recovery of the system.

➢ Interference From Power Lines

- A major source of interference when one is recording or monitoring the ECG is the electric-power system. Besides providing power to the electrocardiograph itself, power lines are connected to other pieces of equipment and appliances in the typical hospital room or physician's office.
- There are also power lines in the walls, floor, and ceiling running past the room to other points in the building. These power lines can affect the recording of the ECG and introduce interference at the line frequency in the recorded trace.

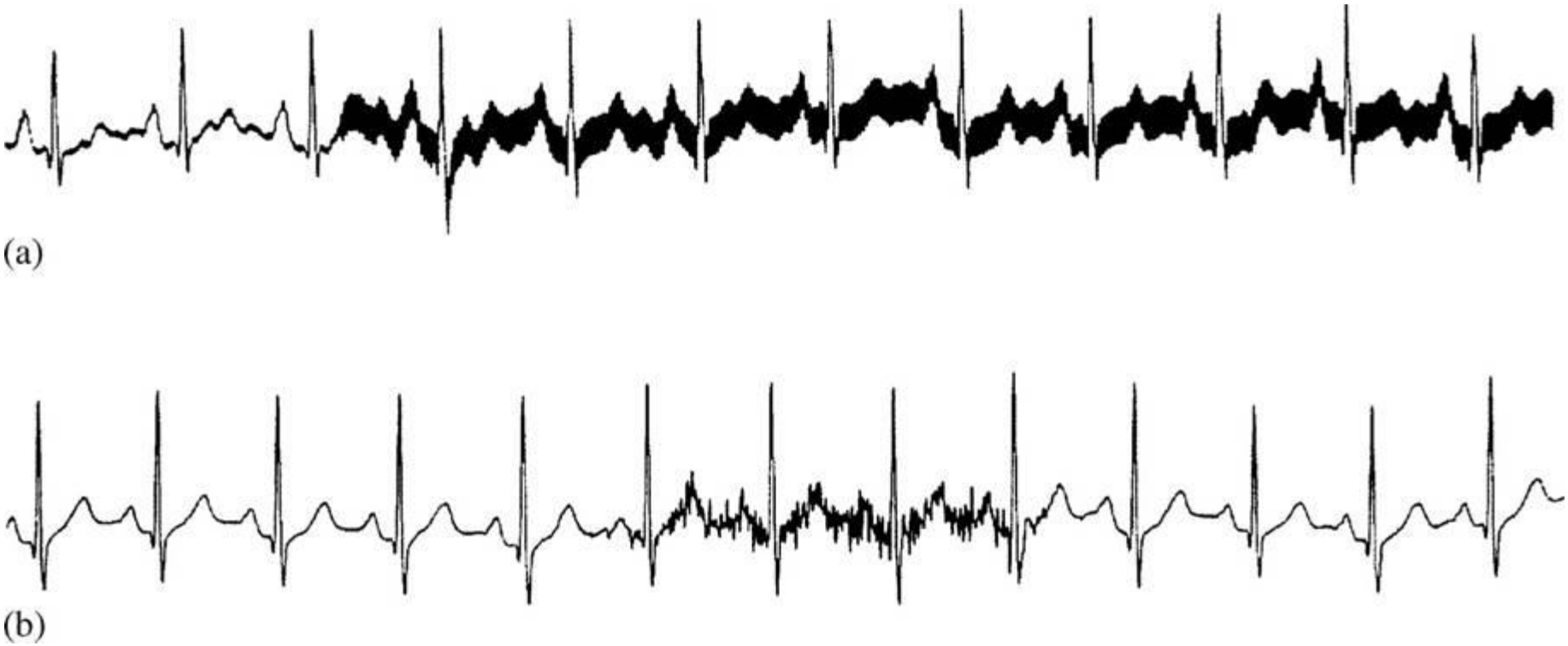
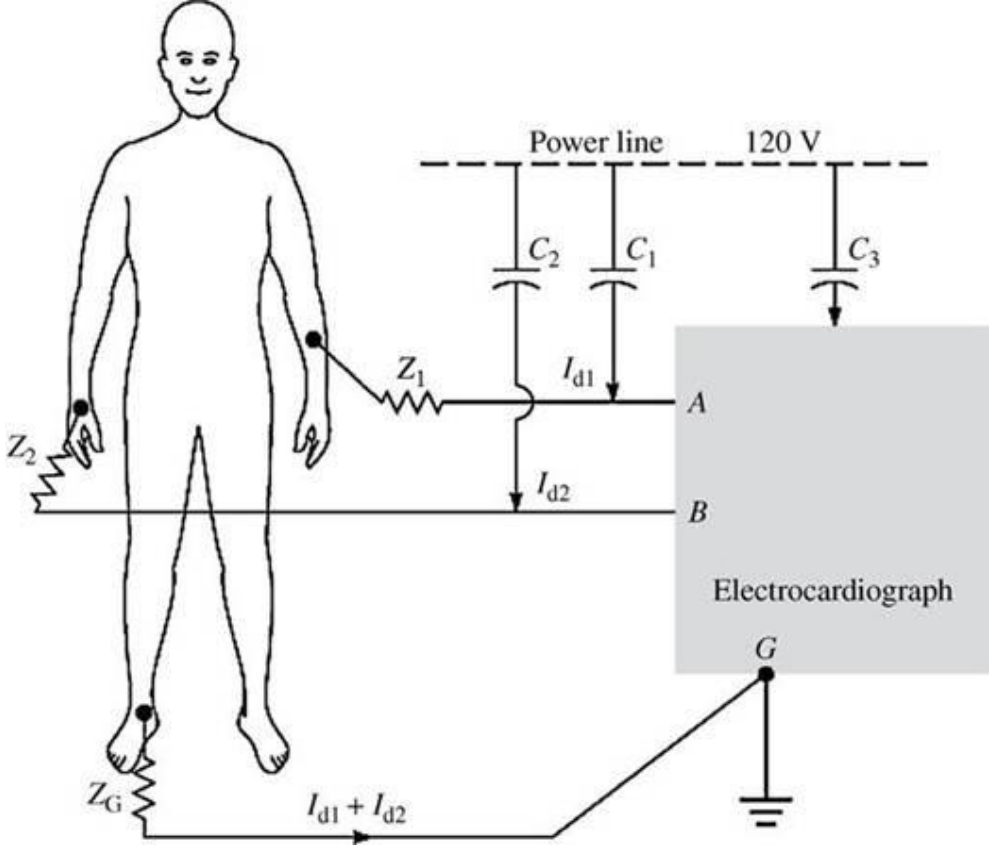


Figure 6.9 (a) 60 Hz power-line interference, (b) Electromyographic interference on the ECG.

- ***Electric-field coupling*** between the power lines and the electrocardiograph and/or the patient is a result of the electric fields surrounding main power lines and the power cords connecting different pieces of apparatus to electric outlets. These fields can be present even when the apparatus is not turned on, because current is not necessary to establish the electric field. These fields couple into the patient, the lead wires, and the electrocardiograph itself.



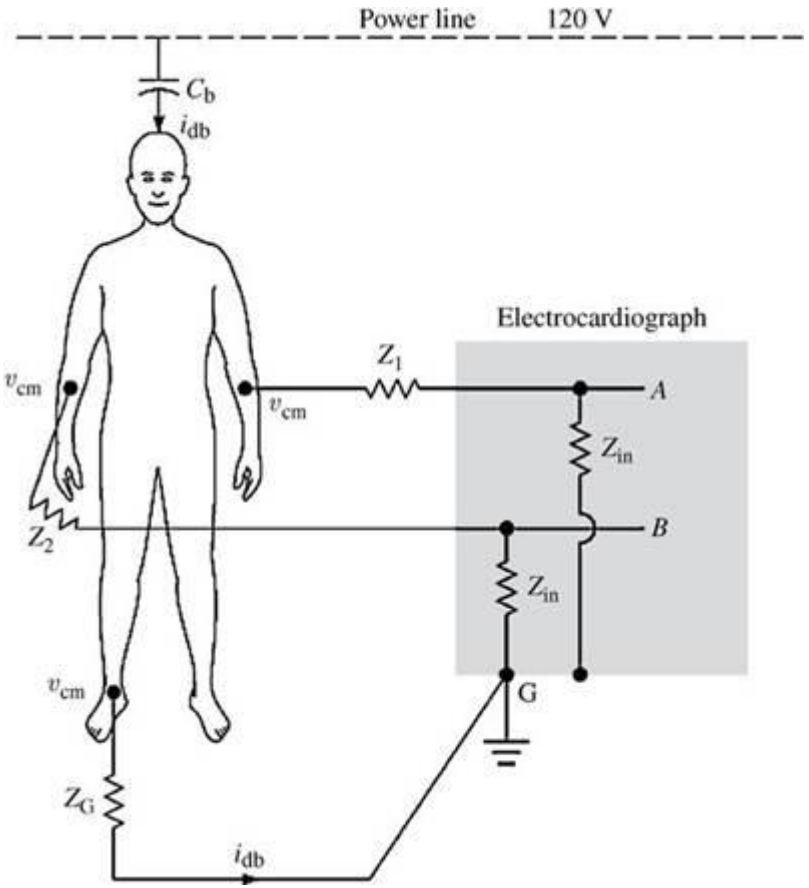
$$v_A - v_B = i_{d1}Z_1 - i_{d2}Z_2$$

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

$$v_A - v_B = (6\,\text{nA})(20\,\text{k}\Omega) = 120\,\mu\text{V}$$

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.

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.



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

$$v_{cm} = (0.2\,\mu A)(50\,k\Omega) = 10\,mV$$

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

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

$$v_A - v_B = (10\,mV)(20\,k\Omega/5\,M\Omega) = 40\,\mu V$$

- The other source of interference from power lines is ***magnetic induction.***
  - Current in power lines establishes a magnetic field in the vicinity of the line. If such magnetic fields pass through the effective single-turn coil produced by the electrocardiograph, lead wires, and the patient, a voltage is induced in this loop. This voltage is proportional to the magnetic-field strength and the area of the effective single-turn coil.

- **How to reduce interfering effect of magtenic induction on ECG?**

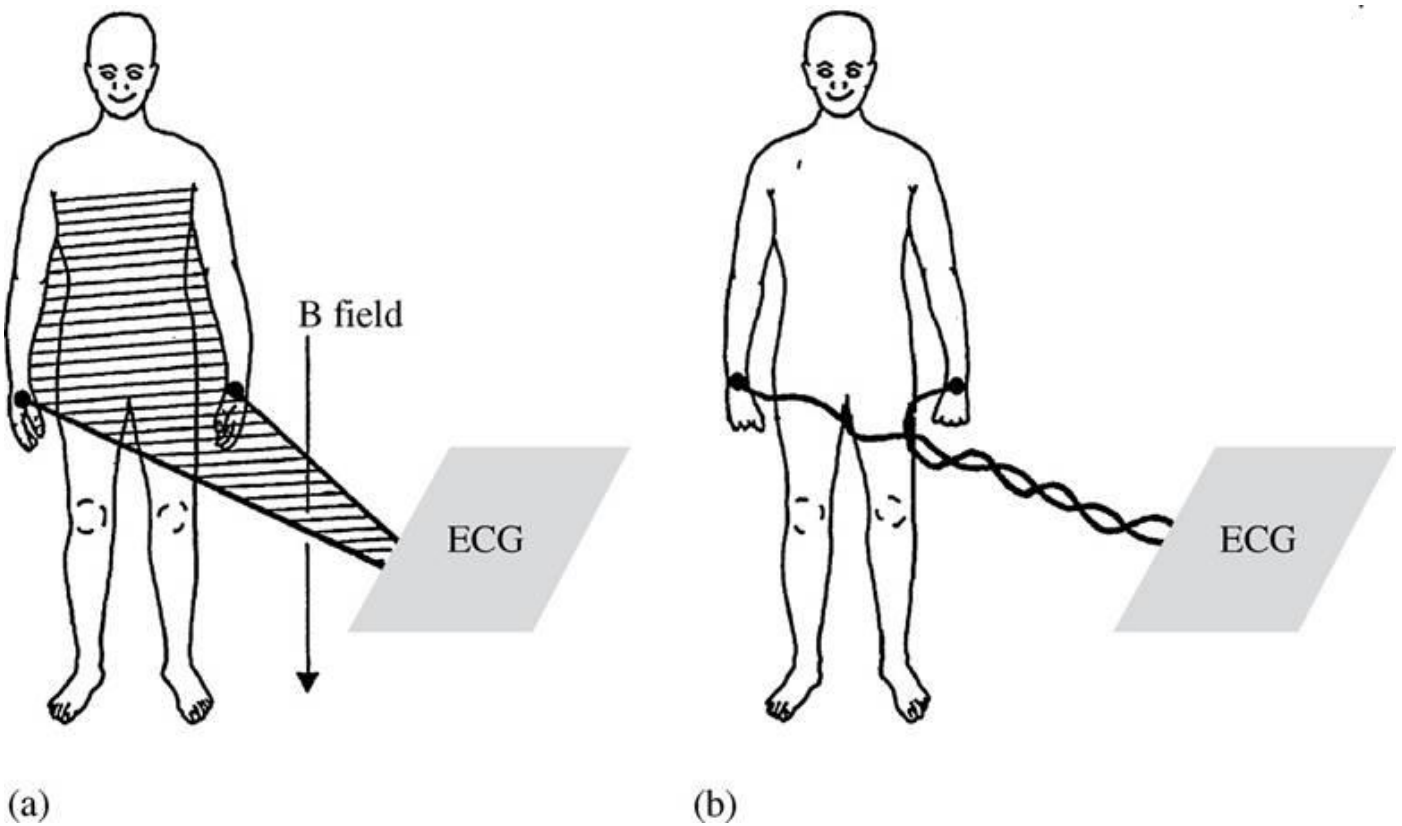


Figure 6.12 Magnetic-field pickup by the electrocardiograph (a) Lead wires for lead I make a closed loop (shaded area) when patient and electrocardiograph are considered in the circuit. The change in magnetic field passing through this area induces a current in the loop, (b) This effect can be minimized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

OTHER SOURCES OF ELECTRIC INTERFERENCE

- Electromagnetic interference from nearby high-power radio, television, or radar

- Lower power electromagnetic interference can arise from local sources such as wireless devices including mobile telephones and wireless computing networks.

- Electrosurgical and diathermy equipment, x-ray machines or switches

- There is also a source of electric interference located within the body itself that can have an effect on ECGs. For example; electromyographic signal that can be picked up by the lead along with the ECG and can result in interference on the ECG, as shown in Figure 6.9(b)

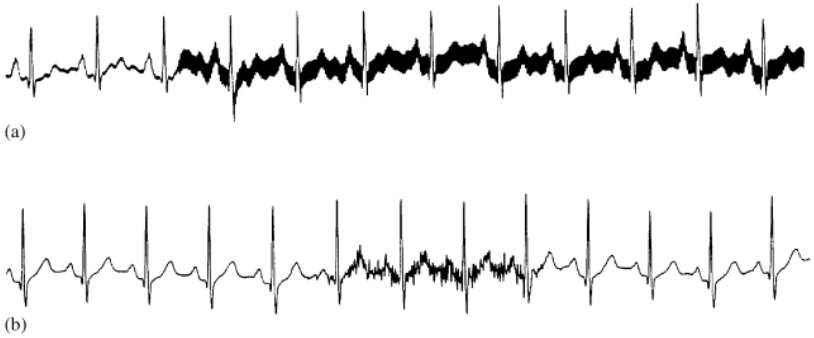


Figure 6.9 (a) A 60 Hz power-line interference. (b) Electromyographic interference on the ECG. Severe 60 Hz interference is also shown on the bottom tracing in Figure 4.13.

TRANSIENT PROTECTION

- For example, in the operating suite, patients undergoing surgery usually have their ECGs continuously monitored during the procedure. If the surgical procedure involves the use of an electrosurgical unit, it can introduce onto the patient relatively high voltages that can enter the electrocardiograph or cardiac monitor through the patient's electrodes.

- If the ground connection to the electrosurgical unit 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. They can also cause severe transients.

- Cardiac monitors and electrocardiographs should be designed so that they are unaffected by such transients. Unfortunately, this cannot be achieved completely. However, it is possible to reduce the effects of these electric transients and to protect the equipment from serious damage.

- Two-terminal voltage-limiting devices are connected between each patient electrode and electric ground

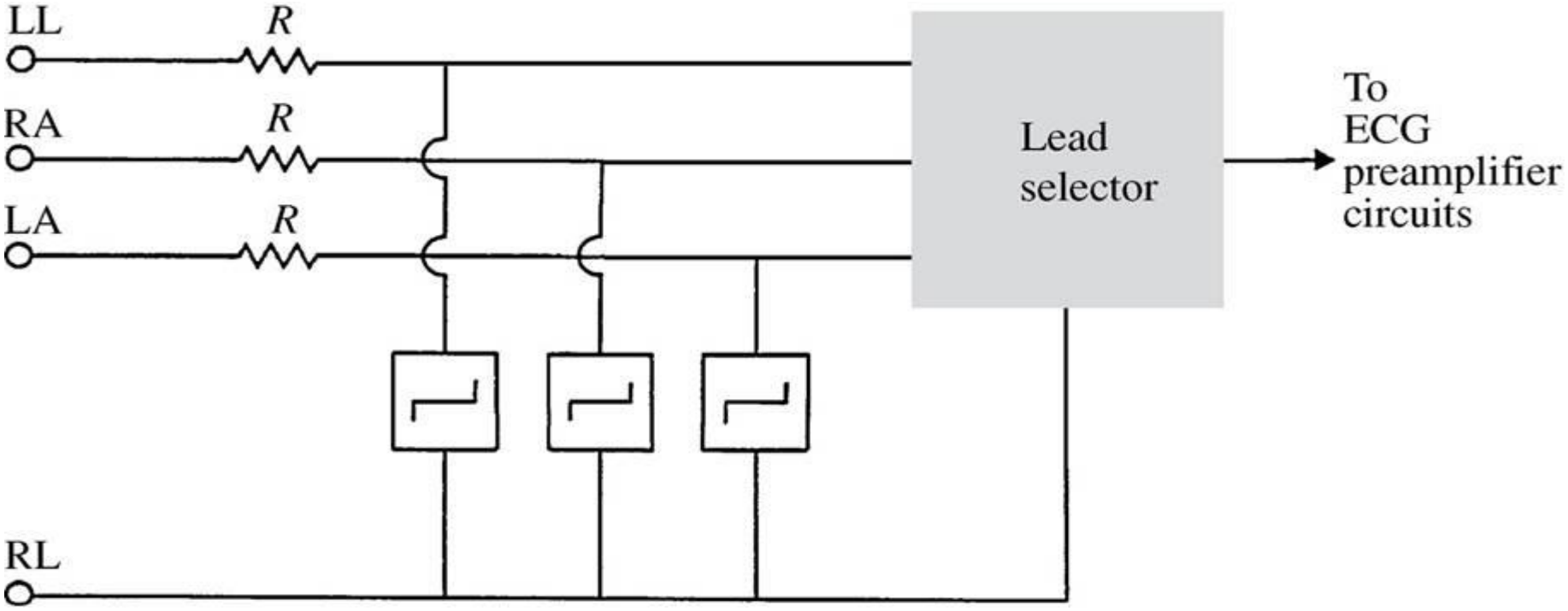


Figure 6.13 A voltage-protection scheme at the input of an electrocardiograph to protect the machine from high-voltage transients. Circuit elements connected across limb leads on left-hand side are voltage-limiting devices.

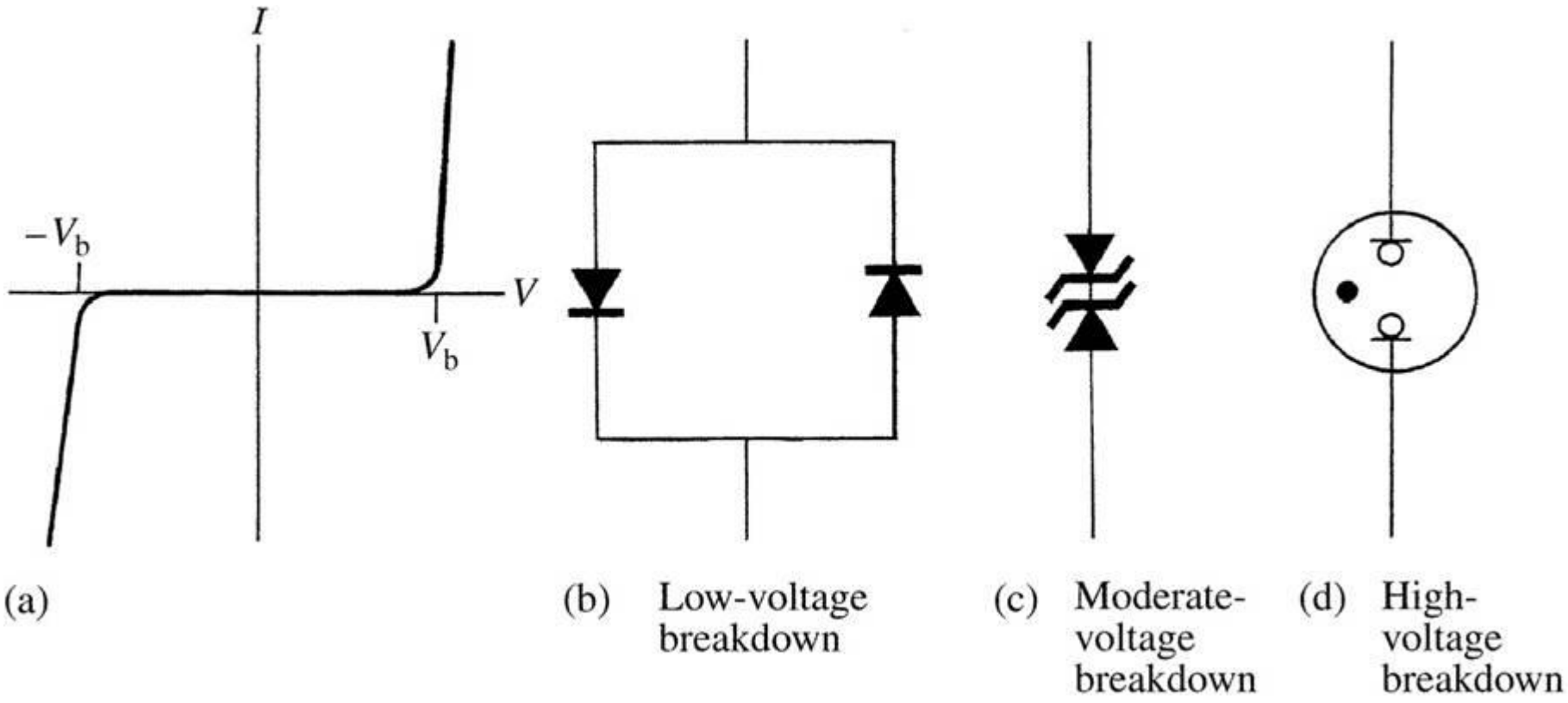


Figure 6.14 Voltage-limiting devices (a) Current–voltage characteristics of a voltage-limiting device, (b) Parallel silicon-diode voltage-limiting circuit, (c) Back-to-back silicon Zener-diode voltage-limiting circuit, (d) Gas-discharge tube (neon light) voltage-limiting circuit element.

➢ Electric- And Magnetic-field Interference

- Electric interference can be introduced in systems of biopotential measurement through capacitive coupling and magnetic induction.

- **These interfering signals may be minimized by eliminating the sources of the signals via shielding techniques**.

    - Electrostatic shielding is accomplished by placing a grounded conducting plane between the source of the electric field and the measurement system.

    - Today, high-quality differential instrumentation amplifiers with high CMRRs make such shielding unnecessary.

➢ Driven-right-leg System

- In most modern electrocardiographic systems, the patient is not grounded at all. Instead, the right-leg electrode is connected to the output of an auxiliary op amp.
- 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. The body's displacement current flows not to ground but rather to the op-amp output circuit. This reduces the interference as far as the ECG amplifier is concerned and effectively grounds the patient

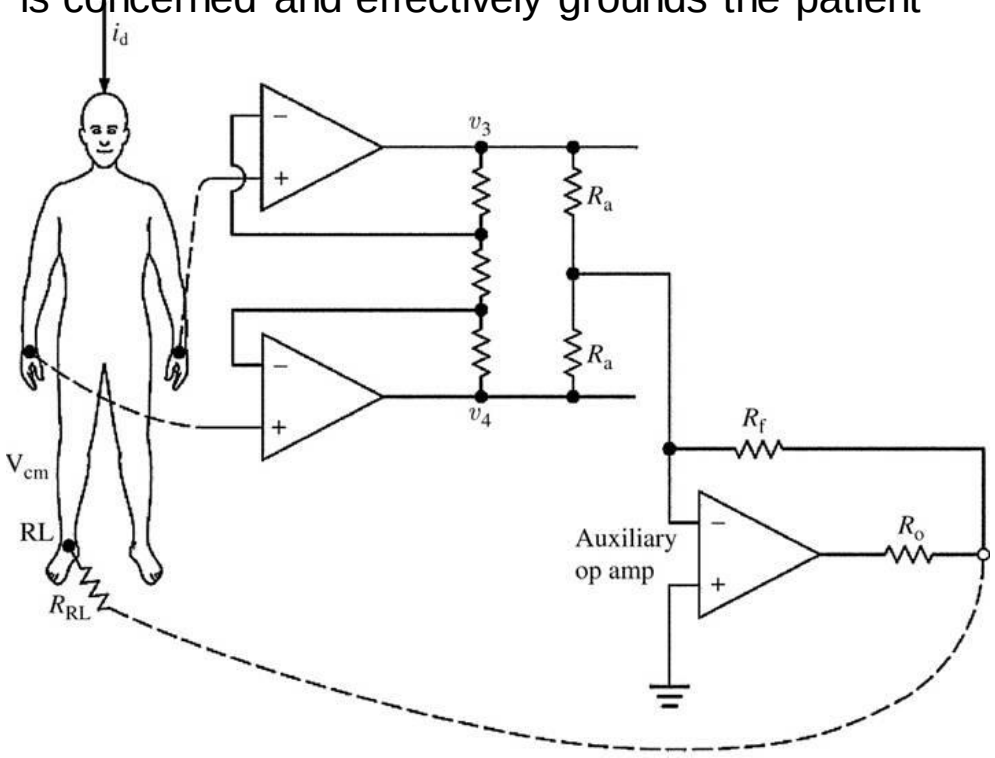


Figure 6.15 Driven-right-leg circuit for minimizing common-mode interference. The circuit derives common-mode voltage from a pair of averaging resistors connected to *v*3 and *v*4 in Figure 3.5. The right leg is not grounded but is connected to output of the auxiliary op amp.

AMPLIFIERS FOR OTHER BIOPOTENTIAL SIGNALS

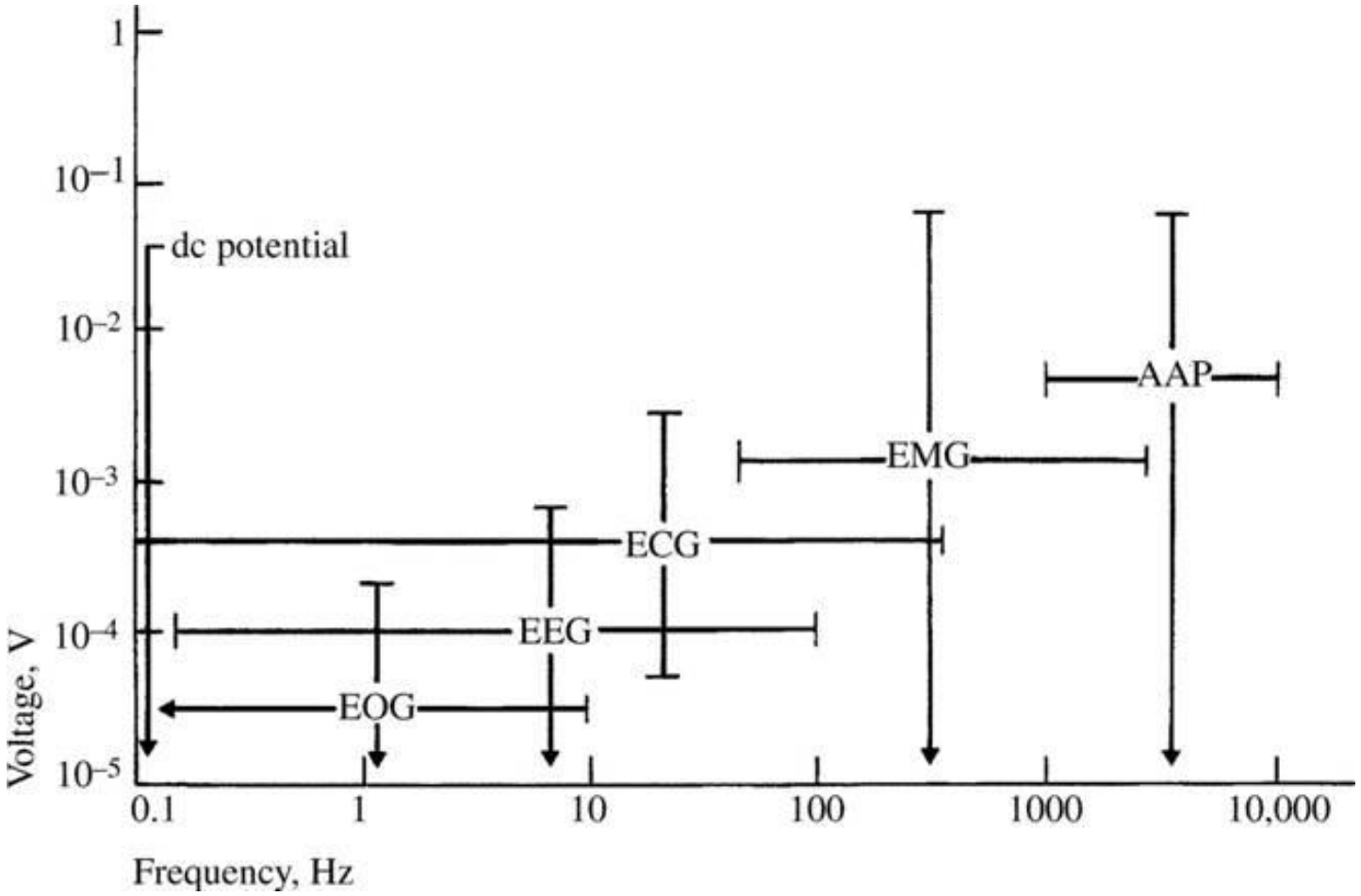


Figure 6.16 Voltage and frequency ranges of some common biopotential signals; dc potentials include intracellular voltages as well as voltages measured from several points on the body. EOG is the electro-oculogram, EEG is the electroencephalogram, ECG is the electrocardiogram, EMG is the electromyogram, and AAP is the axon action potential. (From J. M. R. Delgado, "Electrodes for Extracellular Recording and Stimulation," in *Physical Techniques in Biological Research,* edited by W. L. Nastuk, New York: Academic Press, 1964)

OTHER BIOPOTENTIAL SIGNAL PROCESSORS

➢ Cardiotachometers

- A cardiotachometer is a device for determining heart rate
- The signal most frequently used is the ECG. However, software for deriving heart rate from signals such as the arterial pressure waveform, pulse oximeter pulse waves, or heart sounds has also been developed.

$$v_o = \frac{k}{T_R}$$

where k is a constant and T_R is the interval between QRS complexes

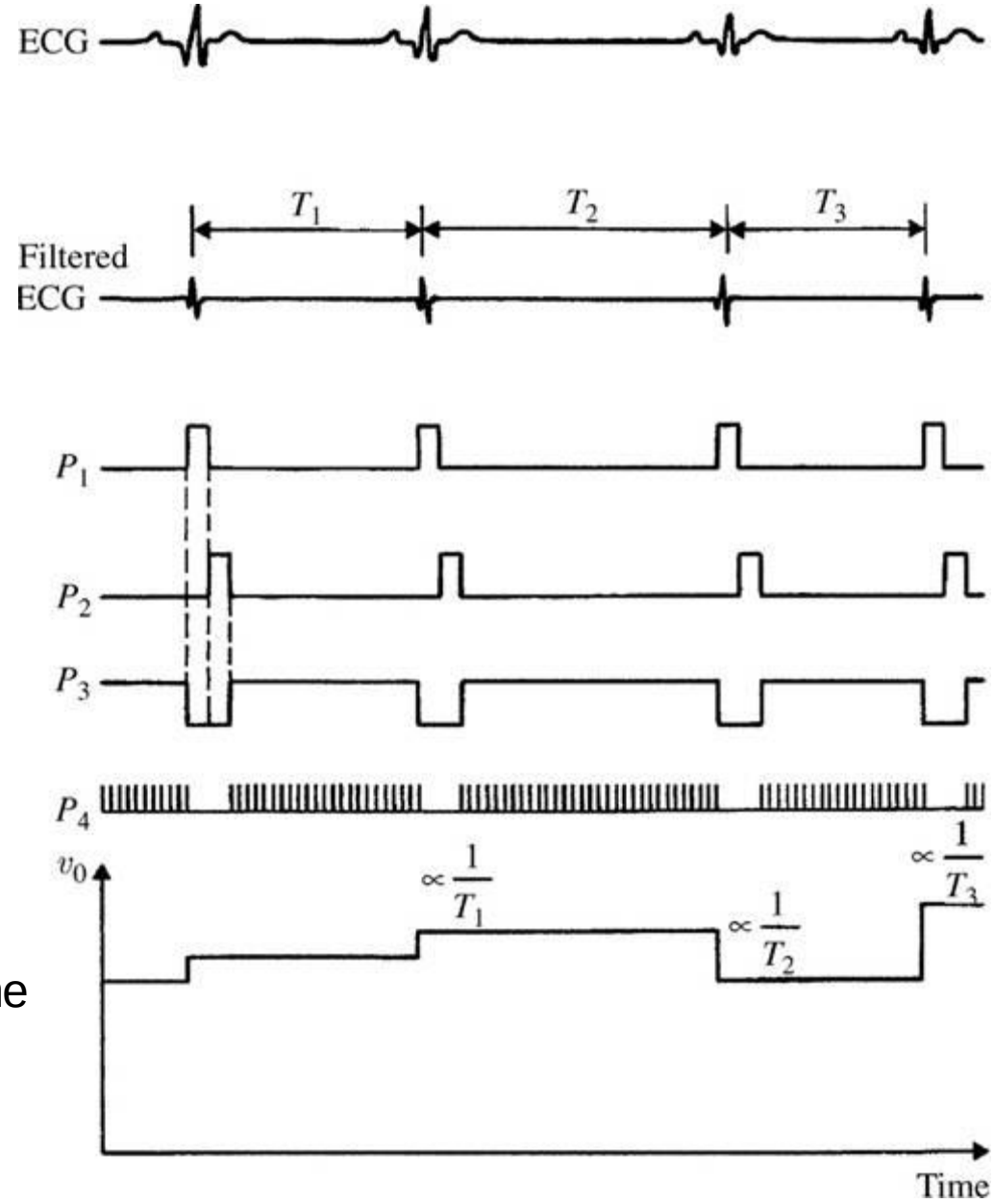


Figure 6.19 Timing diagram for beat-to-beat cardiotachometer.

➢ Electromyogram Integrators

- The raw EMG, amplified appropriately v_1 , is fed to software, which in one example takes the absolute value. As indicated in the waveform of Figure 6.20, only positive-going signals v_2 result following this. The negative-going portions of the signal have been inverted, making them positive. Software then integrates the signal. Once the integrator output has exceeded a preset threshold level v_t , a comparator then reinitiates integration of the EMG until the cycle repeats itself.

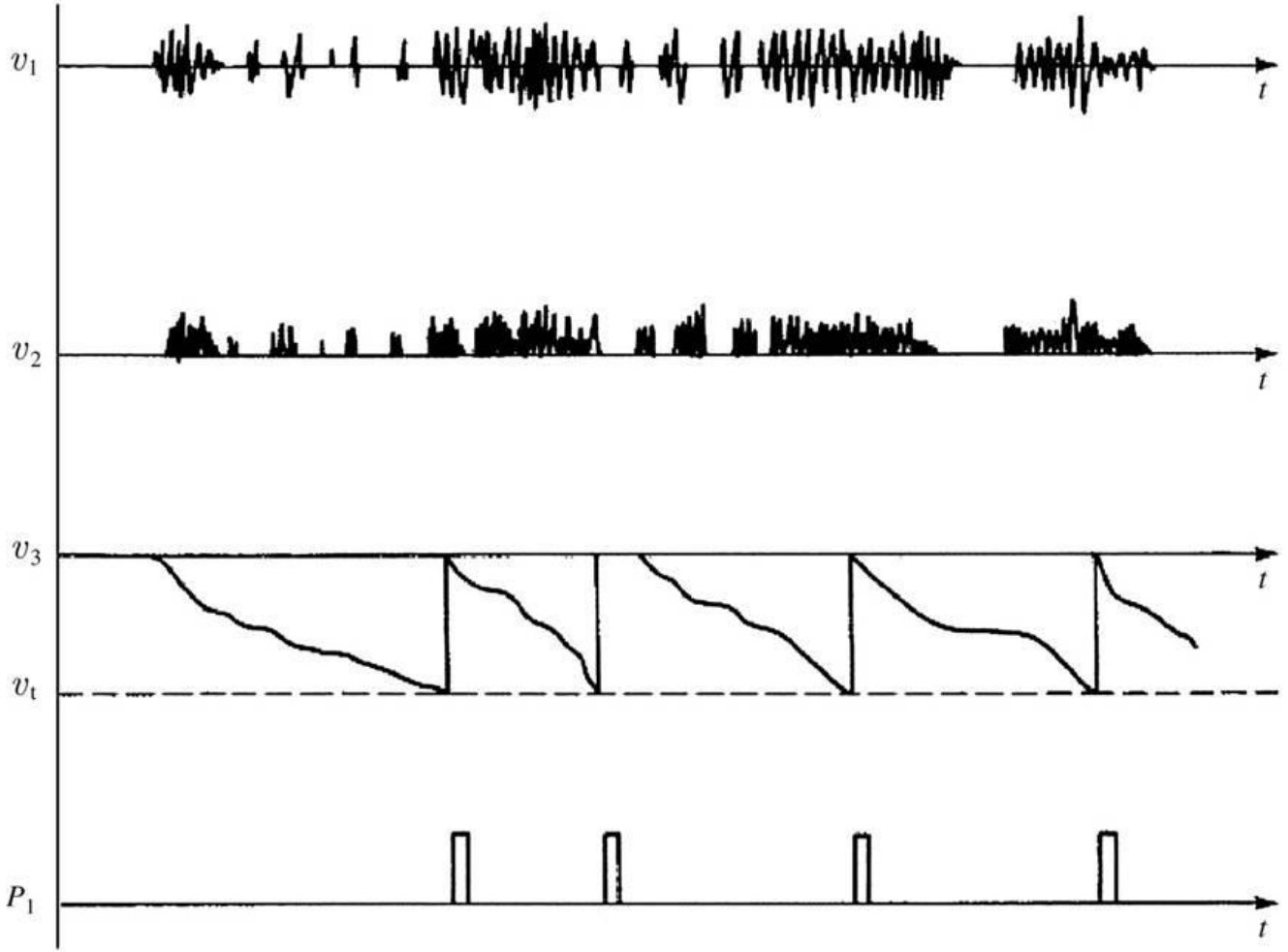
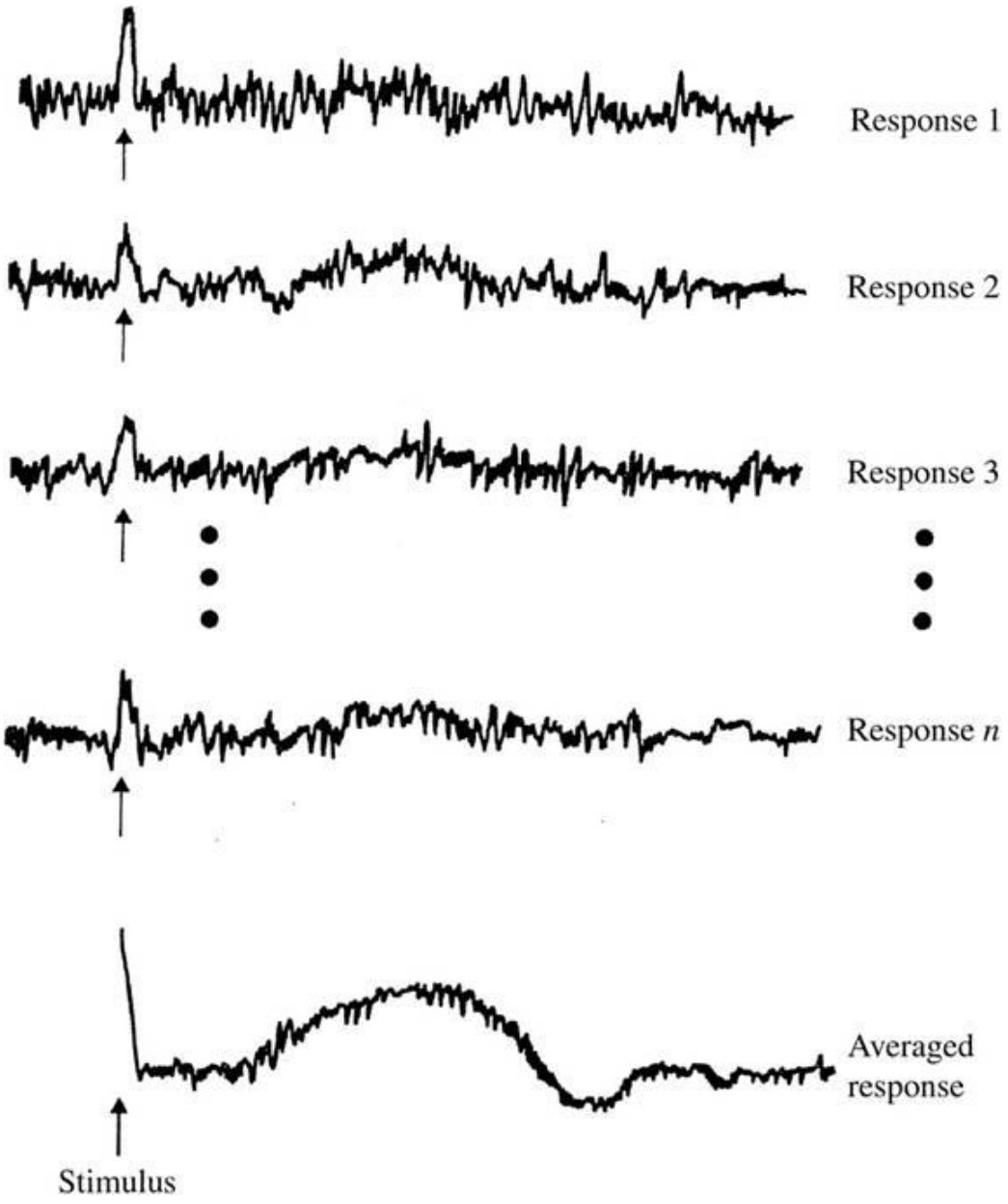


Figure 6.20 The various waveforms for the EMG integrator.

➢ Evoked Potentials And Signal Averagers

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



➢ Fetal ECG

- The fetal ECG signal is usually quite weak; it generally has an amplitude of around 50 μV or less. This makes it extremely difficult to record the heartbeat of the fetus by using electrodes attached to the abdomen of the mother during labor, when the mother is restless and motion artifact as well as EMG interfere. There is also considerable interference from the ECG of the mother

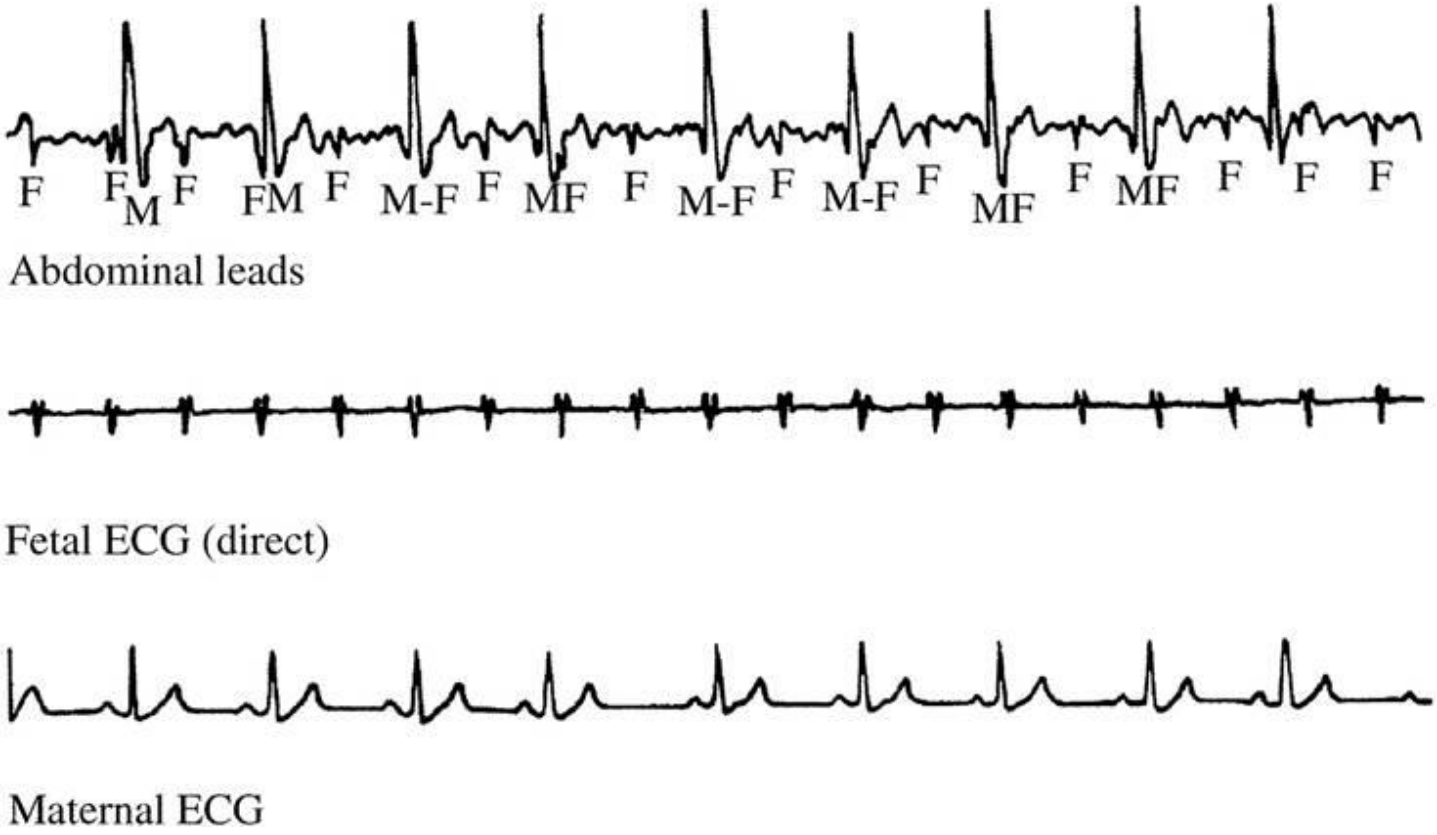
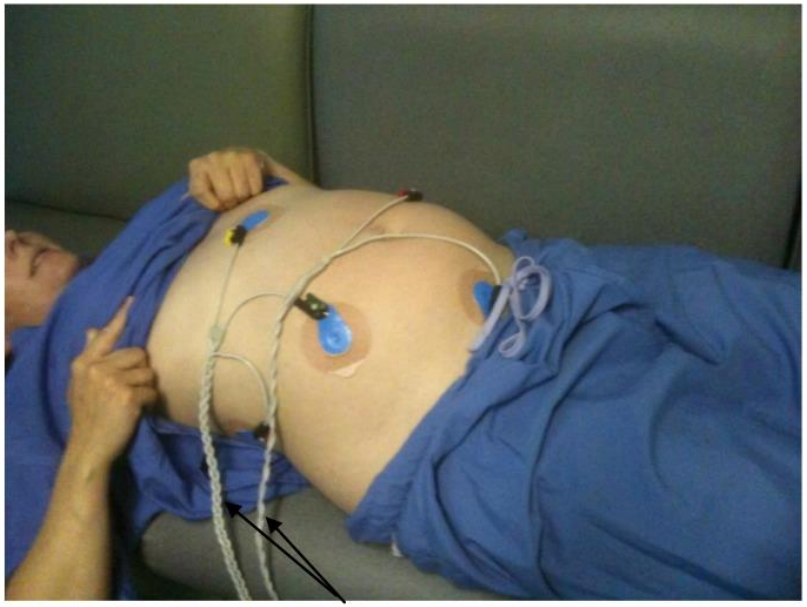


Figure 6.22 Typical fetal ECG obtained from the maternal abdomen. F represents fetal QRS complexes; M represents maternal QRS complexes. Maternal ECG and fetal ECG (recorded directly from the fetus) are included for comparison. (From "Monitoring of Intrapartum Phenomena," by J. F. Roux, M. R. Neuman, and R. C. Goodlin, in *CRC Critical Reviews in Bioengineering,* 2, pp. 119-158, January 1975, © CRC Press. Used by permission of CRC Press, Inc.)

- The QRS complexes of the mother are much stronger than those of the fetus, which makes it difficult to determine the fetal heart rate electronically from recordings of this type.

- Several methods have been devised for improving the quality of fetal ECGs obtained by attaching electrodes to the mother's abdomen. In addition to the signal-averaging technique, physicians have applied various forms of anticoincidence detectors to eliminate the maternal QRS complexes.

- This method uses at least three electrodes:
  - one on the mother's chest
  - one at the upper part or fundus of the uterus
  - one over the lower part of the uterus.



fECG Monitor Twisted Pair Leads and ECG electrodes positioned on a volunteer

Sensors 13(9):11271-9 · September 2013

- A threshold detector determines the mother's QRS complexes and uses this information to turn off an analog switch between the electrodes recording the fetal ECG and the recording apparatus.
- Therefore, whenever a maternal QRS complex is detected, the signal from the abdominal leads is temporarily blocked until the end of the QRS complex, thereby eliminating it from the abdominal recording.
- Note that this technique also eliminates any fetal QRS complexes that occur simultaneously with the maternal ones

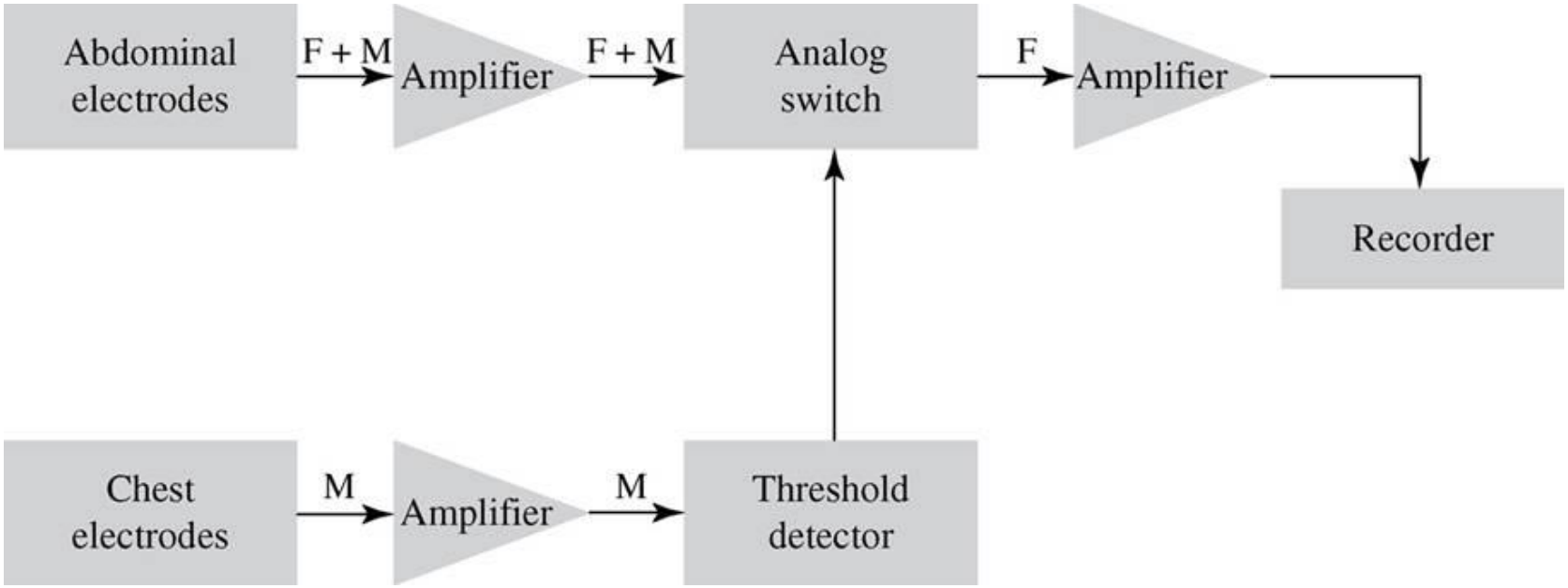


Figure 6.23 Block diagram of a scheme for isolating fetal ECG from an abdominal signal that contains both fetal and maternal ECGs. (From "Monitoring of Intrapartum Phenomena," by J. F. Roux, M. R. Neuman, and R. C. Goodlin, in *CRC Critical Reviews in Bioengineering,* 2, pp. 119–158, January 1975, ©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

CARDIAC MONITORS

- There are several clinical situations in which continuous observation of the ECG and heart rate is important to the care of the patient.

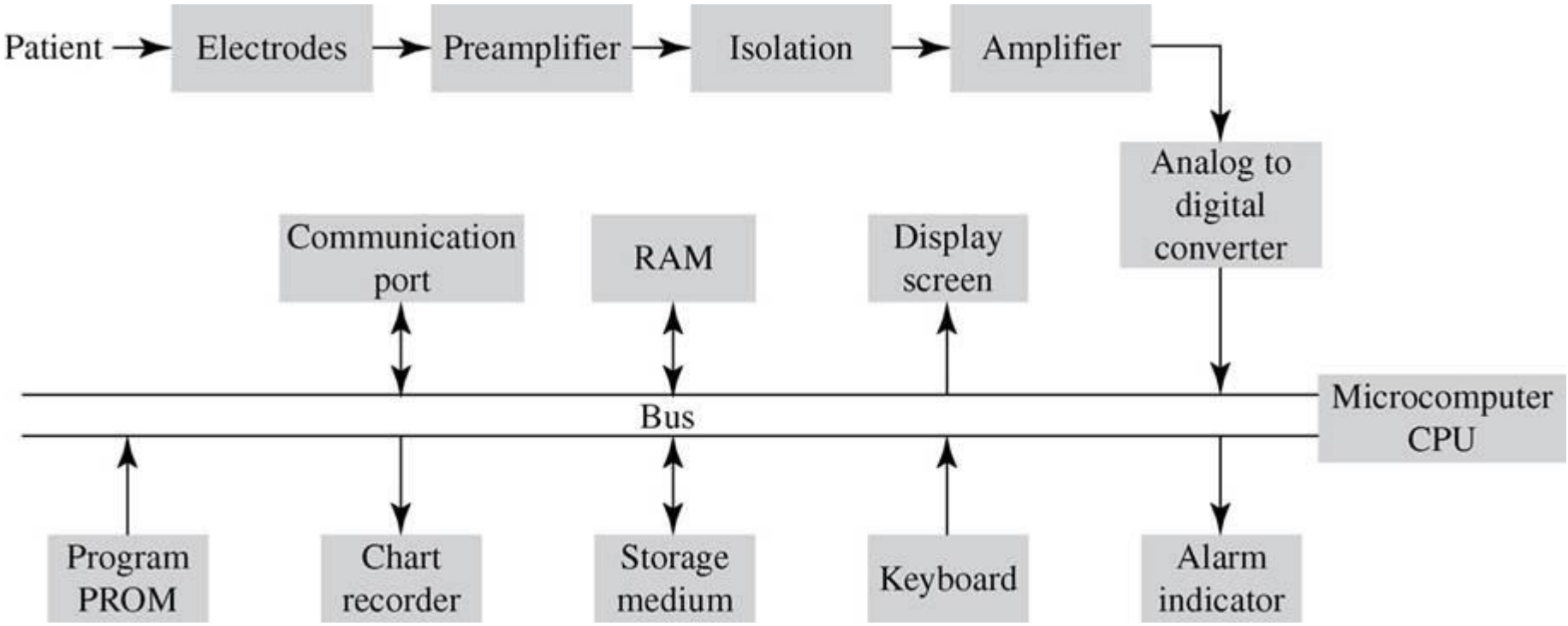


Figure 6.24 Block diagram of a cardiac monitor. The cardiac monitor displays a continuous electrocardiogram and heart rate and also identifies alarm conditions

- Continuous observation of the ECG during the administration of anesthesia helps doctors monitor the patient's condition while he or she is undergoing medical procedures and during recovery from anesthesia.

- Constant monitoring of the ECG and heart rate of the myocardial-infarction patient during the danger period of several days following the initial incident has made possible the early detection of life-threatening cardiac arrhythmias.

- Continuous monitoring of the fetal heart rate during labor may help in the early detection of complications.

- **These and other clinical applications of continuous monitoring of the ECG and heart rate are made possible by cardiac monitors**

- In most modern cardiac monitors, the amplified ECG signal is digitized by an ADC, and the remaining processing is carried out by a computer.

- Digital signal is processed by a microcomputer in the monitor. This system block can perform many functions depending on the program that controls it.

  - The digital signal can be filtered and displayed on a computer screen
  - the heart rate determined by cardiotachometer software
  - alarm conditions identified and alarms sounded
  - data stored in temporary or permanent memory
  - an ECG rhythm strip printed for review and charting
  - communication of the data to other systems within or outside of the hospital.

- Most hospitals also utilize cardiac monitors in an organized system called an *intensive-care* unit . In such units, there are individual monitors at each patient's bedside that display the ECG in real time as well as the heart rate and any alarm conditions that have recently occurred.

- These individual monitors are connected to a central unit located at the nursing station that shows the ECGs for all patients being monitored, along with a heart-rate display and alarm indicator for each patient.

- A printer at the central station can be activated either locally or by remote control from the individual monitors at the patient's bedside.

- Computer algorithms that can recognize cardiac arrhythmias and record the frequency of their occurrence are also included in cardiac monitors.

- Computerized cardiac monitors can be integrated into other hospital information systems. For example; They can interact with other information systems or transmit data to physicians' offices located away from the intensive-care unit.

Microcomputers in cardiac monitors perform two basic functions; data management and data analysis.

- **Ambulatory cardiac monitors** are often used in the diagnosis and treatment of heart disease.

- The most frequently applied ambulatory monitor— the Holter monitor— includes a miniature digital recorder with electronic memory that the patient wears.

- These devices consist of a battery-powered ECG amplifier and recorder that are connected to electrodes placed on the patient's chest.

- Holter monitors are used by physicians to detect cardiac arrhythmias that occur infrequently in patients and are usually not detected during office or hospital examinations.