# Electronics design for biomedical instrumentation

(Master degree in Electronics Engineering and Biomedical Engineering)

## Applications of electronics technologies in medicine and biology:

• Biomedical instrumentation (traditional and innovative) based on acquisition (sensors), amplification (circuits) and processing (systems) of electrical signals with biological origin

• Imaging systems for medical diagnostic employ detectors (solid state), integrated circuits (VLSI) and processing systems (ex. DSP) for the acquisition and the processing of large quantities of information

• Bioelectronics: advanced and multi-disciplinary applications of combined electronics and biology/medicine (*bio-labs on chip*, acquisition/stimulus of cellular electrical signals, electronics prosthesis)

Purpose of the course:

provide a basic knowledge of the most significant use of sensors, circuits, electronics systems in the biomedical instrumentation

Tipologies of addressed topics

Conventional and advanced instrumentation for the analysis of signals of biological origin

Systems for medical imaging based on the use of radiation (X and gamma rays)

The method

Recall of the basic principles of the instrument/technique
$\rightarrow$ analysis and design of sensors and electronics circuits (analog and digital) employed in the instrument

and a special look on...

applications of microelectronics to biomedicine

# Course program:

I part: Electronics for acquisition and processing of biological signals

- Origin of biological signals. Electrodes and sensors.
- Circuits for the amplification and filtering of signals.
  Application: the electrocardiograph.
  Amplifier for bio-potentials: noise, insulation, rejection of common-mode and interferences, ... design examples. Instrumentation amplifiers.
- Implantable bio-medical devices:
  The pacemaker: working principles, batteries, amplifiers, pulse generators, telemetry.
  Special topics on the Pacemaker, low-power amplifiers for bio-signals (articles on course web site).
- Selected applications of microelectronics to bio-medicine: prosthesis for artificial vision.

## II part: Detectors and electronics for medical imaging systems

- Basics on medical imaging. Radiographic and tomographic systems. Figures of merit. Examples of applications.
- Interaction of X and $\gamma$ radiation with matter. X generators . Radioactive emitters $\gamma$ and $\beta$+.
- Fundamentals on detectors for X and $\gamma$ rays. Detectors for medical imaging. The Gamma Camera.
- SPECT and PET detection systems and electronics. PET-TOF.
- Electronics for digital radiography.
- Electronics for *medical imaging*:
  - integrated *front-end* for detectors, electronics noise
  - examples of analog processing circuits
  - circuits for *timing* (PET)

# Informations about the course

Lecturer: Prof. Carlo Fiorini
tel: 3733
email: carlo.fiorini@polimi.it
web: www.deib.polimi.it → docenti → Fiorini
receivability: Wed 14.30-16.30 or on appointment

Course org. : lectures + exercises + seminars

Course material: slides of the lectures, articles, application notes, ... available on web (with password) and dropbox (send me email for access)

Bibliography: Books for consultation:

- Medical Instrumentation: Application and Design, J.G.Webster, John Wiley and Sons, 1998
- Design of Cardiac Pacemakers, J.G.Webster, IEEE, available on web
- Radiation Detection and Measurement, 3rd ed., Glenn Knoll, John Wiley and Sons
- The Physics of Medical Imaging S.Webb, Taylor & Francis, 1988
- Medical Imaging: Principles, Detectors and Electronics, Krzysztof Iniewski, Wiley, 2009
- CMOS: Front-End Electronics for Radiation Sensors, A.Rivetti (e-book available at POLIMI)

(red: I part, blue: II part)

Exam: Oral exam only. In the first two dates (July/Sept.) with possibility of choice of the date in a list with about 20 days, for the other dates, in the official day only.

# Other opportunities during the course

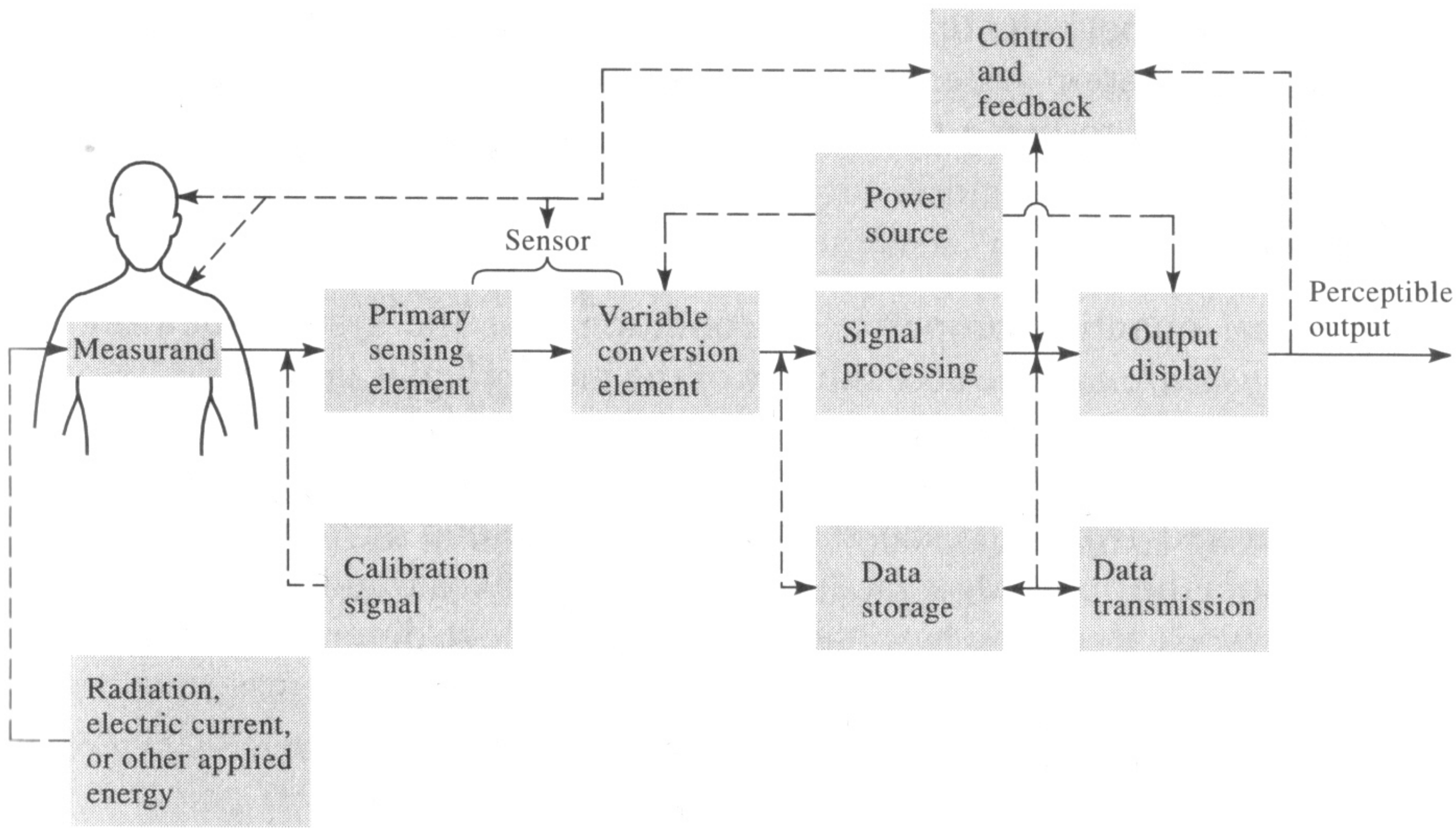
- Complements of electronics topics for biomedical students
  - organize your own dates and times (3-4 lessons of 2 hours each). Topics:
    - the bipolar transistor (BJT)
    - current mirrors, differential stage, cascode stage, CMOS operational amplifiers
    - basics on electronics noise (sources, equivalent noise generators)
- Opportunity for Thesis
- List of topics for thesis on the web
- General presentation of the thesis in April
- call for thesis starting in the I semester (Sept. 2016) already open. (Few topics may be also available also for this II semester).

The course is held in English:

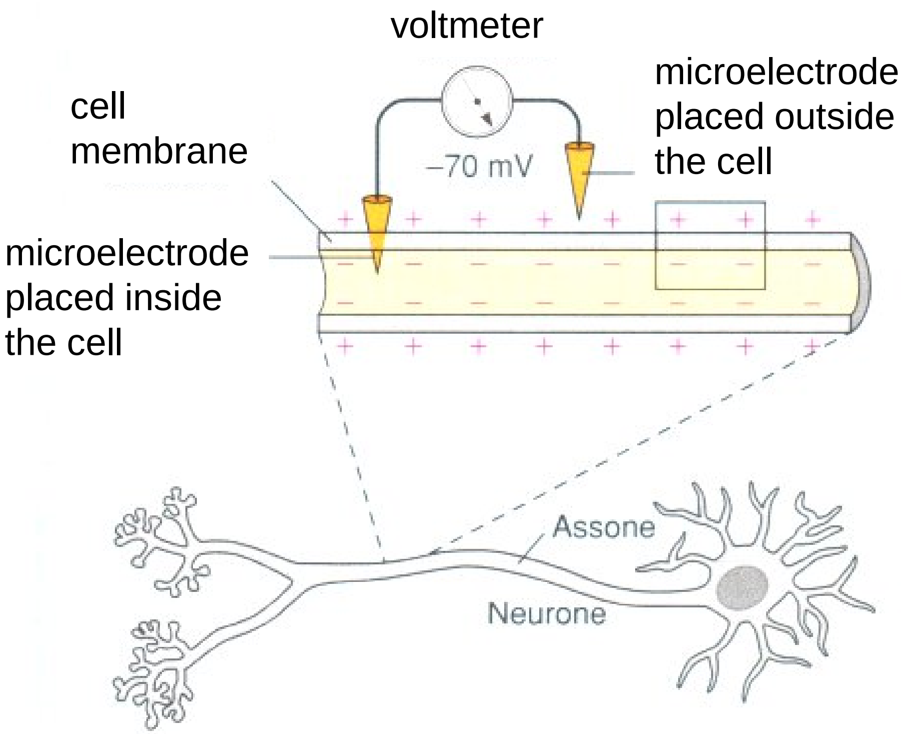
Be patient and please do not esitate to ask if you do not understand my fluent ‘Oxford’ English

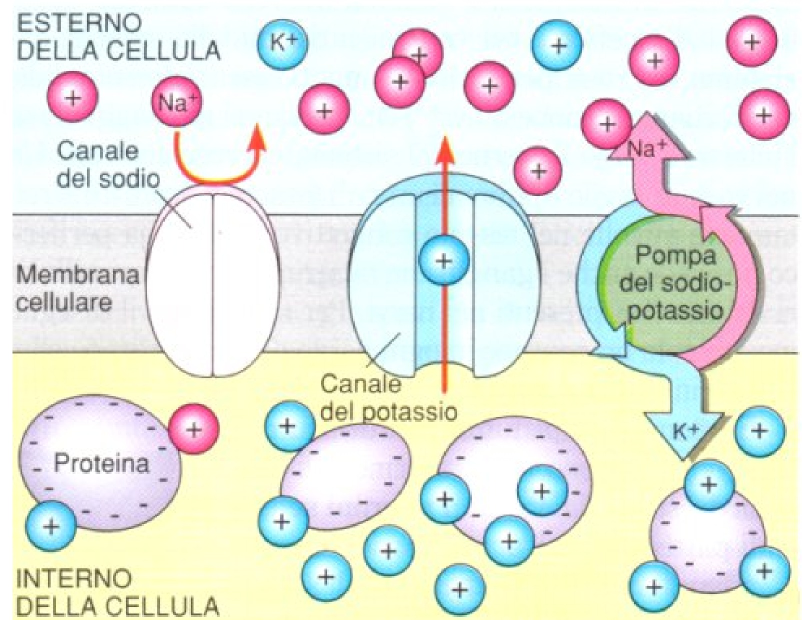
"Relaxing background"

# Biomedical instrumentation

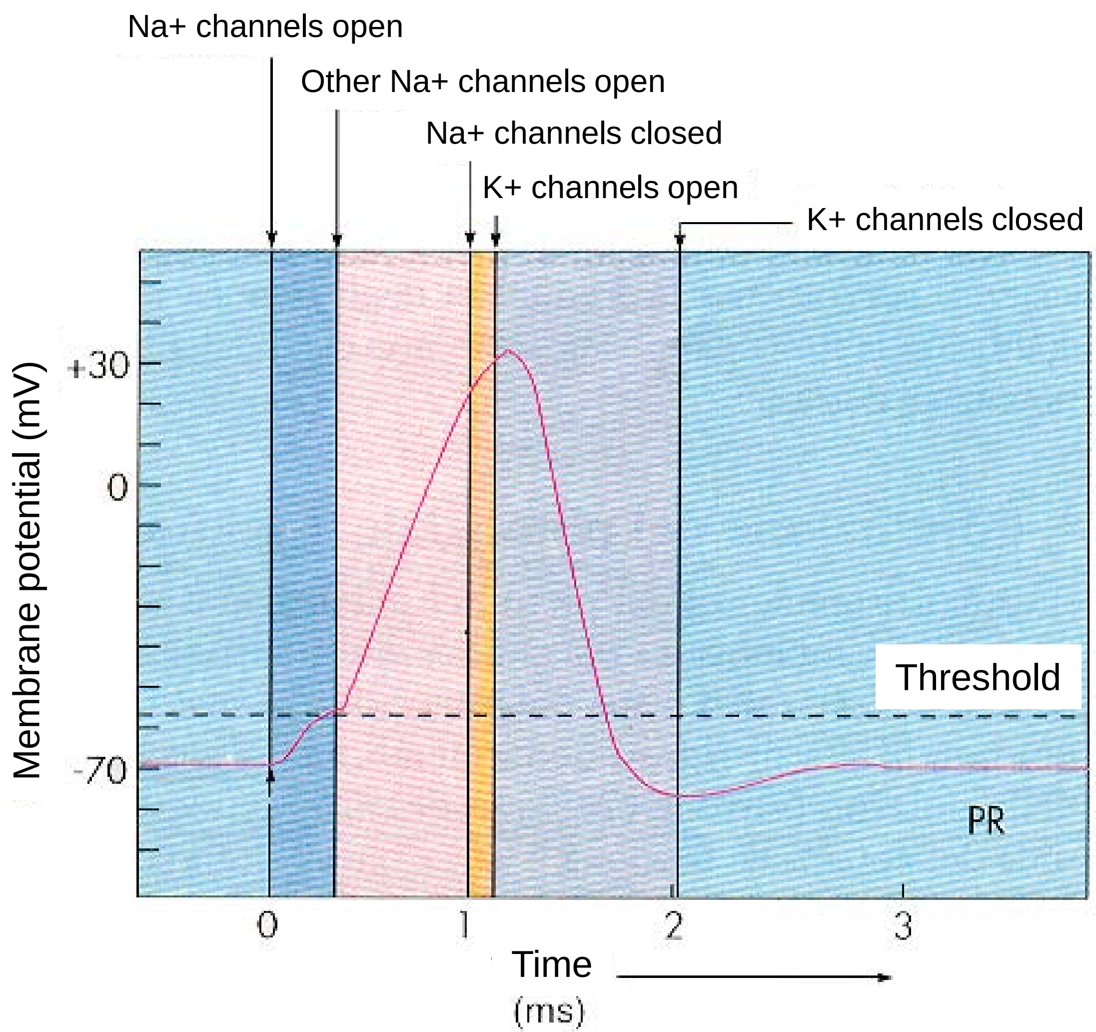


# The biological potentials

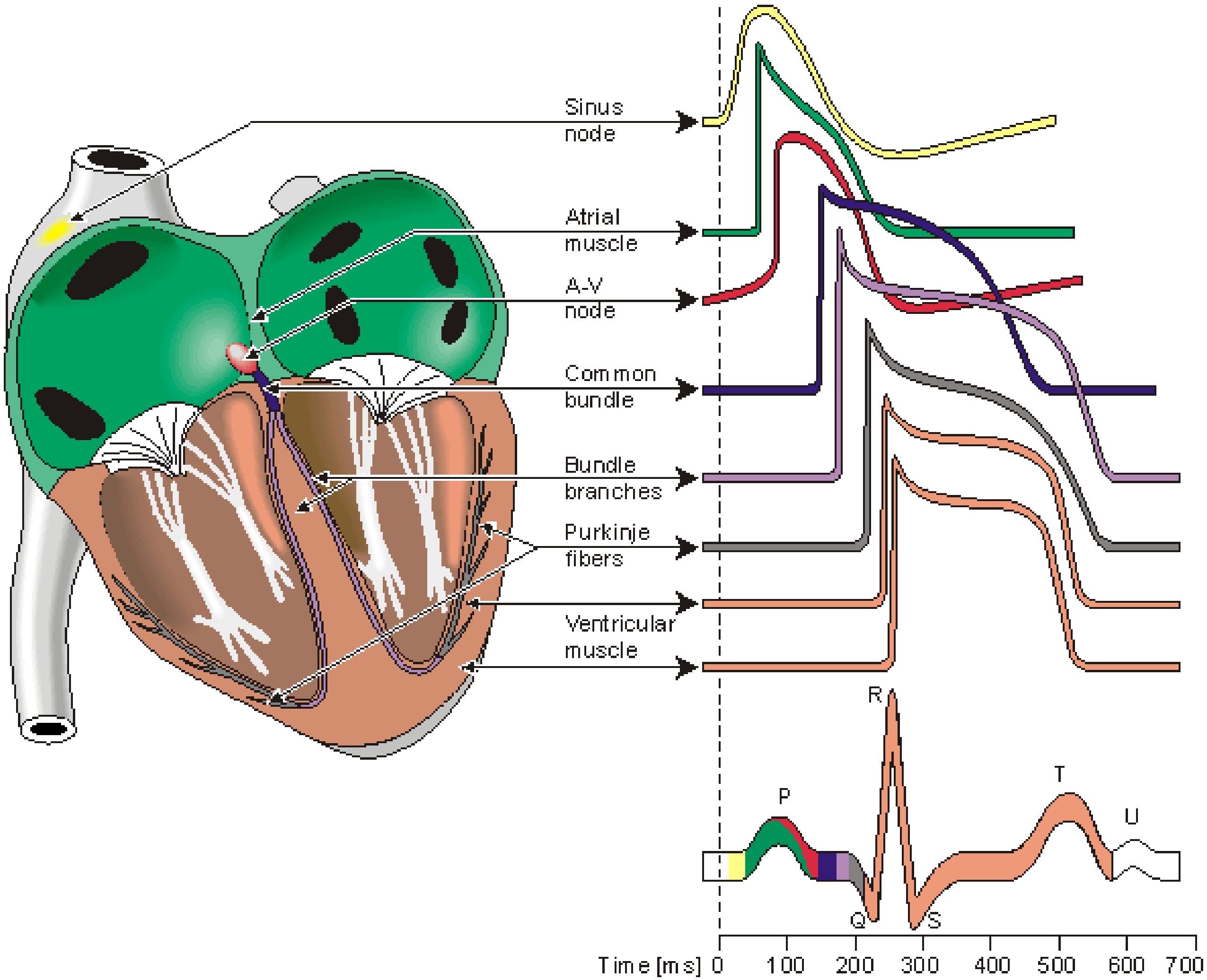


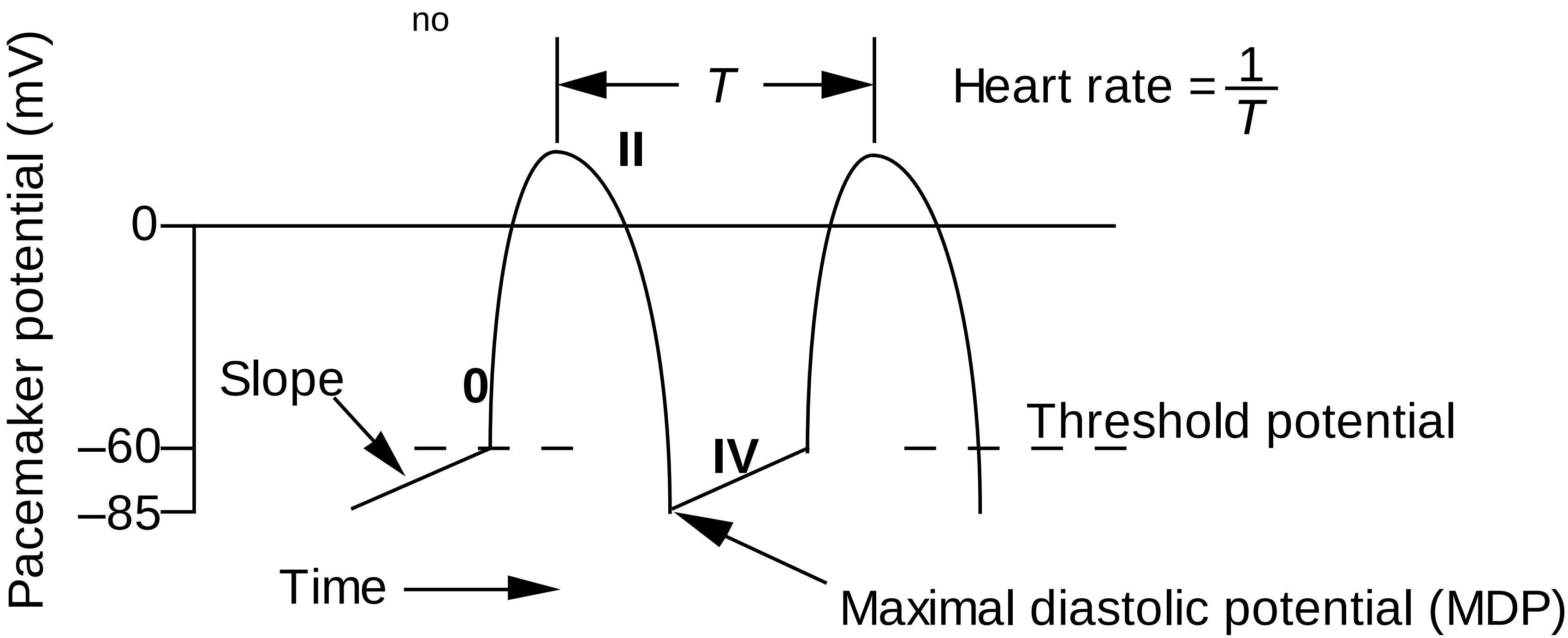



# The action potential



# The bio-potentials in the heart




no
T
Heart rate = $\frac{1}{T}$
II
0
Pacemaker potential (mV)
Slope
0
–60
–85
IV
Threshold potential
Time
Maximal diastolic potential (MDP)

# Measurement of bio-potentials

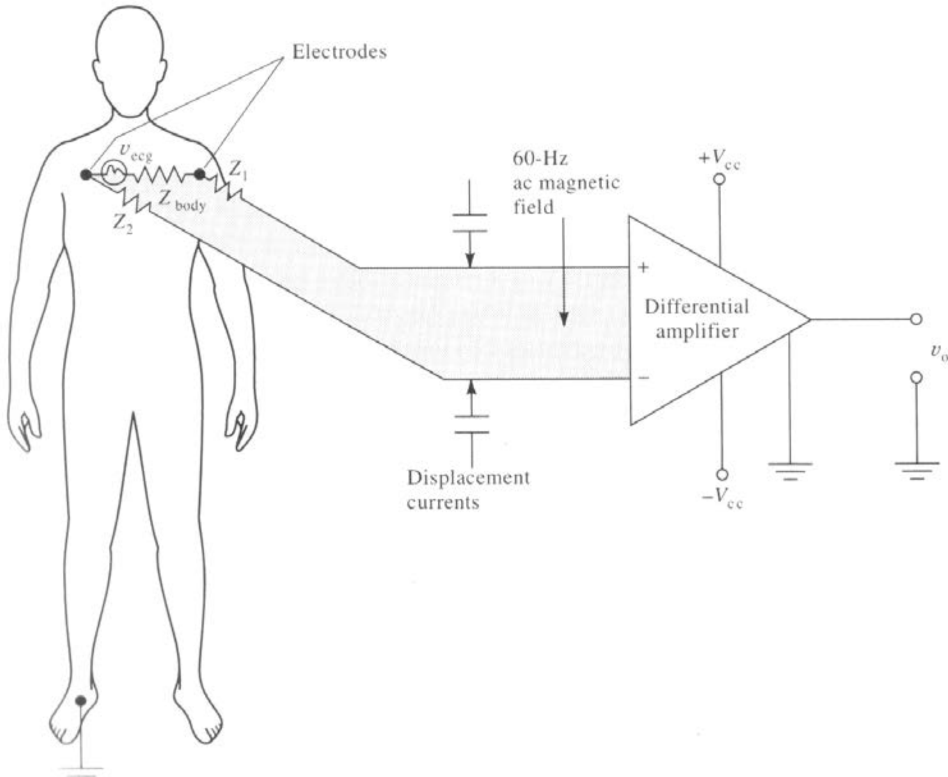
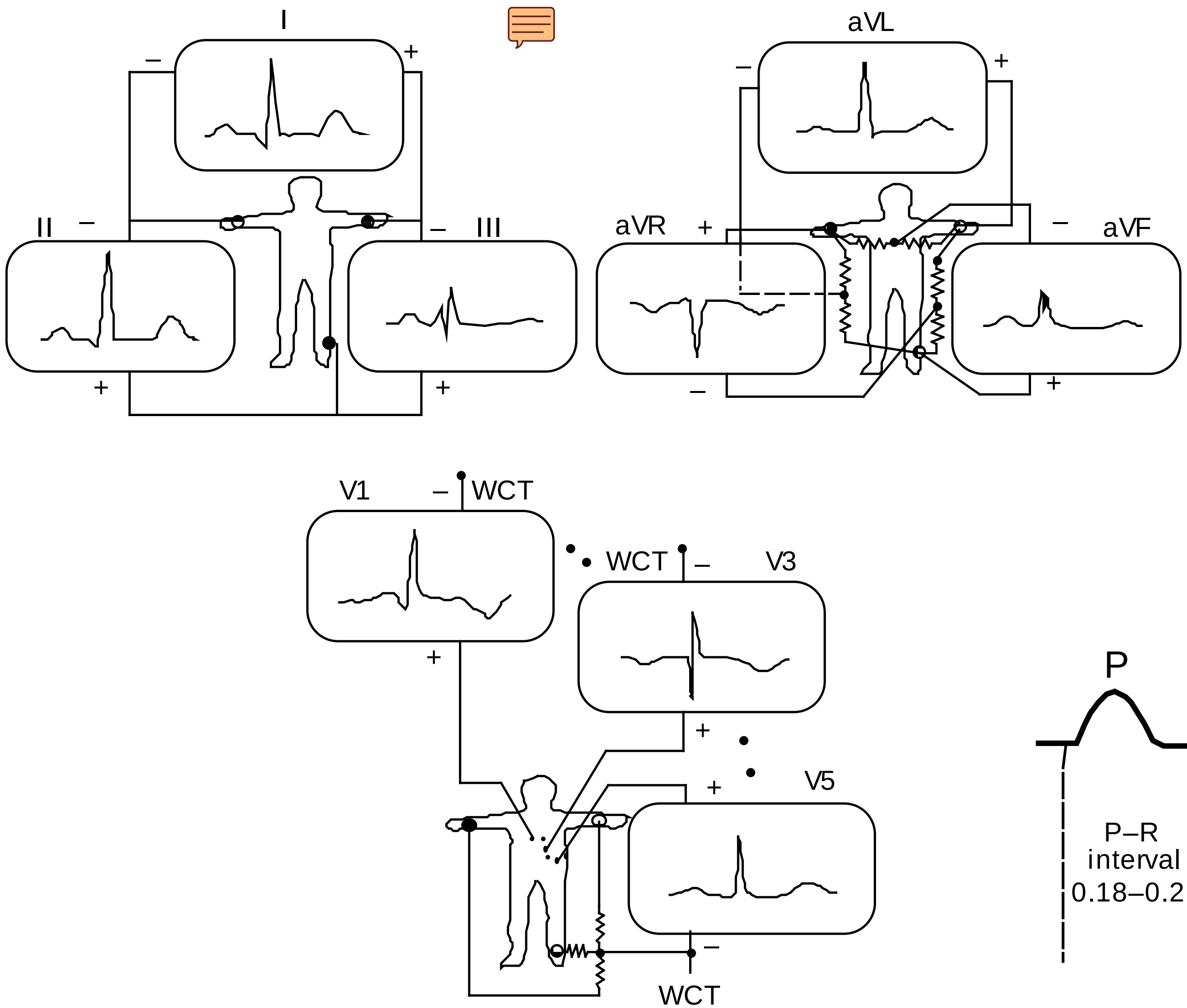
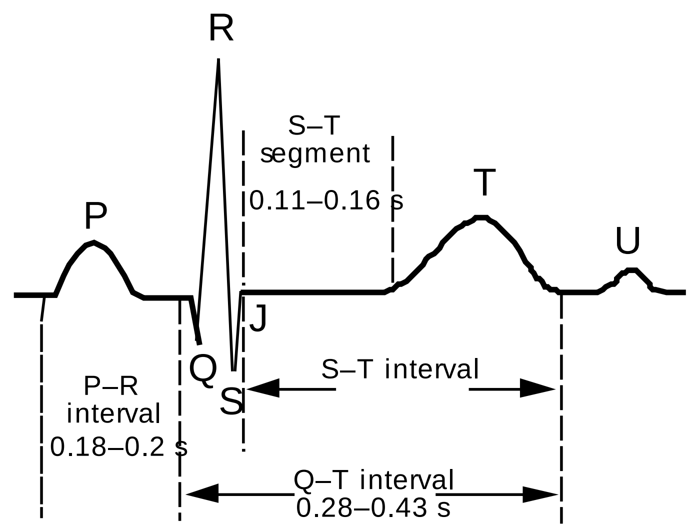



**Figure 1.2 Simplified electrocardiographic recording system** Two possible interfering inputs are stray magnetic fields and capacitively coupled noise. Orientation of patient cables and changes in electrode–skin impedance are two possible modifying inputs. $Z_1$ and $Z_2$ represent the electrode–skin interface impedances.

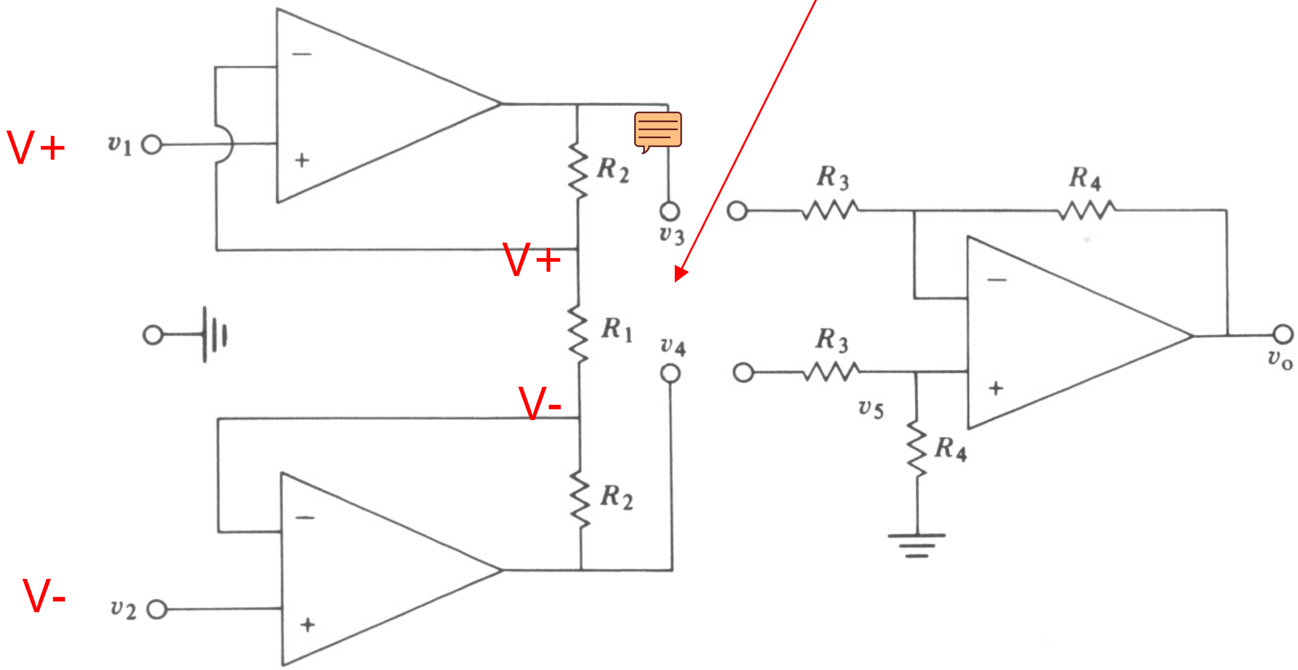
# The electrocardiograph



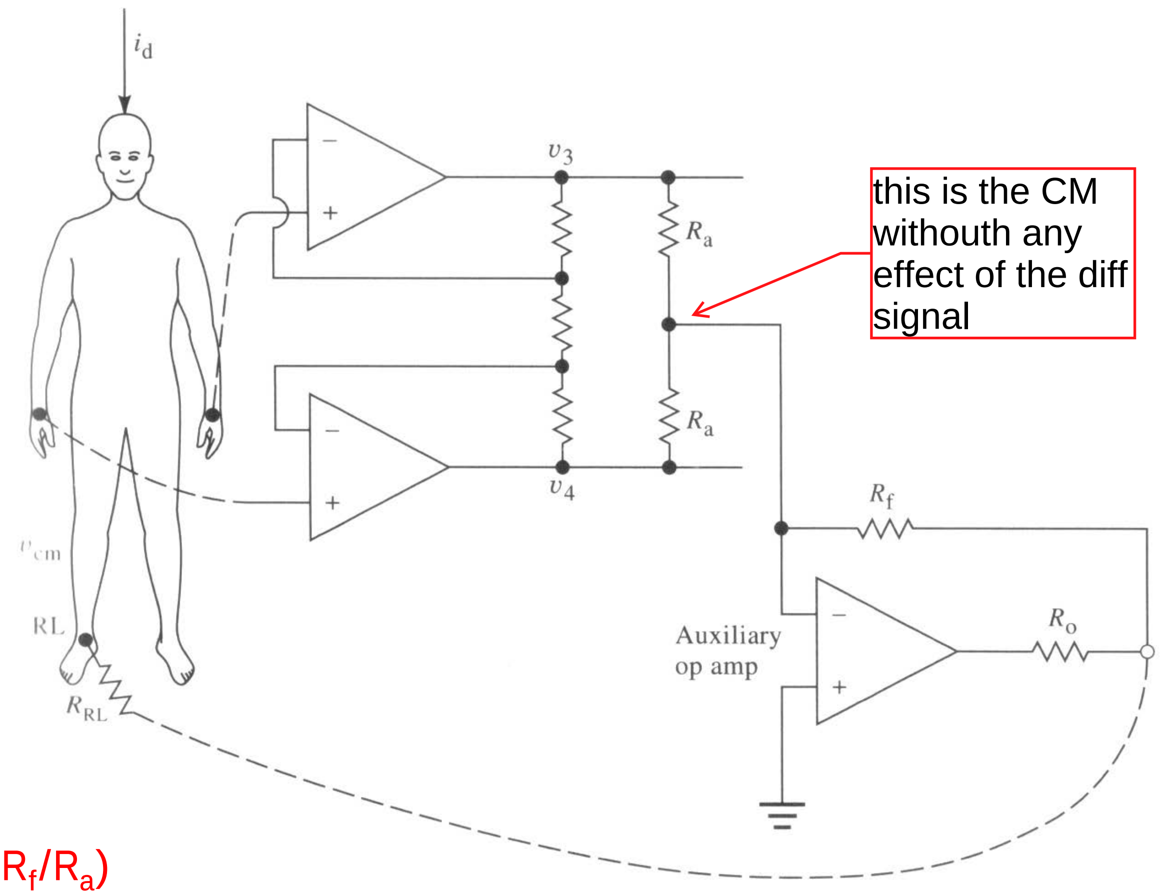



# Instrumentation amplifier

$(V_+ - V_-)\ (1+2R_2/R_1)$



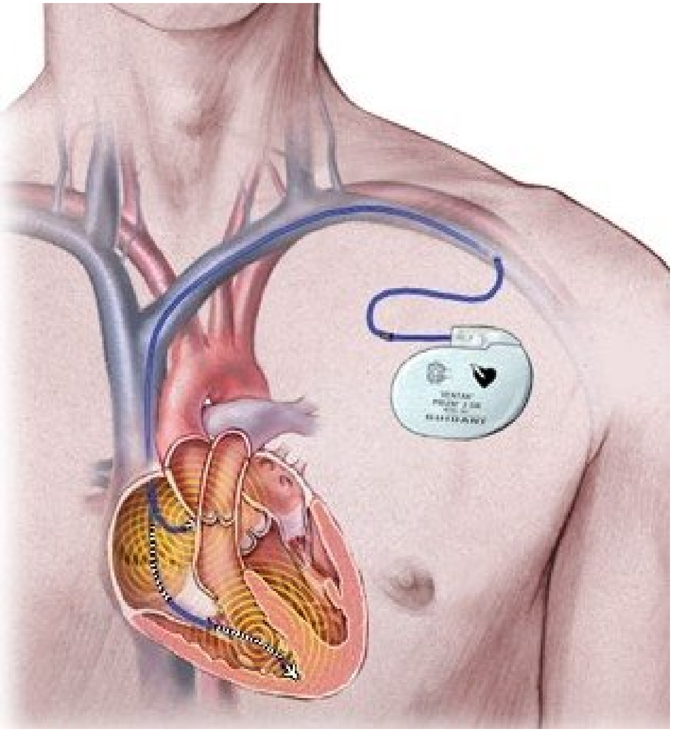
# Example: rejection of common mode

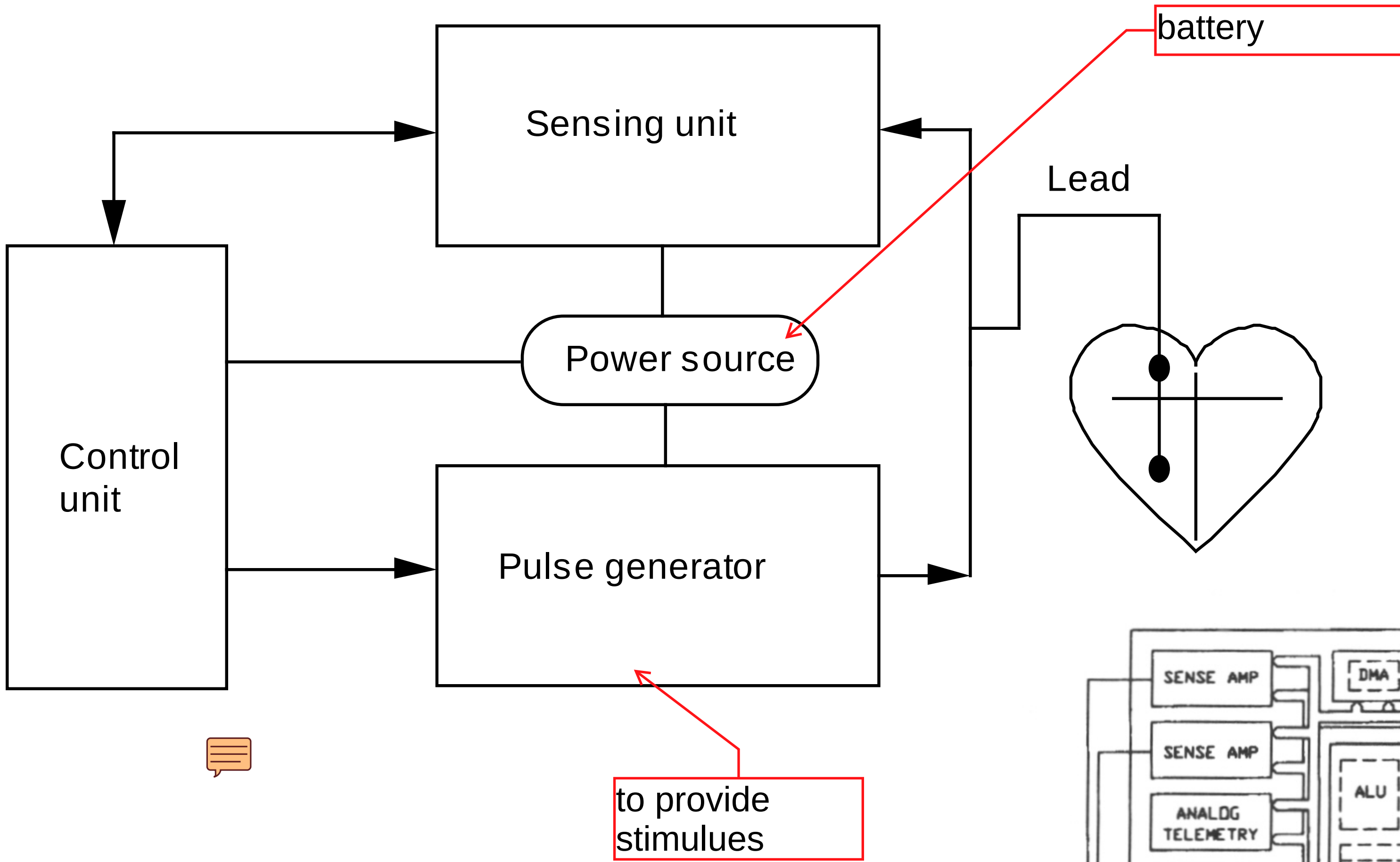



this is the CM withouth any effect of the diff signal

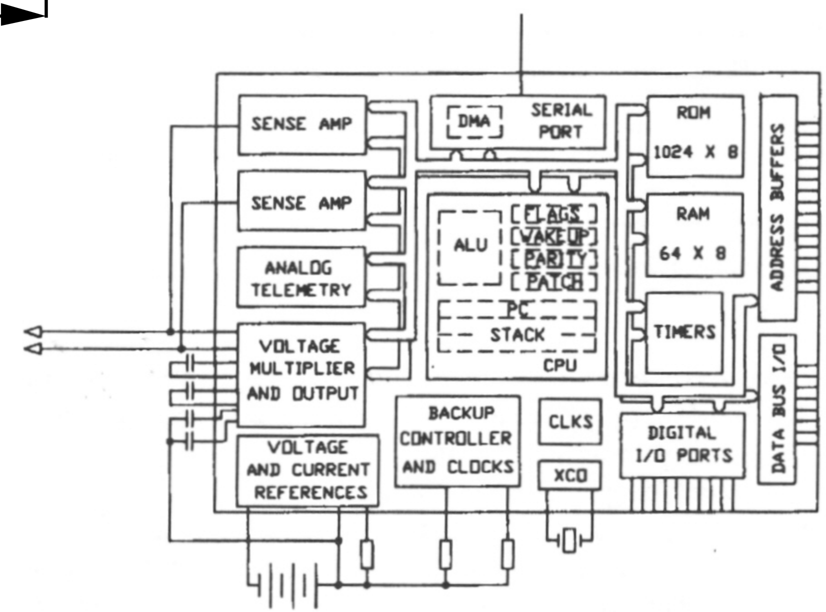
$V_{cm} = i_{db} R_{Lv} / (1+2R_f/R_a)$

# Electronics for implantable prosthesis (pacemaker)



battery
Sensing unit
Lead
Control unit
Power source
Pulse generator
to provide stimulues

SENSE AMP
SENSE AMP
ANALOG TELEMETRY
VOLTAGE MULTIPLIER AND OUTPUT
VOLTAGE AND CURRENT REFERENCES
DMA
SERIAL PORT
ALU
FLAGS
WAKEUP
PARITY
PATCH
PC
STACK
CPU
BACKUP CONTROLLER AND CLOCKS
CLKS
XCO
ROM 1024 X 8
RAM 64 X 8
TIMERS
DIGITAL I/O PORTS
ADDRESS BUFFERS
DATA BUS I/O

# Pacemaker low-power (1.5V, 100nA) readout circuits (1)

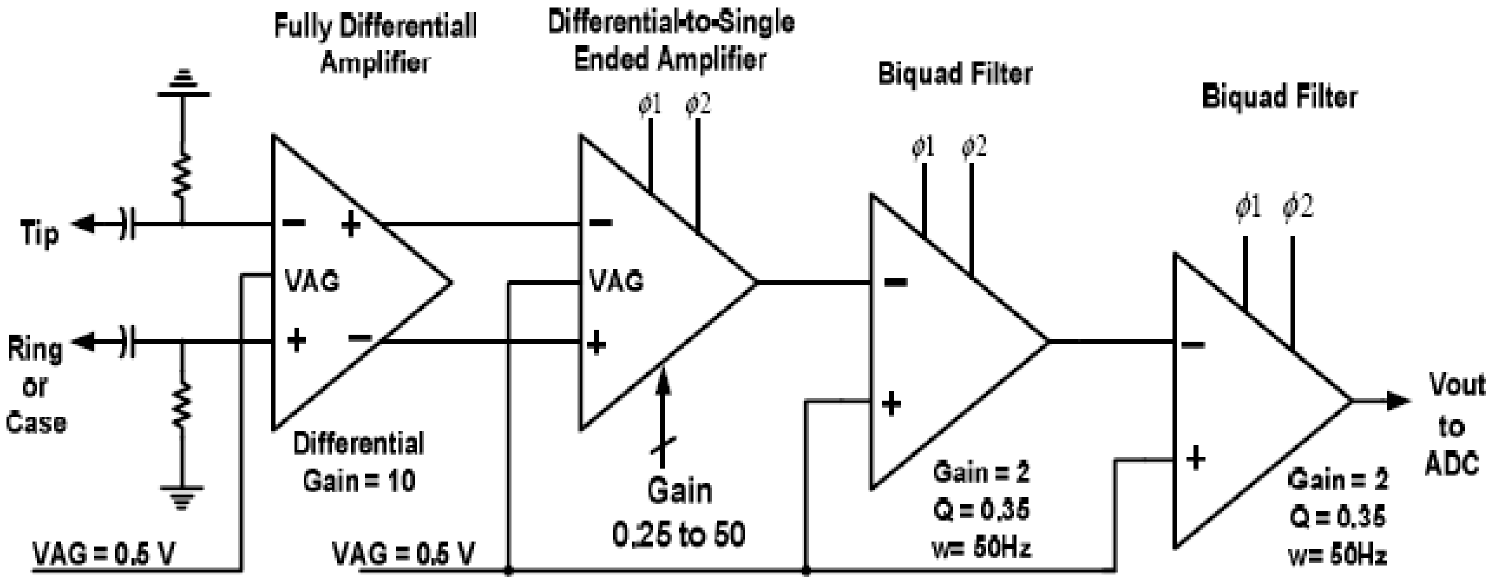



Fig. 1. Block diagram of the implantable filter

# Pacemaker readout circuits (2)

no

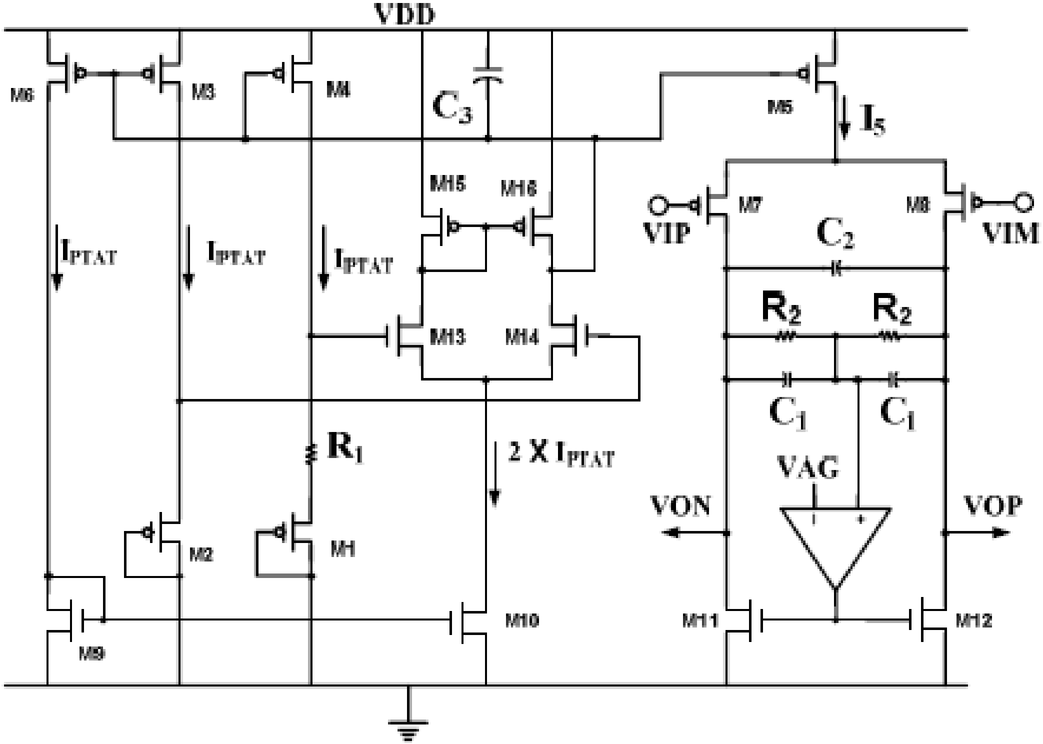



Fig. 4. Low noise fully differential amplifier

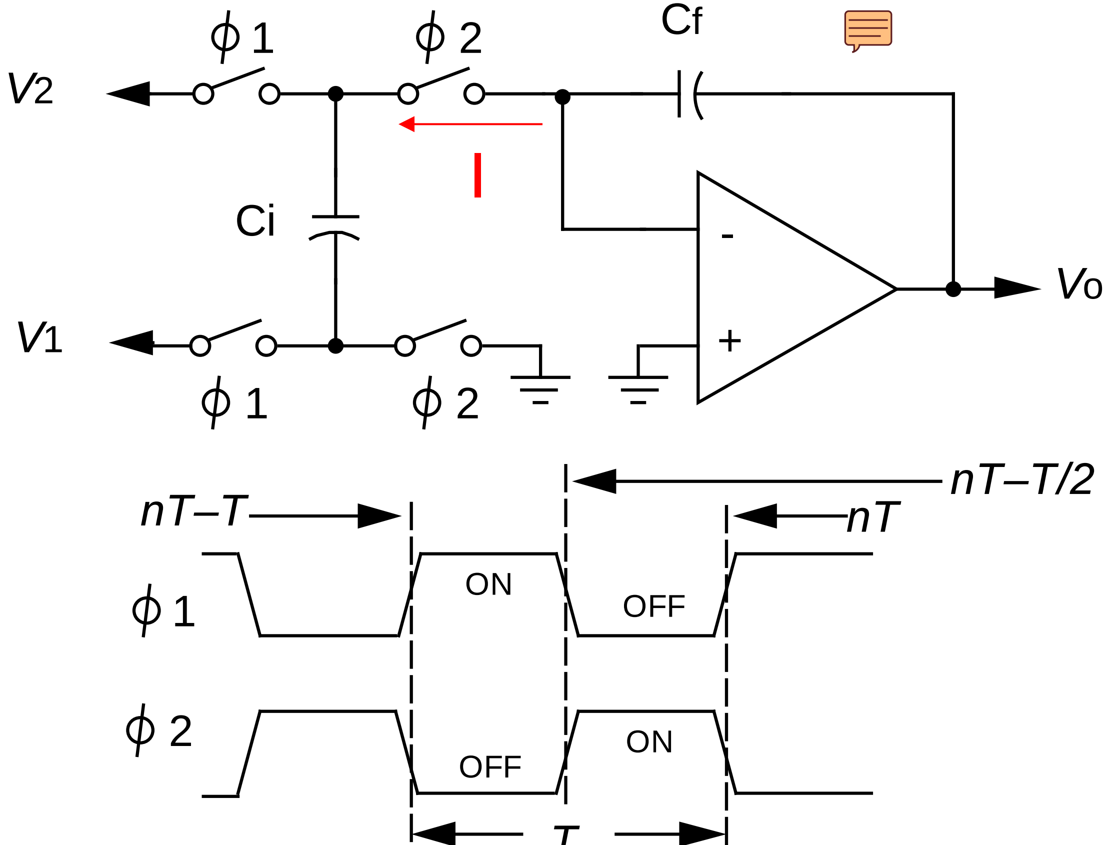
$$I_{PTAT} \cong \frac{nV_T}{R_1} \cdot Ln\left[\frac{(W/L)_1}{(W/L)_2}\right]$$

$$A = \frac{VOP - VOM}{VIP - VIM} = g_{m7} \cdot R_2$$

$$= \left[\frac{(I_5/2)}{n \cdot V_T}\right] \cdot R_2$$

$$A = \frac{1}{2}\left(\frac{R_2}{R_1}\right) \cdot \frac{(W/L)_5}{(W/L)_3} \cdot Ln\left[\frac{(W/L)_1}{(W/L)_2}\right]$$

# Switched capacitors amplifiers




$\Delta Vi = V1 - V2$

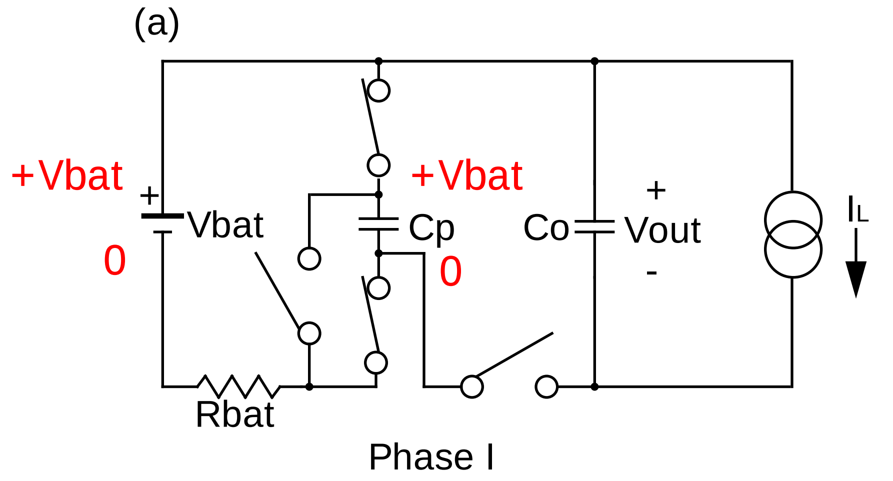
$I = \Delta Vi \times f \times Ci$

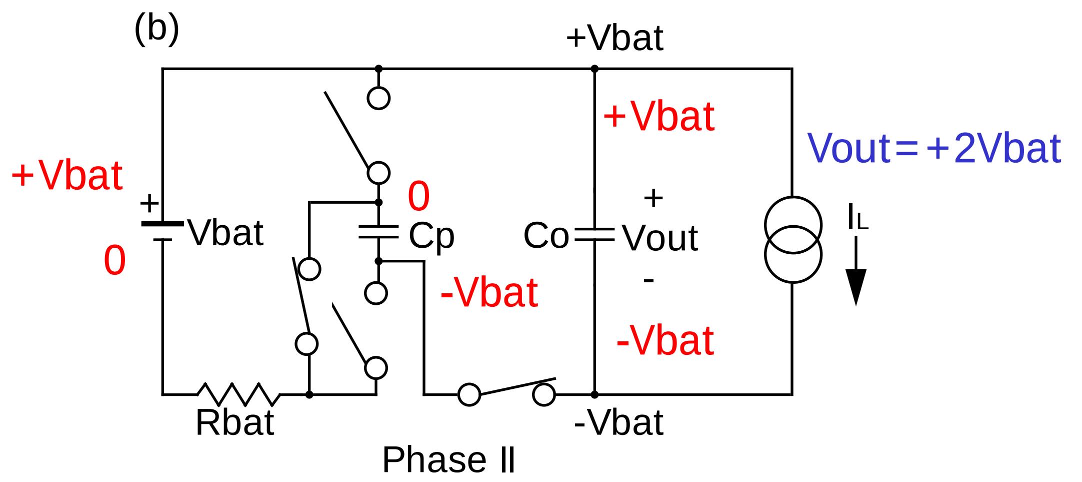
$Reff = \Delta Vi / I = 1/f \times Ci$

$Vo = I \times 1/j\omega C_f$
$= \Delta Vi \times f \times Ci / j\omega C_f$

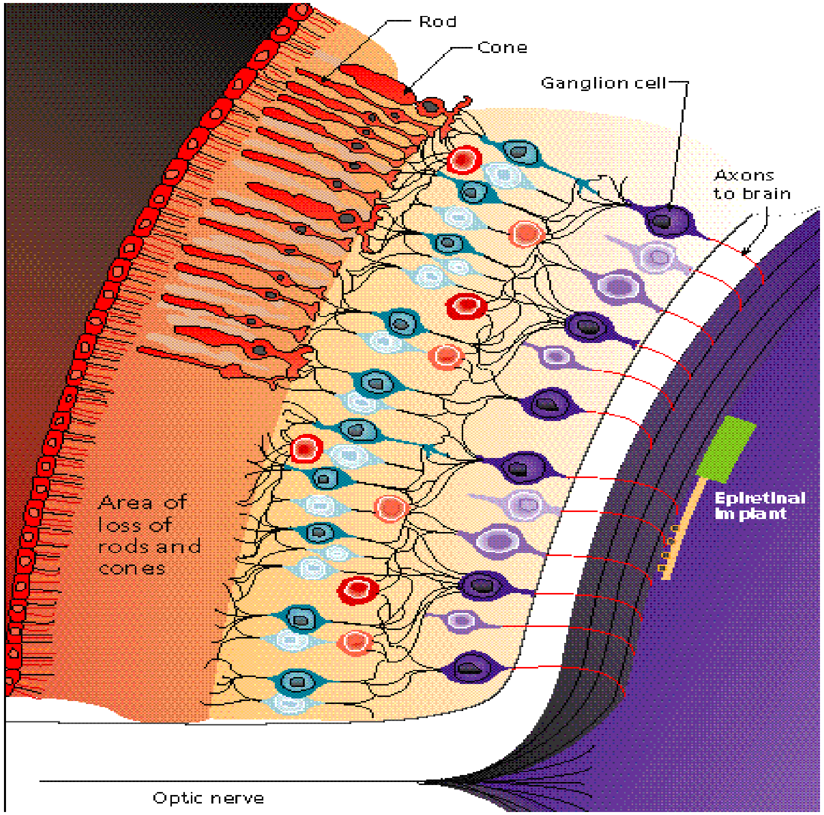
$$\frac{V_o}{\Delta V_i} = \frac{C_i}{C_f} \frac{1}{j\omega T}$$

# Pulses generators (with V > $V_{supply}$)

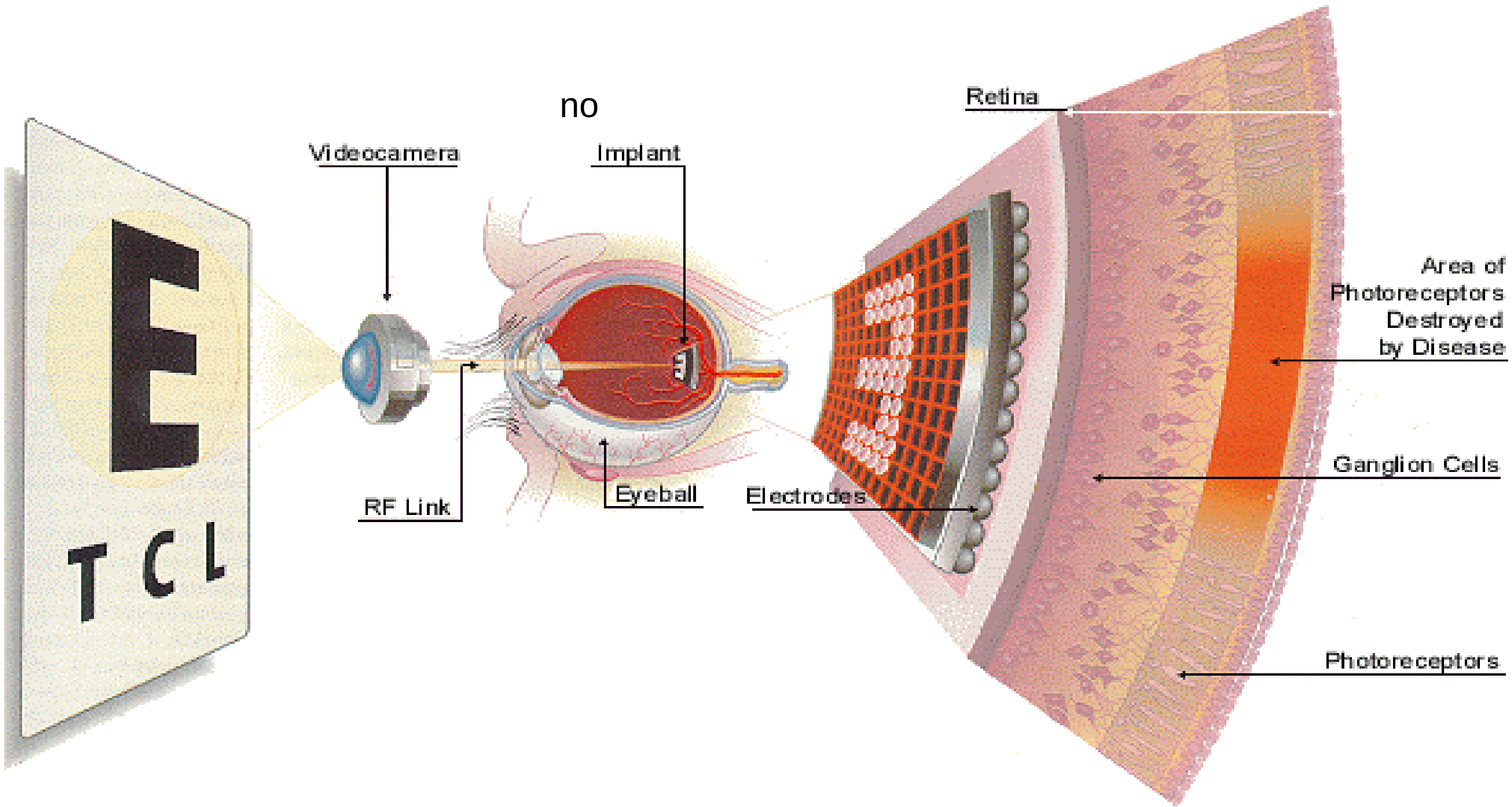


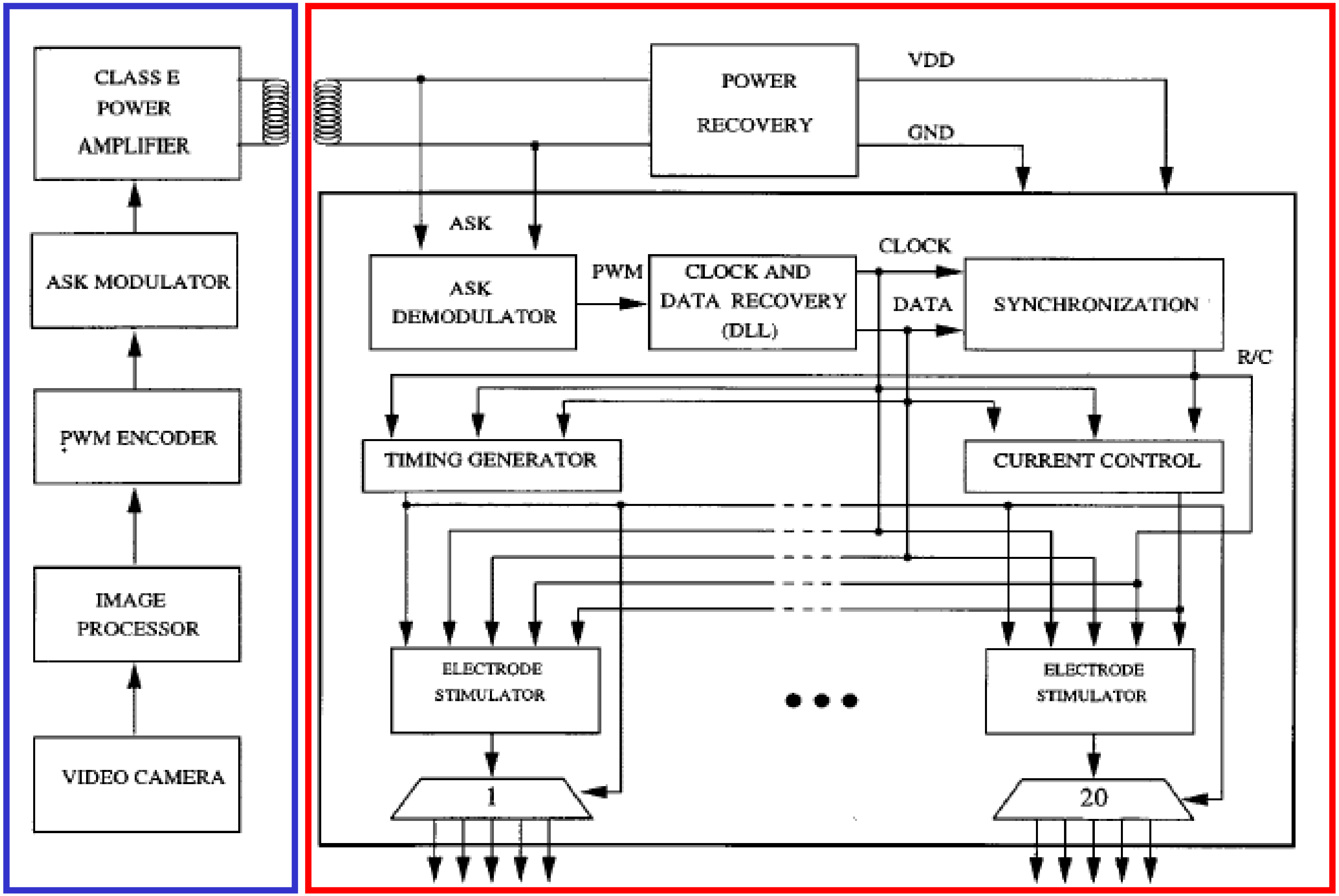



# Artificial vision



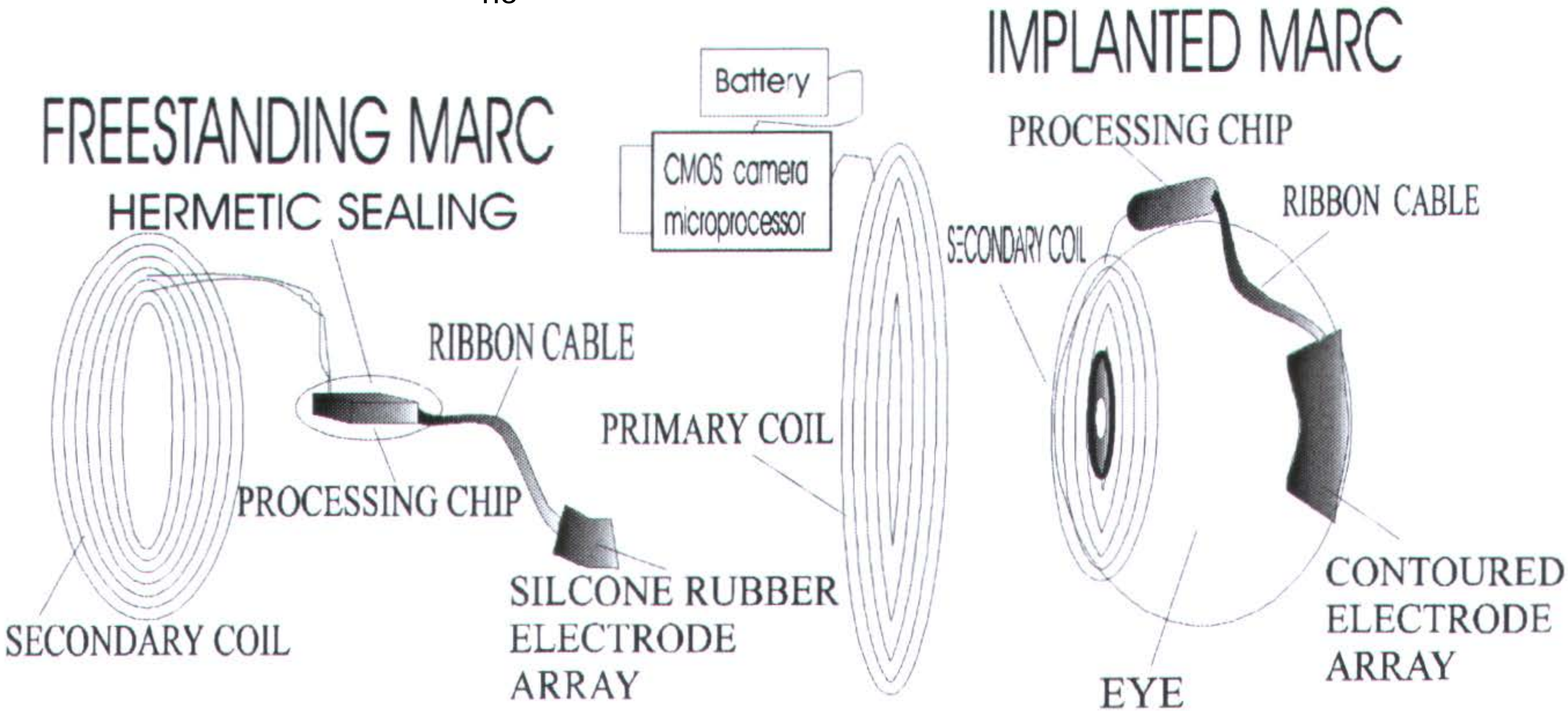
# Multiple Unit Artificial Retina Chipset (MARC)





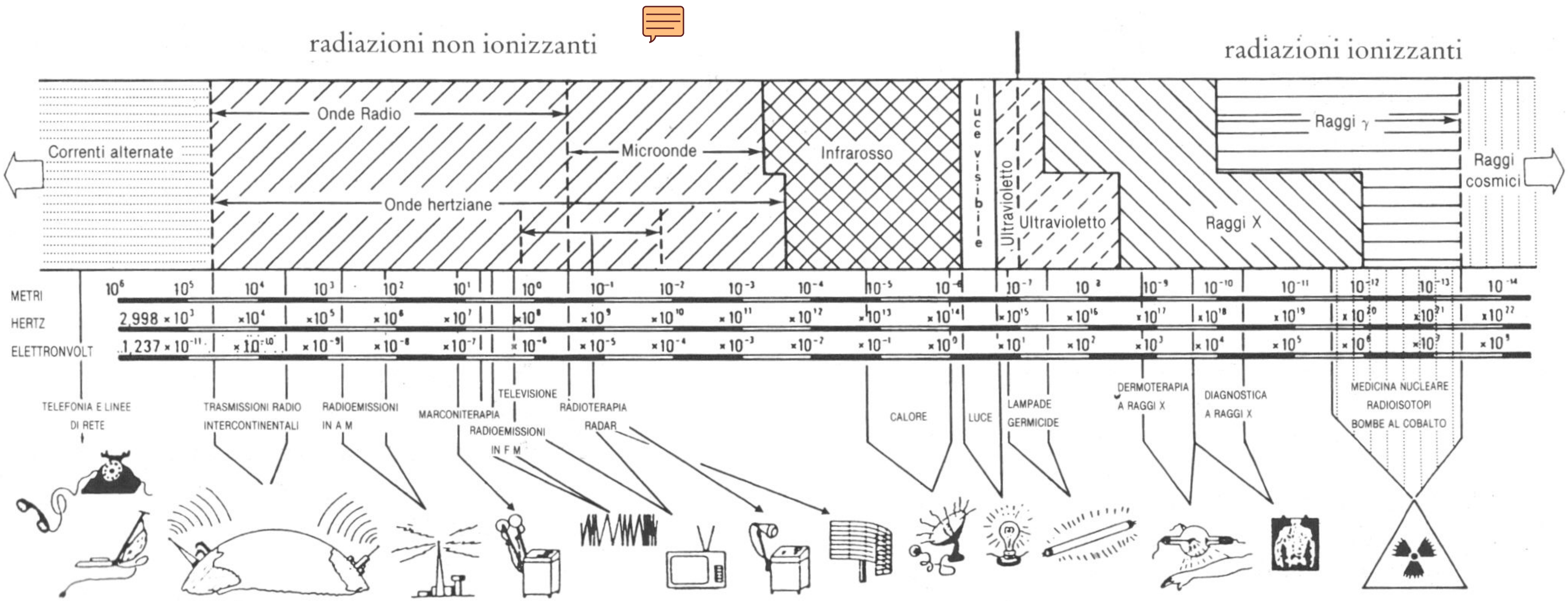

IMPLANTED STIMULATOR

no



FREESTANDING MARC
HERMETIC SEALING
RIBBON CABLE
PROCESSING CHIP
SECONDARY COIL
SILCONE RUBBER
ELECTRODE
ARRAY
Battery
CMOS camera
microprocessor
PRIMARY COIL
IMPLANTED MARC
PROCESSING CHIP
RIBBON CABLE
SECONDARY COIL
CONTOURED
ELECTRODE
ARRAY
EYE

# Diagnostic systems for medical imaging based on X and $\gamma$ rays



# The X rays

**FIGURE 1-1**
A radiograph of the hand taken by Röntgen in December 1895. His wife may have been the subject. (From the Deutsches Röntgen Museum, Remscheid-Lennap, Germany. Used with permission.)

# X rays generators

no

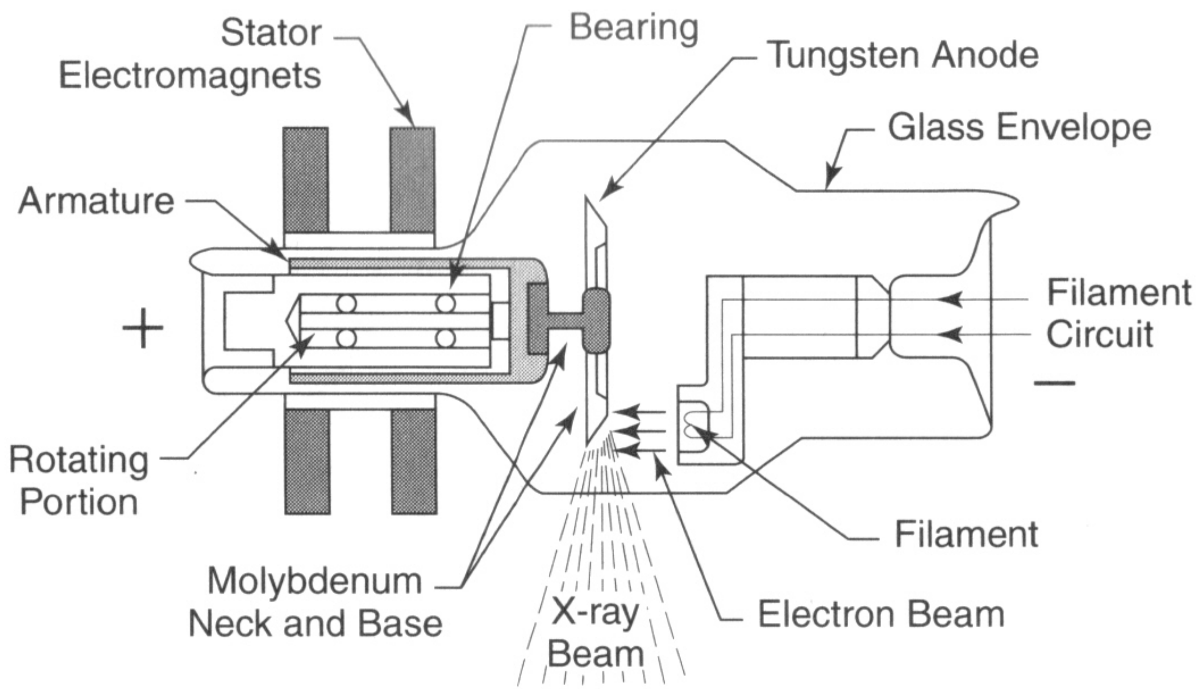
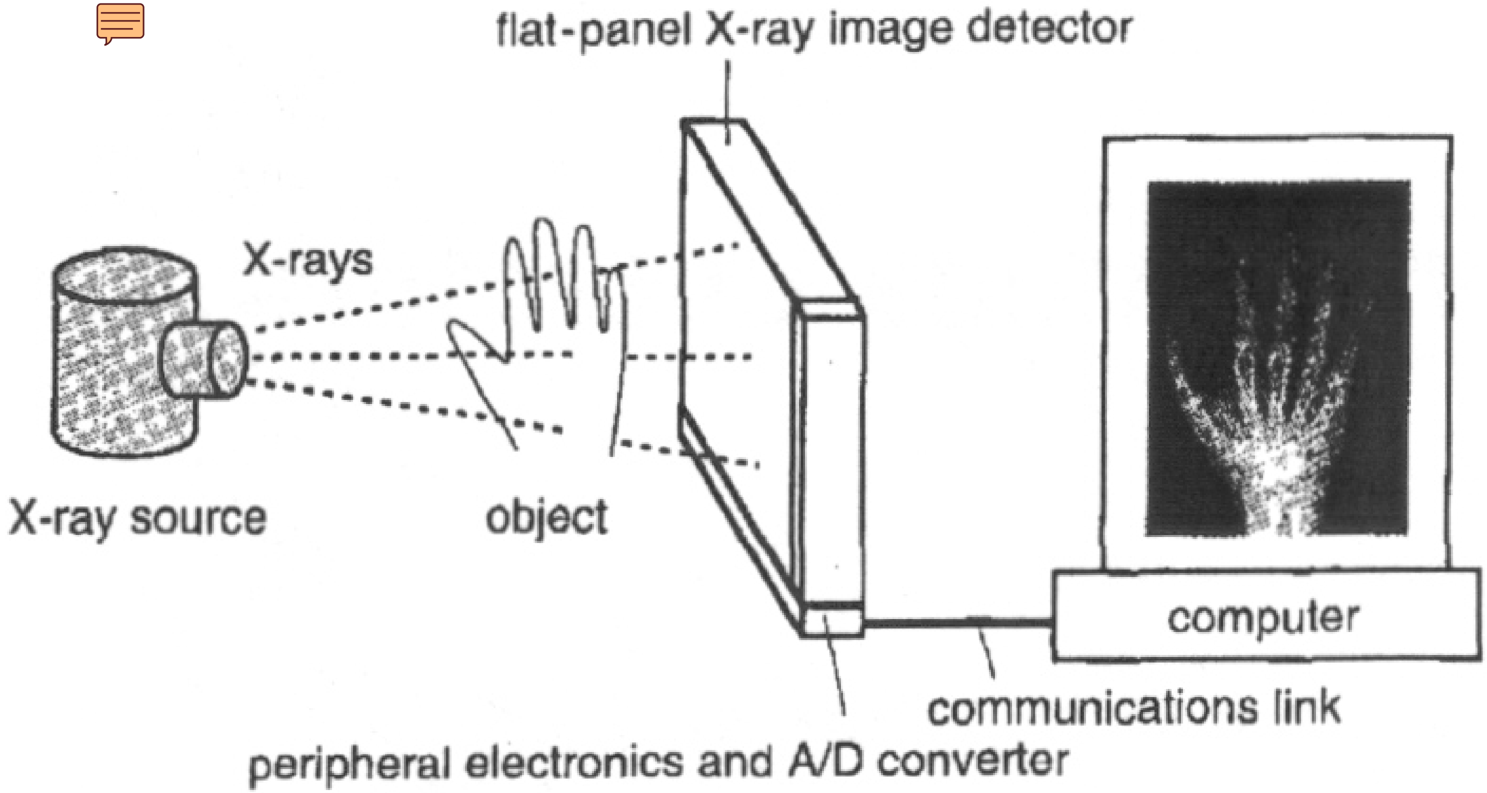
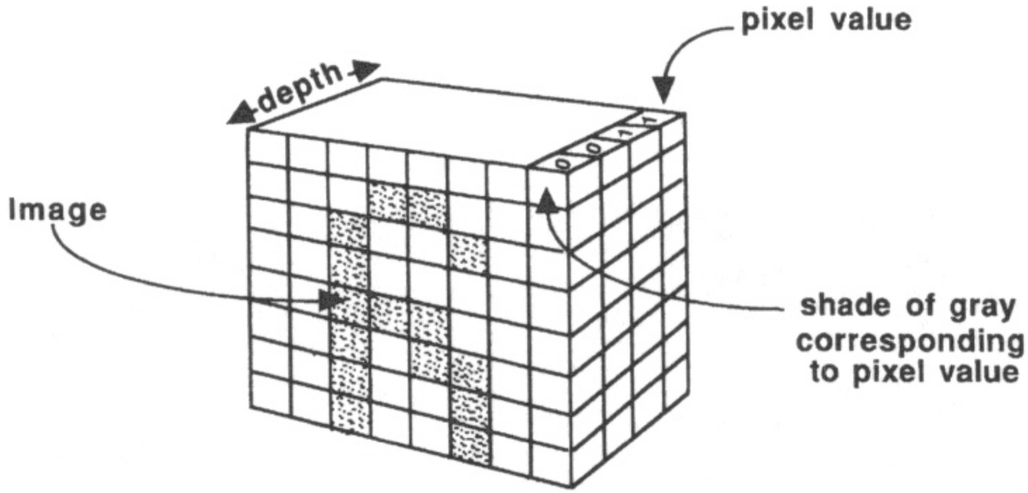



**FIGURE 5-1**
Simplified x-ray tube with a rotating anode and a heated filament.

# Digital radiography





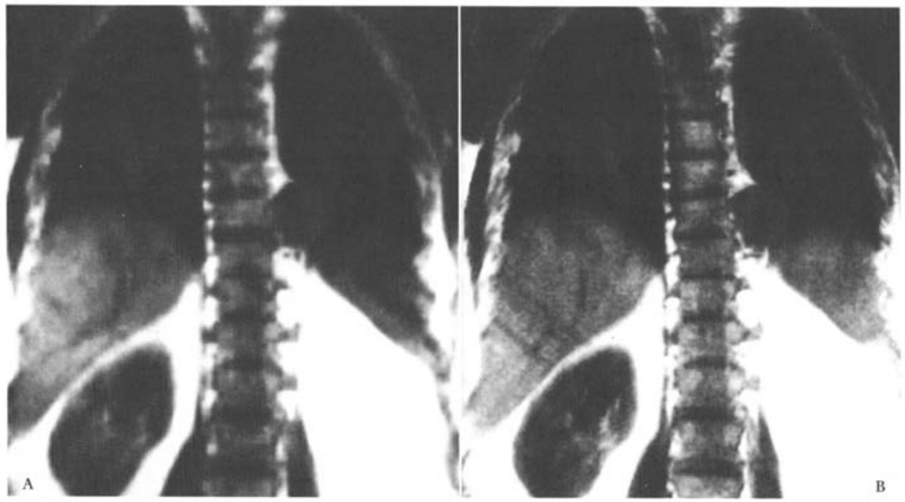
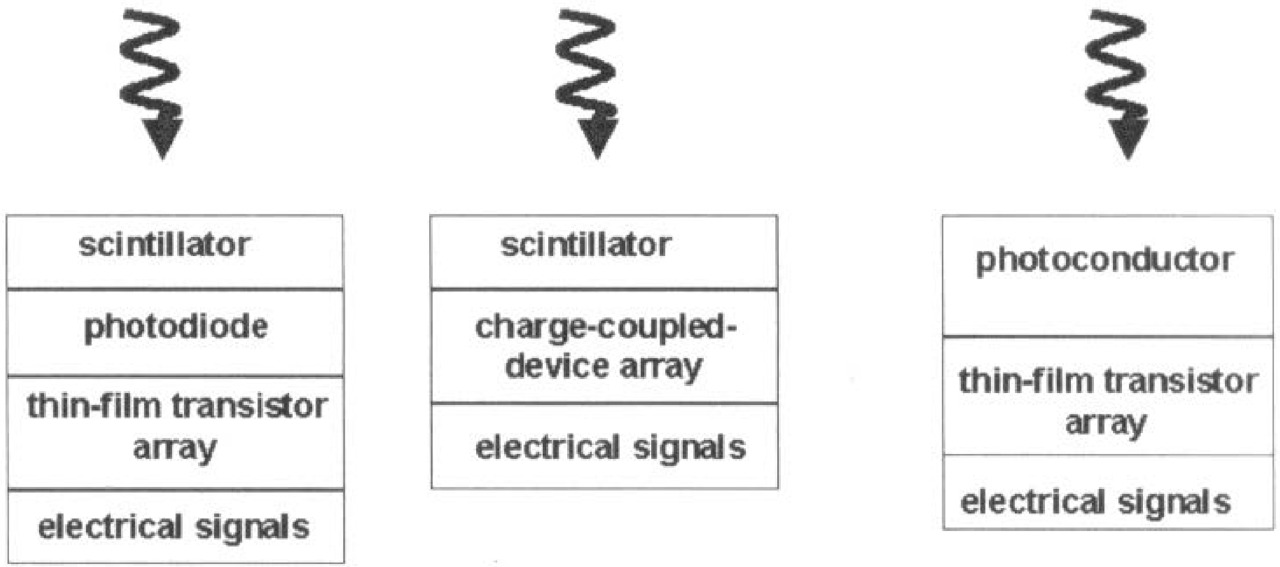
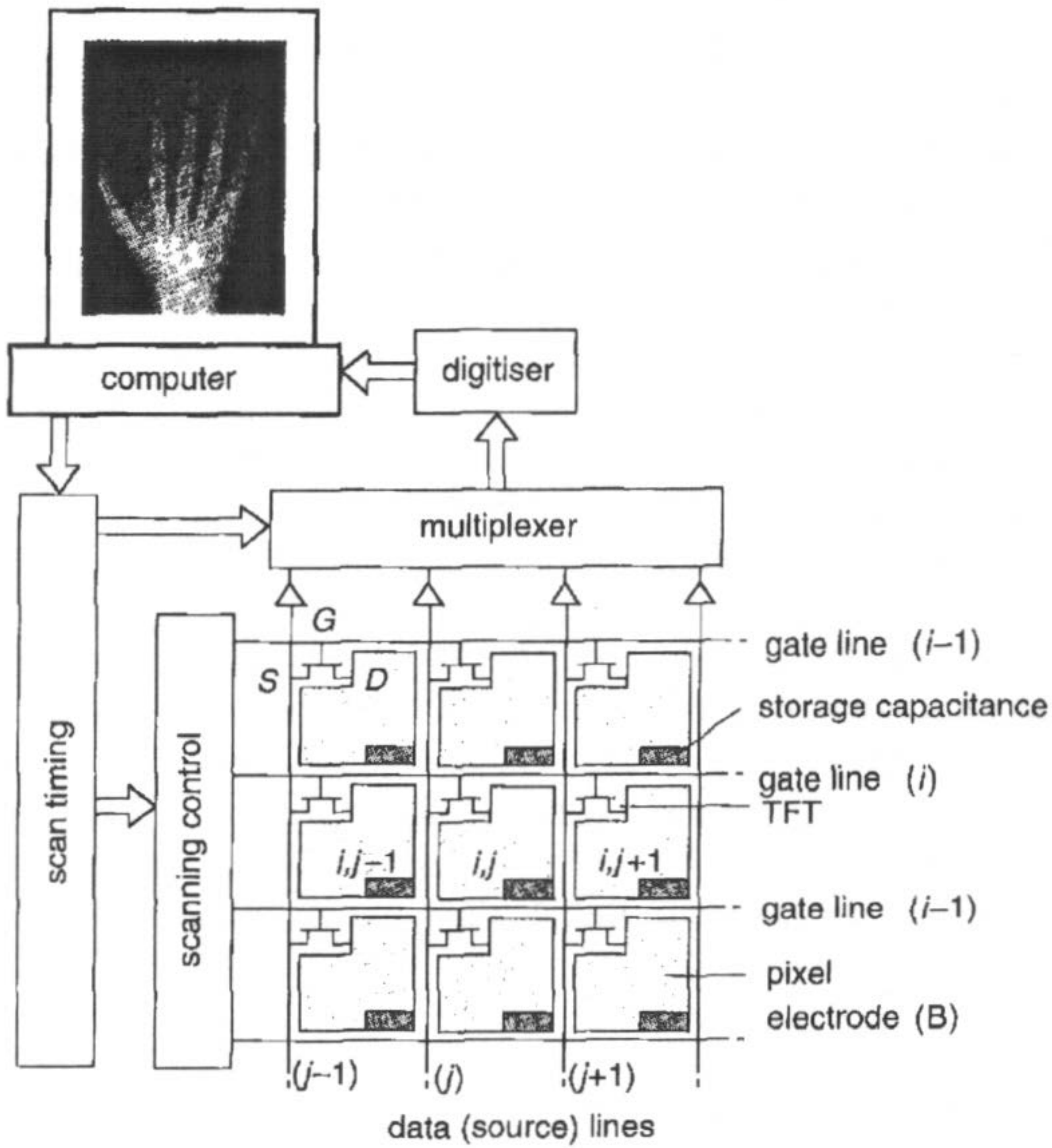




Fig. 26.2A-B – Incremento della risoluzione spaziale dell'immagine ottenuto diminuendo le dimensioni dei pixels.
A: matrice 128 × 128; B: matrice 256 × 256.

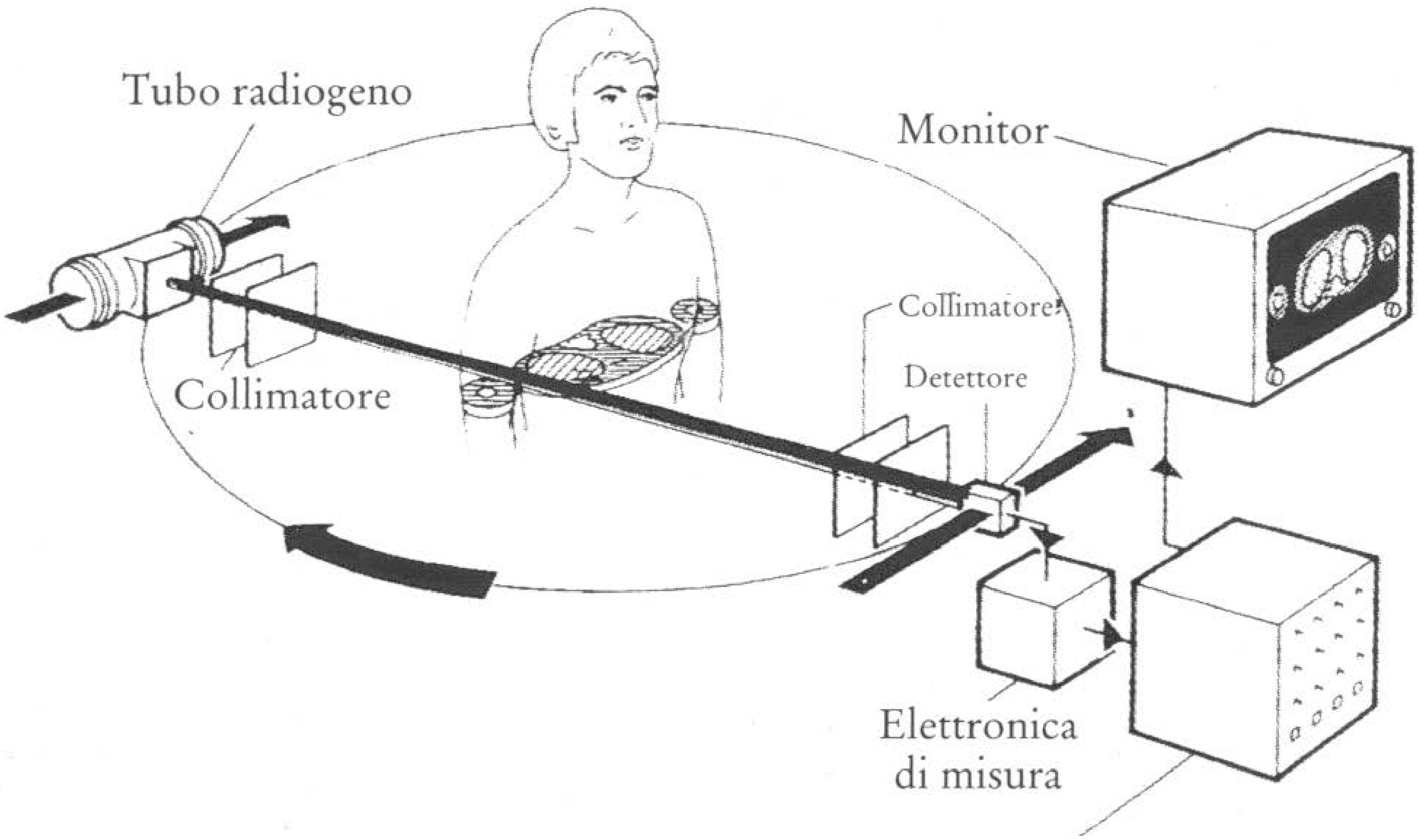
# Detectors for digital radiography

indirect conversion direct conversion

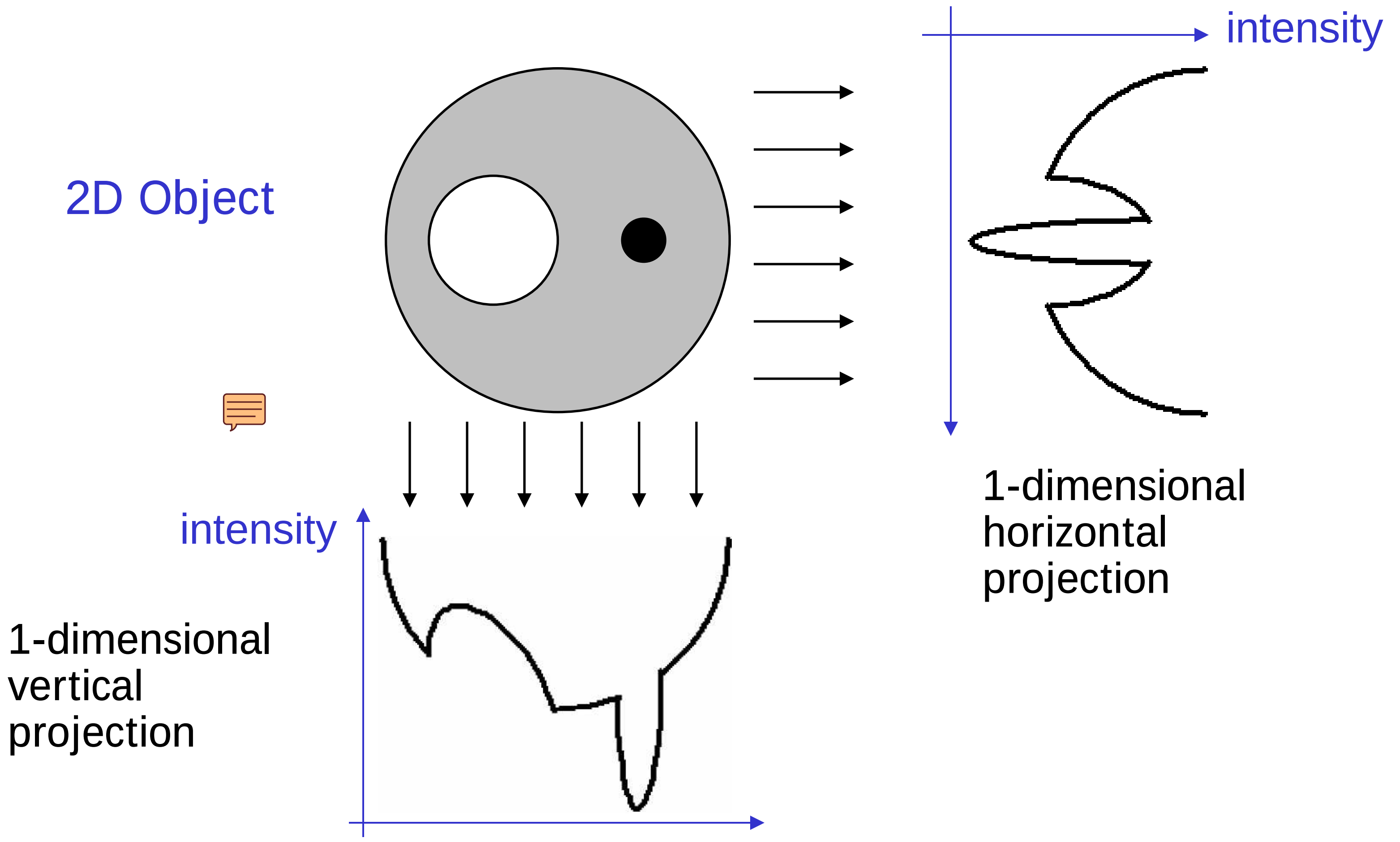



computer
digitiser
multiplexer
scan timing
scanning control
G
S
D
gate line (i–1)
storage capacitance
gate line (i)
TFT
i,j–1
i,j
i,j+1
gate line (i–1)
pixel
electrode (B)
(j–1)
(j)
(j+1)
data (source) lines

# Computerized Tomography (CT, Italian TAC)



# Computerized Tomography: principle




By measuring 1D projections along different angles, it is possible to reconstruct the 2D distribution of the object density

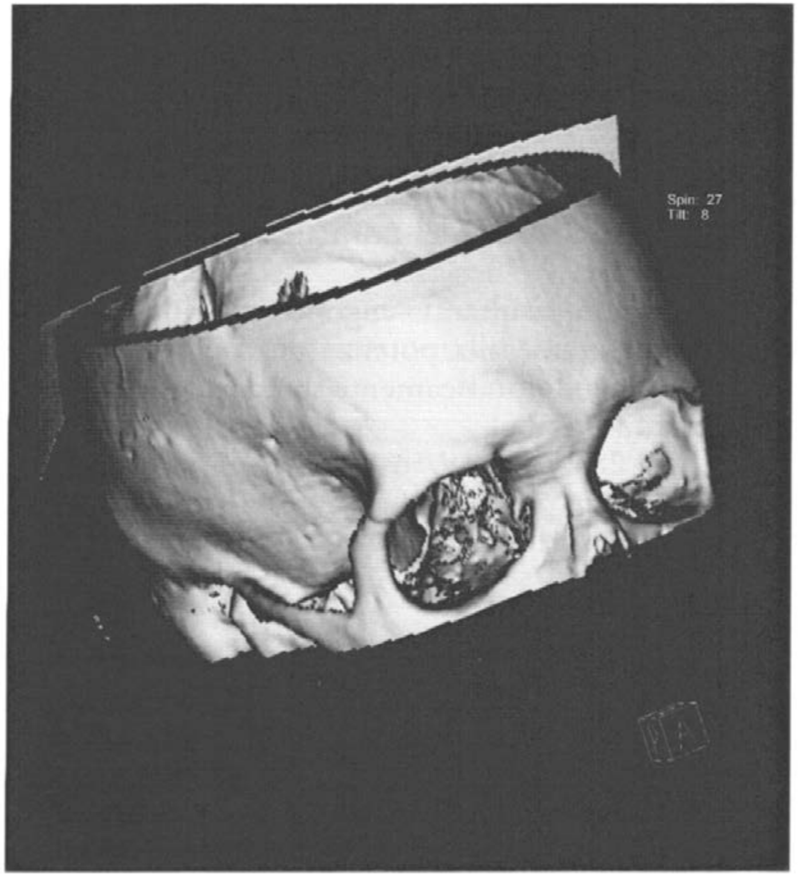



Fig. 28.26 – Articolazione Temporo-mandibolare; Ricostruzione 3D da TC Spirale.

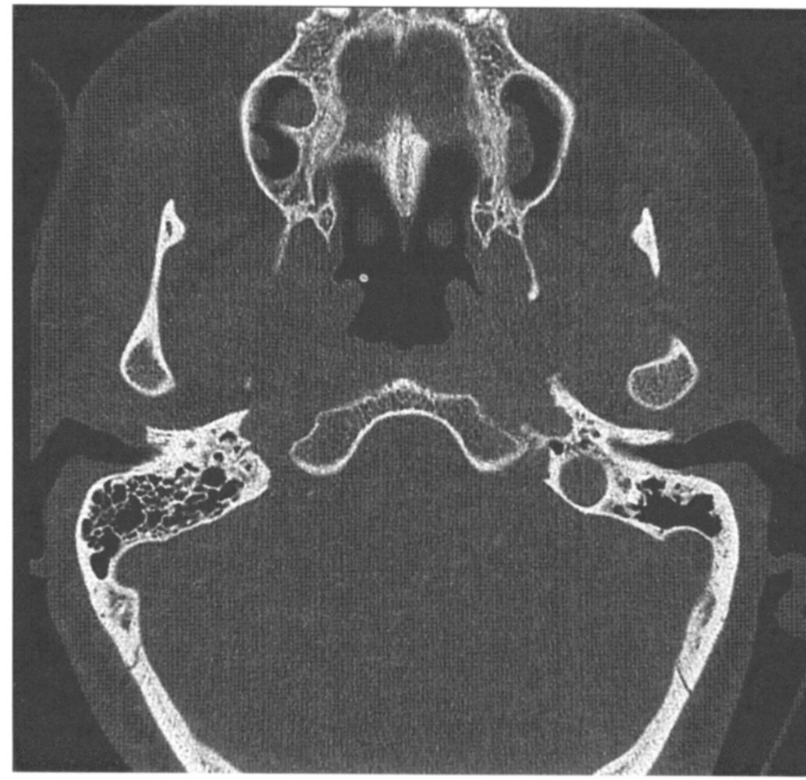
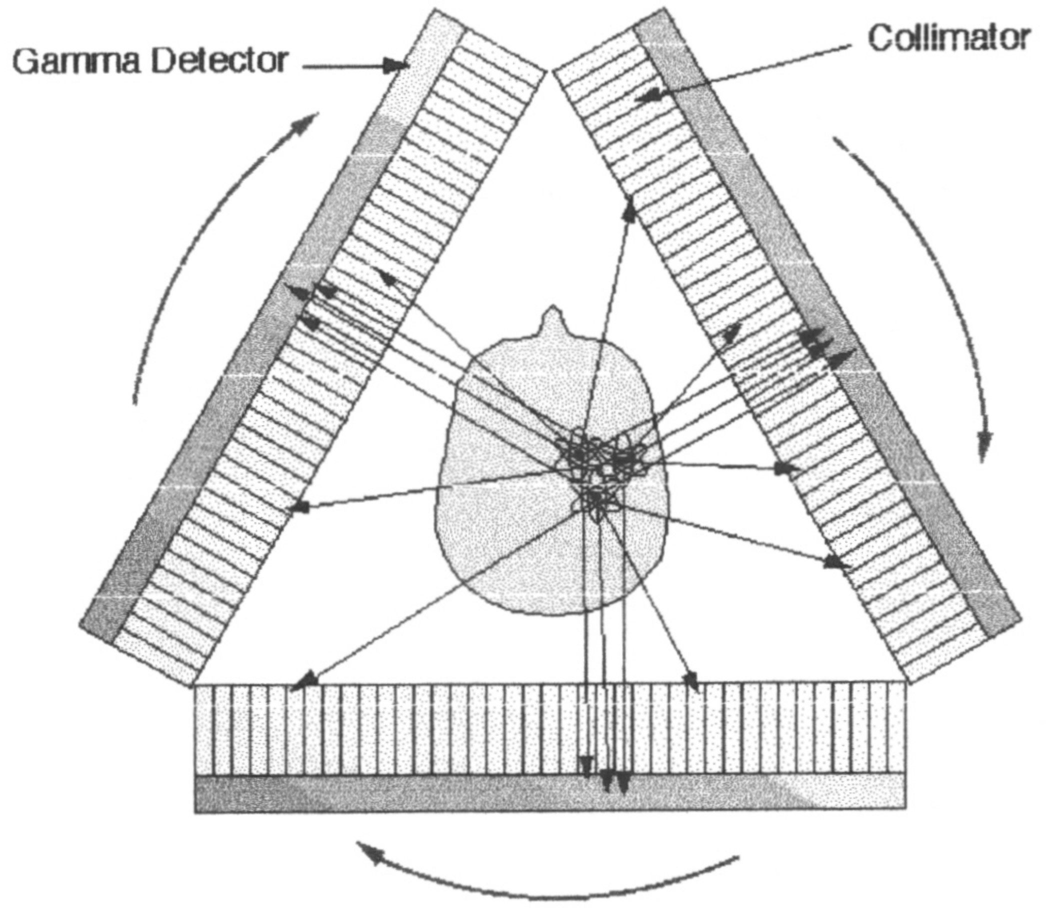
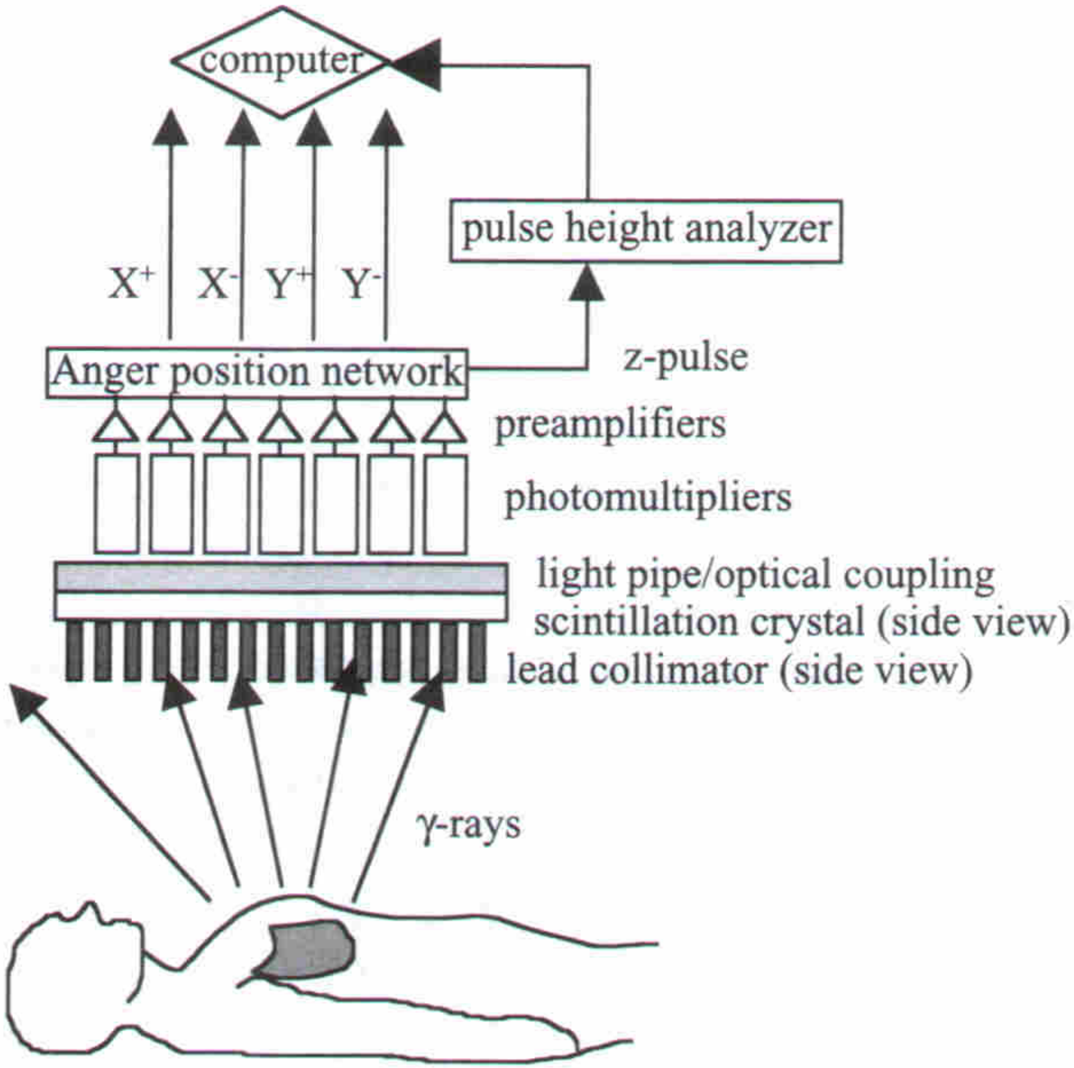


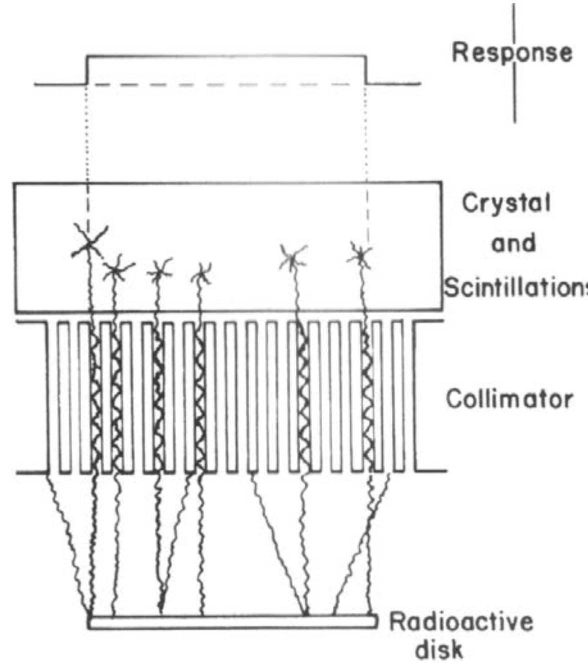
Fig. 28.6 – Immagine Cranio assiale, alta risoluzione; spessore strato 1 mm.; T = 2 sec.

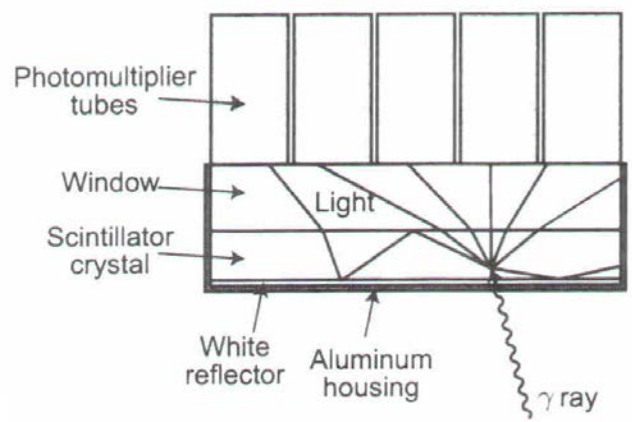
# Single Photon Emission Computed Tomography (SPECT)



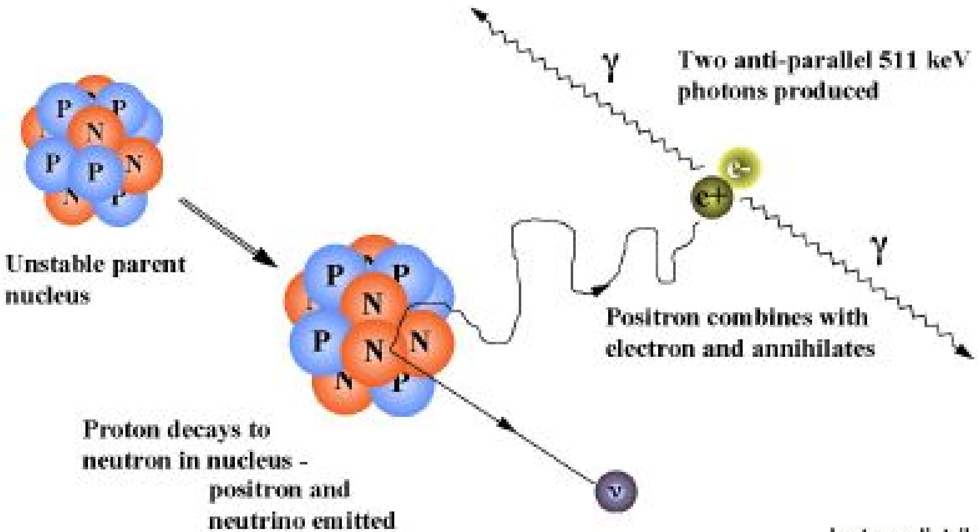
# The Anger camera

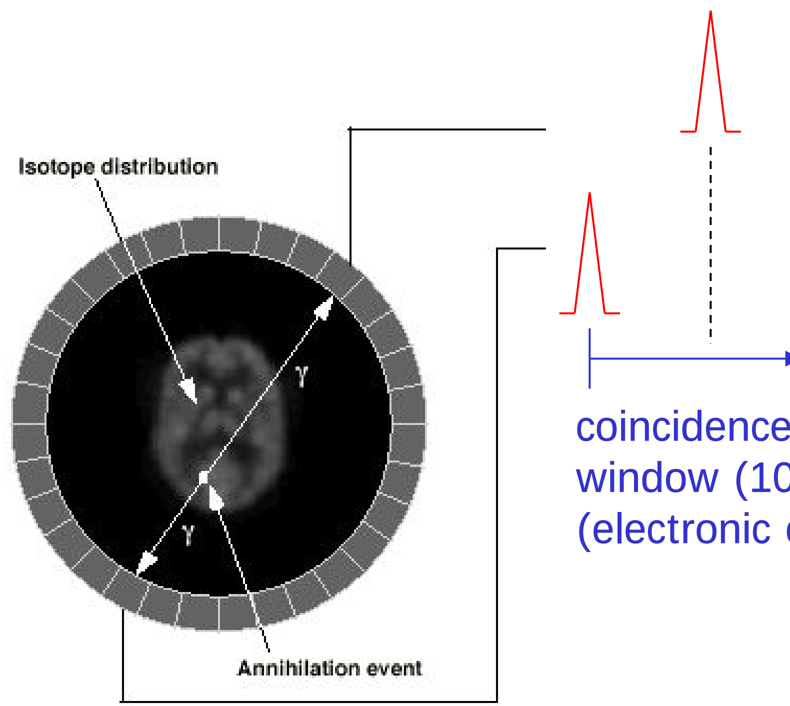


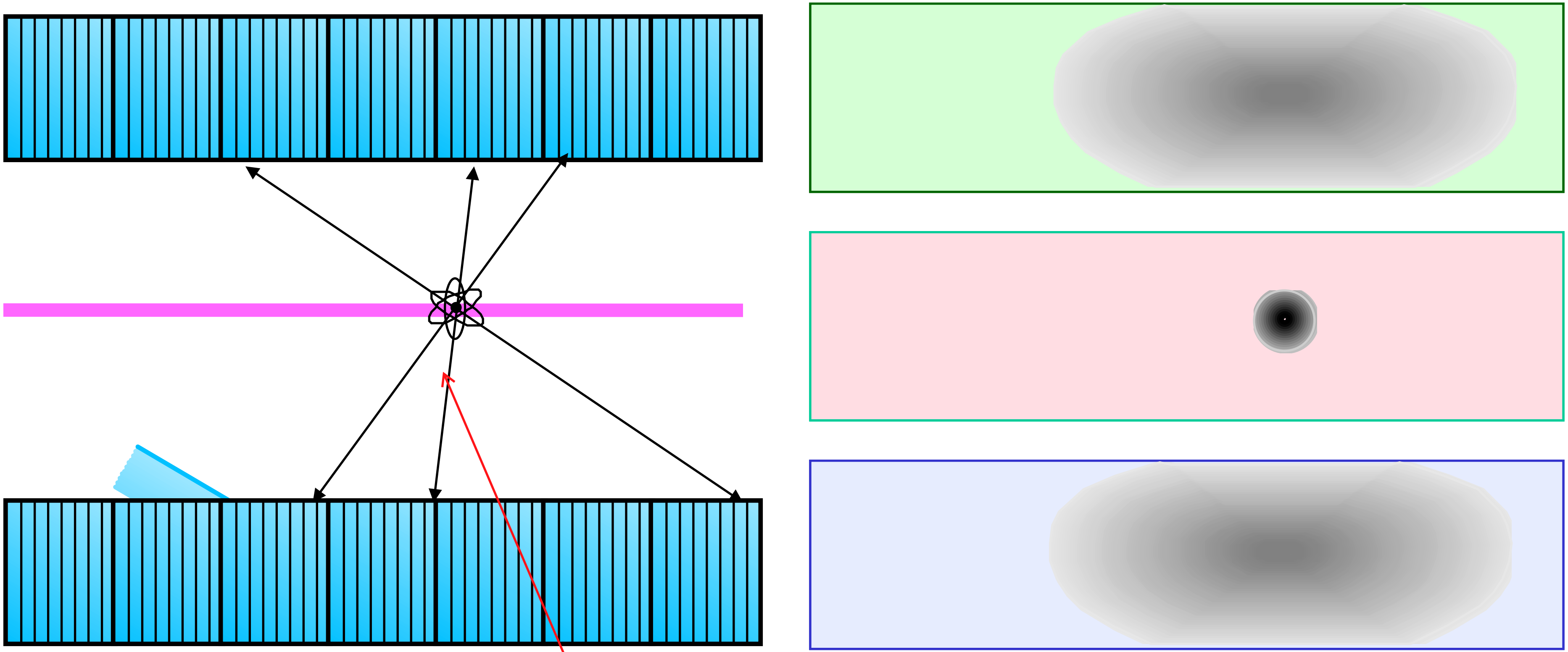



# Positron Emission Computed Tomography (PET)



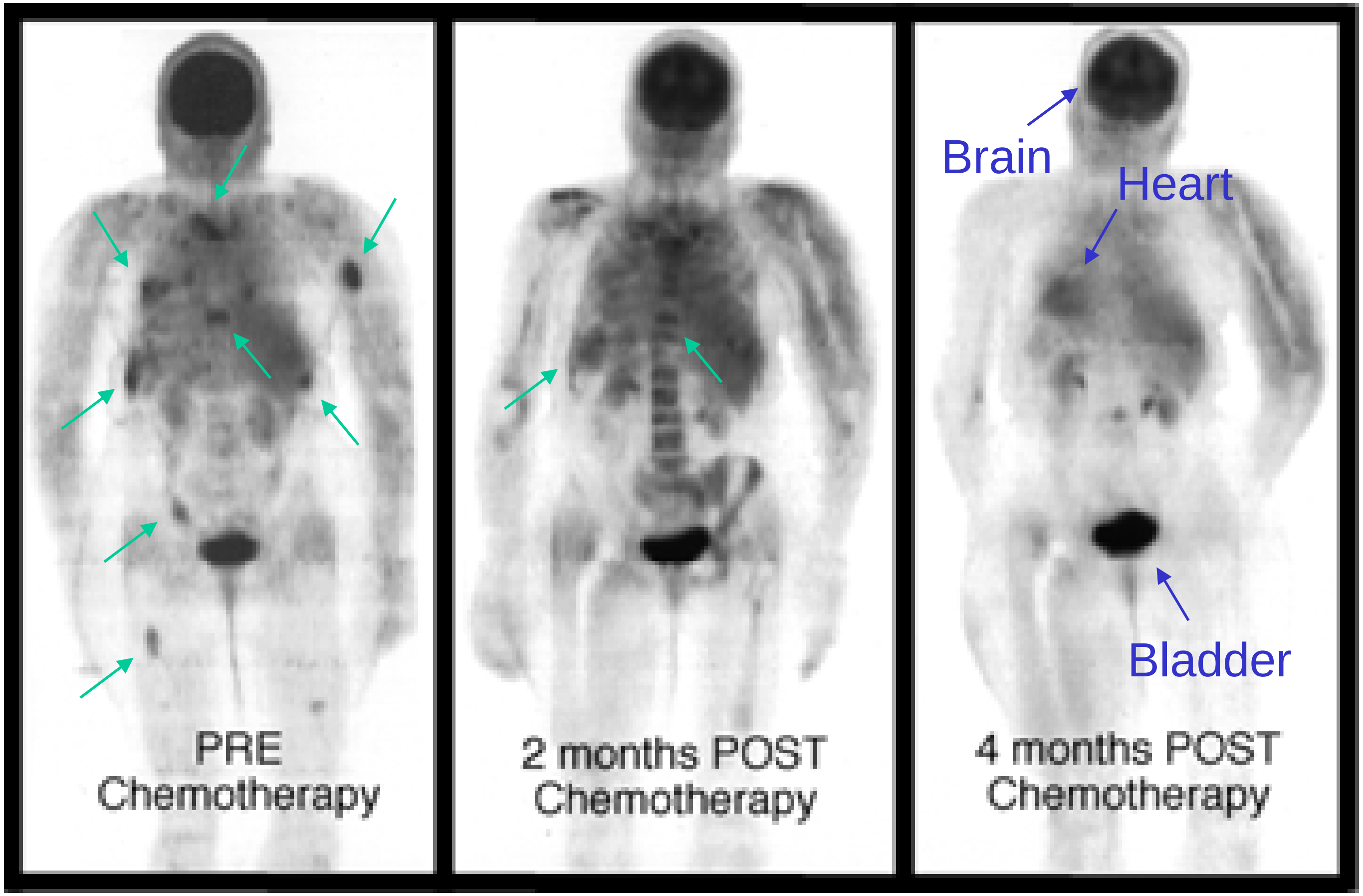




coincidence
window (10ns)
(electronic collimation)



more than one couple of gamma rays. If you wait enough and you collect several of these, at the end you have identified the source of radiation. This i simpified because we have an atom, with an organ we have several atoms, but again we apply nyquist sampling

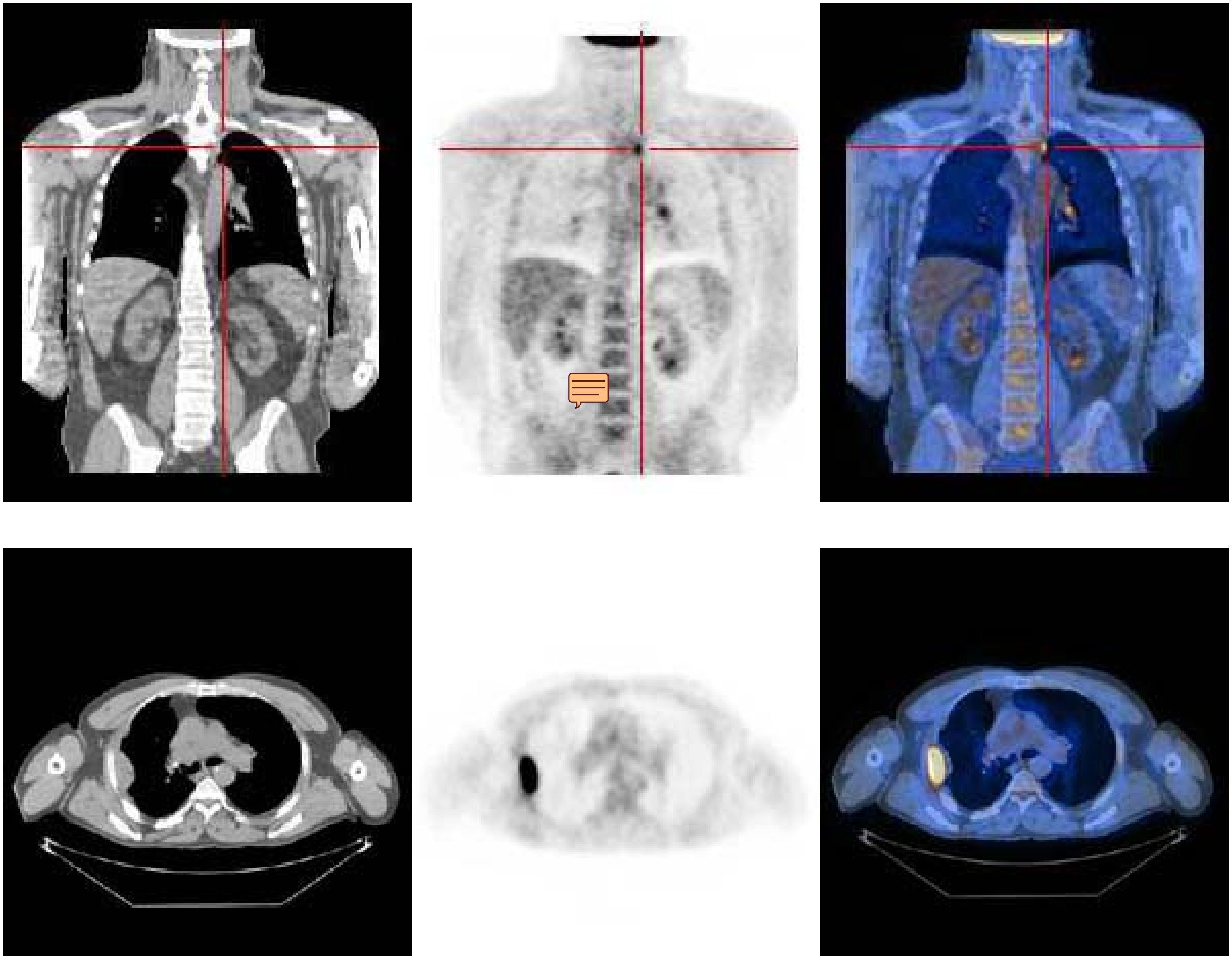
# PET Images of Breast Cancer Patient



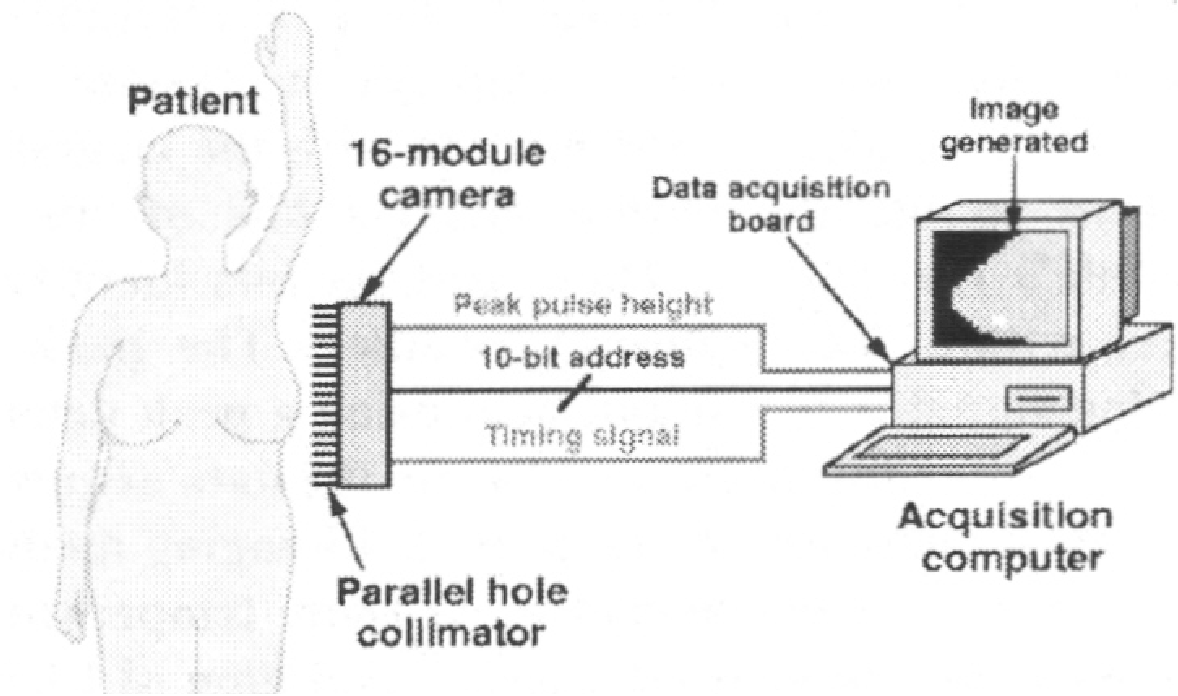

Metastases Shown with Green Arrows

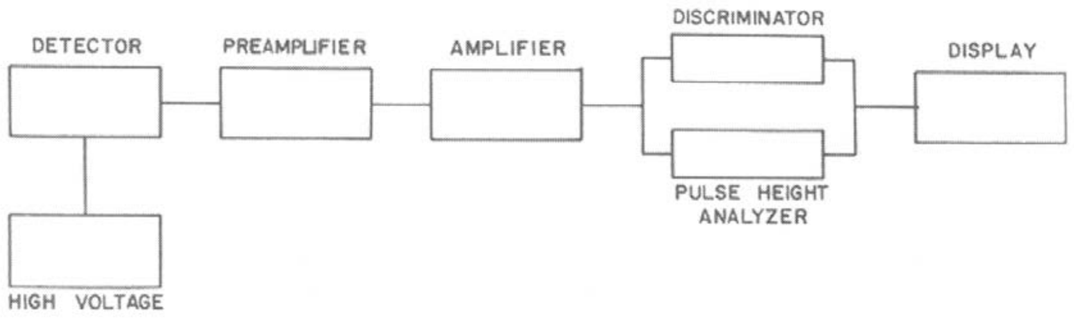
Normal Uptake in Other Organs Shown in Blue

CT PET CT+PET

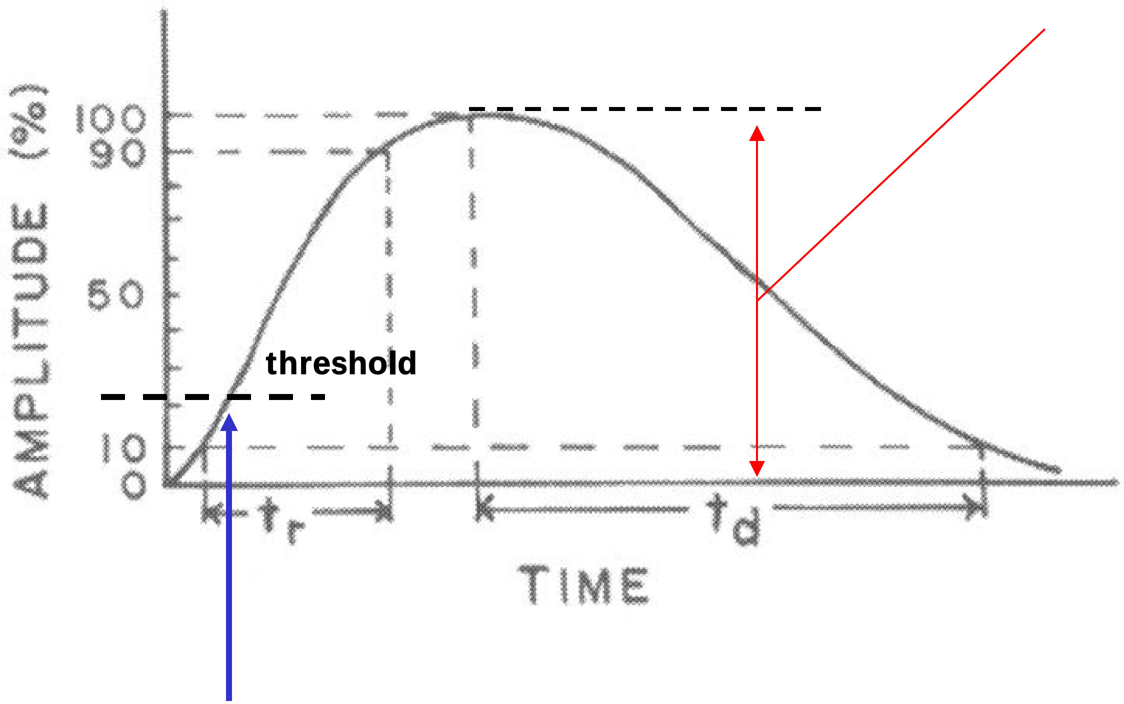


# Electronics for the acquisition and processing of the signals



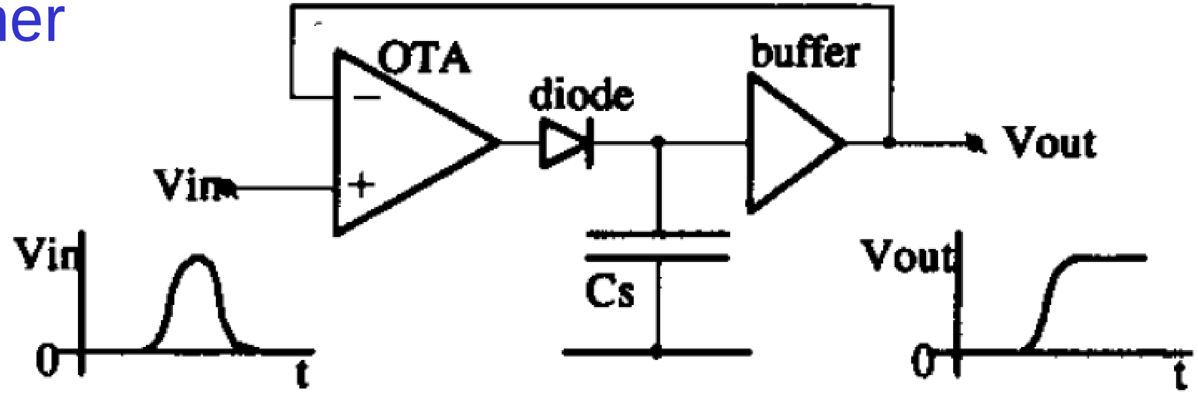



amplitude ⇒ energy, position

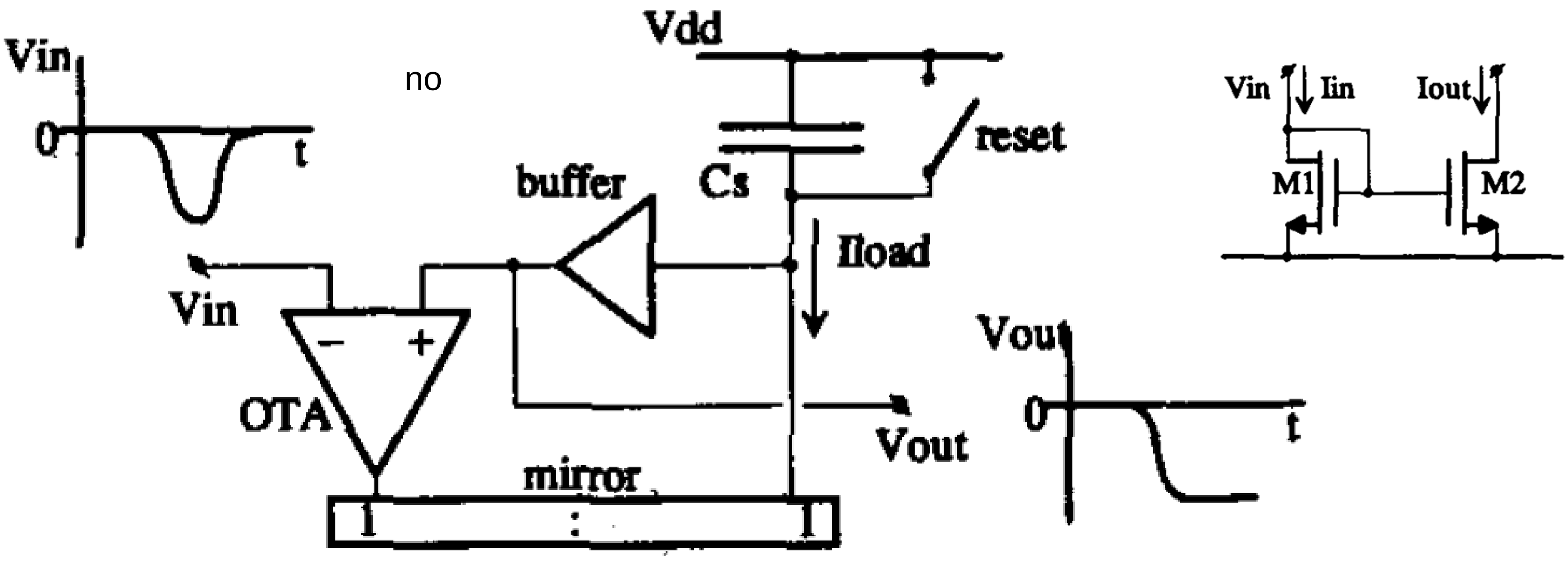



signal arrival time ⇒ *timing* (e.g. for coincidence)

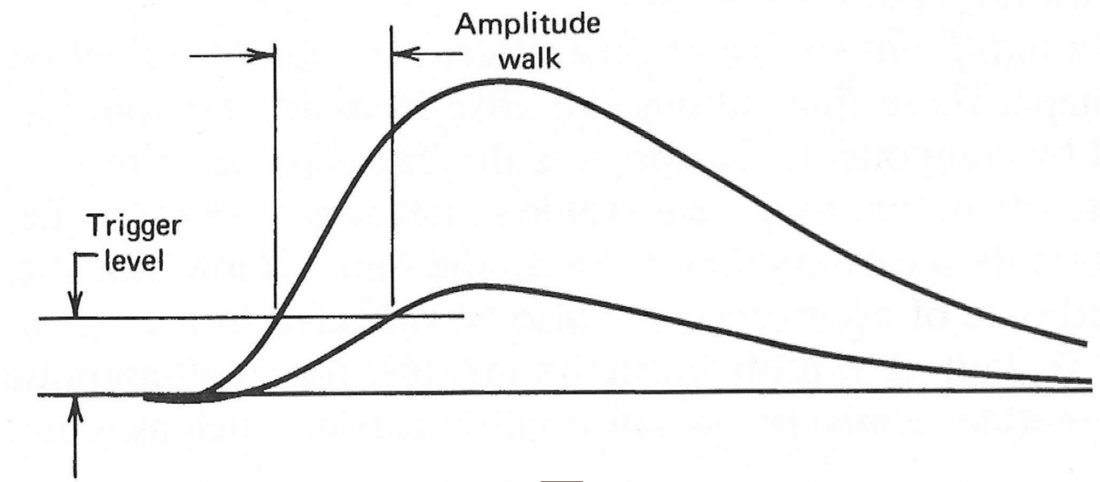
# The Peak Stretcher




no



# Timing techniques (for PET)




leading edge

zero crossing