Module 7

Applications of Embedded Systems

TOPICS IN MODULE 7

Introduction to embedded system applications using case studies – Role in Agriculture sector, Automotive electronics, Consumer Electronics, Industrial controls, Medical Electronics.

Agriculture Sector

Contents

Introduction

- Smart Farming using Embedded Systems
  - Refers to the integration of advanced electronic devices and technologies within agricultural practices to enhance efficiency, productivity.
  - To revolutionize the traditional farming practices by incorporating advanced tools and systems
  - Empowers farmers with:
    - Real time information
    - Data driven decision making
    - Reducing resource wastage

Introduction

- **What is an Embedded System?**
  - A concise definition: "*A specialized computer system designed to perform a specific task within a larger system*."“
  - **Example**: A simple microcontroller-based system controlling a water pump.
- **Why Agriculture Needs Embedded Systems?**
  - *Challenges in traditional agriculture*: Labor shortages, climate change, inefficient resource utilization.
  - *How embedded systems can help*: Precision agriculture, automated tasks, real-time monitoring.

Key Components

- **Microcontroller/Microprocessor:**
  - The "**brain**" of the system.
- **Sensors:**
  - Devices that **collect data** from the environment.
  - ***Examples***: Temperature, humidity, soil moisture, light intensity, pH sensors.
  - A variety of sensors used in agriculture.
- **Actuators:**
  - Devices that **control physical systems**.
  - ***Examples***: Motors, pumps, valves, LED lights.
- **Communication Modules:**
  - Enable data transmission and control.
  - Examples: Wi-Fi, Bluetooth, cellular networks.

Benefits

- **Increased Productivity:**
  - Optimized resource utilization, reduced labor costs.
- **Improved Quality:**
  - Precise control of environmental factors.
- **Reduced Costs:**
  - Efficient use of resources, lower labor costs.
- **Sustainable Agriculture:**
  - Eco-friendly practices, conservation of resources.

Sensors & Actuators

- **Sensor Applications in Agriculture**
  - **Soil Sensors**: Monitor soil moisture, pH, and nutrient levels.
  - **Climate Sensors**: Measure temperature, humidity, and rainfall.
  - **Light Sensors**: Detect light intensity for optimal plant growth.
  - **Gas Sensors**: Detect harmful gases in the environment.

- **Actuator Applications in Agriculture**
  - **Irrigation Systems**: Precise water distribution based on sensor data.
  - **Ventilation Systems**: Adjust airflow to regulate temperature and humidity.
  - **Lighting Systems**: Control artificial lighting for optimal plant growth.
  - **Fertilization Systems**: Precise application of fertilizers based on plant needs.

Communication

- **Wireless Communication:**
  - Wi-Fi, Bluetooth, and cellular networks for remote monitoring and control.
- **Wired Communication:**
  - Ethernet and RS-485 for reliable data transmission.
- **IoT Connectivity:**
  - Connect devices to the internet for real-time data analysis and remote management.

Challenges

- **Power Constraints:**
  - **Limited battery** life in remote areas.
  - Sol: A solar-powered sensor node.
- **Environmental Factors:**
  - **Harsh conditions** can affect sensor and actuator performance.
- **Data Security:**
  - Protect **sensitive data** from unauthorized access.

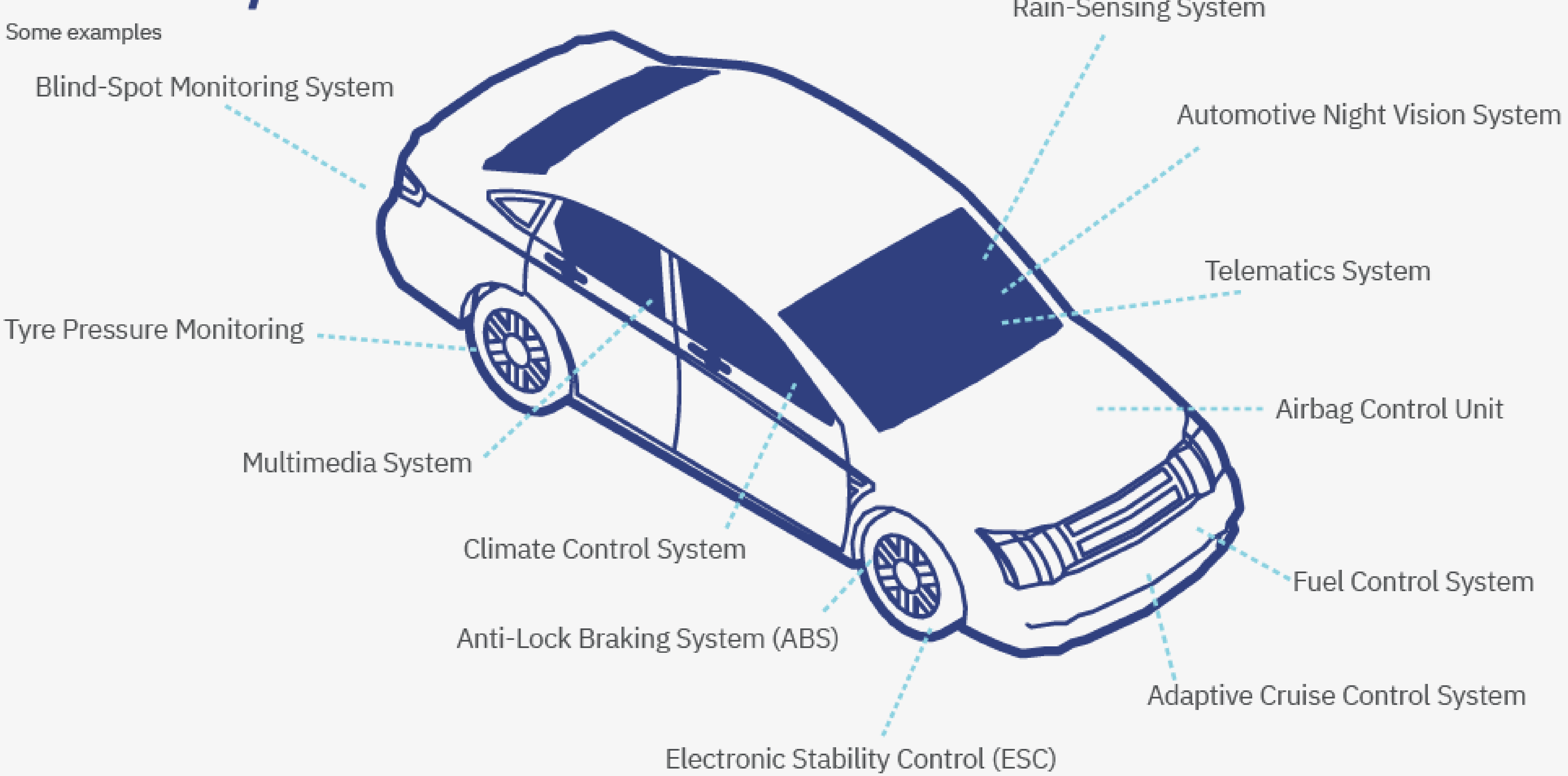
Automotive Electronics

Outline

- CAN (Controller Area Network)
- Airbag System
- Electronic Data Recorders (EDR)
- Anti-lock Braking System (ABS)
- Traction Control System
- Vehicle Stability Control (VSC)
- Cruise Control System
- Advanced Driver Assistance Systems (ADAS)
- Drive-by-Wire Systems

Embedded systems in cars

Some examples



Controller Area Network (CAN)

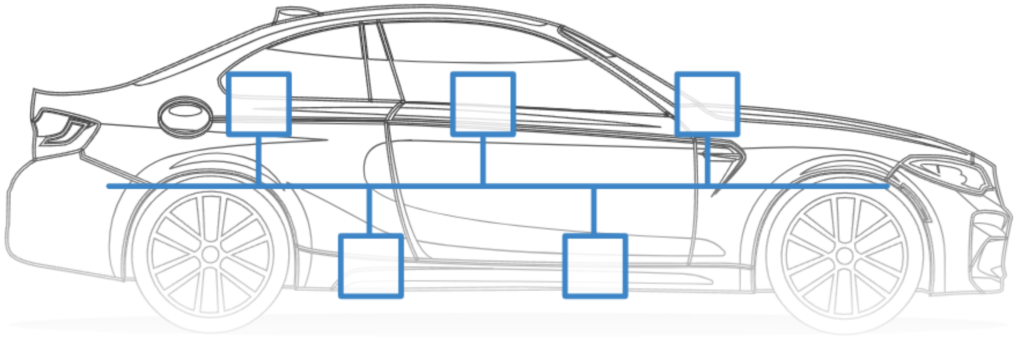
- **Definition**: Controller Area Network, a robust vehicle bus standard.
- **Role**: Allows microcontrollers and devices to communicate without a host computer.
- **Applications**: Used in engine management, ABS, airbags, and other real-time critical functions.
- **Benefits**: Reduces wiring, enables faster data exchange, and improves system robustness.

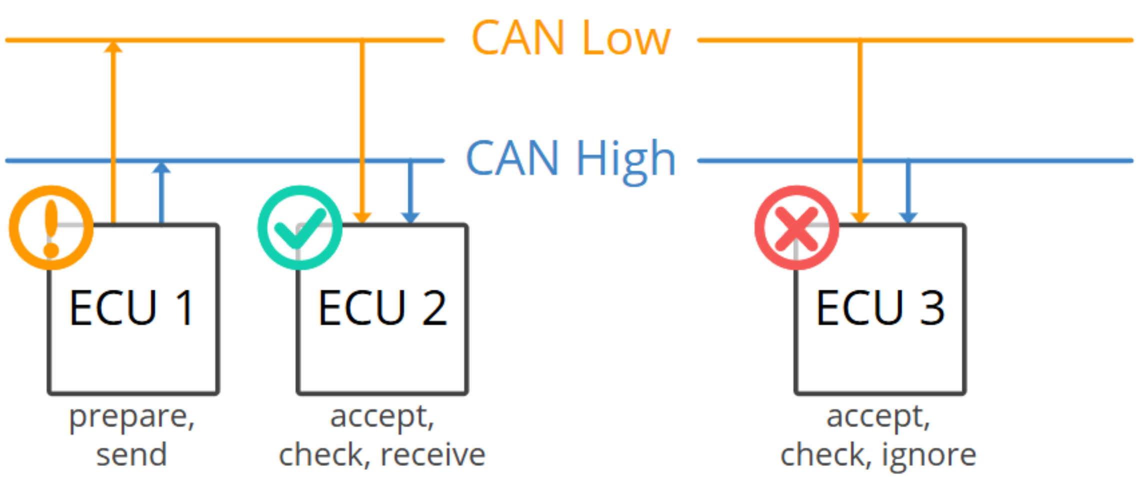
Controller Area Network (CAN)

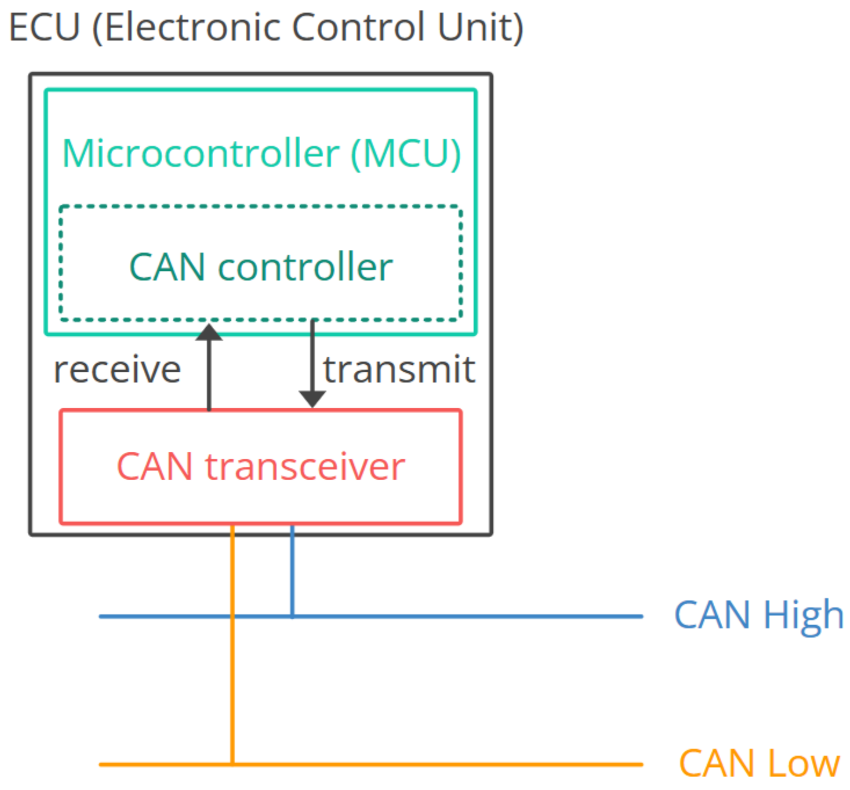
CAN bus versions

Property	Fault-tolerant CAN (low-speed CAN)	Classical CAN 2.0 (high-speed CAN)	CAN FD (Flexible Data-rate)	CAN XL
Max baud rate speed	0.125 Mbit/s	1 Mbit/s	8 Mbit/s (data phase)	20 Mbit/s
Max data payload size	8 bytes	8 bytes	64 bytes	2048 bytes
Baud rate type	Fixed	Fixed	Variable (faster data field)	Variable (higher rates)
Use cases	Fault-tolerant, body control modules	Real-time automotive applications	High data throughput, ADAS, EV applications	Future high-data applications
Key features	Fault-tolerant operation, continue even if one bus line is damaged	Low cost, robust error detection, most commonly deployed	Increased payload, speed and reliability	Increased payload, speed and reliability

Controller Area Network (CAN)

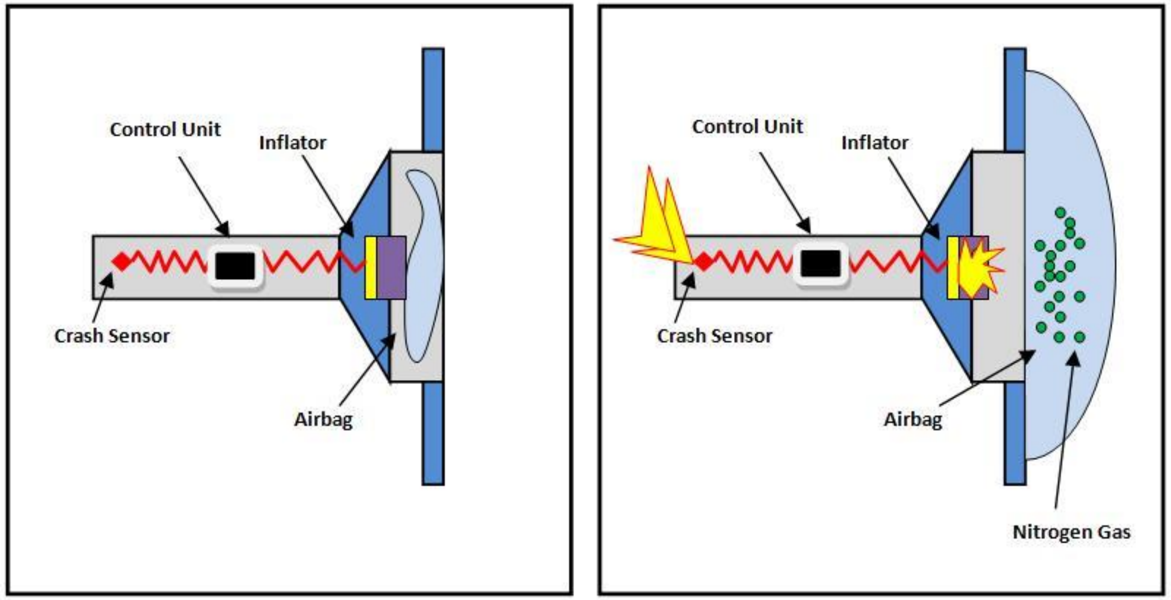






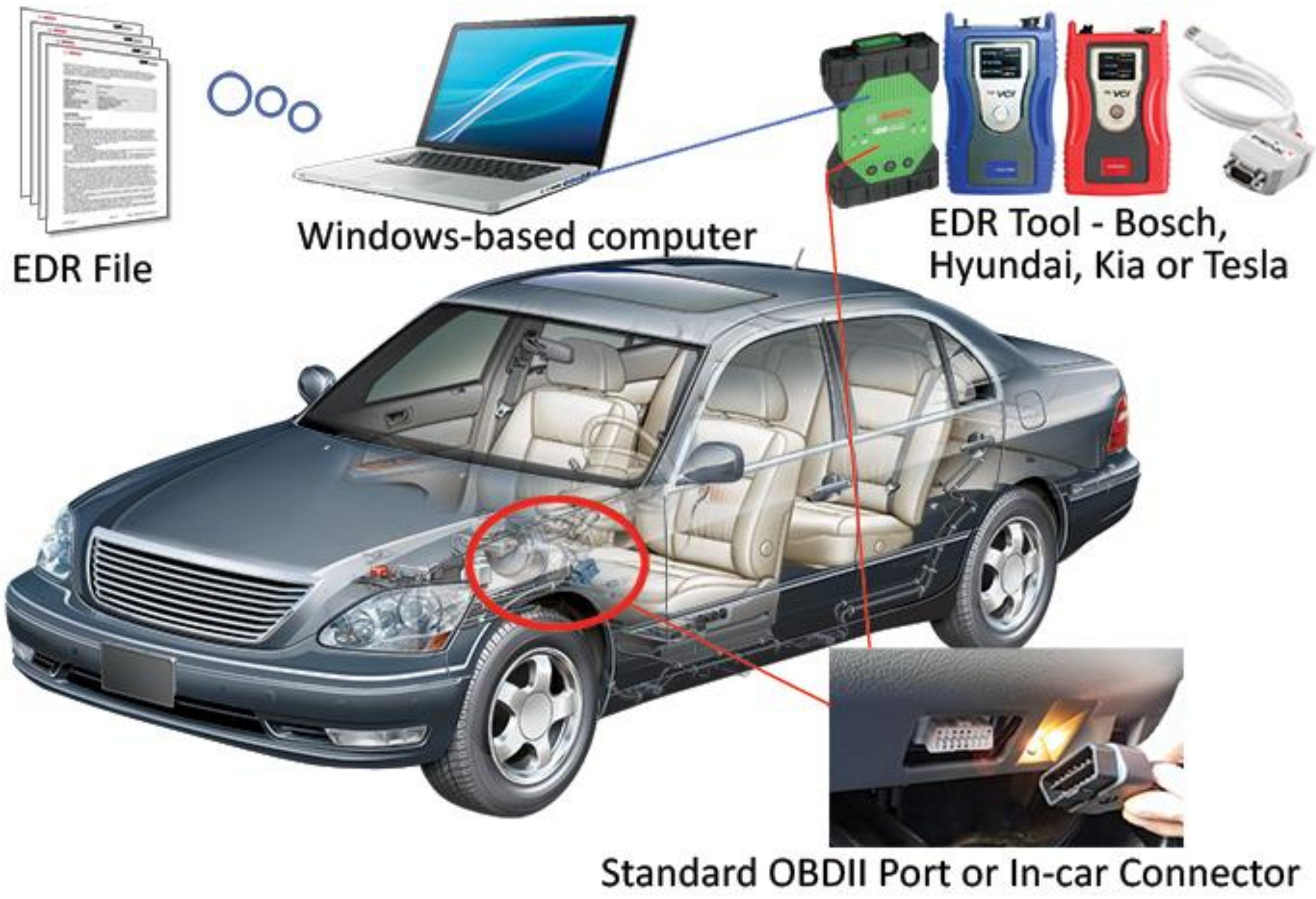
Airbag System

- **System Description:**
  - **Sensors detect collisions** and **trigger airbag deployment.**
- **Embedded Function:**
  - Microcontrollers analyze impact data and activate airbags within milliseconds.
- **Importance:**
  - Prevents serious injuries, one of the primary safety features in modern vehicles.

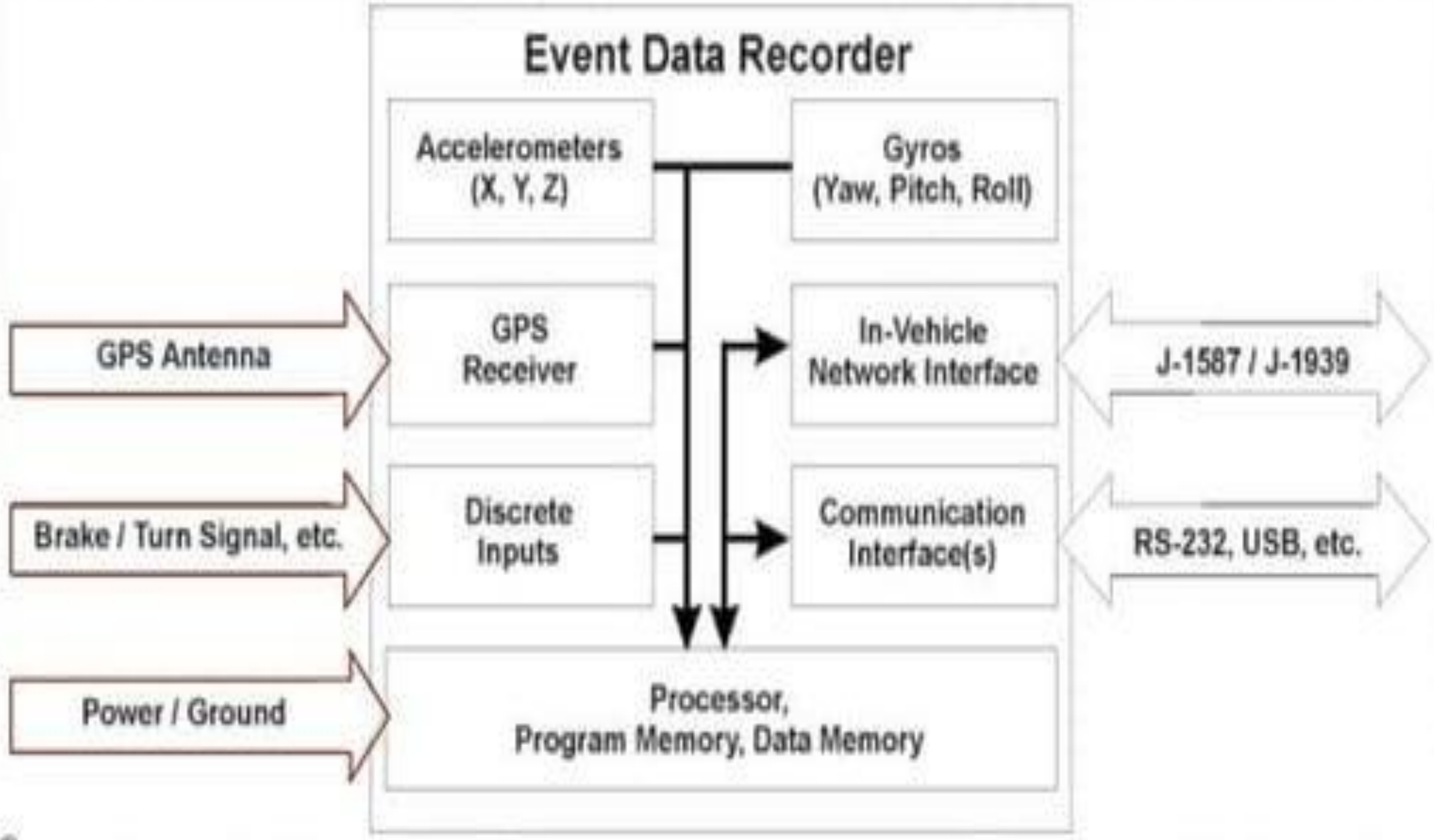


Electronic Data Recorders (EDRs)

- **Definition**: EDRs are often called "**black boxes**" for cars.
- **Function**: **Records critical data** before and during crashes (e.g., speed, braking, seatbelt use).
- **Usage**: Assists in crash analysis, insurance, and safety research.
- **Embedded Role**: Constantly monitors and logs data without affecting vehicle performance.

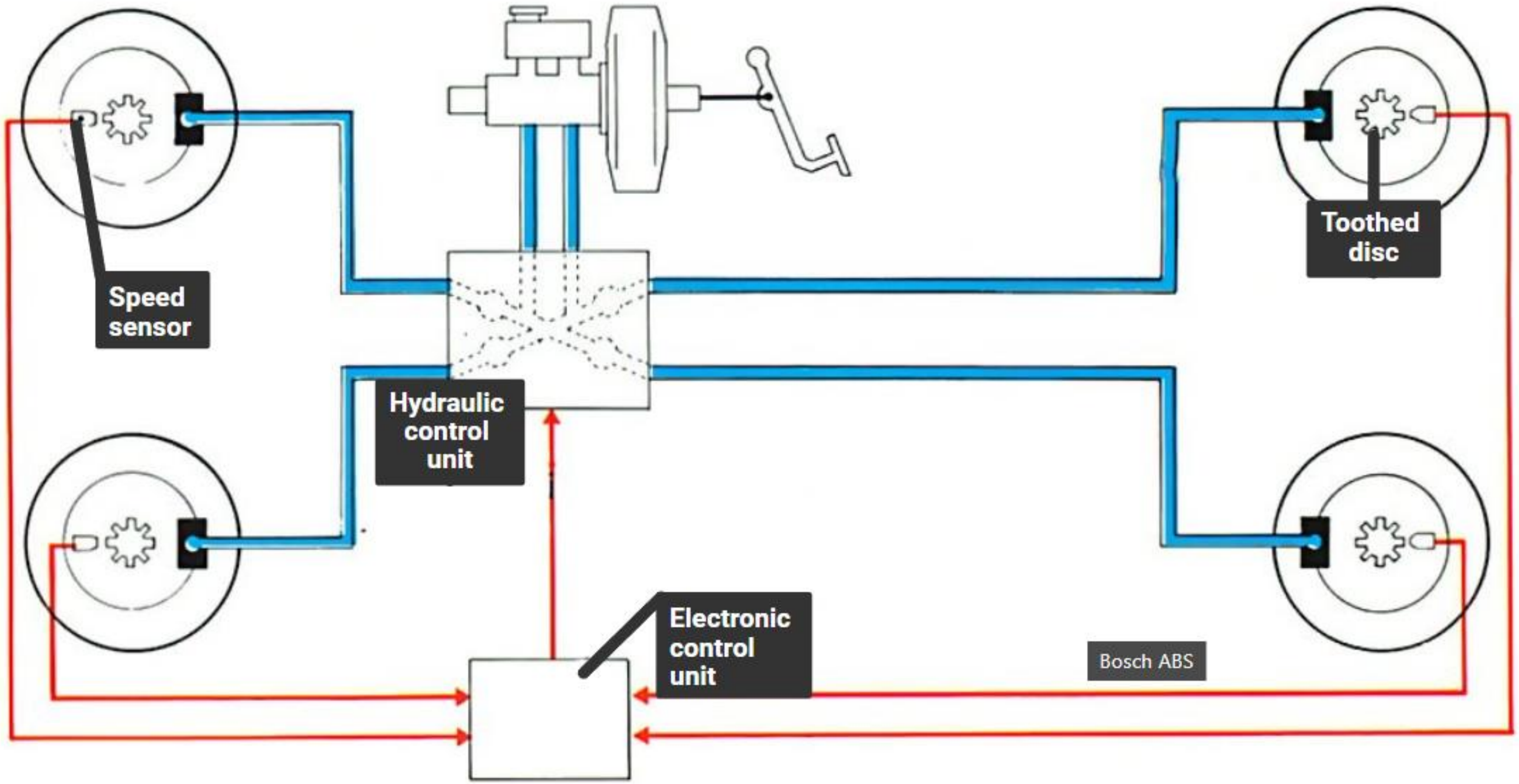

EDR File
Windows-based computer
EDR Tool - Bosch,
Hyundai, Kia or Tesla
Standard OBDII Port or In-car Connector

EDR BLOCK DIAGRAM



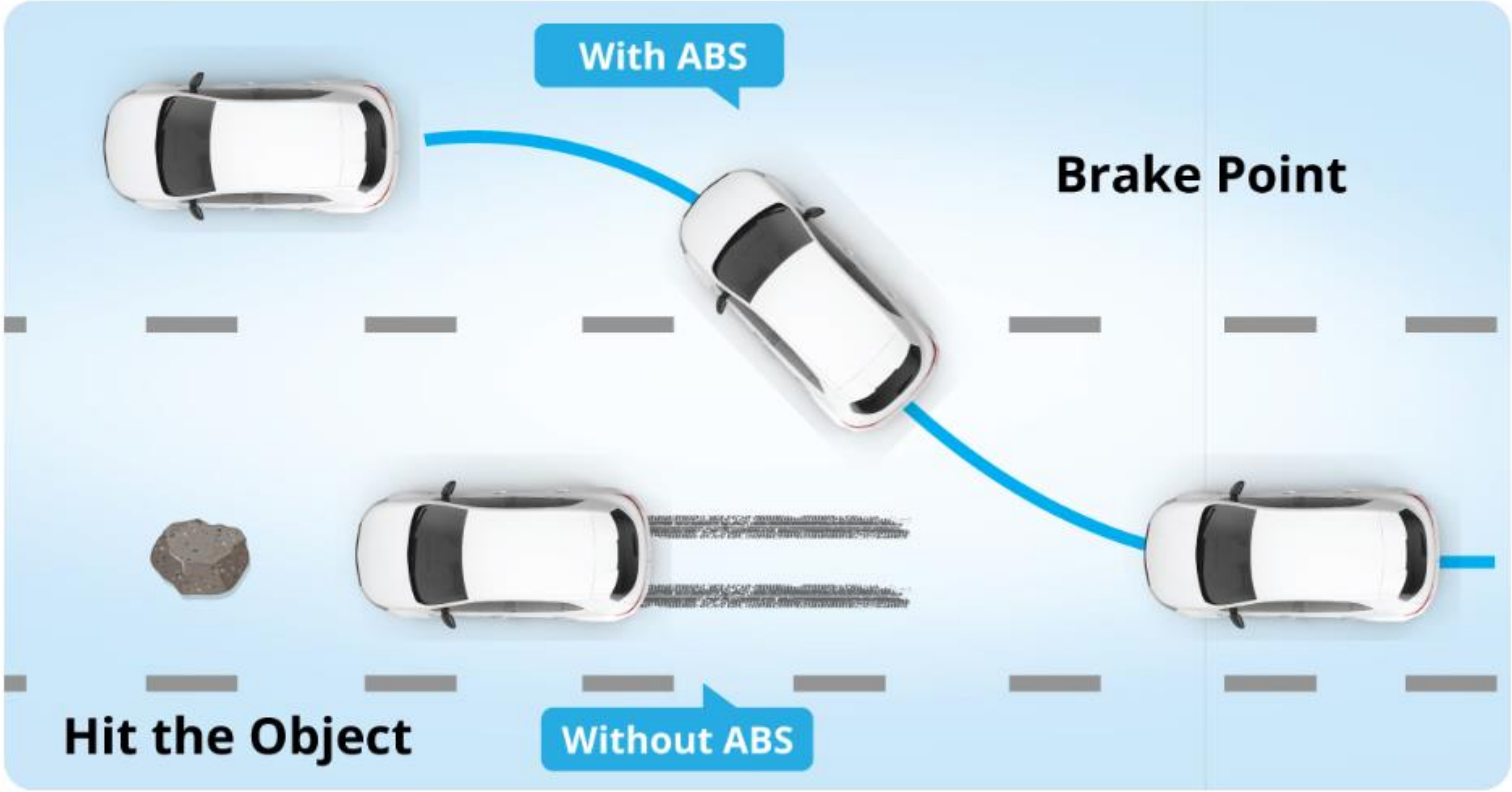
Anti-lock Braking System (ABS)

- System Description:
  - Prevents wheels from locking up during braking.
- Embedded Role:
  - Monitors wheel speed sensors, adjusts braking pressure to maintain traction.
- Benefits:
  - Improves vehicle control during emergency braking, enhances safety on slippery roads.


Speed sensor
Toothed disc
Hydraulic control unit
Electronic control unit
Bosch ABS

Principle of Working

- **Wheel speed sensors** detect whether a **wheel is showing** a **tendency to lock up**.
- **In case of a lock-up tendency**, the *ECU reduces* the *braking pressure individually* at the wheel concerned.
- High-speed correction of braking pressure up to shortly before the lock-up threshold.
- Brake-fluid return together with the closed-loop brake circuits make this safe and cost effective system.

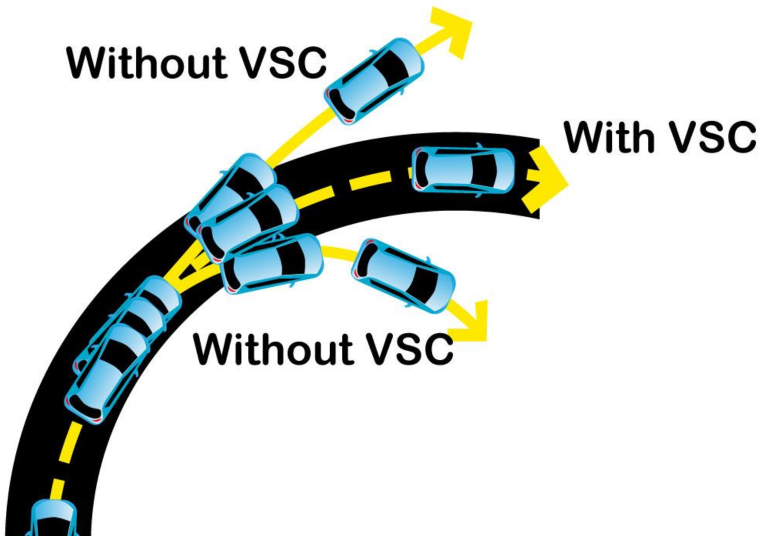

With ABS
Brake Point
Hit the Object
Without ABS

Traction Control System

- **Function**: Prevents wheels from spinning when accelerating, especially on slippery surfaces.
- **Embedded Function**: Monitors wheel speeds, reduces engine power or applies brakes to control wheel spin.
- **Safety Aspect**: Improves handling and stability, especially in adverse weather conditions.

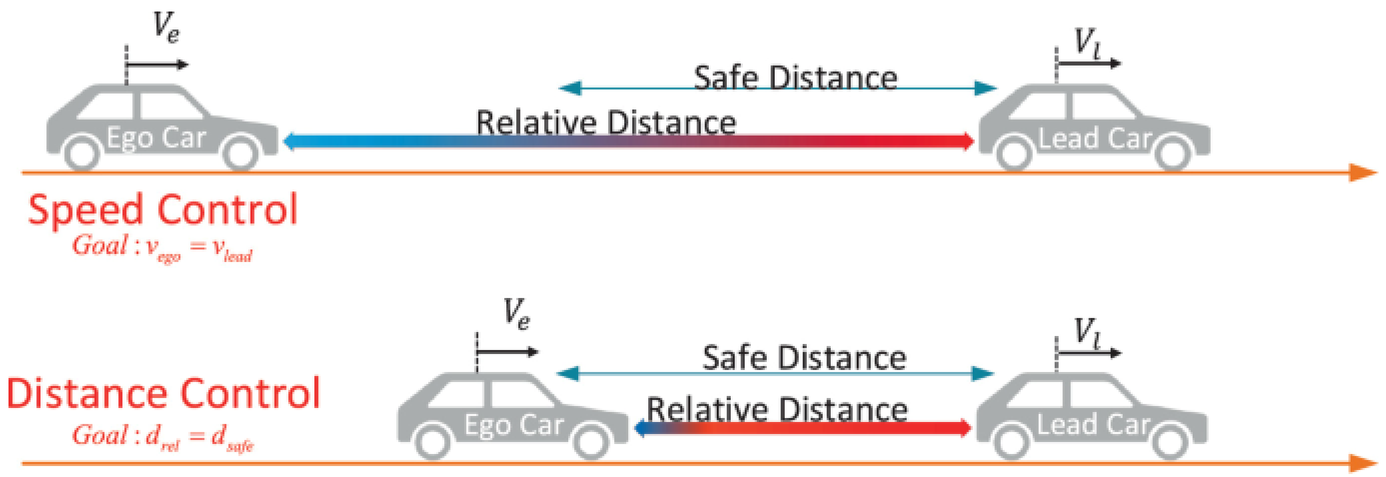
Vehicle Stability Control

- **System Description**: Assists drivers in maintaining control during extreme maneuvers.
- **Embedded Function**: Uses sensors to detect loss of control and applies brakes or reduces engine power.
- **Benefit**: Reduces the risk of rollover or spinouts, improving overall vehicle safety.



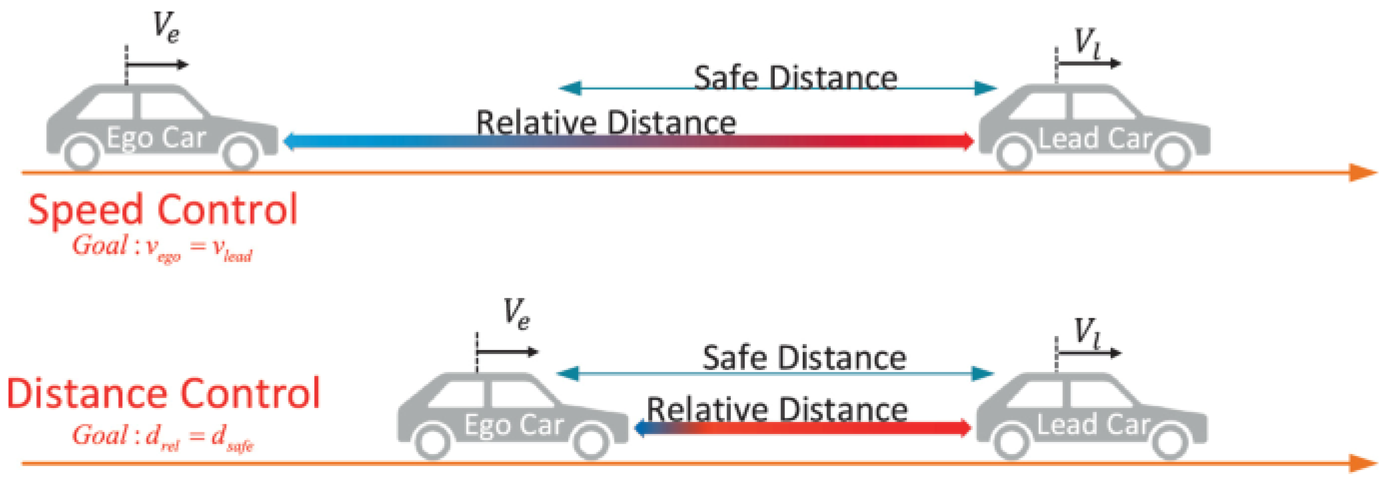
Cruise Control System

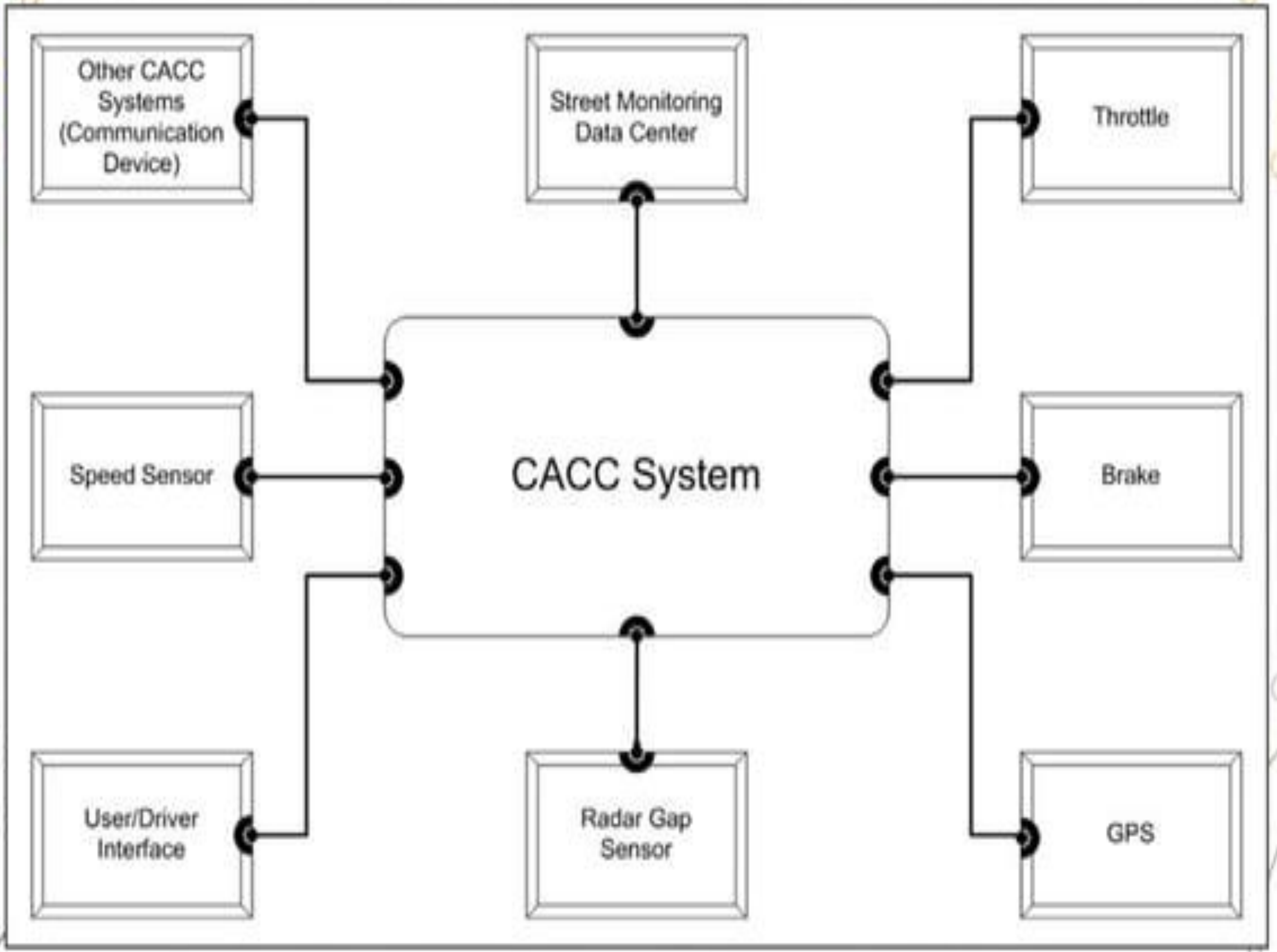
- **Cooperative Adaptive Cruise Control with Collision Warning**
- **CACC :** Cruise at a given speed when the road is clear (cruise control) otherwise follow the car in front, using Radar (adaptive) and/or communications (cooperative).
- **CW:** Warn the driver when an object is being approached oto fast or it is too close.



Cruise Control System

- **System Description**: Maintains a steady speed set by the driver without the need to press the accelerator.
- **Embedded Function**: Sensors monitor speed, adjust throttle position to maintain desired speed.
- **Adaptive Cruise Control**: Advanced system that can adjust speed based on traffic conditions.

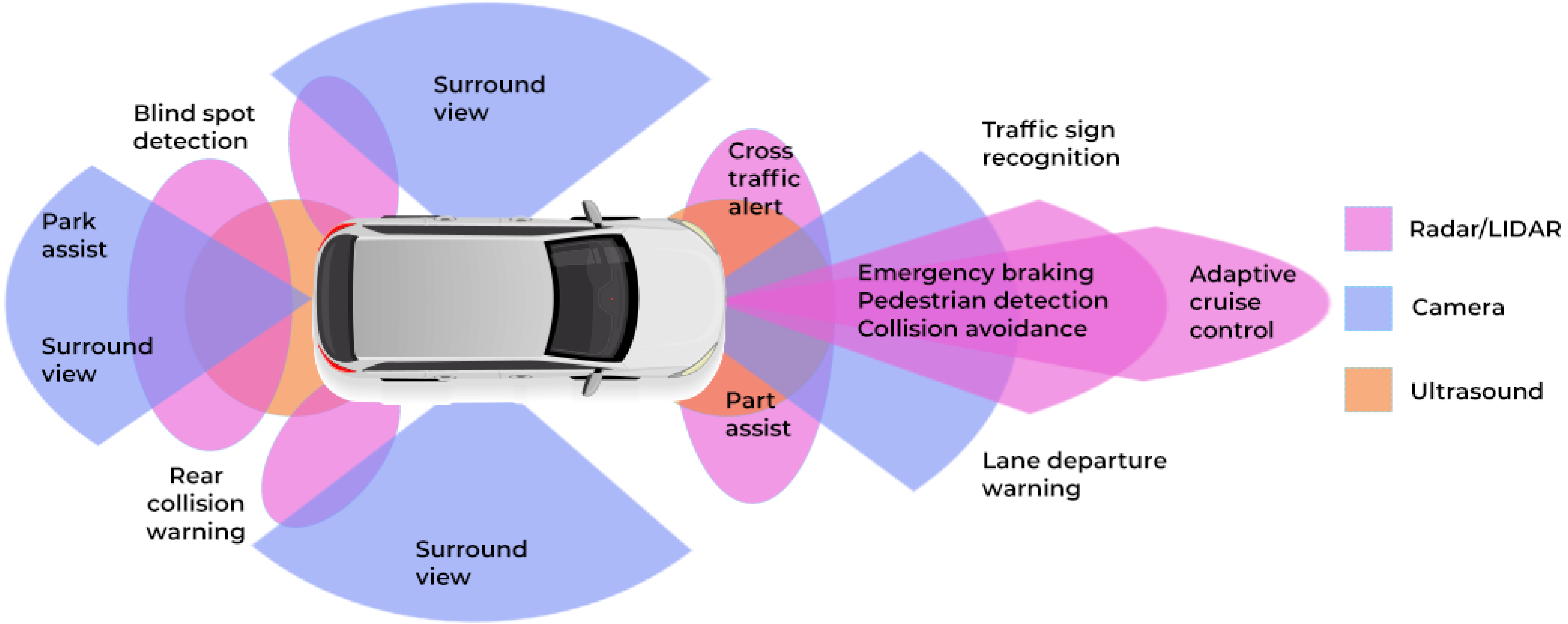



Other CACC Systems (Communication Device)
Street Monitoring Data Center
Throttle
Speed Sensor
CACC System
Brake
User/Driver Interface
Radar Gap Sensor
GPS

ADAS

- **Overview:** Collection of systems designed to assist drivers, including lane-keeping, collision avoidance, and parking assistance.
- **Embedded Role:** Uses multiple sensors (cameras, radar, LIDAR) and real-time data processing.
- **Examples:** Lane Departure Warning, Automatic Emergency Braking, Blind Spot Detection.
- **Future Potential:** Steps toward autonomous driving and enhanced driver safety.

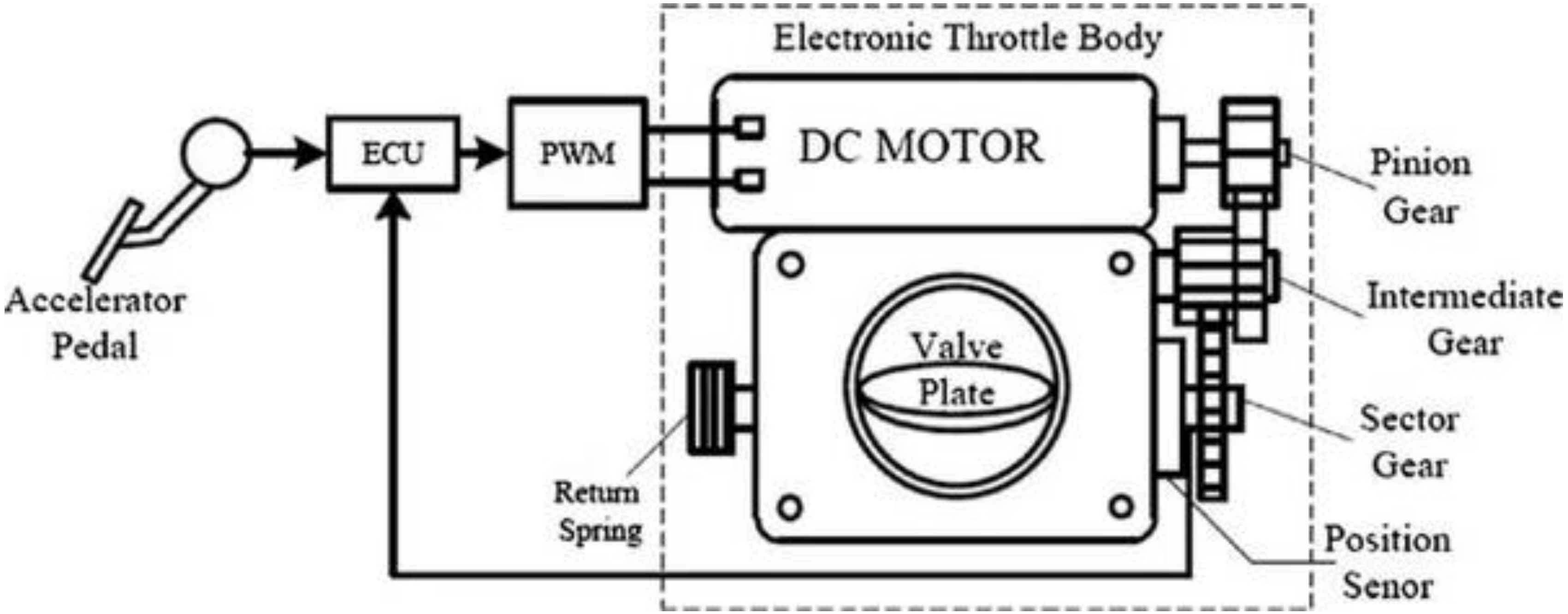
HOW ADAS WORKS



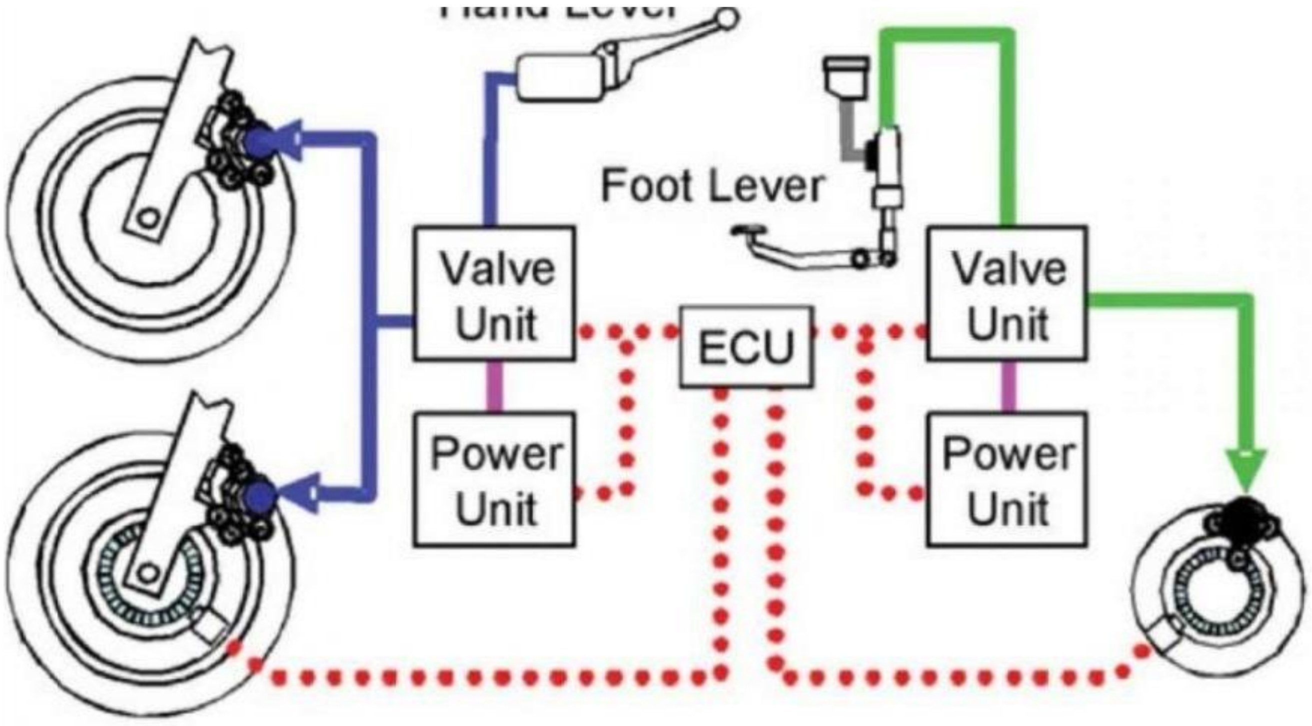
Drive by Wire Systems

- **Definition**: Replaces mechanical control systems (e.g., steering, braking) with electronic controls.
- **Embedded Function**: Sensors and actuators manage inputs like acceleration, braking, and steering.
- **Advantages**: Reduces weight, improves response, and enables more precise control.
- **Applications**: Used in electric vehicles, facilitates autonomous driving technologies.

Throttle by Wire



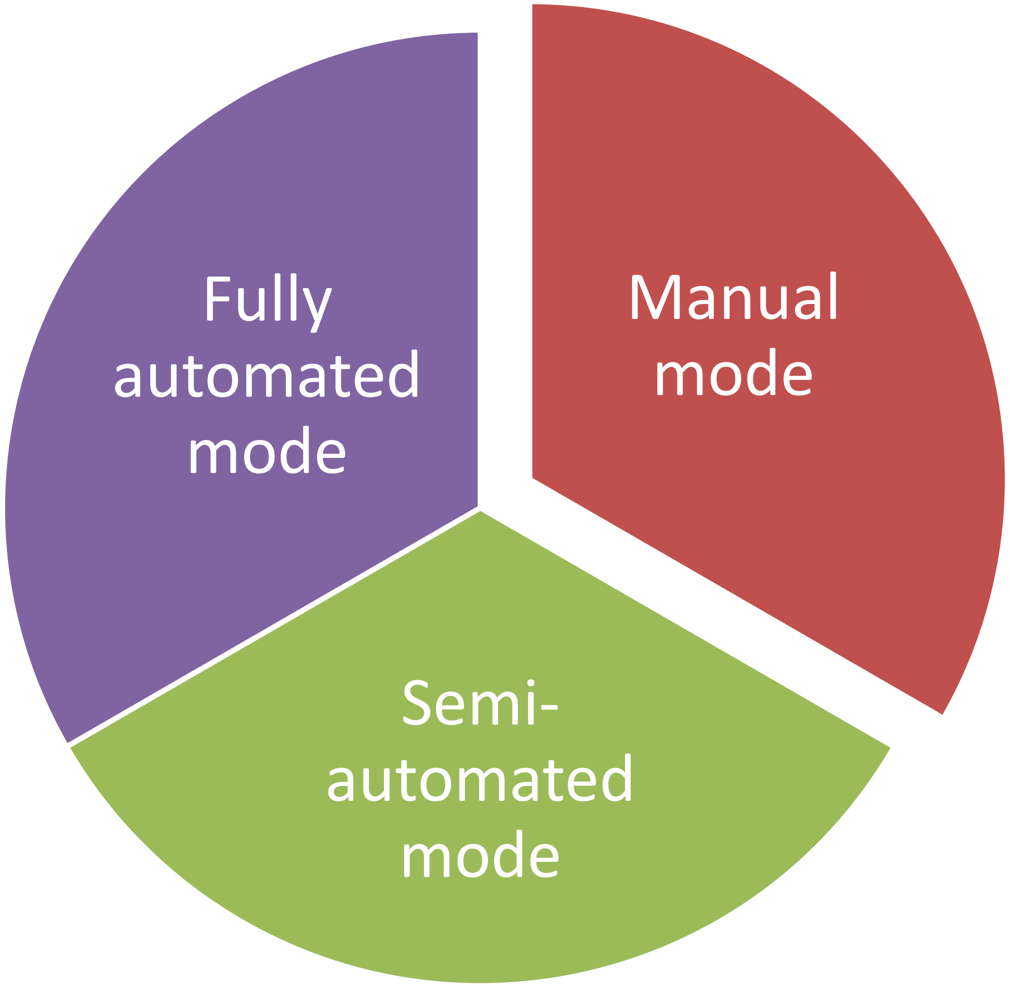
Brake by Wire



Consumer Electronics

Embedded Systems in Washing Machines

Modes



Fully Automated Mode

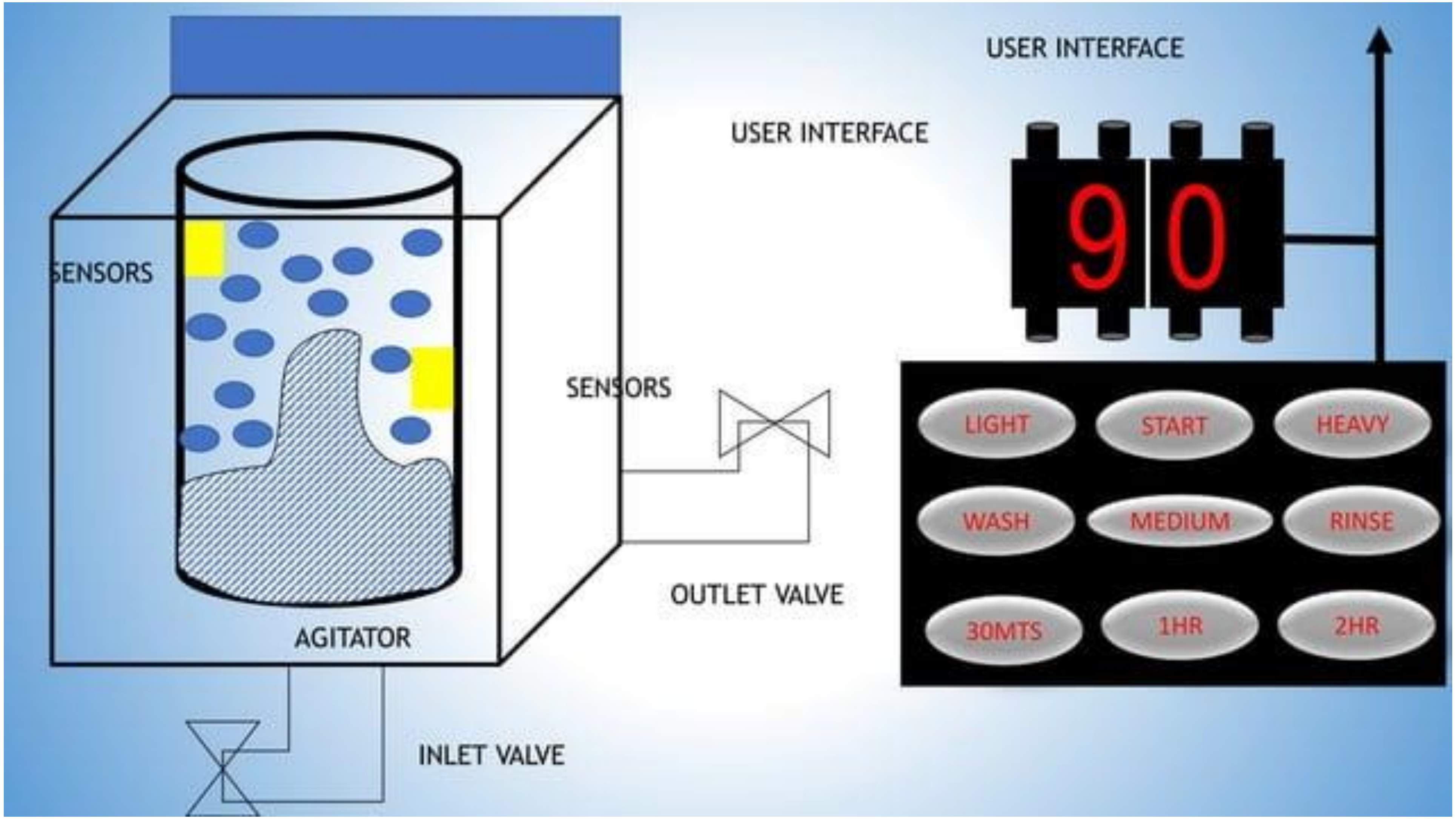
- Senses the requirement of water, water temperature, detergent, load, wash cycle time and perform operations.
- Instantaneously senses cloth quality
- After the completion of work it should notify the user about the completion of the work.
- Once the system is started it performs the task independenly without any user interference.

Semi Automatic Mode

- Once the predefined mode is started the system perform its job.
- Washing conditions are predefined
- After completion it inform the user about the completion of work.

Manual Mode

- User specify which operation, they want to do, provide related information of the control system
  - Example: Only wash mode, or only dry mode.
- User defines the wash cycle and time, amount of water and load.
- User start the machine.
- Specifed operation is performed by the machine.


USER INTERFACE
USER INTERFACE
SENSORS
90
SENSORS
LIGHT
START
HEAVY
WASH
MEDIUM
RINSE
OUTLET VALVE
30MTS
1HR
2HR
AGITATOR
INLET VALVE

Components

- Display Panel
- Sensor
- Water level sensor
- Door sensor
- Driving motor
- Controller
- Pump

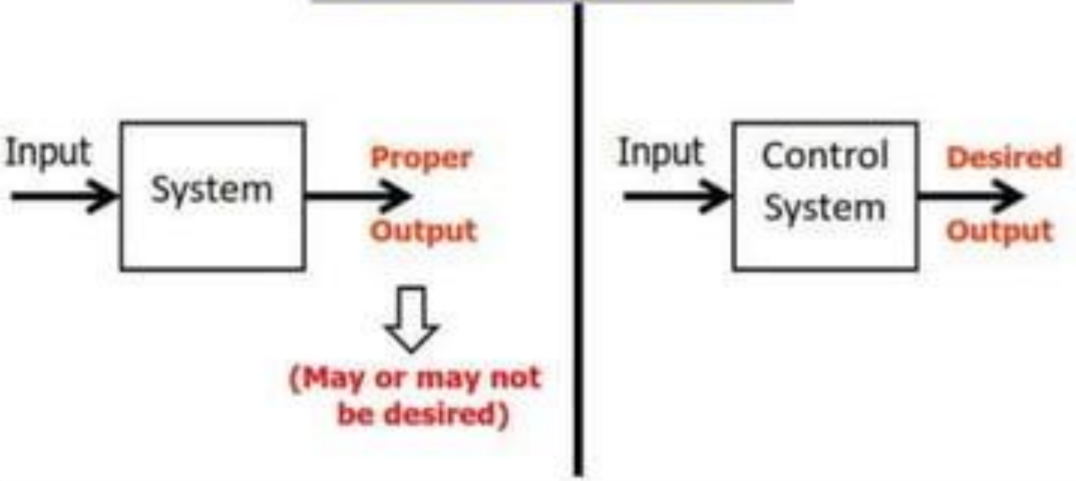
Microcontroller and Prog. Language

- Low-level programming language ,the internal functions and control the Hardware
- Arduino or Raspberry PI
- C/ Embedded C/C++ is a recommendation, C

Industrial controls

Introduction to Control System

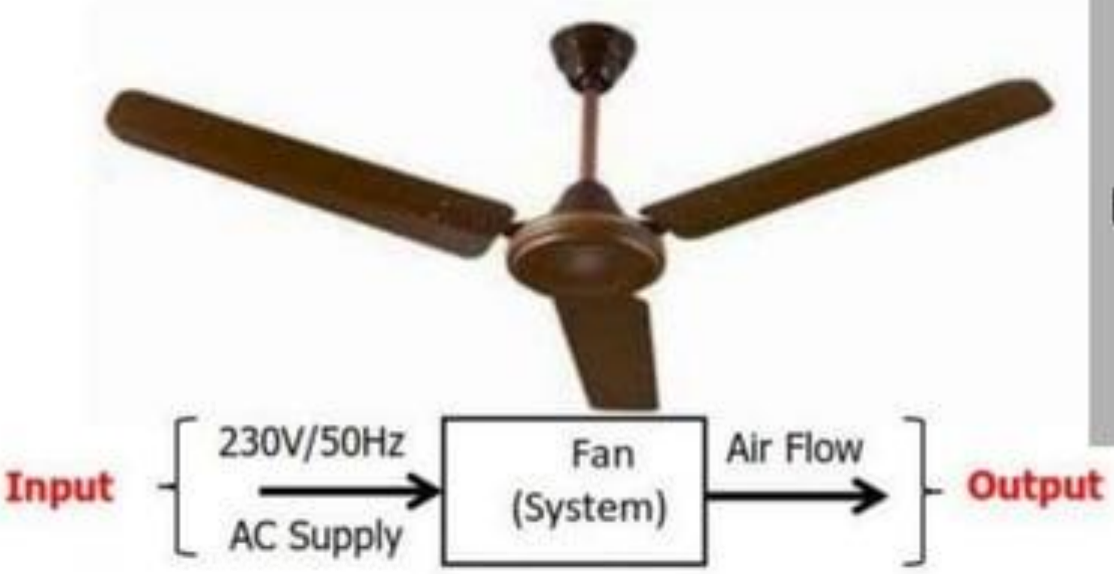
Control System



Difference between system and control system

Introduction to Control System

An example : Fan



- *A Fan with blades but without regulator can be a "SYSTEM" Because it can provide a proper output i.e. airflow*
- *But it cannot be a "Control System" Because it cannot provide desired output i.e. controlled airflow*

A Fan without blades cannot be a "SYSTEM" , Because it cannot provide a desired/proper output i.e. airflow

Levels of automation in the two Industries

- Significant differences are seen in the low and intermediate levels.
- **Device level:** There are differences in the types of actuators and sensors used.
  - **Process industries:** the devices are used mostly for the control loops in chemical, thermal, or similar processing operations.
  - **Discrete manufacturing:** the devices control the mechanical actions of machines.
- **At level 2:** the difference is that unit operations are controlled in the process industries, and machines are controlled in discrete manufacturing operations.
- **At level 3:** the difference is between control of interconnected unit processing operations and interconnected machines.
- **At the upper levels (plant and enterprise):** the control issues are similar, allowing for the fact that the products and processes are different.

Classification of Control System

- In general **control systems** are classified into two categories—***open loop*** and ***closed loop***. Depending upon the nature of signals involved like electrical, mechanical, hydraulic, pneumatic or combination of these signals, the control systems may be classified as ***single input-single output*** (***SISO***) and ***multiple input-multiple output*** (***MIMO***) systems.
- ***SISO system***. As the name indicates, it is a system having a single input and a single controlled variable. The output is produced by the single input solely. Only one input signal flows or passes through the system. The examples of SISO systems are voltage regulators, temperature controllers and so on.
- ***MIMO system***. There are certain systems having multiple inputs and multiple outputs. The systems in which any change in one of the outputs causes a subsequent change in the other output during transient and steady state conditions are called MIMO systems. The examples are boiler in which the controlled variables are steam pressure, temperature, water level and so on. Figure shows block diagram of an MIMO system.

A Typical Analog Control Loop

Figure shows the instrumentation for a typical analog control loop. The entire process would have many individual control loops, but only one is shown here

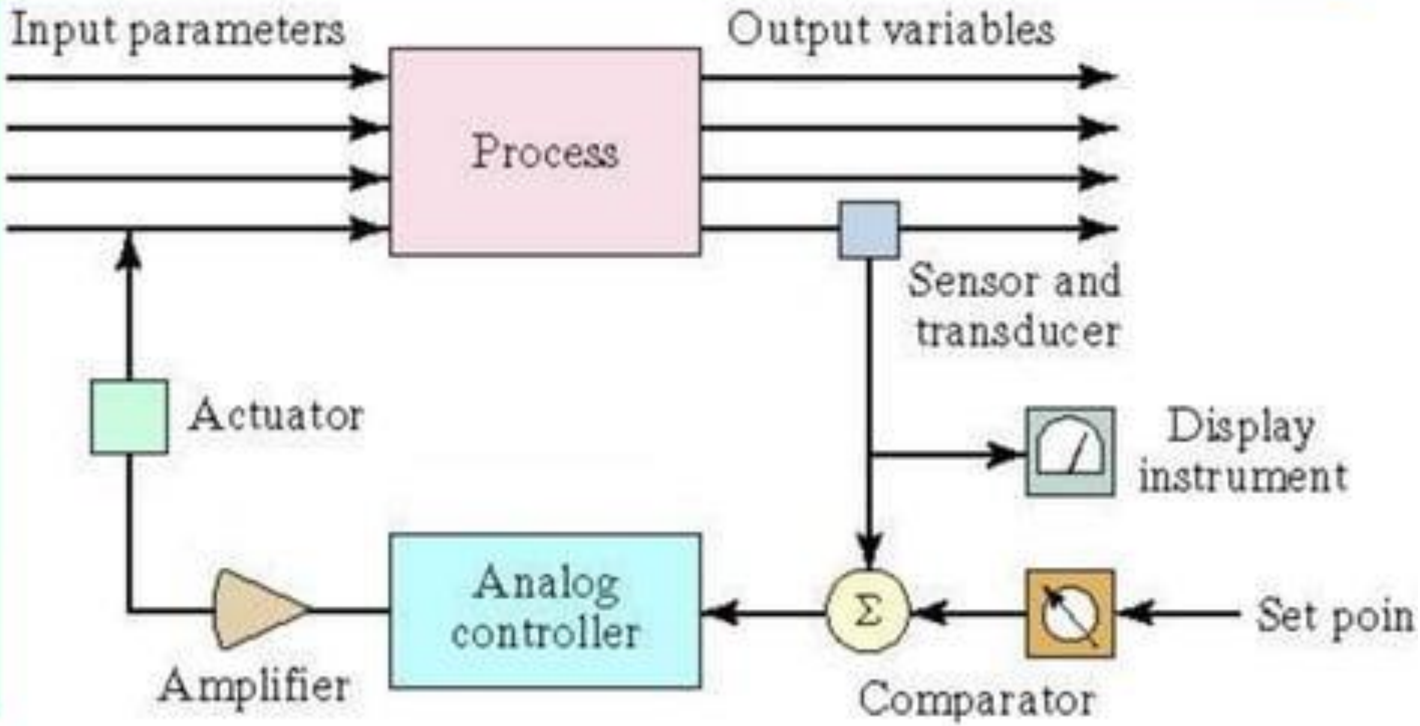


Fig. 5.8 A typical analog control loop

- Typical **hardware components** include the: **sensor** and **transducer**, an **instrument for displaying the output variable**, some means for establishing the **set point** of the loop (a **dial**), a **comparator**, the **analog controller**, an **amplifier**, and the **actuator.**

Components of a Direct Digital Control System

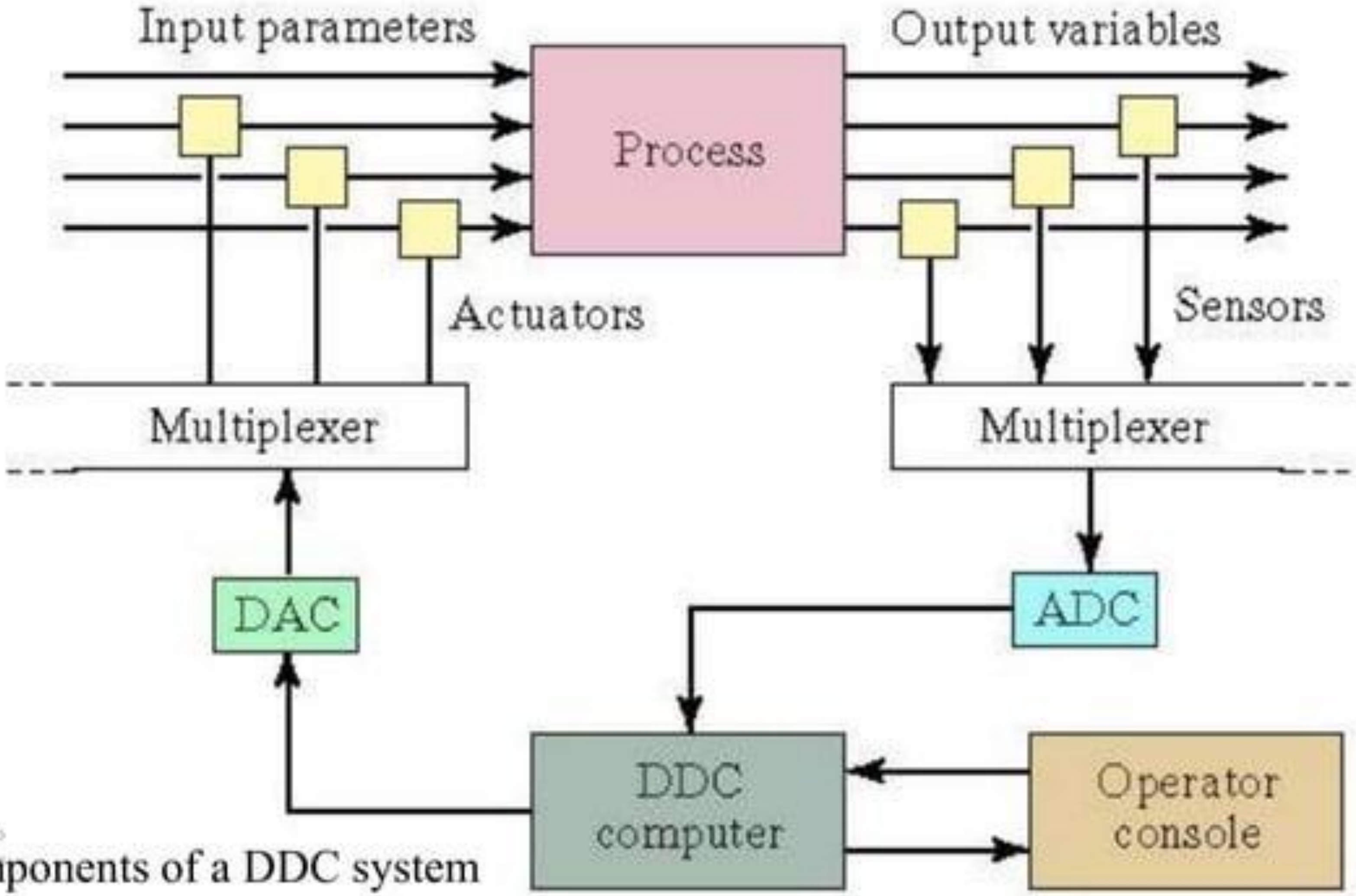
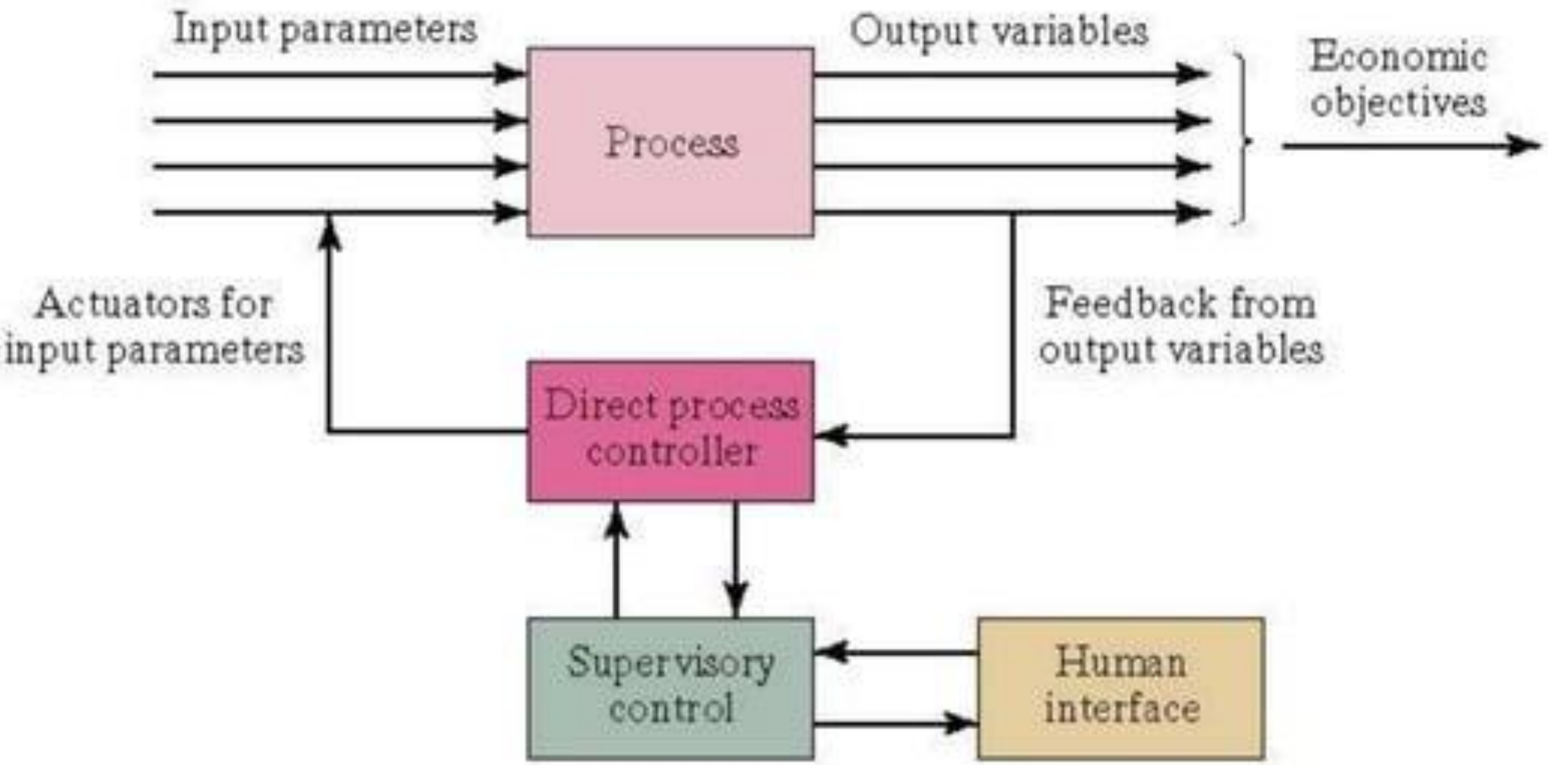
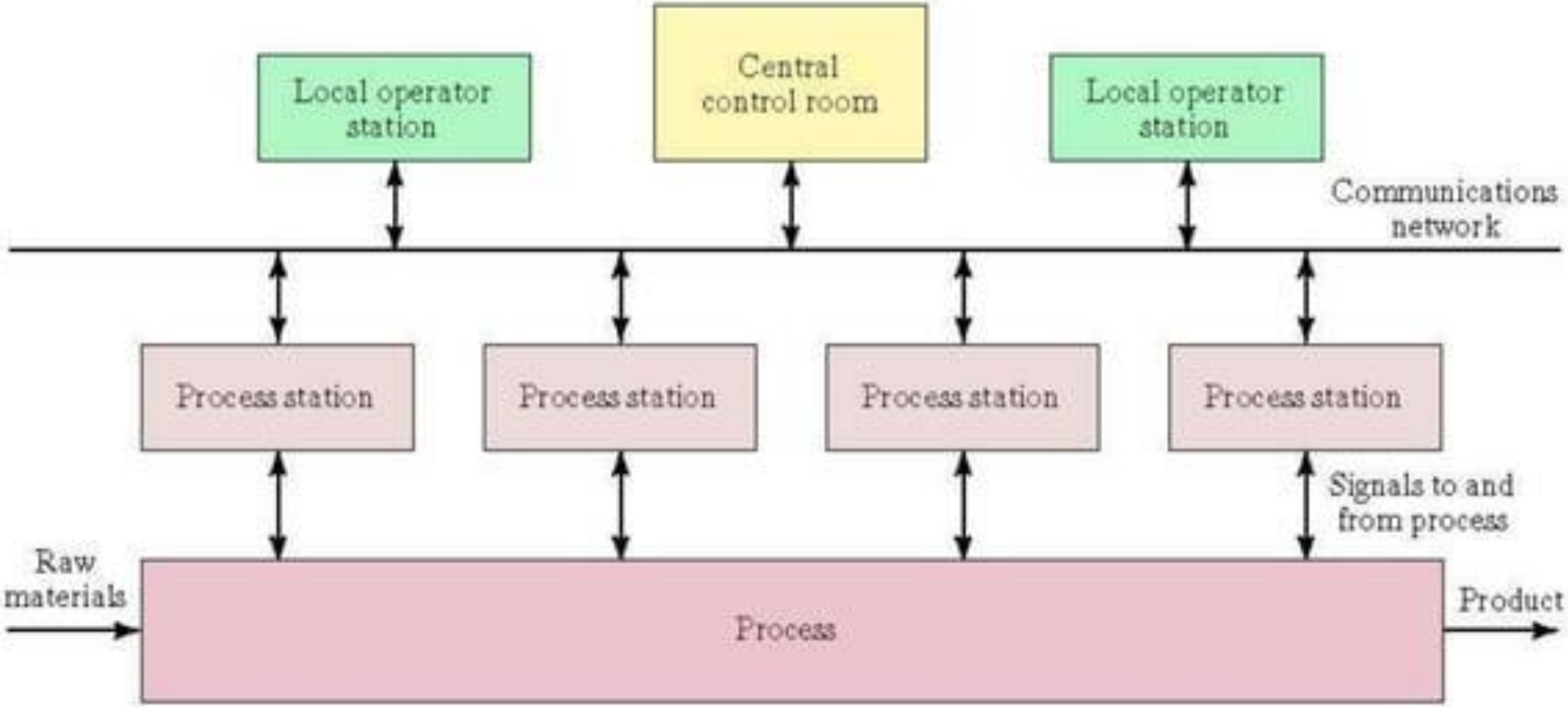


Fig. 5.9 Components of a DDC system

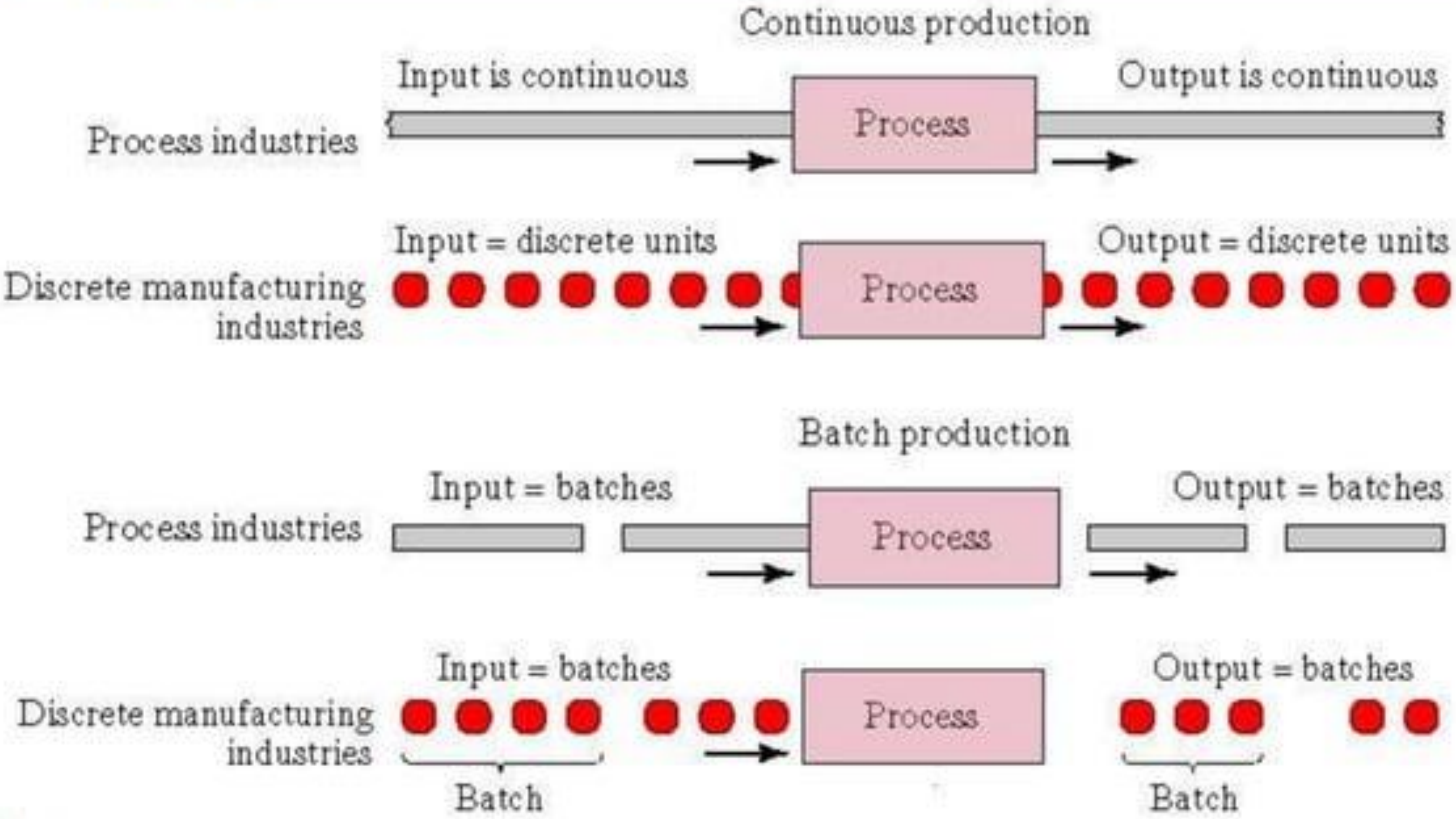
Supervisory Control Superimposed on Process Level Control System



Distributed Control System



Process Industries and Discrete Manufacturing Industries



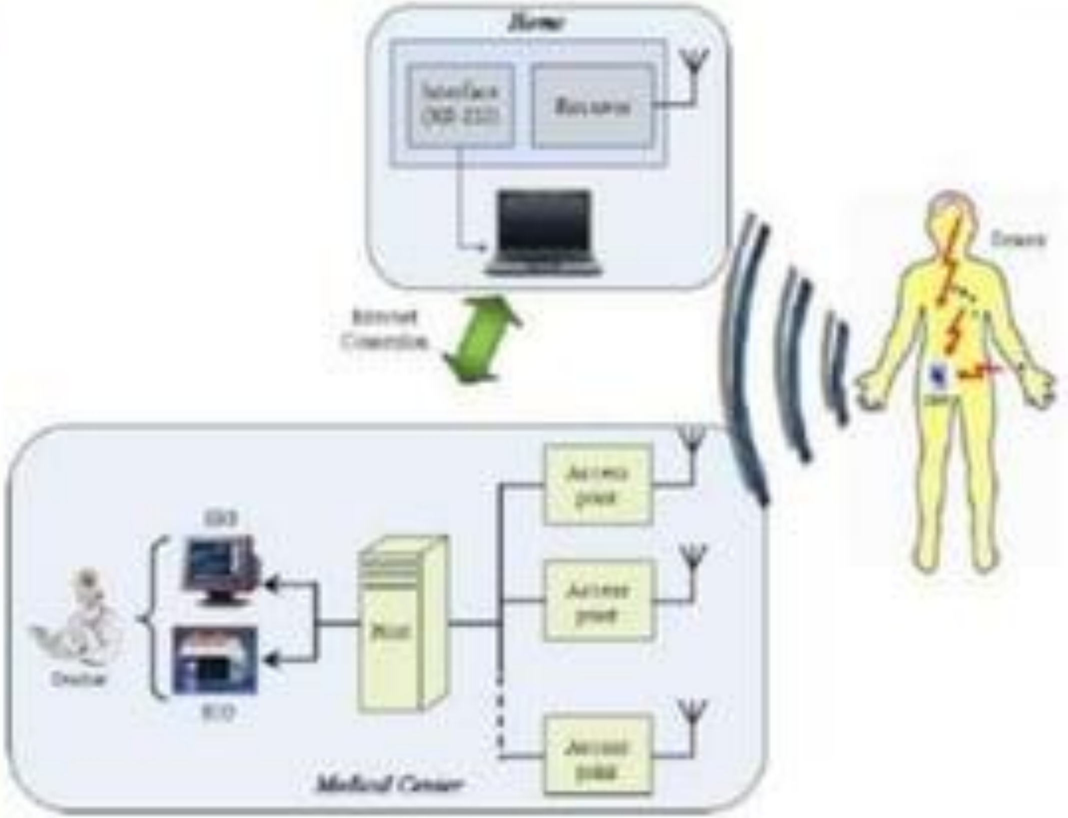
Medical Electronics

Central Monitoring Systems

- With central monitoring, the measured values are displayed and recorded at a central station.
- The signal conditioners are mounted at the bedside and the display and alarms, etc. are located in a central station.
- The central station monitoring equipment may incorporate
  - multi-microprocessor architecture to display a flexible mixture of smooth waveforms
  - alphanumerics and graphics on a single cathode ray tube.
- Presents all the information at a glance and generates audible and visual alarms if preset vital sign limits are exceeded.
- Displays the patient's vital sign data and by watching this data, the attending staff can detect problems before they reach the alarm stage.
- Provides a recording of the ECG and sometimes of other parameters, especially of the few seconds just before an alarm, which shows what kind of irregularity led to the alarm

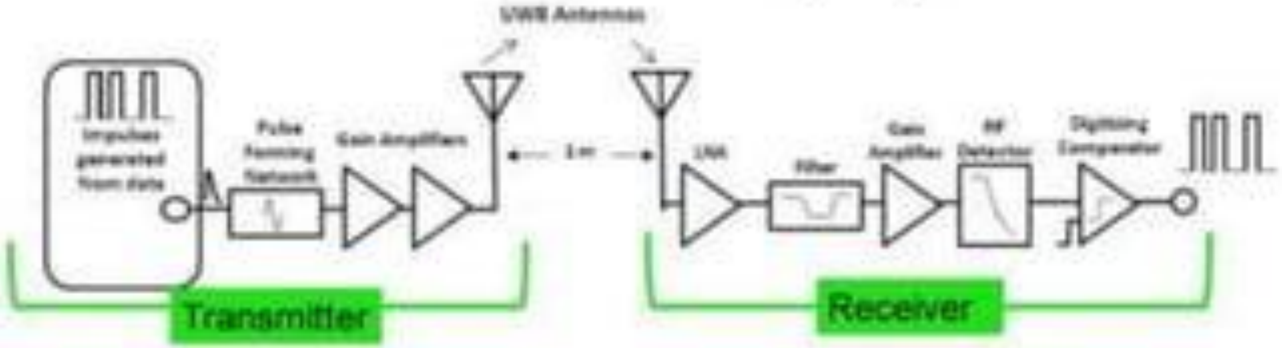
BioTelemetry-- Wireless Telemetry

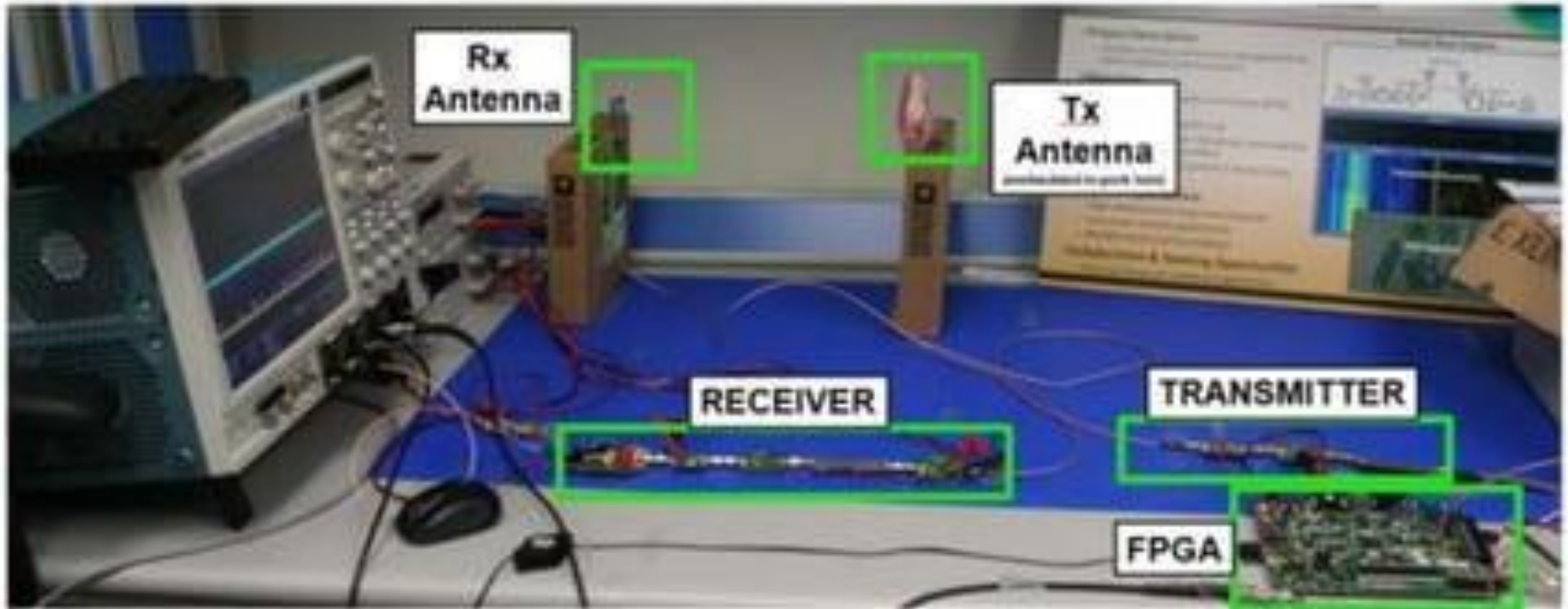
- **Wireless telemetry -** permits examination under normal conditions and in natural surroundings without any discomfort or obstruction to the subject under investigation.
- Factors influencing healthy and sick persons during the performance of their daily tasks can be easily recognized and evaluated.
- Very useful in situations where no cable connection is feasible.
- Study of active subjects like swimmers, riders athletes, pilots, manual labourers is possible .
- Most convenient during transportation within the hospital area as well for the continuous monitoring of patients sent to other wards or clinics for check-up or therapy.



Components of wireless telemetry

- The major components of a wirless telemetry system are
  - Modulation syster
  - Radio carrier
  - Transmitter
  - Receiver



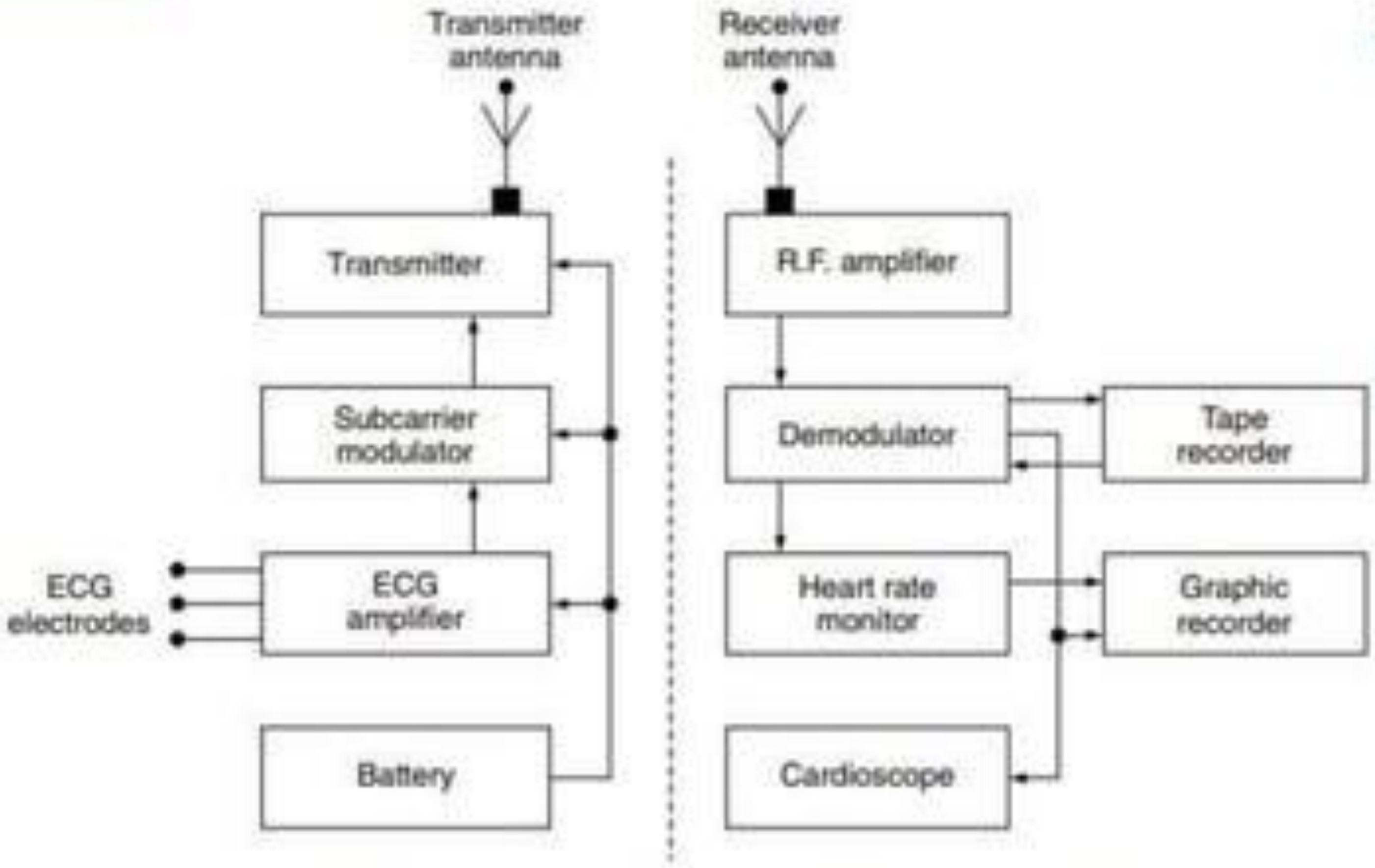


Single Channel Telemetry Systems

- A single physiological parameter is monitored
- We will see
    - **ECG Telemetry System**
    - **Temperature Telemetry System**

ECG Telemetry System

- In wireless telemetry monitoring, the parameter which is most commonly studied is the electrocardiogram.

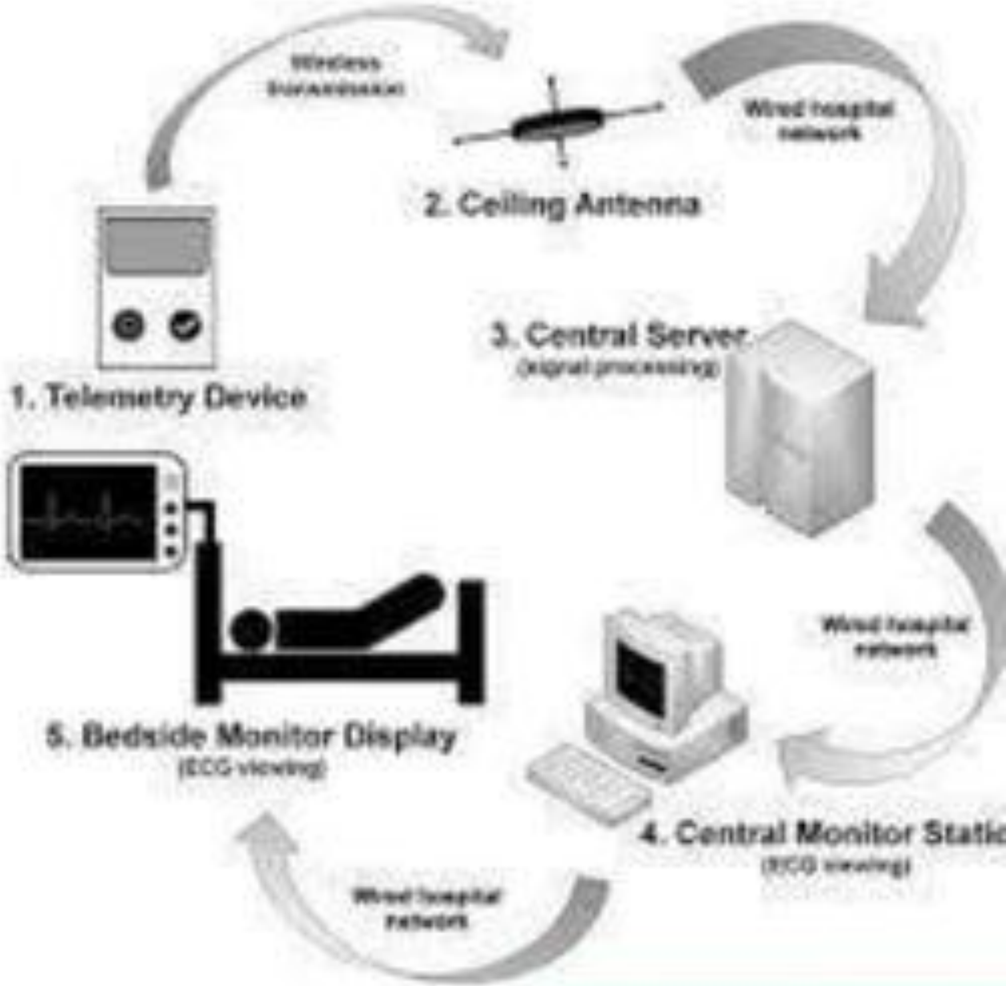


➤ Fig. 9.5 *Block diagram of a single channel telemetry system*

Two main parts:

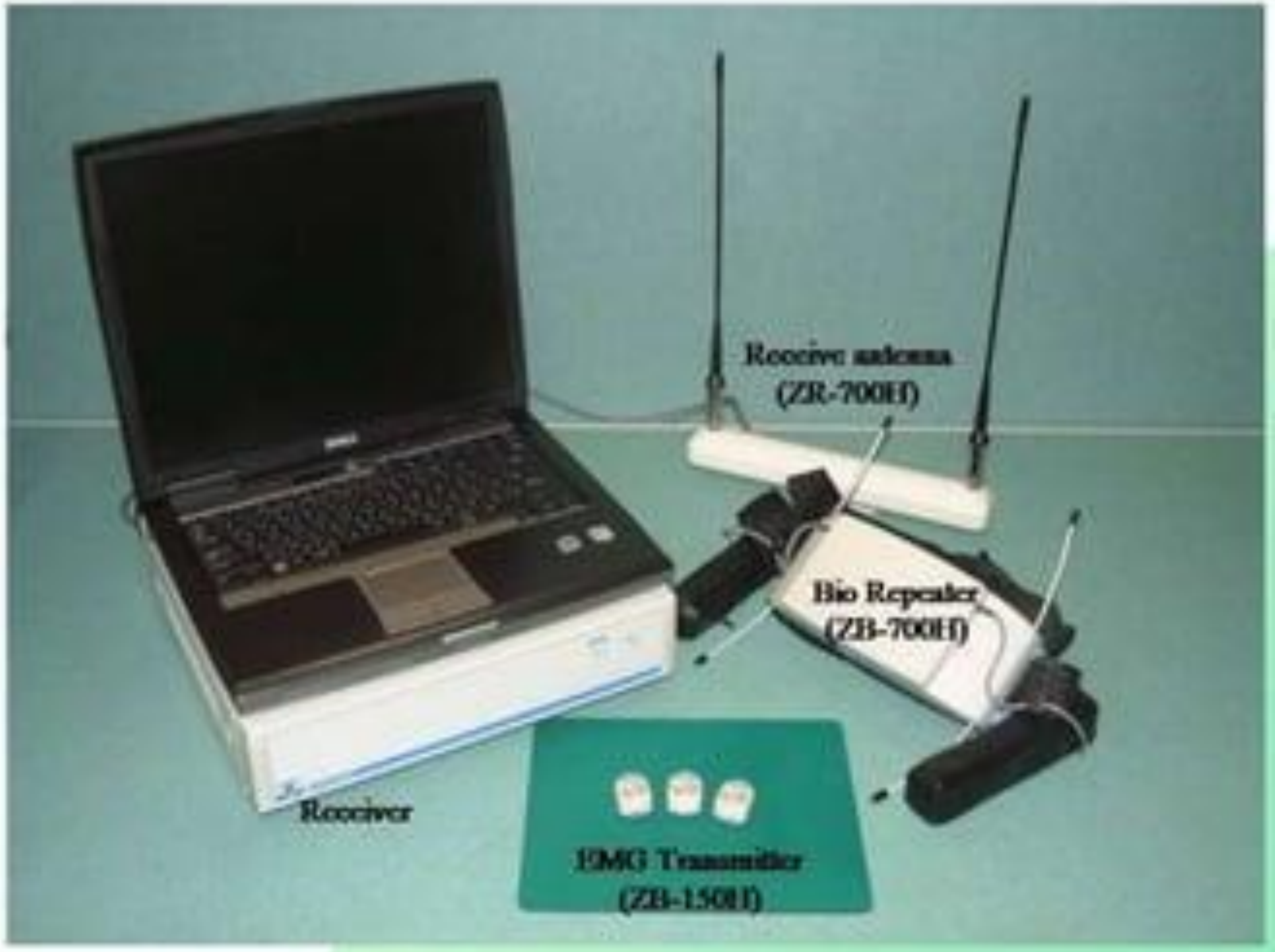
- **Telemetry Transmitter -**consists of
  - an ECG amplifier
  - a sub-carrier oscillator
  - a UHF transmitter
  - dry cell batteries.
- **Telemetry Receiver** consists of
  - a high frequency unit and a demodulator,
  - a cardioscope to display
  - a magnetic tape recorder to store the ECG
  - a heart rate meter with an alarm facility

- For distortion-free transmission of ECG, the following requirements must be met:
    - The subject should be able to carry on with his normal activities whilst carrying the instruments without the slightest discomfort.
    - Motion artefacts and muscle potential interference should be kept minimum.
    - The battery life should be long enough so that a complete experimental procedure may be carried out.
    - While monitoring paced patients for ECG through telemetry, it is necessary to reduce pacemaker pulses.



Multi Channel Telemetry Systems

- Medical measuring problems often involve the simultaneous transmission of several parameters.
- Multi-channel telemetry is particularly useful in athletic training programs
- Several physiological parameters of the person monitored simultaneously.
- ECG and heart rate, respiration rate, temperature, intravascular and intra-cardiac blood pressure.
- Number of sub-carriers used are the same as the number of signals to be transmitted.
- Each channel has its own modulator.
- The RF unit—the same for all channels—converts the mixed frequencies into the transmission band
- Receiver unit contains the RF unit and one demodulator for each channel



- For multi-channel radiotelemetry, various channels of information are combined into a single signal- **multiplexing**.

There are two basic methods of multiplexing.

Frequency–division multiplexing

makes use of continuous-wave sub-carrier frequencies.

Signals frequency–modulate multiple subcarrier oscillators

Does not overlap the frequency spectra of the other modulated signals.

Signals from all channels are added together through a summing amplifier

Gives a composite signal in which none of the parts overlap in frequency.

This signal modulates the RF carrier of the transmitter and is broadcast.

Time–division multiplexing

Multiple signals are applied to a commutator circuit.

Circuit rapidly scans the signals from different channels.

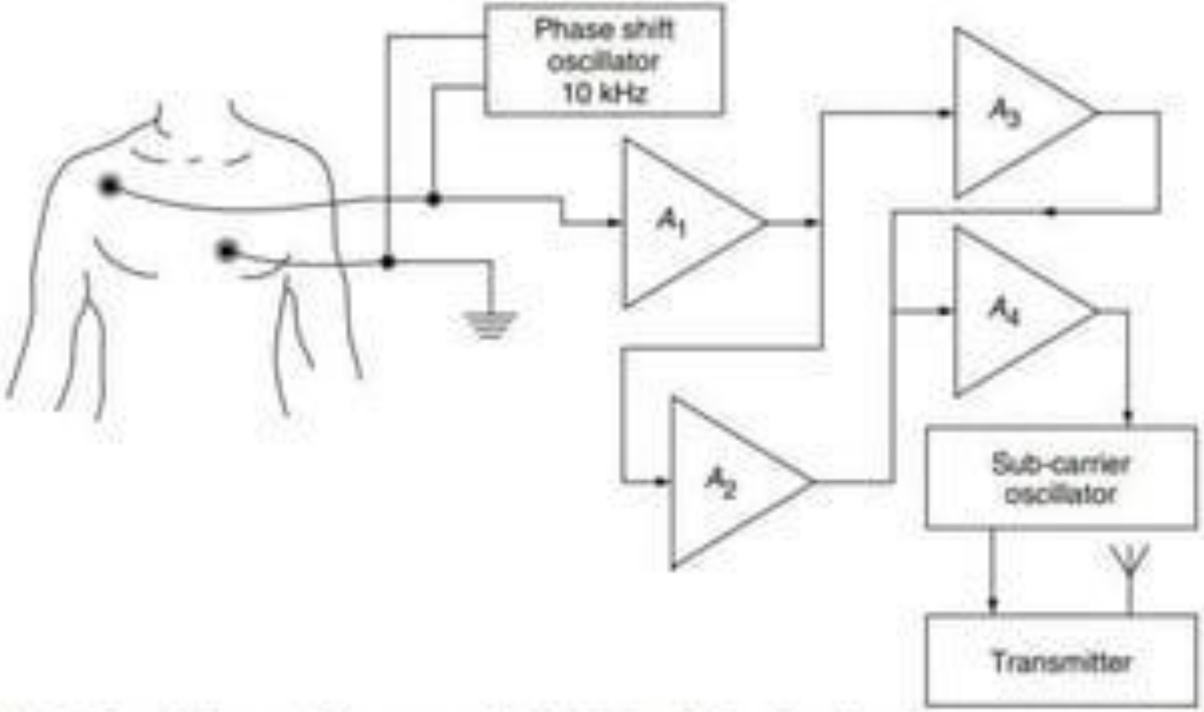
It samples each signal for an instant of time

Gives a pulse train sequence corresponding to input signals.

A frame reference signal is also provided as to make it easy to recognize the sequency and value of the input channels.

Telemetry of ECG and Respiration

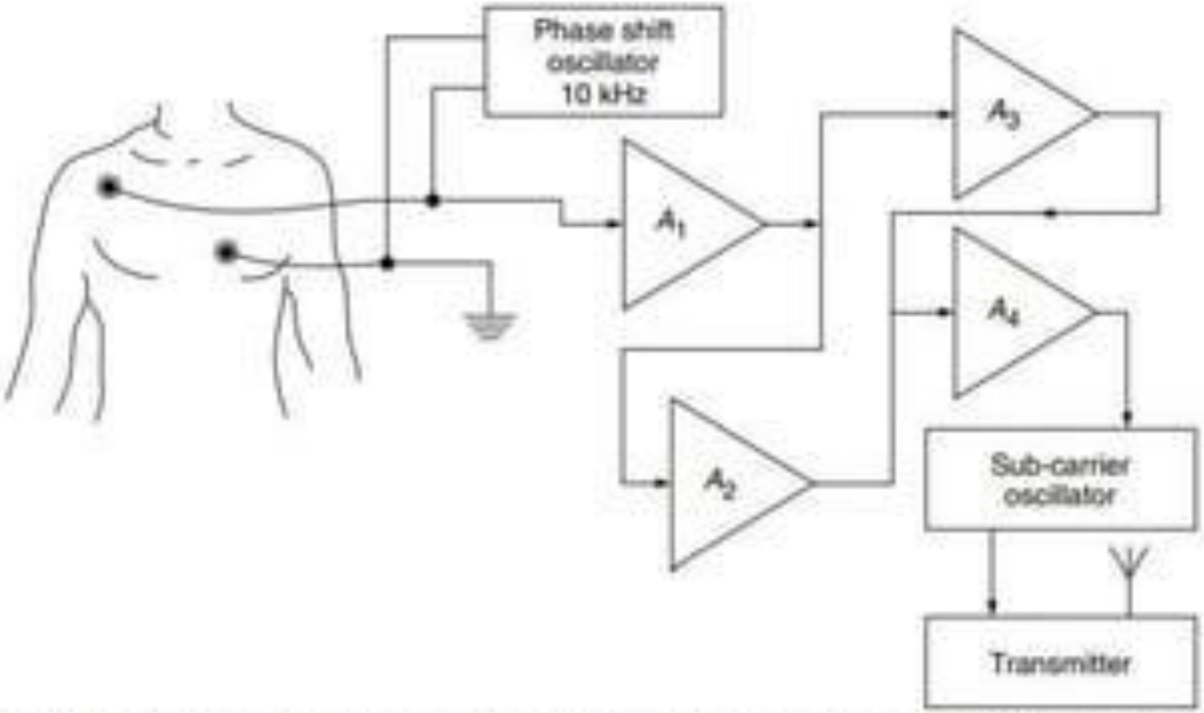
- Respiration is detected by using the same pair of electrodes that are used for the ECG.
- A 10 kHz sinusoidal constant current is injected through electrodes E1 and E2 attached across the subject's thoracic cavity.
- The carrier signal is generated by a phase shift oscillator
- The varying thoracic impedance associated with respiration produces an ac voltage whose amplitude varies with a change in impedance.
- The amplitude varying carrier is amplified by an amplifier A1. An amplifier filterA3 recovers the respiration signal by using rectifiers and a double pole filter.



➤ Fig. 9.10 *Schematic diagram of FM-FM modulated radiotelemetry transmitter for ECG and respiration activity simultaneously (adapted from Beerwinkle and Burch, 1976; by permission of IEEE Trans. Biomed. Eng.)*

Telemetry of ECG and Respiration

- ECG detected by electrodes E1 and E2 is amplified in A1 along with the respiratory signal.
- Passed through a low-pass Butterworth filter stage A2 which passes the ECG signal but blocks respiratory signal.
- The amplified ECG signal is then summed up with the preprocessed respiration signal in A4



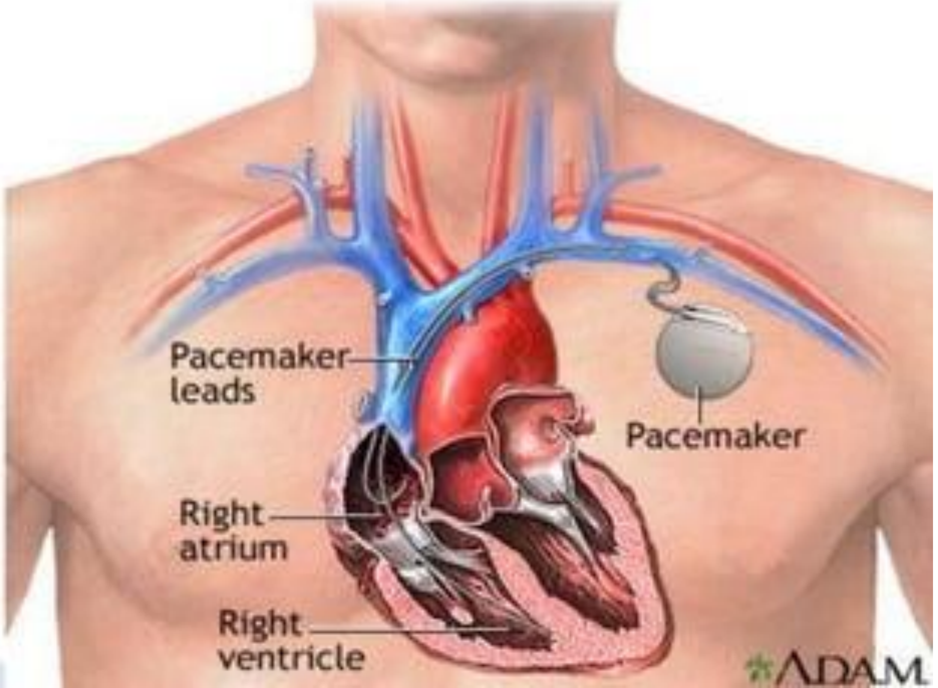
➤ Fig. 9.10 *Schematic diagram of FM-FM modulated radiotelemetry transmitter f ECG and respiration activity simultaneously (adapted from Beerwinkle ar Burch, 1976; by permission of IEEE Trans. Biomed. Eng.)*

INTRODUCTION

Pacemakers are the electrode devices that can be used to initiate the heartbeat when the hearts intrinsic electrical system cannot effectively generate a rate adequate to support cardiac output.

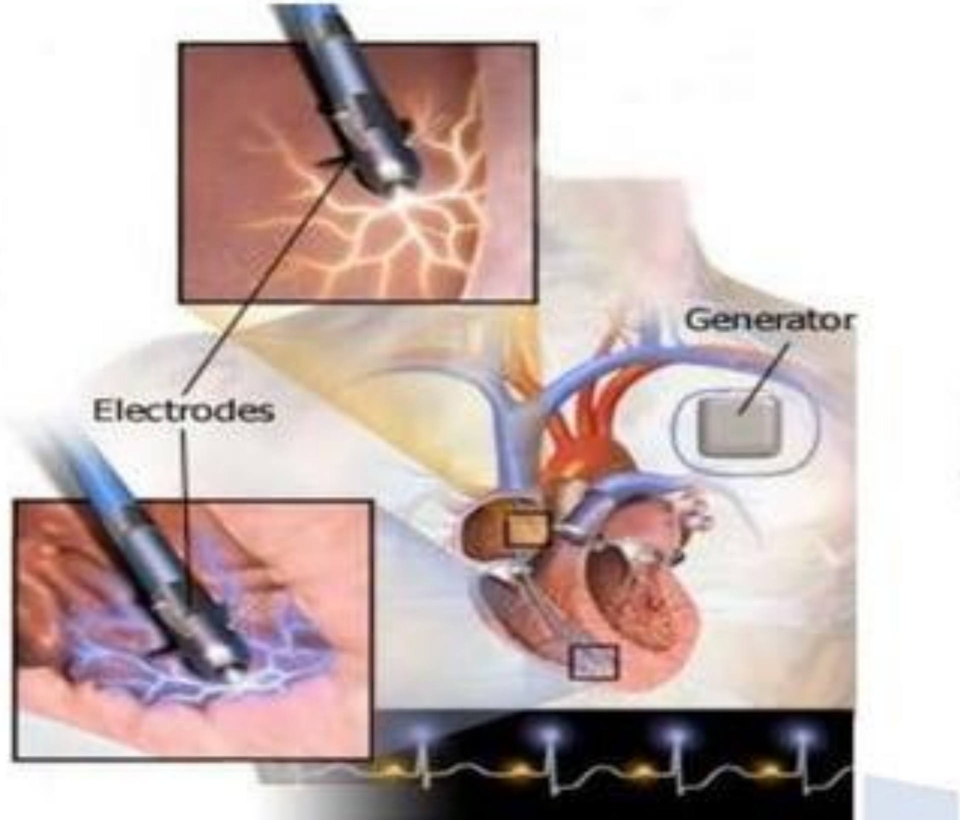
PACEMAKER

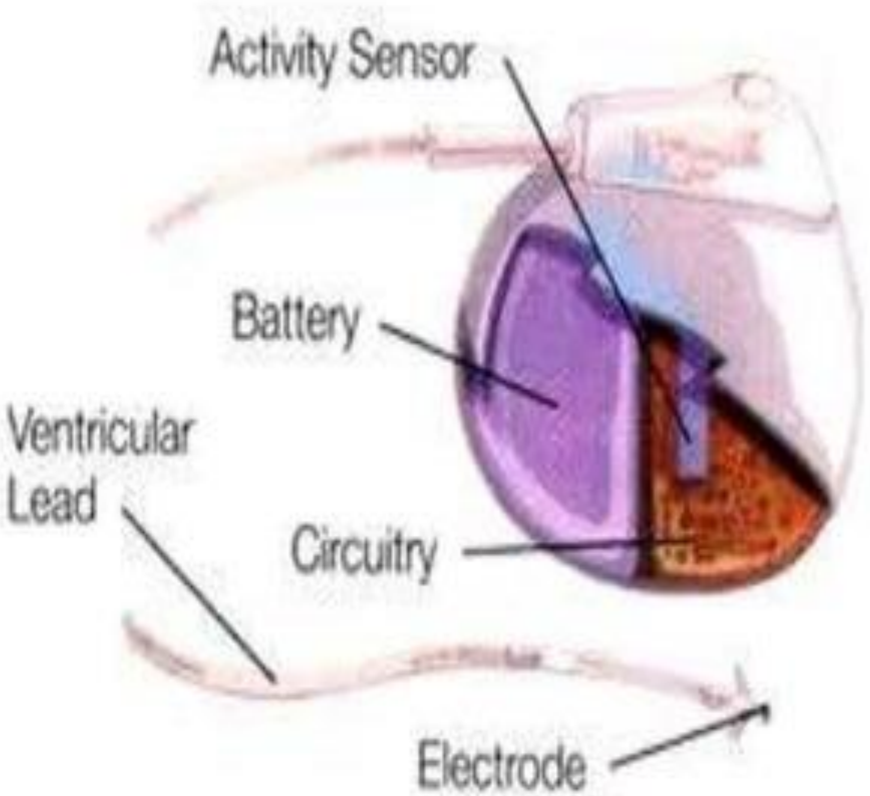
- Pacemakers is an electronic device used to pace the heart when the normal conduction pathway is damaged or diseased.



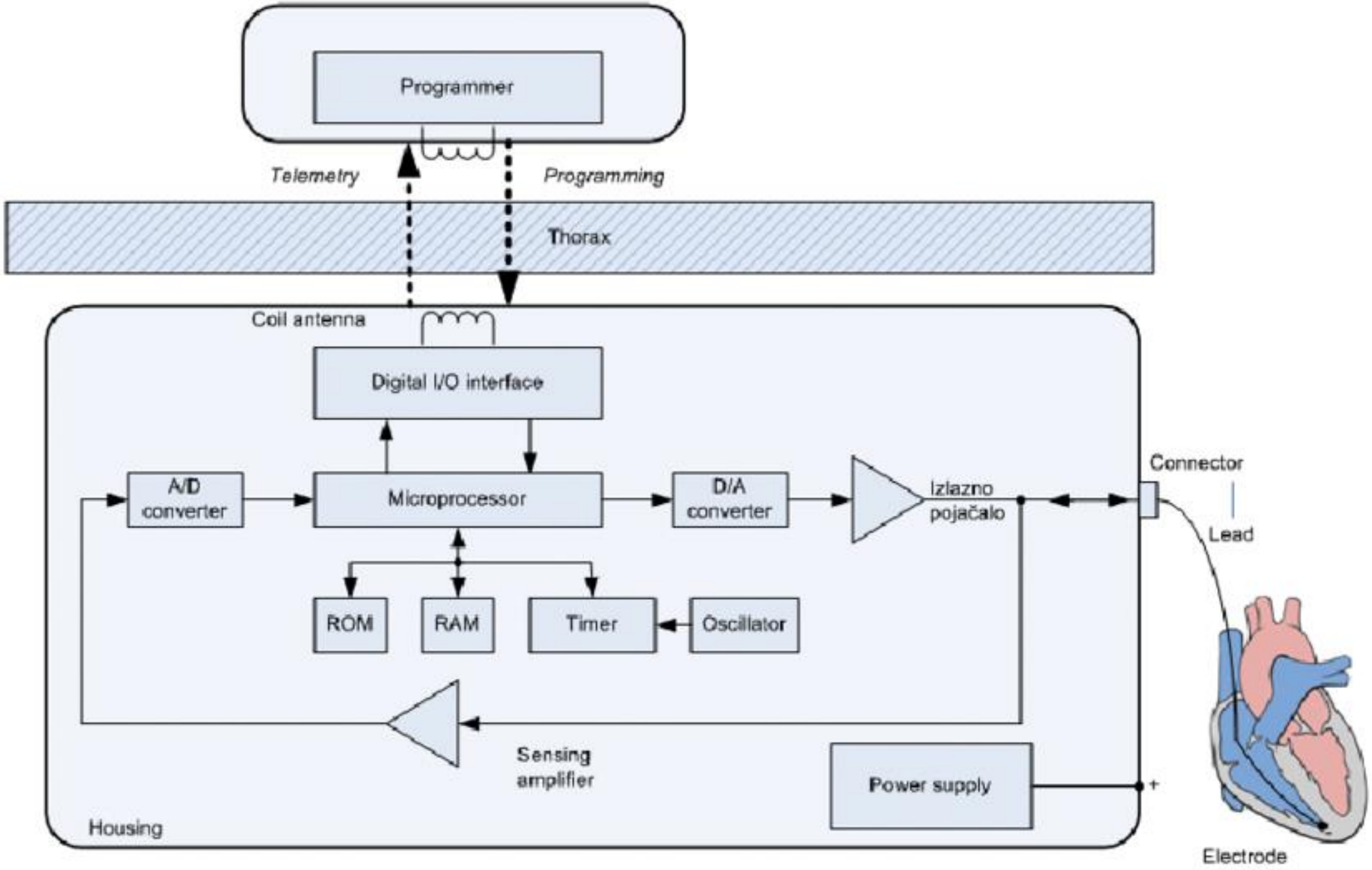
COMPONENTS OF PACEMAKER

- Pulse generator
- Pacemaker electrodes





Pacemaker Block diagram



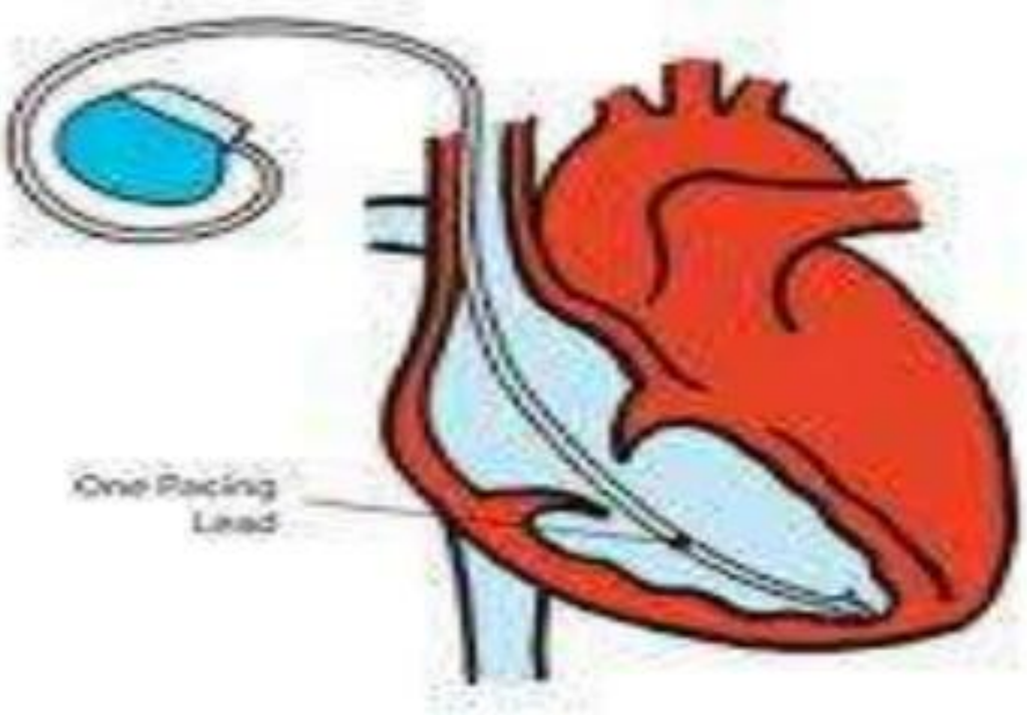
- A pacemaker consists of a battery, a computerized generator and wires with sensors at their tips(called as electrodes). The battery powers the generator and both are surrounded by a thin metal box. The wires connect the generator to the heart.
- A pacemaker helps monitor and control the heartbeat. The electrodes detect heart's electrical activity and send data through the wires to the computer in the generator. If heart rhythm is abnormal, the computer will direct the generator to send electrical pulses to heart. The pulses travel through the wires to reach the heart.

TYPES OF PACEMAKER

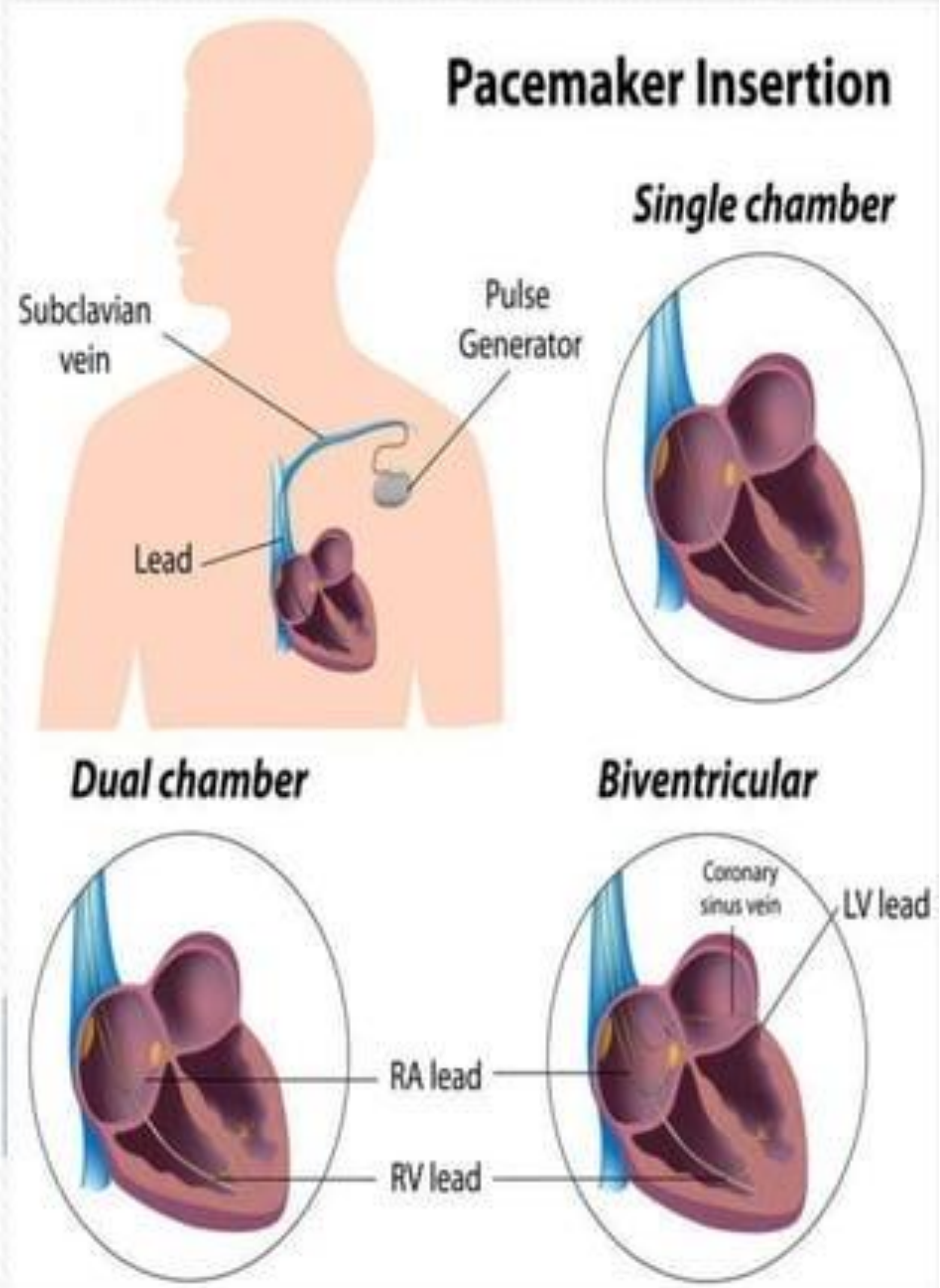
a)Permanent pacemaker
b)Temporary pacemaker

Types of permanent pacemaker

- **Single-chamber pacemaker**.
- In this type, only one pacing lead is placed into a chamber of the heart, either the atrium or the ventricle



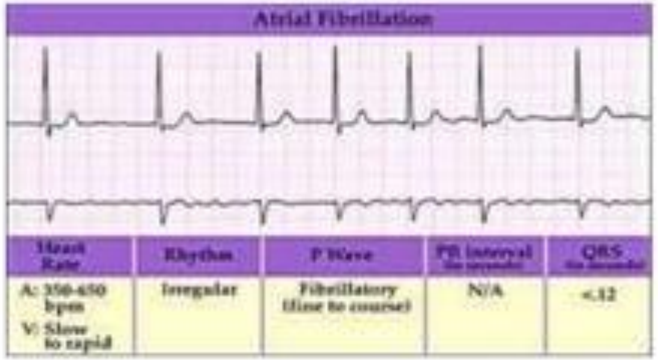
- <u>**Dual-chamber pacemaker**</u>.
- Wires are placed in two chambers of the heart
- One lead paces the atrium and one paces the ventricle
- Closely resembles the natural pacing of the heart.



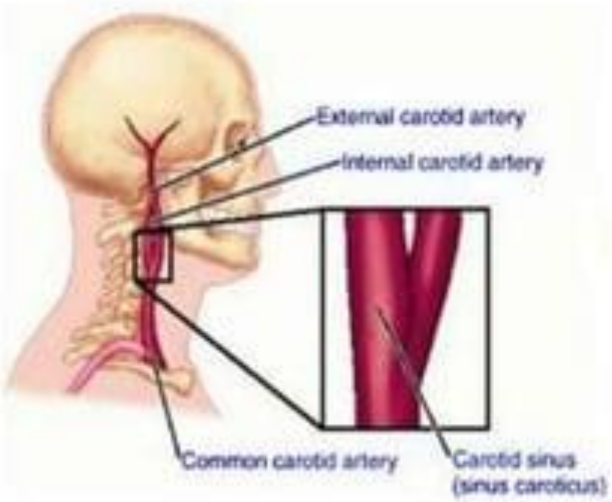
Rate-responsive pacemaker.

- It has sensors that detect changes in the patient's physical activity and automatically adjust the pacing rate to fulfill the body's metabolic needs.

Indication of permanent pacemaker therapy



Chronic atrial fibrillation with slow ventricular response



Hypersensitive carotid sinus syndrome

DEFINITION

Defibrillation is a process in which an electronic device sends an electric shock to the heart to stop an extremely rapid, irregular heartbeat, and restore the normal heart rhythm.

Defibrillator is a device that deliver a therapeutic dose of electrical energy to the affected heart to force the heart to produce more normal cardiac rhythm.

DEFINITION

Cardioversion is a synchronized administration of shock during the R waves or QRS complex of a cardiac cycle.

In defibrillation, electrode paddles are used to direct an electric current through the patient's heart, causes the myocardium to depolarize, which in turn encourages the SA node to resume control of the heart's electrical activity.

PURPOSE

- To correct life threatening fibrillations of the heart, which could result in cardiac arrest.

INDICATION

- PULSELESS VENTRICULAR TACHYCARDIA

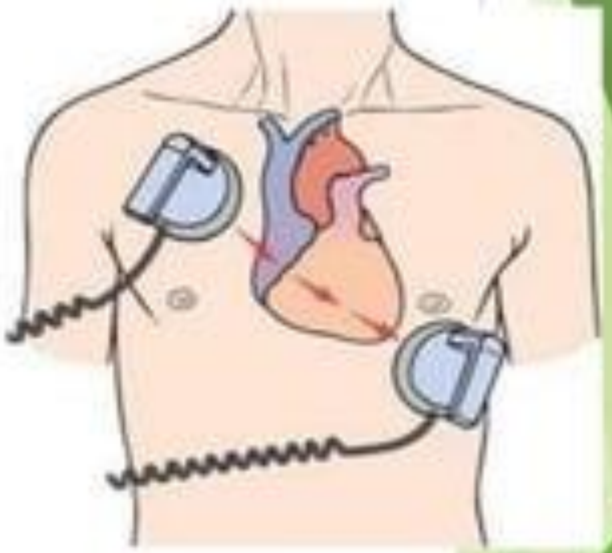
- VENTRICULAR FIBRILLATION

MECHANISM

- Defibrillator delivers a brief electric shock to the heart which enables the heart’s natural pacemaker to regain control and establish a normal heart rhythm.
- 3 features
  - Power source
  - Capacitor
  - 2 electrode

FACTORS AFFECTING DEFIBRILLATION

- Transthoracic impendence
  - Electrode to skin contact
  - Electrode size
  - Phase
- Body size
- Electrode position



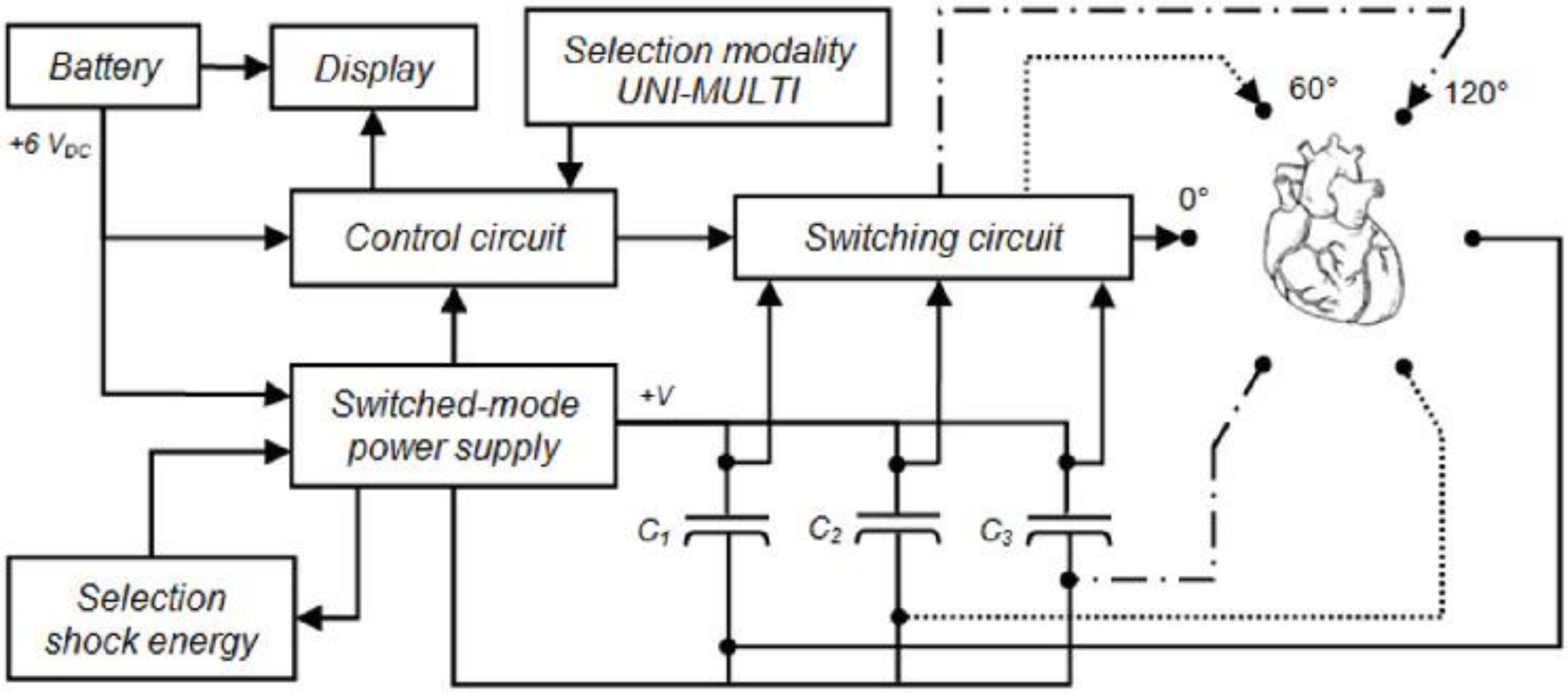
DEFIBRILLATOR ELECTRODES

- Metal Disc 5 x 10 cm

Types

a. Spoon shaped electrode
b. Paddle type electrode
c. Pad type electrode

Defibrillator block diagram



TYPE OF DEFIBRILLATORS

- MANUAL EXTERNAL DEFIBRILLATOR
- MANUAL INTERNAL DEFIBRILLATOR
- AUTOMATED EXTERNAL DEFIBRILLATOR
- WEARABLE CARDIOVERTER DEFIBRILLATOR
- IMPLANATBLE CARDIOVERTER-DEFIBRILLATOR

MANUAL EXTERNAL DEFIBRILLATOR

- First diagnose the cardiac rhythm and then manually determine the voltage and timing for the electrical shock

MANUAL INTERNAL DEFIBRILLATOR

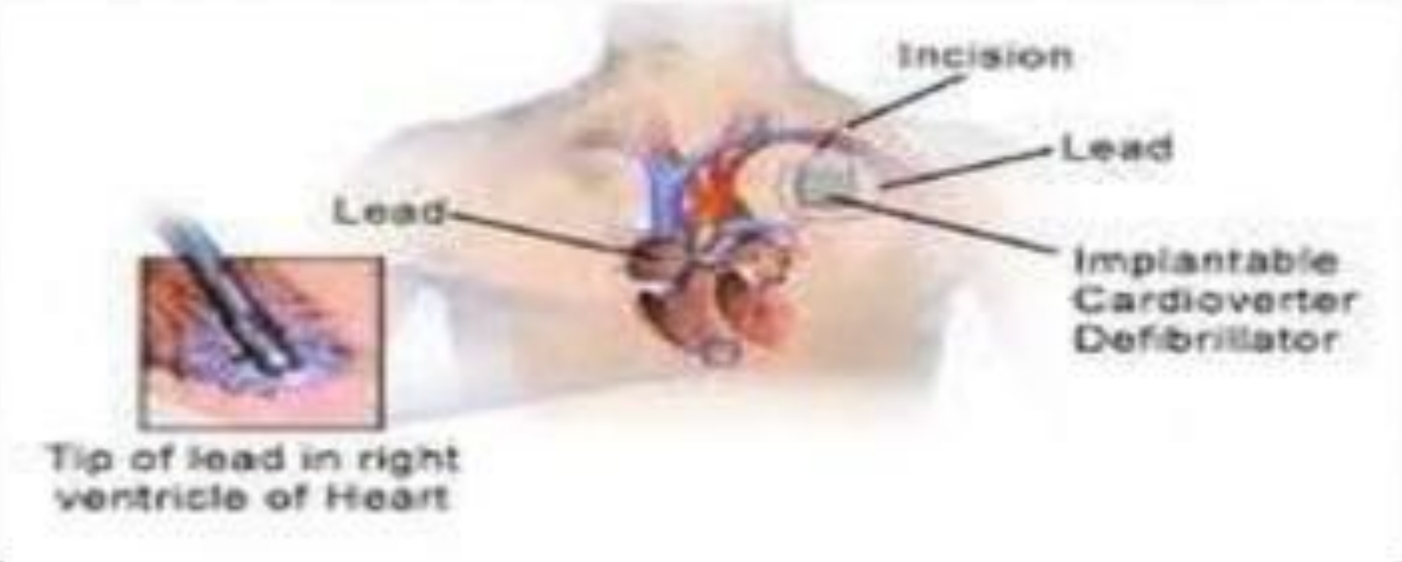
- Delivers the shock through paddles directly on the heart.
- Used in OT - Open heart surgery

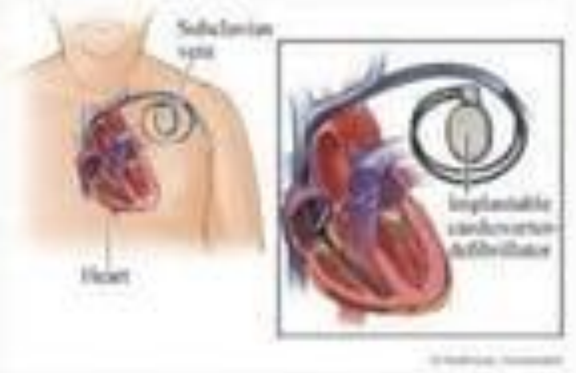
AUTOMATED EXTERNAL DEFIBRILLATOR (AED)

- Defibrillator having rhythm detection capacity and the ability to advise the operator to deliver a shock using hands free defibrillator pads.
- Untrained or briefly trained laypersons.
- Fully automated or semi automated

IMPLANATBLE CARDIOVERTER- DEFIBRILLATOR

- Consists of a lead system of placed via a subclavian vein to the endocardium.
- A battery powered pulse generator is implanted subcutaneously over pectoral muscle.
- Constantly monitor heart rhythm and automatically administer shocks.





Wearable cardioverter defibrillator

- Portable external defibrillator that can worn by at risk patient.
- Monitor 24 hrs a day and can automatically deliver a biphasic shock.

Monophasic versus Biphasic waveforms

- Monophasic defibrillator delivers a charge in only one direction.
- High energy shock (360 -400 J)
- Biphasic defibrillator delivers a charge in one direction for half of the shock and in the electrically opposite direction for second half. (120 -200 J)