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**DEPARTMENT OF BIOMEDICAL ENGINEERING**

**VI Semester**

**BIOMEDICAL DEVICE DESIGN**

**UNIT- II SENSORS, TRANSDUCERS AND EMBEDDED SYSTEMS FOR MEDICAL DEVICES**

## 2.1 Biomedical Sensors and Signal Acquisition

### ➢ Introduction

A **biomedical sensor** is a device that detects a physical, chemical or biological quantity from the human body (or its environment) and converts it into a measurable, usually electrical, signal. A **transducer** is the broader term for any device that converts energy from one form to another. In biomedical instrumentation the sensor is the first element of the measurement chain and therefore decides the quality of everything that follows: no amount of amplification or digital processing can recover information that the sensor failed to capture.

Biomedical signals are very different from signals in conventional electronics. They are **low in amplitude** (microvolts to millivolts), **low in frequency** (DC to a few kHz), buried in noise and interference, and generated by a living, time-varying, non-stationary source. The patient must also be protected from electric shock, so safety requirements are as important as accuracy.

### ➢ Definitions

- ✓ **Sensor:** a device that senses a measurand and produces an output signal related to it (e.g. a thermistor sensing body temperature).
- ✓ **Transducer:** a device that converts one form of energy into another (e.g. a piezoelectric crystal converting pressure into voltage). Sensor + signal-conditioning circuit is often called a transducer system.
- ✓ **Electrode:** a transducer that converts ionic current in the body into electronic current in the wire (e.g. Ag/AgCl ECG electrode).
- ✓ **Actuator:** the reverse of a sensor; converts an electrical signal into a physical action (e.g. infusion-pump motor).

### ➢ Generalised Biomedical Measurement System

Every biomedical instrument, from a clinical thermometer to an MRI scanner, can be represented by the same basic building blocks. The patient (or the biological sample) produces the **measurand**. The **sensor** converts it into an electrical signal, the **signal-conditioning** stage amplifies and filters it, the

**analog-to-digital converter** digitises it, the **processor** extracts clinical information and the **output stage** displays, stores or transmits the result. A **power supply** and **calibration** facility support the whole chain.

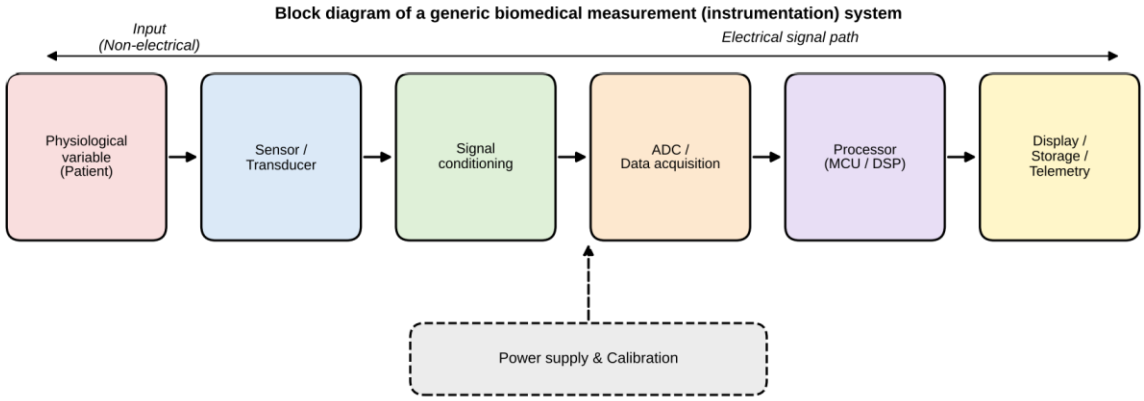


***Fig. 2.1 Block diagram of a generic biomedical measurement system***

**Function of each block**

| Block | Function | Example |
|---|---|---|
| Measurand | Physical / chemical / electrical quantity generated by the body | ECG potential, blood pressure, temperature |
| Sensor / Transducer | Converts the measurand into an electrical signal | Ag/AgCl electrode, thermistor, photodiode |
| Signal conditioning | Amplifies, filters, linearises and isolates the signal | Instrumentation amplifier, band-pass filter |
| Data acquisition (ADC) | Samples and converts the analog signal to digital words | 12/16-bit SAR or sigma-delta ADC |
| Processor | Performs DSP, feature extraction, decision making | Microcontroller, DSP, FPGA |
| Output / Telemetry | Displays, records, alarms, or transmits results | LCD, printer, Bluetooth, cloud |

## ➢Classification of Biomedical Sensors

Sensors can be classified in several ways. The two most common classifications used in examinations are based on the **energy source** (active/passive) and on the **measurand** (what is measured).

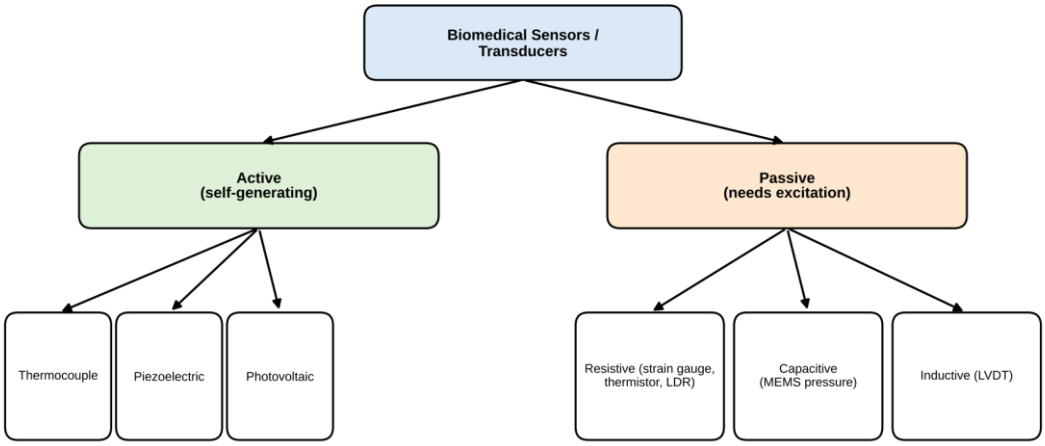


***Fig. 2.2 Classification of sensors / transducers***

**(a) Active (self-generating) transducers**

Active transducers produce an electrical output directly from the measurand without any external power. Examples are **thermocouples** (Seebeck effect – temperature), **piezoelectric crystals** (mechanical stress produces charge – used in pulse and heart-sound sensors and ultrasound probes) and **photovoltaic cells** (light produces voltage).

**(b) Passive transducers**

Passive transducers need an external **excitation** voltage or current; the measurand modulates a circuit parameter (R, L or C). Examples include **resistive** (strain gauge for pressure/force, thermistor for temperature, LDR for light), **capacitive** (MEMS pressure sensor, humidity sensor) and **inductive** (LVDT for displacement).

**(c) Classification by measurand**

| Category | Measurand | Typical sensors |
|---|---|---|
| Bio-electric | ECG, EEG, EMG, EOG | Surface electrodes (Ag/AgCl), needle electrodes |
| Pressure | Blood pressure, intra-ocular pressure, respiratory pressure | Strain-gauge, piezoresistive MEMS, capacitive |
| Temperature | Core and skin temperature | Thermistor, RTD, thermocouple, IR sensor |
| Optical | $SpO_2$, heart rate, glucose | LED + photodiode, photo-transistor |
| Flow | Respiratory flow, blood flow | Pneumotachograph, ultrasonic Doppler, electromagnetic |
| Motion | Activity, gait, tremor | Accelerometer, gyroscope (MEMS) |
| Chemical / biochemical | Blood glucose, pH, $pO_2$, $pCO_2$ | Enzyme electrode, ISFET, Clark electrode |
| Acoustic | Heart sounds, lung sounds, cough | Piezoelectric / MEMS microphone |

## ➢Important Performance Characteristics of Sensors

✓ **Sensitivity:** ratio of change in output to change in input ($S = \Delta Vout / \Delta measurand$).

- ✓ **Range / Span:** the minimum and maximum measurand values that can be measured accurately.
- ✓ **Linearity:** how closely the transfer characteristic follows a straight line.
- ✓ **Accuracy, precision and resolution:** closeness to true value, repeatability, and the smallest detectable change.
- ✓ **Hysteresis:** difference in output when the same input is approached from increasing and decreasing directions.
- ✓ **Response time and bandwidth:** speed with which the sensor follows rapid changes – e.g. an ECG sensor needs at least 0.05–100 Hz bandwidth.
- ✓ **Drift and stability:** slow change of output with time/temperature for a constant input.
- ✓ **Signal-to-noise ratio (SNR) and selectivity:** ability to reject unwanted signals.
- ✓ **Biocompatibility and safety:** material must not cause toxicity, allergy or electric hazard.

## ➢Biopotential Electrodes

Biopotential electrodes form the interface between the body and the electronic instrument. Inside the body, current is carried by **ions**; in the wire it is carried by **electrons**. The electrode–electrolyte interface performs this conversion through an electrochemical reaction, and it produces a **half-cell potential** (about 0.22 V for Ag/AgCl). A stable, non-polarisable electrode is therefore needed.

| Type | Description | Application |
|---|---|---|
| Surface (skin) electrode – Ag/AgCl with gel | Disposable pad, low half-cell potential, low noise | ECG, EEG (cup type), EMG |
| Needle / wire electrode | Inserted into muscle; picks up single motor-unit potentials | Diagnostic EMG |
| Microelectrode | Tip diameter of 1–10 µm; records single-cell potentials | Neuro-physiology research |
| Dry / textile electrode | No gel; capacitive or conductive fabric | Wearable and long-term monitoring |

**Exam tip:** Always state that the skin–electrode impedance (typically 5–50 kΩ) must be kept low and balanced, otherwise the common-mode interference converts into a differential error signal.

## ➢Signal Acquisition – Stages and Requirements

Signal acquisition is the complete process of capturing a physiological signal and turning it into a digital record suitable for analysis. Its main stages are **sensing, pre-amplification, filtering, isolation, sampling and quantisation**. The following requirements apply to most biomedical acquisition systems:

- ✓ **High input impedance (> 10 MΩ)** so the electrode signal is not loaded down by the amplifier.
- ✓ **High common-mode rejection ratio (CMRR > 80–120 dB)** to reject 50 Hz mains pick-up that appears equally on both input leads.
- ✓ **Low noise** (amplifier input noise of a few µV peak-to-peak) because the signals are of microvolt level.

- ✓ **Proper bandwidth** matching the signal, e.g. ECG 0.05–100 Hz; EEG 0.5–70 Hz; EMG 10–500 Hz.
- ✓ **Patient isolation** with leakage current within the limits of IEC 60601-1.
- ✓ **Adequate resolution and sampling rate** satisfying the Nyquist criterion.

**Typical amplitude and bandwidth of common biosignals**

| Signal | Amplitude | Frequency range | Source |
|---|---|---|---|
| ECG | 0.5 – 4 mV | 0.05 – 100 Hz | Heart |
| EEG | 5 – 300 µV | 0.5 – 70 Hz | Brain |
| EMG | 0.1 – 5 mV | 10 – 500 Hz | Skeletal muscle |
| EOG | 10 – 3500 µV | DC – 100 Hz | Eye movement |
| Blood pressure (pulse) | 10 – 400 mmHg | DC – 50 Hz | Arterial pressure |
| PPG ($SpO_2$) | AC ≈ 1–2 % of DC | 0.5 – 10 Hz | Blood volume pulse |
| Body temperature | 32 – 40 °C | DC – 0.1 Hz | Whole body |

## ➢Sources of Noise and Artefacts

- ✓ **Power-line interference (50 Hz):** capacitive and inductive coupling from mains wiring; removed using shielding, driven-right-leg circuit and notch filter.
- ✓ **Motion artefact:** electrode movement changes the half-cell potential; reduced by good gel contact and high-pass filtering.
- ✓ **Baseline wander:** respiration and slow electrode drift (< 0.5 Hz).
- ✓ **EMG interference:** muscle activity adds high-frequency noise to ECG/EEG.
- ✓ **Electrode–skin contact noise and thermal noise** of resistive components.
- ✓ **Radio-frequency interference** from mobile phones and electrosurgical units.

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