Lecture One

Terminology of Medical Devices

According to WHO: ‘Medical device’ means any instrument, apparatus, implement, machine, appliance, implant, reagent for in vitro use, software, material or another similar or related article, intended by the manufacturer to be used, alone or in combination, for human beings, for one or more of the specific medical purpose(s) of:

- diagnosis, prevention, monitoring, treatment, or alleviation of disease,
- diagnosis, monitoring, treatment, alleviation of, or compensation for an injury,
- investigation, replacement, modification, or support of the anatomy or of a physiological process,
- supporting or sustaining life,
- control of conception,
- disinfection of medical devices,
- providing information by means of in vitro examination of specimens derived from the human body;

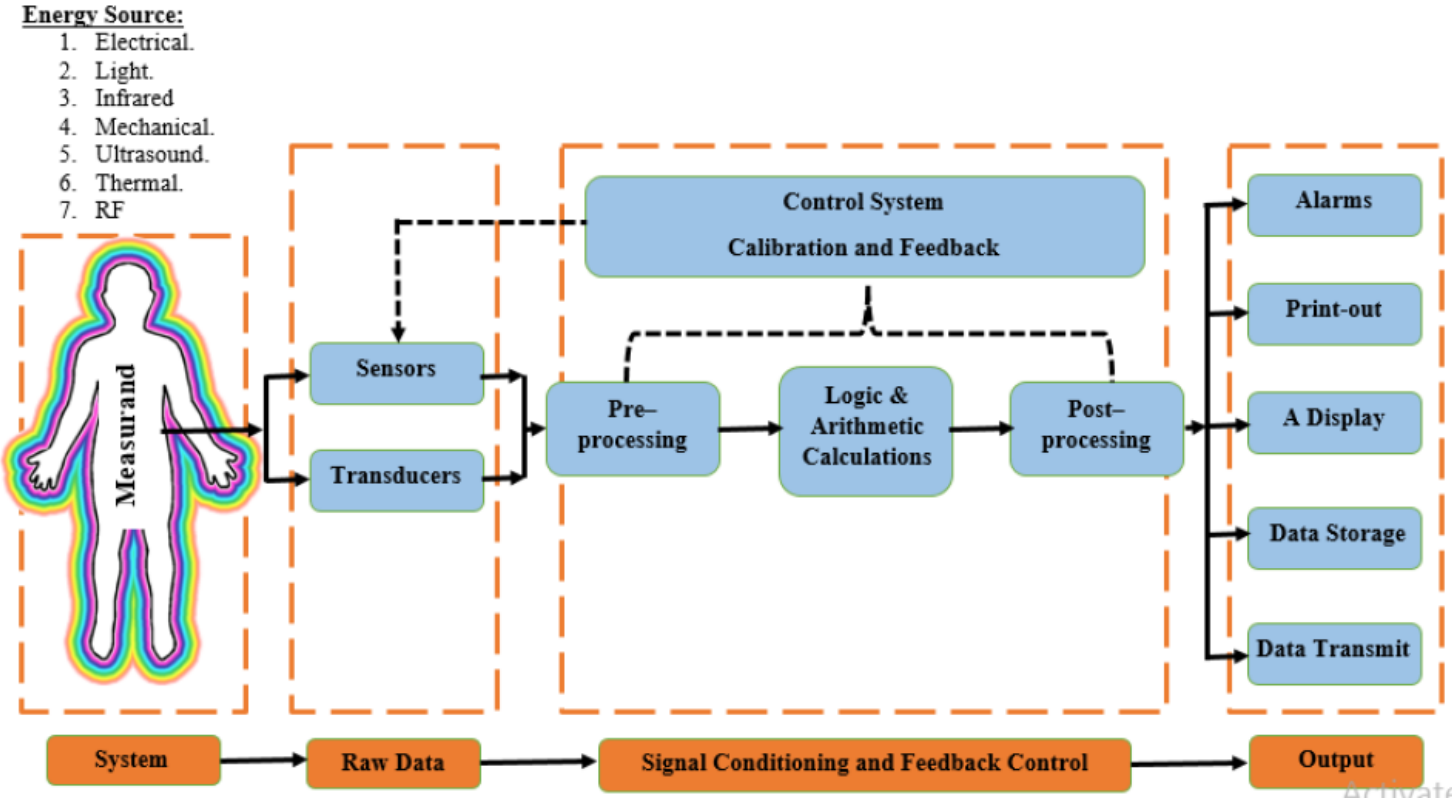
Medical devices don’t achieve their primary intended action by pharmacological, immunological, or metabolic means, in or on the human body, but they may be assisted in their intended function by such means. Products that may be considered to be medical devices in some jurisdictions but not in others include:

- disinfection of substances,
- aids for persons with disabilities,
- devices incorporating animal and/or human tissues,
- devices for in-vitro fertilization or assisted reproduction technologies.

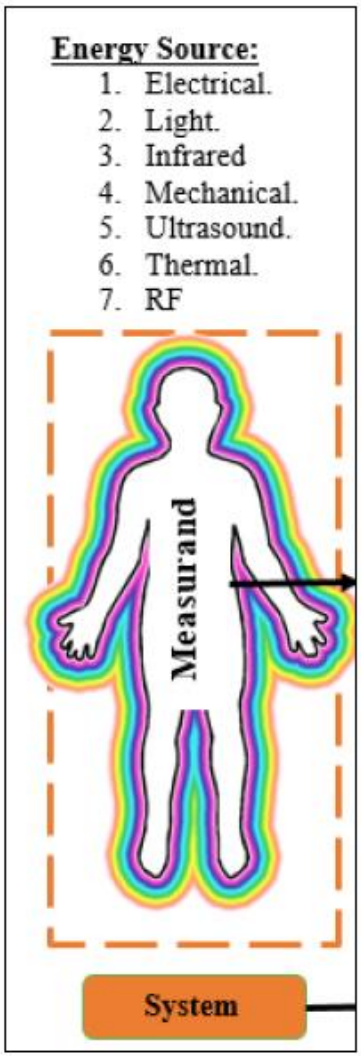
Generalized Medical Instrumentation System

The major difference between this system of medical instrumentation and the conventional instrumentation system is that the source of the signals is living tissue or energy applied to living tissue. The design of the instrument must match:

- Measurement needs (environmental conditions, safety, reliability, etc.)
- Instrument performance (speed, power, resolution, range, etc.)



Measurand

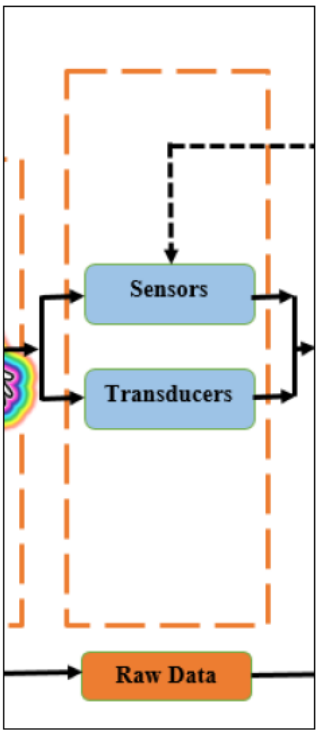


Measurand: the physical quantity, property, or condition that the system measures. Types of biomedical measurands:

- Internal – Blood pressure.
- Body surface – ECG or EEG potentials.
- Peripheral – Infrared radiation.
- Offline – Extract tissue samples, blood analysis, or biopsy.

Typical biomedical measurements quantities: Biopotential, pressure, flow, dimensions (imaging), displacement (velocity, acceleration, and force), impedance, temperature, and chemical concentration. The measurand may be restricted to an exact organ or anatomical structure.

Sensor and transducer



- ***A sensor*** is a device that converts physical measurand to an electrical output, in contrast, ***a transducer*** is a device that convert s one form of energy to another.
- ***Sensor requirements:***

✓ Selective – should respond to a specific form of energy in the measurand.

✓ Minimally invasive (invasive = requiring entry into a part of the body).

Sensor should not affect the response of the living tissue. Most common types of sensors in biomedical systems: displacement and pressure.

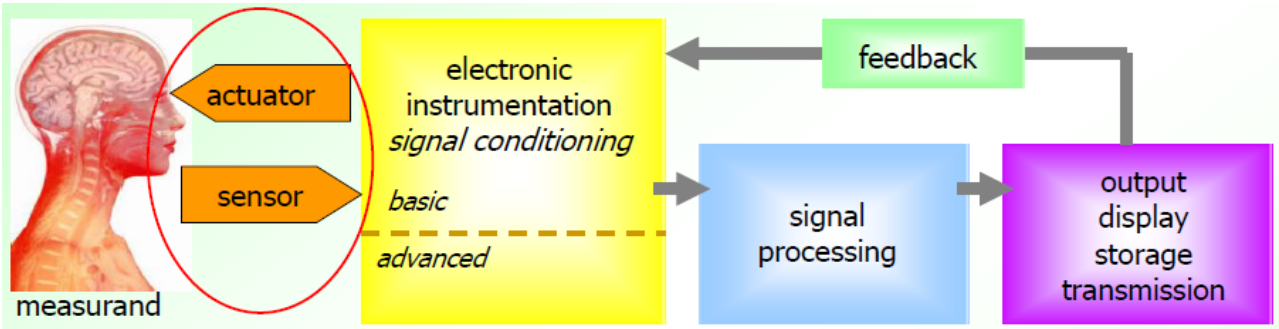
Many sensors have:

✓ 1. A primary sensing element such as a diaphragm, converts pressure to displacement.

✓ 2. A variable conversion element, such as a strain gage, then converts displacement to an electrical voltage

✓ 3. Sometimes the sensitivity of the sensor can be adjusted over a wide range by altering the primary sensing element.

✓ 4. Many variable conversion elements need external electric power to obtain a sensor output.



Signal conditioning

- ***Signal Conditioning:*** Amplification and filtering of the signal acquired from the sensor to make it suitable for display
- ***General categories:***

➢ Analog, digital, or mixed-signal signal conditioning

➢ Time/frequency/spatial domain processing (e.g., filtering)

➢ Calibration (adjustment of output to match theparameter measured)

➢ Compensation (remove undesirable secondary sensitivities)

Preprocessing:

Usually, the sensor/transducer output had a range of millivolts, so it should be amplified initially (pre-amplification) in order to meet the hardware requirements for further processing. The gain of the amplifier on this stage depends strongly on the next stage's requirements. Often the output is converted to digital form and then processed by specialized digital circuits or a microcomputer as there will be logic and arithmetic units.

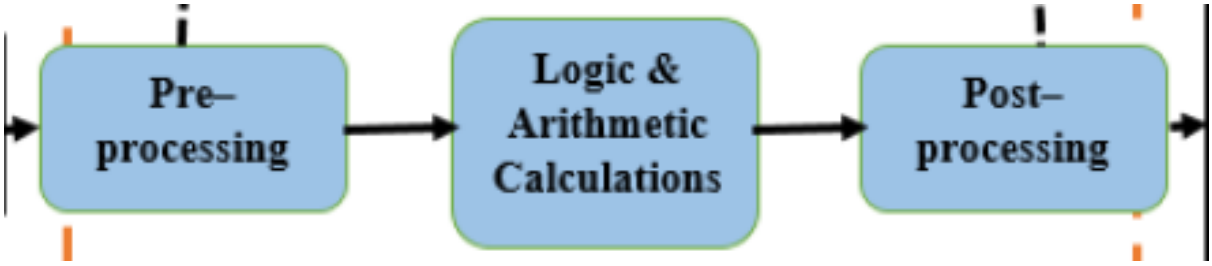
Logic and arithmetic control:

here in this block, the basic and complicated modes of calculations for the raw amplified data gathered from the patient's body through the sensor/transducer are performed.

- For example: signal filtering adjustment, based on operator selection mode, mathematical manipulation between inputs to calculate required parameter and so on.

Postprocessing:

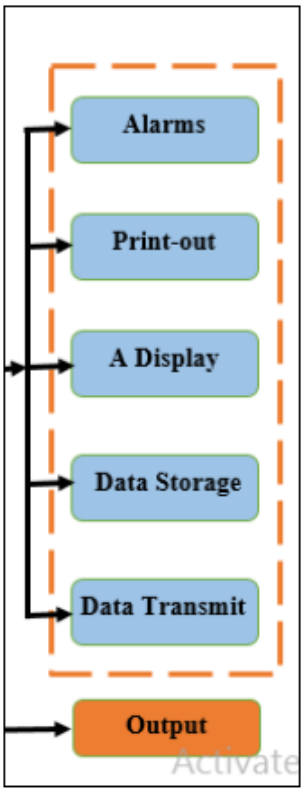
here the final processing is performed. Either based on manipulating the signal to match the requirement of the output elements or to adjust the scale of: time, frequency, and signal level for the real shape mode. Specialized digital circuits or a microcomputer are used to perform several functions like: average repetitive signal, reduce noise, and converting information from the time domain to the frequency domain.



Output:

The results of the measurement procedure must be demonstrated to an arrangement that the human operator can identify. The finest form of the display may be:

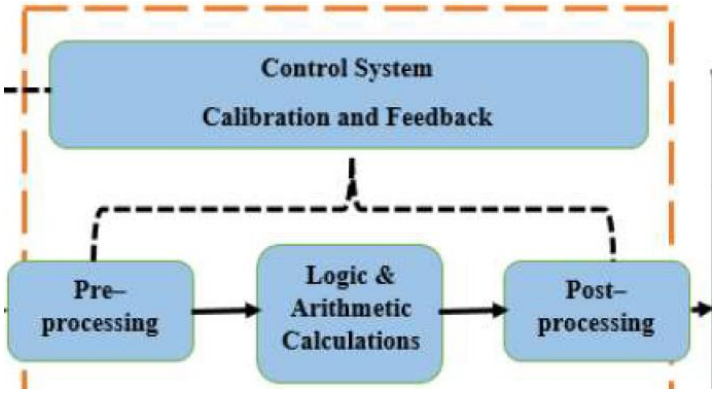
- ✓ a. Arithmetical or graphical,
- ✓ b. Discrete or continuous,
- ✓ c. Long-lasting or brief,
- ✓ d. Depending on the specific Measurand and how the operator will use the evidence.



Although most displays depend on our past experience, some information (Doppler ultrasound signals, for example) is best perceived by the other senses (here, the auditory sense). The different modes suggested In Figure are almost used in most of the medical devices, either alone or by matching number of them according to the device design criteria.

Control system

- A calibration signals with the properties of the Measurand should be applied to the sensor/transducer input, or
- As early in the signal–processing series as possible.
- Many forms into control and feedback may be requisite to elicit the Measurand, to fine-tune the sensor and signal conditioner, and to direct the flow of output for display, storage, or transmission.
- Control or feedback may be automatic or manual.
- Data may be stored concisely to meet the requirements of the signal conditioning or to allow the operator to examine data that precede alarm conditions.
- Otherwise, data may be stored before the signal conditioning, so that different processing arrangements can be used.
- Conventional principles of communication can often be used to transmit data on to remote displays at nurses' stations, medical centers, or medical data–processing facilities.



Lecture Two

Medical Devices: Modes of operation

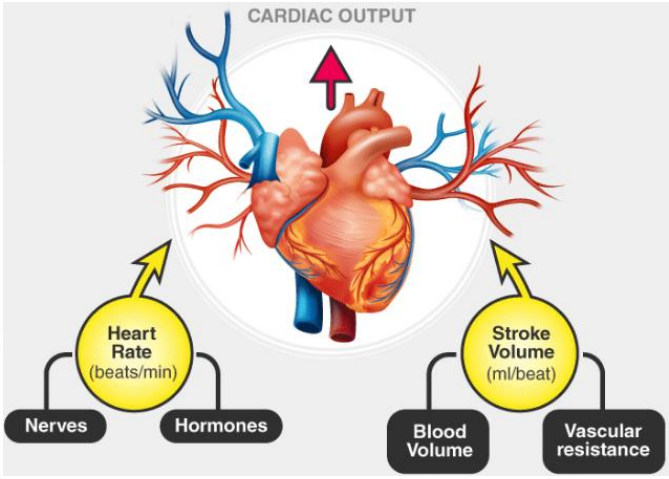
Direct and indirect Modes.

Frequently the chosen measurand can be interfaced directly to a sensor because the measurand is readily available or because suitable invasive techniques are presented. When the desired measurand is unavailable, we can use either an alternative measurand that tolerates a known relation to the desired one or some form of energy or material that interrelates with the desired measurand to create a measurand that is accessible. Examples include cardiac output (volume of blood pump per minute from the heart), determined from respiration and blood gas concentration or from dye dilution; morphology of internal organs, determined from x-ray shadows; and pulmonary volumes, determined from variations in thoracic impedance plethysmography.

CO = HR X SV

CARDIAC OUTPUT	=	HEART RATE	X	STROKE VOLUME
The amount of blood pumped by each ventricle in 1 minute		The number of contractions of the ventricles each minute		The amount of blood ejected from each ventricle with each contraction
AVERAGE 4000 — 5000 ml	=	70	X	70 ml

Factors affecting Cardiac Output	=	Sympathetic nervous system Epinephrine	X	Venous return (preload) Blood Volume Sympathetic nervous system (contractility) Peripheral resistance (afterload)

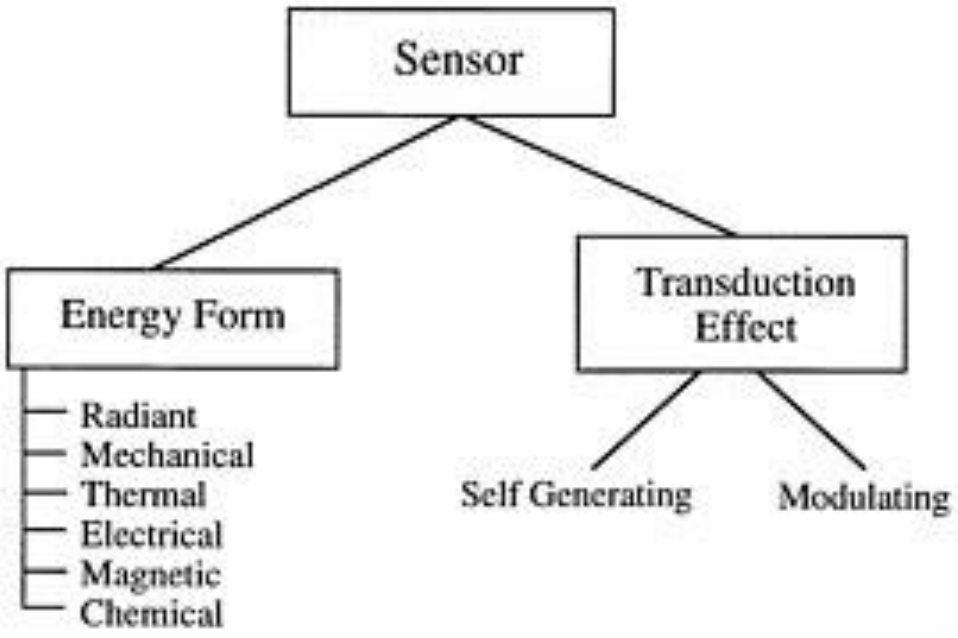


Sampling and continuous modes

Some measurand similar to body temperature and ion concentrations variated so slowly that they may be sampled rarely. Other measures, for example, the electrocardiogram and respiratory gas flow, may need continuous observation. The frequency content of the measurand, the objective of the measurements, the patient's state, and the physician's potential responsibility all guide how often medical data are requisite.

Generating and modulating sensors:

Generating sensors produce their signal output from the energy taken straightly from the measurand itself, like piezoelectric sensors. While in modulating sensors, the measurand modulates the flow of energy from an external source in a means that affects the output of the sensor, like the IR sensor. The photovoltaic cell is a generating sensor because it delivers an output voltage correlated to its irradiation without any other external energy source. Though a photoconductive cell is a modulating sensor to measure its change in resistance with irradiation, we must apply external energy to the sensor.



Analog and digital modes:

Signals that carry measurement data are either analog, meaning continuous, and capable of taking on any value within the dynamic range, or digital, meaning discrete and able to take on only a finite number of different values. Most presently available sensors operate in the analog mode, while some integrally digital measuring devices have been developed.

Enlarged use of digital signal processing had essential simultaneous use of analog to digital (AD) and digital to analog (DA) converters to interface computers with analog sensors and analog devices. Researchers have developed indirect digital indirect sensors that use analog primary sensing elements and digital variable conversion elements (optical shaft encoders). Also, quasi-digital sensors, such as quartz crystal thermometer, give outputs with varying frequency, pulse rate, or pulse duration that is easily converted to digital signals.

Real and Delayed Timed Modes:

Certainly, sensors must obtain signals in real-time as the signals really occur. The output of the measurement system may not display the result immediately, though, because some types of signal processing, such as averaging and transformations, need significant input before any results can be produced. Often, such short delays are suitable unless urgent feedback and control tasks depend on the output. In the case of some measurements, such as cell cultures, several days may be required before an output is obtained.

Medical Instrumentation Constraints.

Nearly all biomedical measurements depend either on some form of energy being applied to the living tissue or on some energy being applied as an incidental consequence of sensor operation. X-ray and ultrasonic imaging techniques and

electromagnetic or Doppler ultrasonic blood flowmeters depend on externally applied energy interacting with living tissue.

Safe levels of these various types of energy are difficult to establish because many mechanisms of tissue damage are not well understood. A fetus is particularly vulnerable during the early stages of development. The heating of tissue is one effect that must be limited because even reversible physiological changes can affect measurements. Damage to tissue at the molecular level has been demonstrated in some instances at surprisingly low energy levels.

The operation of instruments in the medical environment imposes important additional constraints. Equipment must be reliable, easy to operate, and capable of withstanding physical abuse and exposure to corrosive chemicals. Electronic equipment must be designed to minimize electric-shock hazards.

The safety of patients and medical personnel must be considered in all phases of the design and testing of instruments.

Medical and Physiological parameters

No.	Parameter or Measur. Techniques	Definition	Measur. range	Freq. range Hz	Standard sensor or Method	Reference
1	Ballistocardiography (BCG)	It is an old, noninvasive technique used to record the movements of the body synchronous with the heartbeat due to left ventricular pump activity.	0–7 mg	dc – 40	Accelerometer and strain gage.	Zajjur, 2003
			0–100 µm	dc – 40	Displacement Linear Variable Differential Transformer LVDT	
2	Bladder pressure	Measurement of the bladder pressure is one component of an urodynamic study. Normally, the viscoelastic properties of the bladder allow it to store increasing volumes of urine with little change in bladder pressure (compliance) until capacity is reached. There are two interrelated components of bladder compliance, the passive of the connective-tissue elements of the bladder and the active properties of the smooth muscle in the bladder.	1–100 cm H_2O	dc – 10	Strain gage manometer	Levin and Horan, 1999
3	Blood flow	Blood flow can be measured by cannulating a blood vessel, but this has obvious limitations. Blood velocity can be measured with **Doppler flow meters.** Ultrasonic waves are sent into a vessel diagonally, and the waves reflected from the red and white blood cells are picked up by a downstream sensor.	1–300 ml/s	dc – 20	Flowmeter (electromagnetic or Ultrasound)	Barret, et al., 2010
4	Direct Blood Pressure, arterial		100–400 mm Hg	dc – 50	Strain gage manometer	
	Indirect Blood Pressure arterial		25–400 mm Hg	dc - 60	Cuff, auscultation	

Classification of Biomedical Instruments:

The study of biomedical instruments can be approached from at least four viewpoints. Biomedical measurement techniques can be grouped according to the quantity ***sensed***, such as pressure, flow, or temperature. One advantage of this classification is that it makes different methods for measuring any quantity easy to compare.

A second classification scheme uses the ***principle of transduction***, such as resistive, inductive, capacitive, ultrasonic, or electrochemical. Different applications of each principle can be used to strengthen understanding of each concept; also, new applications may be readily apparent.

Measurement techniques can be studied separately for each ***organ system***, such as the cardiovascular, pulmonary, nervous, and endocrine systems. This

approach isolates all important measurements for specialists who need to know only about a specific area, but it results in a considerable overlap of quantities sensed and principles of transduction.

Finally, biomedical instruments can be classified according to the ***clinical medicine specialties,*** such as pediatrics, obstetrics, cardiology, or radiology. This approach is valuable for medical personnel who are interested in specialized instruments. Of course, certain measurements, such as blood pressure, are important to many different medical specialties.

INTERFERING AND MODIFYING INPUTS

Desired inputs are ***the measurands*** that the instrument is designed to isolate. ***Interfering inputs*** are quantities that inadvertently affect the instrument due to the principles used to acquire and process the desired inputs. If spatial or temporal isolation of the measurand is incomplete, the interfering input can even be the same quantity as the desired input.

A typical electrocardiographic recording system, shown in Figure 1, will serve to illustrate these concepts. The desired input is the electrocardiographic voltage v_{ecg} that appears between the two electrodes on the body surface. One interfering input is a 60 Hz noise voltage induced in the shaded loop by alternating environmental current (ac) magnetic fields.

The desired and the interfering voltages are in series, so both components appear at the input to the differential amplifier. Also, the difference between the capacitively coupled displacement currents flowing through each electrode and the body to ground causes an interfering voltage across Z_{body} between the two electrodes and two interfering voltages across Z_1 and Z_2, the electrode impedances.

COMPENSATION TECHNIQUES

1. Inherent Insensitivity: If all instrument components are inherently sensitive only to desired inputs, interfering and modifying inputs obviously have no effect.

2. Negative Feedback: When an adjusting input cannot be avoided, upgraded instrument performance needs a plan that makes the output less reliant on the transfer function.

3. Signal Filtering: a filter splits signals according to their frequencies. Most filters achieve this by reducing the part of the signal in one or more frequency bands.

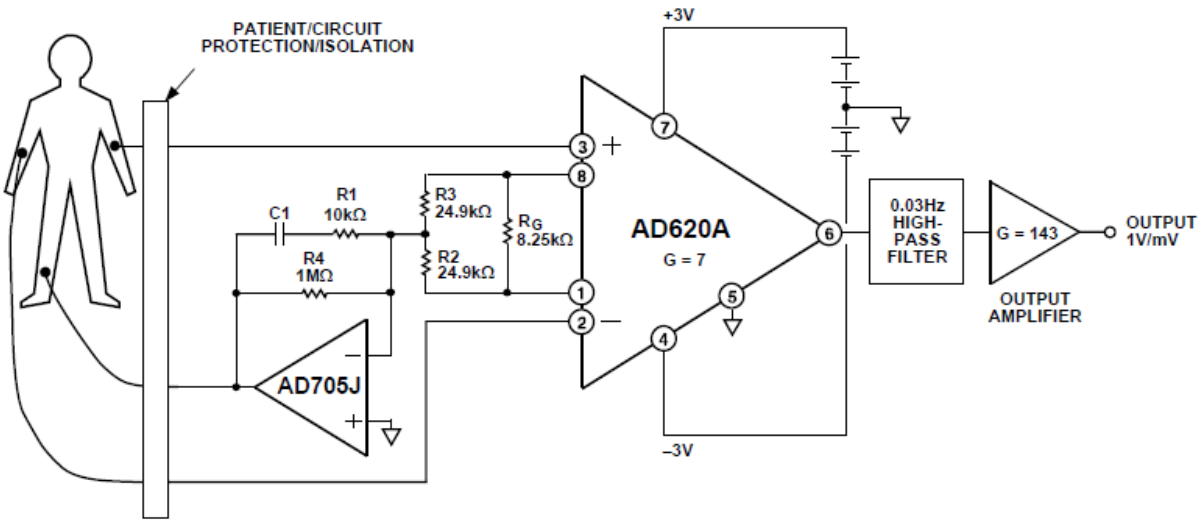
4. Opposing Inputs: when interfering or modifying inputs cannot be filtered, extra interfering inputs can be used to terminate undesired output components.

Homework:

Q1: Describe the quasi-digital sensors.

Q2: List four medical and physiological parameters, and mention their definition, measuring range, frequency range, and standard sensor or method.

Q3: Describe using the following Instrumentation amplifier in ECG circuit AD620A. Note: follow the information in the datasheet



Al-Mustaqbal University

Biomedical Engineering Department

Class: 4th

Subject: Biomedical Instrumentation Design I

Lecturer: Mr. Mahir Rahman Al-Hajaj

1st term – Lect. 3: Generalized Static Characteristics.

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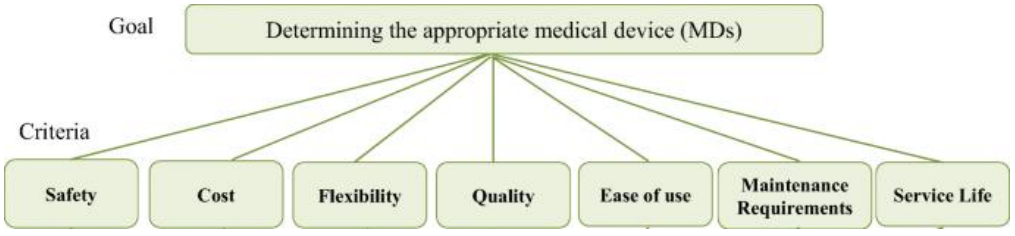
Generalized Static Characteristics

In this lecture, we explore the static characteristics that define the performance and reliability of biomedical instruments, which are crucial in ensuring accurate diagnostics and measurements in medical practice.

- Quantitative criteria for the performance of instruments are needed to enable purchasers to compare commercially available instruments and evaluate new instrument designs.
- These criteria must clearly specify how well an instrument measures the desired input and how much the output depends on interfering and modifying inputs.
- Static characteristics describe the performance of instruments for dc or very low-frequency inputs.
- The properties of the output for a wide range of constant inputs demonstrate the quality of the measurement, including non-linear and statistical effects.



Static Calibration

- The static performance characteristics are obtained in one form or another by a process.
- The calibration procedures involve a comparison of the particular characteristic with either a primary standard, a secondary standard with higher accuracy than the instrument to be calibrated, or an instrument of known accuracy.
- It checks the instrument against a known standard and subsequently for errors in accuracy.

Example: A thermometer used in a clinical setting must be calibrated against a known standard to ensure it gives accurate readings.

Scale range and scale span

- Range of instrument: the region between the limits within which an instrument is designed to operate for measuring, indicating, or recording a physical quantity.
- The Scale Range of an instrument is the difference between the largest and the smallest reading of the instrument. Understanding both the scale range and span of an instrument helps ensure that the device is appropriate for the measurement task and can handle the expected range of inputs."
- The span is the difference between the highest and the lowest point of calibration.
- *For example*, for a thermometer calibrated between 30°C to 40°C,

➢ The range is 30°C to 40°C.

➢ The span is 40 - 30 = 10°C.

Exercise: A scale has a range of 10-100 units and a calibration span of 90 units. Calculate the difference between the scale range and span.

ACCURACY

- The accuracy of a single measured quantity is the difference between the true value and the measured value divided by the true value.

$$Accuracy = \frac{True\ value - Measured\ Value}{True\ Value}$$

- For digital instruments, accuracy is often expressed in terms of digits, whereas for analog instruments, it may be based on divisions.
- This ratio is usually expressed as a percent, like percent of reading, percent of full scale, ± number of digits for digital readouts, or ± 1/2 the smallest division on an analog scale.
- For example, a converter may be termed 12-bit accurate if its error is 1 part in 4096.
- The sources of error contributing to the inaccuracy of a converter or linearly, gain, error, and offset
- error.
- If accuracy is expressed simply as a percentage, full scale is usually assumed.

ACCURACY

Exercise: A digital scale shows a weight reading of 50.2 kg. The true weight is known to be 50 kg. Calculate the percentage accuracy of the scale.

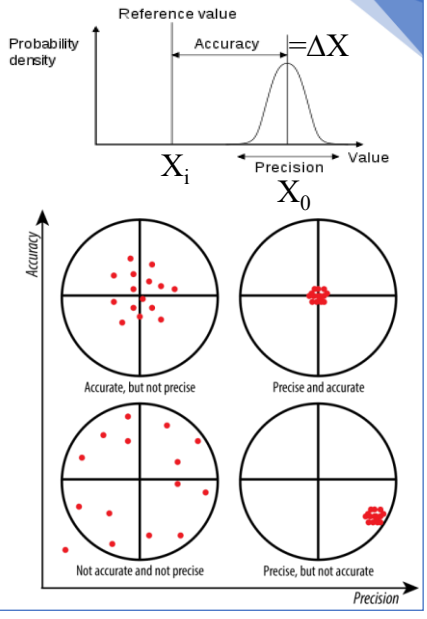
Solution: Accuracy = (True Value - Measured Value) / True Value × 100 = (50 - 50.2) / 50 × 100 = -0.4%.

Exercise: Suppose you calibrate a thermometer using a standard known to be 100°C. If the thermometer reads 99.5°C under the same conditions, calculate the calibration error.

Solution: Calibration error = (True Value - Measured Value) / True Value = (100 - 99.5) / 100 = 0.5%

PRECISION

- The precision of a measurement expresses the number of distinguishable alternatives from which a given result is selected.
- In clinical measurements, even precise instruments may produce inaccurate results if they are not calibrated correctly.
- For example, a meter that displays a reading of 2.434V is more precise than one that displays a reading of 2.43V.
- High-precision measurements do not imply high accuracy, however, because precision makes no comparison to the true value.



RESOLUTION

- Resolution is the smallest incremental quantity that can be measured with certainty.
- Or: the smallest increment of measurement, movement, or other output that a machine, instrument, or component is capable of making.
- If the measured quantity starts from zero, the term threshold is synonymous with resolution.
- Resolution expresses the degree to which nearly equal values of a quantity can be discriminated.

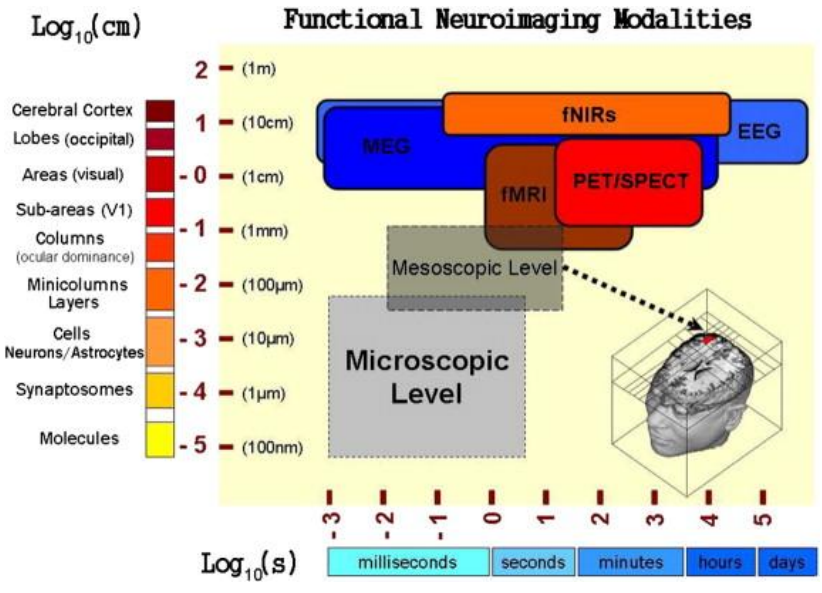
➢ The car's speedometer, with 20Km/h subdivisions, is an example of resolution.

- The resolution of the A/D converter is a measure of the number of discrete digital codes that it can handle and is expressed as the number of bits (binary). For example, for an 8-bit converter, the resolution is 1 part in 256.

➢ For example, a digital thermometer with a resolution of 0.1°C can distinguish temperatures between 23.4°C and 23.5°C.

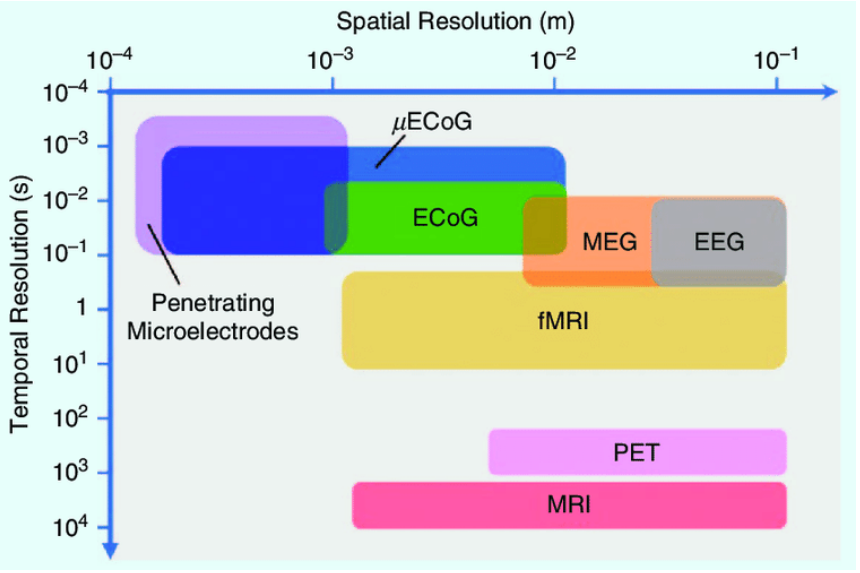
Exercise: If a digital thermometer has a resolution of 0.1°C, what would be the smallest difference between two measurable temperatures?

Solution: The smallest measurable temperature difference is 0.1°C.



Spatial and temporal comparison of the functional neuroimaging modalities.

Biomedical Instrumentation Design



Measures of Middle or Central Tendency

- **Average:** Most typical value or most expected value in a collection of numerical data
- **Mean:** The sum of all values divided by the number of different values. *Symmetrical data*. $\bar{X} = \frac{\sum X_i}{n}$
  - Geometric mean: asymmetric data, need to use a logarithmic scale. $GM = \sqrt[n]{X_1 X_2 X_3 \cdots X_n}$
  - Harmonic mean: Used when data is expressed in ratios (km/h) $HM = n / [1/x_1 + 1/x_2 + 1/x_3 + \ldots + 1/x_n]$
- **Median:** Middle value of the data set. Asymmetrical data due to outliers.
- The mean is typically used for symmetrical data, while the median is more appropriate for skewed distributions.
- **Mode:** Most frequently occurring value in data set.

1, 3, 3, 3, 5, 6, 6, 9, 9, 9 There are two modes: 3 and 9

1, 3, 3, **6**, 7, 8, 9

Median = 6

1, 2, 3, **4**, **5**, 6, 8, 9

Median = (4 + 5) ÷ 2

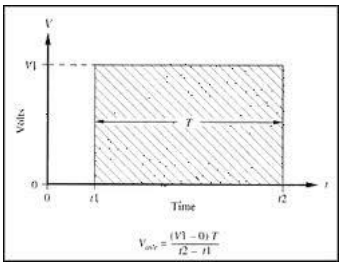
= 4.5

Measures of Middle or Central Tendency

- **Integrated average:**

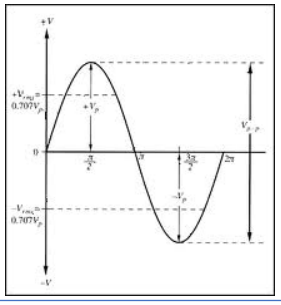
The area under the curve of the function basically signifies the magnitude of the quantity that is obtained by the product of the quantities signified by the x and the y axes.

The area under the Curve = ∫ab f(x)dx



- **Root-mean-square (rms):** the RMS is useful for summarizing the size of random fluctuations.

$$RMS = \sqrt{\frac{\sum(X^2)}{N}}$$



Measures of Spread or Dispersion

- **Standard Deviation:** A Measure of the spread of data about the mean. Used with mean for the symmetric distribution of numerical data (75% always between (X-2s and X+2s)
- In clinical testing, a standard deviation can indicate how much variability exists in patient test results, helping doctors to assess the reliability of the diagnostic method.
- **Coefficient of variation:** standardizes the variation for comparison of distributions measured on different scales. The higher the coefficient of variation, the greater the level of dispersion around the mean.
- **Standard Error of the Mean (SEM)**: expresses the variability to be expected among the means in future samples.

$$s = \sqrt{\frac{\sum(X_i - \bar{X})^2}{n-1}}$$

$$CV = \left(\frac{s}{\bar{X}}\right)(100\%)$$

$$s_{\bar{X}} = s/\sqrt{n-1}$$

Exercise: If a measurement is repeated five times with values: 5.10, 5.12, 5.11, 5.09, and 5.13, calculate the standard deviation to assess the precision of the instrument.
Solution: Calculate the mean and then the standard deviation for these values.

Relationship / Estimation & Hypothesis

- **Correlation coefficient, r:** Measures the relationship between numerical variables X and Y for paired observations

$$r = \frac{\sum(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum(X_i - \overline{X})^2}\sqrt{\sum(Y_i - \overline{Y})^2}}$$

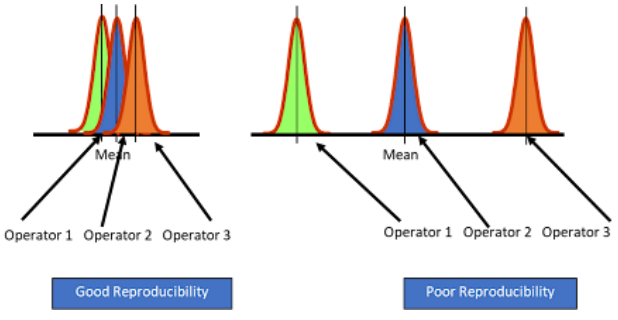
+1: positive, -1: negative linear relationship; 0: no relationship

- **Confidence intervals:** indicate the degree of confidence (percentage) that they contain the true value of a population mean.
- **Hypothesis testing**: reveals whether the sample gives enough evidence for us to reject the *null hypothesis* (a statement expressing the opposite of what we think is true)
- Hypothesis testing in biomedical instrumentation helps determine whether a new device is significantly more effective than existing devices.
- **P-value:** indicates how often the observed difference would occur by chance alone if nothing but chance were affecting the outcome.

Biomedical Instrumentation Design

REPRODUCIBILITY

- The ability of an instrument to give the same output for equal inputs applied over some period of time. It is the closeness of output readings when the same input is applied repetitively over a short period of time.
- The measurement is made on the same instrument, at the same location, by the same observer, and under the same measurement conditions.
- Perfect reproducibility means that the instrument has no drift.
- In medical diagnostics, it is crucial for instruments to consistently produce the same output when the same input is applied.



Drift

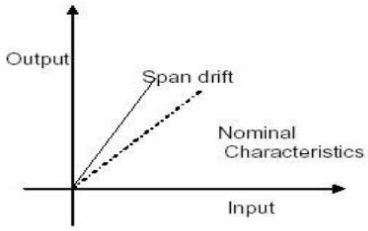
- Drift is a departure in the output of the instrument over a period of time.
- An instrument is said to have no drift if it produces the same reading at different times for the same variation in the measured variable.
- Drift may be of any of the following types;

➢ a) Zero drift: Drift is called zero drift if the whole instrument calibration shifts by the same amount.

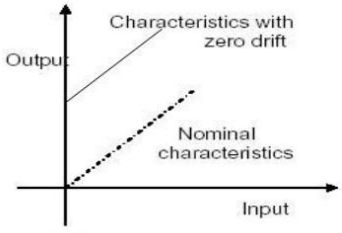
➢ b) Span drift: If the calibration from zero upwards changes proportionately, it is called span drift.

➢ c) Zonal drift: When the drift occurs only over a portion of the span of the instrument, it is called zonal drift.

Exercise: If an instrument exhibits a zero drift of 0.5% every month, calculate the drift after 6 months.
Solution: Drift after 6 months = 0.5% × 6 = 3%.



(Fig) span drift



(fig) zero drif

Thank You
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Al-Mustaqbal University

Biomedical Engineering Department

Class: 4th

Subject: Biomedical Instrumentation Design I

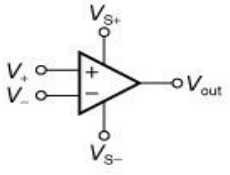
Lecturer: Mr. Mahir Rahman Al-Hajaj

1st term – Lect. 4: Introduction to Amplifiers.

Email: mahir.rahman@uomus.edu.iq

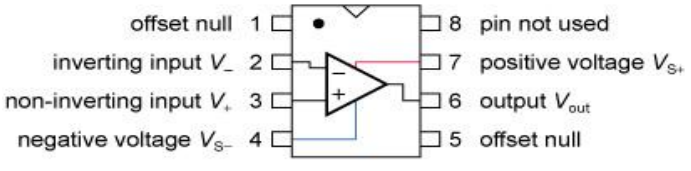
Biomedical Instrumentation Design

• Operational amplifiers are linear devices that have all the properties required for nearly ideal DC amplification and are therefore used extensively in signal conditioning, filtering or to perform mathematical operations such as add, subtract, integration and differentiation.



(a)

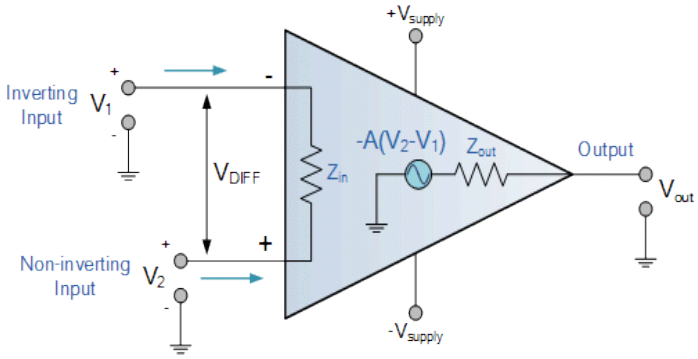
(b)



(c)

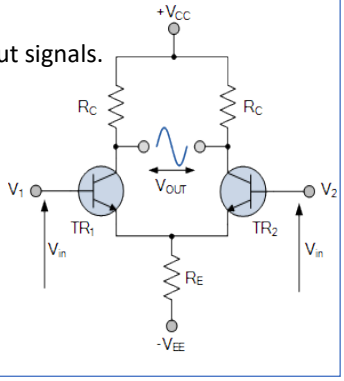
Biomedical Instrumentation Design

- Op-Amp is a three-terminal device which consists of:
- Two high impedance inputs, one is the Inverting Input (-) and the non-inverting Input (+).
- The third terminal represents the op-amp. output port which can sink and source *a voltage or a current.*
- The output signal of a linear op-amp.: is the amplification factor (gain (A)) multiplied by the value of the input signal.



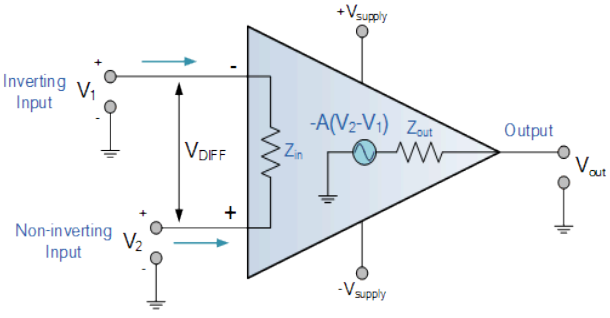
Biomedical Instrumentation Design

- *Differential Amplifier*
- The differential amplifier has two inputs marked V1 and V2, two identical transistors TR1 and TR2 are both biased at the same operating point with their emitters connected together and returned to the common rail, -Vee by way of resistor Re.
- The circuit operates from a dual supply, +Vcc and -Vee.
- The output voltage (Vout) of the amplifier is the difference between the two input signals.



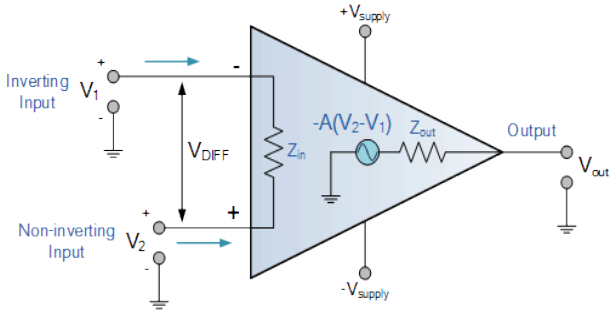
Biomedical Instrumentation Design

- Equivalent Circuit of an Ideal Operational Amplifier
- Open Loop Gain, (Avo): *Infinite* – Open-loop gain is the gain of the op-amp without positive or negative feedback, and for such an amplifier, the gain will be infinite, but typical real values range from about 20,000 to 200,000.
- Input impedance, (Z_{IN}): *Infinite* – Input impedance is the ratio of input voltage to input current and is assumed to be infinite to prevent any current from flowing from the source supply into the amplifiers input circuitry (I_{IN} = 0). Real op-amps have input leakage currents from a few pico-amps to a few milli-amps.



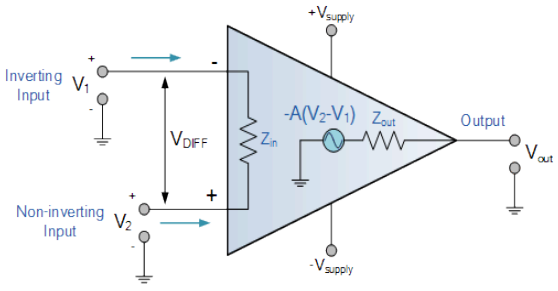
Biomedical Instrumentation Design

- Output impedance, (Z_{OUT}): Zero – The output impedance of the ideal operational amplifier is assumed to be zero acting as a perfect internal voltage source with no internal resistance so that it can supply as much current as necessary to the load. This internal resistance is effectively in series with the load, thereby reducing the output voltage available to the load. Real op-amps have output impedances in the 100-20kΩ range.



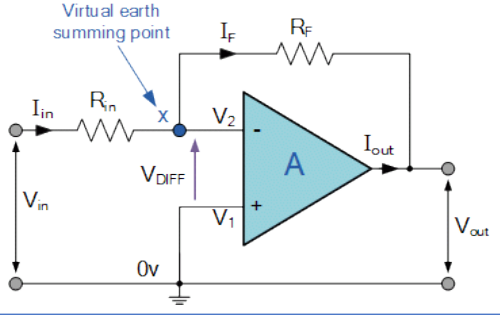
Biomedical Instrumentation Design

- Bandwidth, (BW): Infinite – An ideal operational amplifier has an infinite frequency response and can amplify any frequency signal from DC to the highest AC frequencies, so it is therefore assumed to have an infinite bandwidth. BW of real op-amps is limited by the Gain-Bandwidth product (GB), which is equal to the frequency where the amplifier's gain becomes unity.
- Offset Voltage, (V_{IO}): Zero – The amplifier's output will be zero when the voltage difference between the inverting and the non-inverting inputs is zero, the same or when both inputs are grounded. Real op-amps have some amount of output offset voltage.



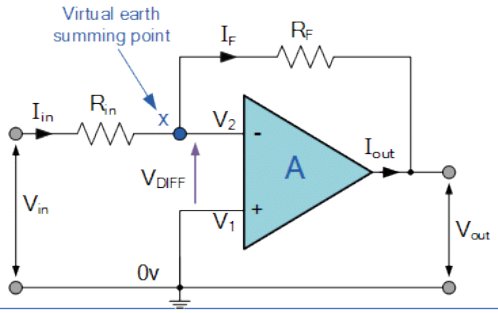
Biomedical Instrumentation Design

- Inverting Operational Amplifier
- The Inverting Operational Amplifier configuration is one of the simplest and most commonly used op-amp topologies.
- Since the Open Loop Gain, (A_{VO}) of an operational amplifier can be very high, as much as 1,000,000 or more, a few micro-volts, (μV) would be enough to cause the output voltage to saturate and swing towards one or the other of the voltage supply rails losing complete control of the output.



Biomedical Instrumentation Design

- Inverting Operational Amplifier
- To control the amplifier's overall gain, a suitable resistor is connected across the amplifier from the output terminal back to the inverting input terminal to both reduce and control the amplifier's overall gain.
- This then produces an effect known commonly as Negative Feedback, and thus produces a very stable Operational Amplifier based system.



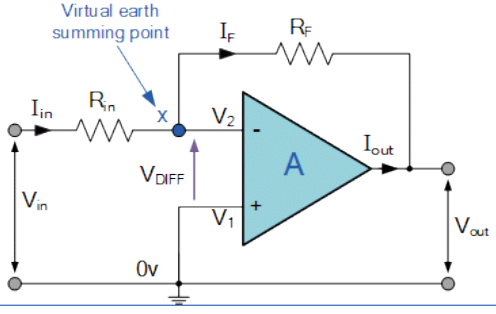
Biomedical Instrumentation Design

- Inverting Operational Amplifier Configuration
- The operational amplifier is connected with feedback to produce a closed-loop operation.
- The Closed-Loop Voltage Gain of an Inverting Amplifier is given as.

$$\text{Gain (Av)} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

- and this can be transposed to give Vout as:

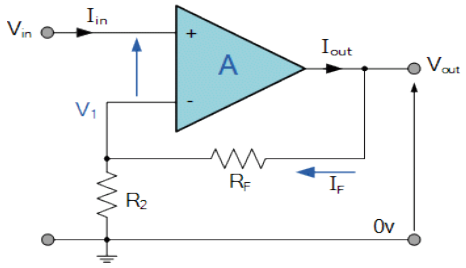
$$\text{Vout} = -\frac{\text{Rf}}{\text{Rin}} \times \text{Vin}$$



Biomedical Instrumentation Design

- Non-inverting Operational Amplifier
- The result of this is that the output signal is “in-phase” with the input signal.
- the closed-loop voltage gain of a Non-inverting Operational Amplifier will be given as:

$$A_{(V)} = \frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_F}{R_2}$$



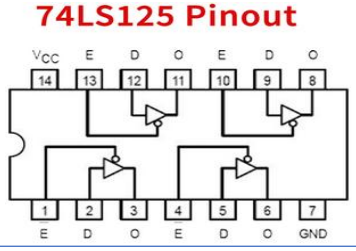
Biomedical Instrumentation Design

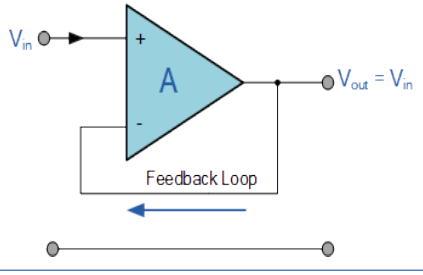
- Non-inverting Voltage Follower
- As the input voltage, Vin, is applied to the non-inverting input, the voltage gain of the amplifier is therefore given as:

$$V_{out} = A(V_{in})$$

$$(V_{in} = V+) \text{ and } (V_{out} = V-)$$

$$\text{therefore Gain, } (A_V) = \frac{V_{out}}{V_{in}} = +1$$





Biomedical Instrumentation Design

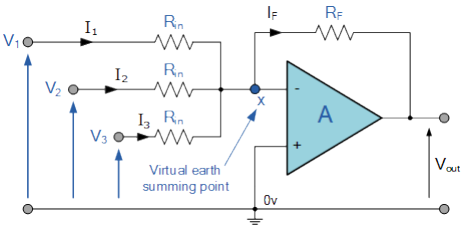
- The Summing Amplifier

$$I_F = I_1 + I_2 + I_3 = -\left[\frac{V1}{Rin} + \frac{V2}{Rin} + \frac{V3}{Rin}\right]$$

Inverting Equation: $Vout = -\frac{Rf}{Rin} \times Vin$

then, $-Vout = \left[\frac{R_F}{Rin}V1 + \frac{R_F}{Rin}V2 + \frac{R_F}{Rin}V3\right]$

$$-V_{OUT} = R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) \ldots.etc$$



- if all the input impedances, (RIN) are equal in value, we can simplify the above equation to give an output voltage of:

$$-Vout = \frac{R_F}{R_{IN}}\left(V1 + V2 + V3 \ldots.etc\right)$$

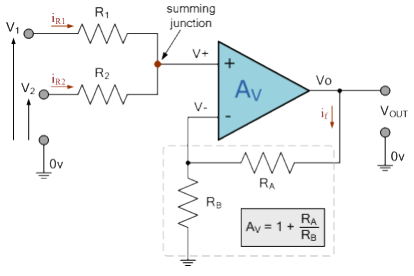
Biomedical Instrumentation Design

- Non-inverting Summing Amplifier
- Here we use the non-inverting input of the operational amplifier to produce a non-inverting summing amplifier.
- The standard equation for the voltage gain of a non-inverting summing amplifier circuit is given as:

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{V_{OUT}}{V+} = 1 + \frac{R_A}{R_B}$$

$$\therefore V_{OUT} = \left[1 + \frac{R_A}{R_B}\right]V+$$

$$\text{Thus: } V_{OUT} = \left[1 + \frac{R_A}{R_B}\right]\frac{V_1 + V_2}{2}$$



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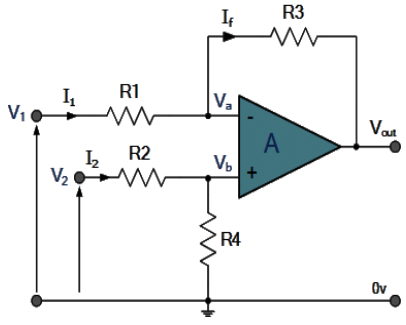
Al-Mustaqbal University
Biomedical Engineering Department
Class: 4th
Subject: Biomedical Instrumentation Design I
Lecturer: Mr. Mahir Rahman Al-Hajaj
1st term – Lect. 5: Amplifiers and Signal Processing, Part 2

Email: mahir.rahman@uomus.edu.iq

The Differential Amplifier

- Amplifies the voltage difference present on its inverting and non-inverting inputs, so its function is a **Subtractor**.
- When R1=R2 and R3=R4 the transfer function for the differential amplifier is:

$$V_{OUT} = \frac{R_3}{R_1}\left(V_2 - V_1\right)$$

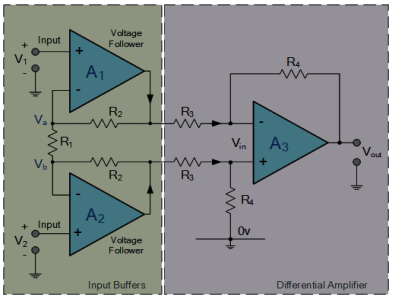


- If R1 = R2 = R3 = R4, then the circuit will become a **Unity Gain Differential Amplifier** and the transfer function for the differential amplifier will be

$$V_{out} = V_2 - V_1.$$

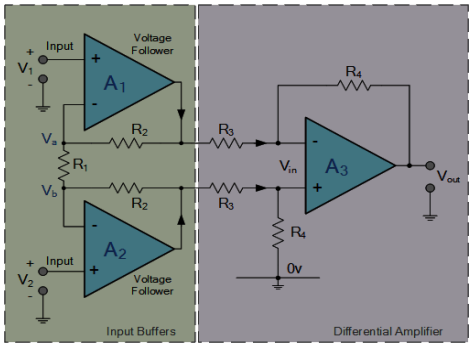
Instrumentation Amplifier

- Instrumentation Amplifiers (in-amps) are very high gain differential amplifiers which have a high input impedance and a single ended output.
- In-amps are mainly used to amplify very small differential signals from strain gauges, thermocouples or current sensing devices in motor control systems.
- In-amp have an internal feedback resistor that is effectively isolated from its input terminals as the input signal is applied across two differential inputs, V1 and V2. In-amp has a very good common mode rejection ratio, CMRR (zero output when V1 = V2).
- A typical example of a three op-amp instrumentation amplifier with a high input impedance (Zin) is given:



Instrumentation Amplifier

- The amplifiers A1 and A2 form a differential input stage acting as buffer amplifiers with a gain of $1 + 2R_2/R_1$ for differential input signals and unity gain for common-mode input signals.
- Since amplifiers A_1 and A_2 are closed loop negative feedback amplifiers, we can expect the voltage at Va to be equal to the input voltage V_1. Likewise, the voltage at Vb to be equal to the value at V_2.



Instrumentation Amplifier

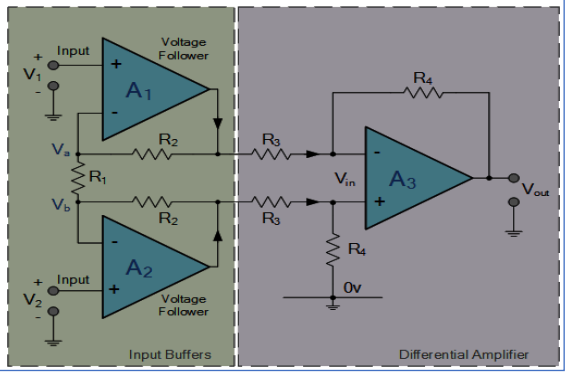
•Since the input voltage at the outputs of amplifiers A_1 and A_2 appears differentially across the three-resistor network, the *differential gain of the circuit can be varied by just changing the value of* R_1.

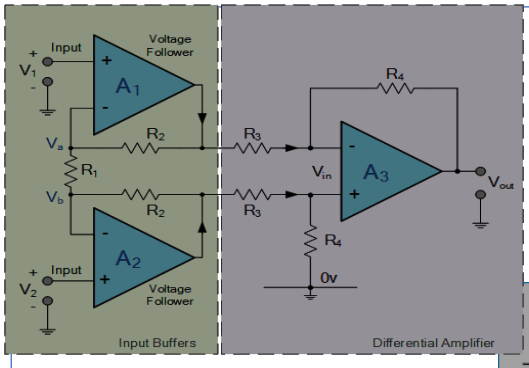
•The voltage output from the differential op-amp A_3, acting as a subtractor, is simply the difference between its two inputs (V2–V1), which is amplified by the gain of A_3.

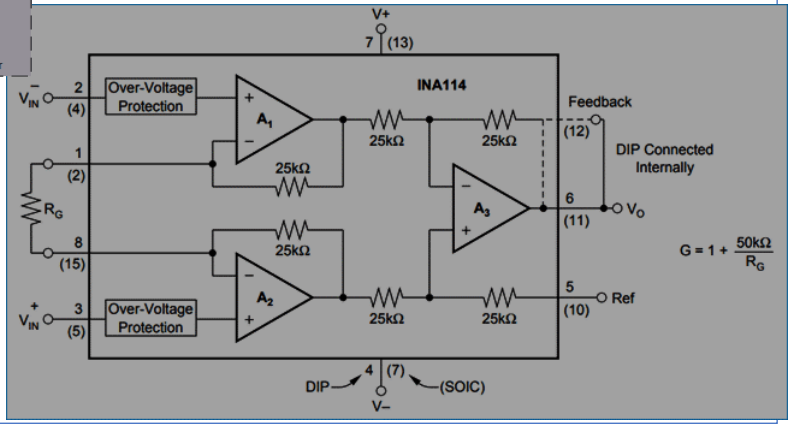
•The gain of A_3 may be unity, (assuming that R_3=R_4).

•The general expression for overall voltage gain of the instrumentation amplifier circuit

$$V_{OUT} = (V_2 - V_1)\left[1 + \frac{2R_2}{R_1}\right]\left(\frac{R_4}{R_3}\right)$$

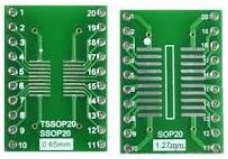


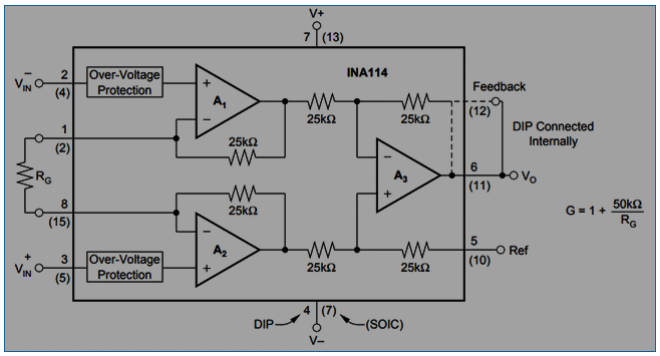




Instrumentation Amplifier

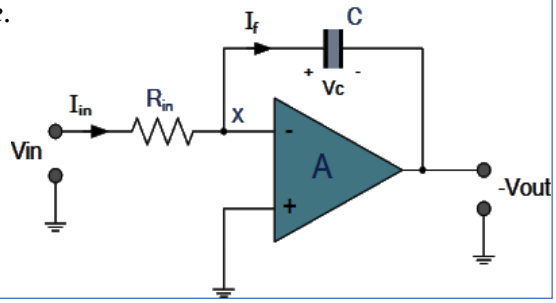
- Instrumentation amplifiers like INA114 IC
- A small outline integrated circuit (SOIC) is a surface-mounted integrated circuit (IC) package which occupies an area about 30–50% less than an equivalent dual in-line package (DIP)





Integrating Amplifier

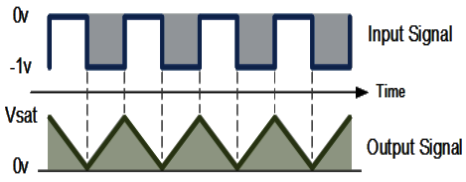
- In the integrator op-amp, the feedback element of an inverting amplifier is a capacitor C with a reactance X; thus, an RC Network will be connected across the operational amplifier feedback path.
- This op-amp performs the mathematical operation of **Integration**, where the output to respond to changes in the input voltage over time as the op-amp integrator produces an *output voltage which is proportional to the integral of the input voltage*.

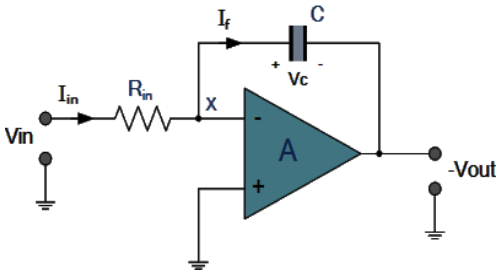


Integrating Amplifier

- The potential voltage, Vc, developed across the capacitor slowly increases, causing the charging current to decrease as the impedance of the capacitor increases.
- This results in the ratio of Xc/Rin increasing, producing a linearly increasing ramp output voltage that continues to increase until the capacitor is fully charged and the capacitor acts as an open circuit ((XC/RIN) now infinite, resulting in infinite gain).
- The output of the amplifier goes into saturation as shown below.

$$V_{out} = -\frac{1}{j\omega RC} V_{in}$$

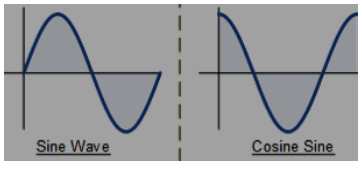


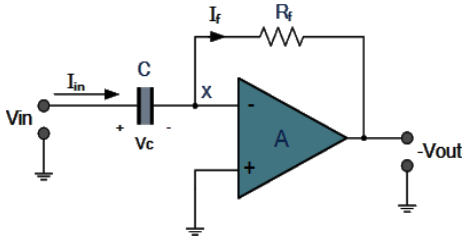


Differentiator amp.

- The input signal to the differentiator is applied to the capacitor.
- The capacitor blocks any DC content, so there is no current flow to the amplifier summing point, X, resulting in zero output voltage.
- At low frequencies, the reactance of the capacitor is "High", resulting in a low gain (R*f*/Xc) and low output voltage from the op-amp. At higher frequencies, the reactance of the capacitor is much lower, resulting in a higher gain and higher output voltage from the differentiator amplifier.
- The ideal voltage output for the op-amp differentiator is given as

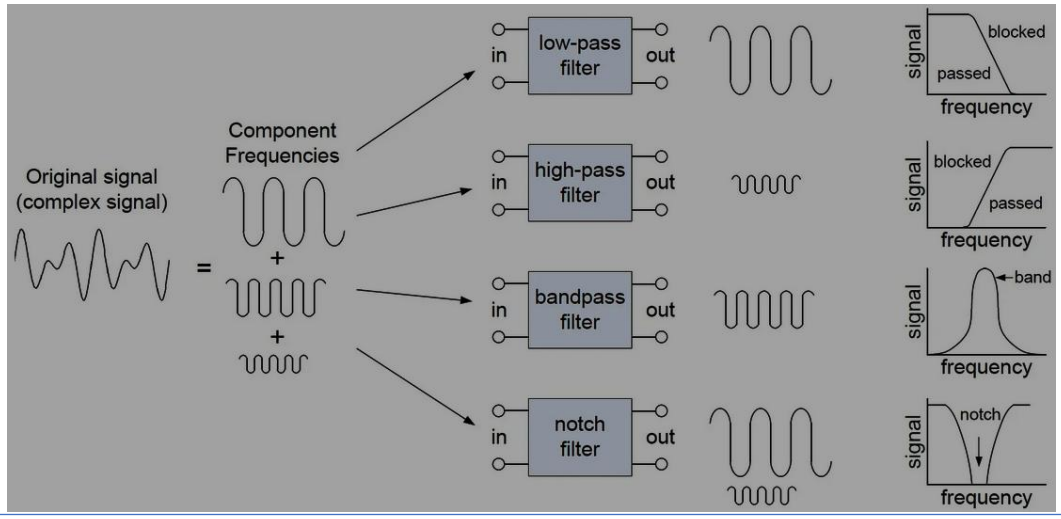
$$V_{OUT} = -R_F C \frac{dV_{IN}}{dt}$$





Active Filters

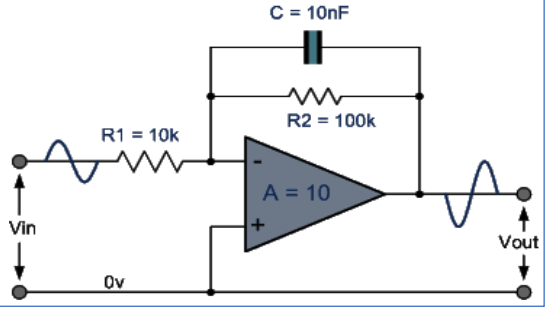
- The Active Filters contain active components such as operational amplifiers, transistors or FET's within their circuit design. They draw their power from an external power source and use it to boost or amplify the output signal.



Low Pass Active Filters

- A capacitor has been connected to its feedback circuit in parallel with R2, and this parallel combination of C and R2 sets the -3dB point as before but allows the amplifiers gain to roll off indefinitely beyond the corner frequency.
- At low frequencies, the capacitor's reactance is much higher than R2, so the dc gain is set by the standard inverting formula of: -R2/R1.
- As the frequency increases the capacitors reactance decreases reducing the impedance of the parallel combination of Xc||R2, until eventually at a high enough frequency, Xc reduces to zero.

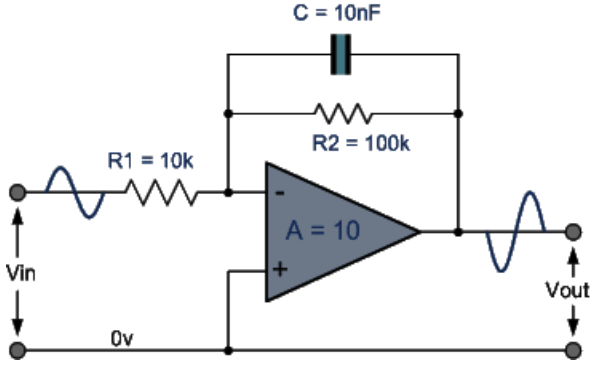
$$fc = \frac{1}{2\pi C R_2} \; Hertz$$



Low Pass Active Filters

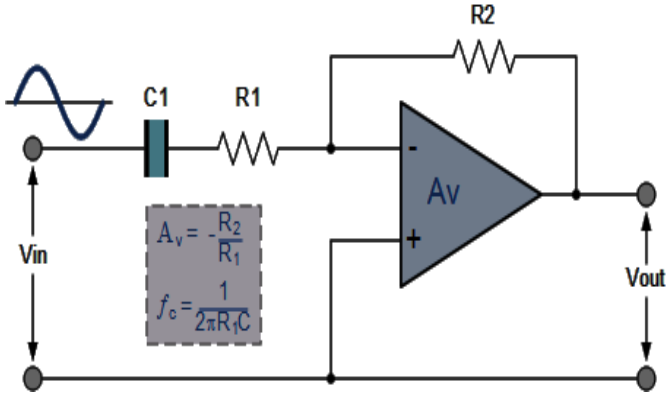
- The advantage of this configuration of LPF is that the circuit's input impedance is now just R1 and the output signal is inverted.
- With the corner frequency determining components in the feedback circuit, the RC set-point is unaffected by variations in source impedance and the dc gain can be adjusted independently of the corner frequency.

$$fc = \frac{1}{2\pi C R_2} \; Hertz$$



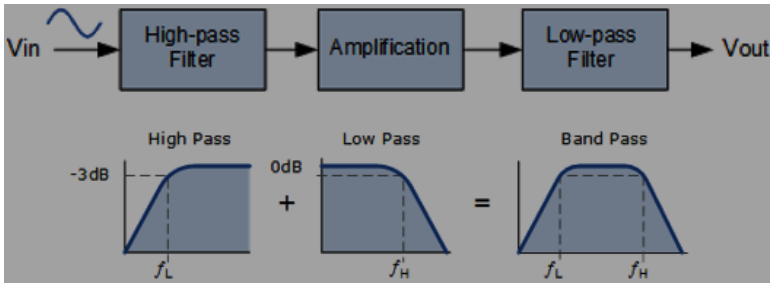
High Pass Active Filters

- The basic operation of an Active High Pass Filter (HPF) is the same as for its equivalent RC passive high pass filter circuit, except the circuit has an operational amplifier or is included within its design providing amplification and gain control



Active Band Pass Filters

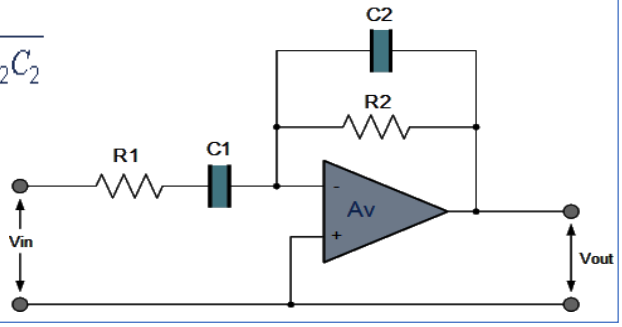
- The Active Band Pass Filter is a frequency-selective filter circuit used in electronic systems to separate a signal at one particular frequency or a range of signals that lie within a certain "band" of frequencies from signals at all other frequencies.
- This band or range of frequencies is set between two cut-off or corner frequency points labelled the "lower frequency" (fL) and the "higher frequency" (fH) while attenuating any signals outside of these two points.
- Simple Active Band Pass Filter can be easily made by cascading together a single Low Pass Filter with a single High Pass Filter as shown:



Active Band Pass Filters

- The cut-off or corner frequency of the low pass filter (LPF) is higher than the cut-off frequency of the high pass filter (HPF).
- The difference between the frequencies at the -3dB point will determine the "bandwidth" of the bandpass filter while attenuating any signals outside of these points.
- One way of making a very simple Active Band Pass Filter is to connect the basic passive high and low pass filters we look at previously to an amplifying op-amp circuit as shown:

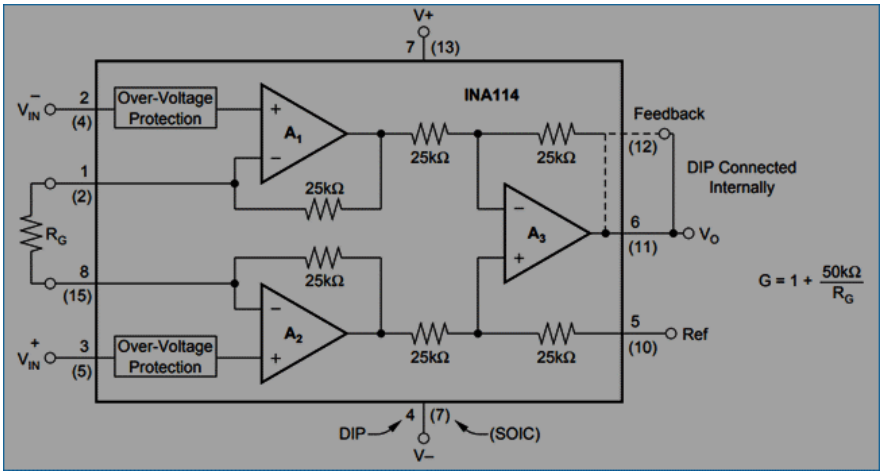
$$Voltage\ Gain = -\frac{R_2}{R_1},\quad fc_1 = \frac{1}{2\pi R_1 C_1},\quad fc_2 = \frac{1}{2\pi R_2 C_2}$$



Question

- Calculate V_o for the In-amp. INA114 IC when Vin-=20µV, Vin+=50µV, Consider RG for the following cases:

I: RG=470kΩ, II:RG=50kΩ, III: RG=20kΩ . Comment on your results.



THANK YOU!

Al-Mustaqbal University
Biomedical Engineering Department
Class: 4th
Subject: Biomedical Instrumentation Design I
Lecturer: Mr. Mahir Rahman Al-Hajaj
1st term – Lect. 6: Temperature measurements.

Email: mahir.rahman@uomus.edu.iq

Temperature Measurements

- *External body temperature* is one of many parameters used to evaluate patients in shock, because the reduced blood pressure of a person in circulatory shock results in low blood flow to the periphery.
- *Infections*: are usually reflected by an increase in body temperature, with a hot, flushed skin and loss of fluids.
- *Anesthesia* decreases body temperature by depressing the thermal regulatory center. Physicians routinely induce hypothermia in surgical cases in which they wish to decrease a patient's metabolic processes and blood circulation.

Temperature Measurements

- In pediatrics, *special heated incubators* are used for stabilizing the body temperature of infants via accurate monitoring of temperature, and regulatory control systems are used to maintain a desirable ambient temperature for the infant.
- In *arthritis*, the temperatures of joints are closely correlated with the amount of local inflammation. The increased blood flow due to arthritis and chronic inflammation can be detected by thermal measurements.
- ***The specific site of body-temperature recording must be selected carefully so that it truly reflects the patient's temperature.***

Temperature Measurements

NORMAL BODY TEMPERATURE RANGES

°F	0 - 2 years	3 - 10 years	11 - 65 years	> 65 years
Oral	—	95.9 99.5	97.6 99.6	96.4 98.5
Rectal	97.9 100.4	97.9 100.4	98.6 100.6	97.1 99.2
Axillary	94.5 99.1	96.6 98.0	95.3 98.4	96.0 97.4
Ear	97.5 100.4	97.0 100.0	96.6 99.7	96.4 99.5
Core	97.5 100.0	97.5 100.0	98.2 100.2	96.6 98.8

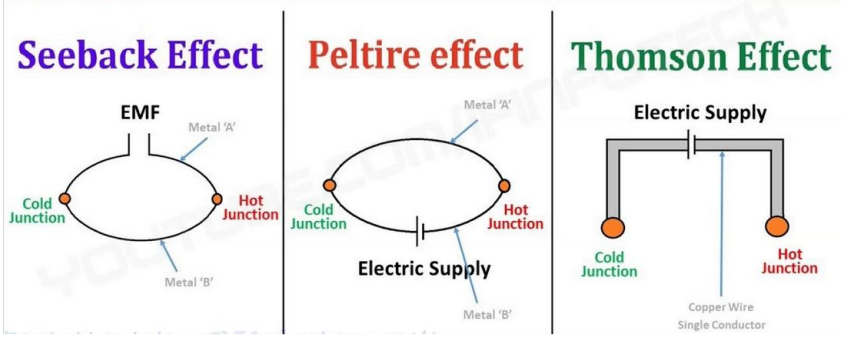
THERMOCOUPLES

- Thermoelectric thermometry is based on the observation that an electromotive force (emf) exists across a junction of two dissimilar metals.

➢ ***Peltier emf:*** is an emf due solely to the contact of two unlike metals and the junction temperature. The net Peltier emf is roughly proportional to the difference between the temperatures of the two junctions.

➢ ***Thomson emf:*** is an emf due to the temperature gradients along each single conductor. The net Thomson emf is proportional to the difference between the squares of the absolute junction temperatures (T1 and T2).

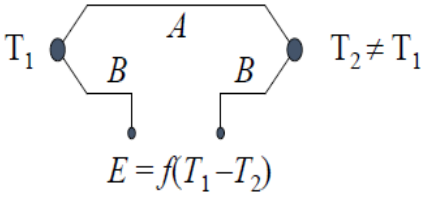
THERMOCOUPLES



Seebeck Effect: Generates an EMF (voltage) when two dissimilar metals are exposed to a temperature difference. This effect is used in thermocouples for temperature measurement.Peltier Effect: Occurs when an electric current flows through two different materials, causing heat absorption at one junction and heat release at the other. It is the basis for thermoelectric coolers.Thomson Effect: Describes heat generation or absorption along a single conductor when an electric current flows through a material with a temperature gradient.

THERMOCOUPLES

- The magnitudes of the Peltier and Thomson emfs depend on the metals chosen. The Seebeck voltage (appears due to current flows in the circuit, that is caused by the difference in temperature between the two junctions) .
- Thermocouple circuit with two dissimilar metals, A and B, at two different temperatures, T1, and T2, and f is the relative Seebeck coefficient of thermocouple (V/K). E is thermo emf.



THERMISTORS

- Thermistors: semiconductors made of ceramic materials that are thermal resistors with a high negative temperature coefficient (NTC) .
- Their resistance decreases as their temperature increases (opposite to metals). The resistivity is between 0.1 and 100Ω.m,
- These devices are small in size (less than 0.5 mm in diameter), have a relatively large sensitivity to temperature changes (-3 to -5 %/°C), and have excellent long-term stability characteristics (±0.2% of nominal resistance value per year).

THERMISTORS

• The empirical relationship between the thermistor resistance Rt, and absolute temperature T in kelvin (K) is:

$$R_t = R_o e^{[\frac{\beta(T_0 - T)}{TT_0}]}$$

• Where: β: material constant for thermistor, K

T_o: standard reference temperature, K

• The value of β increases slightly with temperature. However, this does not present a problem for biomedical work (10 °C to 20 °C).

• β, also known as the characteristic temperature, is in the range of 2500 to 5000 K. It is usually about 4000 K.

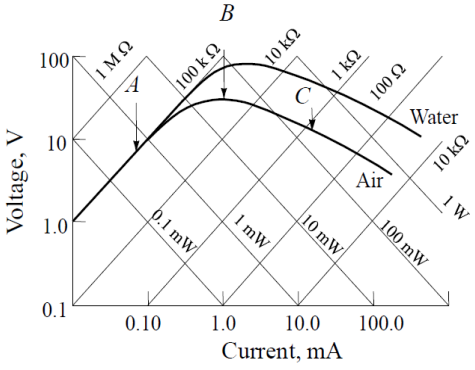
THERMISTORS

• The thermistor's voltage-versus-current characteristic in air and water is plotted in this figure.

• Point A is the maximal current value for no appreciable self-heat.

• Point B is the peak voltage.

• Point C is the maximum safe continuous current in air.

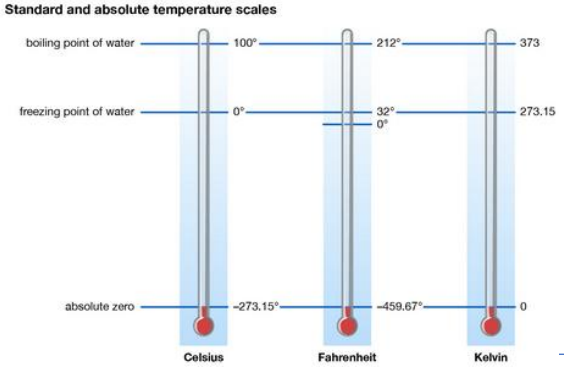


Radiation thermometry

- The radiation thermometry is the relationship between the surface temperature of an object and its radiant power, were it is possible to measure the temperature of a body without physical contact with it.
- In medical thermography, the temperature distribution of the body is mapped with a sensitivity of a few tenths of a kelvin.
- The skin temperature can vary from place to place depending on the cellular or circulatory processes occurring at each location in the body.
- ***HW: Discuss an application of medical thermography.***

Radiation thermometry

- Everybody that is above absolute zero (−273.15 °C) radiates electromagnetic power, that depends on the body's temperature and physical properties. At room temperature, the spectrum is predominantly in the far- and extreme-far-infrared regions.
- A blackbody is an ideal thermal radiator; as such, it absorbs all incident radiation and emits the maximal possible thermal radiation.



Radiation thermometry

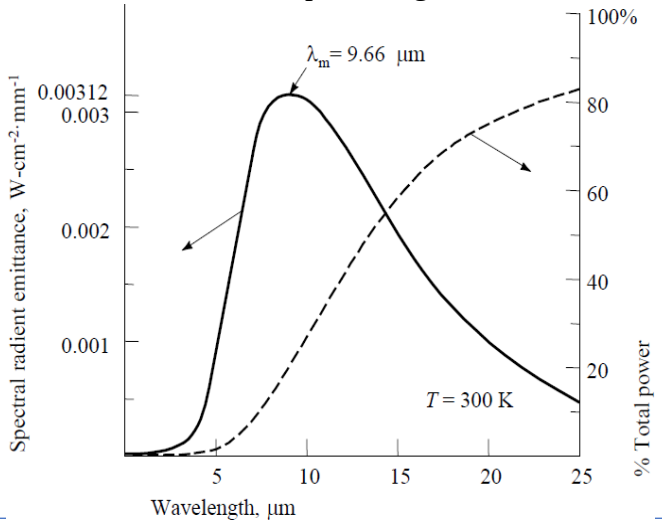
- The radiation emitted from a body is given by Planck's law multiplied by emissivity ε. This expression relates the radiant flux per unit area per unit wavelength W_λ at a wavelength λ (μm) and is stated as:

$$W_\lambda = \frac{\varepsilon C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)} \ (\mathrm{W/cm^2.\mu m})$$

- Where: C1=3.47X100 (W.μm4/cm2) , C2=1.44X104 (μm.K)
- T= blackbody temperature, K
- ε= emissivity, the extent by which a surface deviates from blackbody (ε=1)

Radiation thermometry

- This figure shows the spectral radiant emittance versus wavelength for a blackbody at 300K on the left vertical axis; percentage of the total energy on the right vertical axis.



Radiation thermometry

- This Wien's displacement law gives the wavelength λm for which W_λ is a maximum.

$$\lambda_m = \frac{2898}{T}(\mu m)$$

- The total radiant power *Wt* can be found by integrating the area under the curve. The expression is known as the Stefan Boltzmann law

$$W_t = \varepsilon\, \sigma\, T^4 \ (\mathrm{W/cm2})$$

Where σ is the Stefan-Boltzmann constant equals to: $5.67X10^{-12}$ $(W/cm^2)K^4$.

Radiation thermometry

- The lenses used in infrared instruments must be carefully selected for their infrared spectral properties (standard glass used for the visible spectrum does not pass wavelengths longer than 2μm).
- Some materials (such as arsenic trisulfide) readily pass infrared and not visible light.

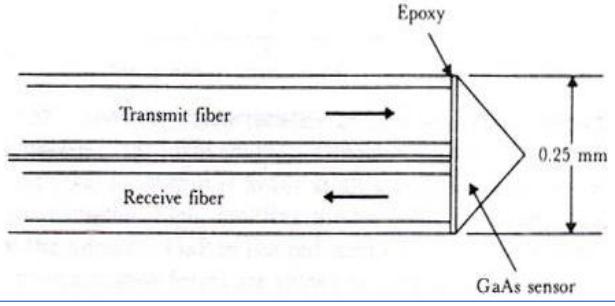
Material	Chemical Symbol	Wavelength μm	Reflection (Two Surfaces)	Knoop Hardness	Soluble in H2O
Calcium Fluoride	CaF2	0.13 – 10	5%	158	Yes
Sapphire	Al2O3	0.15 – 5.5	14%	2000	No
IR Polymer	N/A	0.15 – 22	21%	N/A	No
Germanium	Ge	1.8 – 23	53%	780	No
Zinc Selenide	ZnSe	0.5 – 22	29%	120	No
Barium Fluoride	BaF2	0.15 – 12.5	7%	82	yes

Radiation thermometry

- The Infrared detectors and instrument systems must be designed:
  - ➢high sensitivity because of the weak signals.
  - ➢short response time and appropriate wavelength bandwidth requirements that match the radiation source.
- Thermal and photon detectors are used as infrared detectors. The detectors are of two types:
  - ➢thermal detector has low sensitivity and responds to all wavelengths
  - ➢quantum detectors respond only to a limited wavelength band.

Fiber Optic Temperature Sensors

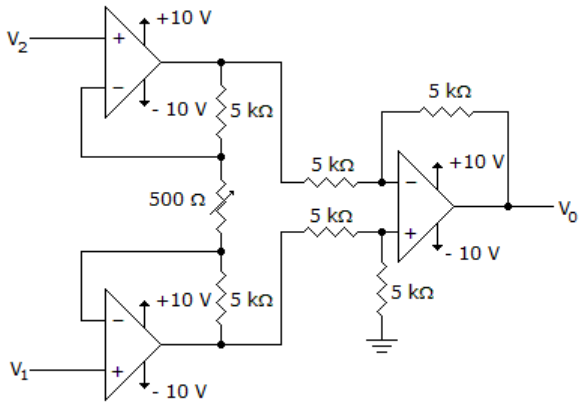
- The Gallium arsenide (GaAs) semiconductor temperature probe contains a small prism-shaped sample of single crystal undoped GaAs that is epoxied at the ends of two side by side optical fibers.
- One fiber transmits light from a light emitting diode source to the sensor, where it is passed through the GaAs and collected by the other fiber for detection in the readout instrument.



THANK YOU!

Q1: Calculate the output voltage for this circuit when V1 = 2.5 V and V2 = 2.25 V.

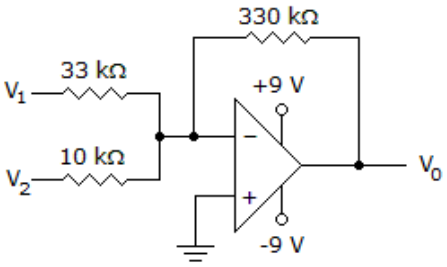
Ans.
Vo = 5.25 V



Q2: Calculate the output voltage if V1 = –0.2 V and V2 = 0 V.

Ans.:

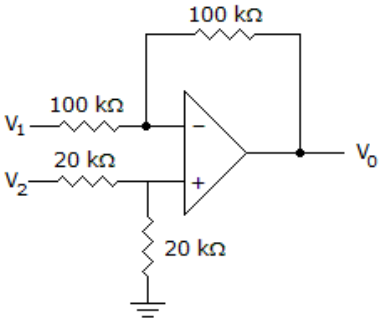
Vo= 2V



Q3: Calculate the output voltage when $V_1 = -V_2 = 1$ V.

Ans.:

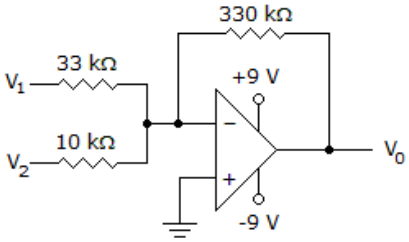
Vo= -2V



Q4: Calculate the output voltage if $V_1 = V_2 = 0.15$ V.

Ans.

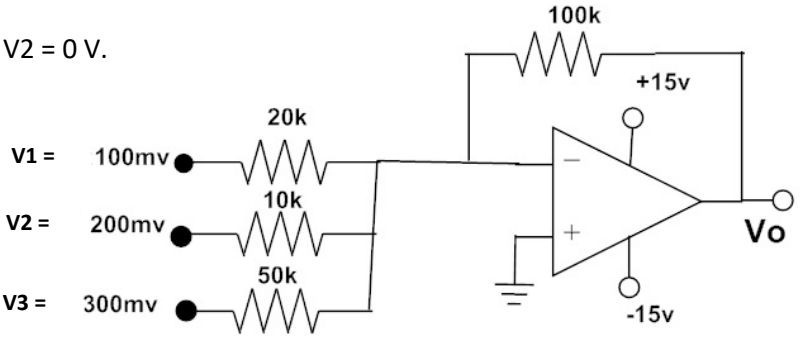
Vo= –6.45 V



Q5: Calculate the output voltage if V1 = –0.2 V and V2 = 0 V.

Ans.

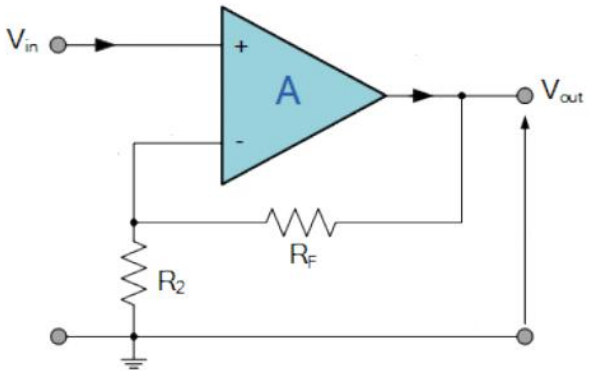
Vo = -3.1V



Q6: Determine the output when Vin=0.8V, Rf=20KΩ, Rf=10KΩ

Ans.

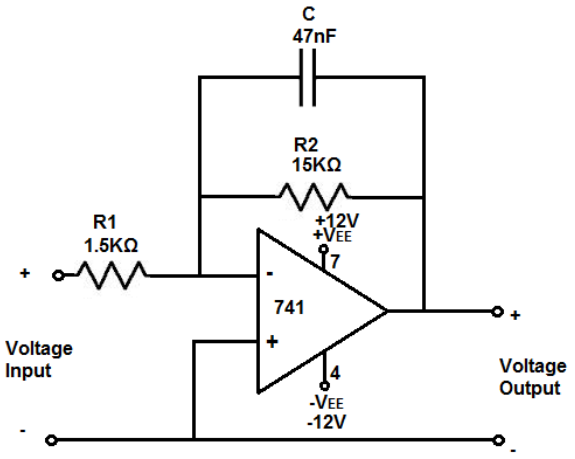
Vo = 2.4V



Q7: Determine the cutoff frequency for the active inverting Op-Amp LPF Circuit.

Ans.

f_c = 226Hz



Q8: Determine the lower and higher cutoff frequencies and gain for the active inverting Op-Amp Bandpass filter Circuit.

Ans.

F_{CL} = 1KHz

F_{CH} = 3.2KHz

Av = -10.