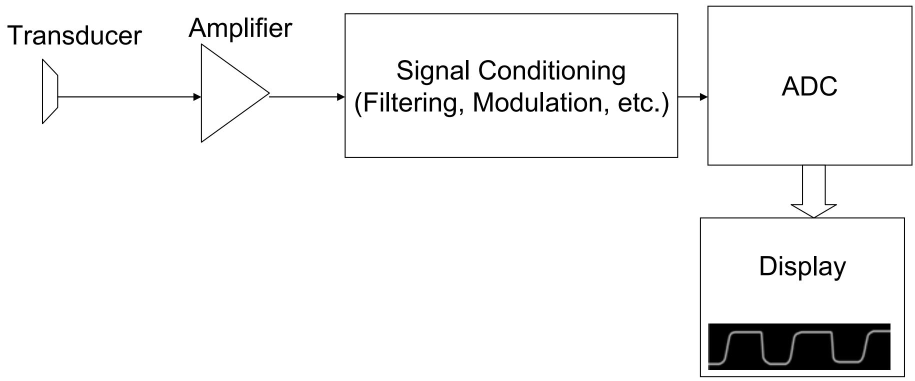
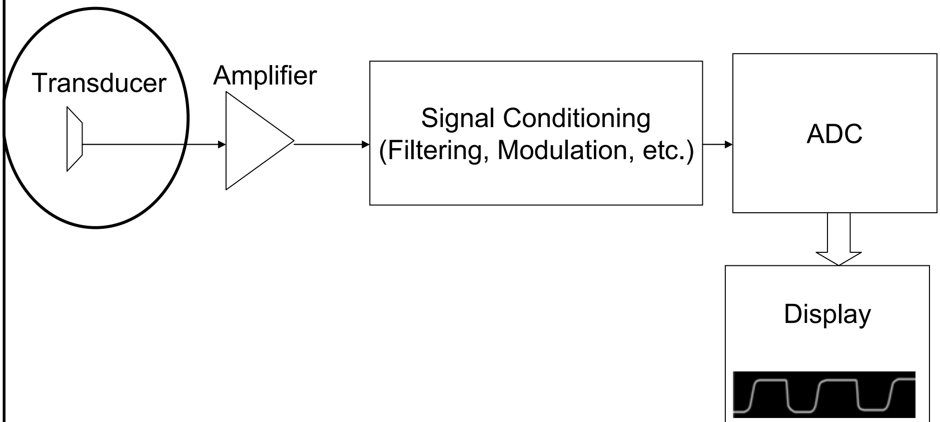
Monitoring in Anaesthesia and Critical Care

Dr. Azzam F. G. Taktak

Physiological Measurement System

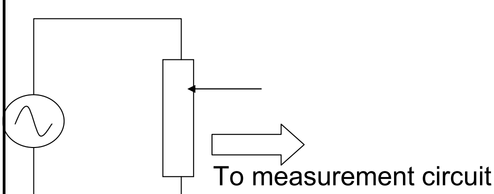


Physiological Measurement System

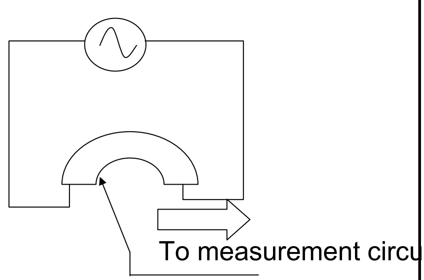


Resistive Sensors

Potentiometers



Translational



Rotational

Resistive Sensors

Strain Gauge

$$R = \rho \frac{L}{A}$$

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - \frac{\Delta A}{A} + \frac{\Delta \rho}{\rho}$$

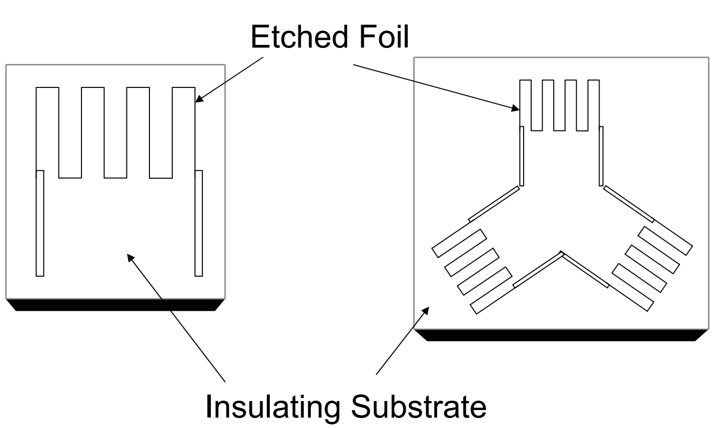
Gauge Factor:

$$G = \frac{\Delta R / R}{\Delta L / L}$$

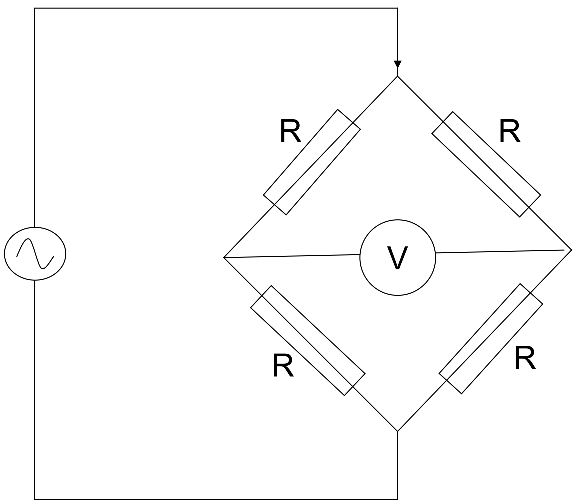
For most metals and alloys G = 2-3
For some semiconductors G = 200

Resistive Sensors

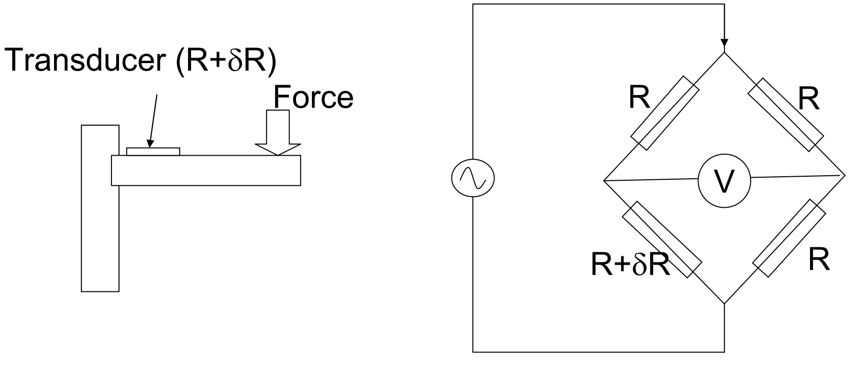
Strain Gauges



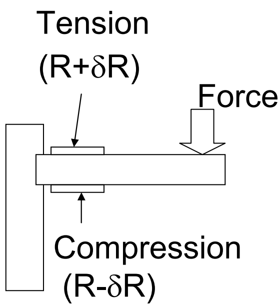
Measurement Circuits

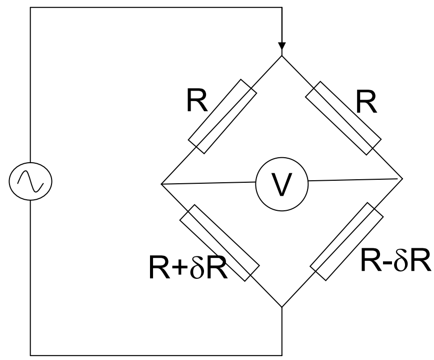


Strain Gauge Measurement



Strain Gauge Measurement





Twice the sensitivity

Inductive Sensors

$$L = n^2 G \mu$$

n = number of turns of the coil
G = geometric form factor
μ = effective permeability of the medium

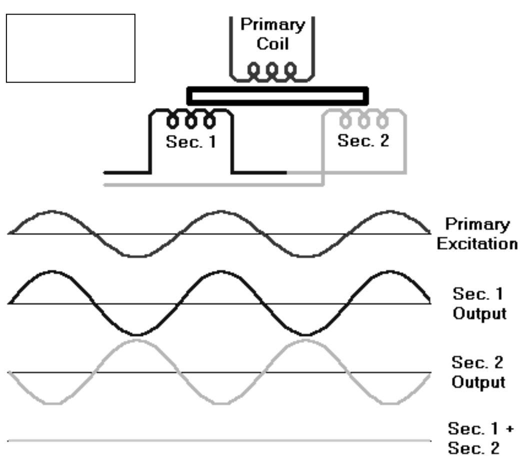
Inductive Sensors

Linear Variable Differential Transformer (LVDT)

• Used in pressure, displacement and force measurements
• Much higher sensitivity than for strain gauges but the processing apparatus is more complex.
• Primary coil wound around a sliding metal core with a secondary winding around the two ends of the core. As the core is displaced the voltage induced in the secondary winding changes such that the output voltage increases as the core moves to each side of the centre position and the phase changes by 180 degrees as it passes through the centre.
• A phase sensitive detector is required to convert the signal into a displacement..

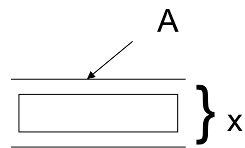
Inductive Sensors

Linear Variable Differential Transformer (LVDT)



Capacitive Sensors

$$C = \varepsilon_0 \varepsilon_r \frac{A}{x}$$



ε_0: dielectric constant of free space
ε_r: relative dielectric constant of insulator (1 in air)

Capacitive Sensors

- Compliant plastics placed between foil layers to form capacitive mats placed under beds
- Used to measure respiratory movements from the lungs and ballistographic movement from the heart
- Layers of mica insulators sandwiched between corrugated metal layers
- Used to measure pressure between foot and shoe

Piezoelectric Sensors

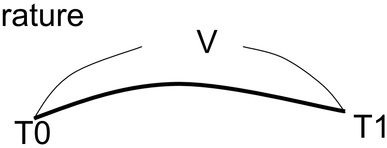
- Some crystals generate voltage when mechanically strained and vice versa
- q=kf where k is the piezoelectric constant
- k = 2.3 pC/N for quartz and 140 pC/N for barium

Piezoelectric Sensors

Temperature Sensors

Thermocouples

If two different metals (or alloys) are joined together, a contact potential results depending on the metals and the junction temperature



Power series $V = a_1(T_1 - T_0) + a_2(T_1 - T_0)^2 + a_3(T_1 - T_0)^3 + ...$

Advantages
-Linear characteristics

Disadvantages
-Unwanted thermo-electric potentials in the measurement circuit
-Reference temperature

Temperature Sensors

Thermistors

Temperature sensitive resistors with –ve temperature coefficient. Made from semiconductor materials

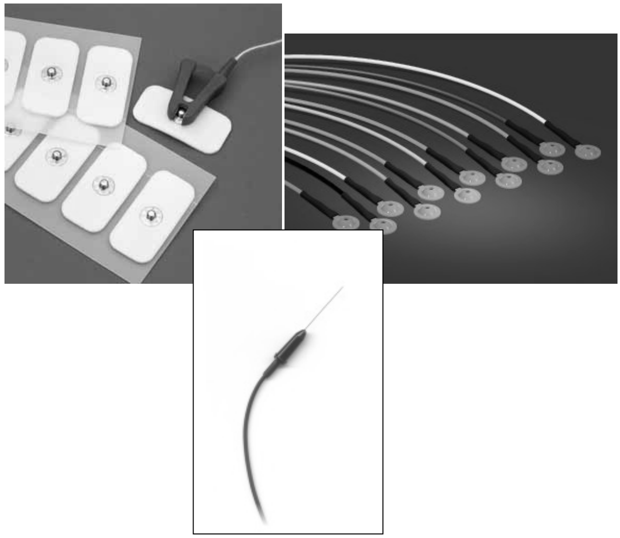
$$R_T = R_{T_0} \exp[\beta(\frac{1}{T} - \frac{1}{T_0})]$$

Advantages
-Large sensitivity
δR=1-3% per degree

Disadvantages
-Highly non-linear
-Self-heating

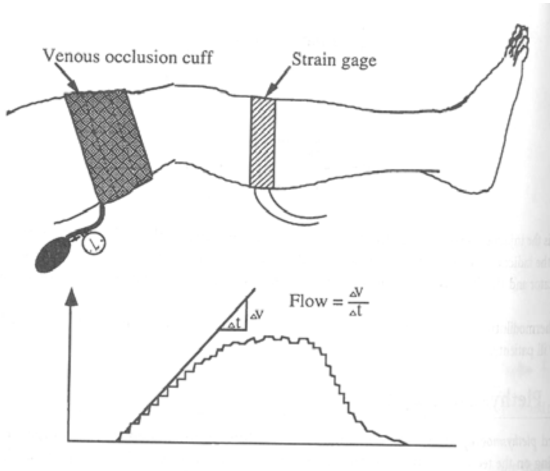
Biomedical Sensors

Biopotential EEG, ECG, EMG, EOG, AEP

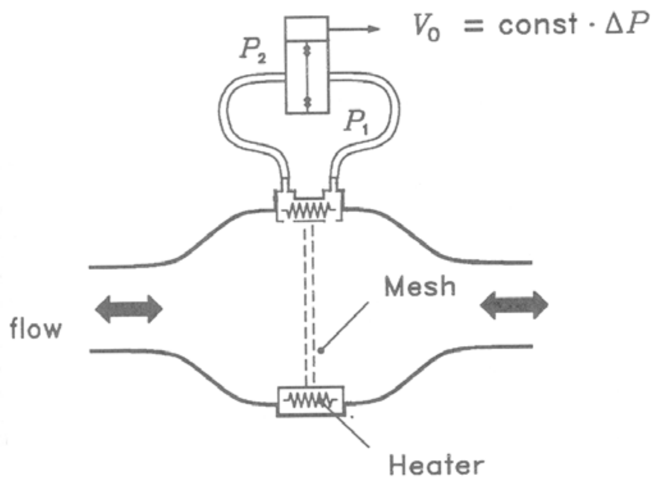


Arterial Pulse Plethysmography

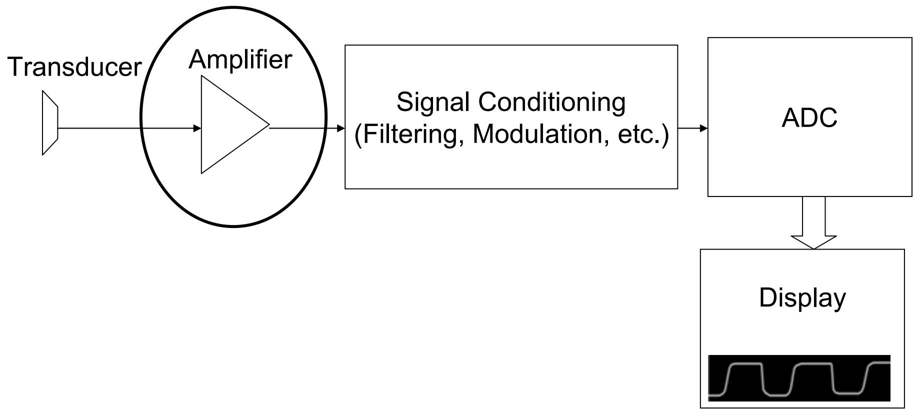
Biomedical Sensors
Blood Flow



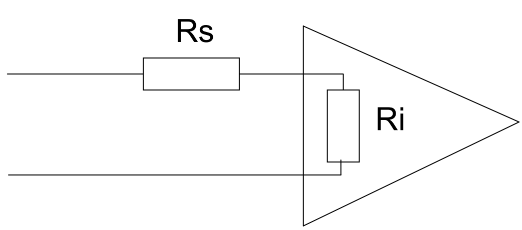
Biomedical Sensors
Ventilation Measurement



Physiological Measurement System



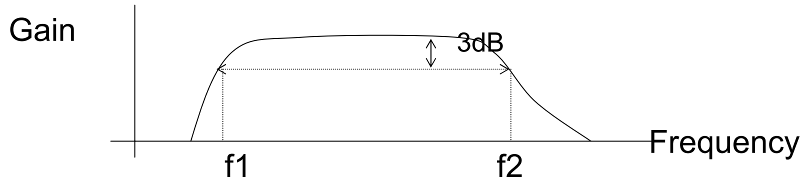
Amplifiers



If a signal of 1 mV is to be measured, and we need signal-to-noise ratio of 60 dB (1000:1), then the output voltage when the two input terminals are joined together must be < 1mV/1000 = 1uV

Ri must be >> Rs. Typically Ri 1-10MΩ

Biomedical Amplifiers



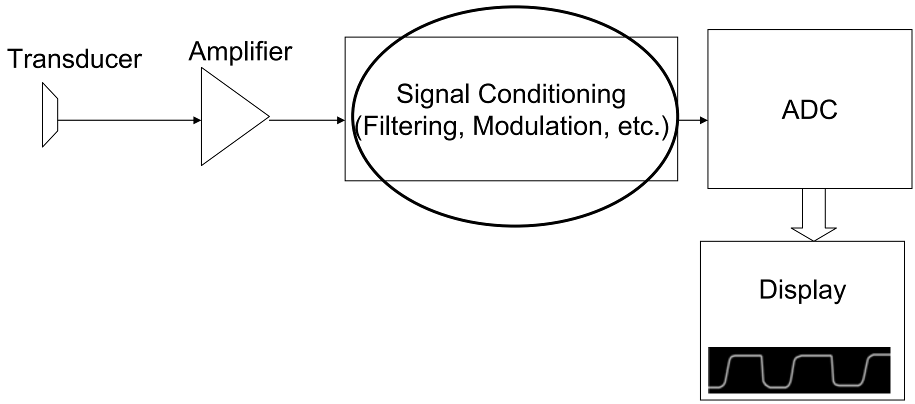
- Bandwidth: The frequency range over which the gain is ≥ 3 dB below the maximum gain
- The bandwidth is made as narrow as possible to exclude unwanted signals and to reduce noise. Random noise has equal power in equal frequency intervals. Therefore reducing the bandwidth by a factor of N reduces the noise power by a factor of N also and the noise voltage by a power of $\sqrt{N}$

Biomedical Signals Amplitude and Frequency Ranges

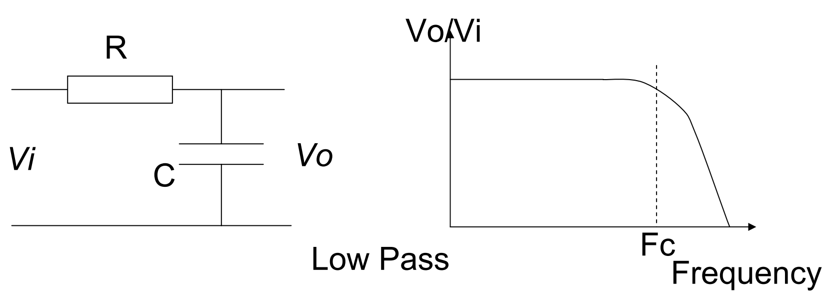
Type of signal	Typical Amplitude
ECG	1mV
EEG	100uV
EMG	300uV
NAP	20uV
Transmembrane potential	100 mV
EOG	500uV

Type of signal	Frequency Range
ECG	0.5 – 100 Hz
EEG	0.5 – 75 Hz
EMG	10Hz – 5kHz
NAP	10 Hz – 10kHz
Arterial Pressure Wave	DC – 40Hz
Respiration	DC – 10Hz

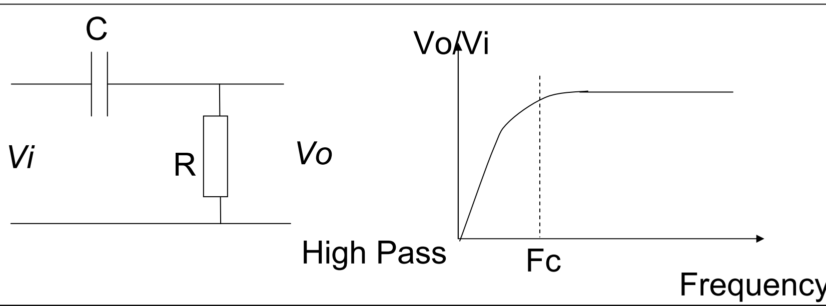
Physiological Measurement System



Filters - Passive

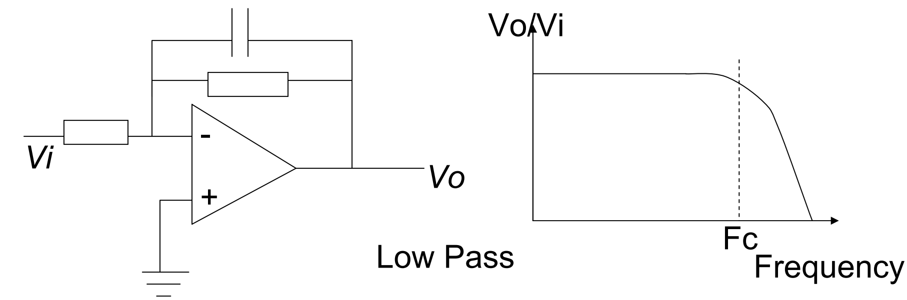


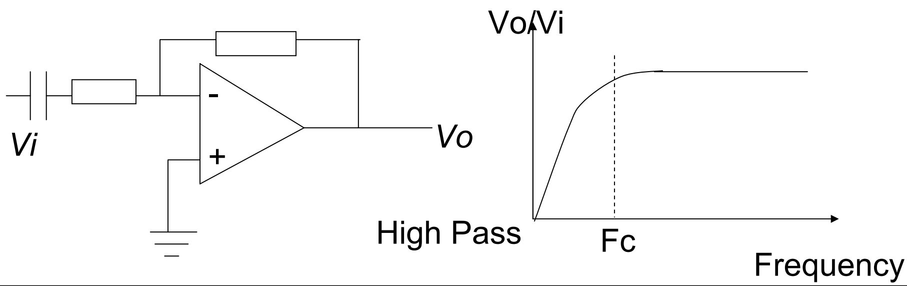
Low Pass



High Pass

Filters - Active

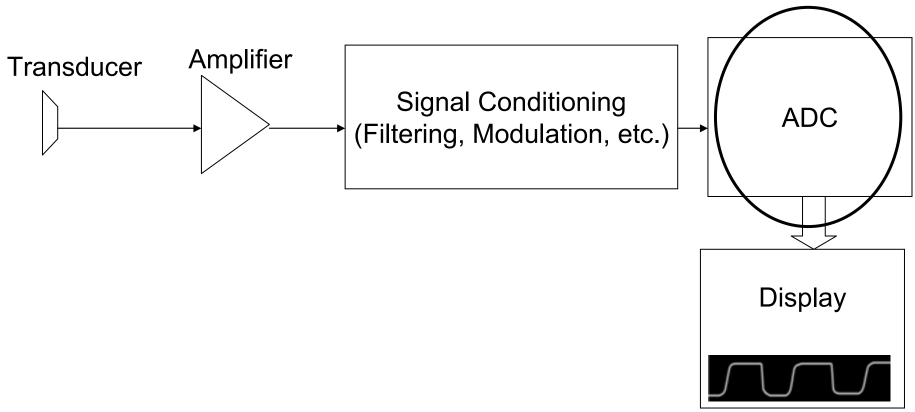




Averaging

- Averaging is used to increase the signal-to-noise ratio. The desired signal responds to the stimulus at the same time interval and will add whereas noise is random and will therefore cancel out.
- If noise is random and has a normal distribution, by taking N number of averages, the noise will be reduced by a factor of $\sqrt{N}$
- In Evoked responses, several hundred responses improve the signal by about 20dB.

Physiological Measurement System



Digital Monitoring

Function	Signal	Min Sampling Rate	Optimal Sampling Rate	Digital Resolution
Neurophysiology	EEG EOG EMG	100Hz 100Hz 100Hz	200Hz 200Hz 200Hz	0.5uV/Bit 0.5uV/Bit 0.2uV/Bit
Respiratory	Oral-Nasal Airflow Resp Movement Oesoph Pressure SaO_2 $TcpO_2/CO_2$ Breathing Sounds	16Hz 16Hz 16Hz 0.5Hz 0.5Hz 1Hz	25Hz 25Hz 100Hz 1Hz 1Hz 5000Hz	n.a. n.a. 0.5mmHg/ Bit 1%/Bit 0.1mmHg/ Bit n.a.
Cardiovascular	ECG Heart Rate Blood Pressure	100Hz 1Hz 50Hz	250Hz 4Hz 100Hz	10uV/Bit 1bpm/Bit 1mmHg/ Bit
Auxiliary	Body Temp Body Position	0.1Hz 0.1Hz	1Hz 1Hz	0.1°C/Bit n.a.

Digital Resolution

Resolution = 2^n - n is the number of bits

Bits	Resolution
8	256
9	516
10	1024
12	4096
16	65536

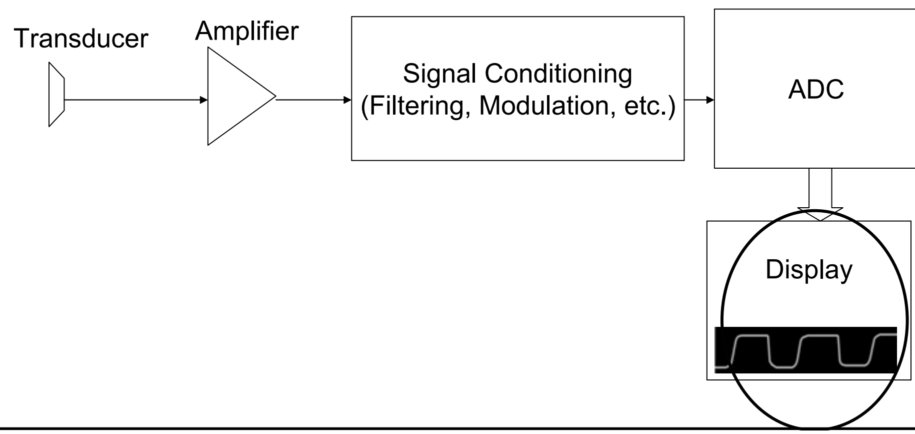
Example

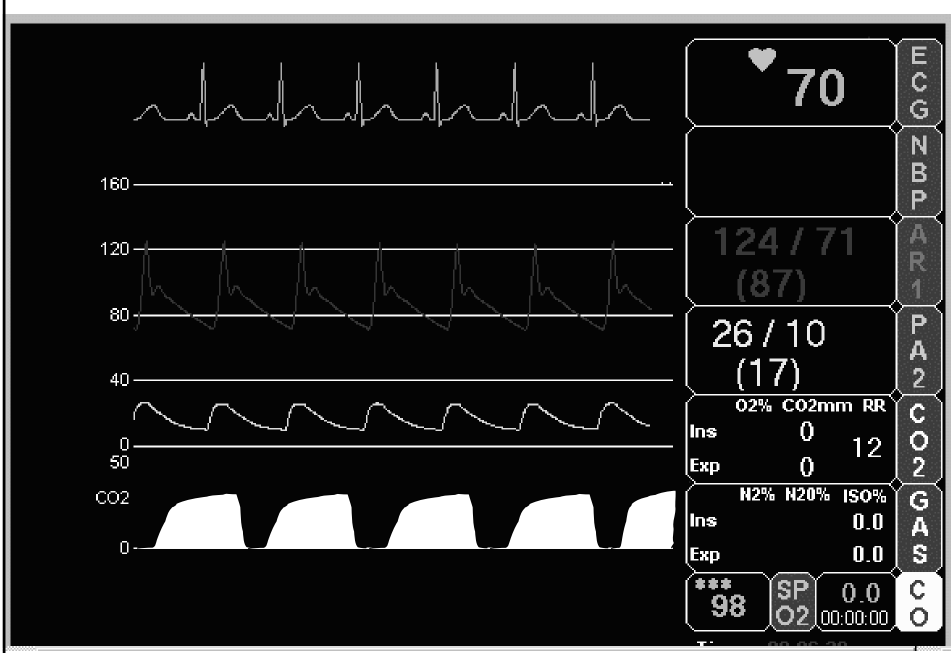
How many bits do you need to digitise the following signals?
Clue: n bits produce 2^n discrete steps

1) Body temperature in the range 10 - 50^{o}C

2) ECG in the range 0 – 2mV

Physiological Measurement System





Displays

- Fundamentals
- Considerations
- Types of Displays
  - LCD
  - CRT
  - Plasma
  - LED

Fundamentals of Light Measurement

- Luminous Flux: Rate at which light energy is emitted. Expressed in lumens (lm)
- Illumination: Luminous flux per unit area. Expressed in Lux (lx)
- Luminance: Brightness. Amount of light emitted by or reflected from a surface. Expressed in candela/m^2 (cd/m^2)
- Reflectance: Ratio of amount of light striking a surface to amount leaving it. Unitless.
- High reflectance (Glare) reduces visual performance

Display Performance Considerations

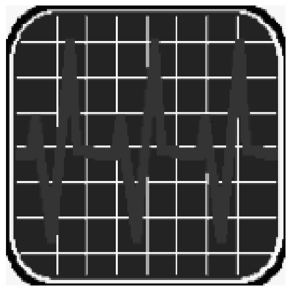
- Resolution: Smallest resolvable object
- Sharpness: Ratio of blurred border zone of letters to their stroke width
- Contrast: Measure of luminance difference between an object and its background
- Flicker: Detectable changes in display luminance
- Critical Flicker fusion Frequency (CFF): Minimum frequency at which flicker occurs, depends on luminance level

Considerations on Choosing a Display

- Environment: Sunlight, night
- Application: Alphanumeric, video images, graphics, combination
- Task Scenario: Portability, handheld, group viewing
- System Characteristics: Weight, volume, power, cost, etc.

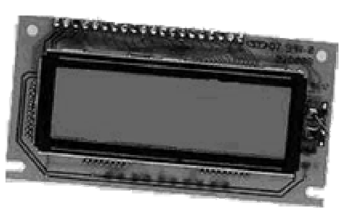
Cathode Ray Tube Displays

- Advantages: versatility, high resolution, fast dynamic response, long life, low cost
- Disadvantages: bulk, vulnerability to ambient reflections, loss of contrast due to light reflection



LCD Displays

- Advantages: very low power consumption, flat display, low cost, excellent contrast in high ambient illumination
- Disadvantages: slow dynamic response, low luminance, limited viewing angle, some temperature dependent features (such as switching thresholds and response times)



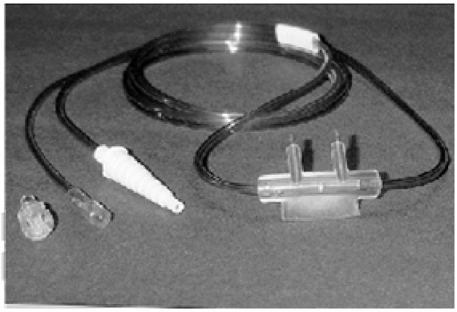
Plasma Displays

- Advantages: enhanced memory capability, brightness, luminous efficiency, no need for continuous refresh signals, excellent contrast ratios in high ambient illumination, long life, robustness
- Disadvantages: high cost, high power consumption

LED Displays

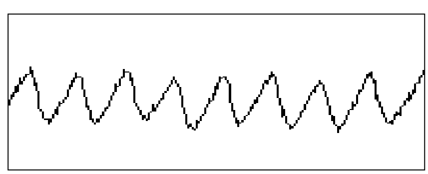
- Advantages: reliability, individual elements can degrade without affecting overall performance, robustness, better viewing angle than LCD, excellent brightness in sunlight
- Disadvantages: high cost, high power consumption, element cross-talk, colour range restriction

Capnography



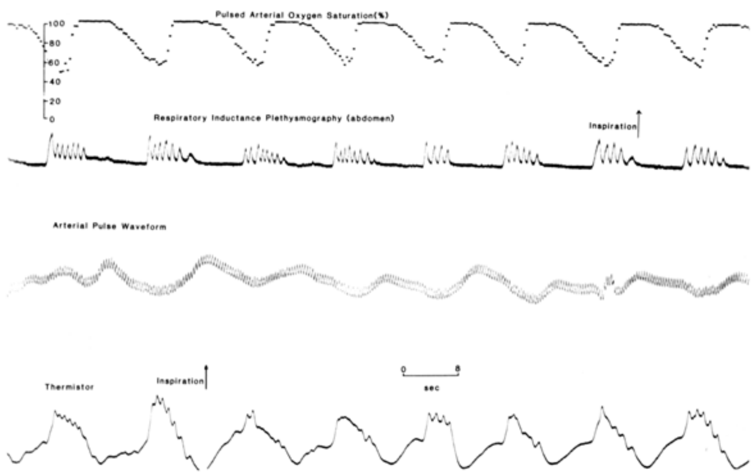
Measures:
End Tidal CO2 (EtCO2)
Respiratory Rate

Pulse Plethysmography

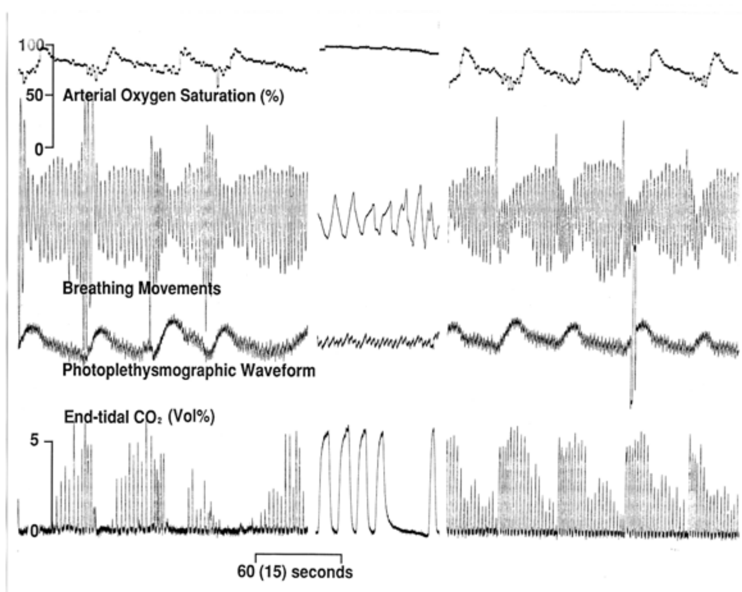


Measures:
Oxygen Saturation (SaO2)
Heart Rate

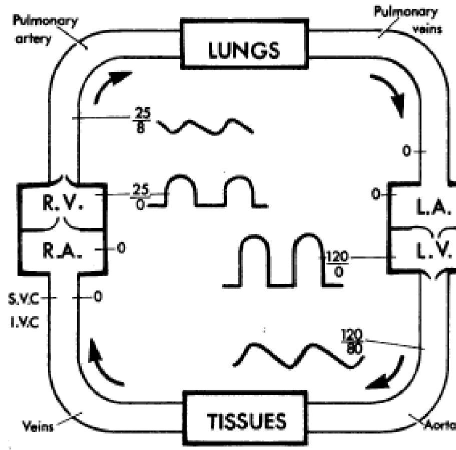
Periodic Breathing



Airway Obstruction



Pressure Monitoring

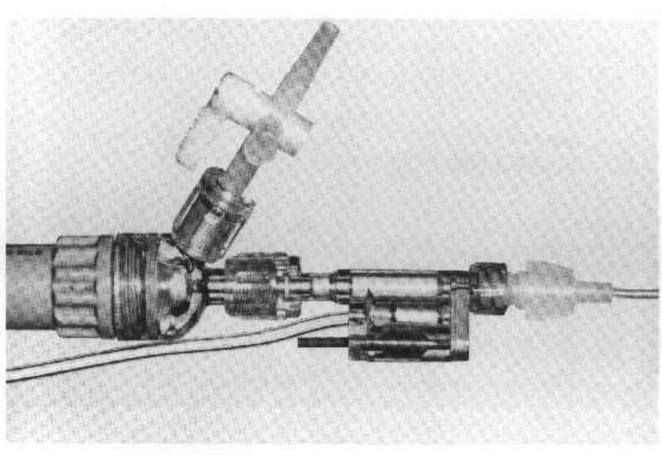


Summary of pressures in different parts of the circulation. Where two pressures are shown, the upper pressure is the pressure during systole and the lower pressure is that during diastole.

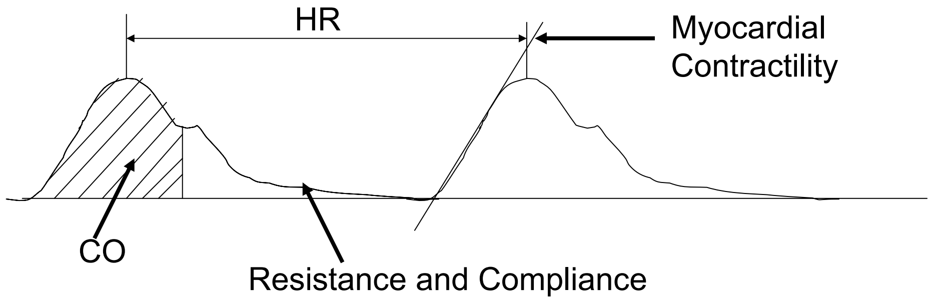
Pressure Monitoring

Arterial Pressure	Central Venous Pressure	Pulmonary Arterial Pressure
The main regulatory mechanism of the cardiovascular system	An estimate of the filling characteristics of the right ventricle	An indication of left ventricular failure

Arterial Pressure Transducer System



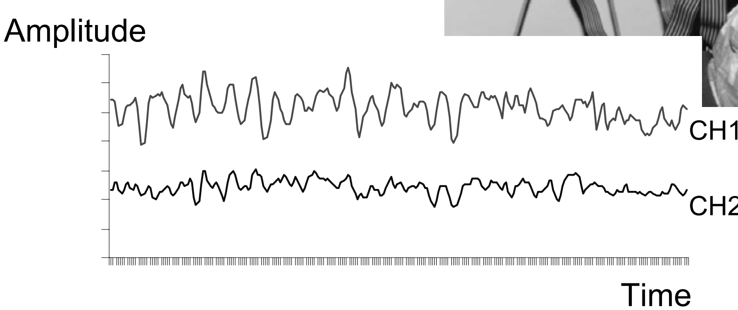
Arterial Pressure Monitoring



Variables measured from BP waveform

- Cardiac output (CO): Ability of the heart to deliver blood to peripheral metabolic sites.
- Left ventricular end-diastolic pressure (LVEDP): Amount of blood in the heart before contraction begins.
- Heart rate (HR): Contraction frequency.
- Myocardial contractility: The effectiveness (force) of the heart's contraction under a given preload.

EEG Signals



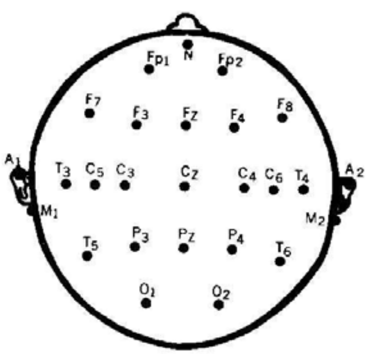
Electroencephalogram Monitoring (EEG)

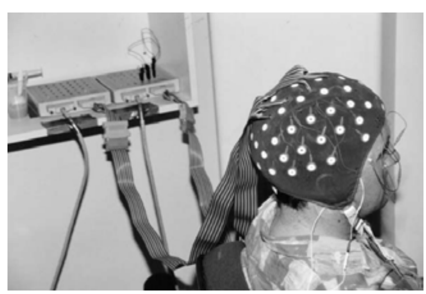
- Practical difficulties
- Small signal. Cortical tissue potentials order of uV, much smaller than muscle activity. ECG 10-30 times higher than EEG

Solutions

- Differential amplifiers
- Signal averaging

EEG Monitoring



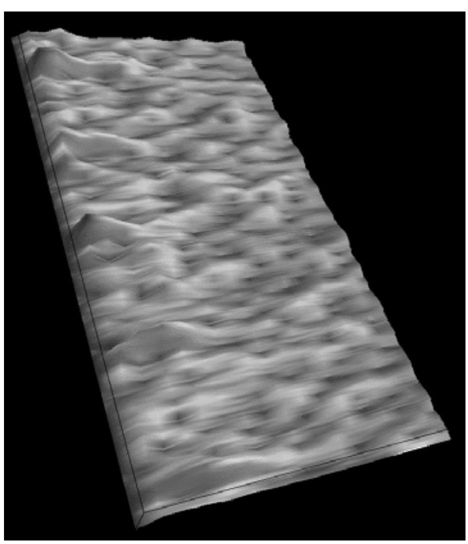


- Use amplifiers with high CMRR ($\geq$ 100dB)
- Select appropriate Gain and Bandwidth
- Reduce electrode impedance

EEG Activity in Adults

- Normal activity: 8-13 Hz, 10-25 uV - alpha
- Sensory stimulation: 10-20 Hz, 5-15uV - beta
- Hyperventilation: 4-8Hz, 10-25 uV - theta
- Hypoxia / ischemia: < 5Hz, 5-50uV - delta

EEG Signals in 3D



EEG Parameters

- Absolute δ power (power in the d frequency range)
- Absolute θ power (power in the q frequency range)
- Absolute α power (power in the a frequency range)
- Absolute β power (power in the b frequency range)
- Total power (absolute total power in the frequency range 0.5 – 30 Hz)
- Spectral edge frequency SEF (frequency in which 95% of the total power lies below it)
- Median frequency MEDFREQ (frequency in which 50% of the total power lies either side of it)

Clinical Assessment During Anaesthesia

- Eye Signs (pupil size, eye movement)
  Eye movement of no value with nitrous narcotic because pupils are small. Good indicator during induction but disappears when anaesthesia is achieved and may not return when decreased
- Blood Pressure
  Possibly best indicator, however, surgery increases blood pressure, some requires lowering it eg cardiac diseases
- Pulse Rate and Heart Rhythm
  Pulse rate varies with blood pressure. Arrhythmia is more likely with halothane and less likely with ether-containing anaesthetic
- Sweating
  Due to increase sympathetic tone
- Respiration
  All anaesthetics can depress respiration leading to apnoea. A good sign but not always available due to need to control respiration. Intercostal activity diminish, abdomen expands and chest retracts. Watch out for airway obstruction
- Muscle Relaxation

Instruments to Aid Monitoring of Anaesthesia

- Oxygen Analysers
  - Paramagnetic: O2 attracted to magnetic field, displaces N2 filled ball in a chamber inside a magnetic field
  - Electrochemical: O2 binds with electrons. Number of electrons (current) proportional to O2 concentration
  - Thermal: different gases have different heat conductivity. Non specific.
- Inhaled Anaesthetic Analyser
  - Infra red expensive, requires calibration, N2O effects
  - Mass spectrometer: expensive, rapid
  - Chromatograph: cheap, slow, requires calibration
  - Quartz: sensitive, rapid, cheap, affected by N2O, water vapour and CO2
- N_2O Analysers
- EEG

Monitoring During Anaesthesia

Apnoea	Minute Ventilation	Gas Exchange	Airway Mechanics	Cardiovascular Function	Muscle Blockade	Temp
Transthoracic Impedance, Chest / Abdomen Movement Air Flow	Spirometery	SaO2 TcpCO2 ETCO2	Dynamic Compliance Stethoscope	Cardiac Output	EMG	Thermistor Thermocouple

Experiences of Awareness in the literature

Awareness in anaesthesia: a prospective study (2000)
R.H. Sandin *et al*. Lancet, 335:707-711

- Scared, tried to move but found it impossible
- Heard someone say "he is awake"
- Tried to get attention but was unable to move and talk
- Felt pain in throat and like he was suffocating
- Heard someone ask "can I cut here?" Felt manipulation but no pain
- Felt incision
- Sharp pain and sense of darkness
- Saw people dressed in green, saw tombstones. Thought she was attending her own funeral. Heard voices speak slowly. Anxiety gradually disappeared after 3 weeks

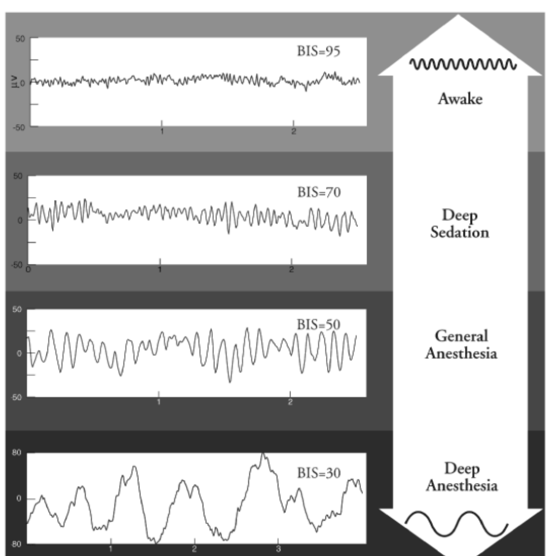
Monitoring Depth of Anaesthesia

"Whoa! *That* was a good one! Try it, Hobbs—just poke his brain right where my finger is!"

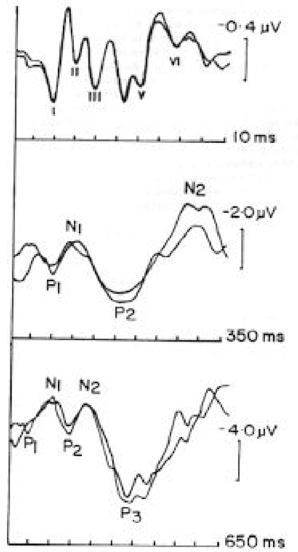
Cerebral Monitoring

- EEG
  - Median frequency, spectral edge frequency, power analysis $\alpha - \beta - \theta - \delta$
- Bispectral Index (BIS)
  - empirical, statistically derived measurement based on a large database of EEG records
- Auditory Evoked Potential
  - Mid-latency response to auditory stimulus

Bispectral (BIS) Index



Auditory Evoked Potential



Subjective Measure

Observer Assessment of Alertness/Sedation Score (OAAS):

5 – Awake

4- Slow response to questions and slurred speech

3- Responds to commands

2- Responds to command only after several attempts and mild prodding

1- Does not respond to commands or shaking

Recommended Reading

- Medical Physics and Biomedical Engineering, Brown BH, Smallwood RH, Barber DC, Lawford PV, Hose DR, ISBN 0-7503-0368-9
- Medical Instrumentation, Webster JG, ISBN 0-471-15368-0
- The Measurement, Instrumentation and Sensors Handbook, Webster JG, ISBN 0-8493-8347-1
- Digital Signal Processing : a Practical Approach, Ifeachor EC, Jervis BW ISBN 0-2015-4413-x
- Introductory Digital Signal Processing, Lynn P, Feurst W, ISBN 0-471-91564-5
- The Art of Electronics, Horowitz P, Hill W, ISBN 0-521-37095-7
- Monitoring in anesthesia, L. J. Saidman, N. T. Smith; ISBN 0409950726

Example

How many bits do you need to digitise the following signals?
Clue: n bits produce 2^n discrete steps

1) Body temperature in the range 10 - 50°C

A) Resolution = (50 – 10) / 0.1 = 400.
We therefore need 9 bits (512)

2) ECG in the range 0 – 2mV

A) Resolution = (2 – 0) / 0.01 = 200.
We therefore need 8 bits (256)