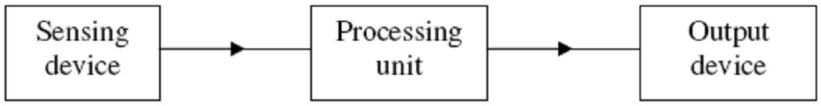
Definitions, laws & principles – Applications of Physics

28. Direct Sensing

28.1 An Electronic Sensor consists of



28.2 Properties of an Ideal Op-amp

• infinite input impedance
• infinite open-loop gain
• zero output impedance
• infinite bandwidth
• infinite slew rate

28.3 Formula for Comparator circuit

$V_{out} = A_0 (V^+ - V^-)$

28.4 Definition of Feedback

The process of taking some, or all, of the output of the amplifier and adding it to the input.

28.5 Definition of Negative Feedback

The process of taking some, or all, of the output of the amplifier and adding it to the input. The output is 180° out of phase with the input

28.6 Benefits of Negative Feedback

1) Increased bandwidth
2) Less distortion
3) Greater operating stability

28.7 Formula for Inverting Op-amps

$$\text{Voltage gain} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

28.8 Formula for Non-Inverting Op-amps

$$\text{Voltage gain} = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_i}$$

28.9 LEDs

Typical forward current = 20 mA
Max. reverse bias voltage = 5 V

29. Remote Sensing

29.1 Definition of attenuation

Decrease in intensity

29.2 Method of Production of X-rays

1) Electrons which are accelerated by using a large p.d. bombards a metal target.
2) The electrons which are decelerated greatly produces Electromagnetic radiation mainly of the X-ray spectrum.
3) The wide range of decelerations gives a continuous spectrum.
4) Some inner shell electrons are knocked out from the atoms. When these inner shell vacancies are refilled by free electrons, X-ray photons are emitted which gives the line spectrum.

29.3 Intensity of X-ray

The intensity of the X-ray beam is determined by the tube current (heater current of the cathode). Higher tube current, higher intensity.

29.4 Hardness of X-ray

The hardness of the X-ray beam (the penetration of the X-rays) is controlled by the tube voltage (voltage between the cathode and the anode). Higher tube voltage, higher penetration.

Note:- Soft X-rays can be removed by using an aluminium filter

29.5 Definition of Sharpness of X-rays

The ease with which the edges of structures can be determined.

29.6 Factors that affect sharpness

-area of target anode (Area small, sharper image)
-size of aperture (Size small, sharper image)
-degree of scattering (less scattering using lead grid, sharper image)

29.7 Definition of Contrast of X-rays

The difference between the degree of blackening between structures.

29.8 Factors that affect contrast

1) exposure time (longer exposure time, better contrast)
2) X-ray penetration (not too weak, not too strong)
3) scattering of the X-ray beam (less scattering, better contrast)

Note:- Contrast may be improved by sandwiching the photographic film between two flat fluorescent screens in a cassette or by using a contrast medium.

Criteria for contrast media:

a) The medium must be non-toxic and safe.
b) It must produce sufficient contrast to accurately outline the organ or vessels of interest.
c) It should have the correct viscosity, miscibility and excretion rate.

29.9 Formula for attenuation of X-rays

$$\frac{I}{I_0} = e^{-\mu x}$$

$$x_{1/2} = \frac{\ln 2}{\mu}$$

29.10 CT Scan

1) CT scan takes many images of a slice at different angles
2) These build up an image of a slice through the body
3) A series of images of slices is made so that a 3D image can be built up
4) This image can then be rotated using a computer

29.11 Principle of Generation of Ultrasound

1) In a piezo-electric crystal such as quartz, when the crystal is unstressed, the centres of charge of the positive and negative ions coincide.
2) When a p.d. is applied across the electrodes coated on opposite sides of the crystal, the positive and negative ions move in opposite directions. This causes the crystal to become either thicker or thinner depending on the polarity of the applied p.d.
3) When a high frequency a.c. voltage is applied across it, the crystal is compressed and extended by the electric field hence vibrating itself and emitting ultrasound.
4) The crystal can be made to vibrate at its resonant frequency by having the appropriate dimensions.

29.12 Formula for Reflected Intensity of Ultrasound

$$\frac{I_R}{I} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

29.13 Formula for attenuation of Ultrasound

$I = I_0 e^{-kx}$

29.14 Definition of Resolution in Ultrasound

Resolution is a measure of the smallest detail that can be detected

Note: Higher frequency produces higher resolution, but greater attenuation.

29.15 Principle of operation of ultrasound
(A-Scan)

1) Short pulses of ultrasound are transmitted into the body.
2) These pulses are partly reflected at the boundary between 2 media
3) The reflected pulses are returned to the transducer where they are detected, processed and displayed
4) The distance between boundaries can be found from the time between transmission and reflection of pulse.
5) The strength of the echo indicates the nature of the boundary
6) A water based gel is used as a coupling medium when the transducer is placed in contact with the skin to reduce reflection at the skin.

(B-Scan)

4) At the boundary between two media, a bright spot is seen on the screen.
5) If an array of crystals is used, then bright spots will be seen on the screen. These bright spots are then connected together to give an image.

29.16 Principle of operation of MRI

1) The part of the body is placed in a large uniform magnetic field.
2) Hydrogen nuclei will precess about the direction of the magnetic field
3) Pulsed R.F. which matches the Larmor frequency is sent to that part of the body
4) Gradient magnets surrounding the part turns on and off in a specific manner.
5) This is to alter the magnetic field in the tissue being examined and allows the position of the resonating nuclei to be determined
6) On relaxation, the hydrogen nuclei emits R.F. pulses which are detected by the RF receiver
7) Since normal and abnormal tissues respond differently to the slight alteration in magnetic field, they will give out differing signals which are processed by the computer and displayed.

30. Communicating Information

30.1 Definition of Modulation

The amplitude or frequency of the carrier wave is made to vary in synchrony with the displacement of the information signal

30.2 Definition of Amplitude Modulation

1) The amplitude of the carrier wave is made to vary in synchrony with the displacement of the information signal.
2) The frequency of the carrier wave does not vary.
3) The variation in the amplitude of the carrier wave is a measure of the displacement of the information signal.
4) The rate at which the carrier amplitude varies is equal to the frequency of the information signal.

30.3 Definition of Frequency Modulation

1) The frequency of the carrier wave is made to vary in synchrony with the displacement of the information signal.
2) The amplitude of the carrier wave does not vary.
3) The change in frequency of the carrier wave is a measure of the displacement of the information signal.
4) The rate at which the carrier wave frequency is made to vary is equal to the (instantaneous) frequency of the information signal.

30.4 Advantages of FM over AM

1) Larger bandwidth so quality of music higher
2) Less noise and interference

30.5 Advantages of AM over FM

1) AM has larger range, so less transmitters required which results in lower costs.
2) AM transmitters and receivers are electronically simpler and cheaper.

30.6 Definition of Bandwidth

Bandwidth is the frequency range occupied by the AM waveform

30.7 Definition of a Digital Signal

Series of pulses producing signals having discrete levels.

30.8 Conditions to recover all the main features of the original analogue waveform

1) Sampling time must be shorter than smallest peak-trough interval (smaller step depth).
2) Voltage interval must be less than smallest peak-trough height (smaller step height).

Note: In order to be able to recover the analogue signal from its digital conversion, the sampling has to occur at a frequency greater than twice the highest frequency component in the original signal.

30.9 Advantages of Digital Signals over Analogue Signals

1) Digital signal can be transmitted over very long distances with regular regenerations without becoming increasingly noisy, as would happen with an analogue signal.
2) Extra information in the form of extra bits of data can be added by the transmitting system. These extra data are a code to be used by the receiving system to check for errors and to correct them before passing the information on to the receiver.

30.10 Disadvantage of Digitals Signals over Analogue Signals

1) Extra circuitry in required for ADC and DAC.

30.11 Comparison between the different channels of communication.

Refer to Table given

30.12 Electromagnetic Spectrum used for Radio Communication

Type of wave	**Frequency**	**Range**		**Frequency band**	**Frequencies**	**Wavelengths**
Surface wave	Below 3 MHz	Up to 1000km	LW radio	LF	30kHz – 300kHz	1 km – 10 km
			MW radio	MW	300kHz – 3MHz	100 m – 1 km
Sky wave	3 MHz – 30 MHz	Worldwide	SW radio	HF	3MHz – 30MHz	10 m – 100 m
Space wave	Greater than 30 MHz	Line of sight	FM radio	VHF	30MHz – 300MHz	1 m – 10 m
			TV broadcast	UHF	300MHz – 3GHz	10 cm – 1 m
			Microwave/ Satellite	SHF EHF	3GHz – 30GHz 30GHz – 300GHz	1 cm – 10 cm 1 mm – 1 cm

30.13 Advantages of Transmission using Optic Fibres

- Optic fibres have a wide bandwidth. This gives rise to a large transmission capacity.
- Signal power losses in optic fibres are relatively small. This allows for longer uninterrupted distances between regenerator amplifiers and reduces the costs of installation.
- The cost of optic fibre is much less than that of metal wire.
- The diameter and weight of fibre optic cables is much less that that of metal cables. This implies easier handling and storage.
- Optic fibres have very high security since they do not radiate energy and thus there is negligible 'cross-talk' between fibres.
- Optic fibres do not pick up electromagnetic interference. This means they can be used in electromagnetically 'noisy' environments, for example alongside electric railway lines. In fact, optic fibre cables are installed along the routes of the National Grid.
- Optic fibre is ideal for digital transmissions since the light is obtained from lasers that can be switched on and off very rapidly.

30.14 Why satellites use two different frequencies of uplink and downlink

The two carrier frequencies are different to prevent the satellite's high power transmitted signal swamping its reception of the very low power signal that it receives.

30.15 Why satellites are used even though AM transmission can cover large distances

(i) Long-distance communication on these wavebands is unreliable. Sky waves rely on ionospheric reflection. These layers of ions vary in height and density according to the time of day. In hilly areas, surface waves give rise to regions of poor reception where there are 'shadows'.
(ii) The wavebands are already filled by existing broadcasts.
(iii) The available bandwidths are too narrow to carry the required amount of information.

30.16 Geostationary Satellites and Polar Satellites

Geostationary

1) Always remain above the same point on the earth
2) Travels from west to east
3) Period of orbit = 24 hours
4) Further away from the earth as compared to polar satellites

Polar

1) Travels from 1 pole to the other

2) Period of orbit = 90 minutes
3) Each orbit crosses the Equator 23° to the west of the previous orbit
4) Nearer to the earth as compared to geostationary satellites

30.17 Advantages and Disadvantages of Geostationary and Polar Satellites

	Advantages	**Disadvantages**
Geostationary	1) Does not need to be tracked by a dish aerial	1) Greater delay during communication 2) Unable to cover the polar regions
Polar	1) Less delay during communication 2) Total global coverage is possible through a network of satellites	1) Needs to be tracked by a dish aerial

30.18 Definition of Attenuation

Decrease in signal power

30.19 Definition of Noise

Unwanted power that covers the whole spectrum

30.20 Number of Decibels

number of decibels = $10 \lg(P_2/P_1)$.

30.21 Attenuation per unit length

$$\text{attenuation per unit length} = \frac{1}{L} 10 \lg \frac{P_2}{P_1}$$

30.22 Roles of the Cellular Exchange

1) permits entry to PSTN
2) selects base station for any handset
3) allocates a carrier frequency/channel
4) monitors handset signal to re-allocate base station

5) allocates time slot for multiplexing
6) keeps track of the handset's location in a database

30.23 Roles of the Base Station

1) detects signal from handset
2) sends out signal to the handset
3) transmits information between the handset and the cellular exchange

30.24 Why the country is divided into a number of cells.

Carrier frequencies can be re-used simultaneously without interference so that number of people making and receiving calls can be increased.

30.25 Role of base station and cellular exchange when the phone is switched on until a call is made

1) When the phone is switched on, the base station picks up the signal from the handset and relays the information to the cellular exchange
2) The cellular exchange stores the location of the handset in its database so that it can be located during a call
3) When a call is made, the cellular exchange will locate the handset and assign 2 frequencies belonging to the base station for the handset to use during the call

30.26 How a call is maintained as a handset moves from one cell to another

1) The signal from the handset is detected by the base stations which are nearby
2) As the handset moves from one base station to another, the signal strength to the first base station will decrease and the signal strength to the second base station will increase
3) The cellular exchange will monitor and compare the signal strengths.
4) When the signal strength from the second base station becomes stronger than the signal strength to the first base station, the cellular exchange will instruct the first base station to drop the call and the second base station to pick up the call using two new frequencies belonging to the second base station.