UNIT V

MEASUREMENTS

Measurement of Impedance, Field/Radiation Pattern and gain of antennas, Ionospheric measurements – Vertical incidence measurements of the ionosphere – Relation between oblique and vertical incidence transmission – System Issues – antenna noise, SNR, and link Budget

1. Impedance Measurement

Impedance Measurement are done according to frequency involved. For Radio frequencies below 30MHz(low frequency).Usually impedance Bridge method is employed for frequencies above 1000 MHz(High frequency)"slotted line" measurement is almost invariably used. However between frequencies 30MHz-1000MHz either method can be used depending on the applications, convenience or availability of equipment. Impedance at a pair of electrical terminals is the ratio of current (I) which flows when a voltage V is applied between the terminals. By generalization of Ohm's law

$$z=\frac{V}{I} \tag{1}$$

Where Z=$R + jX$

R=Resistive components

X=Reactive components

If there is a phase difference θbetween I&V, then

$$\theta=\tan^{-1}\frac{X}{R} \tag{2}$$

The voltage V and current I will be in phase when reactive component X=0.Thus the impedance can be determined by measuring the voltage and current at the terminals.

1.1 Impedance Bridge Method for Low Frequency

Wheat stone bridge is used to measure unknown impedance(resistance, inductance or capacitance) by comparison with known impedances. It consists of 4 impedances connected in four arms of the bridge as shown in figure below.

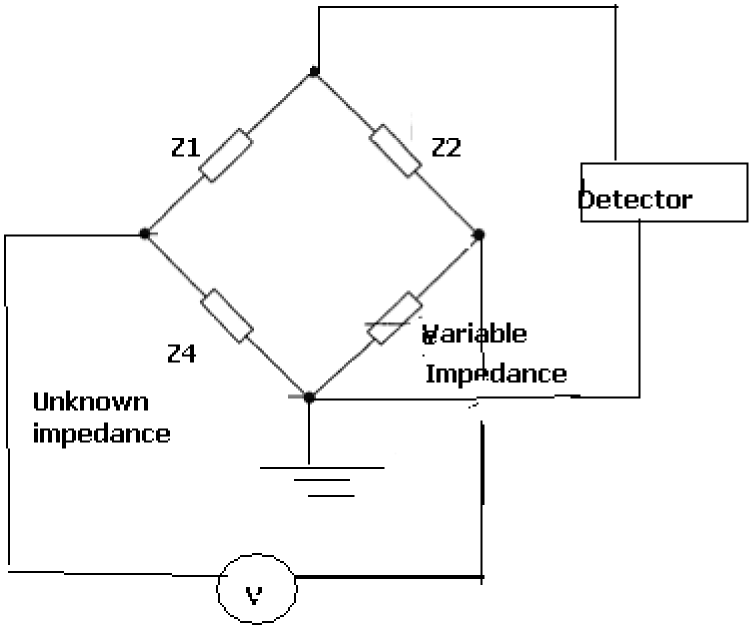


Fig: 1.Wheat stone Bridge for impedance measurement

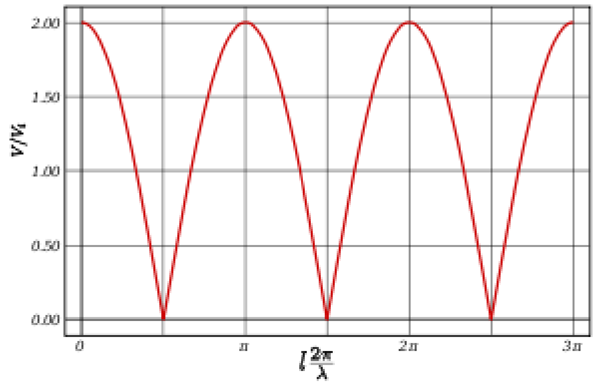


Fig: 2.Standing wave along the line

It may be noted however the bridge is balanced not for impedance magnitude but for also a phase balance. Thus writing in polar form we have

$$\frac{Z1\theta 1}{Z2\theta 2}=\frac{Z4\theta 4}{Z3\theta 3} \quad (3)$$

Thus there are two balance conditions which must be satisfied simultaneously

$Z_1Z_3=Z_2Z_4$ For magnitude balance

Angle$(\theta_1 + \theta_3)= (\theta_2+\theta_4)$ For phase angle balance

Unknown impedance Z_4 is calculated as

$$Z_4 = Z_3\left(\frac{Z_1}{Z_2}\right) \tag{4}$$

For antenna input impedance measurement the antenna input terminals are connected as unknown impedance between point A and D is grounded so it is suitable for a low frequency grounded vertical antenna. For balanced antenna one should see that points A and D of bridge are balanced w.r.t. ground.

The measurements usually are preceded by calibration, the bridge is balanced with unknown impedance terminal short circuited or open circuited. Then the short is removed and unknown impedance is inserted in unknown impedance arm between A and D and the bridge is re-balanced. The unknown impedance is now determined by impedance equation.

1.2 Standing Wave Ratio Method or Slotted Line Method for Impedance Measurement at High Frequency

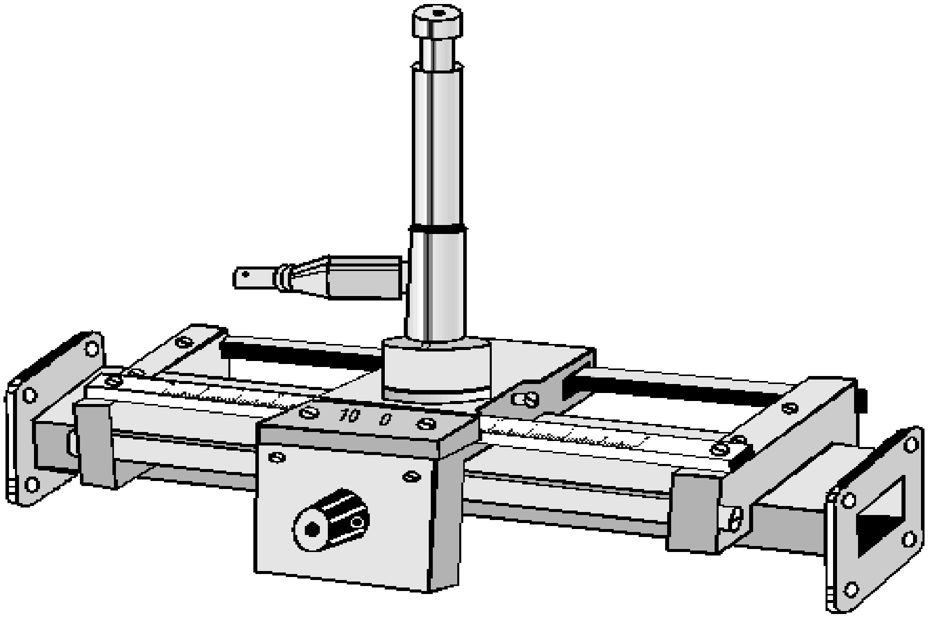


Fig: 3.Prespective view of slotted line arrangement

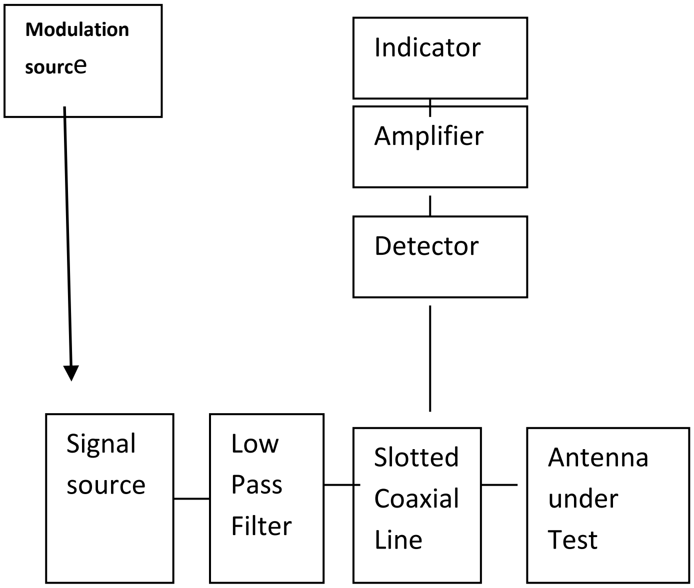


Fig.4.Block diagram of making slotted line measurement

The Experimental set up for determination of standing wave ratio and hence the input impedance is shown in the above figure.

A Transmission line system terminated in an antenna, if not perfectly matched to this feeding transmission line, the incident and reflected waves and consequently produce standing wave will be set up along the transmission line. A part of transmission line is replaced by an axial slotted line, VSWR or impedance measuring set up. As shown the slotted line arrangement consists of a length of a transmission line with an axial slot, along which moves a travelling carriage carrying probe. The probe project through the slot. A voltage measuring device may be in simplest case, a crystal detector and a micro ammeter. A signal source may be a transmitter or oscillator which is connected to left end and right end is connected to the unknown impedance being, measured. The standing wave pattern is obtained by moving the probe along the carriage and observing the resulting variation in the crystal detector output.Infact this device measures electric field intensity but since it is proportional to the voltage between conductors, therefore standing wave indicator is assumed to be a voltage measuring device. The probe in the slotted coaxial cable is moved and two consecutive points of V_{max} and V_{min} are noted. Their ratio will give the VSWR and hence the input impedance.

The probe is inserted deeply into the axial slot line in order to sample the standing wave pattern. Commercial standing wave detectors, a high or low pass filter is used to avoid harmonics spurious signal sources and unwanted signals between slotted line and signal source as shown in block diagram. The modulation source is for modulating signal source with a square or pulse.

2. Radiation pattern Measurement

Radiation pattern of transmitting antenna is described as the field strength or power density at a fixed distance from the antennas as a function of direction. The Radiation pattern of an antenna is a three dimensional figure and it needs measurements of field intensity all over the spatial angles. Hence for radiation pattern of antenna under test the various spatial angles must be specified. The test antenna is assumed to be placed at the origin of spherical coordinate as shown in fig. below

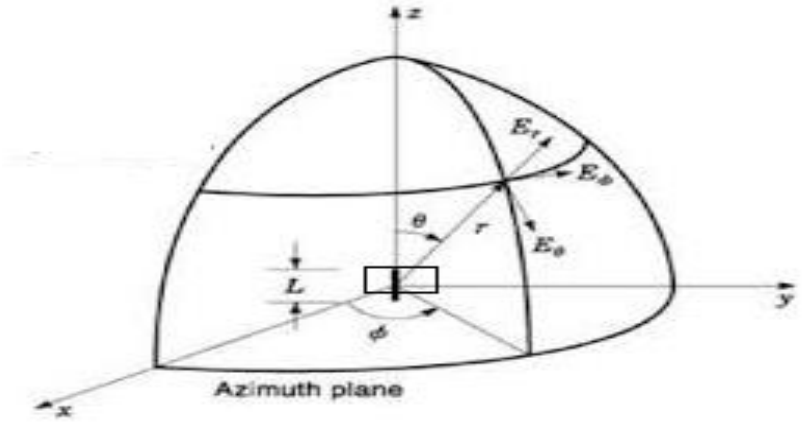


Fig:5 Spherical coordinate system for pattern measurement

XY-Plane is horizontal plane and XZ-plane is vertical plane the radiation pattern is accordingly taken either along latitude as a function of Azimuth angle $\emptyset$ as a function of θ depending upon the application and the information needed.

For most antennas if it is generally necessary to take radiation pattern in XY-Plane (Horizontal plane) and XZ-Plane (Vertical Plane).

For horizontal antenna two patterns are sufficient

(i) The $\emptyset$ component of electric field is measured as the function of $\emptyset$ in XY-Plane ($\theta = 90°$). It is represented as $E_{\emptyset}(\theta = 90°, \emptyset)$ and is called as E-Plane Pattern.

(ii) The $\emptyset$ component of the field is measured as the function of θ in the XZ-Plane ($\emptyset = 0°$). It is represented as $E_{\emptyset}(\theta, \emptyset = 0°)$ is called as H-Plane Pattern.

These two patterns bisect the major lobe in mutually perpendicular planes and hence provide enough information's for a number of applications.

Similarly for vertically polarized antennas:

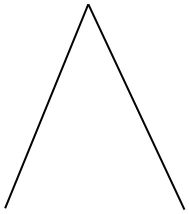
(i) The θ component of electrical field is measured as function of $\emptyset$ in XY-Plane ($\theta = 90°$). It is represented as $E_{\theta}(\theta = 90°, \emptyset)$ and is called as H-Plane Pattern.

(ii) The θ component of electrical field is measured as function of $\emptyset$ in XZ-Plane (($\emptyset = 0°$). It is represented as $E_{\theta}(\theta, , \emptyset = 0°)$ and is called as E-Plane Pattern. For circularly and elliptically polarized antenna measurement of these four patterns would be needed.

2.1 Arrangement for Radiation pattern Measurements

There is a transmitting antenna (Primary Antenna) and the antenna under test is secondary antenna a mount for rotating the primary antenna, a detector and an indicator for indicating the relative magnitude of received field shows the arrangement of radiation pattern measurement the equipment may be entirely automatic or point to point plot.

Primary antenna (Transmitting antenna) Secondary Antenna (Antenna under test)



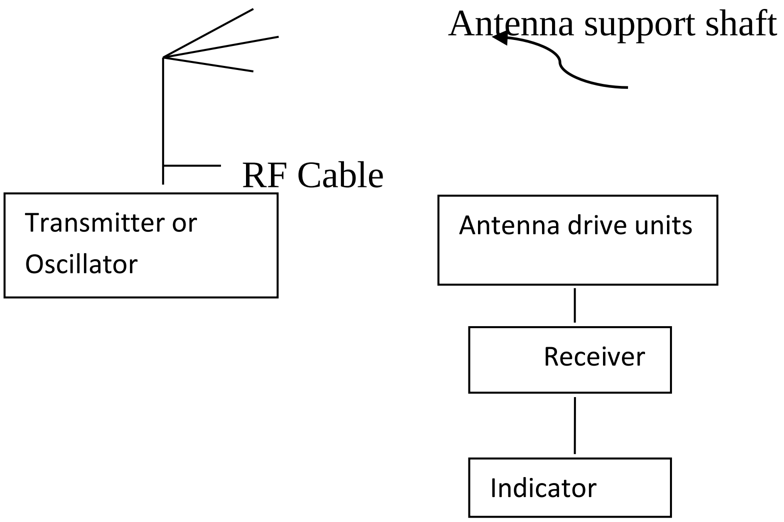


Fig: 6.Radiation pattern measuring set up

It is usual to operate antenna under test as a receiver, placing it under proper illumination by primary antenna. The primary antenna is fixed and the secondary is rotated on a vertical axis by antenna support shaft. If large number of patterns are to be taken" automatic pattern recorder may also be used which is commercially available.

Two methods (a) Distance requirement and

(b) Uniform illumination requirement

(a) Distance Requirement:

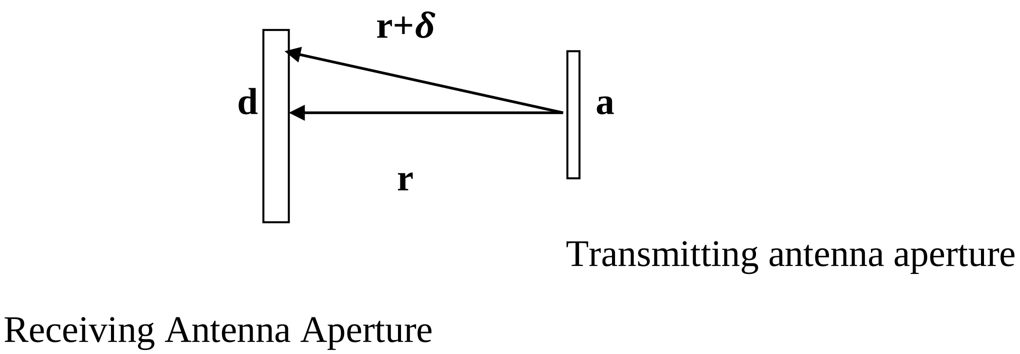


Fig: 7.Phase difference between centre and edges of receiving array for distance requirement

In order to obtain accurate far-field the distance between primary and secondary antenna must be large if the distance between the two antennas is very much small the near field is obtained for accurate far-field pattern measurement the secondary antenna should be illuminated by a plane wave front and plane wave front is obtained only at infinite distance thus the limit specified is that the phase difference between the centre and edge of the antenna under test should not exceed $\frac{\lambda}{16}$ under this condition the distance between primary and secondary antenna should be

$$\boxed{r \geq \frac{2d^2}{\lambda}}$$

d- Maximum linear dimension of either antenna, λ wavelength

r- Distance between TX and RX

The value of r may be calculated in terms of receiving aperture'd' and distance 'r'

$$(r+\delta)^2 = \left(\frac{d}{2}\right)^2 + r^2 \qquad (5)$$

$$r = \frac{d^2}{8\delta} \qquad (6)$$

Uniform illumination requirement

The other requirement for an accurate field pattern is that primary antenna (transmitting) should produce a plane wave of uniform amplitude and phase over the distance at least equal to 'r'. The interference between direct rays and indirect rays should be avoided as far as possible. Besides the reflections from surrounding objects like buildings, trees, etc., should be avoided. Test should be conducted in open plane area and antennas should be directional , installed on higher towers or top of high buildings.

Direct Rays

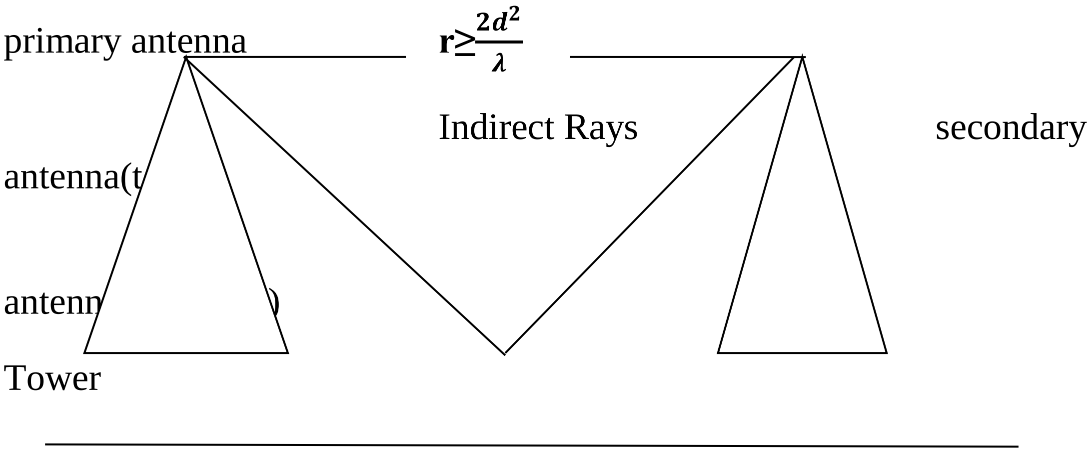


Fig: 8.Experimental set up for antenna test

3. Measurement of gain

Gain = Maximum radiation intensity (subject or test antenna/maximum radiation intensity (reference antenna)

For the same input power of both antennas

Directivity =Maximum radiation intensity/average radiation intensity

Thus again compares the actual antenna with any reference antenna while the directivity is concerned only with a hypothetical isotropic loss less antenna.

Gain of an antenna over an isotropic loss less antenna is given by

G0 = αD **(7)**

G0- Gain with respect to isotropic antenna

D- Directivity α effectiveness ratio

3.1 Measurement of gain by direct comparison method

Gain is a comparison of two antennas and hence gain measurement by comparison is done. At high frequencies the comparison method is one which is commonly used, gain is done by comparing the signal strength transmitted or received with the unknown gain antenna and a standard gain antenna. A standard gain antenna whose gain is accurately known so that it can be used in measurement of other antenna. Electromagnetic horn antenna at microwave frequencies is mostly used as standard gain antenna. The secondary antenna may be an arbitrary transmitting antenna and it is not necessary to know its gain. In place of primary antenna there will be two antennas one the subject antenna under test and the other antenna at a considerable distance so that the coupling or interaction between two antennas can be avoided the experimental setup is a pattern measurement which is shown in fig. below.,

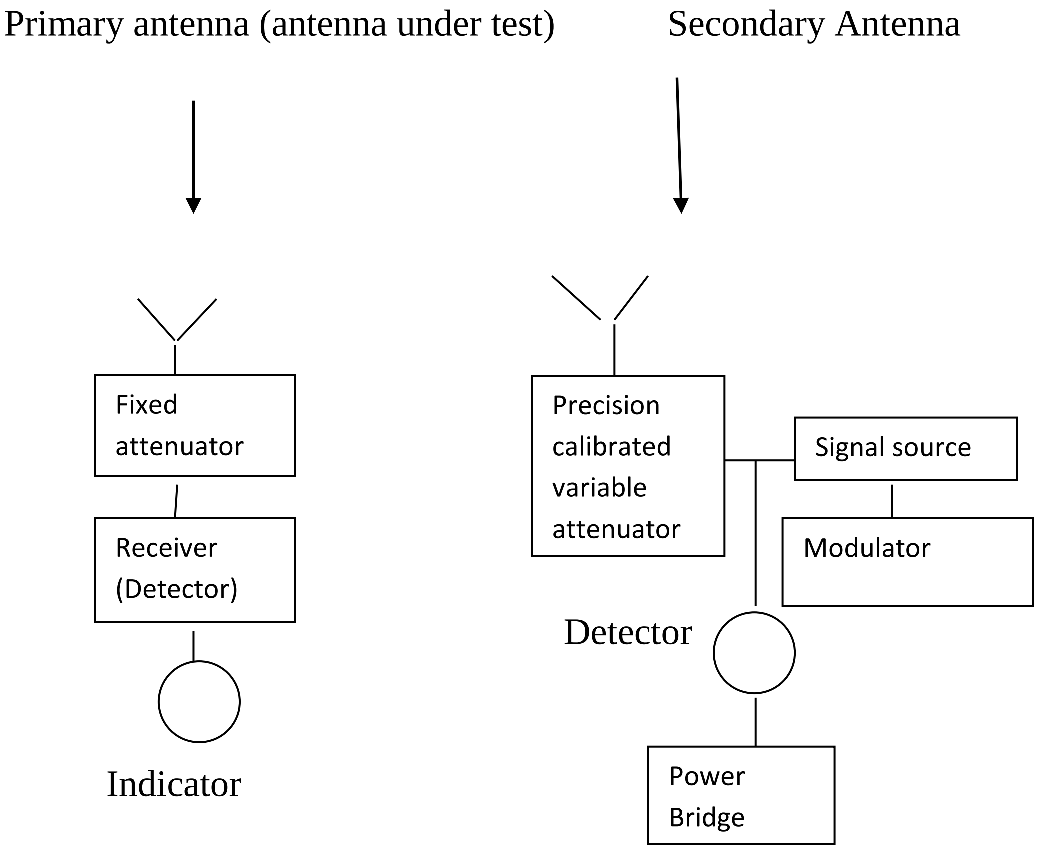


Fig:9 Set up for Gain measurement by comparison method

The distance between the primary and secondary antenna should be $\geq \frac{2d^2}{\lambda}$ and reflection between them should be minimized to the extent possible. The following procedure is adopted for gain measurement

(i) At first the standard antenna is connected to the receiver with the help of switch(S) and the antenna is named at secondary antenna in the direction of maximum signal intensity. The input to the transmitting antenna (secondary antenna) is adjusted to a convenient level and corresponding reading at the receiver (primary antenna circuit)is recorded. The attenuator dial setting and the power bridge reading are also recorded. Say it is W_1 and P_1 respectively

(ii) Now connect the subject antenna whose gain is to be measured in place of standard gain antenna the attenuator dial is adjusted such that receiver indicates the same previous reading with standard gain antenna. Let the attenuator dial setting be W_2 and P_2 two cases arise

Case 1:- When $P_1=P_2$

If $P_1=P_2$ then no correction need to be applied and the gain of the subject antenna under measurement W.r.to standard gain antenna is given by

$$\text{Power gain} = W_2/W_1 \tag{8}$$

W_1 and W_2 are the relative power levels

$$\text{Log } G_p = \log W_2 - \log W_1$$

$$G_p(db) = W_2(db) - W_1(db)$$

Case 2: When $P_1 \neq P_2$

$$P_1/P_2 = P \text{ (Say)}$$

$$10\log P_1/P_2 = P(db)$$

$$G = G_p * P$$

$$G(db) = G_p(db) + P(db)$$

$$G_p(db) = W_2(db) - W_1(db) + P(db) \tag{9}$$

4. Ionospheric measurements – Vertical incidence measurements of the ionosphere:

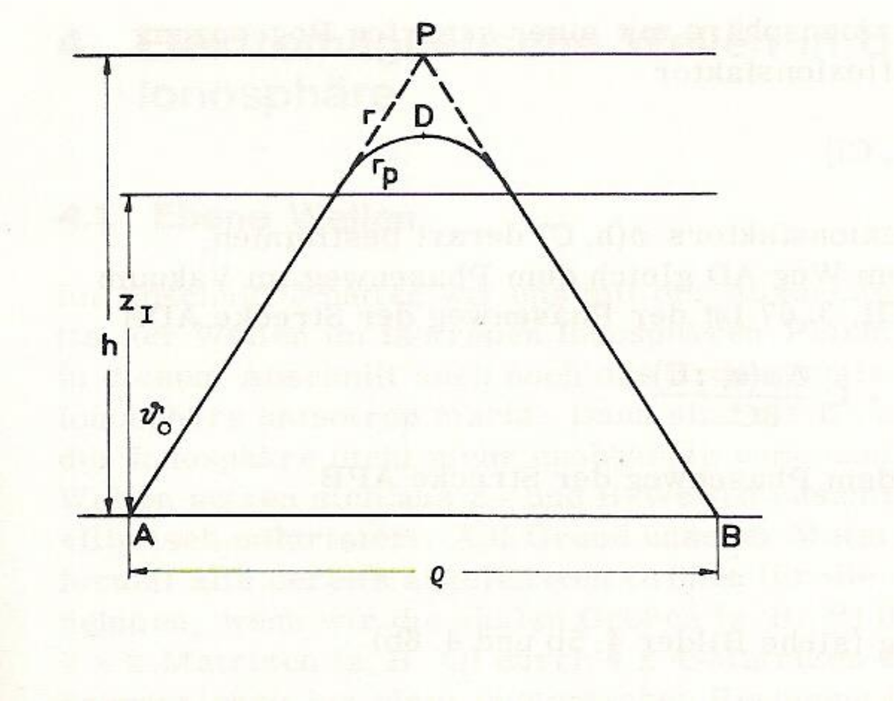


Fig: 10 Vertical incidence measurements of the ionosphere

Waves with frequencies smaller than f_c are reflected within the ionospheric D-, E-, and F-layers. f_c is of the order of 8–15 MHz during day time conditions. For oblique incidence, the critical frequency becomes larger. Very low frequencies (VLF: 3–30 kHz), and extremely low frequencies (ELF: <3 kHz) are reflected at the ionospheric D- and lower E-layer. An exception is whistler propagation of lightning signals along the geomagnetic field lines

The wavelengths of VLF waves (10–100 km) are already comparable with the height of the ionospheric D-layer (about 70 km during the day, and 90 km during the night). Therefore, ray theory is only applicable for propagation over short distances, while mode theory must be used for larger distances. The region between Earth's surface and the ionospheric D-layer behaves thus like a waveguide for VLF- and ELF-waves.

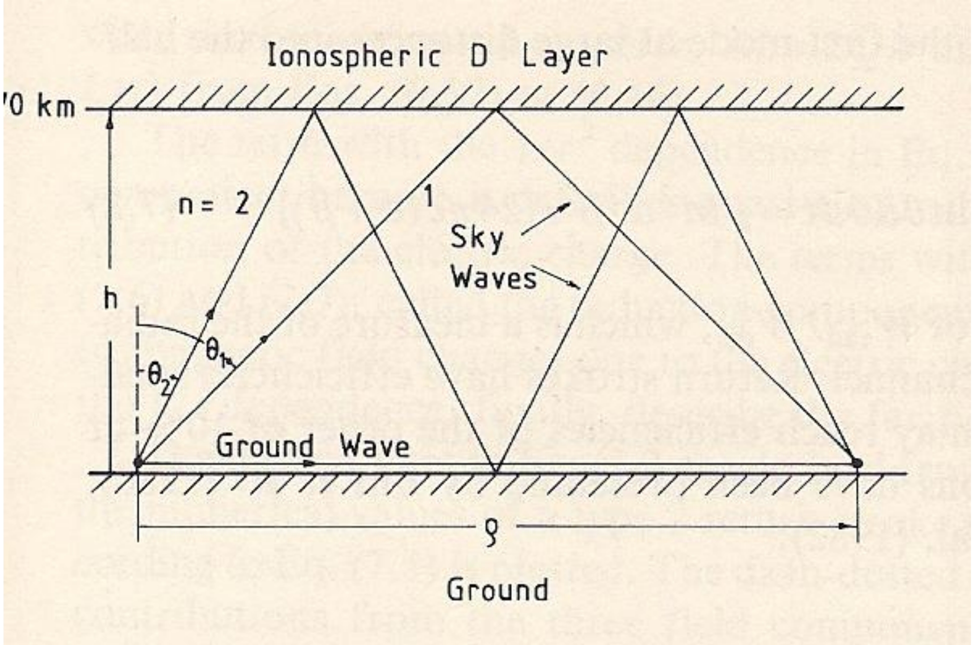


Fig: 11Ionosheric Measurement

In the VLF range, the transfer function is the sum of a ground wave which arrives directly at the receiver and multihop sky waves reflected at the ionospheric D-layer (Figure 10).

For the real Earth's surface, the ground wave becomes dissipated and depends of the orography along the ray path. For VLF waves at shorter distances, this effect is, however, of minor importance, and the reflection factor of the Earth is $R_e = 1$, in a first approximation.

At shorter distances, only the first hop sky wave is of importance. The D-layer can be simulated by a magnetic wall ($R_i = -1$) with a fixed boundary at a virtual height h, which means a phase jump of 180° at the reflection point.[2][5] In reality, the electron density of the D-layer increases with altitude, and the wave is bounded as shown in Figure 11.

5. Antenna Noise Temperature and System Signal-to Noise Ratio

Antenna temperature :

The performance of a telecommunication system depends very much on the signal-to-noise ratio (SNR) at the receiver’s input. The electronic circuitry of the receiver (amplifiers, mixers, etc.) has its own contribution to the noise generation. However, the antenna itself is a significant source of noise. The antenna noise can be divided into two types of noise according to its physical source: - noise due to the loss resistance of the antenna itself; and - noise, which the antenna picks up from the surrounding environment. Any object whose temperature is above the absolute zero radiates EM energy. Thus, each antenna is surrounded by noise sources, which create noise power at the antenna terminals. Here, we will not be concerned with technological sources of noise, which are a subject of the electromagnetic interference science. We are also not concerned with intentional sources of electromagnetic interference. We are concerned with natural sources of EM noise, such as sky noise and ground noise. The concept of antenna temperature is not only associated with the EM noise. The relation between the object’s temperature and the power it can create at the antenna terminals is used in passive remote sensing (radiometry). A radiometer can create temperature images of objects. Typically, the remote object’s temperature is measured by comparison with the noise due to background sources and the receiver itself.

System signal-to-noise ratio (SNR)

Signal-to-noise ratio (abbreviated **SNR** or ***S/N***) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise. While SNR is commonly quoted for electrical signals, it can be applied to any form of signal (such as isotope levels in an ice core or biochemical between cells).

Signal-to-noise ratio is defined as the ratio of the power of a signal (meaningful information) and the power of background noise (unwanted signal)

$$\mathbf{SNR}=\frac{P_{\mathbf{signal}}}{p_{\mathbf{noise}}} \tag{10}$$

A **link budget** is accounting of all of the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fiber, etc.) to the receiver in telecommunication system. It accounts for the attenuation of the transmitted signal due to propagation, as well as the antenna gains, feed line and miscellaneous losses. Randomly varying channel gains such as fading are taken into account by adding some margin depending on the anticipated severity of its effects. The amount of margin required can be reduced by the use of mitigating techniques such as antenna diversity or frequency hopping.

A simple link budget equation looks like this:

Received Power (dB) = Transmitted Power (dB) + Gains (dB) − Losses (dB)

A link budget equation including all these effects, expressed logarithmically, might be

$\mathbf{P_{RX}=P_{TX}+G_{TX}-L_{TX}-L_{FS}-L_{M}+G_{RX}-L_{RX}}$ which is given by

$\mathbf{P_{RX}}$= received power (dBm)

$\mathbf{P_{Tx}}$= transmitter output power (dBm)

$\mathbf{G_{TX}}$ = transmitter antenna gain (dBi)

$\mathbf{L_{TX}}$ = transmitter losses (coax, connectors...) (dB)

$\mathbf{L_{Fs}}$ = path loss, usually free space loss (dB)

$\mathbf{L_{m}}$ = miscellaneous losses (fading margin, body loss, polarization mismatch, other losses...) (dB)

$\mathbf{G_{RX}}$ = receiver antenna gain (dBi)

$\mathbf{L_{RX}}$ = receiver losses (coax, connectors...) (dB)