MODULE 5 | Radar and Navigational Systems (18ECE221T)

Session 1 | Introduction - Four methods of Navigation - Positioning- Errors in Direction Finding & Line of sight Distance measurement

Navigation

- The art of directing the movements of a craft from one point to another along a desired path.

- Various instruments come to the aid of navigation
  - Compass
  - Clock

- Four methods of navigation
  1. Navigation by pilotage
  2. Celestial (or) astronomical navigation
  3. Navigation by dead reckoning
  4. Radio Navigation

- Navigation by pilotage
  - Navigator fixes his/her position on the map by observing known visible landmarks.
  - Eg. Light house in Chennai provides important information about the port for the aircraft

- Celestial Navigation
  - The action of fixing the way by observing sun, moon and stars.
- Navigation by dead reckoning
  - The position of the craft at any instant of time is calculated from the previously determined position.
- Radio Navigation
  - This method is based on the use of EM waves to fix the position of the craft
  - Nowadays using radio navigation extensively

Errors

1. Polarization errors: Due to abnormal polarization
2. Abnormal propagation: due to reflection, refraction and scattering
3. Site errors: Arising from echo signal of neighbouring objects
4. Instrumental: errors arising from imperfection of instruments

Line of sight Distance measurement

Frequencies above 30 MHz follow line of sight propagation. Some sky-wave anomalous propagation occurs occasionally up to 100 MHz.

In the Line-of-sight systems, the frequency of operation will be very high. So, it will have relatively short wavelengths. For instance, at 1 GHz, the wavelength is 1 ft. If a 1 GHz quarter wave antenna (7.5 cm) placed on the ground then even the blade of the grass will mar antenna performance. So, it is necessary to mount the antenna on a pole of 10 ft high.

Next due to short wavelength, reflection phenomenon occurs. So, we will have direct signal and reflected signal

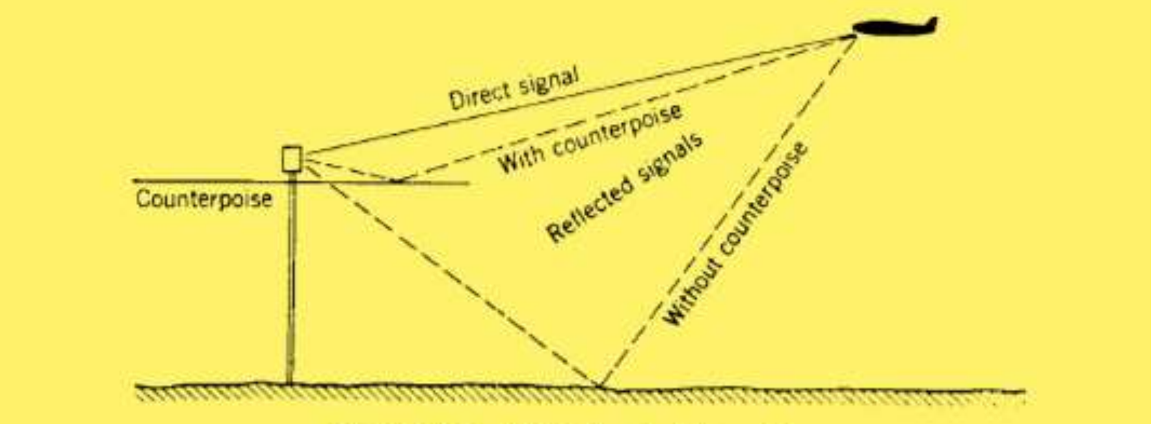


Figure 4.4 Vertical reflection paths.

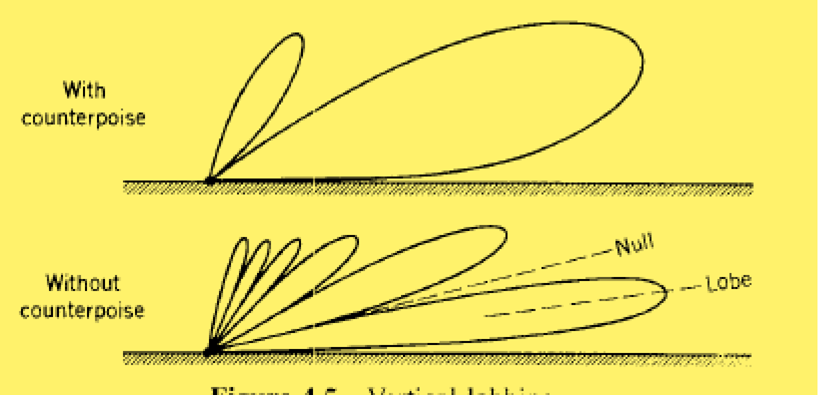
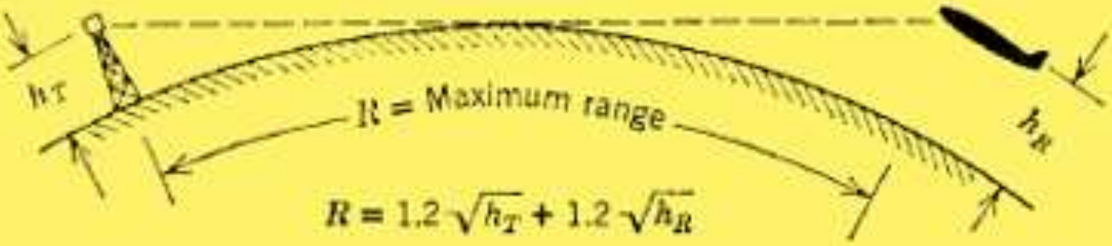


Figure 4.5 Vertical lobbing.

Line-of-sight system on Earth are, subject to the limitations of the horizon. The maximum range obtained is illustrated in Figure 4.6. Beyond the line of sight, the signal strength at these frequencies (1 GHz) drops off suddenly.



$$R = 1.2\sqrt{h_T} + 1.2\sqrt{h_R}$$

R in nautical miles
h in feet

Figure 4.6 Line-of-sight range.

Session 2 | Terrestrial Radio Navigation systems & Radio transmission and Reception

Terrestrial Radio Navigation Systems

- Types
  1. Point Source systems – direction finder, VOR, DME, Tacan
  2. Hyperbolic systems – Loran, Loran C, Decca, Omega
- These systems are used worldwide and provided accurate and reliable positioning and navigation in one or two dimensions for many years

Satellite Navigation Systems – GPS

- You will study it in Session 9

Working of Antenna

If a wire excited by a ac signal that has a frequency to make the length of the antenna wire equal to half of the signal wavelength then signal will be radiated. A similar wire placed far away will be able to pick up the signal.

Half wavelength wires are called resonant dipole antennas.

Modulation is used to incrase the signal frequency. By this antenna length is reduced. For modulation, vaccuum tube, diode and transistors are used. With the use of tubes and transistors low sensitivity receivers were designed.

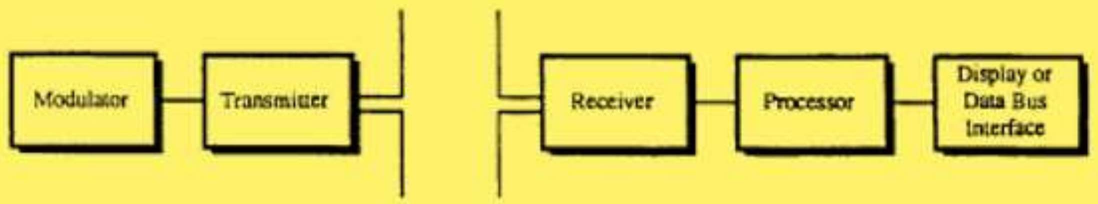


Figure 4.1 Elementary radio-navigation system.

Letter Designation	Frequency Range	Letter Designation	Frequency Range
L	0.39 to 1.55 GHz	X_b	6.25 to 6.90 GHz
L_s	0.90 to 0.95 GHz	K^1	10.90 to 36.00 GHz
S	1.55 to 5.20 GHz	K_u	15.35 to 17.25 GHz
C	3.90 to 6.20 GHz	K_a	33.00 to 36.00 GHz
X	5.20 to 10.90 GHz	Q	36.00 to 46.00 GHz

[1]Includes K_e band, which is centered at 13.3 GHz.

Name	Abbreviation	Frequency	Wavelength
Very low frequency	VLF	3 to 30 kHz	100 to 10 km
Low frequency	LF	30 to 300 kHz	10 to 1 km
Medium frequency	MF	300 to 3000 kHz	1 km to 100 m
High frequency	HF	3 to 30 MHz	100 to 10 m
Very high frequency	VHF	30 to 300 MHz	10 to 1 cm
Ultrahigh frequency	UHF	300 to 3000 MHz	1 m to 10 cm
Superhigh frequency	SHF	3 to 30 GHz	10 to 1 cm
Extremely high frequency	EHF	30 to 300 GHz	10 to 1 mm

1. The propagation speed of radio waves in a vacuum is the speed of light: 299,792.5 ± 0.3 km/sec (usually taken as 300,000 km/sec for all but the most precise measurements).

2. The received energy is a function of the area of the receiving antenna. If transmission is omnidirectional, the received energy is proportional to the area of the receiving antenna divided by the area of a sphere of radius equal to the distance from the transmitter:

$$\frac{Received\ Power}{Transmitted\ Power} = \frac{Receiver\ Antenna\ Area}{Area\ of\ a\ sphere}$$

where R is the range between antennas in the same units as those for the antenna area.

3. Multiple antennas may be used at both ends of the path to increase the effective antenna area. Such increases in area produce an increase in directivity or gain and result in more of the transmitted power reaching the receiver.

The *gain G* of an antenna (in the direction of maximum response) is equal to its *directivity D* times its efficiency. The *maximum effective aperture* or *effective area of an antenna* is equal to Dλ/4π.

It is defined as the ratio of the power in the terminating impedance to the power density of the incident wave, when the antenna is oriented for maximum response and under conditions of maximum power tranfer.

It is also defined as the physical urea times the antenna aperture efficiency (or absorption ratio). The directivity or gain of an antenna is usually expressed as a ratio with respect to cither a hypothetical isotropic radiator or a half-wave dipole. A dipole has an effective area of about 0.13 times the square of the wavelength .

The minimum power that a receiver can detect is referred to as its *sensitivity*. The sensitivity is limited noise existing at the input of the receiver. Two types of noise. Internal and external. Internal noise generated by the receiver circuit and thermal noise. External noise is due to unwanted transmitters, atmospheric noise.

$$N_p = kT\Delta f$$

N_p = Noise power in Watts

K = Boltzmann Constant

T = Temperature in Kelvin

Δf = Noise Bandwidth

Noise Figure is used express the receiver noise in decibels.

4. The minimum bandwidth occupied by the system is proportional to the information rate. For most navigational purposes, the necessary information rate is quite low. For instance, to navigate in a given direction to an accuracy of 500 ft with an aircraft that cannot change its position more than 500 ft in that direction in any one second, new information is needed only once per second.

Most practical systems have employed many times this minimum bandwidth. The reasons include

(a) the need for other services, such as communications on the same channel,

(b) the use of pulse techniques to aid in resolving multiple targets and to reduce the effects of multipath transmission, and

(c) the use of spectrum-spreading techniques to improve signal-to-noise ratio (S/N), accuracy of range measurements, reduction of effects due to interference of site errors.

In summary, to assess the free-space range of a radio system, it is necesary to have at least the following facts: transmitter power and antenna gain, receiver antenna gain and noise figure, the effective bandwidth of the system,ind the effect on system performance of external or internal noise. Combinng the fundamental relations results in the following generalized link budget expression for the required radio transmitter power of

$$10 \log \left(\frac{P_T}{P_N} \right) = \left(\frac{S}{N} \right)_{REQ} + L_P + NF - G_T - G_R - F_N \quad \text{(dB)} \qquad (4.5)$$

where

P_T	is the transmitter power
P_N	is the noise power in receiver
$(S/N)_{REQ}$	is the required signal-to-noise ratio in receiver
NF	is the receiver noise figure
F_N	is the noise improvement factor due to modulation method and bandwidth spreading (e.g., frequency modulation)
G_T	is the transmitter antenna gain

Session 3 | System design considerations-System Performance Parameters & The Loop Antenna - Adcock Direction Finders

1. System Design Considerations

Reasons for use of radio for the measurement of distance

1. Speed of electromagnetic waves are almost constant.

2. Accurate measurement 'differential time' is possible.

Measurement of *differential distance* of two receiving antennas from one transmitter, the *direction* of the transmitter can be determined. In addition to time (and hence distance), angular measurement of direction is also possible. With that user position can be determined.

In Figure 4.7, two receivers (A and B) are arranged on a known baseline, which is assumed to be short with respect to the distance to the transmitter, so that the transmission paths to the two receivers can be considered parallel. A right triangle ABC may then be constructed and θ readily calculated if r is known. The value of r is found by comparing the outputs of the two receivers, noting the time delay between the arrival of identical parts of the signal, and dividing this time delay by the known speed of propagation. Such an arrangement is commonly called a *direction-finder* and is a widely used radio-navigation aid at all frequencies. (In many practical systems, the baseline AB is physically rotated until the delay is zero; the direction of arrival is then on the perpendicular bisector of AB.)

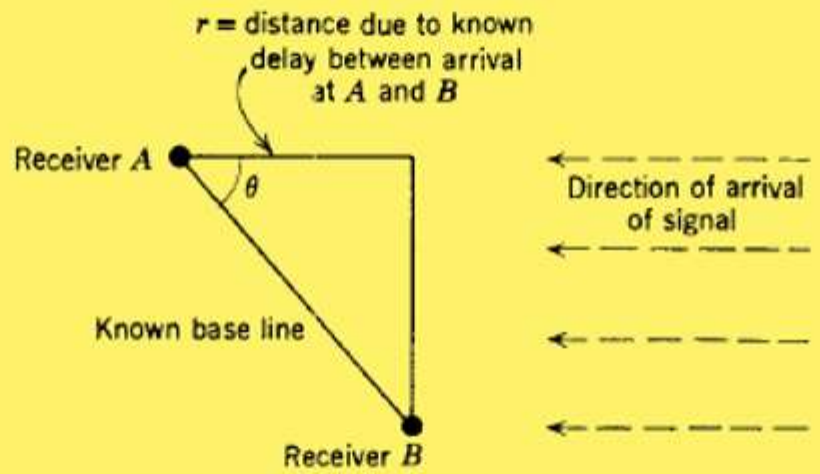


Figure 4.7 Direction-finder principle.

Some of the more common position determination methods are shown in Figure 4.8. With the knowledge of distance (rho) or direction (theta) to a ground station, Lines of Position (LOPs) may be plotted on a map. The LOP of constant direction is a radial from the station; the LOP of constant distance is a circle cantered on the station. The intersection of two LOPs provides a *fix*. It will be seen that the greatest geometrical accuracy occurs when LOPs cross at right angles.

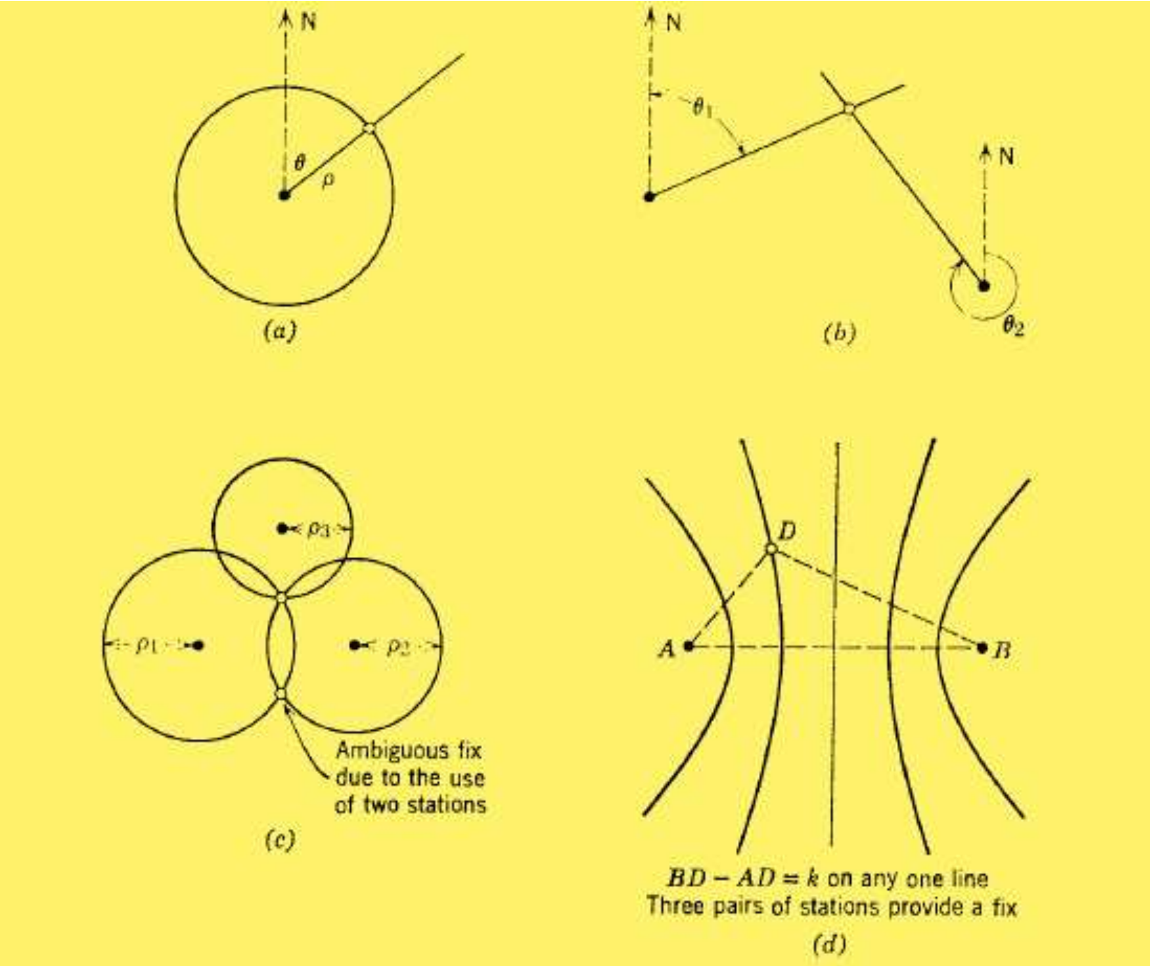


Figure 4.8 Common geometric position fixing schemes: (a) Rho-theta (ρ-θ); (b) theta-theta (θ-θ); (c) rho-rho (ρ-ρ); (d) hyperbolic.

- Rho-theta systems provide a unique fix from a single station, and the LOPs always cross at right angles.
- Theta-theta systems provide a unique fix from two stations. The geometric accuracy is highest when the lines cross at right angles and is poor on a line connecting the stations.

- Rho-rho systems provide an ambiguous fix from two stations and a unique fix from three stations. Geometric accuracy is greatest within the triangle formed by the three stations and gradually decreases as the vehicle moves outside and away from the triangle.

The hyperbolic system uses LOPs that each define a constant difference in distance of two stations. Such systems operate under conditions where the determination of absolute distance to the station is impractical. Three pairs of stations are needed for a unique fix; however, for many practical applications, two pairs suffice. Geometric accuracy is very much a function of the relative station locations. Poor geometry leads to a property frequently called Geometric Dilution of Precision (GDOP).

2. System Performance Parameters

1. Accuracy: It is a statistical measure given as root-mean-square (rms) measurement of its position error over some time interval. It is expressed in two dimensions.

Major factor affecting the radio-navigation system accuracy are as follows

A. Absolute error: It is predictable
B. Repeatable error: It is with known time.
C. Relative errors: error due to a known point
D. Differential errors These are residual errors remain after user applying corrections in differential reference station.
E. Propagation effects: radio transmission is affected by atmosphere. Reflection and refraction play major role
F. Instrumentation errors: error in the radio or display equipment
G. Geometry effects: It is expressed as a quantity Geometric Dilution of Precision. It maps the range and or angle measurements into position error.

2. Coverage: In general, 'coverage limit' is defined by a requirement that a navigation receiver be able to acquire the radio navigation signal as well as use it.

3. Availability: The probability that the system is available for navigation by a suer. In US if a navigation system availability is less than 99.7 % will not considered for use.

4. Integrity: Ability of system to warn the user, when NOT to rely on navigation system. This facility is available in VOR and TACAN

5. Ambiguity: The navigation system identifies two or more possible points with the same set of measurements, with no indication of which is the most nearly correct position. This happens in Omega receivers. Loran-C system is devoid of ambiguity.

6. Capacity: Number of users that the radio-navigation system can accommodate simultaneously. For example, DME and TACAN can handle 110 users at a time. For Loran-C, Omega and VOR no such restrictions.

The Loop Antenna - Adcock Direction Finders

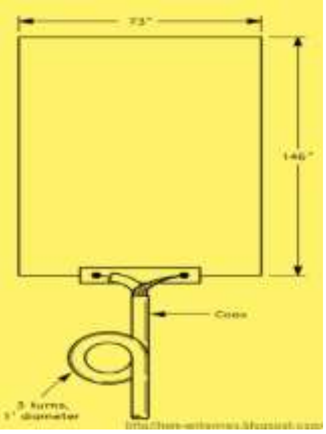


Figure 6. Schematic of a loop antenna

- Loop antenna used for directional finding.
- Voltage is induced in the vertical member. If a plane wave incident on the loop antenna, then voltage induced in the horizontal member should be zero.
- But due to polarization errors (displaced minima, rapid changes in position, poor null etc) in the horizontal member voltage is induced.

TASK : Draw radiation pattern of loop antenna.

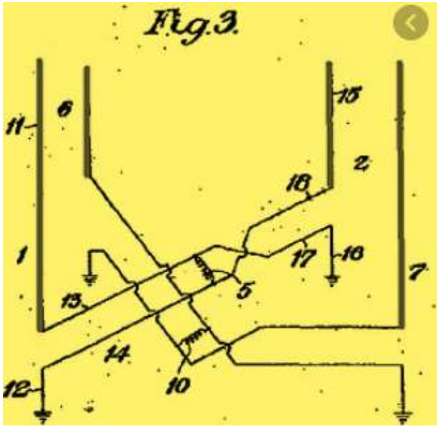


Figure 7. Schematic of an Adcock Antenna

In Adcock antenna polarization errors are removed through dispensing the horizontal member. Here we see four antennas with vertical lines only. The signals are taken to underground receiver or by shielded balanced pair of wires.

1. No voltage is induced

2. Voltage developed also tend to cancel each other due to the arrangement.

Electrically Adcock antenna is equivalent to single turn loop antenna. So, output is low. To increase the amplitude antenna size has to be made large.

The angle of error in Adcock antenna will be in the range of 2° - 6°.