UNIT-IV

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RADIO NAVIGATION

Adcock directional finder - automatic directional finder - hyperbolic Systems of Navigation - Loran and Decca Navigation System - Tactical Air Navigation.

Introduction.

* Navigation, the art of directing the movements of a craft from one point to another along a desired path

* In early days, none of the aids of later navigators, such as the compass, the chronometer and the sextant were available.

* In the twentieth century, Direction finders and other navigational aids were developed.

* This enabled the navigator to obtain a fix using entirely electronic aids.

Four methods of Navigation:

* requires the determination of the position of the craft and the direction in which it has to go to reach the desired destination.

* Divided into four classes.

i) Navigation by pilotage (or visual contact)

ii) celestial or astronomical navigation

iii) Navigation by dead reckoning

iv) Radio Navigation.

Navigation by Pilotage:

* the navigator fixes his position on a map by observing known visible landmarks.

* In air navigation, when ground is visible, the navigator can see the principal features on the ground such as rivers, coast-lines, estuaries, hills etc and thereby fix his position.

* Even at night, light beacons, cities and towns provide information about the position of the craft.

* Pilotage in this sense is possible only under conditions of good visibility.

* Pilotage is also possible with the aid of an air-borne radar and this is called Electronic - Pilotage.

* Radar used - microwave search radar provided with PPI display on which the terrain is mapped.

* Adv. i) Range is high ii) 50 to 100 km - used under conditions of poor visibility.
ii) distance of the objects seen is more accurate.

* Disadv: become useless over stretches of sea if there are no islands in the field of vision.

Celestial Navigation:

* accomplished by measuring the angular position of celestial bodies.

* Navigator measures the elevation of the celestial body with a sextant and notes the precise time at which the measurement is made with a chronometer.

* These two measurements are enough to fix the position of the craft on a circle on the face of the globe.

* If two such observations are made, the position or 'fix' of the craft can be identified as one of the two points of intersections of the circles.

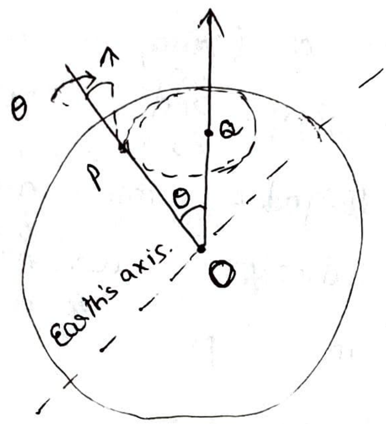


Fig: Principle of celestial navigation.

* P → Position of the craft on the surface of the earth

  Q → Point on the surface of the earth at which the celestial body is (sub-stellar point) at the time of observation.

* Celestial body makes an angle θ with the vertical at P. The arc joining sub-stellar point and the position of the craft also subtends an angle θ at the centre of the earth.

* The locus of all points subtending thin angle is a circle with the substellar point as the centre.

Adv: it is relatively independant of external aids

Disadv: Vissibility should be good.

Navigation by dead-reckoning:

* position of the craft at any instant of time is calculated from the previously determined position, the speed of its motion with respect to earth along with the direction of its motion and the time elapsed.

* requires some means of finding the direction of motion of the craft called track angle and a speed indicator.

* 1st requirement by magnetic compass and the 2nd by an air-speed indicator in aircraft and the mechanical log in ships.

Radio Navigation:

* Based on the use of electromagnetic waves to find the position of the craft.

* The positional information is related principally to

i) the measurement of direction
ii) the measurement of distance
iii) the difference in distance of two transmitters

* This gives the locus of the craft on ~~an~~ a line, circle or a hyperbola

* Intersection of two or more such loci gives the fix or position of the craft.

Radio Direction Finding:

* determination of the direction of arrival of electromagnetic waves at the receiving station.

* The direction finder may be located either on the craft or on ground.

* In former case, the determination of the bearing of two or more fixed stations will give a 'fix'. In latter case, the ground station finds the bearing of the craft and passes on the information to the craft by a radio commn. channel.

Errors in Direction Finding:

a) Erros due to abnormal polarization of the incoming wave

b) Errors due to abnormal propagation

c) Site errors, arising from re-radiation of energy from neighbouring objects

d) Instrumental errors, arising from imperfection of the receiving apparatus.

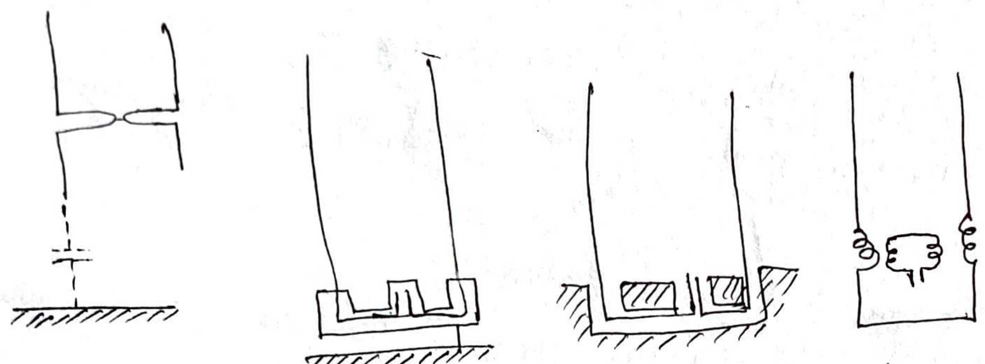
Adcock Direction Finders:

* Designed to eliminate polarization errors by dispensing with the horizontal members.

* Consists of a pair or more of vertical antennas, the signals from these being taken to the receiver either by underground conductors or by shielded balanced pair of wires.

* In the 1st case, no voltages will be induced in the horizontal member if the conductivity of the earth is good and in the second case, whatever voltages induced in the two horizontal members tend to cancel out.

* Fig. below shows several forms of Adcock antenna generally called U-type or H-type depending on the position of the horizontal members, relative to the vertical members.



a) 2° - 6°

b) 6° - 10°

c) <5°

d) > 1°

Fig: Adcock direction finders.

* Electrically, the Adcock antenna is equivalent to a single turn loop and therefore for equal sized ones, the o/p of the former is very low.

* To compensate for this, the vertical antennas are made large and consequently, a fixed antenna system in conjunction with a goniometer is employed at low, medium and high frequencies.

* The need for large antennas also makes the Adcock direction finder unsuitable for mobile installations.

* Another disadvantage - it has a high internal impedance which is largely capacitive and presents some difficulties in connecting it to the iput circuits of a receiver.

* Sense finding in the Adcock antenna system is carried out in the same manner as in the loop systems by using a vertical antenna.

* It is not completely free from polarization error because some voltage is induced in the horizontal members even when buried under ground.

* In antennas of the type shown in above fig., which are used commonly in the VHF band, errors can arise due to unequal capacitance between the antenna and the earth, but they become less as the height of the antenna system above the earth is increased.

Automatic Direction Finders:

* Manually - operated direction-finders have the virtue of relative simplicity and auditory discrimination in the presence of interfering signals.

* In many situations, the need for an operator and the slowness inherent in manual operation are serious disadvantages.

* When the ground-direction-finder has to take the bearing of an aircraft and pass on the information to the control tower, an automatic Direction finder is advantageous

a) Radio Compass.

* Is an air borne direction finder operating in the LF/MF band (200-3000 kc/s.

* uses a loop antenna in a servo feed-back system

* The loop antenna is coupled to the servo-motor which is actuated by an error signal derived from the loop o/p and turns the loop until the error signal and therefore the loop o/p is zero.

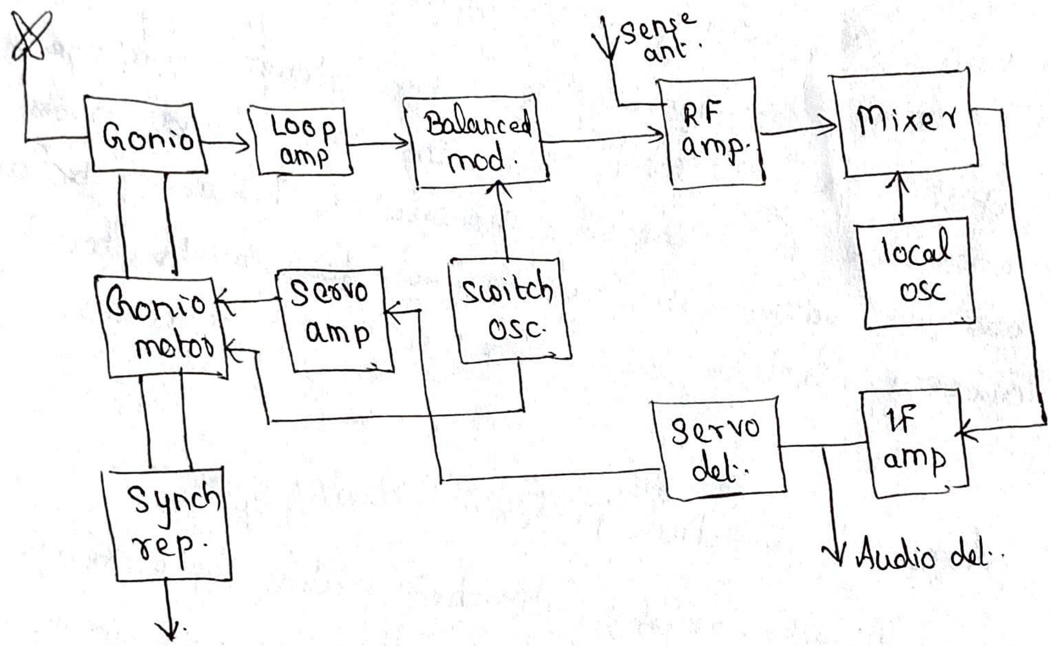


Fig. Block diagram of a radio compass receiver.

* The equipment is provided with a pair of fixed loops and a gonio whic is mechanically coupled to a motor and a synchro-generator.

* Motor is a 2 φ one which is actuated by the switching oscillator and receiver o/p.

* Former constant i/p and therefore provides a fixed reference and the latter, a signal in phase with this or exactly 180° out of phase, depending on the position of the loop w.r.to the direction of arrival of the signal.

* The direction of the torque on the motor correspondingly changes its sign depending on the position of the loop and the motor tends to move the gonio to the position of the zero torque or the null.

* The o/p of the gonio is fed to the balanced modulator and modulated by a signal from the switching oscillator.

* The o/p of the balanced modulator, which consists only of the side band component is combined with the sense aerial i/p, which is phase shifted so as to be in phase with the suppressed carrier of the signal.

* resultant fed to a superheterodyne amplitude-modulated receiver.

* The demodulated o/p of this will have a switching freq. waveform, the phase of which will be determined.

b) A VHF Phase-Comparison Automatic Direction-Finder.

* The DF employs a pair of fixed Adcock antennas with a capacitance goniometer to obtain the rotating figure-of-eight pattern.

* Instead of using a vertical antenna for obtaining a fixed phase signal, an unbalanced o/p is taken from the capacitance goniometer rotor.

* The vector sum of the voltages induced in the rotor, when combined with the figure-of-eight pattern gives the required cardioid.

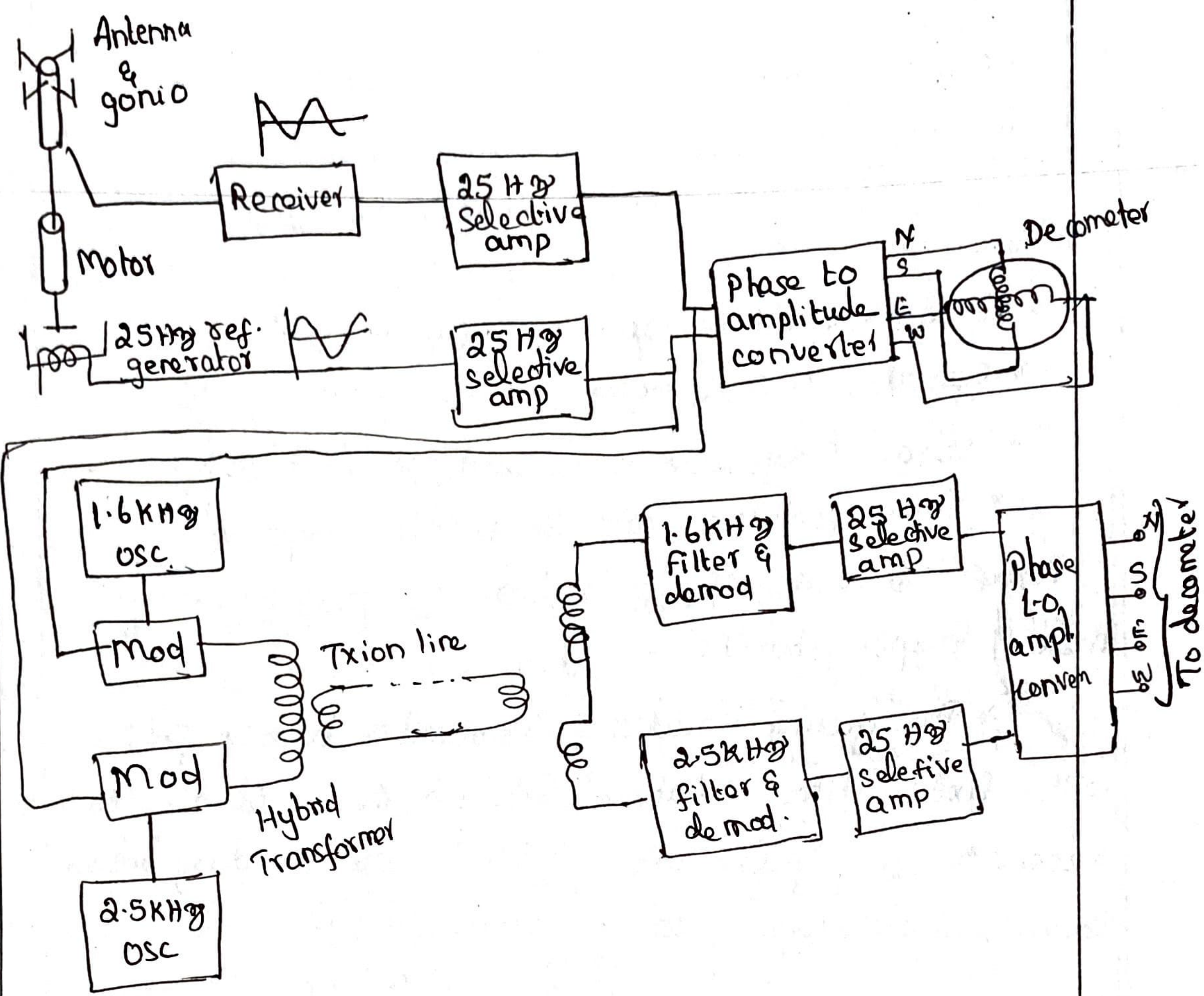
* The gonio rotor is coupled to a motor and rotated at 25 rps.

* To the same shaft is attached an ac generator which gives a 25 Hz ac voltage of fixed reference phase

* Signal from the goniometer, which is modulated at 25 Hz by the rotation of the motor is applied to the receiver and after demodulation and amplification is passed through a selective amplifier and is applied to a phase measuring device along with the signal from the reference generator.

* For remote indication, the two 25 Hz signals are made to amplitude modulate two audio frequency carriers which are then transmitted to the remote point where they are demodulated and the two modulating 25 Hz signals are recovered. These are then applied to a phase-meter.

* The DF operates on a VHF radio telephone channel.



Hyperbolic Systems of Navigation:

* Hyperbolic systems are based on the measurement of the difference in the time of arrival of electromagnetic waves from two transmitters to the receiver in the craft.

* The name arises from the fact that the locus of points which have a constant value of such a delay is a hyperbola on a plane surface.

* Three systems are in current use : DECCA , LORAN and OMEGA .

LORAN - A :

* Stands for 'Long range navigational aid' .
* Operates in the higher MF band around 2 MHz
* Loran-c operates in a band around 100 KHz .
* These facilities can be used by ships and by aircraft because of the nature of propagation in these frequency bands .
* The ground stations transmit a train of pulses with fixed time relation between them and at the receiver , these pulses are identified and the delay between them is measured on a CRT .

Incomplete .

Ground - Controlled Approach System:

* This is a high-precision radar system sited near the airport runway, with the help of which a controller on the ground can bring the aircraft into approach zone and then guide it along the path of decent to a point very near the runway.

* The system consists of two separate radars, one called the surveillance radar element (SRE) and the other called the precision approach radar (PAR).

* The former is a search radar with a PPI display which helps to locate the aircraft at a relatively distant point and bring it to within a few miles from the runway from the proper direction approach end of the

Surveillance Radar Element:

* The following data relating to an early version of SRE are listed below.

Wavelength : 10 cm

Peak Power : 80 kW

Pulse length : 0.5 μsec

Pulse repetition frequency : 2000

Scan rate : 30 rev/min

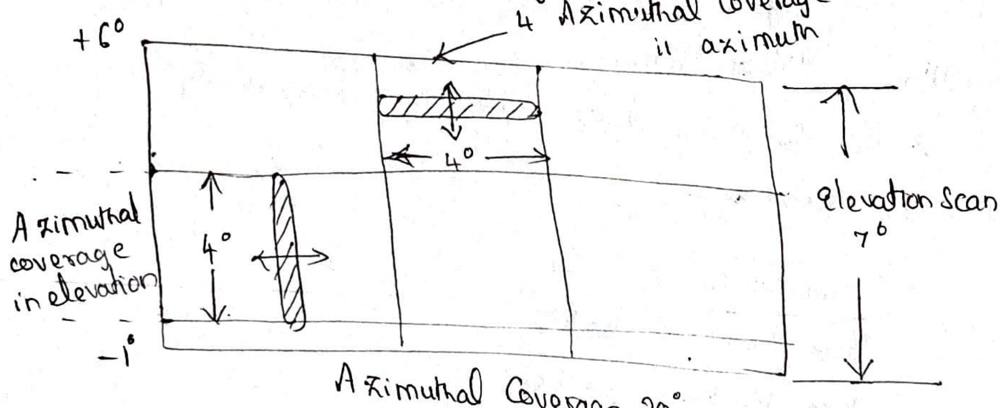
Beam width in the horizontal plane : approx. 0.5°

* The fan-shaped beam covers about 20° in the vertical plane.

(b) Precision Approach Radar.

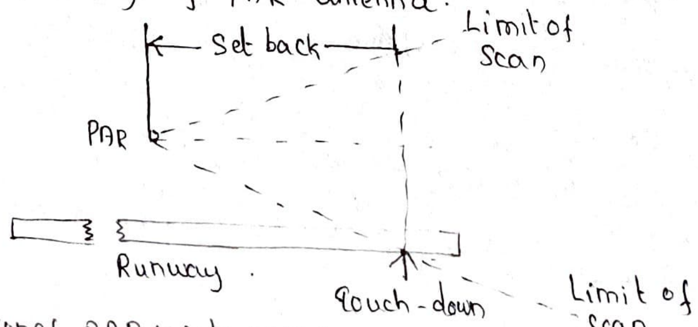
* maximum range : 15 - 20 km
* Scans the approach zone both in azimuth and elevation.
* The radar has to scan a 20° azimuth sector and a 7° elevation sector to meet the operational requirements.
* The beam width in the scanning direction is 0.5°.
* Therefore a separate antennas are used for azimuth and elevation scannings.
* The coverage is limited to 4°.

ie the elevation scan should be capable of azimuthal movement of 16° and the azimuthal scan an elevation movement of 3°.



Shaded rectangles show section of beam [4° x 0.5°]

a) Coverage of PAR antenna.



b) Position of PAR w.r.to runway

* The PAR uses a single radar transmitter which is connected alternately to the two antennas i.e the two scans are interlaced.

* The data pertaining to the equipment are as follows.

Transmitter power (peak)	:	50 kW
Frequency	:	9080 MHz
Pulse width	:	0.18 μsec
Prf	:	3.825 kHz
Range discrimination	:	200 ft
Azimuth discrimination	:	0.6°
Elevation discrimination	:	0.6°

* Rapid scanning of the antenna beam is required in the PAR as the information has to be rapidly renewed.

* The narrow beam requirements given above dictate a large antenna aperture and therefore a physically large antenna.

* Scanning by movement of the whole antenna presents practical problems.

* We employ an array of dipoles fed from and mounted on a wave-guide the width of which is varied.

* The array consists of 209 dipoles spaced 1.92 cm apart which are mounted on the side of the waveguide and terminate in a probe which couples with the waveguide and draws a certain amount of power.

* RF power fed at one end of the waveguide and its far end is terminated with a resistance load so as to prevent reflections.

* The array produces a beam of width of which is nearly constant and the orientation of which is dependent on the wavelength in the guide.

* This wavelength can be altered by altering the width of the wave-guide.

* change in wavelength changes the relative phases of the current fed to the antennas and this has the effect of changing the direction of maximum radiation.

* This wave-guide called 'squeezable wave-guide'.

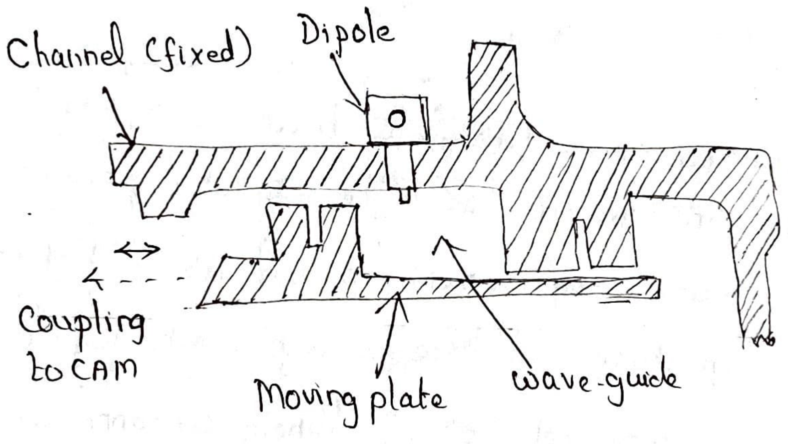


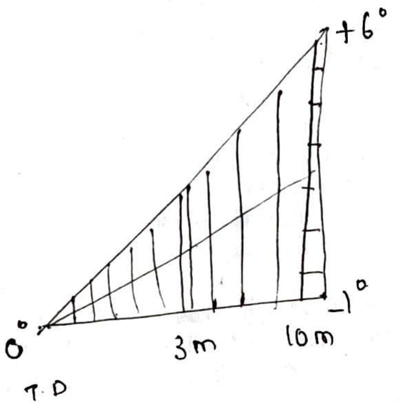
Fig: "Squeezable" wave-guide.

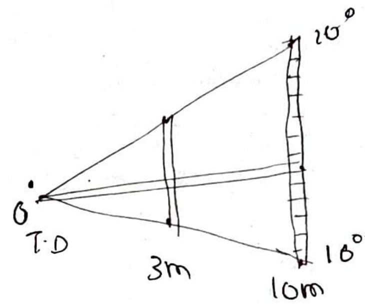
* Data obtained by the PAR are displayed on two long-persistence CRT, one displaying the range and elevation angle and the other the range and azimuth angle.

* The two display tubes are mounted on a single console and one controller uses both.

* While the radar itself is located near the runway end, the console may be in the control tower.

* The two points will be connected by cables which carry the control signals and video data.





a) elevation b) azimuth.

fig: PAR display a) elevation b) azimuth.

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Radio direction finder

Operation-*Radio Direction Finding* works by comparing the signal strength of a directional antenna pointing in different directions. At first, this system was used by land and marine-based radio operators, using a simple rotatable loop antenna linked to a degree indicator. This system was later adopted for both ships and aircraft, and was widely used in the 1930s and 1940s. On pre-World War II aircraft, RDF antennas are easy to identify as the circular loops mounted above or below the fuselage. Later loop antenna designs were enclosed in a aerodynamic, teardrop-shaped fairing. In ships and small boats, RDF receivers first employed large metal loop antennae, similar to aircraft, but usually mounted atop a portable battery-powered receiver.

In use, the RDF operator would first tune the receiver to the correct frequency, then manually turn the loop, either listening or watching an S meter to determine the direction of the *null* (the direction at which a given signal is weakest) of a long wave (LW) or medium wave (AM) broadcast beacon or station (listening for the null is easier than listening for a peak signal, and normally produces a more accurate result). This null was symmetrical, and thus identified both the correct degree heading marked on the radio's compass rose as well as its 180-degree opposite. While this information provided a baseline from the station to the ship or aircraft, the navigator still needed to know beforehand if he was to the east or west of the station in order to avoid plotting a course 180-degrees in the wrong direction. By taking bearings to two or more broadcast stations and plotting the intersecting bearings, the navigator could locate the relative position of his ship or aircraft.

Later, RDF sets were equipped with rotatable ferrite loopstick antennae, which made the sets more portable and less bulky. Some were later partially automated by means of a motorized antenna (ADF). A key breakthrough was the introduction of a secondary vertical whip or 'sense' antenna that substantiated the correct bearing and allowed the navigator to avoid plotting a bearings 180 degrees opposite the actual heading. After World War II, there many small and large firms making direction finding equipment for mariners, including Apelco, Aqua Guide, Bendix, Gladding (and its marine division, Pearce-Simpson), Ray Jefferson, Raytheon, and Sperry. In aircraft equipment, Bendix and Sperry-Rand were two of the larger manufacturers of RDF radios and navigation instruments.

Usage in Maritime and Aircraft Navigation-Radio transmitters for air and sea navigation are known as *beacons* and are the radio equivalent to a lighthouse. The transmitter sends a Morse Code transmission on a Long wave (150 - 400 Khz) or Medium wave (AM) (520 - 1720 Khz) frequency incorporating the station's identifier that is used to confirm the station and its operational status. Since these radio signals are broadcast in all directions (omnidirectional) during the day, the signal itself does not include direction information, and these beacons are therefore referred to as non-directional beacons, or **NDBs.**

As the commercial medium wave (AM) broadcast band lies within the frequency capability of most RDF units, these stations and their transmitters can also be used for navigational fixes. While these commercial radio stations can be useful due to their high power and location near major cities, there may be several miles between the location of the station and its transmitter, which can reduce the accuracy of the 'fix' when approaching the broadcast city. A second factor is that some AM radio stations are omnidirectional during the day, and switch to a reduced power, directional signal at night.

RDF was once the primary form of aircraft and marine navigation. Strings of beacons formed "airways" from airport to airport, while marine NDBs provided navigational assistance to small watercraft approaching a landfall. In the 1950s the aviation NDBs were augmented by the VOR system, in which the direction to the beacon can be extracted from the signal itself, hence the distinction with non-directional beacons. Use of marine NDBs was largerly supplanted in North America by the development of LORAN in the 1970s.

Today many NDBs have been decommissioned in favor of faster and far more accurate GPS navigational systems. However the low cost of ADF and RDF systems, and the continued existence of AM broadcast stations (as well as navigational beacons in countries outside North America) has allowed these devices to continue to function, primarily for use in small boats, as an adjunct or backup to GPS.

Automatic Direction Finder (ADF)

A typical aircraft ADF indicator

An *Automatic Direction Finder* (ADF) is a marine or aircraft radio-navigation instrument which automatically and continuously displays the relative bearing from the ship or aircraft to a suitable radio station. ADF receivers are normally tuned to aviation or marine NDBs operating in the LW band between 190 - 535 kHz. Like RDF units, most ADF receivers can also receive medium wave (AM) broadcast stations, though as mentioned, these are less reliable for navigational purposes.

The operator tunes the ADF receiver to the correct frequency and verifies the identity of the beacon by listening to the Morse code signal transmitted by the NDB. On marine ADF receivers, the motorized ferrite-bar antenna atop the unit (or remotely mounted on the masthead) would rotate and lock when reaching the null of the desired station. A centerline on the antenna unit moving atop a compass rose indicated in degrees the bearing of the station. On aviation ADFs, the unit automatically moves a compass-like pointer (RMI) to show the direction of the beacon. The pilot may use this pointer to *home* directly towards the beacon, or may also use the magnetic compass and calculate the direction from the beacon (the *radial*) at which their aircraft is located.

Unlike the RDF, the ADF operates without direct intervention, and continuously displays the direction of the tuned beacon. Initially, all ADF receivers, both marine and aircraft versions, contained a rotating loop or ferrite loopstick aerial driven by a motor which was controlled by the receiver. Like the RDF, a sense antenna verified the correct direction from its 180-degree opposite.

More modern aviation ADFs contain a small array of fixed aerials and use electronic sensors to deduce the direction using the strength and phase of the signals from each aerial. The electronic sensors listen for the *trough* that occurs when the antenna is at right angles to the signal, and provide the heading to the station using a direction indicator. In flight, the ADF's RMI or direction indicator will always point to the broadcast station, regardless of the aircraft's attitude or heading. Such receivers can be used to determine current position, track inbound and outbound flight path, and intercept a desired bearing. These procedures are also used to execute holding patterns and non-precision instrument approaches.

Typical NDB services ranges - Class of NDB Transmission Power Effective Range

Locator	below 25 watts	15 NM
MH	below 50 watts	25 NM
H	50 to 1,999 watts	50 NM
HH	2,000+ watts	75 NM

Station passage-As an aircraft nears an NDB station, the ADF becomes increasingly sensitive, small lateral deviations result in large deflections of the needle which sometimes shows erratic left/right oscillations. Ideally, as the aircraft overflies the beacon, the needle swings rapidly from directly-ahead to directly-behind. This indicates *station passage* and provides an accurate position fix for the navigator. Less accurate station passage, passing slightly to one side or another, is shown by slower (but still rapid) swinging of the needle. The time interval from the first indications of station proximity to positive station passage varies with altitude — a few moments at low levels to several minutes at high altitude.

Homing-The ADF may be used to *home* in on a station. Homing is flying the aircraft on the heading required to keep the needle pointing directly to the 0° (straight ahead) position. To home into a station, tune the station, identify the Morse code signal, then turn the aircraft to bring the ADF azimuth needle to the 0° position. Turn to keep the ADF heading indicator pointing directly ahead. Homing is regarded as poor piloting technique because the aircraft may be blown significantly or dangerously off-course by a cross-wind, and will have to fly further and for longer than the direct track.

Tracking-The ADF may also be used to *track* a desired course using a ADF and allowing for winds aloft, winds which may blow the aircraft off-course. Good pilotage technique has the pilot calculate a correction angle that exactly balances the expected crosswind. As the flight progresses, the pilot monitors the direction to or from the NDB using the ADF, adjusts the correction as required. A direct track will yield the shortest distance and time to the ADF location.

RMI-A *Radio-Magnetic Indicator* is an alternate ADF display providing more information than a standard ADF. While the ADF shows relative angle of the transmitter with respect to the aircraft, an RMI display incorporates a compass card, actuated by the aircraft's compass system, and permits the operator to read the magnetic bearing to or from the transmitting station, without resorting to arithmetic.

Most RMI incorporate two direction needles. Often one needle (generally the thin, single-barred needle) is connected to an ADF and the other (thicker and/or double-barred) is connected to a VOR. Using multiple indicators a navigator can accurately fix the position of their aircraft without requiring station passage. There is great variation between models and the operator must take care that their selection displays information from the appropriate ADF and VOR.

- It operates in LF and MF band (190-1799 KHz), thus it is based on GROUND WAVE propagation
- Its range is not limited to line-of sight distance
- It can receive on both AM radio stations and NDB (non directional beacons)
- Its operation is similar to listening to a transistor radio.
- As the radio is rotated signal become weaker or stronger. No signal position indicates the direction of the station.
- ADF system consists of two main components :
  - Ground stations
  - Aircraft component

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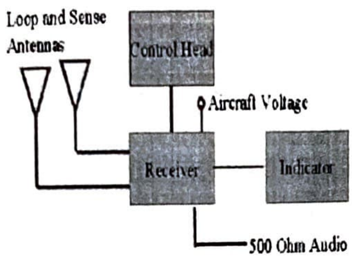
Ground stations

- They transmit omnidirectional (in every direction) signals.
- They are called nondirectional beacons (NDB).
- Stations have a vertical antenna which emits vertically polarized signal, that is magnetic field of the radio wave horizontal to the ground, electrical field is vertical

Aircraft components of ADF

- Antennas
- Receiver
- Control head
- Indicator

ADF external block diagram

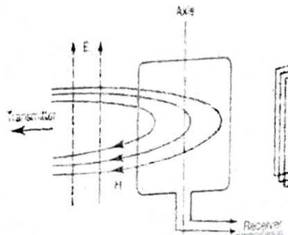


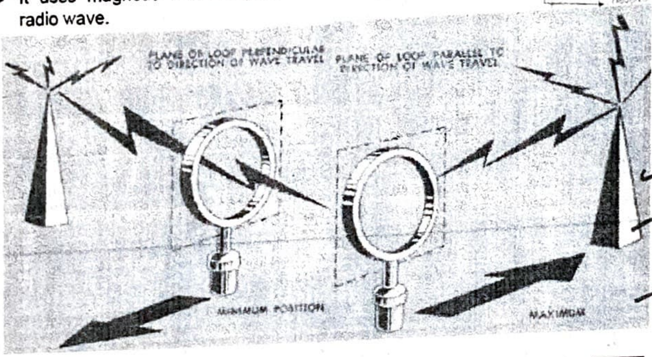
Two antennas are used for ADF:

- Loop antenna
  It indicates the ***direction*** of the ground station.
- Sense antenna
  It indicates the ***sense*** of the station (if station is in front/back or to the right/left of the aircraft)

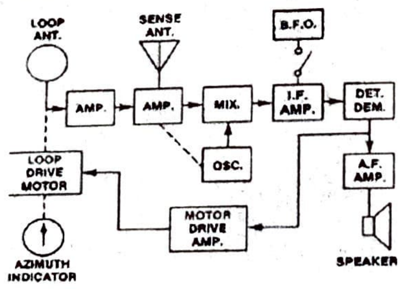
Loop antenna

- It is a directional antenna
- It indicates the direction of the station, but cannot determine if the station is in front/back or to the right/left of the aircraft.
- It is in the shape of rectangular or circular loop.
- It uses magnetic field component of the radio wave.





- It is not strictly required to rotate the loop antenna to find the null position.
- Modern aircraft use two loops mounted perpendicularly and connected to a device called goniometer.
- By this way, all rotating parts are packaged in receiver box.



- **ANT position :**It is used to receive weather information or to listen to other comm. Only sense antenna is in use.
- **ADF position :** It is used for navigation
- **BFO position :** It is used to identify stations during no modulation periods.