MODULE 5 | Radar and Navigational Systems (18ECE221T)

Session 4 | Direction Finding at Very High Frequencies - Automatic Direction Finders & VHF Omni Directional Range (VOR) - VOR Receiving Equipment - Range and Accuracy of VOR

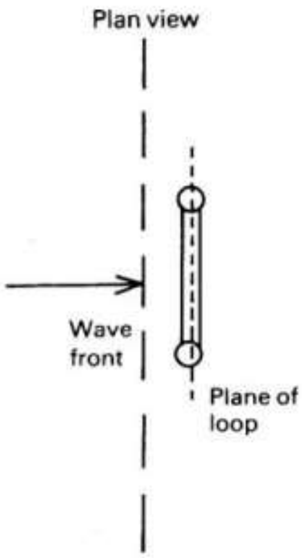
Direction Finding at Very High Frequencies

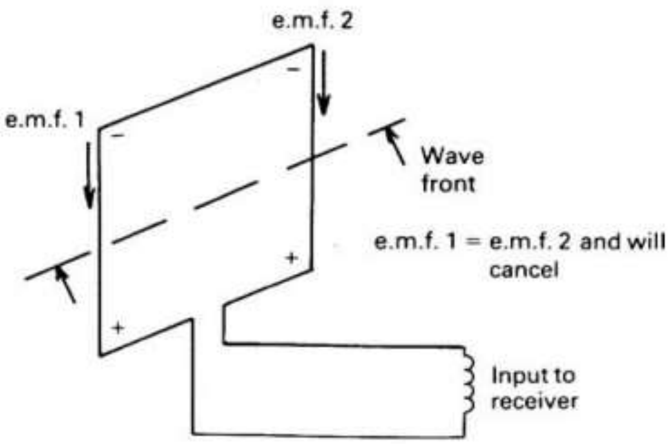
- In Aeronautical navigation (direction finding) 100 – 150 MHz is widely used.
- Direction finding is done by ground installation and aircraft bearing (position) is passed to aircraft by radio telephony.
- Adcock direction-finders are used.
- In VHF band – complete antenna system is compact. So, it can be rotated with ease.
- Types:
    1. Manually Operated – A rotatable antenna system is mounted on a mast above direction finder hut. Inside the hut receiver is present.
    2. Automatic System – Uses crossed-H Adcock antenna with a capacitor goniometer.
- VHF is confined to line of sight (LoS) propagation.
- Used for aircraft bearing and sometimes harbour control.
- Error: Polarization and Site irregularities

Source:

1. N. S. Nagaraja, Elements of Electronic Navigation, 2nd Edition, Tata McGraw Hill Publication, New Delhi, pp. 21 – 22.

Recap on Loop Antenna





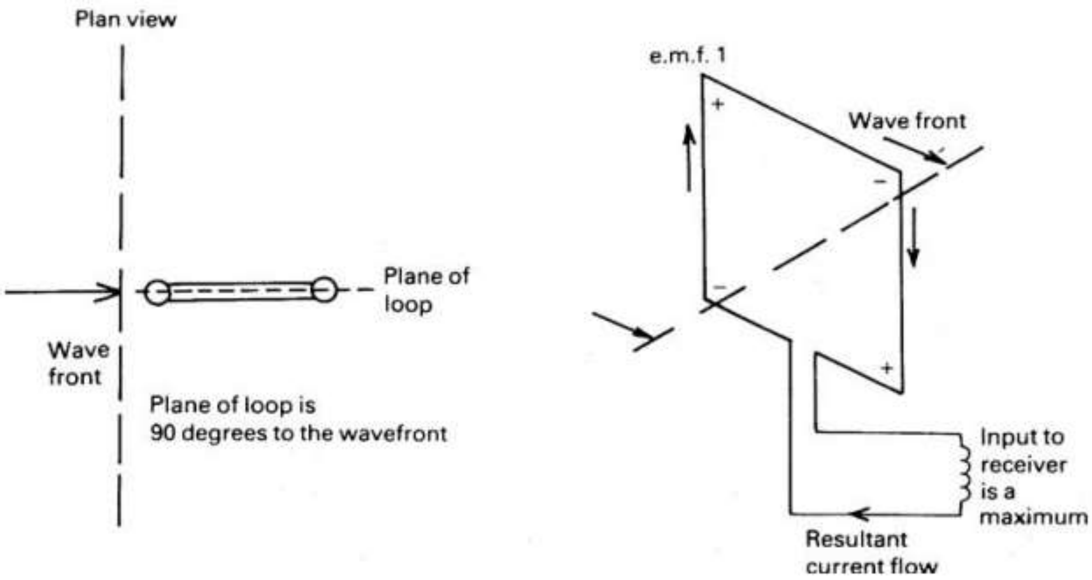


Figure 10.4 (a)The resultant input to a receiver is zero if the plane of the loop is parallel with the travelling wavefront.(b)The input is a maximum if the loop plane is at 90° to the received signal.

Picture Courtesy: Electronic Navigation Systems by Laurie, Butterworth Heinemann Publishers

Automatic Direction Finders

The ADF works by using the electromagnetic properties of the signal produced by the beacon. Two antennae are required, which are known as the loop antenna and the sense antenna.

The Loop Antenna:

The loop antenna can be simplistically described as two insulated coils of wire wound perpendicular to each other onto a ferrite core. The bi-directional antenna is horizontally polarized, and couples with the magnetic component of the beacon signal. The maximum voltage is induced when the antenna coil is perpendicular to the transmitter. As the antenna pattern contains two nulls, it cannot determine whether the signal is from the 0° or 180° position, hence the need for the sense antenna.

The Sense Antenna:

In its basic form, this can be a long wire antenna, often seen mounted from the aircraft cabin roof to the tail fin. For more modern types of antennae, both loop and sense are located in the same teardrop-shaped housing, mounted as near to the aircraft centreline as possible. This omnidirectional capacitive antenna couples with the electric component of the signal.

The Composite Effect:

In a typical ADF receiver, the signals received by the loop and sense antennae are combined to create the equivalent of a cardioid pattern, as shown in Figure 1.

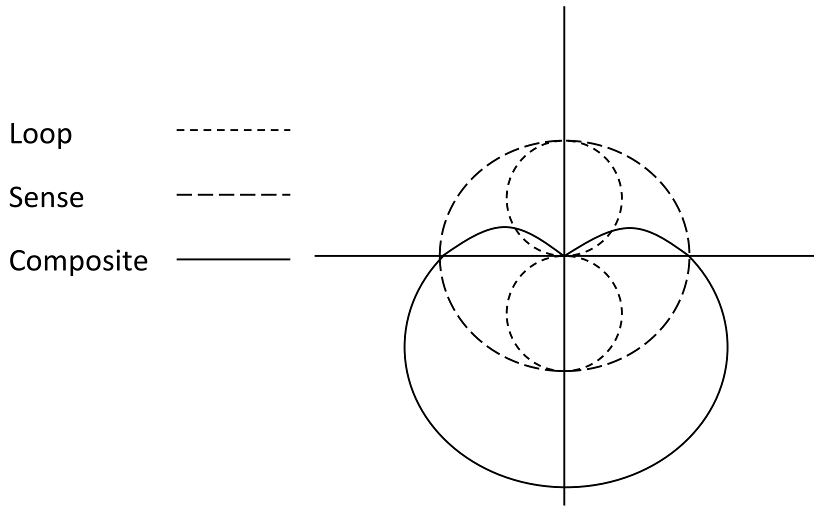


Figure 1 – ADF Antenna Patterns

As is often the case, the resultant signal null is more discrete than the maximum zone. Therefore, the ADF equipment can be positively and accurately tuned to the null. The ADF electronically and/or mechanically aligns the null with the transmitter station by rotating a goniometer. If the goniometer coil is not exactly in the null, a loop voltage will be generated which is applied to a bi-phase motor which rotates the goniometer until it is in the null. Since the phase of the loop antenna signal either leads or lags that of the sense antenna depending upon which side of the null the rotor is positioned, the goniometer can be rotated in the correct direction to achieve the null.

The output from the goniometer is then used to drive the needle on the ADF display in the cockpit.

Reference:

1. ADF_NDB_Protection_Issue 2.doc

Radio Compass:

Loop Antenna uses servo feedback system. The loop antenna is designed to positioned to null.

The error signal is got from loop antenna and that drives the servo system. When the error changes its sign as it passes through zero, we need a phase sensitive detector.

Two Phase motor is used. One is actuated by switched oscillator and other from receiver output. The received signal is in phase with switched oscillator or shift of 180° based on position of loop w.r.to direction of arrival of the signal.

Based on the signal motor tend to move the Gonio.

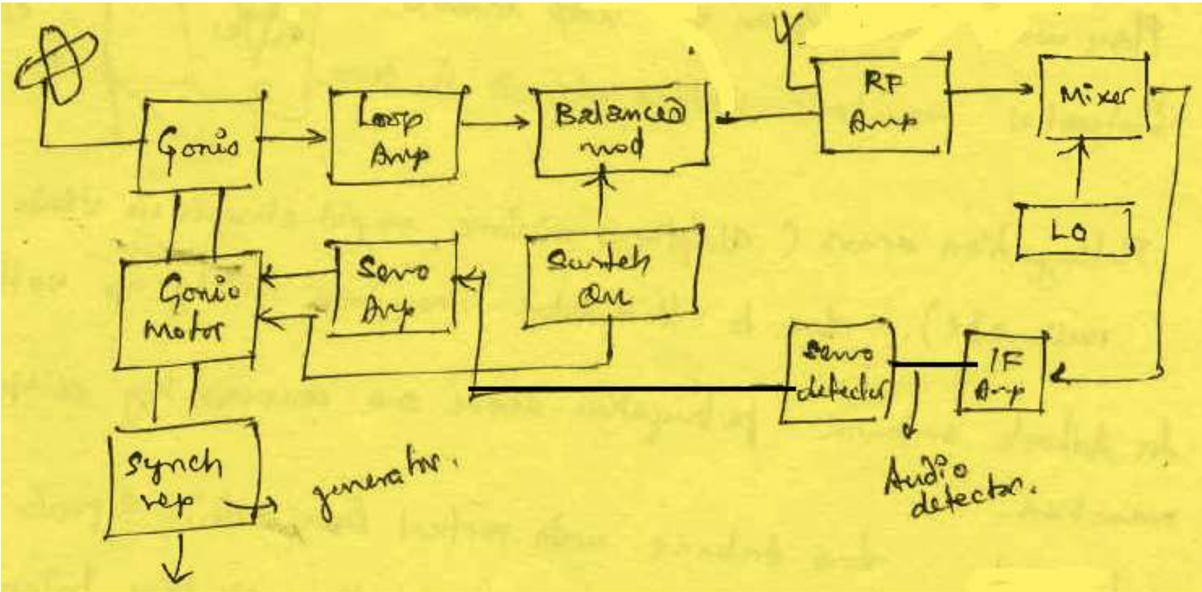


Figure 8. Block Diagram of a radio compass receiver

Balanced modulator output consists of side bands only. It is combined with sense arial output. It is fed to AM superheterodyne receiver.

Assume output of the switching oscillator is sinusoidal. The balanced modulator gives the product of the Gonio signal and switching sinusoid.

$$e_0 = A cos\omega_s t\ [cos\theta . cos\omega_c t]$$

e_0= Balanced modulator output

$cos\omega_s t$ = Switching Frequency

$cos\omega_c t$ = incoming carrirer Frequency

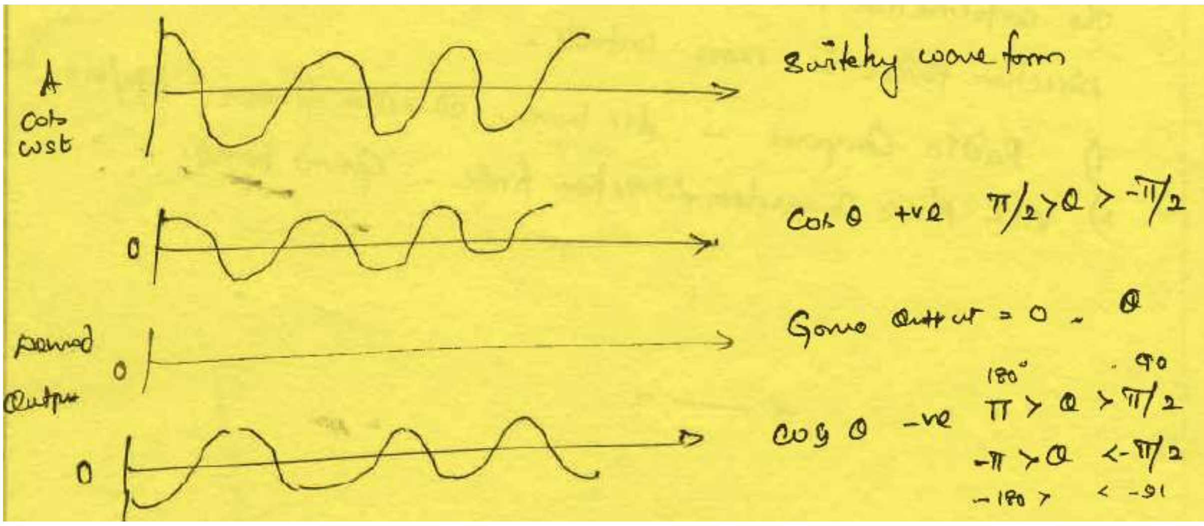
θ = Orientation of Goniometer w.r.to reference direction

Vertical antenna signal is $Bcos\omega_c t$ (B > A)

$$e_{in} = Acos\omega_s t\ [cos\theta . cos\omega_c t] + \ Bcos\omega_c t$$

$$e_{in} = B\left[1 + \frac{A}{B}cos\theta.cos\omega_c t\right]cos\omega_c t$$

e_{in} = input to AM receiver



Carrier ω_c is amplitude modulated by ω_s i.e., message signal. The phase and amplitude of modulating signal is dependent on θ.

The amplified demodulated output is not fed to second winding of two-phase gonio motor due to low power efficiency. Instead, motor control circuit is employed. They use thyrotrons.

Advantages of Radio Compass

1. Widely used but does not provide precise bearing
2. It is simple and availability of large number of ground transmitting antenna for getting bearing
3. Modern version uses ferrite core loops and transistorized equipment. So, they are compact.

Source:

1. N. S. Nagaraja, Elements of Electronic Navigation, 2nd Edition, Tata McGraw Hill Publication, New Delhi, pp. 21 – 25.

VHF Omni Directional Range (VOR)

VOR is a combination of navigation and communication. It means it can be used for airport and aeroplane communication and aeroplane can use VOR signals to find the bearing (position).

In 1946, VOR become a US standard later it was adopted by the International Civile Aviation Organization (ICAO) and became an international standard.

VOR operates on 108 – 118 MHz frequency band. The channel spacing is 100 kHz. Sometimes it is 50 kHz.

Its operational service volume is up to 130 nautical miles from the station.

. Three types of VOR stations

1. T (Terminal VOR)
2. L (Low Altitude VOR)
3. H (High Altitude VOR)

VOR (communication) signal comprises speech signals (300 Hz – 10 kHz). VOR (navigation signal) comprises of two phases. First phase is called Reference Phase and second is called Variable Phase. RP is broadcast in all directions. In VP is rotating a beam, the difference of phase between the RP and the VP is used by the VOR receiver in the airplane to calculate the bearing from the station.

~~RP is frequency modulated. The resting frequency is 9960 Hz. The frequency goes up down by $30x$ per second. The series will be 10,440 Hz, 10,410 Hz, 10, 380 Hz, 10,350 Hz, … 9,960 Hz, 9,930 Hz, 9,900 Hz, 9,870 Hz, …. 9,480 Hz. Maximum frequency is 10,440 Hz (9960 + 480) and minimum frequency is 9480 Hz (9960 – 480).~~

RP is frequency modulated. A 30 Hz is the message signal. The frequency change is ± 480 Hz.

VP is amplitude modulated with 30 % depth of modulation.

The RP antenna will have omni-directional radiation pattern and VP antenna will have dipole radiation pattern As VP antenna is rotating at a 30 Hz rate. This in turn produces a rotating cardioid pattern and 0° points to true North.

Alford loop consist of four radiators to form a square. They are horizontally polarized. Each radiator is less than λ/4 and care is taken to have current at the center. At any instant current at the radiators are equal and alternatively varying so as to produce a dough-nut figure radiation pattern

A 1020 Hz that contains the airport identity in Morse code is added with to the 9960 Hz signal.

The transmitter is crystal controlled and can generate power up to 200 Watts. In the transmitter is 332 teeth tone wheel is present. It is driven by a motor. The tone wheel is arranged in such a way to produce 9,480 Hz to 10,440 Hz. Power to drive the motor is taken from the transmitter output. But the transmitter output is modulated. To remove high frequency components, it is fed to the modulation eliminator. Around 25 % of power of the transmitter power is used to drive the motor.

The goniometer feeds the unmodulated transmitter power first to the northwest-southeast pair of Alfrod loop and then 90 later, to the northeast -southwest pair of Alford loops. When combined with the modulated energy applied simultaneously to all loops, this variation generates a rotating cartdioid.

The four Alford loops are arranged in a tight square and placed on a counterpoise. The loops are protected from the weather by a plastic radome, often hemispherical in shape.

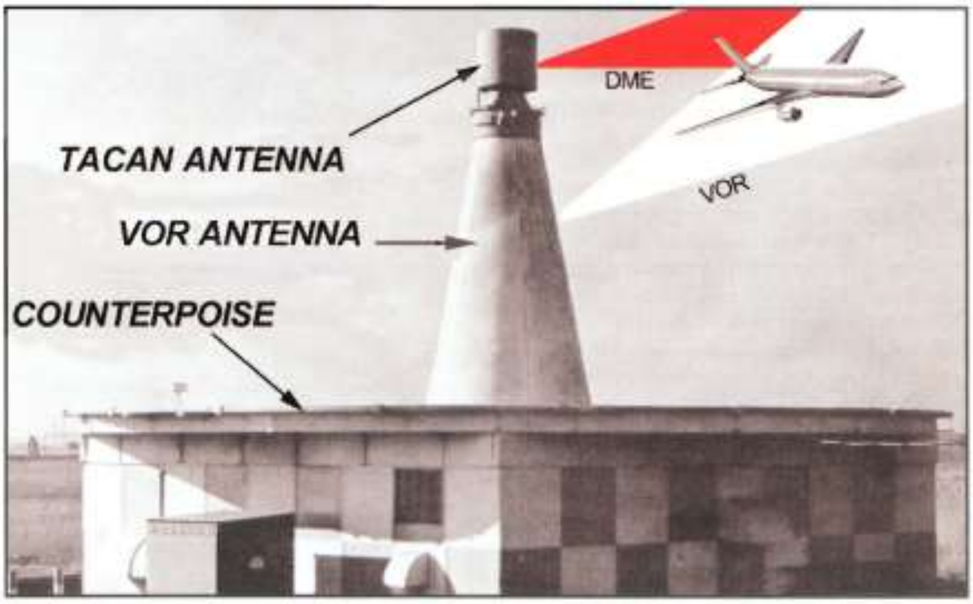
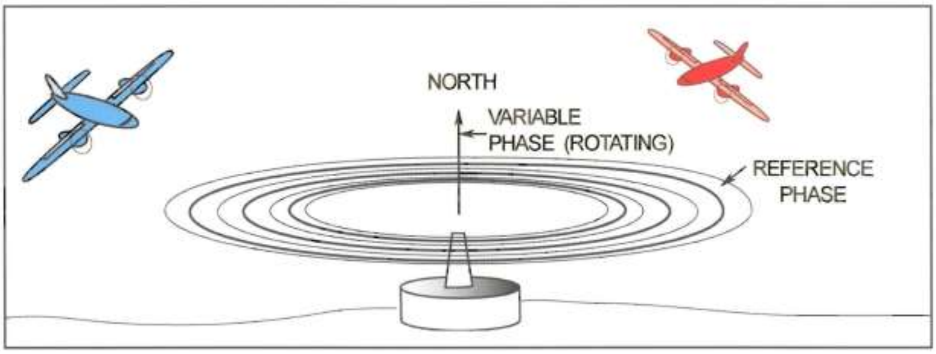


Figure 1. Ground Station with VOR System Picture Courtesy [1]

Figure 2. RP and VP Picture Courtesy [1]



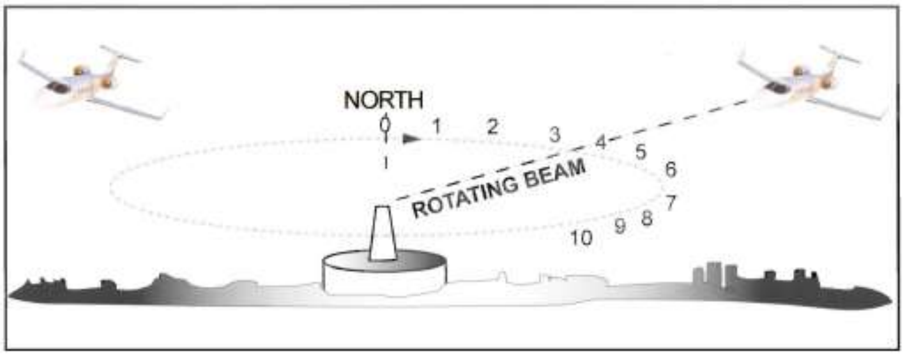


Figure 3. RP and VP Picture Courtesy [1]

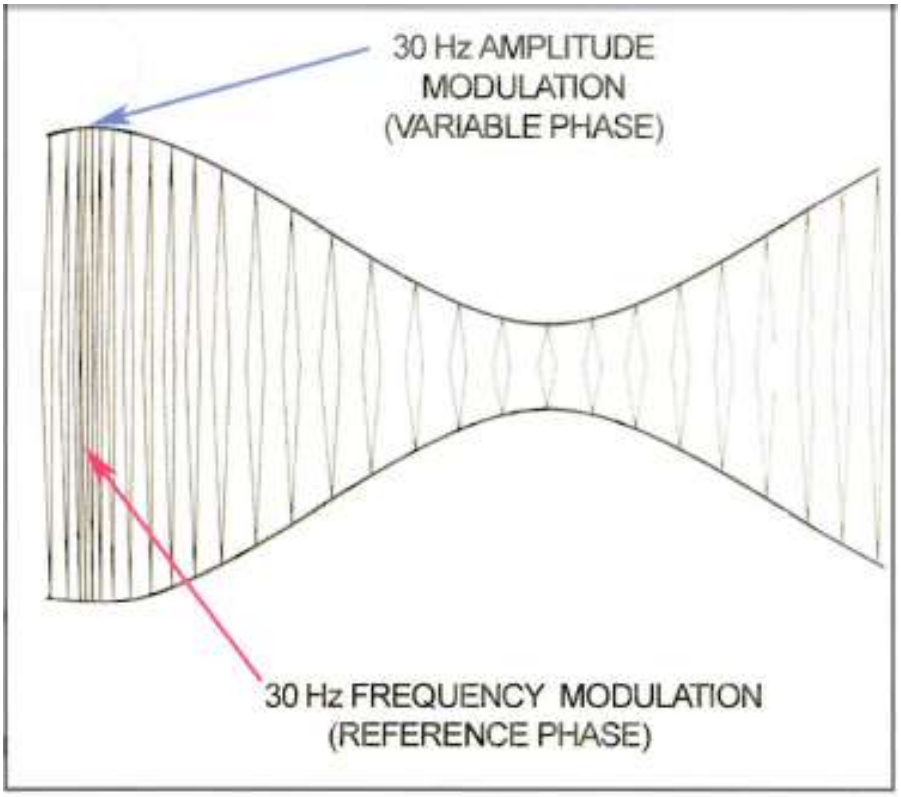


Figure 4. AM and FM signal

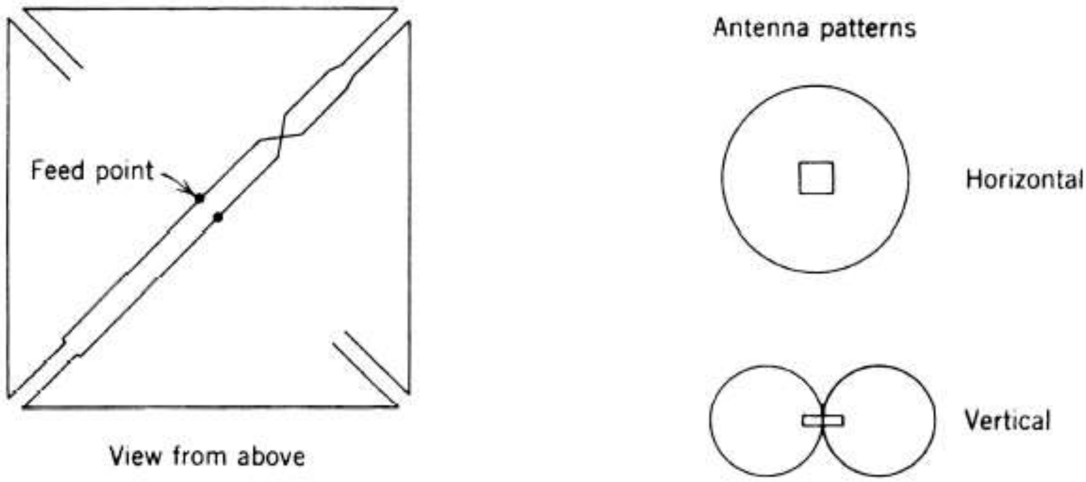


Figure 4.14 Alford loop.

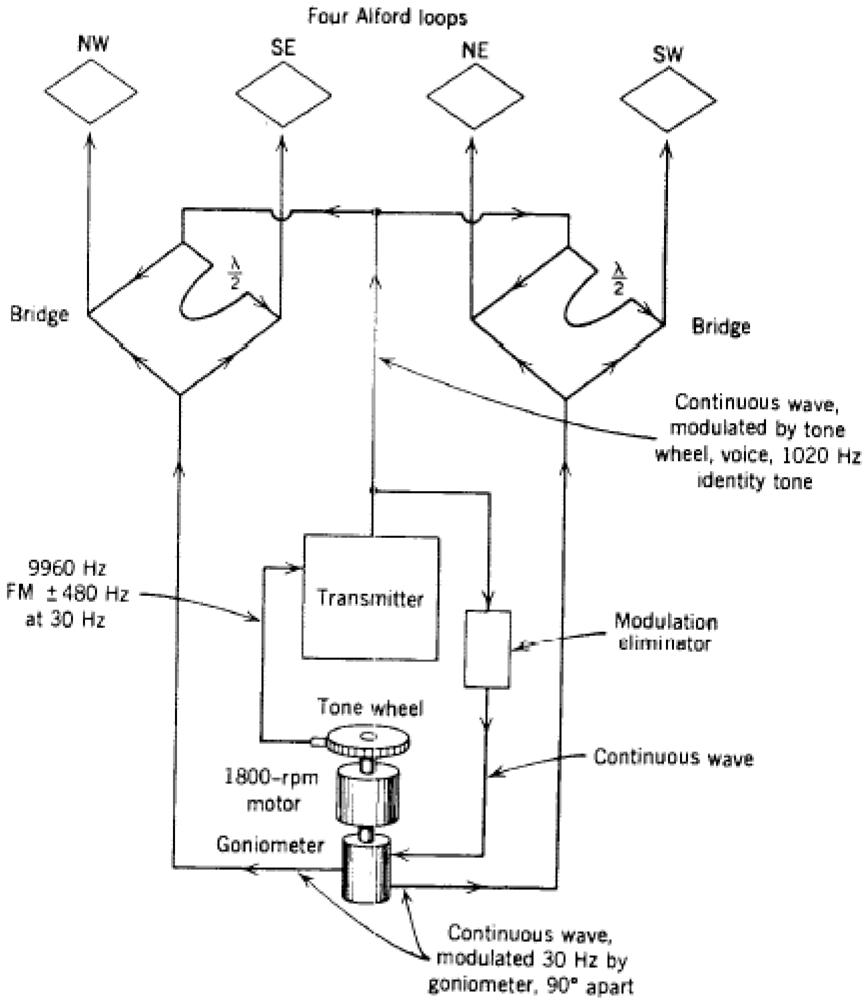


Figure 4.15 VOR block diagram.

VOR Receiving Equipment

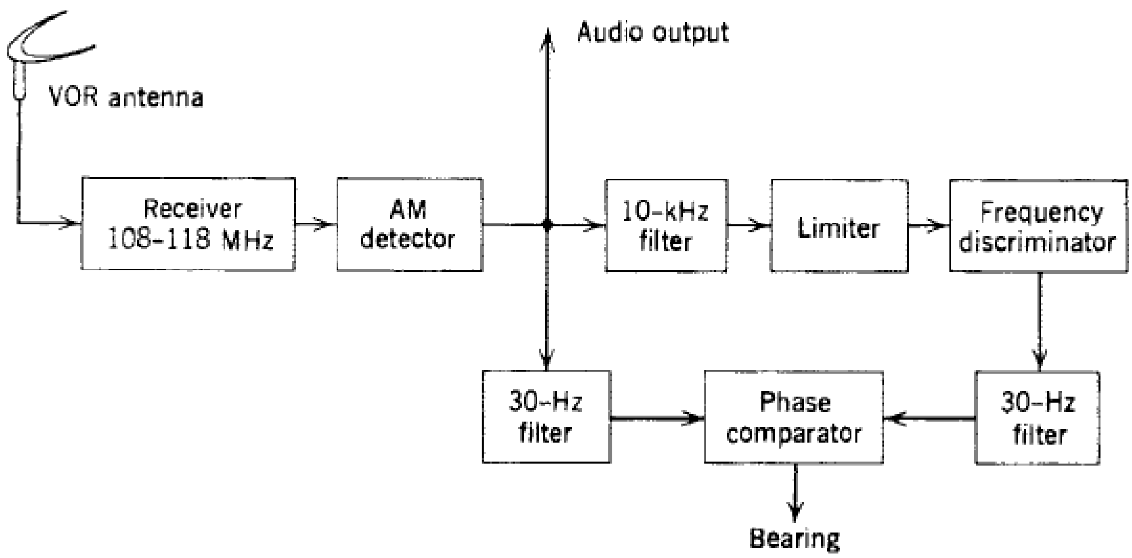


Figure 4.16 VOR receiver.

TASK: Discuss the working of Receiver and AM detector within 6 lines. Write the role of filter, limiter and FM detector (6 lines)

The output of AM detector has following four signals.

(1) a 30 Hz tone produced by the rotation of ground station antenna.

(2) Voice signal – if sent

(3) 1020 Hz airport identifier

(4) a 9960 Hz FM signal

The voice signal and 1020 Hz airport identifier are fed to the airplane audio system. The 30 Hz signal filtered and send to phase comparator. The output of the AM detector is filtered (10 KHz) and sent to FM detector (technical term - discriminator). The output of FM detector is fed to the Phase comparator. The output of Phase comparator is the bearing (position) of the aircraft.

References

1. Avionics VOR-ILS-MLS-ADF - SkillsCommons Large File Makeover Example - SkillsCommons Repository | https://www.skillscommons.org/handle/taaccct/3512
2. Myron Kayton and Walter R. Fried. Avionics navigation systems. Wiley- India, 2010.
3. N. S. Nagaraja, "Elements of Electronic Navigation Systems", Tata McGraw-Hill, Second Edition, 2000

Range and Accuracy of VOR

- VOR operates in VHF range so essentially in LoS.
- Due to refraction 10 – 15 % increase of range possible
- LoS depends upon the height of VOR antenna and of the aircraft
- For example, aircraft flying in 20,000 ft (Approx. 6000 meter) will have a range of 335 km.
- Sources of errors
  1. Ground station and aircraft equipment - Ground station is error is mainly octagonal error present in the installed two antenna pairs and goniometer. Aircraft equipment error is due to circuit and component imperfections.
  2. Site irregularities – It is due to the path difference between direct signal and reflected signal (signal hit the objects and get reflected towards receiver antenna). It cannot be easily eliminated.
  3. Terrain features – error due to hills, lakes, mountain ranges etc.
  4. Polarization – Vertical component of the radiated field is not 90 ° apart from horizontal component. Solution is to make the aircraft receiver less sensitive to vertical component.

Source: N. S. Nagaraja, Elements of Electronic Navigation, 2nd Edition, Tata McGraw Hill Publication, New Delhi, pp. 42 – 43.

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 comes due to the locus of points which have a constant value of such a delay is hyperbola on a plane of surface.

Referring to the Fig. 4.1, Let us assume Station A and B make synchronous transmission. The receiver at the point P is capable of measuring the interval between the time of arrival of the radiations from the two stations.

The interval $t_d = \frac{AP}{c} - \frac{BP}{c}$

Where c = Velocity of light, $AP = \sqrt{(x+d)^2 + y^2}$, $BP = \sqrt{(x-d)^2 + y^2}$

$$AP - BP = \sqrt{(x+d)^2 + y^2} - \sqrt{(x-d)^2 + y^2} = I\ (constant)$$

I = difference between path lengths AP and BP. Simplifying, this equation may be put in the form

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

Where $a^2 = \frac{l^2}{4}$, $\quad b^2 = d^2 - \frac{l^2}{4}$

This is the equation of hyperbola with foci at A and B. All the possible values of the delay t_d, give a family of confocal hyperbolae.

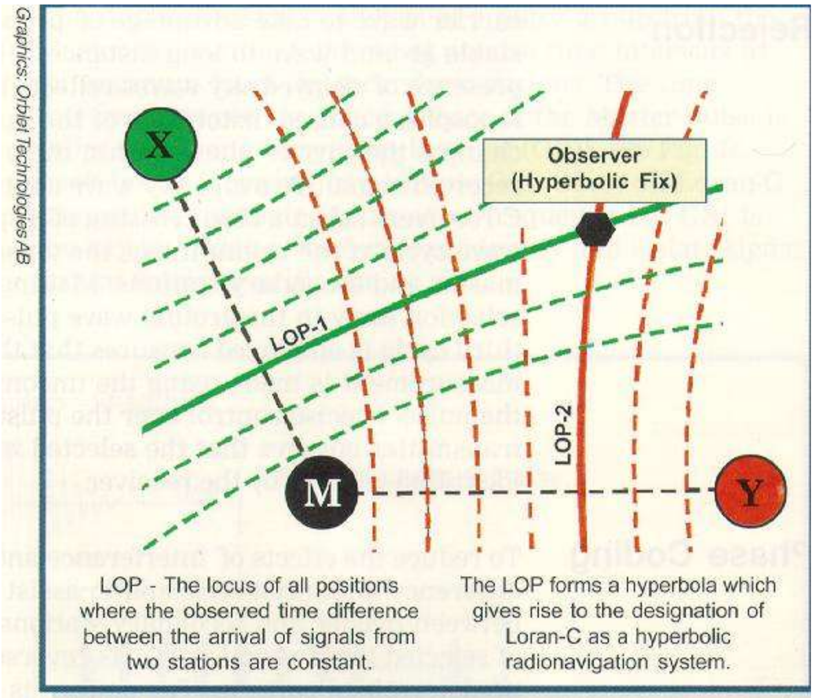


Figure 1. Hyperbolic System. Picture Courtesy [1]

The determination of the delay locates the ¢raft on one of these hyperbolae. If there is a third synchronized station C, the determination of the delays between the reception of signals from A and B and also between those from 8 and C would locate he craft on two hyperbolae. and their intersection gives the fix as shown in Fig. 1.

This is the basic principle of hyperbolic navigational systems. LORAN, DECCA and OMEGA are examples for hyperbolic systems.

LORAN

Loran stands for Long Range Navigational aid.

LORAN C

Loran - C operates in the band 90-110 kHz. It is a development arising out of the wartime work on low frequency Loran.

The advantage of the low frequency is that the range of groundwave transmission is very much larger than at 2 MHz (Loran A) and attenuation is nearly the same over Land and sea.

Large ground wave range permits larger separation between master and slave stations.

The base-Line for Loran C are generally several hundred kilometres.

Base-Line for Loran-C are generally several hundred kilometres

With the limited bandwidth available for Loran—C. the pulse width has to be very long a this by itself would reduce the accuracy of the system.

Greater accuracy is attained be matching the carrier frequency cycles within the pulse. To enable this, the carriers of the transmitters are derived from caesium atomic clocks and the pulse envelope is standardised and accurately controlled. The master and slave stations carriers are accurately matched.

Time measurement accuracy attainable in the order of 0.1 µsec. The errors from this source are in fact smaller than the errors introduced by the uncertainties and changes in the velocity of propagation of the ground wave.

The travel time T between two points at a distance D apart is given by

$$T = Dv + C_t$$

C_t= correction term

$$v = \frac{c}{n}$$

Where v = velocity of propagation of ground wave, c = velocity of light, n = refractive index of atmosphere.

Though for higher precision, ground waves have to be used, over considerable areas, sky waves may have to be used. This would introduce errors because of the delay increase consequent on the increased path length. These can be corrected by the published estimated delays.

The Loran-C transmitters transmit pulses of long duration but accurately controlled envelope. The envelope is designed in such a way that 99 % of the energy is confined within the 90 – 100 KHz band.

The pulse repetition frequency is locked to 100 KHz. This helps to maintain pulse shape.

The peak power is 1 MW. The transmissions actually consist of a succession of pulses, eight in number for the slave Stations and nine in the case of the master station, as shown in Fig. 2. These pulses are stored and combined in the receiver to improve the signal/noise ratio. The ninth pulse transmitted by the master station is used for coding to indicate malfunction in any station.

Loran has a range of 3500 km over sea and 2200 km over land.

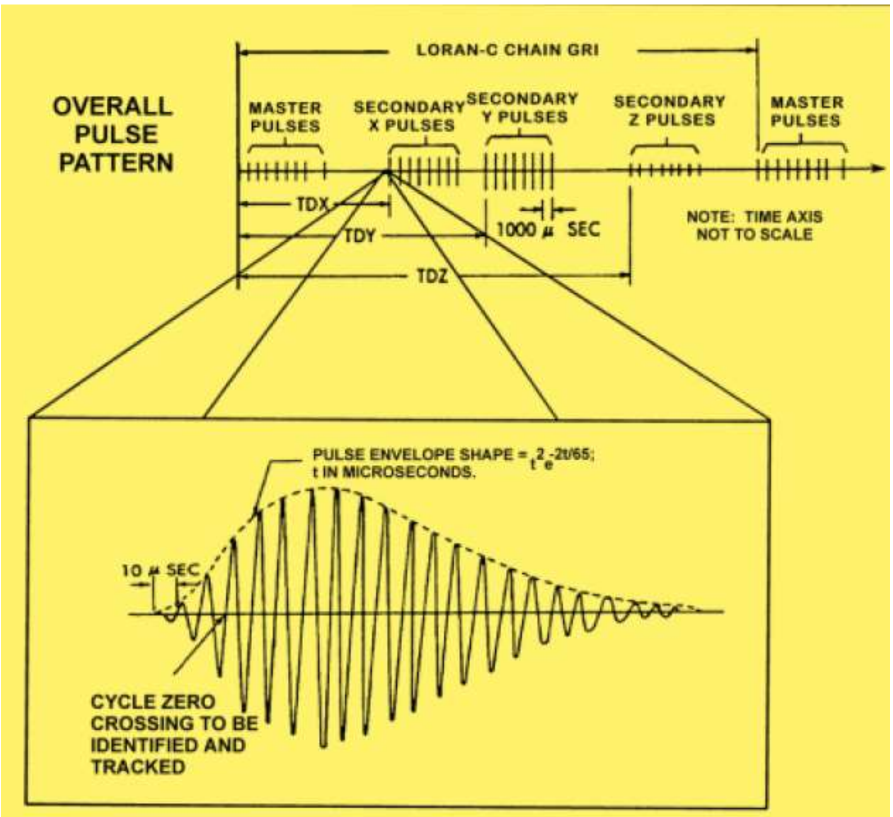


Figure 2. Pulse shape of Loran – C   Picture Courtesy [2]

References

1. http://www.ans.nau.edu.ua 10 L MLAT PPT
2. http://fer3.com/arc/imgx/bowditch1995/chapt12.pdf

NOTE:

The basic measurements made by Loran-C receivers are to determine the difference in the time-of-arrival (TD) between the master signal and the signals from each of the secondary stations of a chain. In Loran-C, each TD value is measured to a precision of about 100 nanoseconds or better. As a rule of thumb, 100 nanoseconds correspond to about 30 meters. The principle of time difference measurements in hyperbolic mode is illustrated in the Figure 1.

Session 6 | The Decca Navigation System – Decca Receivers & Range and Accuracy of Decca

Decca Navigational System (DNS) operates on LF band (70 – 120 KHz) and employs unmodulated continuous wave.
Here the phase difference between the signals of two stations are used instead of time of arrival.
Decca consists of four stations. (1 master and 3 slaves). This gives rise to 3 sets of hyperbolic position lines
Intersection of two hyperbolic lines forms a fix. To distinguish individual stations, they all radiate in harmonic frequencies.

Master Station	Slave Station	Common Harmonic
6f	8f (Red)	24f
6f	5f (Purple)	30f
6f	9f (Green)	18f

Where f = 14 kHz.   Red, Purple and Green are colours used in the charts.

Station A transmit at $n_1 f$ and station B transmit at $n_2 f$

At point P, $\cos\left(2\pi n_1 f t - \frac{2\pi\,\overrightarrow{AP}}{\lambda_1}\right)$ and $\cos\left(2\pi n_2 f t - \frac{2\pi\,\overrightarrow{BP}}{\lambda_1}\right)$

Assume $m_1 n_1 = m_2 n_2$

m_1 th harmonic

The phase difference between the output is $\frac{2\pi}{\lambda_{mn}}\left(\overrightarrow{AP} - \overrightarrow{BP}\right)$ Where $\lambda_{mn} = \frac{c}{m_1 n_1 f} = \frac{c}{m_2 n_2 f}$

The phase difference is measured is thus same as if two stations are radiated in the common harmonic frequencies.

0° - 360° Phase Ambiguity

1. The movement along the line $\frac{\lambda_{mn}}{2}$ being a change of phase of 360°. The average value is 500 m. A base line length will have 100 to 200 km. So, one can expect 100s of phase changes.
2. Decometer (Phase measuring meter) will do one complete revolution for each 360° phase change. Another pointer is used to count the number of revolutions made.
3. The region defined by two adjacent hyperbolae which correspond to a phase change of 360° is called a lane.

- The region between two adjacent hyperbolae is called a zone. Each zone comprises of number of lanes.
- Number of lanes in a zone = ratio of wavelength of f and common harmonics
- If the phase measurement is accurate then position can be fixed with little probability of error.

- Lane identification is called ‘course fixing’ and the determination of the line of position within a lane is called ‘fine fixing’.
- Lane identification signals are sent for short intervals thrice a minute, each time master and slave make simultaneous transmission.
- For fine fixing, there will be a slight change in master carrier frequency.

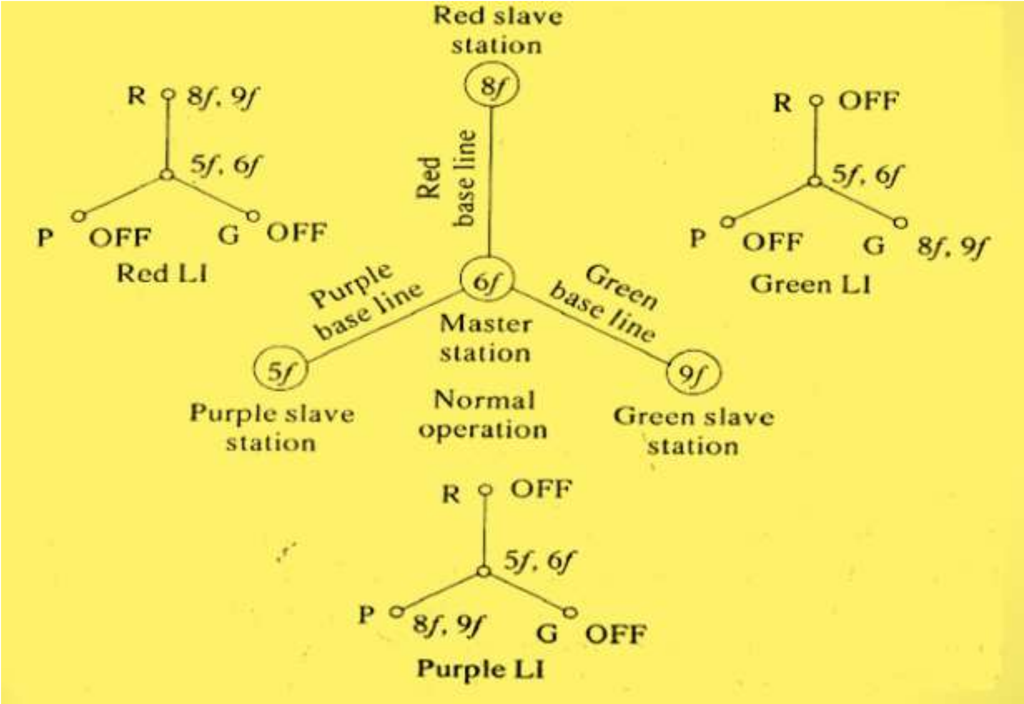


Figure 1. Normal Transmission and Lane Identification. Picture Courtesy [2]

*LI – Lane Identification

Lane Identification Sequence

1. Beginning Master transmits 6f – 60 Hz for $^1/_{12}$ seconds to initiate Red lane identification cycle.
2. Then Master 5f, 6f and Sleve 8f and 9f for $^1/_2$ second.
3. Normal transmission resumes
4. 16^{th} second, Master 6f+60 Hz and Slave Green 8f & 9f. To identify Green Lane
5. Normal transmission resumes
6. 30 sec, 6f+60 Hz and 6f – 60 Hz for $^1/_2$ second and followed by 6f+ 60 Hz for $^1/_{25}$ seconds.
7. Resume normal transmission

Decca Receivers

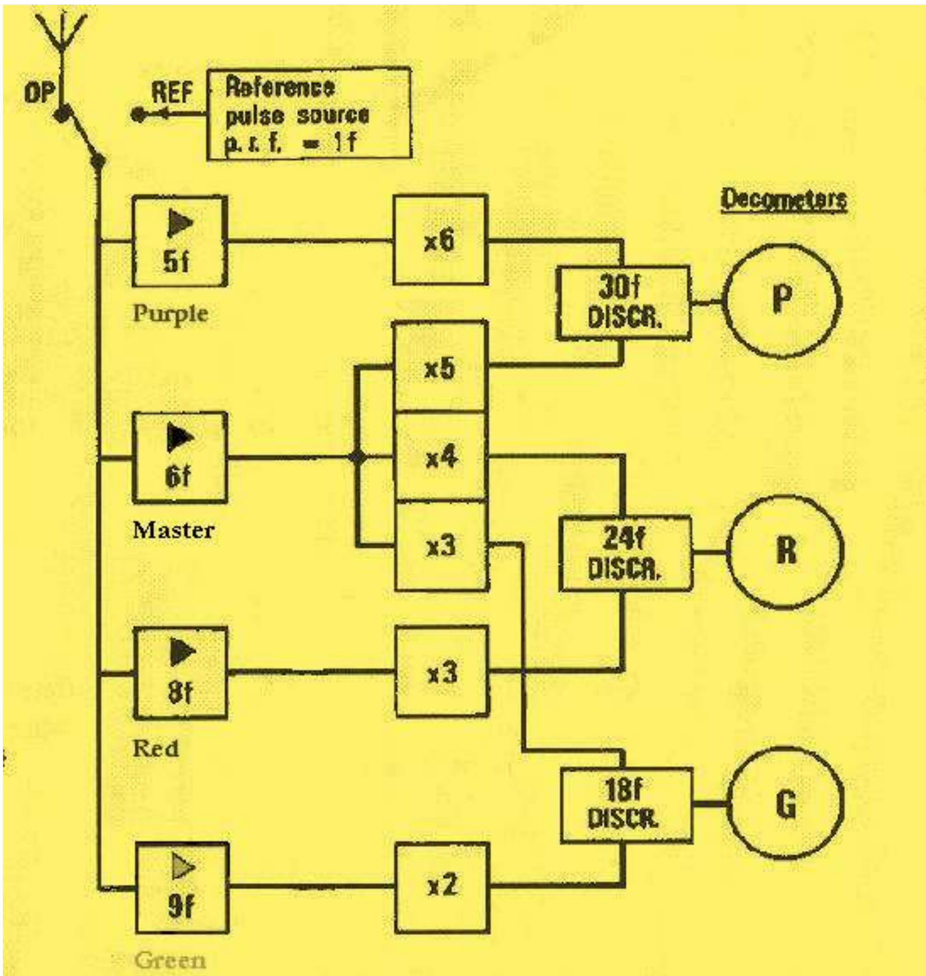


Figure 3. Decca Receiver block diagram. Picture Courtesy [3]

Working

The received four frequencies (say 5f & 6f from master and 8f & 9f from slave) are separated by crystal filters, amplified and applied to frequency multipliers. Output of the multipliers are fed to the discriminators and then to decometers. The meters indicate the phase difference between two signals fed to the discriminators. Thus, position can be identified.

Range and Accuracy of Decca

For a radial error of 100 m, the range is about 300 km when the distance between the master and slave is 200 km. The instrumental errors in Decca are very small.

References

1. N. S. Nagaraja, Elements of Electronic Navigation, 2nd Edition, Tata McGraw Hill Publication, New Delhi, pp. 54 – 59.
2. https://www.darshan.ac.in/Upload/DIET/Documents/EC/CH_7 TO 12 PPTs_31122015_044257AM.pdf
3. http://www.jproc.ca/hyperbolic/decca_oview.html