MODERN

ELECTRONIC NAVIGATION AIDS

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CONTENTS

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CHAPTER I

INTRODUCTION

WAVE PROPAGATION

The surface of the earth is surrounded by the atmosphere, which is divided into layers viz. *Troposphere, Stratosphere, Mesosphere, Ionosphere* etc. Due to the solar radiation emitted by the sun, which contains ultra violet and other rays, the molecules of gases present in these layers give away electrons i.e. negatively charged particles and as a result the molecules themselves become positively charged. This process of separating ions is called Ionization.

The part of the atmosphere above the surface of the earth where these ionized layers are found is known as ionosphere and has an appreciable effect on propagation of radio waves. This layer is further sub divided into *D, E and F layers*. The intensity of ionization varies with the distance from the surface of the earth, time of the day and atmospheric conditions.

The ionosphere can affect the radio waves in the following two ways

- The radio waves travelling from one place to another in which the density of ionization is different will undergo a change in its direction of propagation of radio waves, which is called as refraction, and waves can be refracted back to the earth. The refraction or bending of the radio waves depends on frequency, density of ionization and angle of incidence. These factors will have the following affect on the radio waves

- Frequency of radio waves

Higher the frequency of radio waves, lesser is the possibility of the waves returning back to the earth i.e. they penetrate the ionosphere and go into the space.

- Density of ionization

Greater the density of ionization, more the possibility of waves of a given frequency to be bend sufficiently and return to the earth and

- Angle of incidence

Lower the angle of incidence of a given wave, higher the possibility of waves returning to the earth.

AND

- The charged particles of the ionosphere can reduce the energy of the radio waves causing attenuation to the signals and in some cases the low frequency signals are completely absorbed by D layer of the ionosphere.

D LAYER

The lower most layer of the ionosphere is known as D layer, which extends from 50 to 90 kilometers above the surface of the earth. The density of the ionization in this layer is less as compared to E and F layer. During the night - time de-ionization takes place and the density of ionization reduces to such an extent that this layer does not exist. The low frequency signals are absorbed by this layer and are also known as *Absorption* layer.

E LAYER

This layer is just above the D layer and extends from 90 to 150 kilometers above the surface of the earth. The density of the ionization in this layer is sufficient to refract the radio waves back to the earth. During the nighttime the density of ionization reduces, but unlike D layer it does not totally disappear. It is also known as *Kennelly - Heaviside* layer named after the two scientists who discovered this layer.

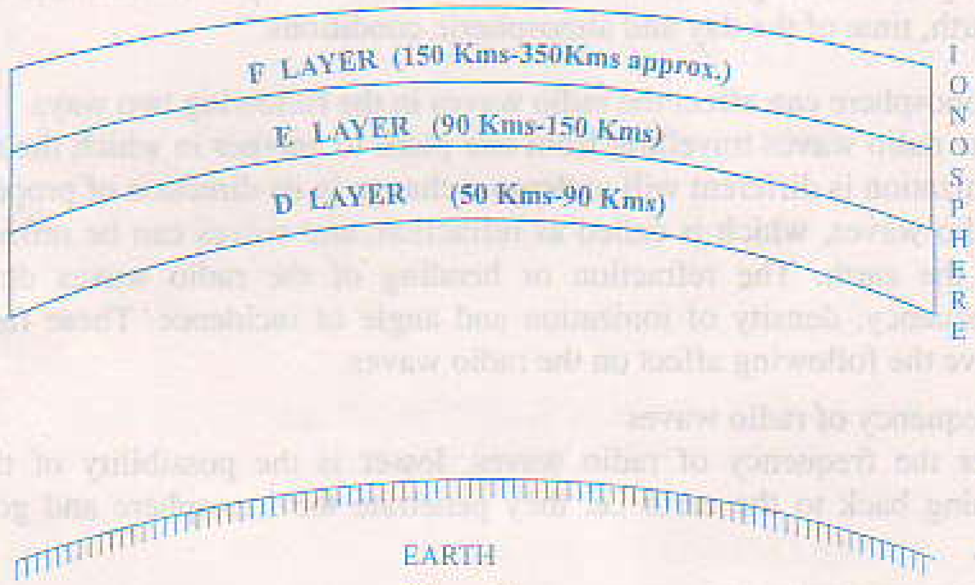


Figure1

Various layers of the ionosphere with their respective heights from the *surface f the earth*

F LAYER

The uppermost layer of the ionosphere is known as F layer and extends from 150 to 350 kilometers approximately above the surface of the earth. During the daytime of the summer season this layer is divided into two layers called F_1 and F_2 and merges to form a single layer during the nighttime. The density of ionization in this layer is much more as compared to D and E layers. This layer is also known as *Appleton* layer.

The radio waves radiated by transmitting antenna of any frequency mostly travel along the three paths

- Ground wave
- Direct wave and
- Sky wave

GROUND WAVE

In this type of propagation, the radio waves travel along the surface of the earth. When these waves strike the earth surface, some of the energy is absorbed and absorption of energy is more by solid ground than the water since land is better conductor than water. Absorption of energy is more for higher frequency hence ground wave is not suitable for propagation of high frequencies. The ground wave becomes weaker and weaker as it travels along the surface of the earth till it becomes so weak that it is no longer useful. The ground wave is not affected by day and nighttime, season, atmospheric condition etc.

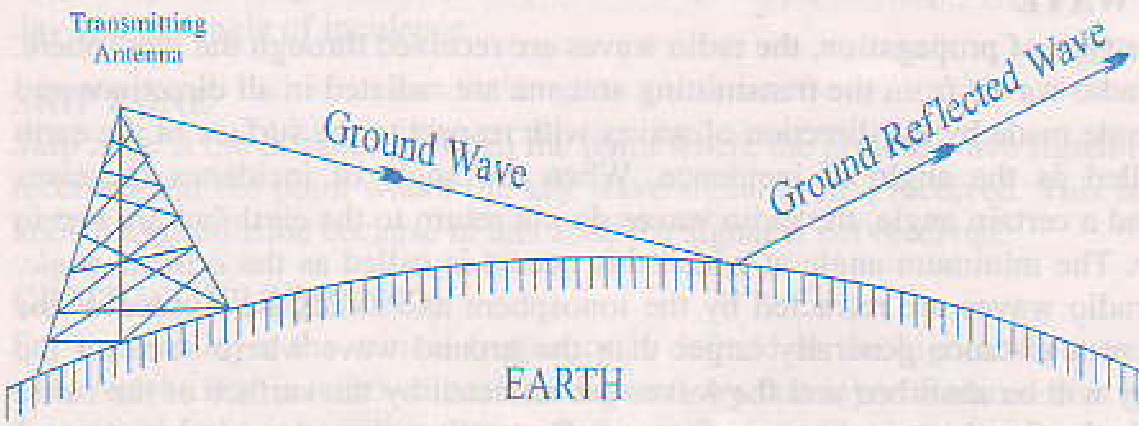


Figure 2
Ground Wave

It is used in Decca, Loran C, medium wave communication etc. and medium frequencies up to 2 MHz are generally used for ground wave propagation.

DIRECT WAVE

In this type of propagation, the radio waves travel directly from transmitting antenna to the receiving antenna at a height of about 15 kilometers above the surface of the earth. As the frequency increases, the ionosphere is not capable of refracting these waves back to the earth and are lost in space. As the absorption by the earth's surface is more, the distance travelled by the radio waves will be limited. This range normally extends beyond the horizon due to the curvature of the earth and is used for line of sight communication.

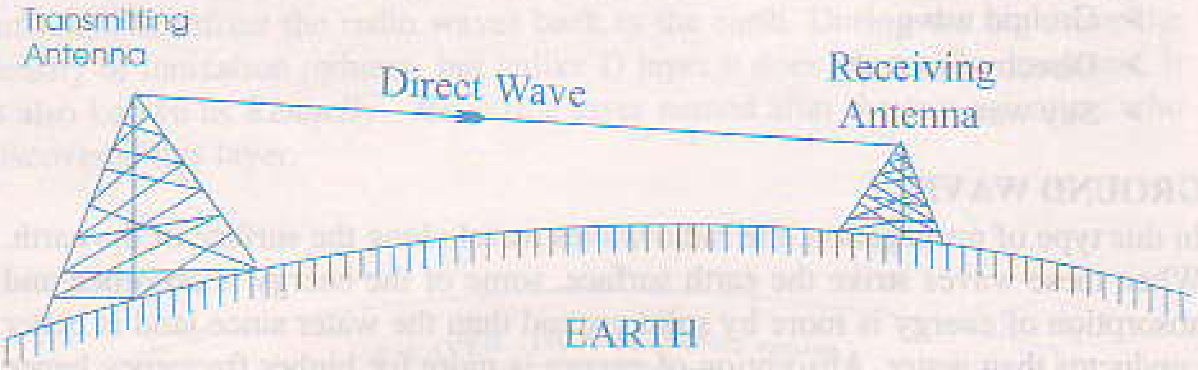


Figure 3
Direct Wave

It is used in Radar, TV, VHF communication etc. Frequency used by this type of propagation is above 30 MHz i.e. VHF band onwards.

SKY WAVE

In this type of propagation, the radio waves are received through the ionosphere. The radio waves from the transmitting antenna are radiated in all directions and the angle made by the direction of waves with respect to the surface of the earth is called as the angle of incidence. When the angle of incidence increases beyond a certain angle, the radio waves do not return to the earth but are lost in space. The minimum angle at which this occurs is called as the *critical angle*. The radio waves are refracted by the ionosphere and strike the surface of the earth at a distance generally larger than the ground wave where some of the energy will be absorbed and the waves get reflected by the surface of the earth. This is the first hop as shown in figure 4. Depending upon the power output of the transmitter, multiple hops can occur. It is because of this phenomenon that long distance communication is possible with sky wave propagation.

This wave is affected by time of the day, season and atmospheric conditions. The frequency used for sky wave propagation is from 2 MHz to 30 MHz.

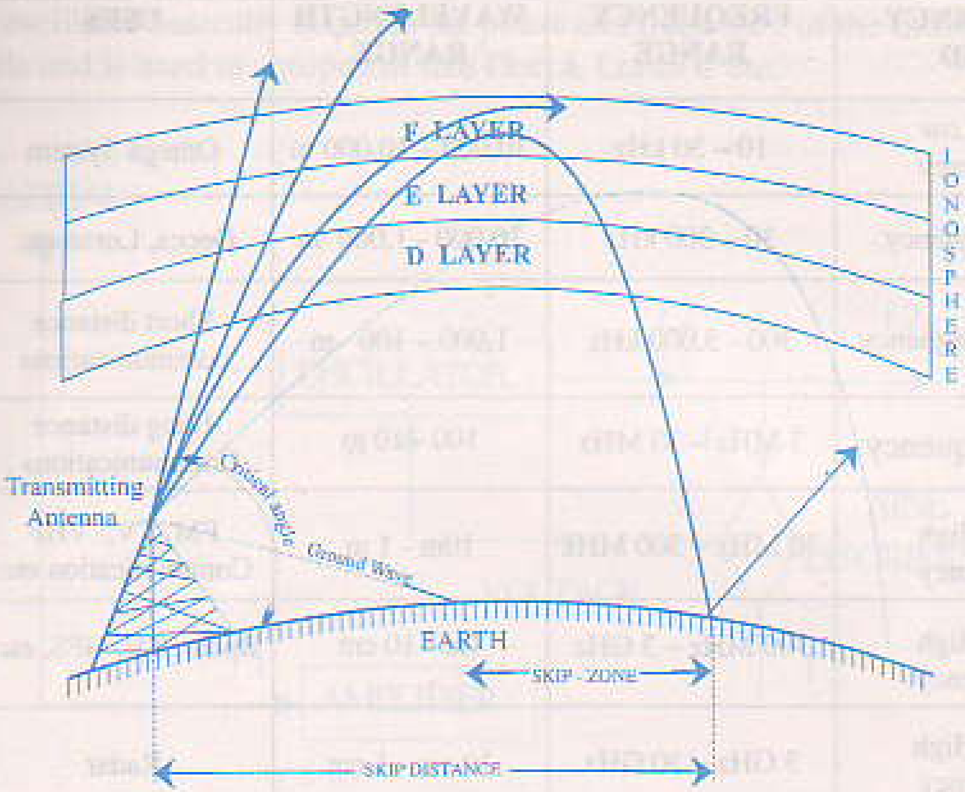


Figure 4
Sky Wave

SKIP DISTANCE

Skip distance is the distance between the transmitting antenna and the point where sky wave signal is first received. It depends upon frequency, time of the day and the angle of incidence.

SKIP ZONE

Skip zone is the distance between the point where the ground wave signal is last received and the point where the sky wave signal is first received. This is also known as dead zone because in this zone the signal is not received.

CRITICAL FREQUENCY

For a given layer the critical frequency is defined as the highest frequency of radio waves that is returned back to the earth by that layer. Radio waves above the critical frequency will penetrate the ionosphere and go into space.

CRITICAL ANGLE

The angle of incidence above which the wave no longer returns to earth but travels outward into space is called as the critical angle. This depends on frequency and density of ionization.

RADIO SPECTRUM

FREQUENCY BAND	FREQUENCY RANGE	WAVELENGTH RANGE	USES
Very Low Frequency	10 – 30 kHz	30,000 – 10,000 m	Omega System
Low Frequency	30 – 300 kHz	10,000 - 1,000 m	Decca, Loran etc.
Medium Frequency	300 - 3,000 kHz	1,000 – 100 m	Short distance communications
High Frequency	3 MHz – 30 MHz	100 - 10 m	Long distance Communications .
Very High Frequency	30 MHz – 300 MHz	10m - 1 m	FM, TV, VHF Communication etc.
Ultra High Frequency	300 MHz – 3 GHz	1m - 10 cm	Radar, TV, GPS, etc.
Super High Frequency	3 GHz – 30 GHz	10 cm - 1 cm	Radar
Extremely High Frequency	30 GHz – 300 GHz	1cm - 0.1 cm	Experimental

OSCILLATOR

This circuit produces electrical sinusoidal waves of desired frequency, which is generated by LC tank circuit. The frequency of oscillations is governed by the value of the coil (L) and capacitor (C) and the desired frequency can be achieved by changing the value of either coil or capacitor. LC circuit may be replaced by a crystal because it produces a very stable frequency and the frequency of the oscillation depends on the value of the crystal. The frequency is inversely proportional to time taken to complete one cycle i.e. $T = 1/f$

ATOMIC CLOCK OR ATOMIC OSCILLATOR

The atomic oscillator generates a very stable frequency and is determined by the atoms of Rubidium or Caesium. Its relative accuracy i.e. ratio of frequency deviation to original frequency, $\Delta f / f$ is of the order of 10^{-11}. This means that after 10^{11} oscillations, the oscillator may have generated one oscillation more or less than it should have done.

FLY WHEEL OSCILLATOR

This oscillator basically acquires the phase and frequency of the incoming signals and is used in equipment like Decca, Loran C etc.

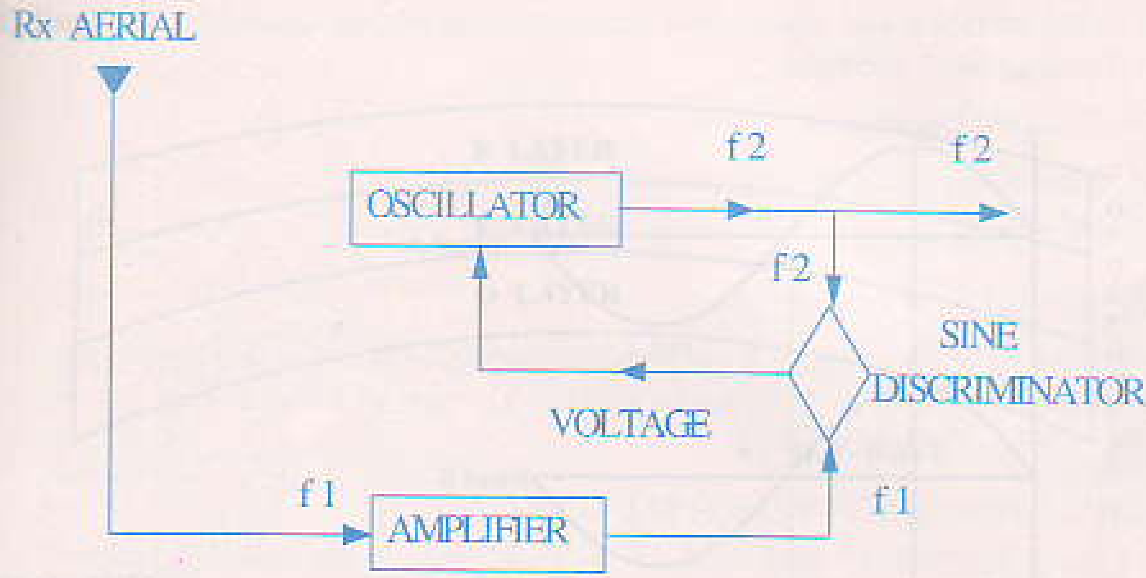


Figure 5
Fly wheel oscillator circuit

As shown in figure 5, the received frequency f_1 is amplified and given to the sine discriminator. The frequency f_2 generated by the oscillator is also given to the discriminator. The sine discriminator measures the phase difference between these two frequencies and depending on the phase difference a voltage is produced which is fed to the oscillator. This voltage keeps adjusting the frequency f_2 till the two frequencies are in phase and when these two frequencies are in phase, the voltage produced will be zero. The magnitude of the voltage produced will depend on the phase difference between the two signals.

SENSITIVITY

It is the ability of the receiver to receive the weakest of weak signals and amplify it sufficiently to make them audible.

SELECTIVITY

It is the ability of the receiver to select the desired frequency and reject all the unwanted signals at near by frequencies.

PHASE

If two signals start and finish at the same time, then these two signals are in step and said to be in phase. Phase does not depend on the magnitude of the two signals and it can also determine the time difference between the two signals.

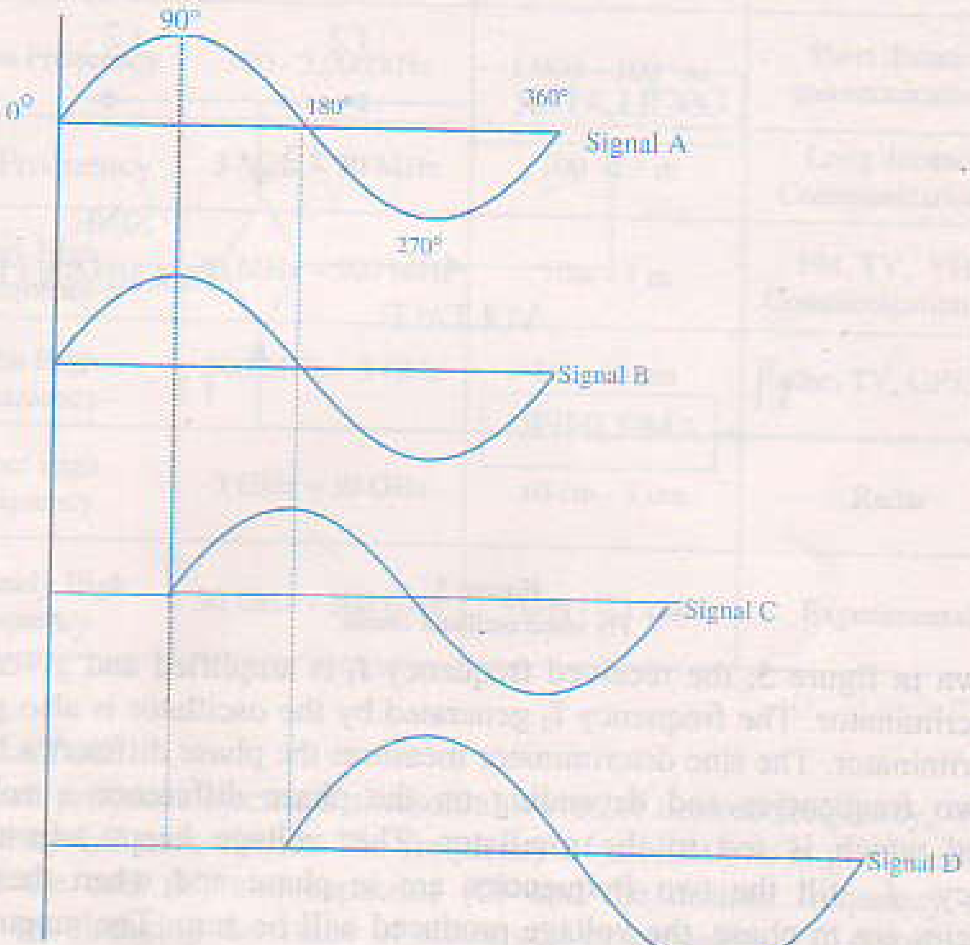


Figure 6
Phase comparison of the two signals

As shown in figure 6, the following observations can be made-

- Signals A and B are in phase
- Signals A and C are out of phase by 90° or we can say that Signal A is leading C by 90° or signal C is lagging A by 90° and
- Signals A and D are 180°out of phase.

FADING

When ground and sky wave signals are received simultaneously by the receiving aerial, they may or may not be in phase. If these two signals are in phase they add up and when not in phase they produce a resultant. Thus the signal strength to the receiver keeps fluctuating and this affect is known as fading.

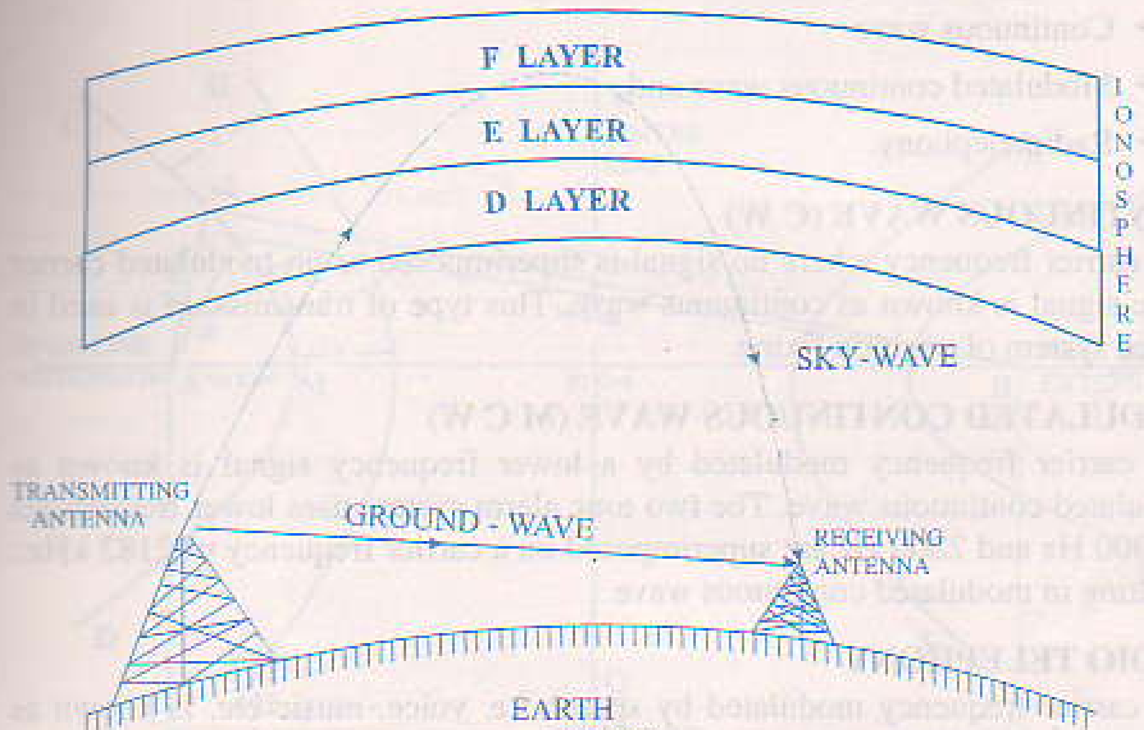


Figure 7
Simultaneous reception of ground and sky wave signals resulting in fading

NOISE

Unwanted signal in the receiver is called interference. The intentional interference to obstruct communication is called *jamming whereas un-*intentional interference is called *noise*.

Noise originated outside the receiver may be either man made or natural. Man-made noise originates in electric appliances, motor ignition systems, generator, other sources of sparks etc.

Natural noise is caused by static i.e. disturbance in the atmosphere such as thunderstorms etc.

SIGNAL TO NOISE RATIO

The relative amount of noise present in an amplifier is usually expressed by the signal to noise ratio and it also indicates how weak a signal voltage can be received over the receiver noise level e.g. if the signal output of an amplifier is 500 mV and noise voltage is 50 mV, the signal to noise ratio is 10 and being a ratio, it has no unit.

MODE OF TRANSMISSION

The audio frequency (20 Hz to 20 kHz) by itself is not in a position to travel to a longer distance hence it requires some carrier to carry this frequency to a longer distance. This carrier is known as carrier frequency or radio frequency. The audio frequency is superimposed on the carrier frequency, which is known as modulated carrier wave. The carrier frequency can be transmitted by any one of the following three methods

- Continuous wave
- Modulated continuous wave and
- Radiotelephony.

CONTINUOUS WAVE (C W)

The carrier frequency where no signal is superimposed or un-modulated carrier wave signal is known as continuous wave. This type of transmission is used in Decca system of position fixing.

MODULATED CONTINUOUS WAVE (M C W)

The carrier frequency modulated by a lower frequency signal is known as modulated continuous wave. The two tone alarm system uses lower frequencies of 1300 Hz and 2200 Hz are superimposed on a carrier frequency of 2182 kHz., resulting in modulated continuous wave.

RADIO TELEPHONY

The carrier frequency modulated by speech i.e. voice, music etc. is known as radiotelephony and this type of transmission is generally used for commercial purposes. VHF communication uses radiotelephony.

HYPERBOLA

Hyperbola is defined as a locus of all points having a constant difference in distance from two fixed points known as foci. The line joining the two foci is called base line and can be extended on either side of the foci as base line extension. The hyperbola, which is equidistant from the two foci, will be perpendicular to the base line and is called centre line.

In figure 8, A and B are the two foci and AB is the base line which is extended on either side as base line extension. PQ is the hyperbola equidistant from the two foci and is called centre line. CD, EF, GH & RS are other hyperbolae drawn on the base line AB where difference in distance at any point on any one hyperbola from these two foci will be constant.

Considering the hyperbola CD, the difference in distance from the two foci at any point on this hyperbola is constant. For example, point M is 30 kilometers from A and 80 kilometers from B, hence the difference in distance is 50 kilometers. Similarly point L is 40 kilometers from A and 90 kilometers from B, the difference in distance is again 50 kilometers.

Also considering the point N, which is 50 kilometers from A and 100 kilometers from B, the difference in distance is once again 50 kilometers. Hence on the hyperbola CD, any points will have a constant difference in distance of 50 kilometers from the two foci A and B.

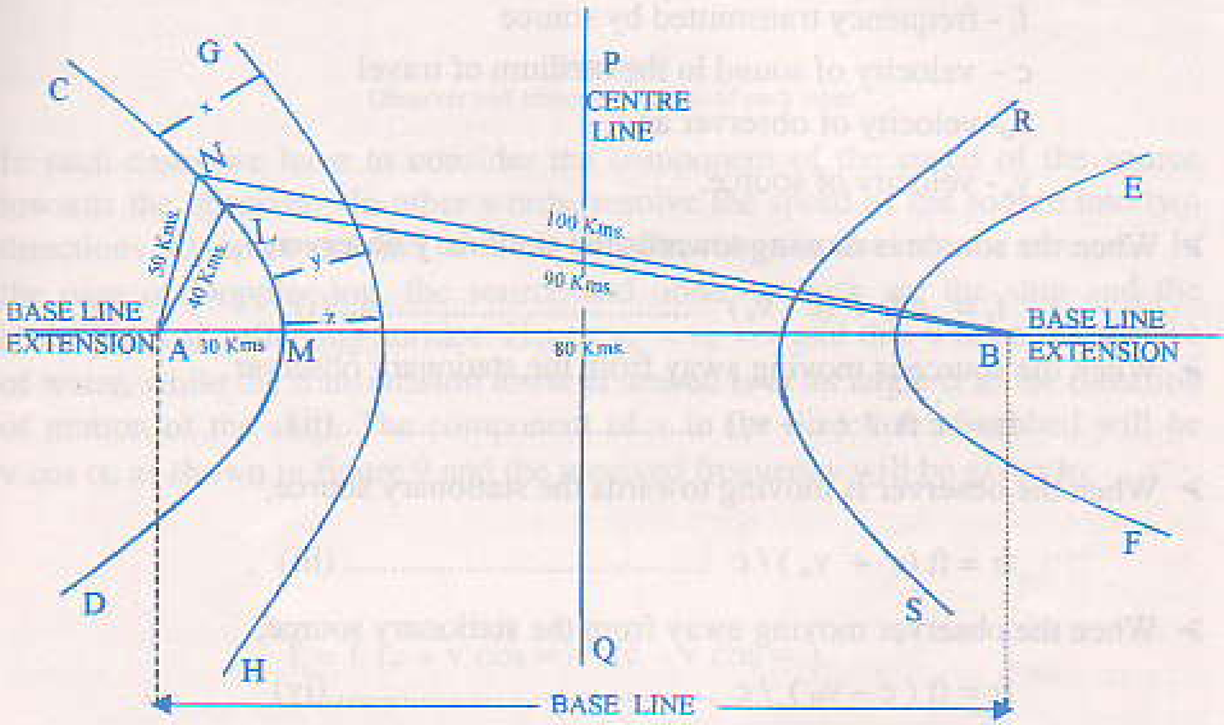


Figure 8
Hyperbola

A mirror image of hyperbola CD is drawn as hyperbola EF having a constant difference in distance of 50 kilometers, but it is on the other side of the centre line.

In this manner a number of hyperbolae can be drawn on either side of the centre line having constant difference in distance from the two foci.

The distance between any two consecutive hyperbolae on the base line is same and is minimum. This distance increases as we go away from the base line i.e. x > y > z

These hyperbolae can also be drawn with a constant difference in phase or constant difference in time from the two foci. These hyperbolae are used in hyperbolic navigation system of position fixing such as Decca and Loran C respectively, where the master and slave stations are two foci to form the respective hyperbolae.

DOPPLER EFFECT

The apparent change in frequency received by an observer is due to the relative motion between the source and the observer. This is based on the principle of Doppler effect. The frequency received by the observer can be calculated by one of the following formula where abbreviation used in the formula are as follows

f_r - frequency received by observer

f_t - frequency transmitted by source

c - velocity of sound in the medium of travel

v_o- velocity of observer and

v_s - velocity of source.

- When the source is moving towards the stationary observer,

$f_r = c f_t / (c - v_s)$ .... (i)

- When the source is moving away from the stationary observer,

$fr = c ft / (c + v_s)$ .... (ii)

- When the observer is moving towards the stationary source,

$fr = ft (c + v_o) / c$ .... (iii)

- When the observer moving away from the stationary source,

$fr = ft (c - v_0) / c$ .... (iv)

- The combined effect of source and observer both moving towards each other

$fr = ft (c + v_o) / (c - v_s)$ .... (v)

- The combined effect of source and observer both moving away from each other

$fr = ft (c - v_o) / (c + v_s)$ .... (vi)

In all the above cases we have considered the observer to be in the path of the source. This is not always so specially in case of satellite navigator when we consider satellites not passing the observers zenith and Doppler log where we artificially generate the Doppler shift.

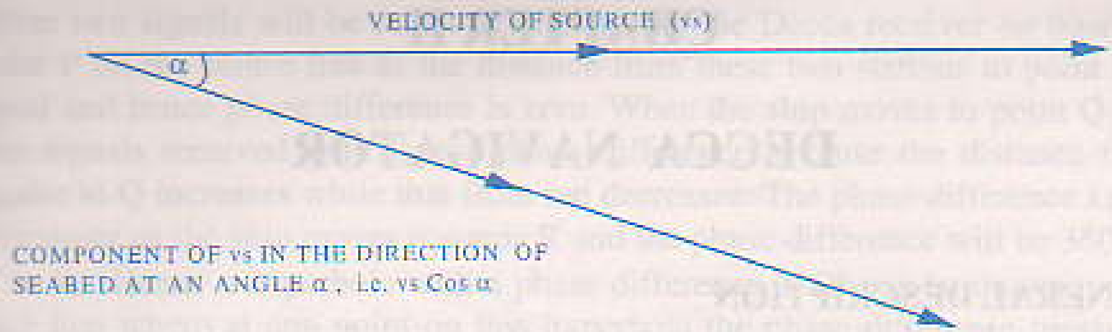


Figure 9
Observer and source not in path of each other

In such cases we have to consider the component of the speed of the source towards the observer. In other words, resolve the speed of the source into two directions 90° apart and one of these two directions is towards the observer. In the case of Doppler log, the source and observer both are the ship and the seabed acts as reflecting surface. Hence $v_o = v_s = v$ and this v is on the surface of water, while the transmission towards seabed is at an angle α to the direction of motion of the ship. The component of v in the direction of seabed will be $v \cos \alpha$, as shown in figure 9 and the received frequency will be given by

$$f_r = f_t (c + v \cos \alpha) / (c - v \cos \alpha).$$

CHAPTER II

DECCA NAVIGATOR

GENERAL DESCRIPTION

Decca is a hyperbolic navigation system of position fixing which measures the phase difference between the continuous wave (C.W.) signals transmitted by master and slave stations. This system is organised in chains, each chain comprises of one master and usually three slave stations known as red, green and purple. These four stations are arranged in pairs i.e. master - red, master - green and master - purple. The phase difference measurement is always carried out between master and slave signals and to differentiate the hyperbolae produced by these pairs, each has been assigned with a distinguishing colour i.e. red, green and purple. These colours identify the decometers of the Decca receiver and the Decca charts are superimposed with lattice of respective colour.

There are about 48 chains in different coastal regions all over the world, each chain gives the navigational coverage of about 240 nautical miles approx. from the master station and is used for coastal navigation.

PRINCIPLE

In the following figure, master and red slave stations transmit continuous wave signals with a constant phase difference of 0°, in other words these two signals are in phase.

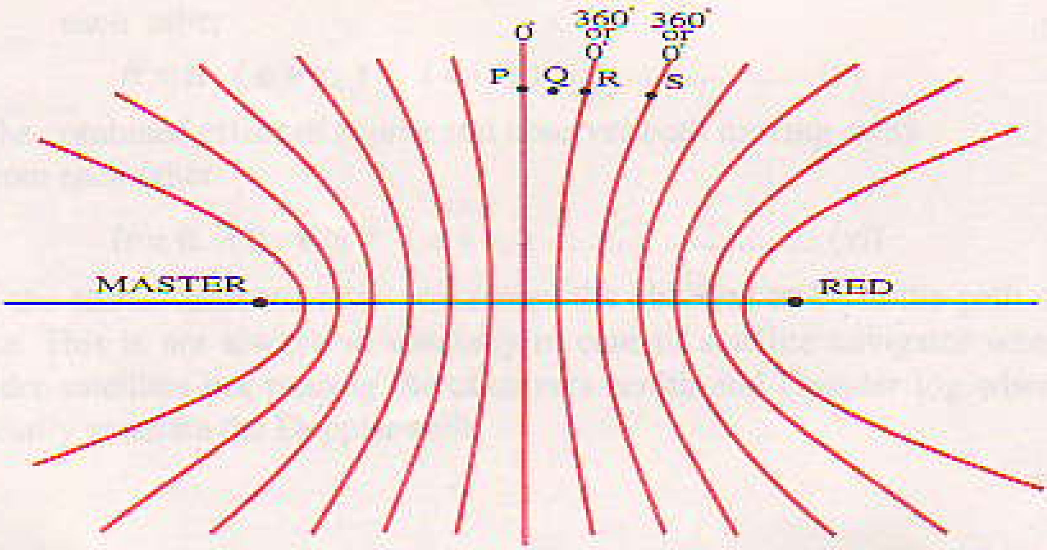


Figure1
The lattice drawn between master and red slave combination

These two signals will be received in phase by the Decca receiver on board at point P on the centre line as the distance from these two stations to point P is equal and hence phase difference is zero. When the ship moves to point Q, the two signals received will have a phase difference because the distance from master to Q increases while that from red decreases. The phase difference keeps increasing as the ship moves towards R and the phase difference will be 360° or 0° at R. Hence a hyperbola with a phase difference of 0° can be drawn on the base line where at any point on this hyperbola the phase difference measured between master and red slave signals will be 0°. As the ship continues to move further away from point R, the phase difference will again start increasing till point S where it again becomes 360° or 0°.

Using this principle, successive hyperbolae with 0° phase difference between master and red slave signals can be drawn on either side of center line as shown in figure 1.

Similarly using the above principle a number of hyperbolae can be drawn having a phase difference of 0° between master and green slave signals as shown in figure 2.

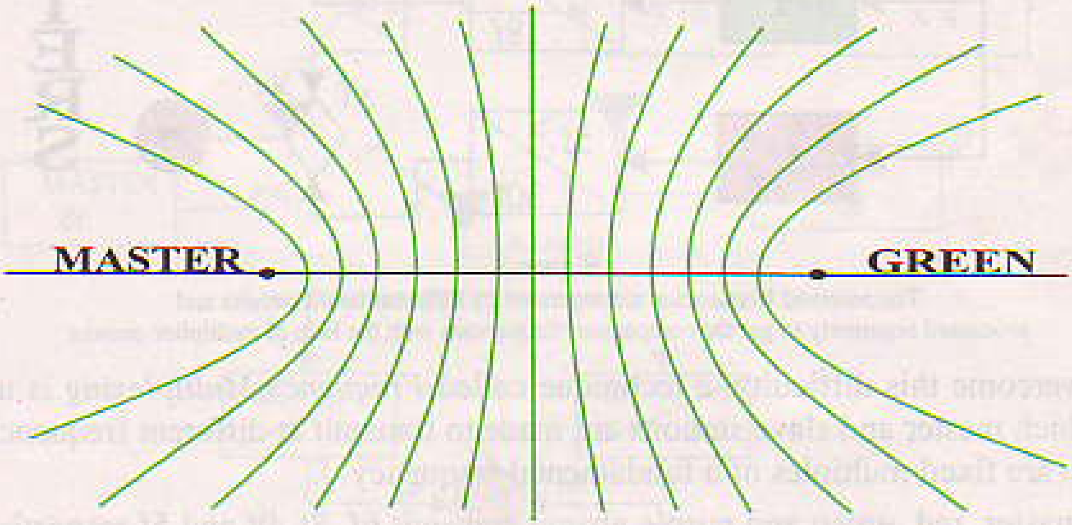


Figure 2
The lattice drawn between master and green slave combination

The master and purple slave signals combination will give another set of hyperbolae having 0° phase difference and these will be printed with purple colour on the chart. The hyperbolae between master and purple slave combinations with purple colour are not shown in this book.

These hyperbolae with each master and slave combination are drawn on the Decca charts of a given chain with respective colours i.e. red, green and purple, which are used for fixing the ship's position.

DISTINGUISHING BETWEEN MASTER AND SLAVE SIGNALS

In a Decca chain, if master and slave stations transmit on same frequency (say 340 kHz), these frequencies will be received by the receiving aerial on board and since the frequency is same it will not be possible to separate them to measure the phase difference. Phase difference measurement between master and slave signals can be carried out only when their frequencies are separated.

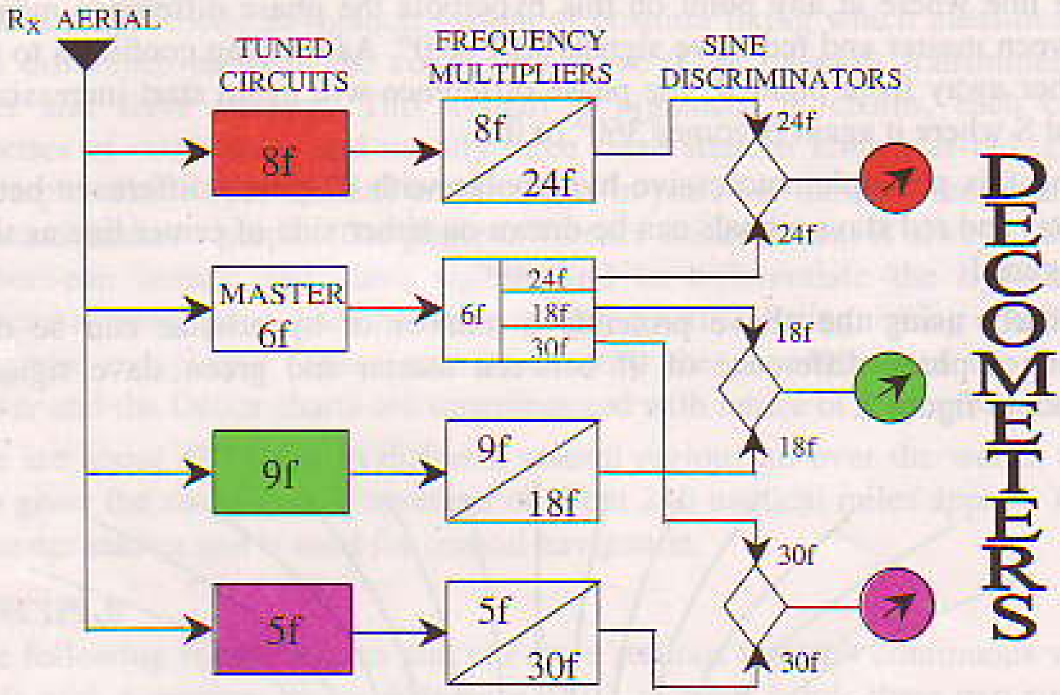


Figure 3

The received frequencies are separated by different tuned circuits and processed separately to get the comparison frequencies with the help of multiplier circuits

To overcome this difficulty, a technique called *Frequency Multiplexing* is used by which master and slave stations are made to transmit at different frequencies, which are fixed multiples of a fundamental frequency *f*.

The master, red, green and purple always transmit 6f, 8f, 9f and 5f respectively and the receiving aerial on board will receive these frequencies. These frequencies can now be separated easily by different tuned circuits and the receiver can easily distinguish the frequency from master and slave stations. In order to measure the phase difference between master and slave pair, they should have same comparison frequency hence the received frequencies are processed separately to get the comparison frequency using frequency multiplier circuits as shown in figure 3. The comparison frequencies for master-red, master-green and master-purple pairs are 24f, 18f and 30f respectively. These multiples of transmission and comparison frequencies remain same for all the chains but the fundamental frequency changes from chain to chain. The fundamental frequency *f* will be selected between 14kHz and 14.33 kHz for any given chain.

PHASE SYNCHRONISATION

In Decca system Master and slave stations always transmit their signals with a constant phase relationship which can be achieved by any of the following two methods

➢ Triggering method

In this method the signal from master is received by all the slave stations, they convert it into a multiple frequency and then each slave station transmits this signal with a constant phase difference with master signal and thereby maintaining steady phase relationship.

Figure 4 shows the triggering method in which the master signal of 6f is received by the red slave station, which converts it into the multiple frequency and finally red slave station transmits 8f with a constant phase difference with master signal. Similarly the green and purple slave stations also receive the master signal 6f and convert this into multiple frequency to get 9f and 5f respectively.

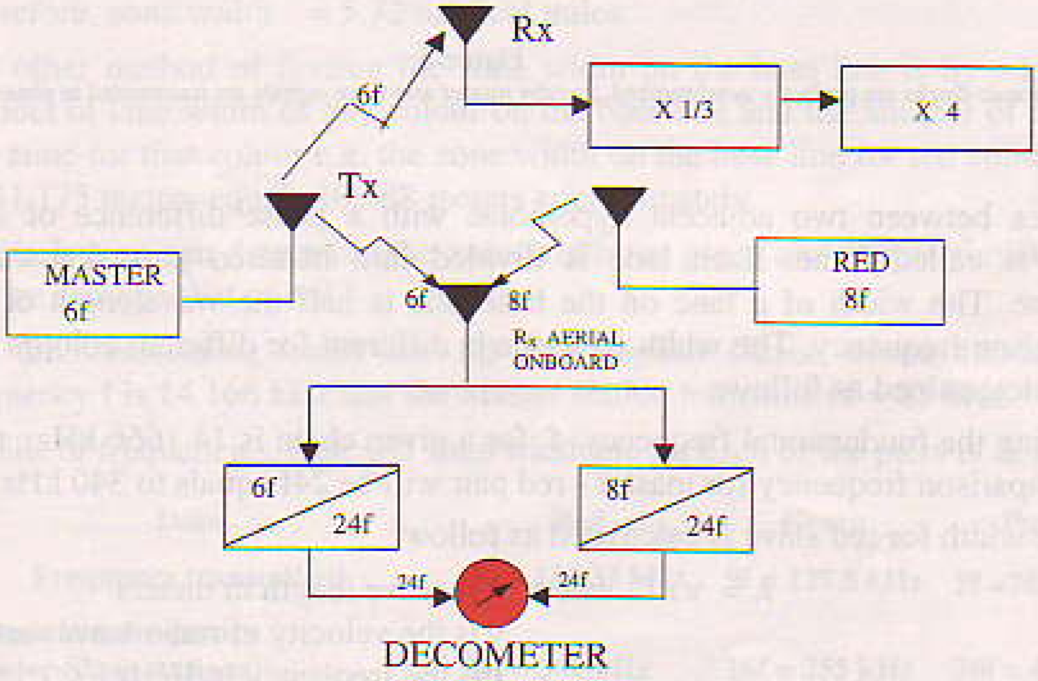


Figure 4

The signals from master received by red slave, converted to 8*f and transmitted in phase with master station*

➢ Synchronisation method

In this method the master and slave stations are equipped with atomic clocks which are perfectly time synchronised and transmit the signal with constant phase difference.

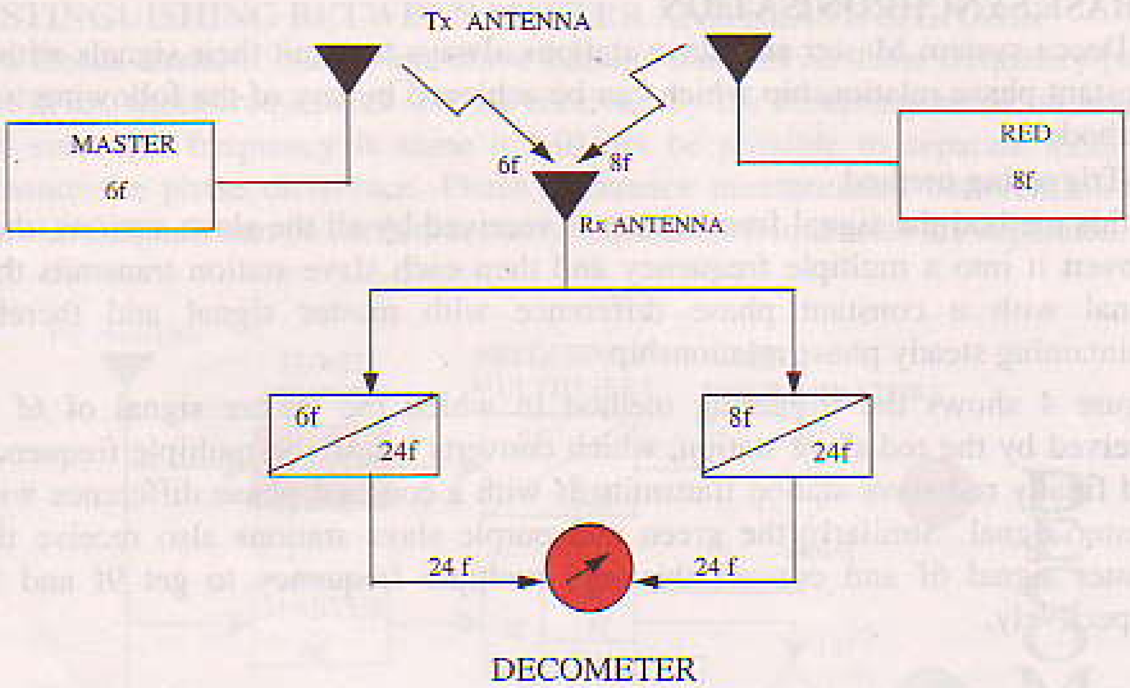


Figure 5
The atomic clocks are perfectly synchronized, thereby master and slave signals are transmitted in phase

LANE

The area between two adjacent hyperbolae with a phase difference of zero degree is called Lane. Each lane is divided into hundred parts known as centilane. The width of a lane on the base line is half the wavelength of the comparison frequency. The width of a lane is different for different colours and can be determined as follows

Assuming the fundamental frequency f for a given chain is 14.1666 kHz., then the comparison frequency for master - red pair will be 24f equals to 340 kHz.

Lane width for red slave is calculated as follow

$\lambda = v / f$ where λ is wave length in meters
v is the velocity of radio waves and
f is the frequency in Hertz.

$\lambda = v / f$

$= 300 \times 10^6 / 340 \times 10^3$ meters.

$= 882.35$ meters

Therefore, lane width $\lambda/2 = 441.175$ meters.

Similarly comparison frequency, wave length and lane width of master - green and master - purple pairs can bé worked out.

ZONE

A set of lanes is referred to as a zone. The number of lanes in a zone depends on the master - slave combination being used. One zone of the master - red slave has 24 lanes numbered 0 to 23. Similarly one zone of the master-green slave has 18 lanes numbered 30 to 47 and master - purple has 30 lanes numbered 50 to 79. The zones are named A to J and these letters may be repeated as required. The distance between two similar zone letters is far apart to cause any ambiguity. The zones are named from master towards the slave station. The width of a zone is half the wavelength of the fundamental frequency f. For a given chain the zone width is same for all the colours.

The width of a zone on the base line is determined as follows

$\lambda = v / f$

$= 300 \times 10^6 / 14.i66 \times 10^3$ meters.

= 21,177 meters approximately.

and $\lambda/2$ = 10,588 meters approximately

Therefore, zone width = 5.72 nautical miles.

The other method of finding the zone width on the base line is by taking the product of lane width of any colour on the base line and the number of lanes in one zone for that colour e.g. the zone width on the base line for red colour is 24 x 441.175 meters equals 10,588 meters approximately.

Similarly you can determine the zone width for green and purple slaves which will be same as that of red.

We are considering chain no. 5B i.e. English Chain whose fundamental frequency f is 14.166 kHz and the Master station transmits 6f = 85 kHz.

Details of frequencies, lane and zone width etc for each of the pairs is as follows

Data	Red	Green	Purple
Frequency transmitted	**8f = 113.33 kHz**	**9f = 127.5 kHz**	**5f =70.83 kHz**
Comparison frequency (Master-Slave stations)	**24f = 340 kHz**	**18f = 255 kHz**	**30f = 425 kHz**
Lane width on base line	**441.17 meters**	**588.23 meters**	**352.9 meters**
Zone width on the base line	**5.72 Nm**	**5.72 Nm**	**5.72 Nm**
Total number of lanes	**24 lanes**	**18 lanes**	**30 lanes**
Lane number marked on chart and decometers	**0 to 23**	**30 to 47**	**50 to 79**
Zone letters	**A – J**	**A – J**	**A – J**

DECOMETER

The Decca receiver is measuring the phase difference between the master and slave station signals. This phase difference is indicated in terms of centilanes on the decometer. The area between the two adjacent hyperbolae is divided into 100 centilanes, it is also equal to phase difference of 360°, hence one centilane equals 3.6° of phase difference.

The decometer consists of a centilane pointer, lane and zone indicator. The lane numbers and zone letters are indicated through window. Lane indicator is mechanically coupled to the electrically driven centilane pointer. When the ship is on a particular lane, the phase difference between the master and slave signals will be zero and at that instant the centilane pointer will be indicating 0 centilane. As the ship moves away from the lane, there will be a phase difference between the master and slave signals, which will cause the centilane pointer to move. When the ship reaches the adjacent lane, the centilane pointer completes one circle and since the lane indicator is mechanically coupled to it, the lane number increases or decreases accordingly. The centilane pointer will move clockwise or anti-clockwise depending upon whether the ship is moving away or towards the master station and the lane number increases as we go away from master towards slave station.

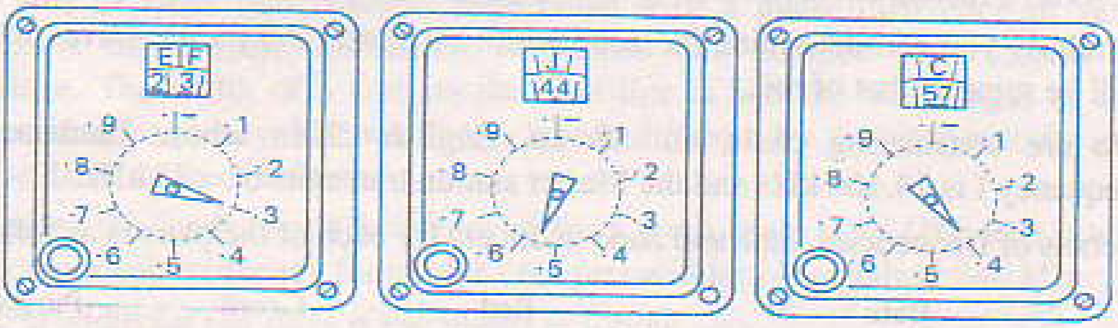


Figure 6
The decometers showing the zone lane and centilane reading for each colour

The zone indicator is mechanically coupled to the lane indicator and when the lane indicator crosses the number of lanes in the respective master - slave pair, the zone letter will change from one to another.

There is a dot and dash symbol marked below the window in which zone letters and lane numbers are marked. On the zone windows, when two letters appear then the correct letter will be the one positioned over the same symbol as that displayed under the lane number e.g. the correct reading on the red decometers as shown in fig. 6 will be F 3.30, while that of green and purple will be J 44.57 and C 57.40 respectively.

Each Decca receiver has three decometers, one for each colour i.e. red, green and purple to indicate three LOPs, which are used for fixing the position of the ship.

LANE SLIP

The lane indicator is mechanically coupled to the electrically driven centilane pointer and when the ship crosses one lane, the centilane pointer completes one revolution and the lane reading changes accordingly. Due to various factors, there is a possibility that the lane indicator does not show the correct reading and this error in the lane reading is known as **Lane Slip.**

Lane slip is possible when ground and sky wave signals are received simultaneously and if these two signals are equal in amplitude but 180 degrees out of phase, they cancel out each other and no signal will be given to the receiver. Suppose this happens when the red decometer indicates A 15.16 and the ship is still moving but the centilane pointer will remain at 16 centilanes. After some time when normal signal is received, at this instant the ship is on 94 centilanes within the same lane, therefore, the correct reading should have been A 15.94. The centilane pointer will now move from 16 centilanes to 94 centilanes through the shortest path i.e. backwards via zero and the reading obtained from the decometer will be showing A 14.94, instead of A 15.94. Thus an error in the lane reading of the decometer occurs, called lane slip. There are many other factors, which can also cause lane slip.

Following are some of the factors which can cause lane slip

- Mal-functioning in the Decca chain
- Other stations transmitting on Decca frequencies
- Simultaneous reception of sky wave and ground wave
- Man made noise and strong static
- Function switch left at Ref. position for long time
- Variation in supply voltage
- Hold button is pressed for long time during inter chain fixing

The lane slip can be detected by any of the following methods

- compare the position with other position fixing methods available
- continuous plotting of Decca positions at regular intervals
- by referring to lane identification

LANE IDENTIFICATION

The decometer by itself cannot determine in which lane the ship is, but within the lane it always gives the correct position, hence initially the ship's position is plotted on the Decca chart by some other available means and the reading obtained for zone letter and lane number for each colour are manually fed to the respective decometers. The lane number will keep changing as the ship crosses from one lane to another. However due to various factors the lane slip may take place and the decometer may not indicate the correct lane. The Lane Identification circuit is introduced to check for lane slip and also for initial fixing of the position.

The width of the lane on the base line is half the wavelength of the comparison frequency and if the comparison frequency is reduced the wavelength and hence the lane width will increase.

Since we know that the width of one zone on the base line is equal to half the wavelength of the fundamental frequency f and if phase comparison between master and slave is measured at the fundamental frequency f, then the width of the lane will be equal to a zone. Now since we have made the zone as a lane and if there is a separate decometer, then the centilane pointer will make one revolution when the ship crosses one zone (i.e. 24 lanes in case of red slave). This centilane pointer could now be used to identify in which lane the ship is in e.g. if the centilane pointer of this decometer shows 40 centilanes, it would mean that ship is on lane number 9 (i.e. 0.4 x 24 = 9.6, hence ship is in 9th lane). Since there is no such decometer, this calculation is done internally by the receiver and the reading is indicated on the Lane Identification indicator.

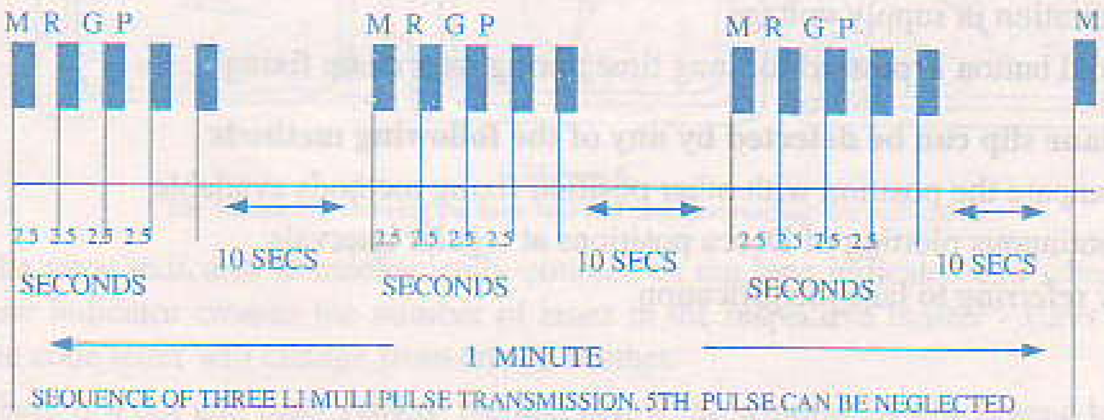


Figure 7
Sequence of three Lane Identification multi pulse transmission pattern

In order to obtain the fundamental frequency f, the Lane Identification signals are transmitted by all the stations three times in a minute and each station transmits on all the four frequencies i.e. 5f, 6f, 8f and 9f for first half second during the specified 2.5 seconds interval. This type of transmission is known as **multi pulse transmission**.

When the master transmits all the four frequencies for half second, all the other stations cease to transmit. These frequencies are received on board and from these frequencies the fundamental frequency *f* is obtained.

During the normal transmission of the master, the 6f fly - wheel oscillator circuit acquires phase and frequency of the master signal. This frequency is divided by 6 to obtain the fundamental frequency *f*, which is used for phase comparison with *f* obtained during multi pulse transmission to achieve lane identification.

The phase comparison is now carried out between the frequency *f* obtained during the LI transmission from the *master* and the frequency *f* obtained during normal transmission of the master. The LI indicator should show one of the these readings i.e. 23.8, 23.9, 00.0, 00.1 or 00.2 and LI zero has to be depressed, if any one of the above reading is not indicated.

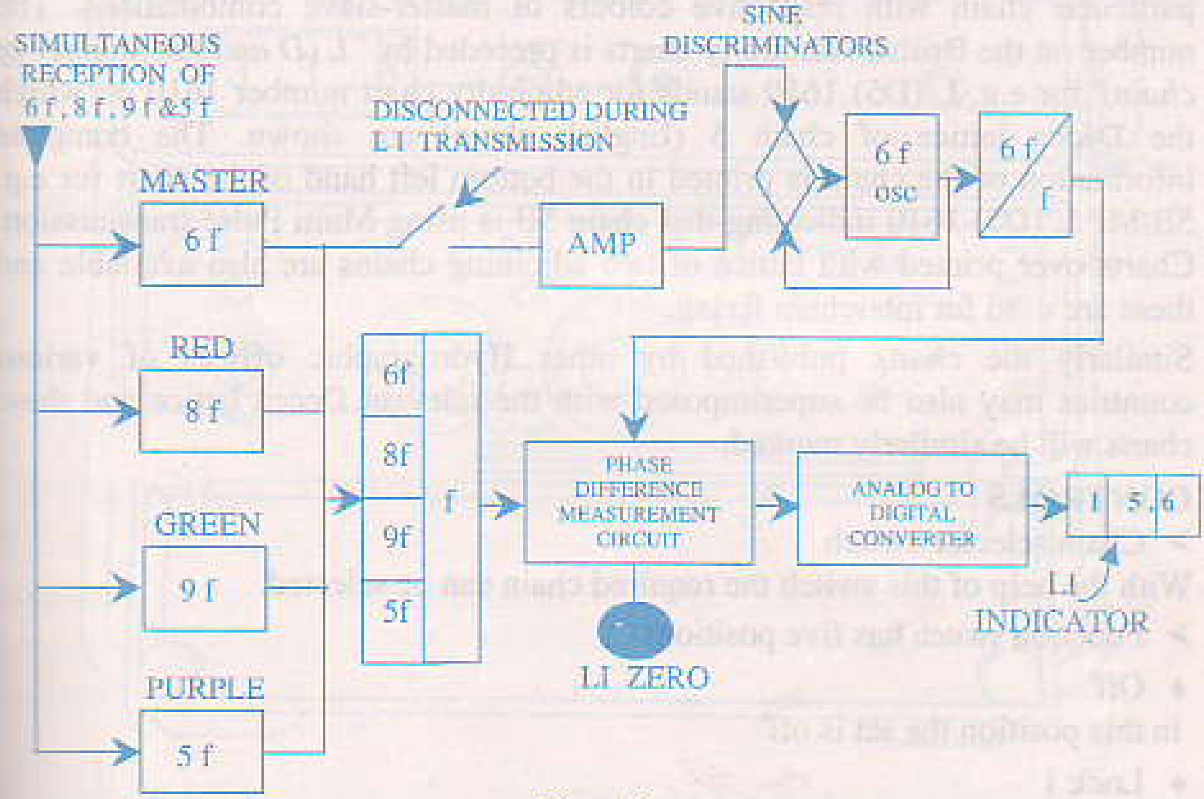


Figure 8
Block diagram of Lane Identification

Subsequent to the LI transmission of the master station and after an interval of 2 sec. the red slave transmits the LI signals i.e. all the four frequencies for half second during the specified 2.5 seconds interval. During this transmission all the other stations including the master will cease to transmit. From these four frequencies, the fundamental frequency *f* is worked out. The phase comparison is carried out between frequency *f* of the master and the frequency *f* obtained from the red slave. The lane number of the red slave achieved by this comparison is displayed on the LI indicator. Similarly lane numbers for green and purple slaves are obtained during their respective LI transmissions.

There is only one LI indicator and hence the lane numbers for all the colours will be displayed on the same indicator sequentially i.e. red, green and purple in that order, but the sequence will always start with master reading first followed by the other colour. This sequence is repeated after every 20 seconds. The LI indicator will show the centilanes also along with the lane number, but only in tens and this is not accurate.

The advantage of multipulse transmission is that the phase of frequency *f* obtained during the LI transmission from the four frequencies will not be affected even if any one of these frequencies has sky wave interference.

DECCA CHARTS

These are normal navigational charts, superimposed with Decca lattice for the particular chain with respective colours of master-slave combinations. The number on the British Admiralty charts is preceded by '*L (D and the number of chain)*' for e.g. L (D5) 1610 stands for admiralty chart number 1610 on which the Decca lattice of chain 5 (English chain) are shown. The complete information of the chain is printed in the bottom left hand of the chart for e.g. 5B/MP L (D5) 1610 indicating that chain 5B is using Multi Pulse transmission. Charts over printed with lattice of two adjoining chains are also available and these are used for interchain fixing.

Similarly the charts published by other Hydrographic offices of various countries may also be superimposed with the relevant Decca lattice and these charts will be similarly marked.

CONTROLS

- Chain selector switch

With the help of this switch the required chain can be selected.

- Function switch has five positions

- Off

In this position the set is off

- Lock 1

In this position the receiver initially tries to lock on to the incoming signals and once the signal is locked on, centilane pointers of all the decometers stops flickering. The lock lamp glows when the master signal is locked on.

- Ref

In this position all the centilane pointers should read zero, if not it can be set to zero by the respective zero control knob.

- Lock 2

It has a similar function as that of locks 1 and is required because in reference position the aerial gets disconnected to check the phase drift - taking place within the receiver.

♦ Op

In this position the normal operation of the receiver is carried out.

➤ Decometer

There are three decometers provided one for each colour to indicate the zone, lane and centilane reading.

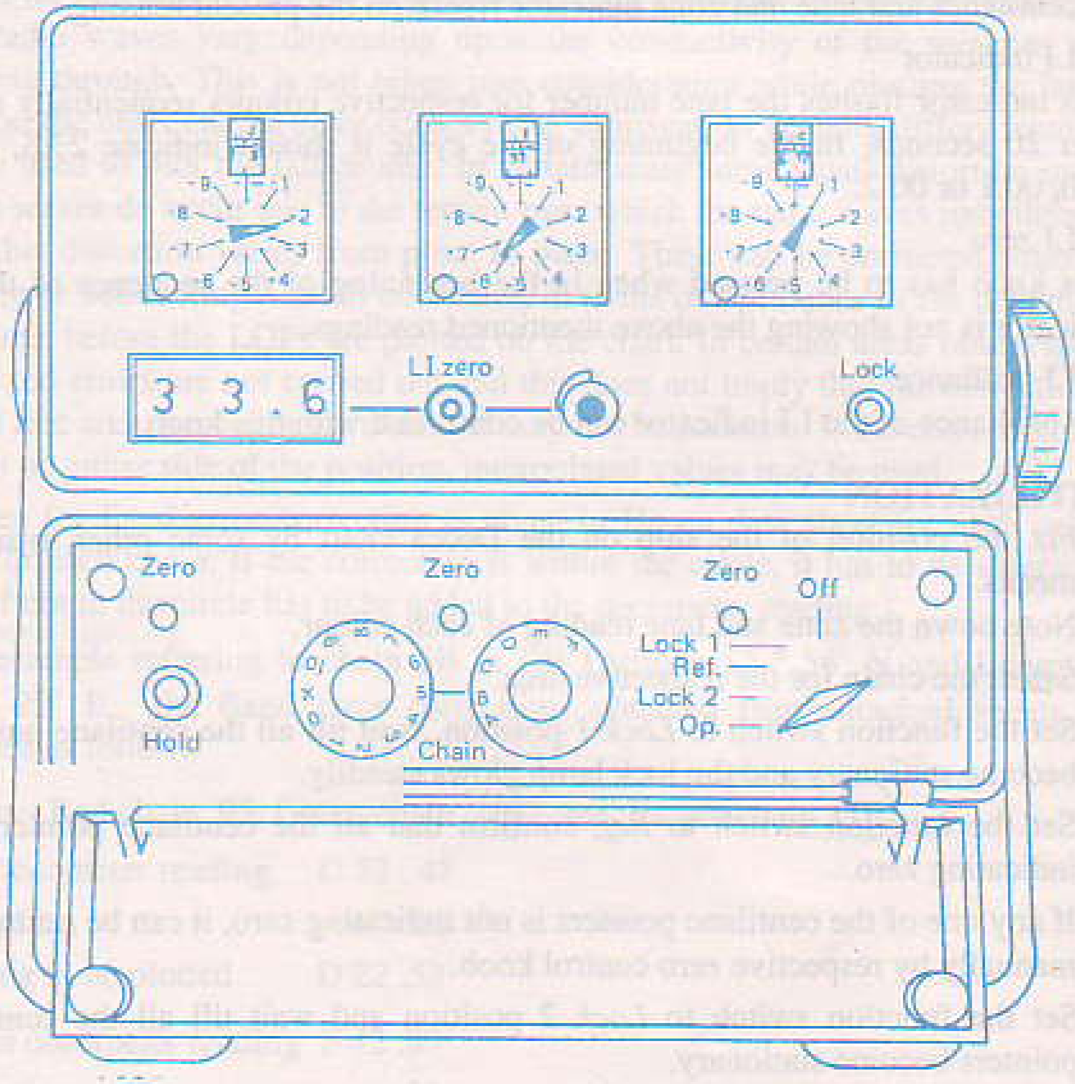


Figure 9
Mark 21 Decca receiver

➤ Reset

Each decometer has been equipped with a reset knob to set the zone and the lane reading manually. This is done at the time of initialization, when correct zone letter and lane number are manually selected by the navigator for each colour to the respective decometers.

- Zero Control knob

In **Ref** position, all the centilane pointer of the decometers should read zero and if any one of the centilane pointer is not showing zero, it can be set to zero with zero control knob. Each decometer has a respective zero control knob.

- Hold Push Button

When this is depressed the centilane pointers of all the decometers should read 12 centilanes and lane and zone indicator freeze on the present reading.

- LI indicator

This indicator flashes the lane number for respective colours sequentially every after 20 seconds. In the beginning of the cycle it should indicate 23.8, 23.9, 00.0, 00.1 or 00.2.

- LI zero

This knob has to be pressed when in the beginning of the sequence of the LI indicator is not showing the above mentioned readings.

- LI brilliance

The brilliance of the LI indicator can be controlled with this knob.

INITILIZATION

- Fix the position of the ship on the Decca chart by some other available means.
- Note down the zone and lane reading of each colour.
- Select the chain for the respective area.
- Set the function switch to *Lock 1* position, wait till all the centilane pointers become stationary and the lock lamp glows steadily.
- Set the function switch to *Ref*, confirm that all the centilane pointers are indicating zero.
- If any one of the centilane pointers is not indicating zero, it can be set to zero manually by respective zero control knob.
- Set the function switch to *Lock 2* position and wait till all the centilane pointers become stationary.
- The zone and lane reading of each colour as noted above are fed manually to the respective decometers by reset knob.
- Set the function switch to *Operation* and compare the lane number of the decometers with the lane number indicated by the LI indicator. If the two readings are not matching reset the respective decometer lane number to read the one indicated by the LI indicator.
- The set will now be working normally and fixes can be plotted as per the readings obtained from the decometer.

ERRORS

There are two errors in this system

- Fixed or Systematic error and
- Variable or Random error

Fixed or Systematic error

The lattice - line printed on the Decca charts for each master - slave pairs are based on the velocity of the radio waves being constant. In fact the velocity of the radio waves vary depending upon the conductivity of the medium it is passing through. This is not taken into consideration while plotting the lattice line on the chart and an error occurs if the propagation velocity differs from the value used to plot the lattice line. In certain areas some small distortion in the radio waves do occur due to the terrain over which the radio waves pass through and this distortion varies from place to place. These can be corrected either by adding or subtracting a small correction in terms of centilanes to the decometer readings before the LOPs are plotted on the chart. In certain areas observations for fixed errors are not carried out and this does not imply that the correction is nil in that area, hence the fix obtained may not be accurate. If the corrections are given on either side of the position, interpolated values may be used.

Values for fixed error correction is given in Decca data sheet for each colour and for each chain. If the correction is within the circle, it has to be subtracted and if not in the circle has to be added to the decometer reading.

For example referring to chain 5B in DR Latitude 52 ° 58' N and Longitude 001° 20' E, the fixed error corrections obtained from attached sheets are applied as follows

Errors - Red chain **05**, Green chain **(05)** and Purple chain **(10)**

Red decometer reading	D 22 . 48
correction	+ . 05
reading to be plotted	D 22 .53
Green decometer reading	F 42 .87
correction	- .05
reading to be plotted	F 42 . 82
Purple decometer reading	A 65 . 46
correction	- . 10
reading to be plotted	A 65 . 36

Some of the Decca charts have this correction incorporated while plotting the lattice and on such charts this correction is not to be applied. Indication to this effect is given in notices to mariners and in chain data sheets.

Variable or Random error

This error is caused due to simultaneous reception of ground and sky waves and as the distance of the ship from the transmitting station increases, the chances of sky wave interference is more. The magnitude of this error depends on the time of the day/night, season and atmospheric conditions. Since all these conditions are variable, it is very difficult to predict the value of this error, hence due allowance should be given to this error. The estimated value of this error is given in Decca data sheets based on 68% probability of accuracy, whereas ALRS Volume II gives 95 % probability. Higher the probability, lower the accuracy of the fix.

Considering the same position as above for fixed errors i.e. Latitude 52° 50' N and Longitude 001° 20' E, in area of chain 5B, the *predicted coverage and accuracy diagram (68 % probability level) for times other than full day-light coverage (refer Decca data sheet 6)* shows that the ship is in contour b and if we consider midnight of 24th May then *time and seasons factor diagram (refer Decca data sheet 7)* indicates the condition prevailing is summer night. With this information, refer to the *random fixing errors* at sea level in nautical miles (refer Decca data sheet 8) at 68 % probability level which indicates error to be 0.13 nautical mile.

Having plotted the position, after applying the correction for fixed errors, the variable error of 0.13 nautical mile has to be allowed for. This is achieved by drawing two parallel lines at a distance of 0.13 nautical mile on either side of the two LOPs as shown in figure 10.

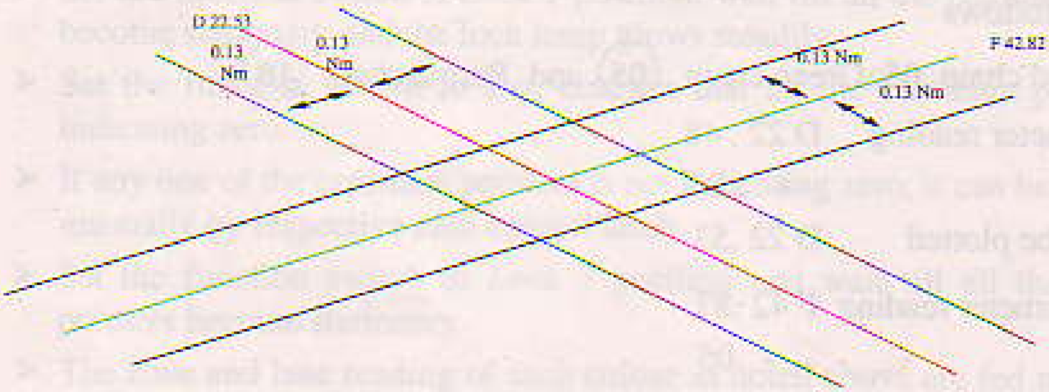


Figure 10
Variable errors allowed for as diamond of errors

The resultant area is diamond shaped and there is 68 % probability that the ship is within this diamond i.e. there are 32 % chances that the ship is outside this diamond. This is also referred to as **diamond of errors**. For the same area in daytime i.e. at say 1000 hrs, the *full day light coverage and accuracy* diagram (refer data sheet 5) shows an error of 50 meters only and this can be neglected.

POSITION FIXING

The readings obtained from the decometers are the Lines of Position, referred to as LOPs and to fix the position of the ship minimum two LOPs are required. On the basis of the angle of cut, the two most suitable LOPs are chosen for position fixing, which can be obtained from Decca data sheet 1 or if the lattice of only two colours are printed on the chart then the decometer reading of only those two colours are taken e.g. the reading of the decometers are red F3.30, green J 44.37 and purple C 57.40. The lattice printed on the chart is only those of green and purple, hence J 44.37 and C 57.40 readings will be taken for fixing the position. The fixed error corrections are to be applied to each of the decometers readings before plotting them on the chart. The point of intersection of these two LOPs is at point **P** on the chart as shown in figure 11 and this gives ship's position at sea.

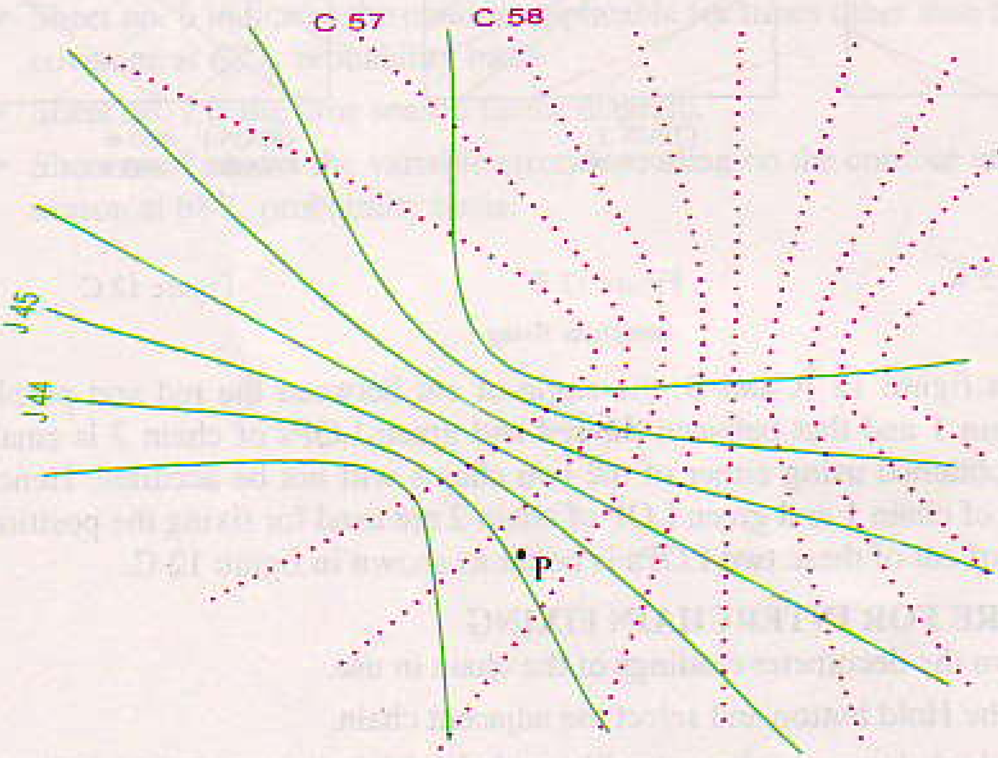


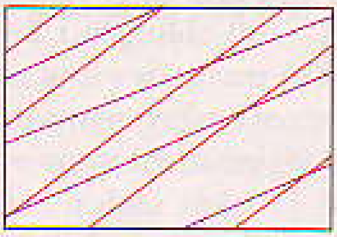
Figure 11
Position fixing using 2 colours i.e. green and purple

NOTE

The accuracy of the fix is subjected to variable error and hence it is necessary to allow for this error which can be obtained from Decca data sheets. To plot the position special Decca charts are required. Alternatively modern day receivers convert the position to latitude and longitude and in such cases no special Decca charts are required and the correction for fixed errors are fed into the receivers, but variable errors have to be considered

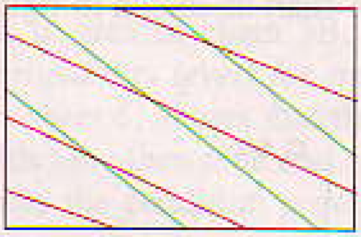
INTERCHAIN FIXING

In the fringe area of Decca coverage of a particular chain, the angle of cut between the two LOPs will be small and the fix obtained will not be accurate. In order to improve the accuracy of the fix, interchain fixing is adopted where the LOP of one chain and that of the adjoining chain are used for fixing the position. This will give a better angle of cut between the two LOPs. This technique can be used only when the LI circuit is operational in Decca receiver. In addition to the normal Decca charts separate interchain fixing charts are also available.



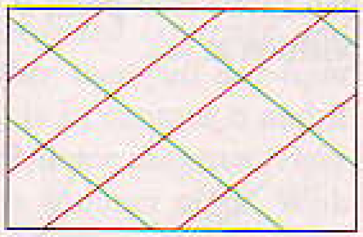
CHAIN 1
RED & PURPLLE

Figure 12 A



CHAIN 2
RED & GREEN

Figure 12 B



CHAIN 1 RED &
CHAIN 2 GREEN

Figure 12 C

Interchain fixing

As shown in figure 12 A and B, the angle of cut between the red and purple LOPs of chain 1 and that between the red and green LOPs of chain 2 is small and the fix obtained using either of the two chains will not be accurate. Hence the red LOP of chain 1 and green LOP of chain 2 are used for fixing the position as the angle of cut of these two LOPs is better as shown in figure 12 C.

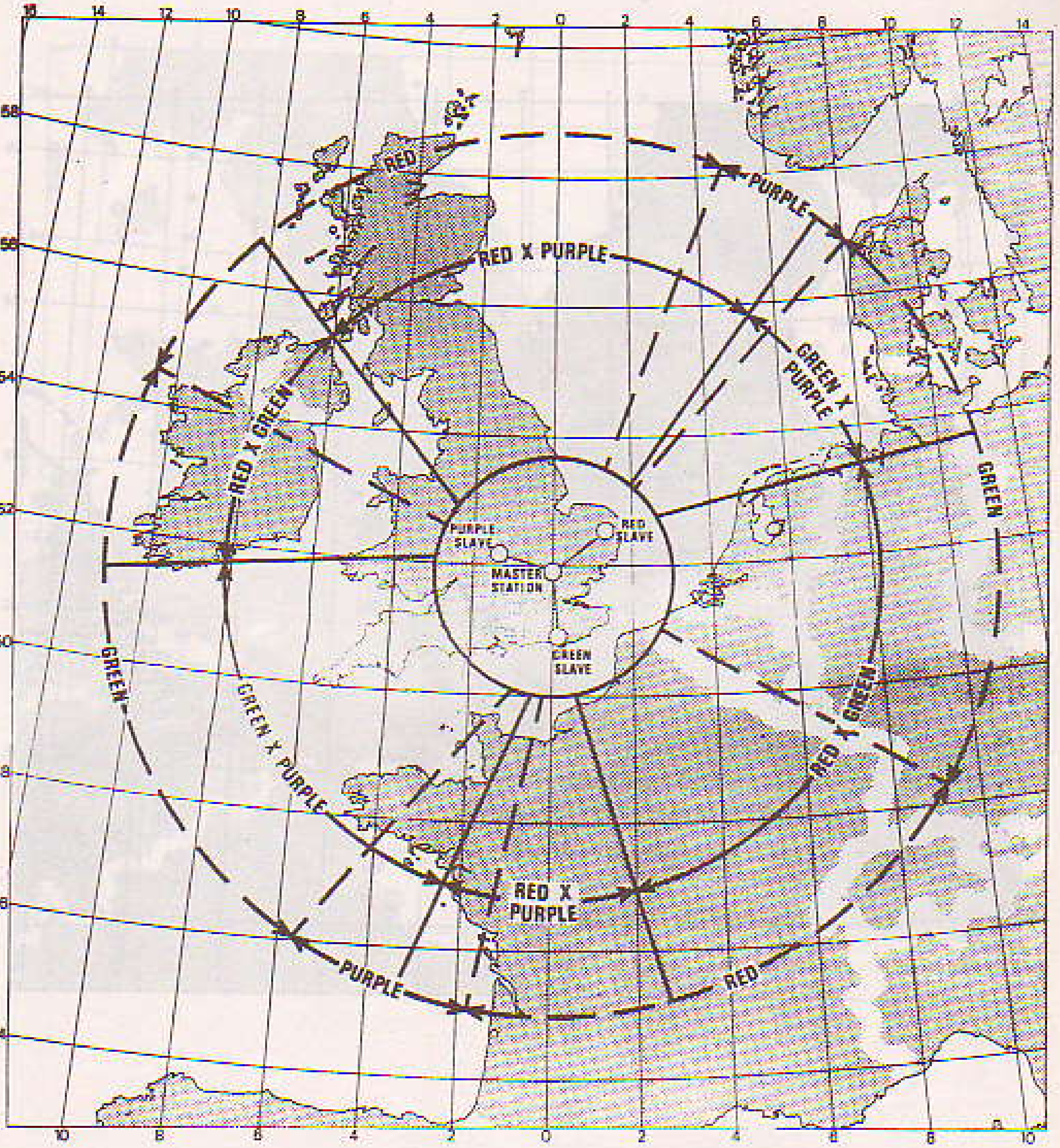
PROCEDURE FOR INTERCHAIN FIXING

- Note down the decometer readings of the chain in use.
- Depress the Hold button and select the adjacent chain.
- Wait for lock lamp to glow steadily and the LI indicator should indicate 23.8, 23.9, 00.0, 00.1 or 00.2, if not press LI zero.
- Note down the lane readings of all the three colours from the LI indicators.
- Select the original chain in use and follow procedure laid down in 3 above.
- Note down the lane reading of all the three colours for the chain in use.
- Release the hold button.
- Compare the lane reading of all the decometers with the lane reading shown by LI indicator
- The lane readings shown by the decometers and LI indicator should be same, otherwise set the respective decometer reading with reset knob.

DATA SHEETS

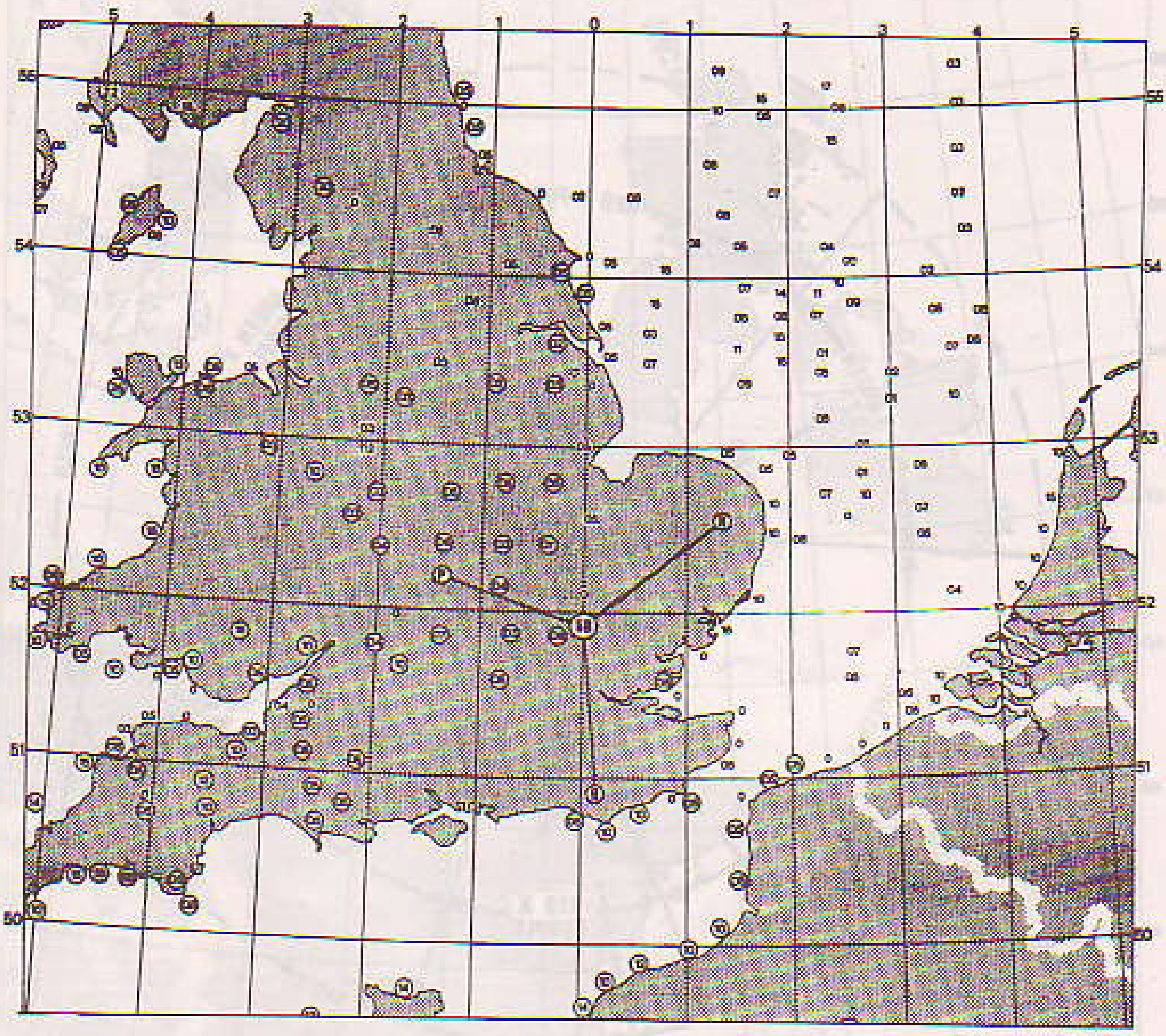
Attached are data sheets for chain 5B English Chain

- Sheet no. 1 has three circles. In the inner circle, choice of colours for best angle of cut and hence positions fix is obvious. Between the inner and the middle circle, the colour pairs for the best position fix are given in sectors, while between the middle and outer circle, only single colour giving the best position line are indicated and this colour may be used for interchain fixing.
- Sheet no.2, 3 and 4 gives the correction in centilanes to fixed errors in this chain coverage for red, green and purple colours respectively. Figures encircled to be subtracted and not encircled to be added to the LOP readings before plotting them.
- Sheet no. 5 gives the variable error for full day light coverage at 68°/₀ probability basis.
- Sheet no. 6 indicates the contour applicable for times other than full day light coverage at 68°/₀ probability basis.
- Sheet no. 7 is the time season factor diagram.
- Sheet no. 8 shows the variable error depending on the contour and prevailing season at 68°/₀ probability basis.



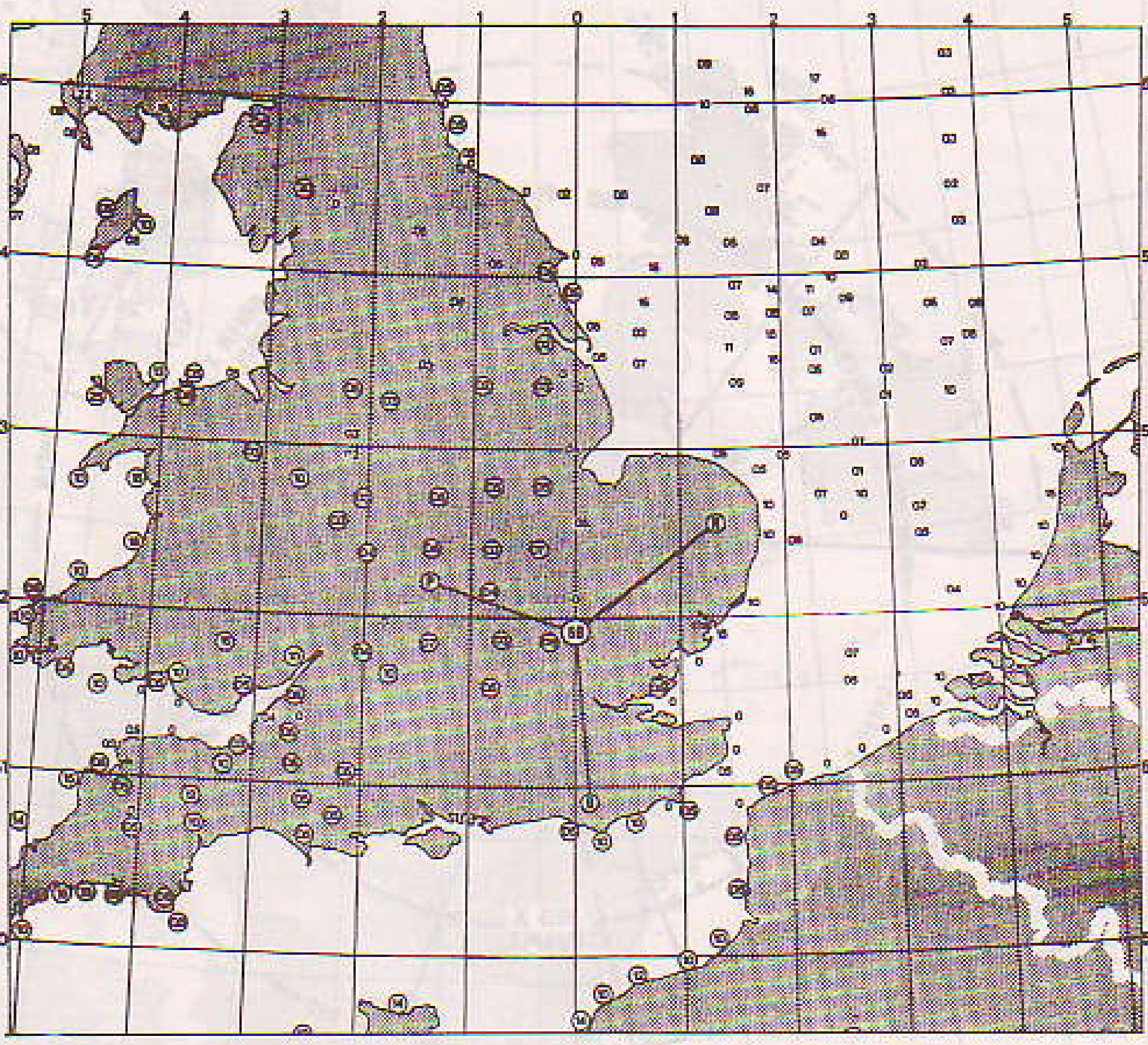
DATA SHEET No 1

Chart showing Decca lattice colours to be used for obtaining a good angle of cut in Decca coverage area of chain - 5B



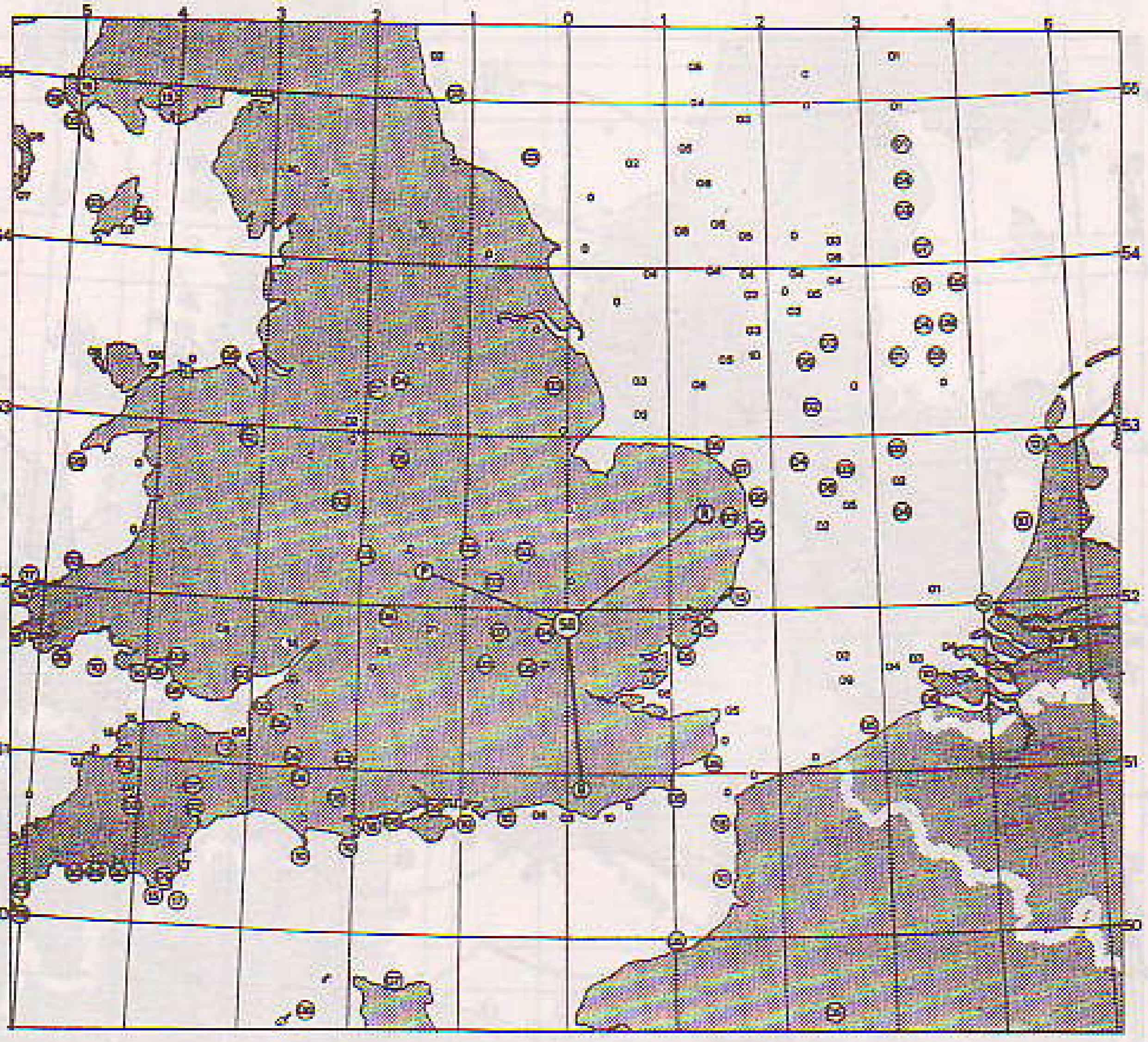
DATA SHEET No 2

Chart showing the fixed error corrections for Red LOPs – chain 5B



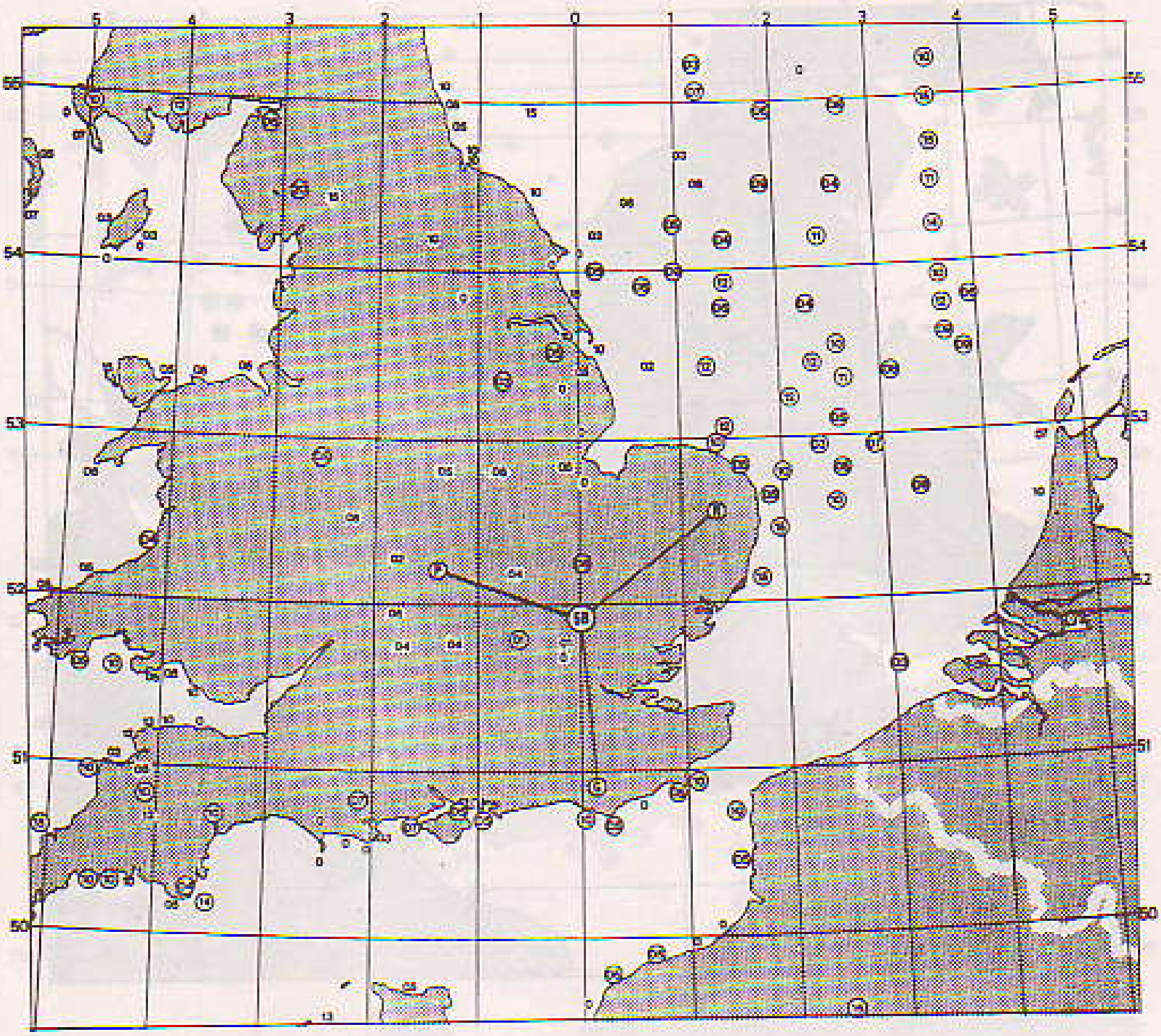
DATA SHEET No 2

Chart showimg the fixed error corrections for Red LOPs – chain 5B



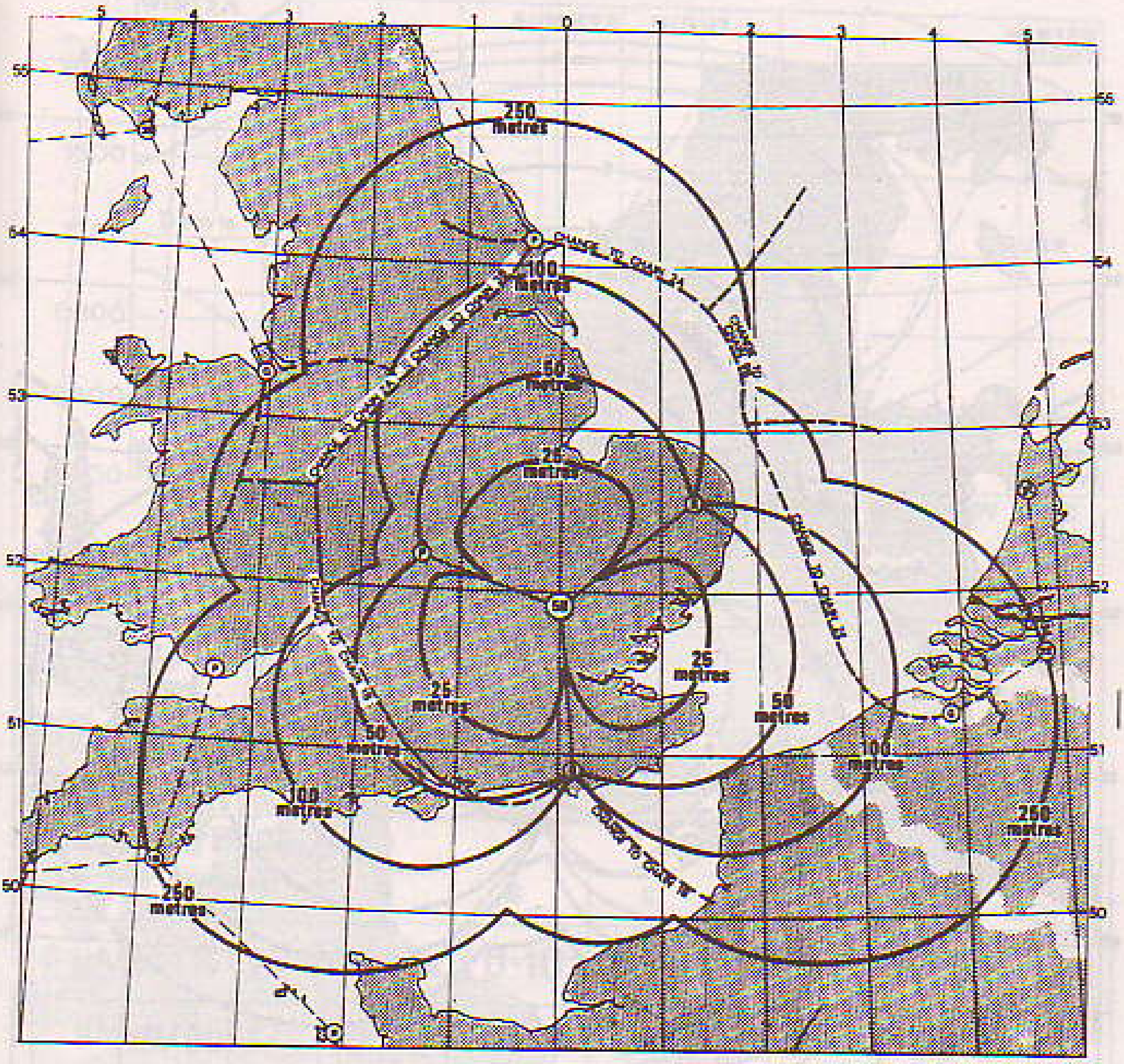
DATA SHEET No 3

Chart showing the fixed error corrections for Green LOPs – chain 5B



DATA SHEET No 4

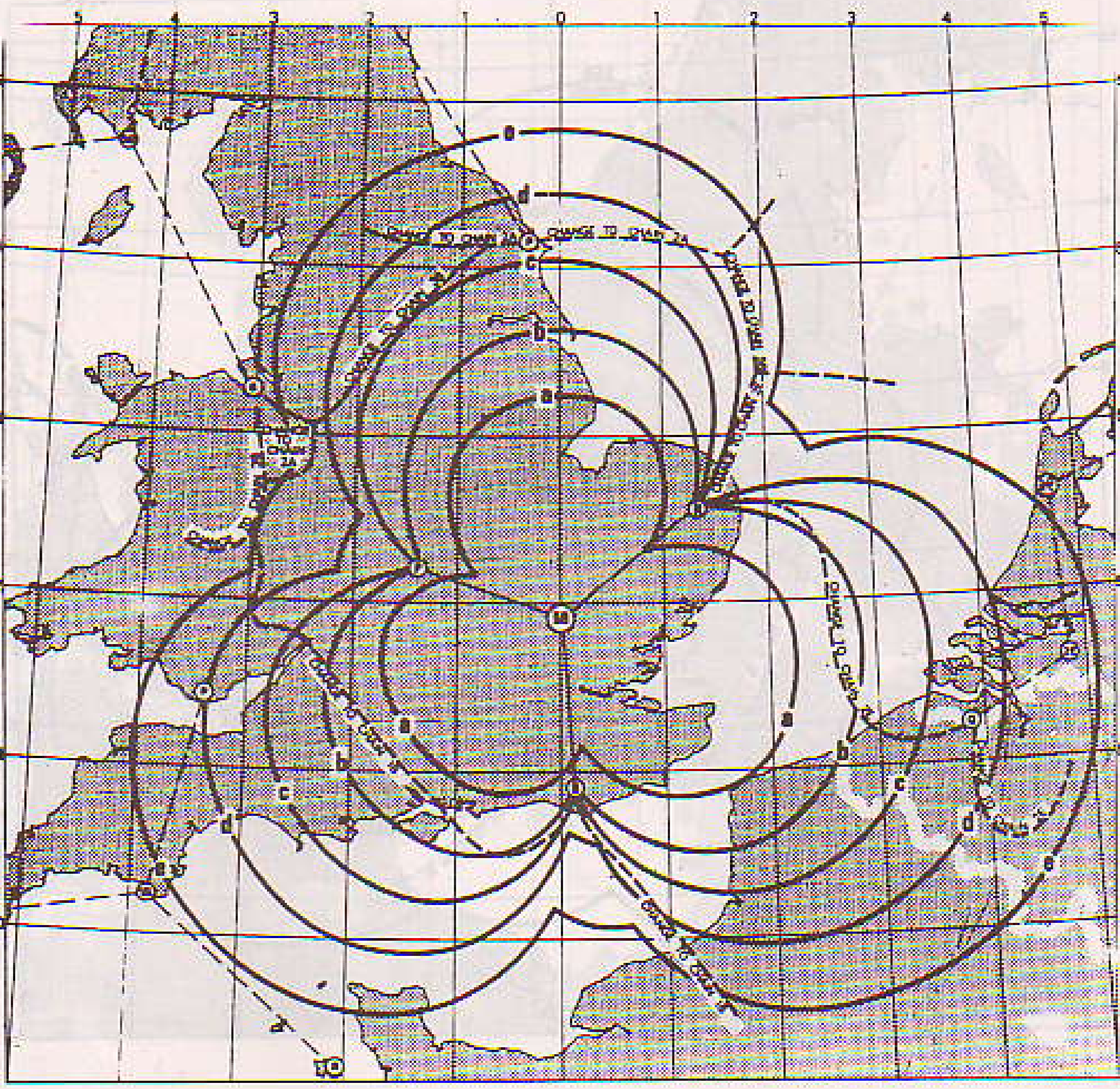
Chart showimg the fixed error corrections for Purple LOPs – chain 5B



DATA SHEET No 5

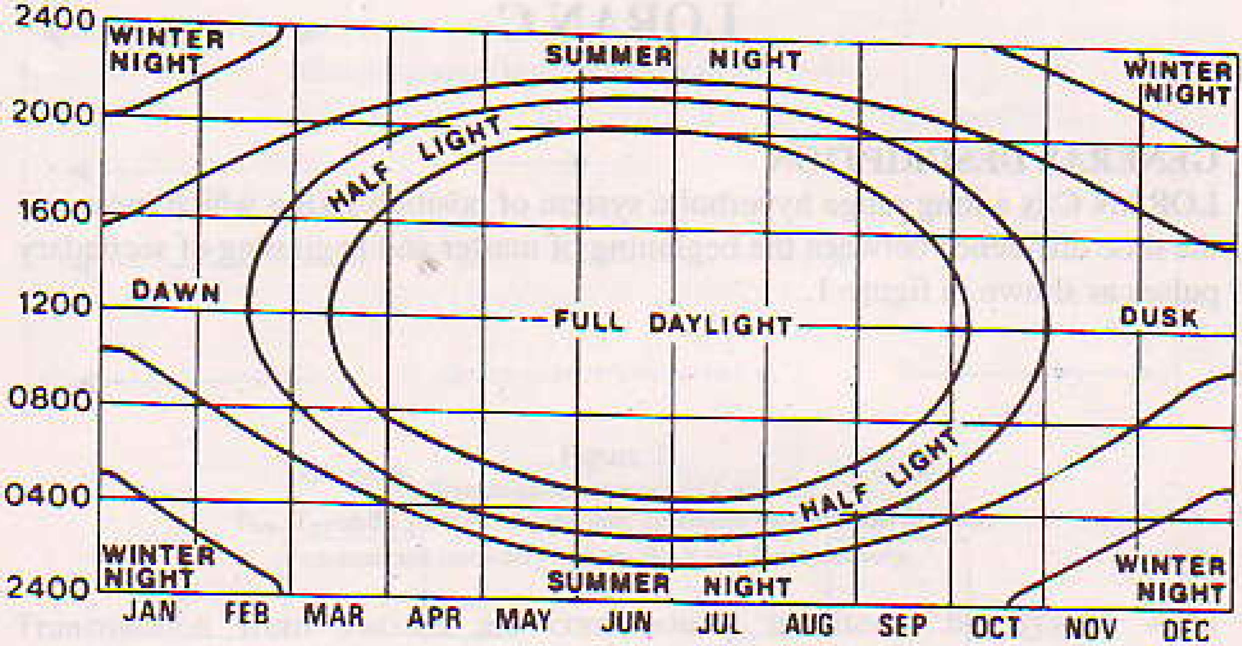
Chart showing predicted coverage & Accuracy based on 68% probability during full day light time – chain 5B

The bold full line enclose areas within which the fix – repeatability error dose not exceed the figures shown on 68% of occasions



DATA SHEET No 6

Chart showing predicted coverage & Accuracy based on 68% probability during times other then full day light time– chain 5B



DATA SHEET No 7

TIME AND SEASON FACTOR DIAGRAM CHAIN - 5B

DECCA PERIOD See Time and Season Factor Diagram below	CONTOUR				
	a	b	c	d	e
HALF LIGHT	<0·10	<0·10	<0·10	0·13	0·25
DAWN/DUSK	<0·10	<0·10	0·13	0·25	0·50
SUMMER NIGHT	<0·10	0·13	0·25	0·50	1·00
WINTER NIGHT	0·10	0·18	0·37	0·75	1·50

DATA SHEET No 8

RANDOM FIXING ERRORS AT SEA LEVEL IN NAUTICAL MILES 68% PROBABILITY LEVEL – CHAIN – 5B

CHAPTER III

LORAN C

GENERAL DESCRIPTION

LORAN C is a long range hyperbolic system of position fixing which measures the time difference between the beginning of master and beginning of secondary pulses as shown in figure 1.

Figure 1
Time difference measurement between master and secondary pulse

This system comprises of chains and each chain comprises of one master (M) and usually two to four secondary stations called W, X, Y and Z. Each station transmits a group of eight pulses on a carrier frequency of 100 kHz at a specified group repetition interval (GRI) as shown in figure 2. The duration of each pulse is of 250 µs and the interval between two consecutive pulses is 1000 µs. The master station always transmits nine pulses, so that the receiver can easily distinguish between the master and secondary pulse. The interval between eighth and ninth pulse is 2000 µs.

The secondary stations always transmit in sequence after the transmission from the master with pre-determined delay so that they are received in the same sequence throughout the coverage area. All the secondary stations maintain precise time delay with respect to master station, which is achieved by atomic clocks.

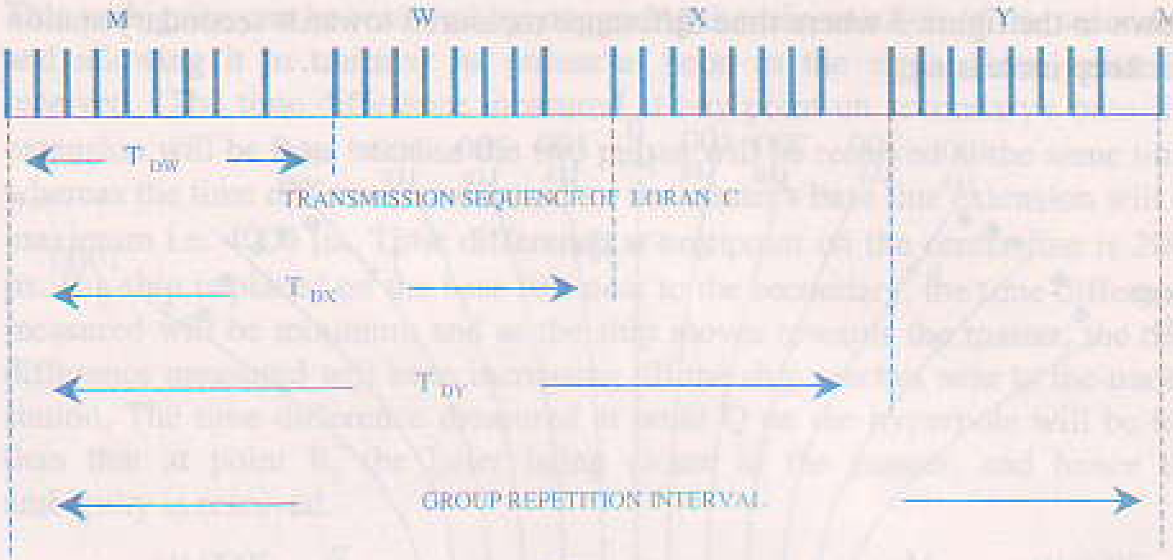


Figure 2
Transmission sequence of Loran C
T_{DW}, T_{DX} and T_{DY}, represent the time difference measurement between master and secondary stations W, X and Y respectively.

Transmission from stations are continuously monitored by System Area Monitor (SAM) and any malfunction in the chain is indicated by the secondary blink i.e. the first two pulses of the affected secondary station are switched on and off according to specified code. The secondary stations do not blink when the master station is malfunctioning. The ground wave coverage is ranging from 800 to 1200 nautical miles depending upon transmitter power and attenuation over the signal path.

PRINCIPLE

In figure 3, assuming that the master station and secondary station W are placed 324 nautical mile apart (corresponding to 2000 µs approximately) and these stations are transmitting their pulses simultaneously. These pulses will be received at the same time by the receiver on board at P on the center line as the distance from P to these two stations will be same hence the time difference measured is 0 µs. The time difference measured on either side of the base line extensions will be maximum i.e. 2000 µs because the signal from either of the stations will take 2000 µs to travel to the other station. As the ship moves toward the secondary station W from point P, the distance from master to ship increases while that to secondary decreases hence the pulses will not be received simultaneously, resulting in a time difference measured between the arrival of master and secondary pulses. This time difference measured will keep increasing as the ship is moving towards the secondary. Assuming the time difference measured at point Q is 100 µs then a hyperbola can be drawn on the base line where at any point on this hyperbola the time difference measured is 100 µs. Similarly a number of hyperbolae can be drawn on the base line as shown in the figure 3 where time difference measured towards secondary station will keep increasing.

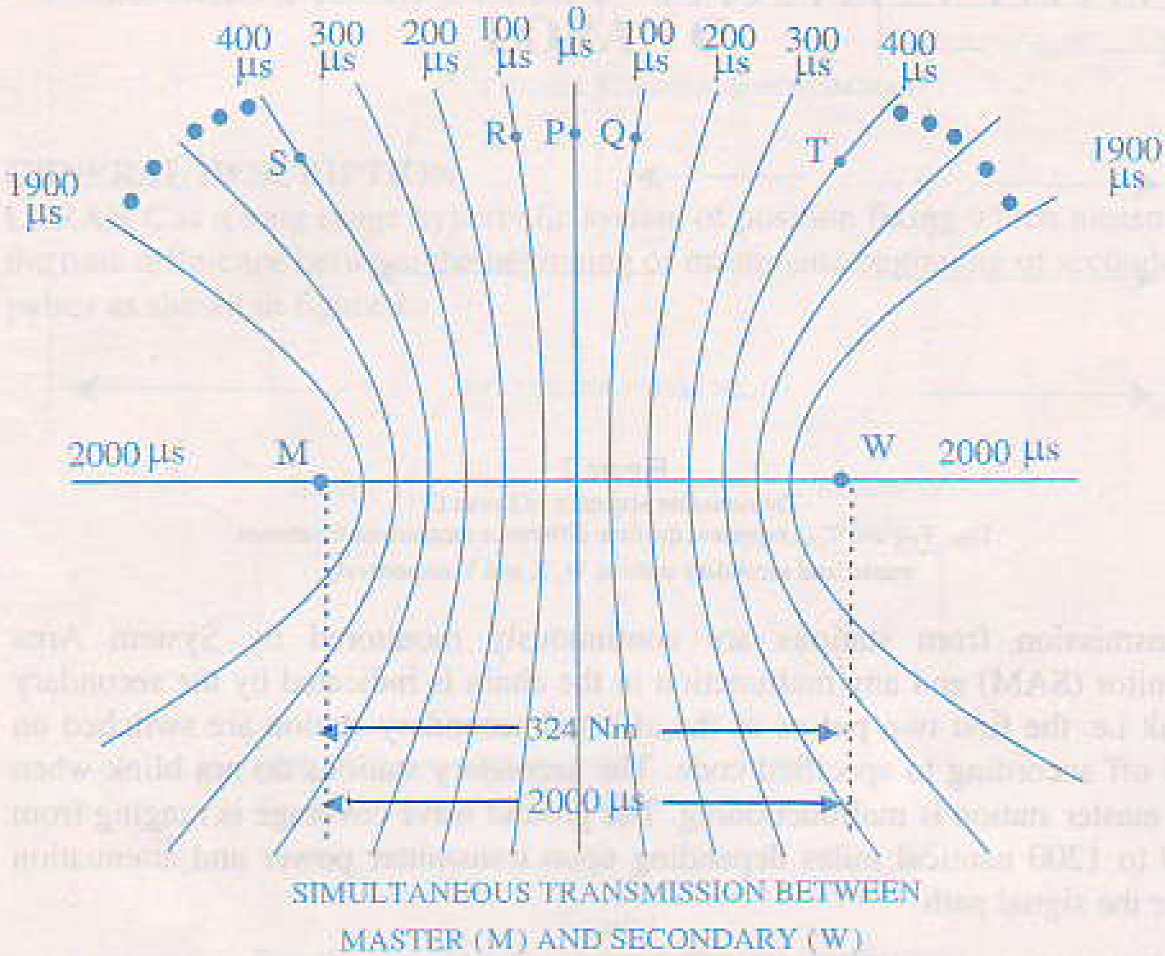


Figure 3

Simultaneous transmission

Note: The velocity or radio waves = 300 x 10^6 meters/sec

= 300 meters/ µ sec

In 2,000 µ secs, the radio wave travels 2,000 x 300 = 6,00,000 meters.

= 324 nautical mile.

Consider the ship on the centre line and moving towards the master, in this case also the time difference measured between reception of master and secondary signals will keep on increasing. When the time difference measured reaches 100 µs, another hyperbola R can be drawn where again at any point on this hyperbola the time difference measured is 100 µs. Similarly a number of hyperbolae can be drawn with increasing time difference towards master. Suppose a time difference of 400 µs is calculated by the receiver, the ship could be on the lattice S or T and the position of the ship could be easily determined as these two lattices are far apart as shown in figure 3. However, if the time difference measured is small i.e. less than 100 µs, the ship could be between lattice Q and R i.e. close to and on either side of the centre line causing an ambiguity.

This ambiguity can be resolved by staggering the transmission of the secondary and allowing it to transmit its pulses as soon as the signal from master is received. The time difference measured at any point on secondary's base line extension will be 0 μs because the two pulses will be received at the same time, whereas the time difference measured on the master's base line extension will be maximum i.e. 4000 μs. Time difference at any point on the center line is 2000 μs. If a ship is placed on the base line near to the secondary, the time difference measured will be minimum and as the ship moves towards the master, the time difference measured will keep increasing till the ship reaches near to the master station. The time difference measured at point Q on the hyperbola will be less than that at point R, the latter being closer to the master, and hence the ambiguity is resolved.

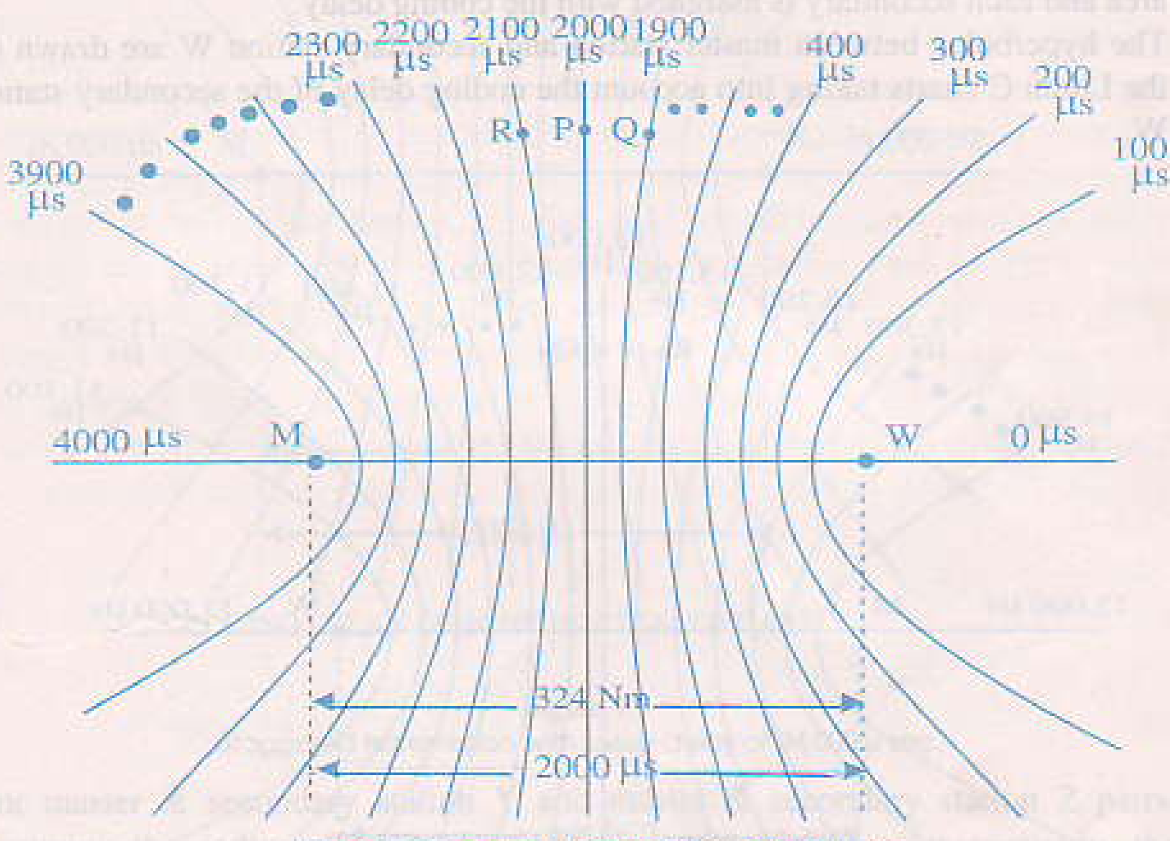


Figure 4
Staggered transmission

However with this arrangement, another difficulty arises near to the secondary station i.e. the time difference upto one pulse length can not be measured because before the pulses from the master is completely received, the pulses from secondary will start arriving at the receiver at point A as shown in figure 5.

The pulses from these two stations will overlap and it becomes very difficult to separate them in order to measure the time difference.

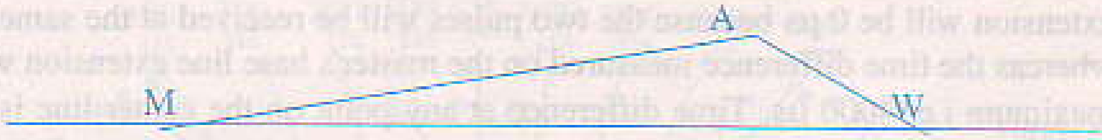


Figure 5
Signals of master and secondary stations overlap at A

This difficulty is overcome by delaying the transmission of the secondary for a short period after it receives the signals of the master. This delay in transmission from the secondary is known as **Coding Delay**. The coding delay ensures that the pulses from the master will always be received first throughout the coverage area and each secondary is assigned with the coding delay.

The hyperbolae between master station and secondary station W are drawn on the Loran C charts taking into account the coding delay of the secondary station W.

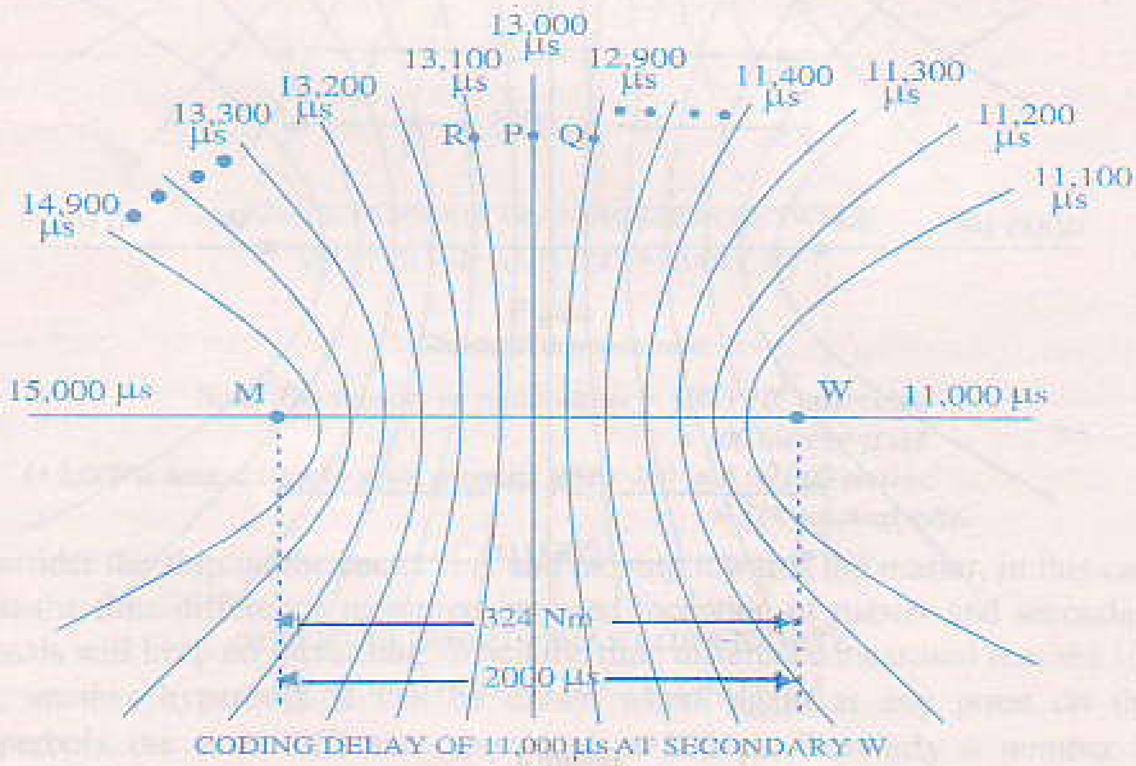


Figure 6
Staggered transmission with coding delay of 11,000 µ sec.

Similarly hyperbolae are also drawn on the Loran C charts between master and other secondary stations with the respective coding delay incorporated.

Assuming the coding delay of the secondary stations W and X for a given chain to be 11,000 µs and 24,000 µs respectively then the hyperbolae printed on the Loran C charts will be as shown in figure 6 and 7

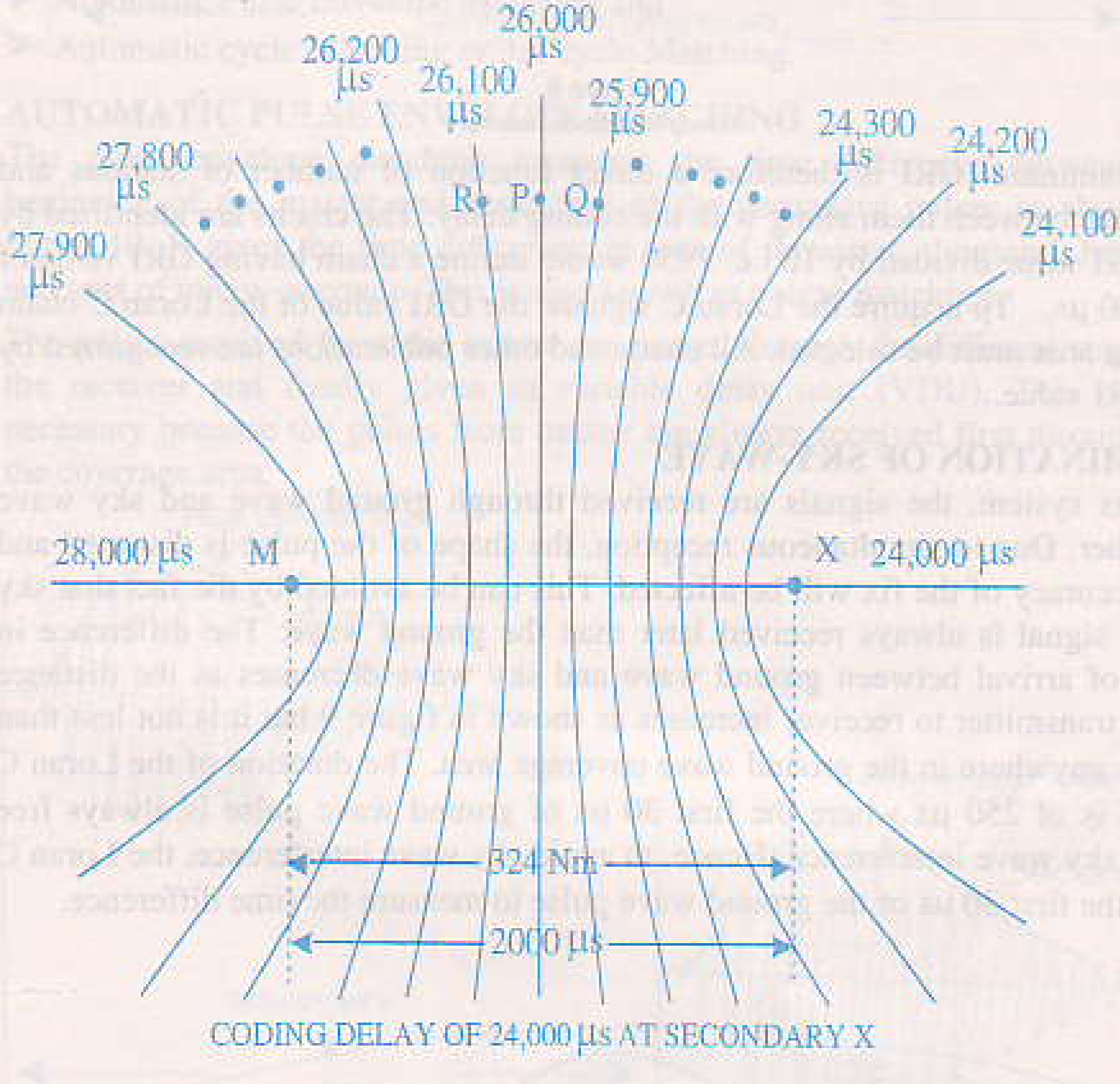


Figure 7
Staggered transmission with coding delay of 24,000 µ sec

For master & secondary station Y and master & secondary station Z pairs, assuming the coding delay to be 35,000 µs and 47,000 µs respectively, the student may himself draw the hyperbolae.

GROUP REPETITION INTERVAL (GRI)

In this system, each station transmits a group of 8 pulses on a carrier frequency of 100 kHz and to prevent the interference between the chains, each station transmits their pulses at a specified interval as shown in figure 8. The group repetition interval is the total time between the beginning of master pulse of one sequence and the beginning of the master pulse of the next sequence. Each chain has a different GRI value and should have sufficient time to contain the master and secondary pulses.

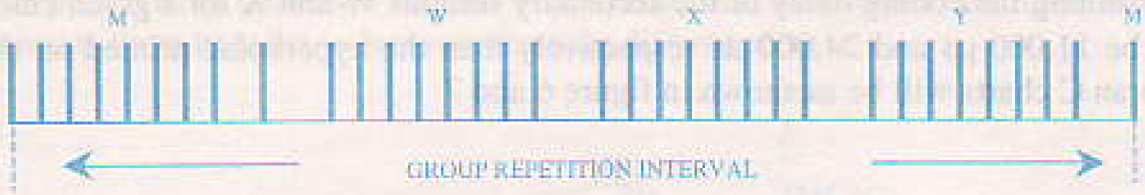


Figure 8
Group Repetition Interval

The minimum GRI is therefore a direct function of number of stations and distance between them along with the coding delay. The chains are identified by its GRI value divided by 10 i.e. 7950 would define a chain having GRI value of 79,500 μs. To acquire the Loran C signals, the GRI value of the Loran C chain of that area must be selected. All charts and other publications are recognized by its GRI value.

ELIMINATION OF SKY-WAVE

In this system, the signals are received through ground wave and sky wave together. Due to simultaneous reception, the shape of the pulse is distorted and the accuracy of the fix will be affected. This can be avoided by the fact that sky wave signal is always received later than the ground wave. The difference in time of arrival between ground wave and sky wave decreases as the distance from transmitter to receiver increases as shown in figure 9 but it is not less than 30 μs anywhere in the ground wave coverage area. The duration of the Loran C pulse is of 250 μs where the first 30 μs of ground wave pulse is always free from sky wave interference. Hence, to avoid sky wave interference, the Loran C uses the first 30 μs of the ground wave pulse to measure the time difference.

Figure 9
Difference in time of arrival between ground wave and sky wave is more at A than at B

TIME DIFFERENCE MEASUREMENT

The time difference measurement is carried out by the following methods

- Automatic Pulse Envelope Matching and
- Automatic cycle Matching or 3rd cycle Matching.

AUTOMATIC PULSE ENVELOPE MATCHING

The pulse envelope matching measures the time difference between the beginning of the master and beginning of the secondary pulses as shown in figure 10. It gives the time difference in tens of thousand, thousand, hundred and tens of micro- seconds. This is also known as coarse matching.

The pulses received from the master are passed through the different stages of the receiver and finally given to variable delay unit (VDU). This unit is necessary because the pulses from master are always received first through out the coverage area.

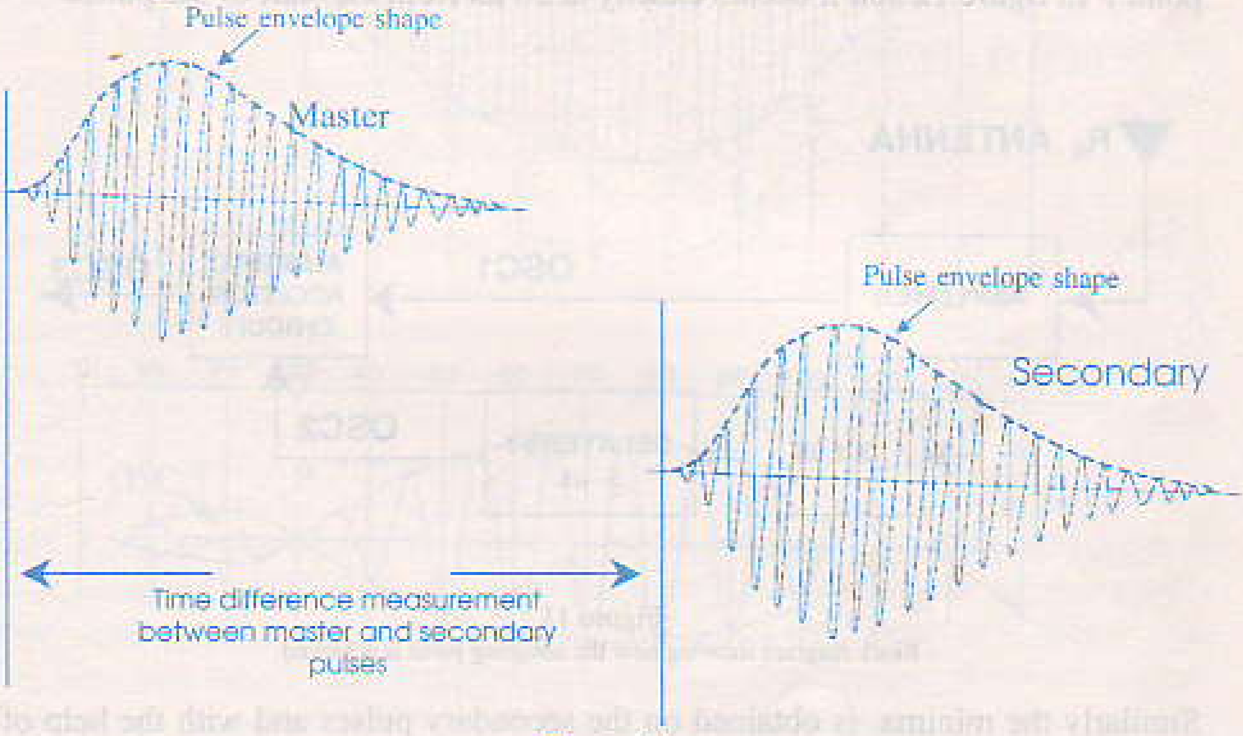


Figure 10
Time difference is measured between the beginning of each master pulse and beginning of each secondary pulse respectively

When the pulses from the secondary stations are received, the beginning of the delayed master pulses are made to coincide with the beginning of the incoming secondary pulses using a fly-wheel oscillator circuit and the time difference is measured automatically. This time difference measured is indicated in a digital read out along with the fine time difference measured by automatic cycle matching.

AUTOMATIC CYCLE MATCHING OR 3rd CYCLE MATCHING

There are different methods by which cycle matching can be achieved. It gives the time difference in unit and tenth of unit and is termed as fine matching.

In one of the method, the receiver selects a reference point on the master and secondary pulses, which is usually 30 µs after the start of the pulse or 3rd cycle of the 100 kHz carrier frequency. This point is chosen because the amplitude of the 1st cycle is weak and although the amplitude of 7th cycle is maximum, but there is a possibility of sky wave interference in the latter. The 3rd cycle has reasonable amplitude and is always free from sky wave interference.

The received pulses from the master is amplified which is shown as osc1 in the figure11 and 12. These pulses are further amplified 1.35 times and delayed by 5 µs which is shown as osc2. These two are algebraically added and osc3 is obtained, which has well-defined minima. This minima is used as sampling point P in figure 12 and it occurs exactly at 30 µs from the start of the pulse.

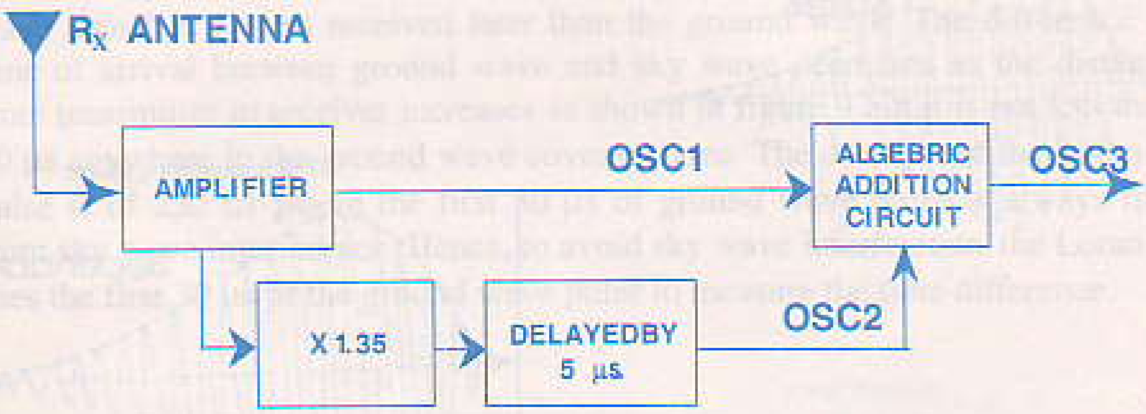


Figure 11
Block diagram showing how the sampling point is achieved

Similarly the minima is obtained on the secondary pulses and with the help of fly wheel oscillator circuit the time difference measurement is carried out between the minima of the master and that of the secondary.

This time difference along with the time difference measured by the automatic pulse envelop matching will give total time difference between the master and secondary pulses.

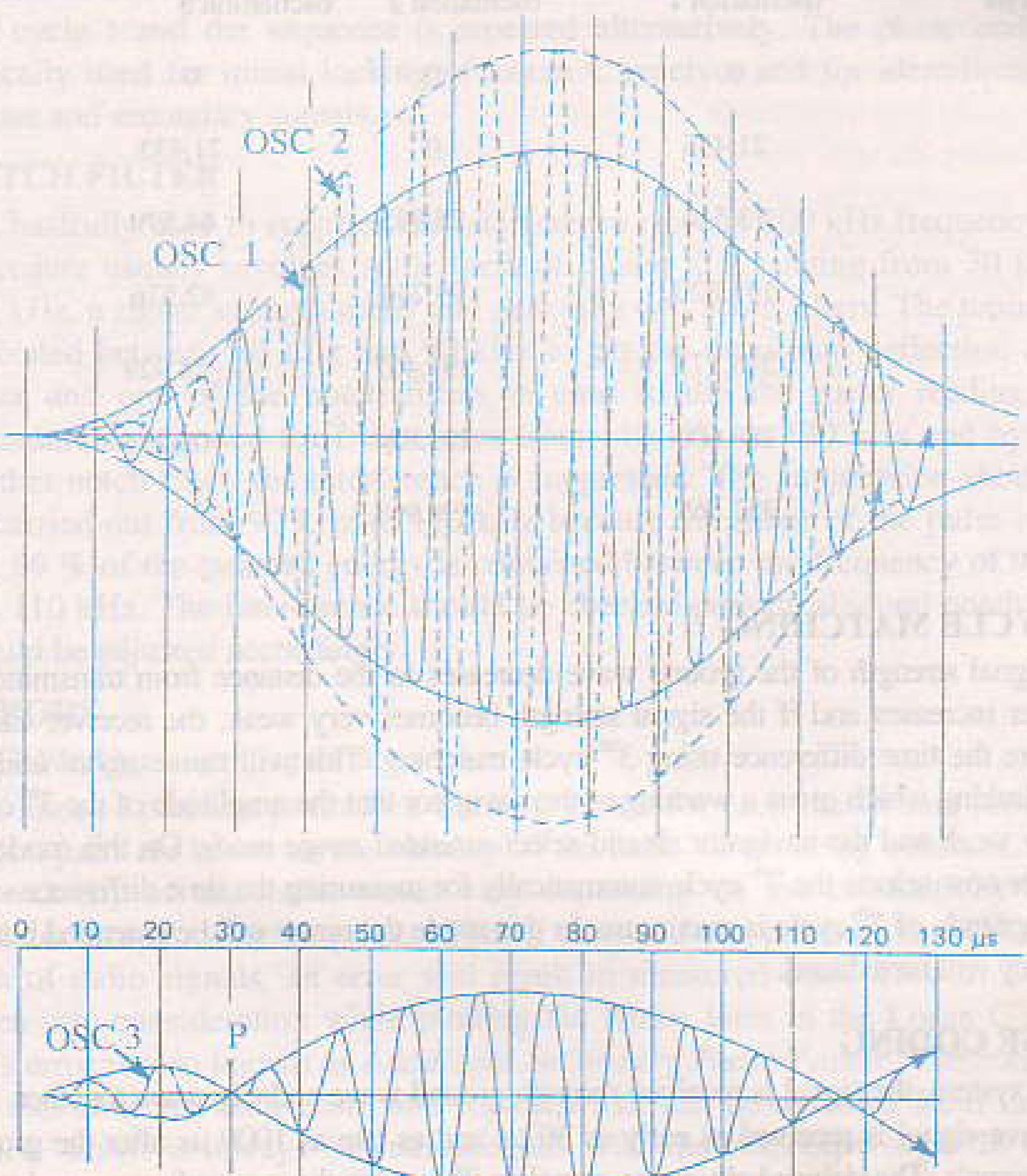


Figure 12

The amplified pulse is shown as osc 1. This is multiplied by 1.35 and delayed by 5 µ secs gives osc 2. Algebric sum of osc 1 and osc 2 gives osc 3 which has a well defined minima (P) at 30 µ secs.

NOTE

To obtain the sampling point at exactly 30 µs the amplitude of oscillation 1 which is given by the formula $t^2 e^{-2t/65}$ is multiplied by 1.35 and delayed by 5 µs to get oscillation 2. These two are algebraically added and oscillation 3 is obtained. This is shown in table below at intervals of 5µs. We can see that the amplitude of oscillation 3 is initially increasing and then starts decreasing and if the other parameters are fed to the equation , the sampling point is obtained exactly at 30 µ s.

Table indicating amplitude of oscillation at interval of 5μ s

time in μs	oscillation 1	oscillation 2	oscillation 3
0	0	0	0
5	21.435	0	21.435
10	73.514	28.935	44.579
15	141.820	99.244	42.576
20	216.173	191.457	24.929
25	289.606	291.834	02.234
30	357.565	390.968	-

7th CYCLE MATCHING

The signal strength of the ground wave decreases as the distance from transmitter to receiver increases and if the signal strength becomes very weak, the receiver cannot measure the time difference using 3rd cycle matching. This will cause *signal lamp to* start blinking which gives a warning to the navigator that the amplitude of the 3rd cycle is very weak and the navigator should select *extended range mode*. On this mode the receiver now selects the 7th cycle automatically for measuring the time difference since the amplitude of 7th cycle is maximum. In this mode the range will be extended but the accuracy will be reduced.

PHASE CODING

In this system, the signal is received through ground wave and sky wave together. The sky wave signal is received as early as 30 μs and as late as 1000 μs after the ground wave signals. The delayed sky wave signals will overlap the succeeding ground wave signal, which will cause distortion in the received signal and the accuracy will be affected. Hence the phase of the each pulse of the 100 kHz is changed with a pre-determined sign as shown in the following table.

	Master	Secondary W	Secondary X	Secondary Y
Cycle 1	+--+++++ -	+-+-++--	+-+-++--	+-+-++--
Cycle 2	++--+-+- +	++++++--+	++++++--+	++++++--+

The negative sign in the table stands for a pulse, which is 180° out of phase with normal pulse. The master station has a different code from the secondary stations and all the secondary stations have the same code. These codes are same in all the chains through out the world. The transmission sequence consists of cycle 1 and cycle 2 and the sequence is repeated alternatively. The phase coding is basically used for initial locking of Loran C receiver and for identification of master and secondary signals.

NOTCH FILTER

It is basically used to suppress the interference close to 100 kHz frequency. The procedure usually involves some form of tuning dial ranging from 70 kHz to 130 kHz, a signal strength meter and generally two notch filters. The tuning dial is rotated between 70 kHz and 90 kHz to get the maximum deflection on the meter and one of the notch filters is used to dip the meter reading. This procedure is repeated for frequencies from 110 kHz to 130 kHz and by using another notch filter, the interference is suppressed. The suppression should not be carried out from 90 kHz to 110 kHz because the shape of the pulse is such that 99 % of the radiated energy is contained between the frequency of 90 kHz and 110 kHz. The interference should be checked periodically and notch filters should be adjusted accordingly.

ERRORS

➢ Ground wave propagation error

The lines of position printed on Loran C charts for each master and secondary station pairs are based on the velocity of the radio waves being constant. In fact the velocity of the radio waves vary depending on the conductivity of the medium through which it passes. Thus if an island or a patch of land falls in the path of radio signals, an error will result in measured time. This error is not taken into consideration while plotting the lattice lines in the Loran C charts. This error is also known as *Additional Secondary Phase Factor*. The correction for this error for each chain and for each pair can be obtained from Loran C tables, which is always in microseconds with the respective sign. In certain areas the ASF corrections are already incorporated while plotting the lattice and in such areas no separate ASF correction is required. This will be indicated on the charts when included. If this correction is not incorporated, it has to be calculated algebrically to the reading obtained from the receiver before plotting the LOPs.

For example at 1400 hrs, in DR Latitude 48° 24′ N and Longitude 056° 23′ E, the Loran C reading and correction from ASF tables is as follows

7930 –X	T_G 16468.5 µs	7930 –Z	T_G	56236.8 µs
correction	- 16.6 µs			+ 12.4 µs
corrected LOPs	16451.9 µs			56249.2 µs

The corrected LOPs has to be plotted on the chart is as above.

➢ Sky wave error

Sky wave corrections are necessary when the signals of master and secondary are both received through sky waves or one of them is through sky wave while the other through ground wave. These corrections are also available in Loran C tables and there are separate corrections for the two. When both signals are through sky wave the correction is marked Ts. If the signals from master are through sky wave while that secondary is through ground wave, the correction will be printed as T_{SG} and will be positive, while if the signal from master is through ground wave and that of secondary through sky wave, the correction being printed as T_{GS} and will be negative. These corrections are necessary because the LOPs printed on the charts are based on ground wave propagation velocity being constant.

For example at 2200 in DR Latitude 46° 45′ N Longitude 056° 15′ W the Loran C reading obtained is as follows

7930 –X T_S 28468.60 7930 –Z T_{SG} 56284.40

The sky wave reading must be corrected to the equivalent ground wave reading and these corrections are taken from the attached Loran C tables –

7930 –X	T_S 28468.60 µs	7930 –Z	T_{SG} 56284.40 µs
correction	+ 3.05 µs		+ 57.00 µs
corrected LOPs	28471.65 µs		56341.40 µs

The corrected LOPs to be plotted is as above.

➢ Lattice error

In the outer fringe of the Loran C coverage the angle of cut between the two LOPs of the same chain is small and the fix obtained will not be accurate. This error is common to all the hyperbolic position fixing system. Unlike the Decca system, there is no method of interchain fixing.

➢ Synchronization error

The secondary stations are perfectly time synchronized with master station so that they have a precise time interval between them which is achieved by providing atomic clock to each station. Any discrepancy in this will cause an error and if it exceeds ± 0.2 µs, it is indicated by the secondary blink.

➢ Envelope to cycle discrepancy

In order to measure the accurate time difference, the shape of the pulse should not be distorted. When passing through different media, there is a possibility that the shape of the pulse may get distorted and thereby the accuracy is affected.

➢ Receiver error

Under severe noise conditions if the receiver selects a wrong cycle, instead of the 3rd cycle the time difference measurement will be in error.

POSITION FIXING

The measured time difference between master and secondary stations is indicated on a digital read out and is referred to as line of position (LOPs). To fix the position of the ship minimum two LOPs are required and this is obtained by using same master but another secondary station. This reading will also be displayed on the digital read out. On the basis of angle of cut, the most suitable LOPs are chosen for fixing the position. Before plotting the LOPs, the required correction obtained from Loran C table must be applied. The corrected LOPs for chain 7930 are as follow

7930-X 28471.65 µs 7930-Z 56341.40 µs

7930-X, 28471.65 µs and 7930-Z, 56341.40 µs indicate the time difference measured between master & secondary stations X and master & secondary stations Z respectively for chain 7930.

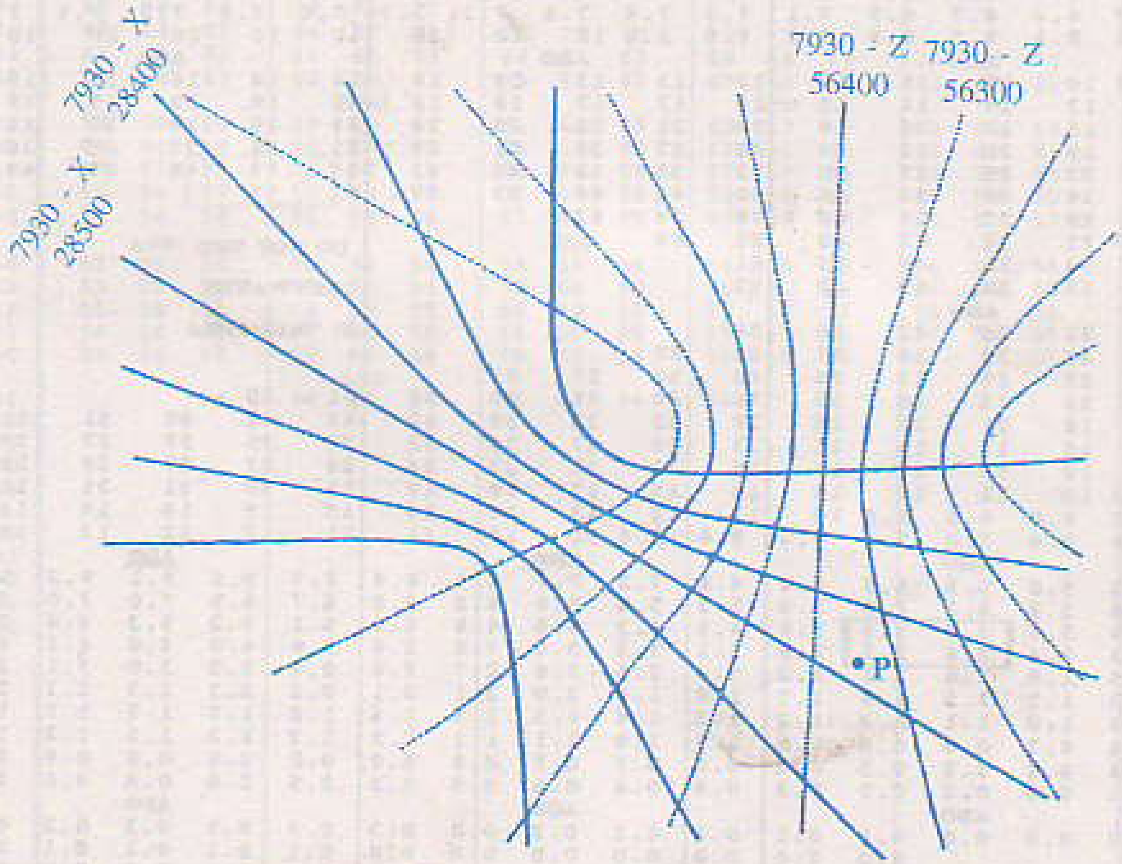


Figure 13
Position of the ship plotted with Loran-C readings obtained from Master – Secondary X and Master- Secondary Z of chain 7930.

The point of intersection of these two LOPs i.e. 28471.65 µs and 56341.40 µs is at point **P** on the chart as shown in figure 13, which gives ship's position.

SKYWAVE CORRECTION

NIGHTTIME (h = 91 km.)

Longitude—59°W to 45°W

Latitude North	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	Latitude North
89																89
88																88
87																87
86																86
85																85
84																84
83									0.0	0.0	0.0					83
82	0.0	0.0	0.0	0.0	0.0	.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	82
81	0.2	0.2	0.2	0.2	0.3	.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	81
80	0.4	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.2	0.2	0.2	80
			ADD					ADD					ADD			
79	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.3	79
78	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.5	78
77	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.8	77
76	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.6	1.6	1.5	1.5	1.4	1.3	1.3	76
75	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.2	2.2	2.2	2.1	2.0	2.0	1.9	75
74	2.9	3.0	3.0	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.0	3.0	2.9	2.8	2.7	74
73	3.8	3.9	4.0	4.0	4.1	4.2	4.2	4.2	4.2	4.2	4.2	4.1	4.1	4.0	3.9	73
72	4.9	5.0	5.2	5.3	5.4	5.5	5.6	5.7	5.7	5.7	5.7	5.7	5.6	5.5	5.4	72
71	6.2	6.4	6.7	6.9	7.1	7.3	7.4	7.6	7.7	7.7	7.8	7.8	7.7	7.6	7.5	71
70	7.8	8.1	8.5	8.8	9.2	9.5	9.8	10	10	10	10	10	10	10	10	70
			ADD					ADD					ADD			
69	9.7	10	11	11	12	12	13	13	13	14	14	14	14	14	14	69
68	12	13	14	14	15	16	17	17	18	18	19	19	19	19	19	68
67	15	16	17	18	19	20	21	22	23	24	25	25	26	26	26	67
66	17	19	20	22	24	26	27	29	31	32	33	34	35	35	35	66
65	20	22	25	27	30	32	35	38	40	43	45	47	48	49	49	65
64	23	26	29	32	36	40	44	48	53	57	61	65				64
63	26	29	33	38	42	48	54	61								63
62	28	32	36	42	48	56	64				DO NOT USE					62
61	29	33	38	45	52	61										61
60	29	33	38	45	52	62					SKYWAVES					60
			ADD													
59	27	31	36	42	50	58					IN THIS AREA					59
58	25	29	33	38	44	52	60									58
57	22	25	29	33	38	44	50	57	65							57
56	19	22	25	28	32	36	40	45	50	56	61	65				56
55	16	18	21	23	26	29	32	35	39	42	45	48	50	51	51	55
54	13	15	17	19	21	23	25	27	30	32	34	.35	37	37	37	54
53	11	12	14	15	17	18	20	21	23	24	26	27	27	28	28	53
52	9.0	10	11	12	13	14	15	17	18	19	19	20	21	21	21	52
51	7.3	8.0	8.8	9.6	10	11	12	13	14	14	15	15	16	16	16	51
50	5.8	6.4	7.0	7.6	8.2	8.8	9.4	10	11	11	11	12	12	12	12	50
			ADD					ADD					ADD			
49	4.6	5.0	5.5	5.9	6.4	6.8	7.3	7.7	8.1	8.4	8.7	9.0	9.1	9.2	9.3	49
48	3.6	3.9	4.3	4.6	5.0	5.3	5.6	5.9	6.2	6.5	6.7	6.9	7.0	7.0	7.1	48
47	2.8	3.1	3.3	3.6	3.8	4.1	4.3	4.6	4.8	4.9	5.1	5.2	5.3	5.4	5.4	47
46	2.2	2.4	2.6	2.7	2.9	3.1	3.3	3.5	3.6	3.8	3.9	4.0	4.0	4.1	4.1	46
45	1.6	1.8	1.9	2.1	2.2	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.0	3.1	3.1	45
44	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.1	2.2	2.3	2.3	2.3	2.3	44
43	0.9	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.7	1.7	43
42	0.6	0.7	0.8	0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.3	42
41	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9	41
40	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	40
			ADD					ADD					ADD			
39	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	39
38				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	38
37											0.0	0.0	0.0	0.0	0.0	37
36																36
35																35
34																34
33																33
32																32
31																31
30																30
	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	

Longitude—59°W to 45°W

NIGHTTIME

GROUNDWAVE TO SKYWAVE CORRECTION (Tsg)

NIGHTTIME (h = 91 km.)

Tsg - SKY WAVE FROM MASTER & GROUND WAVE FROM SECONDARY

Longitude—59°W to 45°W

LATITUDE NORTH	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	LATITUDE NORTH
69																69
68																68
67																67
66																66
65																65
64																6
63																63
62																62
61																61
60																60
59																59
58																58
57																57
56																56
55																55
		ADD														
54	68	69	71	73												54
53	65	66	68	69	71	72										53
52	63	64	65	66	67	68	70	71	72	73						52
51	61	62	63	64	65	65	66	67	68	68	69	69	70	70	70	51
50	60	60	61	62	62	63	63	64	65	65	66	66	66	66	66	50
					ADD						ADD					
49	59	59	60	60	60	61	61	62	62	63	63	63	63	63	63	49
48	58	58	58	59	59	59	60	60	60	61	61	61	61	61	61	48
47	57	57	57	58	58	58	58	59	59	59	59	59	59	59	59	47
46	56	56	57	57	57	57	57	58	58	58	58	58	58	58	58	46
45	56	56	56	56	56	56	57	57	57	57	57	57	57	57	57	45
		ADD						ADD						ADD		
44	55	55	56	56	56	56	56	56	56	56	56	56	56	56	56	44
43	55	55	55	55	55	55	55	56	56	56	5.	56	56	56	56	43
42	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	42
41	54	55	55	55	55	55	55	55	55	55	55	55	55	55	55	41
40	54	54	54	54	54	54	55	55	55	55	55	55	55			40
					ADD											
39			54	54	54	54	54	54	54	54						39
38																38
37																37
36																36
35																35
34																34
33																33
32																32
31																31
30																30
	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	

Longitude—59°W to 45°W

NIGHTTIME

CHAPTER IV

GLOBAL POSITION FIXING SYSTEM

GENERAL DESCRIPTION

It is a satellite based navigation system consisting of 24 orbiting satellites in 6 different orbit paths. This system is more accurate than any other existing system with worldwide coverage in all weather conditions.

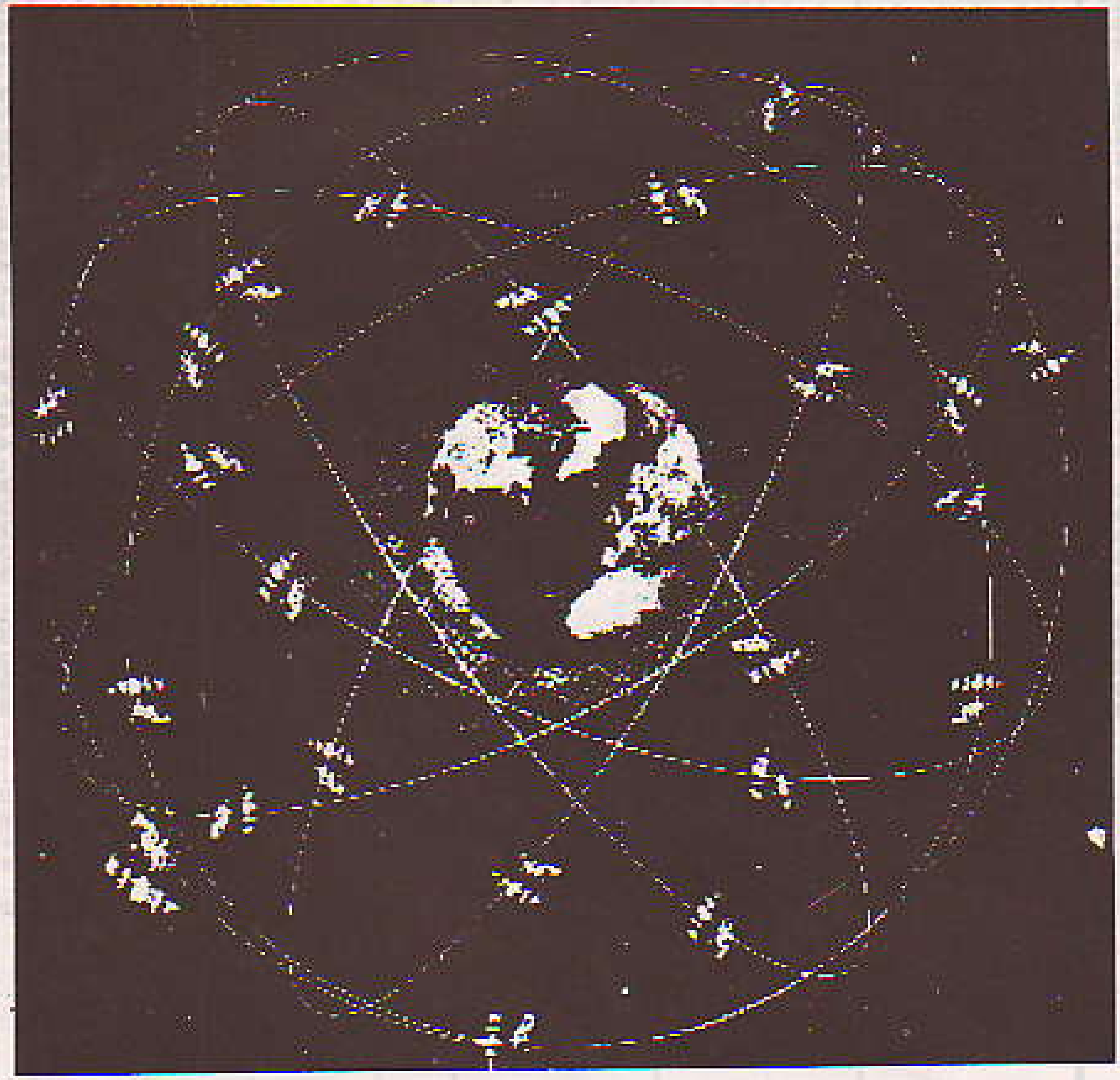


Figure 1
Configuration of 24 satellites evenly distributed in 6
Different orbital planes forming a birdcage around the earth

The GPS signal consists of a **pseudo random code, ephemeris and almanac data.** The pseudo random code identifies the satellite because each satellite is having unique code. Ephemeris data is constantly transmitted by each satellite and contains important information such as status of the satellite, current date and time. The almanac data tells the GPS receiver where each satellite should be at any time through out the day. Each satellite transmits almanac data showing the orbital information for that satellite and for every other satellite in the system. In other words each satellite transmits a message which essentially says **I am satellite X, my position is currently Y and this message was sent at time Z.** The user's GPS receiver reads the message and saves the ephemeris and almanac data for fixing the position.

Each satellite transmits two codes i.e. P code and C/A code known as precision code and coarse acquisition code respectively. All civilian GPS receivers decode the C/A code and it also helps the military receivers to access the more accurate P code, which is available only to US military users and its allies. These codes are modulated by phase modulation technique on two carrier frequencies i.e.

L1 = 1575.42 MHz and L2 = 1227.60 MHz. The L1 signal consists of both the codes i.e. P code and C/A code while the L2 consists of only P code.

The C/A code is made up of a sequence of 0s and 1s called chip, having a frequency of 1.023 MBits/sec and in terms of distance measurement it approximates to 293 meters. The duration of each chip is about 1µs and entire sequence is of one millisecond. The code sequence of 1023 such chips arranged in pseudo random order known to the receiver and repeated every after one millisecond.

Figure 2
C/A code

In the case of P code the chip frequency is 10.23 MBits/sec, the duration of each chip is 0.1 µs and in terms of distance it amounts to 29.3 meters. The full code length is of 267 days and each satellite is allocated only a 7 days piece of the code, during this period there is no repetition of the code.

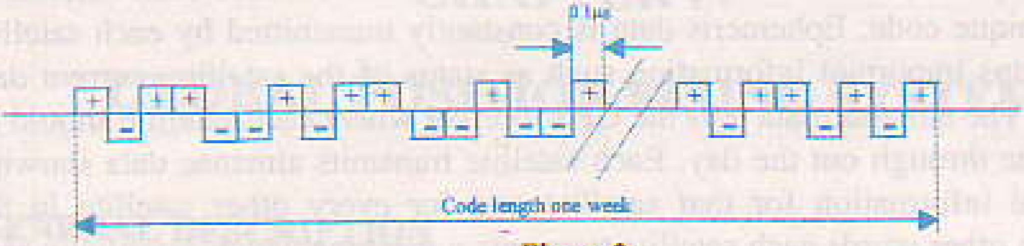


Figure 3
P Code

the C/A code and then transferring to the P code by using Hand Over Word (HOW) contained in 30 seconds navigational message.

The function of these codes is as follows

- For satellite identification since each satellite has a unique code and
- For measurement of the propagation time from satellite to user.

SEGMENTS OF GPS

This system is divided into three segments

- Ground based segment
- Space segment and
- **User's Segment**

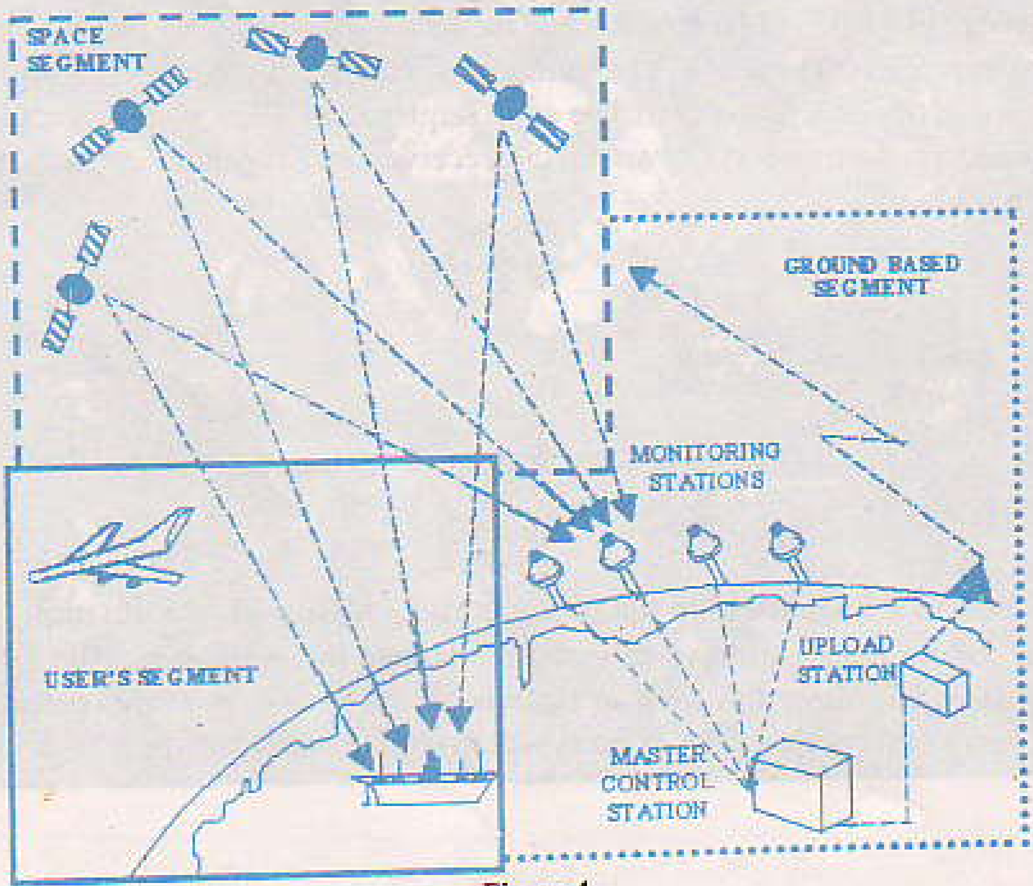


Figure 4
Segments of GPS

GROUND BASED SEGMENT

It consists of four land based monitoring stations located at Atlantic area, Pacific area, Diego Suarez and Indian Ocean. It also has a master control station and upload station located at Colorado Springs in USA. The monitoring stations track the satellites, obtain the data from these satellites and pass the information to master control station. After receiving the data from the monitoring stations, the master control station does the necessary computation to predict the future path and position of all the satellites. The master control station also determines the error of the atomic clocks in all the satellites. The updated data are fed to the upload station, which in turn transmits the same data to each satellite three times a day.

SPACE SEGMENT

It consists of 24 operational satellites evenly placed in 6 different orbits. All the satellites have a propulsion system to maintain their orbital path and can be remotely controlled. The angle between each of the 6 orbital planes and the equatorial plane i.e. inclination is 55°. The difference in the right ascension of the ascending nodes of successive orbit planes is 60°. These satellites are launched at a height of 20,200 kilometers above the earth's surface. The orbital speed of each satellite is 3.9 kilometers / sec and it takes 12 hrs to complete one orbit. Each satellite that passes over the zenith of the observer will remain above the horizon for about 5 hours approximately and it has coverage of 4500 nautical miles approx. These satellites are so launched in the orbit that a receiver placed anywhere on the surface of the earth can receive signals from minimum 4 satellites with an elevation of more than 9.5 °.

USER SEGMENT

It consists of a receiving antenna, receiver with built in computer and display unit. The receiver locks on to one satellite and from this satellite it obtains the almanac of all the other satellites and thereby selects the four most suitable satellites for position fixing. The fix obtained is displayed on the display unit along with other information such as course and speed made good etc.

Receivers designed to receive only one frequency are known as single frequency receiver. To enhance the position accuracy, there are dual frequency receivers that can receive both the frequencies.

NAVIGATIONAL MESSAGE

Each satellite transmits a navigational message of 30 seconds in the form of 50 Bits / sec data frame. This data, which is different for each satellite, is previously supplied to the satellites by master control station and is divided into 5 sub-frames. Each sub frame commences with telemetry word (TLM) containing satellite status followed by hand over word (HOW) data for acquiring P code from C/A code. The 1st sub frame contains data relating to satellite clock correction. The 2nd and 3rd sub frames contain the satellite ephemeris defining the position of the satellite. The 4th sub frame passes alphanumeric data to the user and will only be used when upload station has a need to pass specific message. The 5th sub gives the almanac of all the other satellites which includes data on satellite health and identity codes thus allowing the user for optimum, choice of the satellites for position fixing.

POSITION FIX

The position fix obtained by the receiver is basically by determining the distances from the receiver to each of the selected satellites. The range measurement is achieved by measuring the propagation time from the selected satellite to the receiver. The method used for measuring the time taken by the satellite signals to reach the receiver is based on the satellite and the receiver simultaneously generating an identical series of C/A codes and by careful matching the codes, the auto-correlation is achieved between the incoming signals and those generated within the receiver hence time taken for the satellite signals to reach the receiver is obtained as shown in figure 5.

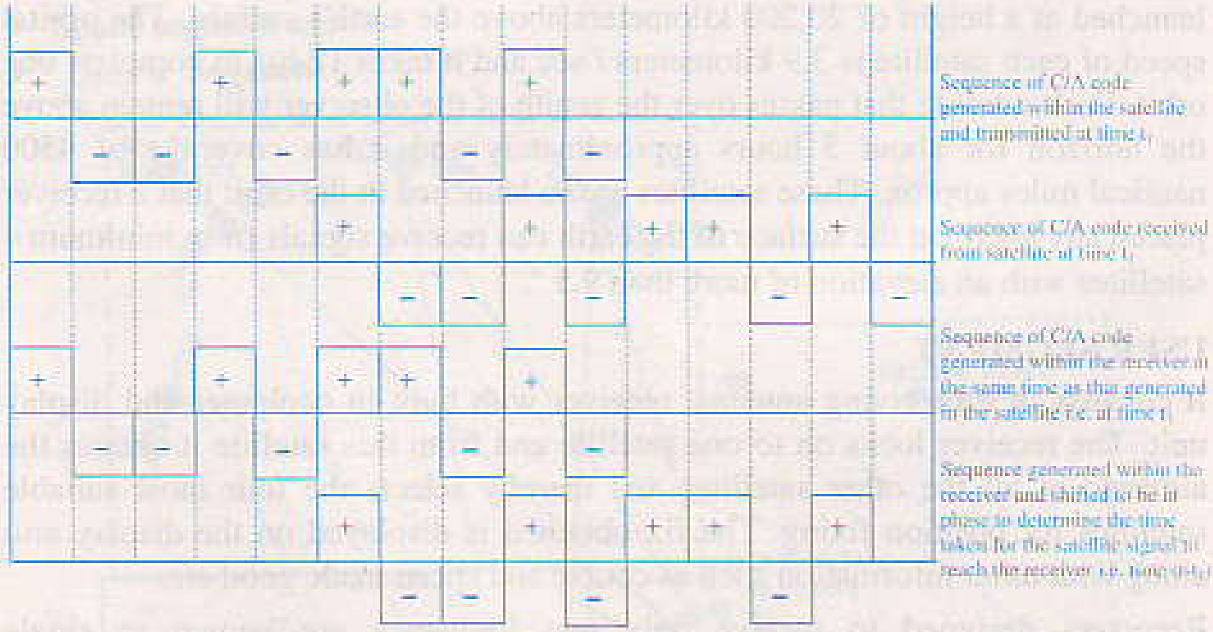


Figure 5

Determination of time taken by satellite to reach receiver

The product of the velocity of radio waves and the time taken for the satellite signal to reach the receiver will give the range (R) of the satellite to the user i.e.

$$R = C \times (t-t_1)$$

Where C is the velocity of the radio waves and

$(t-t_1)$ is the time taken for satellite signals to reach receiver.

All the satellites are equipped with atomic clocks and since these clocks are very expensive, the receivers are not provided with atomic clocks. The user's clock is therefore, not properly synchronized with satellite clocks. This gives an error in range measurement and the range obtained is termed as pseudo range. Hence there are four unknowns i.e. latitude, longitude, altitude (x, y, z coordinates) of the user as well as the user's clock error with respect to satellite clock.

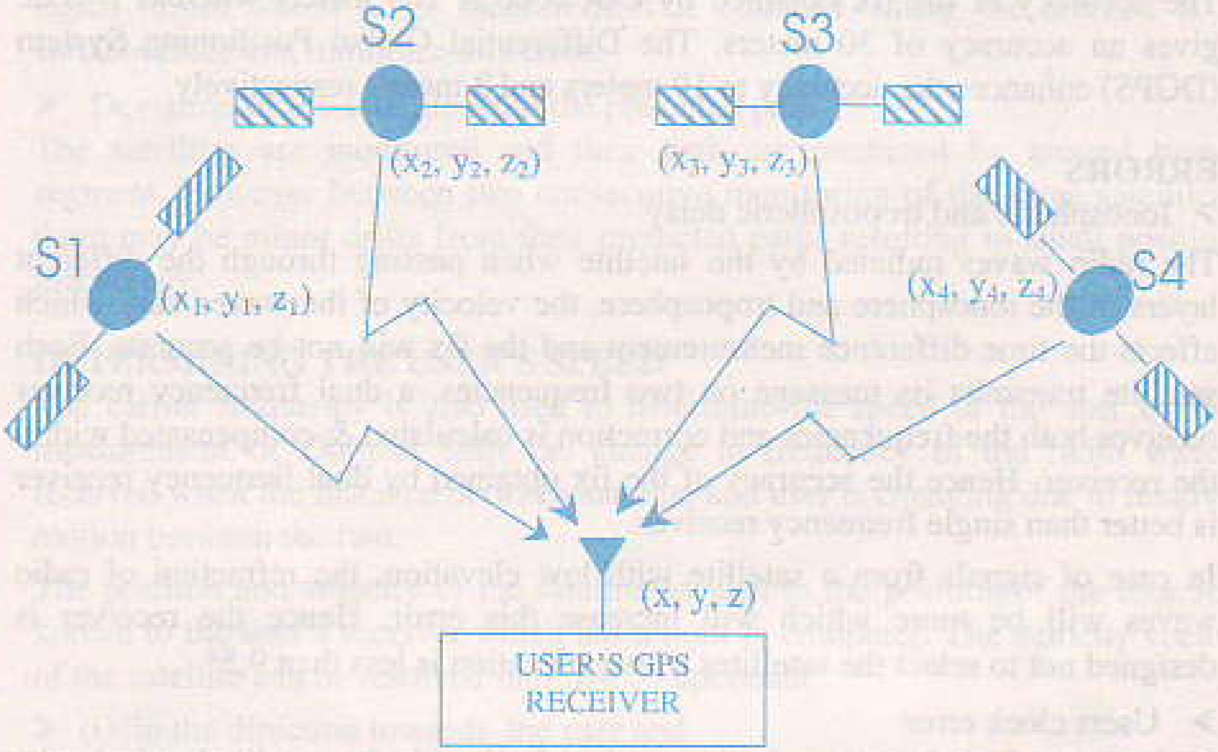


Figure 6

S1, S2, S3 and S4 are the four satellites used for fixing the user's position

The position of the satellite S_1 (x_1, y_1, z_1) is known to the user by 30 seconds navigational massage and from this satellite the following equation is obtained

$$PR_1 - C \times \Delta t = \sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2}$$

Where PR1 is the pseudo range from satellite S_1

C x Δt is error in range measurement due to the error in the user's clock.

Since there are four unknown, they can be resolved from four equations obtained from four different satellites, the other three satellites giving the following three equations

$$PR_2 - C \times \Delta t = \sqrt{(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2}$$

$$PR_3 - C \times \Delta t = \sqrt{(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2}$$

$$PR_4 - C \times \Delta t = \sqrt{(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2}$$

With the help of these equations the 3-D fix can be obtained. In the case of a ship floating on water, a 2-D fix (i.e. longitude and latitude) is required and three equations from three satellites will be sufficient to fix position. The ship's position could also have been determined by two equations obtained from two different satellites if the satellite and the user's clocks are perfectly synchronized.

The accuracy of the fix obtained by C\A code is 100 meters whereas P code gives an accuracy of 30 meters. The Differential Global Positioning System (DGPS) enhances the accuracy to 10 meters and 3 meters respectively.

ERRORS

- Ionospheric and tropospheric delay

The radio waves radiated by the satellite when passing through the different layers of the ionosphere and troposphere, the velocity of the waves vary which affects the time difference measurement and the fix will not be accurate. Each satellite transmits its message on two frequencies, a dual frequency receiver receives both the frequencies and correction is calculated & compensated within the receiver. Hence the accuracy of the fix obtained by dual frequency receiver is better than single frequency receiver.

In case of signals from a satellite with low elevation, the refraction of radio waves will be more which will increase this error. Hence the receiver is designed not to select the satellites whose elevation is less than 9.5°.

- Users clock error

If the user clock is not perfectly synchronized with the satellite's clock, the range measurement will not be accurate and the range measurement along with the clock error is known as pseudo range. This error can be eliminated within the receiver on board by obtaining the pseudo range from three satellites and is done automatically within the receiver

- Satellite clock error

This error is caused due to the error in the satellite's clock w.r.t. GPS time. This is monitored by the ground based segments and any error in the satellite's clock forms part of the 30 seconds navigational message.

- Geometric dilution of precision

The geometry of the position of the satellite determines the angle of cut which in turns governs the quality of the position obtained. Wider the angular separation between the satellites, more accurate is the fix as the intersection will be almost at right angles. The lower the GDOP value higher the accuracy of the fix and this GDOP value is indicated on the display unit. Since the receiver knows the position of all the satellites through 30 seconds navigational message, it is programmed to select the best available satellites considering their elevation and geometry.

- Multipath error

This error is caused by satellite signals arriving at the ship's antenna both directly from the satellite and having been reflected by some other objects. Thus the two signals are received simultaneously which will cause the distortion of signal from which range measurement is obtained. Siting the antenna at a suitable place can minimize this error.

- Deviation of the satellite from the predicted path

The satellites are monitored and their path are predicted by ground based segment. However between two consecutive monitoring of the same satellites, there may be minor drifts from their predicted paths resulting in small position inaccuracy.

DETERMINING THE USER'S SPEED

The carrier frequency is also used to determine the speed of the user by the measurement of Doppler shift i.e. change in frequency of the radio waves received when the distance between satellite and user is changing due to relative motion between the two.

The position and velocity of the satellite as well as the position of the user are known to the user's receiver which has a built in computer. The velocity vector of the satellite can be resolved into two components

- (i) in the direction towards the user and
- (ii) in the direction perpendicular to (i).

The second component is not considered because speed in this direction will not cause Doppler shift. The receiver calculates the velocity vector of the satellite in the direction towards the user. If the relative approach speed between satellite and the user's speed based on the Doppler shift measurement is not equal to the satellite's speed vector towards the user; the difference can only arise due to user's speed towards or away from the satellite.

Similarly with the help of two other satellites, the receiver can calculate two additional speed vectors and these speed vectors will be towards or away from the respective satellites. These velocity vectors are resolved into three other vectors i.e. x, y and z coordinates and with these three vectors the course and speed of user is calculated. The speed so determined is not accurate because the frequency used in this system is very high and Doppler shift measurement is not accurate.

DIFFERENTIAL GPS

The differential GPS system is used to enhance the accuracy of the normal GPS system so that it can be used for survey, drilling, oceanography etc. where higher accuracy of position fixing is required.

The DGPS reference station is situated at a fixed location and from this position the GPS receiver tracks all the satellites within its site, obtains data from them, and computes the correction based on the position obtained from the GPS and its actual position. These corrections are then broadcast to GPS user's to improve their positional accuracy.

There are two methods by which the DGPS station can transmit the corrections

- Computing and transmitting a position correction in terms of Δ latitude, Δ longitude and Δ altitude i.e. x, y and z coordinates and
- Computing pseudo range correction to each satellite which is then broadcast to the user and applied to the user's pseudo range measurement before the position is calculated by the onboard receiver resulting in a higher accuracy of position fix.

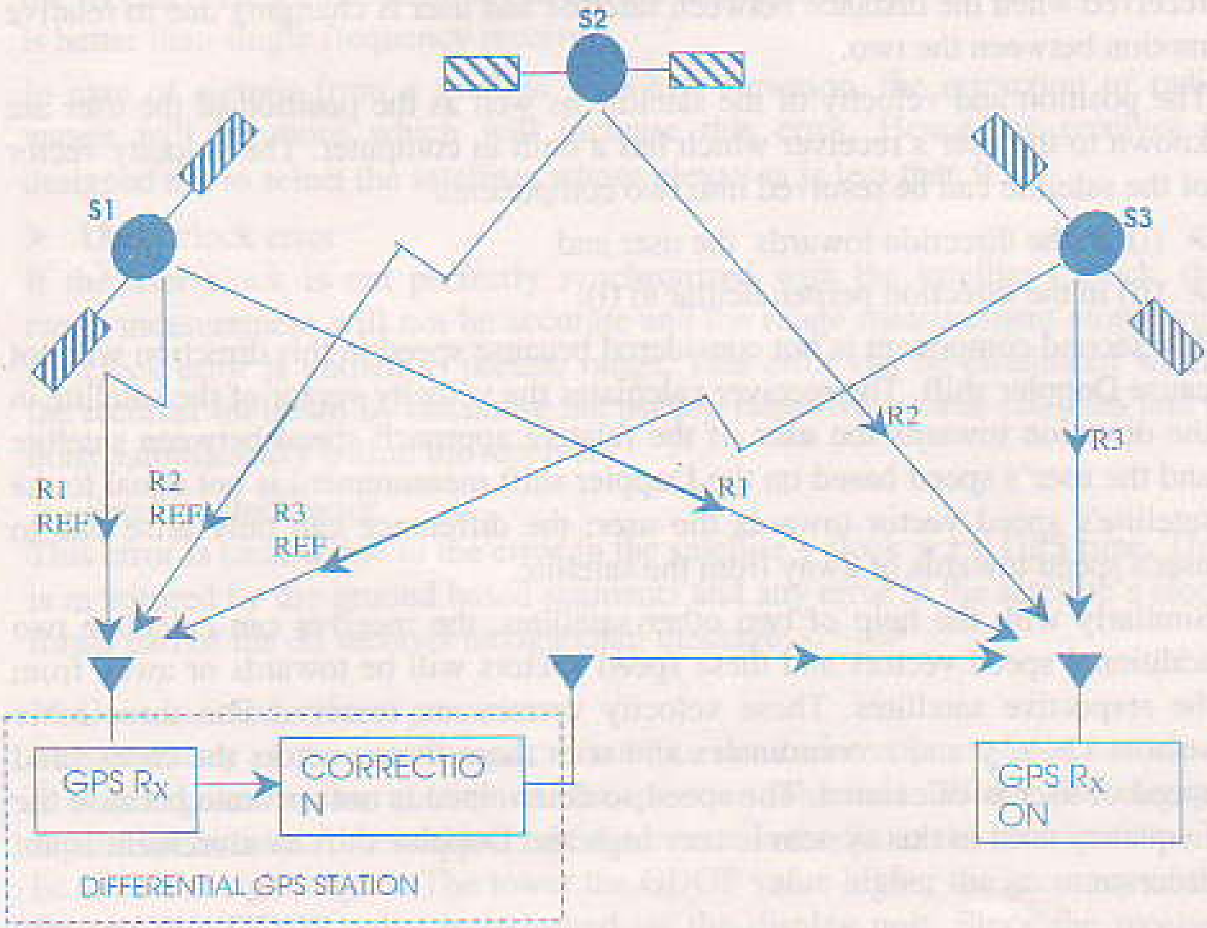


Figure 7
Block diagram of DGPS

The first method in which the correction in terms of x-y-z coordinates is broadcast, requires less data than the second method but the accuracy decreases as the distance from reference station increases. In this method the reference station as well as the user should select the same satellite, which is practically not possible as the user cannot select the satellites manually.

In the second method, the reference station receives signals from all the visible satellites and measures the pseudo range to each of them. Since the satellite signals contain information on the precise satellites position and the reference station knows its position, the true range of each satellite is calculated. By comparing the calculated true range and measured pseudo range, the correction can be determined for each satellite. These corrections are then broadcast which is applied to the pseudo range measured by the user.

CHAPTER V

ECHO SOUNDER

GENERAL DESCRIPTION AND PRINCIPLE

Echo sounder is electronic equipment, which measures the depth of seabed. In this system, acoustic pulses of very short duration are transmitted vertically at the rate of 5 to 600 pulses per minute having a beam width of 12 to 25°. These pulses strike the seabed and get reflected back towards the receiving transducer as echoes. These received echoes are converted into electrical signals by the receiving transducer and after passing through the different stages of the receiver, the current is supplied to stylus which burns out the coating of the thin layer of aluminium powder and produces a black mark on the paper indicating the depth of the seabed. The time taken by the waves to travel to and fro from the seabed is measured and depth can be determined by the formula

$$d = v \times t / 2$$

where d is the depth of the seabed

v is the velocity of acoustic wave in the seawater and

t is time interval for acoustic wave to travel to and fro from seabed.

The performance of an echo sounding system depends on the accuracy with which the acoustic wave propagates through seawater, since it calculates the depth by precisely measuring the time taken for a pulse of energy to travel to seabed and return. The speed of the acoustic wave through seawater at a temperature of 16°C and salinity of 3.4% is 1505 m/sec, but for calculation the velocity is approximated to 1500 m/sec. The speed of the acoustic wave varies when salinity, temperature or pressure changes and any variation in the velocity of the acoustic wave from the accepted value of 1500 m/sec will cause an error in recorded depth. If the time taken for the pulse to travel to and fro from the seabed is one second, then the depth of the seabed below the transducer is 750 meters.

When the pulses strike the seabed, they get reflected in different directions (diffused reflection) and not only one in direction (specular reflection). The diffused reflection is desirable because of the motion of the ship and higher frequency gives greater diffused reflection.

PULSE LENGTH

The duration of the pulse in an echo sounder is generally from 0.2 to 2 milliseconds and varies from set to set. The pulse length changes with range scale and for shallow depth short pulse is used whereas for greater depth the equipment changes over to long pulse. The minimum measurable depth will depend on pulse length and theoretically equals to half pulse length. The stylus is rotating at a scale speed equal to half the speed of the acoustic waves. In other words the time taken for the stylus to travel from top to bottom on the paper is exactly equal to that for an acoustic pulse to travel twice the distance of the range selected. The echo cannot be received till the transmission is over hence for a pulse length of 2 milliseconds, the theoretical minimum measurable depth will be 1.5 meters and any depth less than this will not be recorded. The minimum measurable depth is calculated by

$$D_{min} = v \times l / 2$$

Where D_{min} is minimum measurable depth

v is the velocity of acoustic waves and

l is pulse length in second

If the pulse length is 2 millsecond then the minimum measurable depth will be

$$D_{min} = v \times l / 2$$

$$= 1500 \times 2 / 1000 \times 2 \text{ meters}$$

$$= 1.5 \text{ meters}$$

The duration of the pulse also determines the resolution of the equipment. It enables the objects close to seabed to be recorded separately.

The discrimination (D) between echoes is $D = v \times l$

If the pulse length is 0.5 millisecond then,

$$D = v \times l$$

$$= 1{,}500 \times 0.5 \times 10^{-3} \text{ meter}$$

$$= 0.75 \text{ meter}$$

and if the pulse length is 2 millisecond then,

$$D = 3 \text{ meters.}$$

Hence a short pulse length is superior when the objects to be displayed are close together in seawater. This is used in **SONAR** system.

PULSE REPETITION FREQUENCY (P R F)

The number of pulses transmitted per second is known as Pulse Repetition Frequency and this determines the maximum depth, which can be measured. The maximum depth (R) can be measured is determined by the formula

$R = v \times t / 2$

Where v is the velocity of acoustic wave and

t is the time between two successive – pulses in seconds.

If the PRF is one per second, i.e. t = 1,

i.e. $R = v \times t / 2$

$= 1500 \times 1 / 2$

$= 750$ meters

then the maximum depth recorded is 750 meters

Similarly if 2 pulses are transmitted in one second, i.e. t = 0.5,

The maximum depth recorded is 375 meters.

The PRF is automatically selected and changes as the range scale is changed. For lower range scales a higher PRF is used since the time required for the echoes to return from shallow depths is less and hence more pulses can be transmitted per second enabling the observer to get more echoes and thereby quickly monitor the changing depths when in shallow waters. As the range scale is increased the PRF is reduced since echoes need more time to return.

TRANSMISSION FREQUENCY

The frequency of acoustic wave transmitted in an echo sounder is of great importance. The choice of frequency is a compromise between the size of transducer, freedom from external noise and minimum attenuation. If the transmission frequency is within the **audio frequency range,** then the receiving transducer will pick up other audible noise from other source such as

- vibration of the ship's propeller
- the noise due to ship's engine
- noise due to seawater hitting the hull of the moving ship with considerable force.

These noises will effect the weak echoes returning from the seabed

If the frequency of the transmission is high then the

- attenuation is more
- higher the frequency, smaller the wave length and smaller the size of transducer which cannot produce sufficient power and
- higher the frequency more is the diffused reflection, which is desirable.

Considering the above factors, the transmission frequency should not be within audio frequency range and also it should not be very high. Hence to compromise between the two, the transmission frequency used in echo sounding system is generally between 30 kHz and 55 kHz, which is termed as ultra sonic frequency or super sonic frequency.

PROPAGATION CHARACTERISTICS OF ACOUSTIC WAVE

➢ Velocity of the acoustic wave in seawater

The velocity of acoustic wave through seawater at temperature of 16°C and salinity of 3.4% is 1505 m/sec, approximated to 1500 m/sec for calculation purposes. The velocity of the acoustic wave varies from 1445 m/sec to 1535 m/sec and the factors, which influence the velocity of the acoustic wave through seawater, are temperature, pressure and salinity. The effect of temperature and salinity is more pronounced than that of pressure. If the echo sounder is correctly calibrated for salt water, it will indicate depths in fresh water about 3% higher than the actual depth.

➢ Reflective surface of the seabed

The amplitude of the reflected energy varies with nature of the seabed. The main type of seabed and the attenuation caused by them is as follows

Soft mud	- 15 db
Mud/ Sand	- 9 db
Sand/ Mud	- 6 db
Sand	- 3 db
Stone/ Rock	- 1 db

➢ Frequency of transmission

The frequency of transmission varies from set to set. Higher the frequency, greater the attenuation and more the diffused reflection.

➢ Beam width

If the beam width is too large, the attenuation is more because the signal spreads over the larger area.

➢ Attenuation

Attenuation of the acoustic wave depends on various factors such as frequency of transmission, beam width, reflecting surface of the seabed, marine growth, shoals of fish etc.

➢ The angle of incidence of the propagated waves

The energy of the echoes reflected by the seabed will be more when the acoustic wave is transmitted vertically than when the wave is transmitted at an angle.

FUNCTION OF VARIOUS STAGES OF THE ECHO SOUNDER

The echo sounding equipment consists of the following stages

➢ Oscillator unit

This unit produces a high voltage oscillation of desired frequency and the output is given to the transmitting transducer.

➢ Transmitting transducer

The transmitting transducer may be of electrostrictive or magnetostrictive type, installed as pierced hull or internal installation respectively. It converts the electrical signals into acoustic waves and transmits them towards the seabed.

➢ Receiving transducer

The Receiving transducer receives the echoes from the seabed and converts them into electrical signals, which are sent to the amplifier unit.

➢ Amplifier unit

The Amplifier unit amplifies the weak electrical signals received from the transducer and gives to the recorder unit.

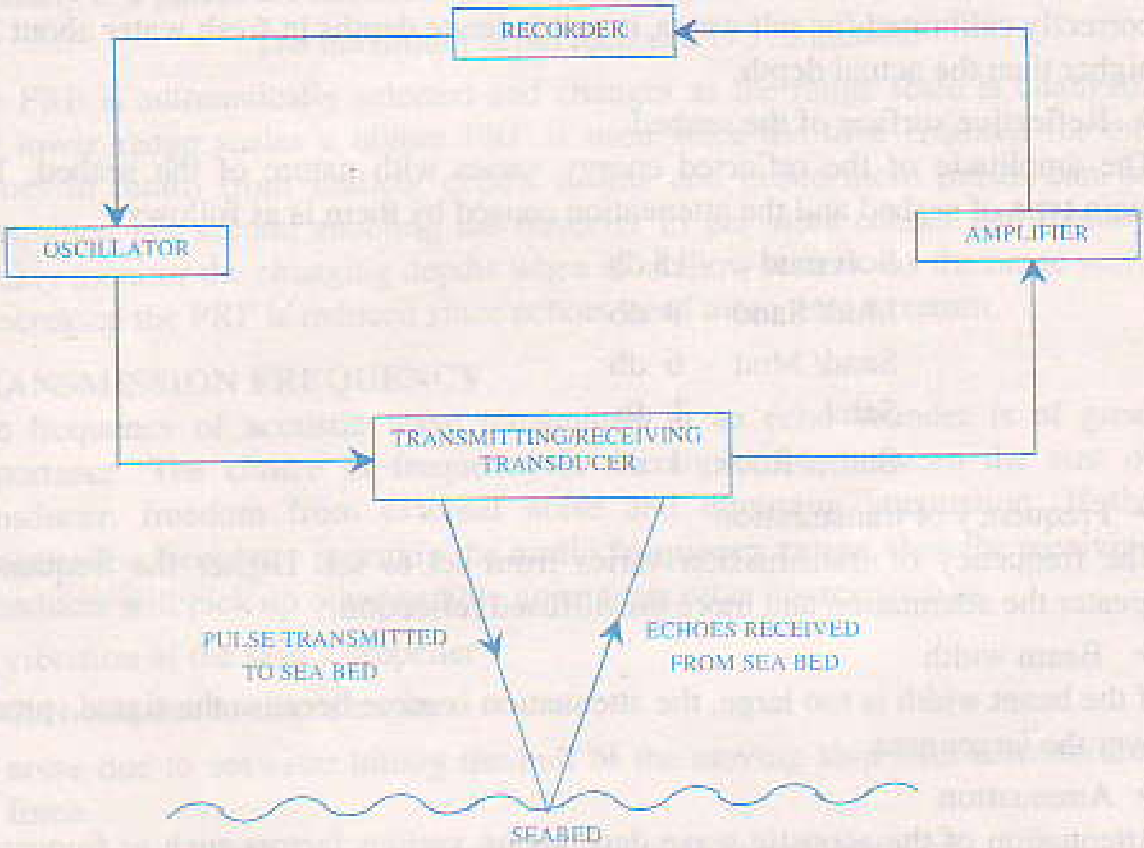


Figure 1

Block diagram of Echo sounder

➢ Recorder unit

The Recorder unit controls the transmission of the acoustic pulses and records the depth on the paper.

➢ Power supply unit

This unit gives the required voltages to the different stages of the echo sounding equipment.

TRANSDUCER

The function of a transducer is to convert electrical energy to acoustic energy during transmission and to convert the acoustic energy into electrical energy during reception of the echo.

There are two types of transducer

- Electrostrictive transducer and
- Magnetostrictive transducer

Electrostrictive transducer

This type of transducer works on the basic principle of piezo electric effect i.e. certain crystalline materials such as Quartz, Rochelle salt, Tourmaline etc. have the property that when pressure is applied to the two opposite faces , a difference of potential is created which is proportional to the applied pressure or when an alternating voltage is applied, the crystal starts vibrating or oscillating. This type of transducer is also known as **Piezostrictive transducer**.

The electrostrictive transducer uses the property of a crystal for transmission and reception of acoustic waves in water. The crystal is firmly fixed between two steel plates so that they act as a single unit. The purpose of the steel plates is to provide solid and robust housing for the crystal as well as suitable contact surface for seawater as shown in the figure 2.

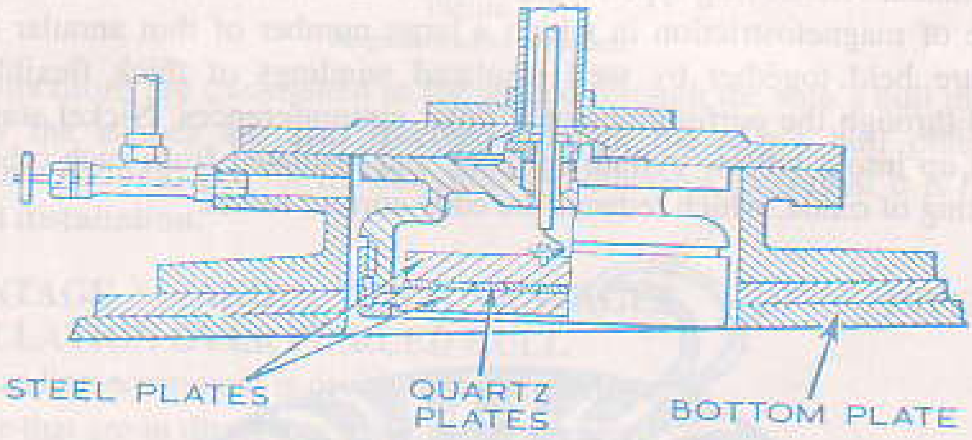


Figure 2
Electrostrictive transducer

When an alternating voltage is applied between the steel plates, the quartz and the steel plates start vibrating together. The vibration will be of very high amplitude, if the frequency of the alternating voltage is equal to the resonance frequency of the crystal. The lower of the two steel plates is in direct contact with the water, which will cause the vibration in seawater. The vibration is always perpendicular to the plate, hence it is always kept horizontally. Generally only one transducer is used for transmission and reception of the signals and this transducer is always mounted as **Pierced hull.**

Magnetostrictive transducer

The magnetostrictive transducer works on the basic principle of magnetostriction i.e. when a bar of Ferro-magnetic material such as Nickel is wound with a coil in which when an alternating voltage is applied, the length of this material will always contract irrespective of the direction of the current and it comes back to its original length when the current comes to zero. The other Ferro- magnetic materials are Cobalt, Steel etc.

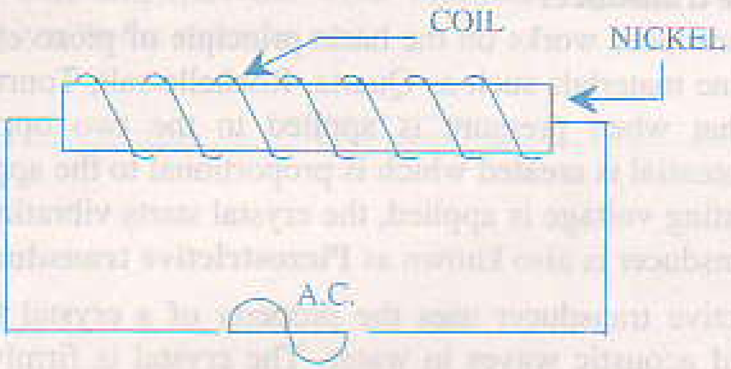


Figure 3
Nickel bar under the influence of alternating current, contracts irrespective of the direction of the current and returns to its original length whenever the current comes to zero

The laminated Nickel ring type magnetostrictive transducer works on the basic principle of magnetostriction in which a large number of thin annular disc of Nickel are held together by well insulated windings of thick flexible wire threaded through the perforations near outer circumferences. Nickel stampings are built up into a hollow cylindrical pack and insulated from each other by a thin coating of oxide, which reduces the eddy current losses.

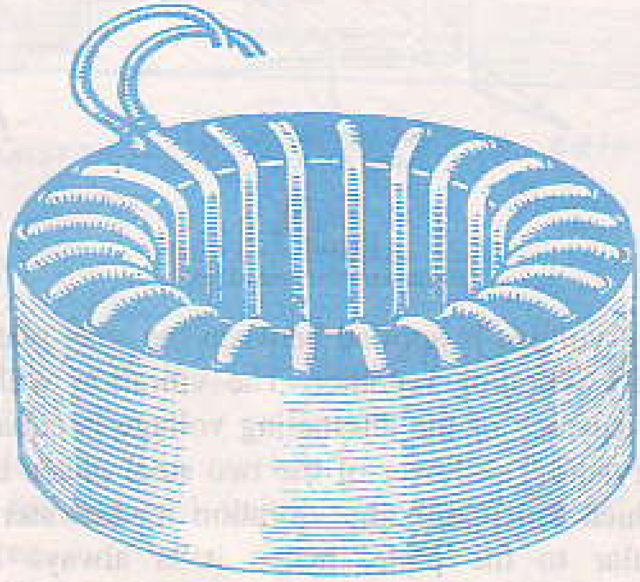


Figure 4
Laminated Nickel ring type of magnetostriction transducer

When an alternating current is passed through the windings of the coil, the contraction and subsequent expansion in the Nickel takes place circumferentially along the path of the magnetic field produced by the coil. Thus the whole outer area of the cylindrical pack is set in motion at its natural resonant frequency and the acoustic vibrations are passed on to the surrounding medium i.e. water because this transducer is fitted in the water tank as shown in figure 5

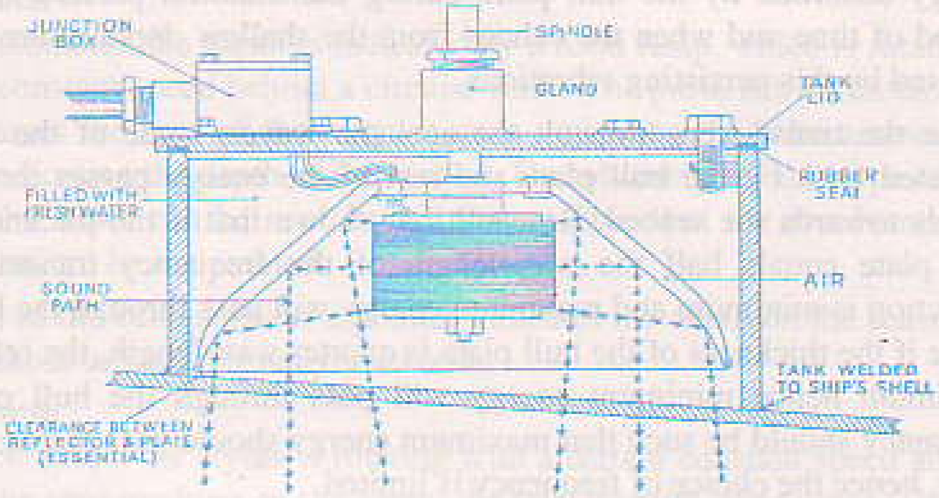


Figure 5
Magnetostrictive transducer

These vibrations are transmitted to the seabed through the ship's hull plate and similarly the echoes are also received through the ship's hull plate. Two transducers are used one for transmission and other for reception. It is fitted as **Internal installation.**

ADVANTAGE AND DISADVANTAGES OF INTERNAL INSTALLATION OVER PIERCED HULL

Echo sounding equipment is divided into two categories

- Those that are in direct touch with seawater and
- Those that transmit and receive acoustic vibrations through ship's hull plate

The former requires the hull of the ship to be pierced and is referred to as pierced hull or outboard type of transducer. The second type is known as internal installation or inboard type, since no part of the equipment is in direct touch with sea water and the vibrations are transmitted and received through the ship's hull plate.

Advantages

- The ship's hull plate is not cut hence the continuity of the hull is maintained and
- The transducer can be fitted and repaired without taking the ship to dry dock.

Disadvantages

- In the internal installation only 15% of the total power output passes through the ship's hull plate.
- The losses in the hull plate occurs twice per sounding hence the received energy becomes so weak that it has to be amplified many times to produce a mark on the paper.
- In order to measure the shallow depth, two transducers are required as the energy absorbed by the hull plate during transmission persists for certain period of time and when the echoes from the shallow depth return, they are affected by this persisting vibrations.
- When the transducers transmit the acoustic waves, some of the energy is reflected back by the hull plate and rest of the energy passes through and travels towards the seabed. Research has shown that if the thickness of the hull plate equals half the wavelength of the frequency transmitted, the reflection is minimum and maximum energy will pass through the hull plate, while if the thickness of the hull plate is quarter wavelength, the reflection is maximum hence minimum energy will pass through the hull plate. The frequency should be such that maximum energy should pass through the hull plate, hence the choice of frequency is limited.

SITING OF TRANSDUCER

For optimum performance of an echo sounding system, the position in which a transducer is situated is of great importance and it must be away from areas close to noise source. The main problem encountered is the aeration i.e. air bubbles which pass close to the transducer and act as large reflectors of the transmitted energy. Hence it is necessary to choose a site where the bubble stream is negligible or non-existent. There are few positions on the ship that are suitable in every respect and this position will vary from ship to ship hence siting of the transducer for different ships are mentioned below

- On large, fast, deep draught ships, the best position is the forward end between 1/8 and 1/4 of the ship's length from the bow
- On medium speed ships, the forward most position is usually the best unless the vessel has a light draught in which case 3/4 length from the bow is preferred.
- In case of slow cargo vessels of light draught, the best position is 3/4 length from the bow.
- On oil tankers, the transducer should be fitted at the forward end of the engine room.
- On very large size ships, two transducers are fitted- one at the forward end and the other well aft. The choice of the transducer to be used can be selected from the bridge.

- In case of pierced hull, the transducer is fitted near the centre line and flush with the keel plate.

INDICATORS

The depth of the seabed can be indicated by the following method

- Echometer and
- Echograph

Echometer

In an echometer, the depth is indicated by a neon lamp, which is rotating with a certain constant speed behind a circular scale. The pulse is transmitted when the lamp passes the zero of the circular scale and when the echo arrives the lamp glows indicating the depth of the seabed. The advantage of this type of indicator is that the depth can be read from a distant place but the disadvantage is that record can not be maintained

In some of the echo sounder a pointer indicates the depth on the scale but these two methods are not normally used now.

Echograph

In an echograph the stylus is rotating with a certain constant speed and when it passes the zero marking on the paper, the transmission takes place. The speed of the stylus is such that the time taken for the stylus to travel from top to bottom is exactly equal to that for a acoustic pulse to travel twice the distance of the range selected. When the echo is received by the transducer, it converts into electrical signals which passes through the different stages of the receiver and current is given to the stylus, which burns out the coating on the paper and produces black marking indicating the depth of the seabed. The paper is placed over a very fine flat metal sheet, which is rolled between two spools and moves slowly from one spool to another. The approaching end of the paper is marked by a broad red line, which indicates that the paper needs to be changed in short time. One paper roll runs for 30 to 100 hours depending on the speed at which it is used.

The advantages of echograph over echometer are

- Permanent recording can be maintained which is useful for evidence.
- Rate of change of the depth can be seen clearly and
- All echoes are displayed.

In most of the cases, the echograph and the digital readout both are provided to record and indicate the depth of the seabed.

RANGING

In an echo sounder the stylus is rotating with certain constant speed and the transmission takes place when the stylus passes the zero mark. When the higher range scale is selected, the transmission will still take place when the stylus comes to zero but the stylus speed is reduced because the stylus has to remain on the paper for longer period of time since the echoes are returning from greater depth. This system is known as ranging and the range scales are generally provided as

0 - 50 meters
0 - 100 meters
0 - 200 meters
0 - 300 meters
0 - 400 meters & so on.

Since the same length of paper now covers a larger depth, the graduations become closer and it becomes difficult to read the depth accurately. Phasing arrangement is used to avoid this.

PHASING

In phasing arrangement, the speed of the stylus motor is kept constant but the transmission point is advanced. As shown in figure 6, four sensors are positioned around the stylus belt and stylus is rotating at a constant speed. A magnet mounted on the belt generates the pulse when it passes the sensor, which in turn activates the transmitter.

When the minimum range (0 to 100 meters) is selected, the sensor 1 is used and the delay circuit arrangement is such that the transmission occurs exactly when the stylus passes the zero mark. The bottom scale of the paper will depend on the speed of the stylus motor and it is set to 100 meter.

On selecting the higher range (100 to 200 meters), the sensor 2 is used for activating the transmitter and the zero of the scale is so shifted that the top of the paper corresponds to 100 meters. Since the speed of the stylus motor remains same, the bottom graduation corresponds to 200 meters. Similarly for measuring higher ranges, different sensors are selected and the transmission time will advanced accordingly.

The speed of the stylus will remain same as long as each range scale corresponds to similar difference of depth i.e.

0 - 100 meters
100 - 200 meters
200 - 300 meters
300 - 400 meters & so on…

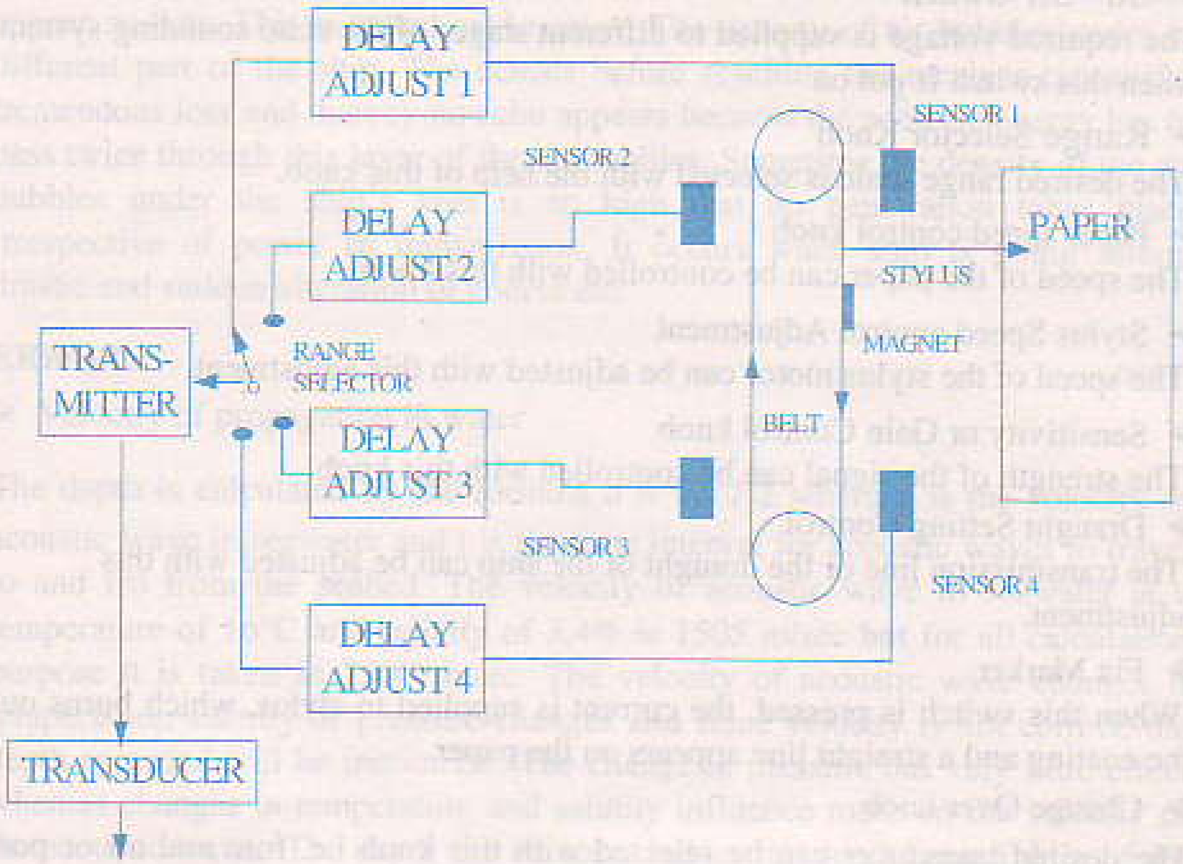


Figure 6
Block diagram of phasing

It is always advisable to start the echo sounder at minimum range scale when phasing facility is provided so that shallow depths are not missed.

In certain echo sounding systems the **Ranging and Phasing** arrangements are used in combination such system is known as phased ranging On such systems the range scale will not be uniform and may be provided as follow

0 - 100 meters
100 - 200 meters
200 - 400 meters
400 - 800 meters & so on.

In this case the transmission time is advanced as well as the speed of the stylus motor is changed depending upon the range chosen.

CONTROLS OF ECHO SOUNDER

- On - Off Switch

The required voltage is supplied to different stages of the echo sounding system when this switch is put on

- Range Selector Knob

The desired range scale is selected with the help of this knob.

- Paper speed control knob

The speed of the paper can be controlled with this knob

- Stylus Speed control Adjustment

The speed of the stylus motor can be adjusted with this adjustment.

- Sensitivity or Gain Control knob

The strength of the signal can be controlled with this knob.

- Draught Setting Control

The transmission line or the draught of the ship can be adjusted with this adjustment.

- Fix Marker

When this switch is pressed, the current is supplied to stylus, which burns out the coating and a straight line appears on the paper.

- Change Over knob

The desired transducer can be selected with this knob i.e. fore and aft or port and starboard. This arrangement is generally used in VLCC or ULCC.

- Panel Brilliance Control

The brilliance of the panel can be controlled with this knob.

ZERO MARK AND DRAUGHT SETTING

When a pulse is transmitted, part of signal is given to stylus to produce a mark at zero on the paper and draught setting is done by delaying the signal sent for zero marking by that particular draught. In this case the depth indicated will be actual depth of water and not under keel clearance

CROSS NOISE

If the sensitivity of the amplifier is high, just after the zero marking a narrow line along with several irregular dots and dashes appear and this is called *Cross Noise*. This is caused as part of the transmitted energy is picked up directly by transducer. In addition when aeration is present, the reflection from these air bubbles may also result in cross noise. If the intensity of the cross noise is high, it will completely mask the shallow water depths. To avoid this, the amplification should be less immediately after transmission and increase gradually so that the weak echoes returning from the deep water should be marked with sufficient clarity. It is done automatically by swept gain control circuit.

AERATION

Vibration causes air bubbles in the water and echoes caused by these air bubbles appear as dots. This is called as *Aeration*. The density of air bubbles varies at different part of the ship. The echoes before reaching the receiver can suffer tremendous loss and thereby no echo appears because the acoustic energy has to pass twice through this layer of the air bubbles. Sometime the density of the air bubbles under the ship's keel is so high that no penetration takes place irrespective of power of transmission. It occurs when ship is going astern, drastic and sudden alteration of course etc.

ERRORS

➢ Velocity of propagation in water

The depth is calculated by the formula $d = v.t / 2$ where v is the velocity of acoustic wave in seawater and t is the time interval for acoustic waves to travel to and fro from the seabed. The velocity of acoustic wave in seawater at a temperature of 16°C and salinity of 3.4% is 1505 m/sec but for all calculation purpose it is taken as 1500 m/sec. The velocity of acoustic wave changes if temperature, salinity or pressure changes and since velocity is not correct, the depth recorded will be inaccurate. The change in pressure has very little effect whereas changes in temperature and salinity influence more on the velocity of the acoustic wave. The depth can be corrected to true depth from Tables of the velocity of Sound in pure water and seawater- Refer NP 139 (HD 282)

➢ Stylus speed error

The stylus is rotating with a certain constant speed and the speed of the stylus is such that the time taken for the stylus to travel from top to bottom is exactly equal to that for a acoustic pulse to travel twice the distance of the range selected. Due to the fluctuation in the supply voltage, the speed of the stylus motor changes hence the depth recorded will be inaccurate. It should be checked periodically and adjusted as per the instruction given in the manual.

➢ Multiple echoes

The echo may be reflected a number of times between the keel and the seabed, thereby giving multiple depth marks on the record, in such a case the first echo is the correct depth. It can so happen that the echo sounder is selected on a higher range i.e. 100 - 200 meters and the actual depth of the seabed is 60 meter. In this case the depth will also be recorded at 120 / 180 meters as the echo has travelled twice / thrice between keel and seabed and no depth is recorded at 60 meters. This could lead to serious consequences and must be avoided. Hence the echo sounder must be started at minimum range scale when *phasing* facility is provided

➢ Pythagoras error

This error is found when two transducers are used one for transmission and other for reception. The error can be determined by the formula

$$e = d - \sqrt{(d^2 - x^2 / 4)}$$

where d is recorded depth and

x is spacing between two transducers

This error is more dangerous in shallow depth and is negligible when one transducer is used because the same transducer is used for transmission and reception of the acoustic waves.

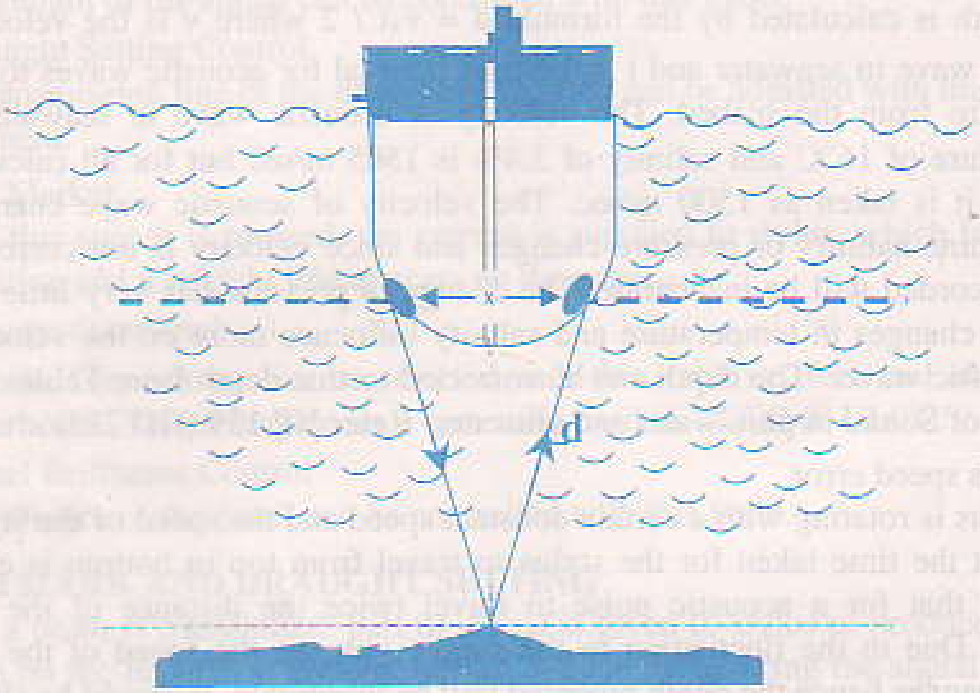


Figure 7
Pythagoras error

➢ Thermal and Density layers

The density of the water varies with temperature and salinity, which will tend to form different layers. It is possible for echoes to return from the surface of these layers and a faint line will appear between zero and actual depth.

➢ Zero line adjustment error

If the zero adjustment is not correct, the depth recorded will not be correct.

MAINTENANCE

The routine maintenance to be carried out will be different for each model and the respective manual should be consulted.

Following is general maintenance that should be carried out regularly to maintain the equipment in efficient working condition.

- Stylus speed is to be checked often and must be adjusted as per the manual. The speed of the stylus motor is very important to indicate the correct depth.
- Prior to leaving the dry dock, it is necessary to check the transducer to ensure that they have not been painted and it should be free from grease.
- Carbon dust must be cleared regularly while using the dry paper.
- As per the manual, it must be lubricated as and when necessary.
- Accuracy must be checked with lead line whenever an opportunity arises, like when at anchor or at berth etc.

CHAPTER VI

DOPPLER LOG

GENERAL DESCRIPTION

Doppler log is based on the principle of Doppler shift in frequency measurement i.e. apparent change in frequency received when the distance between source and observer is changing due to the motion of either source or observer or both. In Doppler log an observer is moving with a source of sound towards a reflecting plane, then the received frequency

$$fr = ft\ (c + v) / (c - v)$$

where fr = received frequency

ft = transmitted frequency

c = velocity of sound in seawater and

v = velocity of the vessel

By measuring the received frequency (fr) & knowing the value of transmitted frequency (ft) and velocity of sound in seawater (c), the speed of the vessel v can be determined.

PRINCIPLE

A transducer is fitted on the ship's keel which transmits a beam of acoustic wave at an angle ∝ usually 60° to the keel in the forward direction, this gives the component v Cos ∝ of the ship's velocity towards the sea bed thus causing the Doppler shift and the received frequency

$$fr = ft\ (c + v \cos\alpha) / (c - v \cos\alpha) \quad \ldots\ldots\ldots\ldots\ldots \quad (i)$$

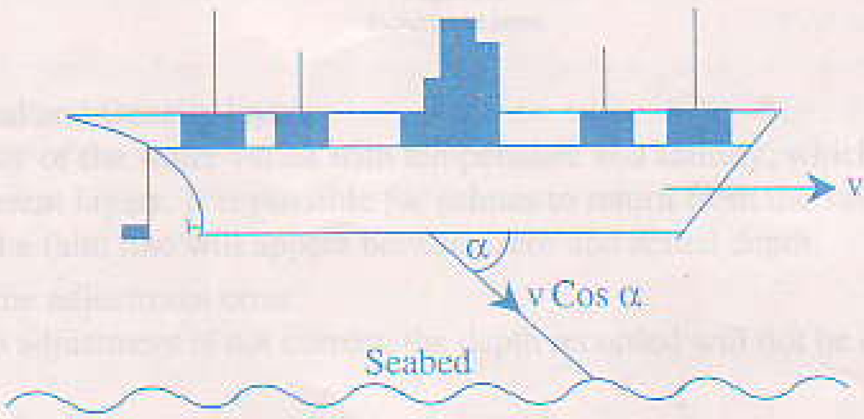


Figure 1
Acoustic beam transmitted at an angle α towards seabed

If the waves are transmitted directly towards the seabed perpendicular to the keel, there will be no Doppler shift and the transmitted and received frequency will be the same. This is because the component of ship's speed towards the seabed is zero (i.e. v Cos 90).

According to the Binomial expansion, we have

$$1/(1 - x) = 1 + x + x^2 + x^3 + \text{-------} \quad \text{(ii)}$$

Dividing numerator and denominator of equation (i) by **c**, we get

$$fr = ft\,(1 + v \cos \propto / c) \times \frac{1}{(1 - v \cos \propto / c)}$$

By using the formula (ii) in this equation and on simplification we get,

$$fr = ft\,(1 + 2v \cos \propto / c + 2v^2 \cos^2 \propto / c^2 + \ldots)$$

since $v \cos \propto << c$, neglecting higher powers of $v \cos \propto / c$ we get,

$$fr = ft + 2v\,ft \cos \propto / c$$

$$fr - ft = 2v\,ft \cos \propto / c \quad \ldots\ldots\ldots\ldots\text{(iii)}$$

$$v = c\,(fr - ft) / 2\,ft \cos \alpha. \quad \ldots\text{(iv)}$$

With the help of this formula we can calculate the speed of the ship, considering that there is no vertical motion.

In practice the ship has some vertical motion and the Doppler shift measurement will have a component of this vertical motion. In this case Doppler shift measurement will be

$$fr - ft = 2v\,ft \cos \alpha / c + 2\,Vv\,ft \sin \alpha / c$$

$$fr - ft = (2v\,ft \cos \alpha + 2\,Vv\,ft \sin \alpha) / c \quad \ldots\text{(v)}$$

where Vv represents the vertical motion of the ship.

This problem is overcome by installing two transducers, one transmitting in the forward direction and another in the aft direction at the same angle. This arrangement is known as Janus configuration as shown in figure 2. In this case the forward transducer will give Doppler shift

$$\text{i.e. } fr_f - ft = 2v\,ft \cos \alpha / c + 2\,Vv\,ft \sin \alpha / c$$

$$fr_f - ft = (2v\,ft \cos \alpha + 2\,Vv\,ft \sin \alpha) / c \quad \ldots\ldots\text{(vi)}$$

where fr_f is the frequency received by the forward transducer

while the aft transducer will have the component v Cos α with negative sign since the transducer is moving away from the reflecting surface i.e. the seabed and hence the Doppler shift measured will be

$$fr_a - ft = -2v\,ft \cos \alpha / c + 2\,Vv\,ft \sin \alpha / c$$

$$fr_a - ft = (-2v\,ft \cos \propto + 2\,Vv\,ft \sin \propto) / c \quad \ldots\ldots\ldots\ldots\text{(vii)}$$

where fr_a represents frequency received by the aft transducer.

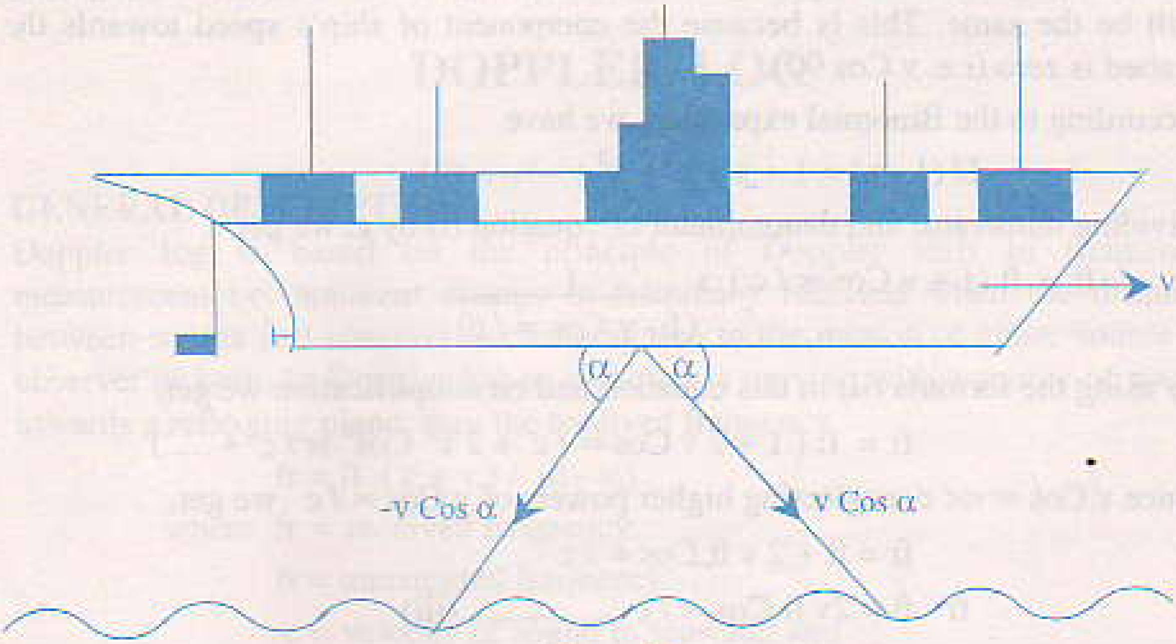


Figure 2
Janus configuration

In formula (vi) and (vii) Vv will have the same sign since both the forward and aft transducers will move upwards or downwards together.

By measuring the difference between the two Doppler shift frequencies, the vertical component will cancel out while the horizontal will add i.e.

$$(fr_f - ft) - (fr_a - ft) = (2 \text{ v ft Cos } \alpha + 2 \text{ Vv ft Sin } \alpha)/c$$
$$- (-2 \text{ v ft Cos } \alpha + 2 \text{ Vv ft Sin } \alpha)/c$$

$$fr_f - ft - fr_a + ft = 2 \text{ v ft Cos } \alpha / c + 2 \text{ Vv ft Sin } \alpha / c$$
$$+ 2 \text{ v ft Cos } \alpha / c - 2 \text{ Vv ft Sin } \alpha / c$$

$$fr_f - fr_a = 4 \text{ v ft Cos } \alpha / c$$

$$\text{i.e. } v = c\,(fr_f - fr_a) / 4 \text{ ft Cos } \alpha \quad \ldots\text{(viii)}$$

Thus v i.e. speed of the ship can be calculated. The speed of the ship as determined by the above formula is the speed over ground, unaffected by set and drift since the echoes are coming from the seabed. This is also referred to as **bottom track or ground track.**

The transmitted pulse has certain power and can go up to a limited depth usually 200 meters. Beyond this depth, the echoes from the seabed become very weak and the strength is not sufficient to calculate the Doppler shift.

In such a case echoes are also available from water layers between 10 and 30 meters below the keel and hence Doppler shift is possible, enabling measurement of speed. But this will give us speed over water. This is referred to as **water track** and does not allow for set and drift.

When the ship moves at high seas at the usual sea speed it carries some mass of surrounding water with it and thereby providing a distinct layer of water between 10 and 30 meters below the keel and this depth depends on the draft and speed of vessel. Below this depth the water is still and hence there is a distinct separation between the two layers of water which provides the echoing surface of the acoustic waves. These echoes are of course weak since the echoing surface is actually liquid, but stronger than the echoes coming from the depths of over 200 meters. The speed worked out does not depend on the depth from which the echoes are received. The strength of the echoes indicates whether the ship is on bottom track or on water track.

ATHWARTSHIP'S SPEED

Doppler log on ground track mode can provide athwartship's speed as well and for this purpose a similar Janus configuration is used on the port and starboard sides. The athwartship speed is calculated in the similar manner as mentioned above.

EFFECT OF VARIOUS SHIP CONDITION AND SHIP MOTION

➢ **Heaving**

Any vertical movement Vv will have component Vv sin α in the direction of the acoustic wave, resulting in an error in Doppler shift

$$= 2 \text{ Vv ft Sin } \alpha / c.$$

Hence the Doppler shift measurement at forward transducer will be given by

$$fr_f - ft = 2 \text{ v ft Cos } \alpha / c + 2 \text{ Vv ft Sin } \alpha / c$$

and that at the aft transducer will be given by

$$fr_a - ft = - 2 \text{ v ft Cos } \alpha / c + 2 \text{ Vv ft Sin } \alpha / c$$

By measuring the difference between the two Doppler shift frequencies, the vertical component will cancel out while the horizontal will add i.e.

$$(fr_f - ft) - (fr_a - ft) = (2 \text{ v ft Cos } \alpha + 2 \text{ Vv ft Sin } \alpha) / c$$
$$- (-2 \text{ v ft Cos} \propto + 2 \text{ Vv ft Sin} \propto) / c$$

$$fr_f - ft - fr_a + ft = 2 \text{ v ft Cos } \alpha / c + 2 \text{ Vv ft Sin } \alpha / c$$
$$+ 2 \text{ v ft Cos } \alpha / c - 2 \text{ Vv ft Sin } \alpha / c$$

$$fr_f - fr_a = 4 \text{ v ft Cos } \alpha / c$$

Therefore, $v = (fr_f - fr_a)\, c / 4ft \text{ Cos } \alpha$

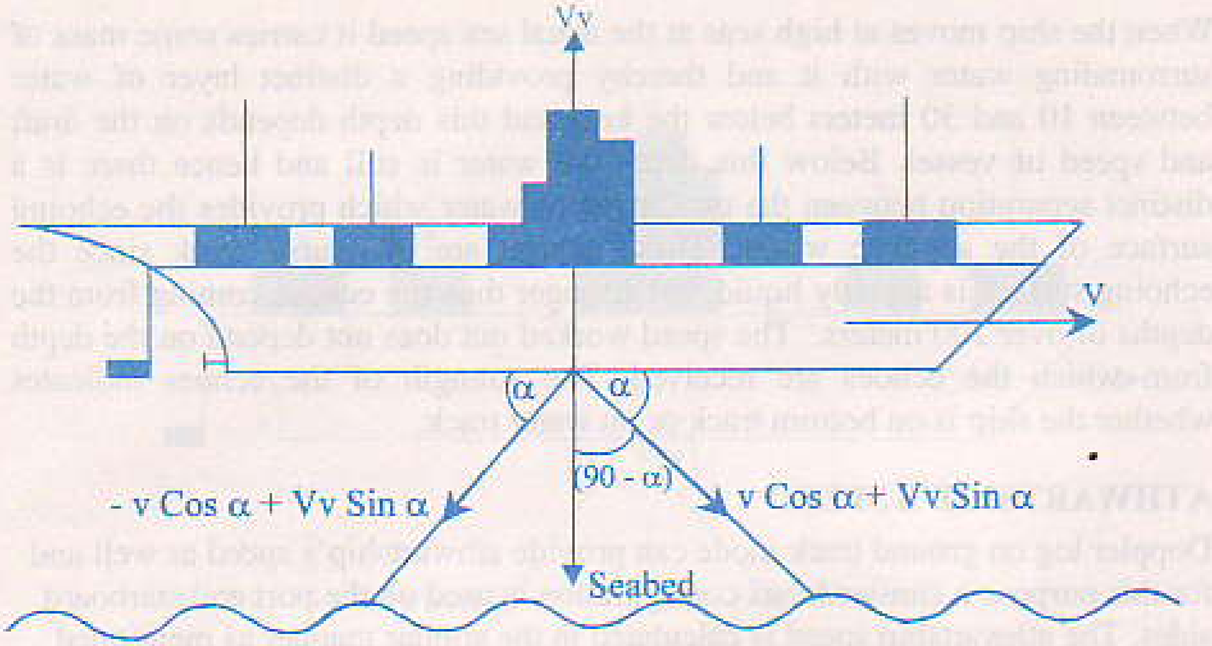


Figure 3
Effect of heaving

Thus any vertical movement has got no effect on the speed indicated.

➢ **Trim**

The trim of the vessel has very less affect on fore and aft speed and no affect on athwartship speed.

♦ **When down by stern**

When trimmed by an angle β, the forward transducer will transmit at an angle (α - β) while the aft transducer will transmit at an angle (α + β) as shown in figure 4 and the Doppler shift frequency measurement by the forward transducer will be

$$fr_f - ft = 2\ v\ ft \cos(\alpha - \beta) / c$$

while the Doppler shift frequency measurement by the aft transducer will be

$$fr_a - ft = -2\ v\ ft \cos(\alpha + \beta) / c$$

$$\text{Thus } fr_f - fr_a = 2\ v\ ft\ [\cos(\alpha - \beta) + \cos(\alpha + \beta)] / c$$

$$= 2\ v\ ft\ [\cos\alpha \cos\beta + \sin\alpha \sin\beta$$
$$+ \cos\alpha \cos\beta - \sin\alpha \sin\beta] / c$$

$$= 2\ v\ ft\ (2 \cos\alpha \cos\beta) / c$$

$$= 4\ v\ ft \cos\alpha \cos\beta / c$$

$$v = (fr_f - fr_a)\ c / 4\ ft \cos\alpha \cos\beta$$

Note

$$\cos(\alpha + \beta) = \cos\alpha \cos\beta - \sin\alpha \sin\beta$$

$$\text{and } \cos(\alpha - \beta) = \cos\alpha \cos\beta + \sin\alpha \sin\beta$$

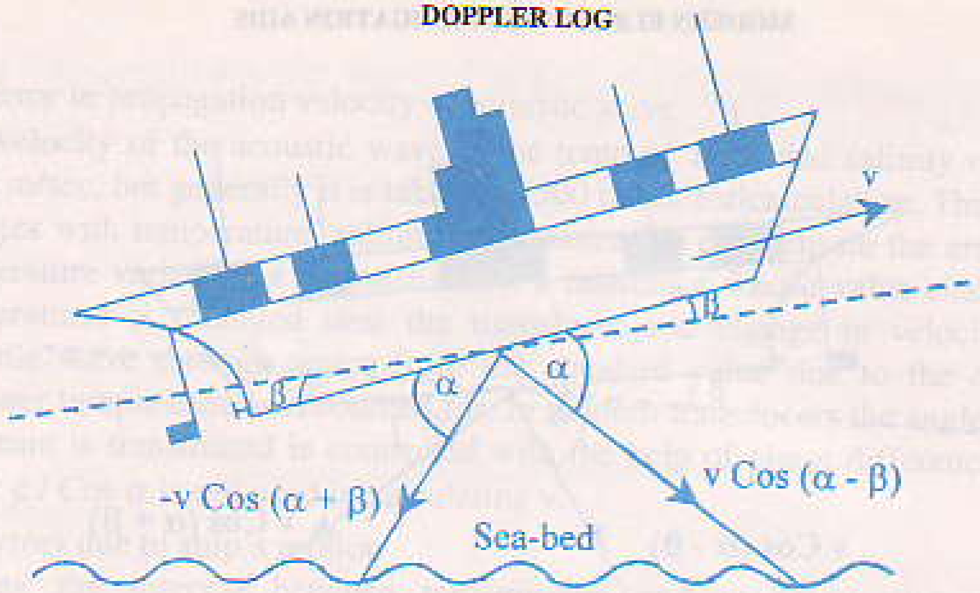


Figure 4
Ship trimmed- down by stern at angle β

The above formula gives the actual speed in trimmed condition while the speed indicated is calculated by given formula

$$v = (fr_f - fr_a)\, c \,/\, 4\, ft \cos\alpha$$

Hence Actual speed = Indicated speed / Cos β.

- **When down by head**

When trimmed by head at angle β, the forward transducer is now transmitting at angle (α + β) while the aft transducer is transmitting at an angle (α- β) as shown in figure 5, hence

$$fr_f - ft = 2\, v\, ft \cos(\alpha + \beta) / c \quad \text{and}$$

$$fr_a - ft = -2\, v\, ft \cos(\alpha - \beta) / c$$

$$\text{Thus } fr_f - fr_a = 2\, v\, ft\, [\cos(\alpha + \beta) + \cos(\alpha - \beta)] / c$$

$$= 2\, v\, ft\, [\cos\alpha \cos\beta - \sin\alpha \sin\beta + \cos\alpha \cos\beta + \sin\alpha \sin\beta] / c$$

$$= 2\, v\, ft\, (2 \cos\alpha \cos\beta) / c$$

$$= 4\, v\, ft \cos\alpha \cos\beta / c$$

$$v = (fr_f - fr_a)\, c / 4\, ft \cos\alpha \cos\beta$$

Once again indicated speed is less than actual speed by factor of 1 / Cos β i.e. whether down by head or down by stern,

Actual speed = Indicated speed / Cos β

Maximum trim permitted under Marpol Annex I Reg 13 is 1.5% of ship's length. Hence $\beta = \tan^{-1} 1.5/100$,

$\beta = 0.86°$

and $\cos\beta = \cos 0.86° = 0.9998874$.

Now if the indicated speed is 16 knots, the actual speed = 16 /. 998874
= 16.001689 kts.

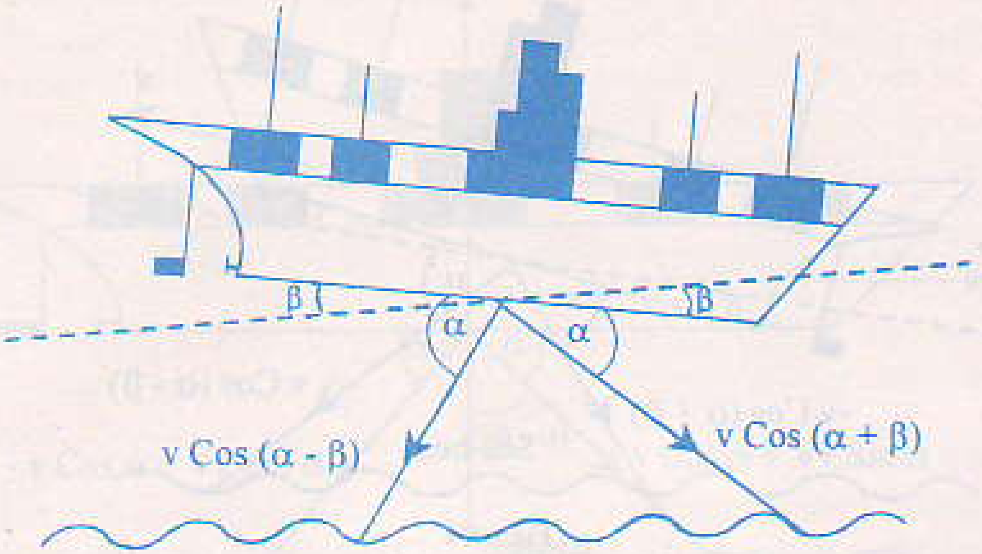


Figure 5
Ship trimmed-down by head at angle β

We notice that the difference is only in the third and fourth decimal places. In other words it is negligible difference. In fact this difference may not be indicated on the display, since the display shows only up to two decimal places. Note that change of trim does not effect the athwartships speed.

➢ **Pitching**

The effect of pitching is similar to a vessel with trim changing continuously. When the vessel is pitching, the indicated speed will fluctuate between actual speed and a value lower then the actual speed depending on the angle at which it is pitching. Pitching does not effect athwartships speed.

➢ **List and rolling**

Effect of list on athwartships speed will be the same as the effect of trim on the forward and aft speed i.e.

Actual speed (ath) = Indicated Speed (ath) / Cos list

This is irrespective of the side to which the ship is listed. When the vessel is rolling, the indicated athwartship speed will fluctuate between the actual speed and the indicated lower speed worked out by the above formula depending on the angle of roll. List and rolling does not effect the fore and aft speed.

ERRORS

➢ Error in transducer orientation

The transducers should make a perfect angle of 60° with respect to the keel or else the speed indicated will be inaccurate.

➢ Error in oscillator frequency

The frequency generated by the oscillator must be accurate and constant, any deviation in the frequency will result in the speed indicated being in error.

➢ Error in propagation velocity of acoustic wave

The velocity of the acoustic wave at the temp of 16°C and salinity of 3.4% is 1505 m/sec, but generally it is taken as 1500 m/sec for calculation. This velocity changes with temperature, salinity or pressure. To compensate the error due to temperature variation, a thermistor (i.e. a resistance whose value changes with temperature) is mounted near the transducer and change in velocity of the acoustic wave through water from the standard value due to the change in seawater temperature is accounted for. In modern transducers the angle at which the beam is transmitted is controlled with the help of phase difference and the factor c / Cos α is not used in calculating v.

➢ Errors due to ship's motion

During the interval between transmission and reception, the ship may marginally roll or pitch and thereby the angle of transmission and reception can change and for a two degree difference between the angle of transmission and reception, the net effect will be an error of 0.10% of the indicated speed which is marginal and can be neglected.

➢ Errors due to the effect of rolling and pitching

The effect of pitching will cause an error in the forward speed but it has no affect on the athwartship speed. Similarly rolling will cause an error in athwartship, but not in forward speed.

$$\text{Actual Speed} = \text{Indicated speed} / \cos\beta$$

Where β is the angle of pitching for forward speed and angle of roll in case of athwartship speed, e.g. if the ship is pitching at an angle of 10° and the indicated speed is 15 knots, then the

$$\text{Actual speed} = 15/ \cos 10^\circ$$

$$\text{i.e. Actual speed} = 15.23 \text{ kts.}$$

This error will increase with angle of pitch i.e. in rough seas. The digital readout will fluctuate between the actual speed (i.e. at the instant when the pitch angle is zero) and a value lower than the actual speed (i.e. when the angle of pitch is maximum).

The athwartship speed assumes importance only at the time of berthing where the rolling is negligible and hence the above formula is generally used in case of forward speed only.

➢ Error due to inaccuracy in measurement of comparison frequency

The difference in the frequencies received by the forward and aft transducers must be measured accurately as any error in this will be directly reflected in the speed of the vessel.

➢ Error due to side lobe

When the side lobe reception dominates over the main beam reception, there will be an error in the speed indicated. This error is more pronounced on a sloppy bottom, where the side lobe will be reflected at a more favourable angle and will have path length less than the main beam.

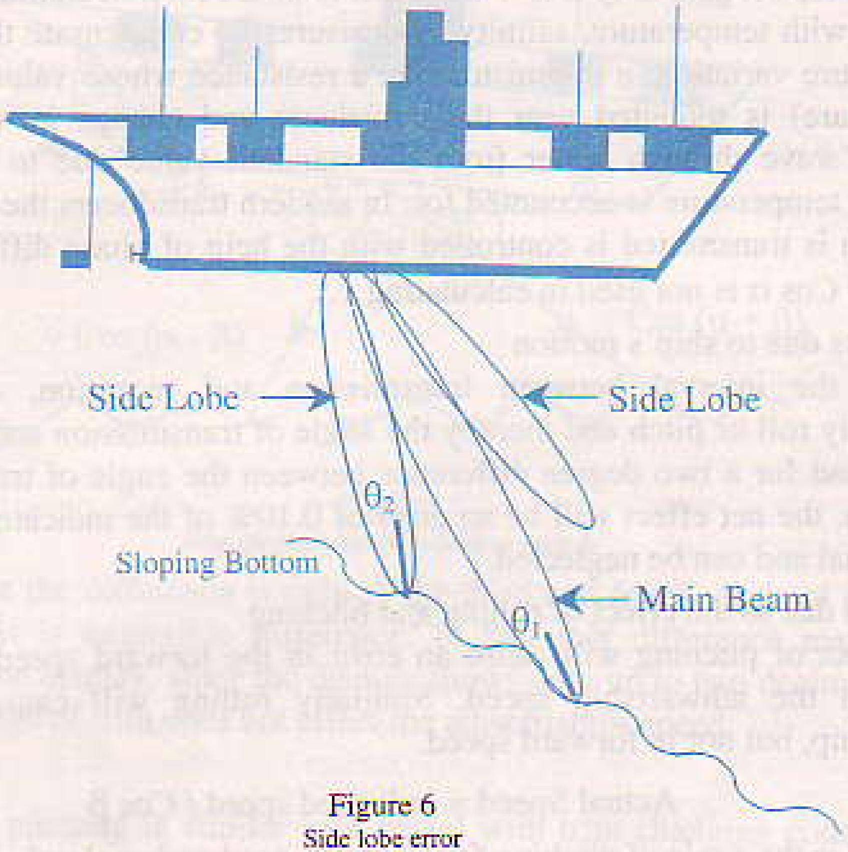


Figure 6
Side lobe error

This error cannot be eliminated with the help of Janus configuration and to reduce this error the beam of the transmitted acoustic wave is reduced. However a minimum beam width of 4 to 6° is required

CALIBRATION

It is very important for any instrument to be calibrated correctly before being used and in a Doppler log the calibration has to be done in two steps

- Firstly the zero on scale should be set correctly and this can be done and checked whenever the ship is berthed at a jetty or at anchor when the speed over ground is zero and
- The second is the scale calibration and should be done during sea trial when time taken to cover a measured mile is noted and the speed is calculated This calculated speed must match with the displayed reading and in case of any discrepancy between the two, the equipment can be adjusted. Once these two calibrations are done the Doppler log can be used effectively.

Built - in - correction for deviation of speed of acoustic wave through water and angle α.

We already know that

$$v = (fr_f - fr_a) \times c / 4\ ft \cos\alpha$$

In the above formula the factor c, Cos α and ft can be eliminated by a special type of transducer. This transducer consists of 72 electrostrictive elements possessing the piezostrictive property. A set of only 4 transducers are shown in figure 8.

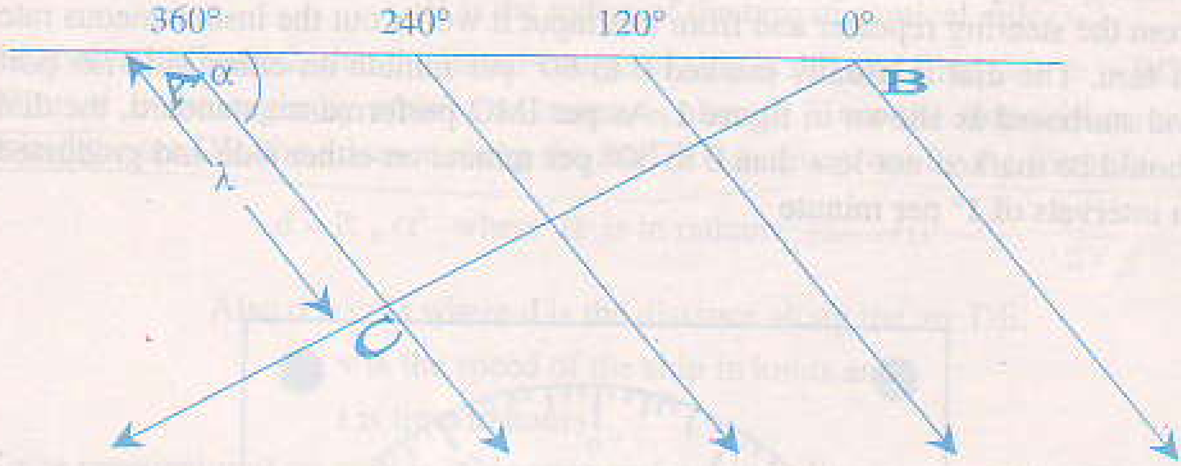


Figure 8

Special design of transducer used to generate acoustic wave at angle α using phase difference technique

Each of the elements is supplied with an alternating voltage differing in phase by 120° and the acoustic wave thus created has the same phase difference. All the points on the line AB are in phase and such a plane is called a wave front.

$$\cos\alpha = AC/ AB \ldots\ldots\ldots\ldots\ldots\ldots(i)$$

$$AC = \lambda \quad \ldots\ldots\text{refer figure 8}$$

$$\text{where } \lambda = c / ft \ldots\ldots\ldots\ldots\ldots\ldots\ldots(ii)$$

$$\text{Therefore } AC = c / ft \ldots\ldots\ldots\ldots\ldots\ldots(iii)$$

$$\text{Hence } \cos\alpha = (c / ft) / AB$$

$$\text{or } c / \cos\alpha = f\,t\ AB \ldots\ldots\ldots\ldots\ldots(iv)$$

$$\text{We know, } v = (fr_f - fr_a)\ c / 4ft \cos\alpha \ldots(v)$$

Substituting the value of equation (iv) in equation (v)

$$\text{We get, } v = (fr_f - f_{ra})\ AB / 4$$

Thus by using these transducers the error due to c, Cos α and ft can be eliminated. The distance AB is fixed and with (fr_f - f_{ra}) being measured accurately, v can be calculated

CHAPTER VII

RATE OF TURN INDICATOR

GENERAL DESCRIPTION

The rate of turn indicator is equipment, which indicates the instantaneous rate at which the ship is turning. This indicator is fed with 60 to 200 pulses per minute from the steering repeater and from this input it works out the instantaneous rate of turn. The dial is usually marked 0 to 60° per minute on either side i.e. port and starboard as shown in figure 1. As per IMO performance standard, the dial should be marked not less than 0 to 30° per minute on either side and graduated in intervals of 1° per minute

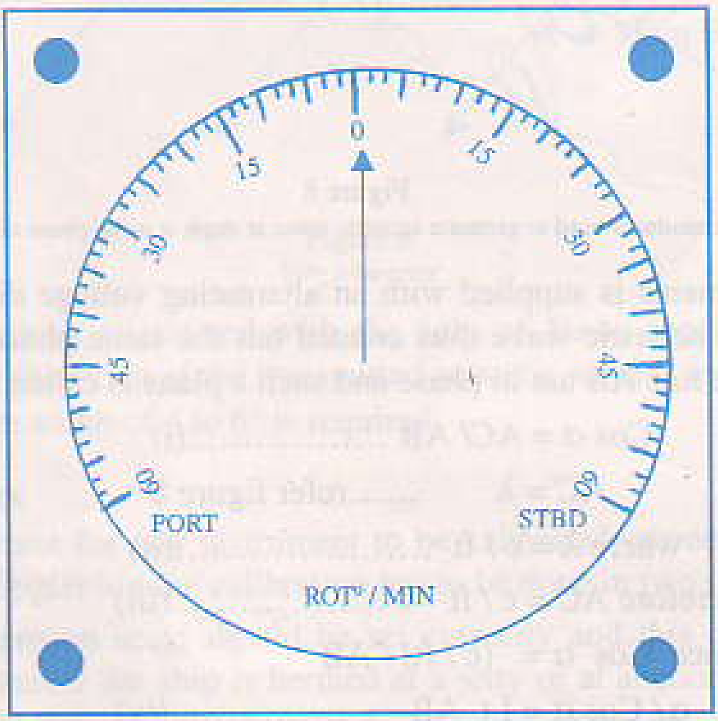


Figure 1

It is well known fact that when the ship turns, she actually traverses some distance round the arc of a circle and cannot execute sharp turns about a point. Moreover when designing traffic separation schemes and narrow channels, the recommended routes take into consideration the fact that the ship will move along the arc of a circle while executing a turn, rounding a sharp bend or any other alteration of course. To enable a ship to execute a turn or an alteration of course the **Rate of Turn Indicator** is very useful equipment.

As per SOLAS chapter V regulation 12 (n), it is now mandatory for ships above 1,00,000 tonnes gross and constructed on or after 1st September 1984 to have a rate of turn indicator. As per latest IMO recommendation large course alteration have to be planned along circular tracks with wheel over point marked and the progress of the ship continuously monitored.

The rate of turn is based on the formula

Rate of Turn = v / R degree per minute

Where v is the speed of the vessel over ground and

R is the radius of the turn in nautical miles.

As shown in figure 2, that the initial course of ship is AB and final course is BC, θ° or α^c is the angle by which the course is altered. Since the ship will travel round the arc DE, the distance along the arc DE i.e. d is given by the formula

$$d = R \cdot \alpha^c \quad \text{where } \alpha \text{ is in radians} \text{ ....(i)}$$

Also d = v . t where d is the distance along the arc DE,

v is the speed of the ship in knots and

t is time in hours

Since practical unit on ship is in degrees and not in radians, we need to convert radians to degrees and we know that $1^c = 57.3^\circ$

Therefore, $d = R\,\theta^\circ / 57.3$ ....(ii)

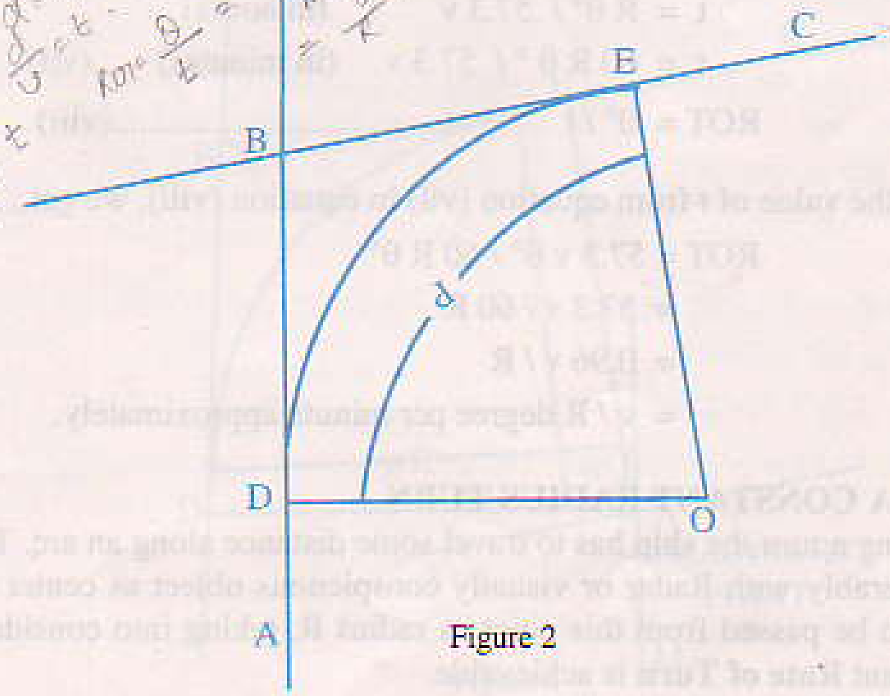


Figure 2

Note: For students interested in knowing how equation 2 is obtained from equation 1, please refer the following

$$\text{Since } 1^c = 57.3^\circ$$

$$\alpha \text{ radian} = (57.3\ \alpha)^\circ,\ (\text{using } 57.3\ \alpha = \theta^\circ) \ldots\ldots (iii)$$

Therefore, from equation (i),

$$d = R\,(57.3\ \alpha)^\circ \ldots\ldots\ldots\ldots (iv)$$

Although the unit of measure of the angle has changed from radians to degrees, the distance d remains same. To maintain d constant in equation (iv), we have to divide the RHS by 57.3

$$\text{Hence } d = R\ (57.3\ \alpha)^\circ / 57.3$$

$$d = R\,\theta^\circ / 57.3 \qquad \text{refer equation (iii)}$$

e.g. if R = 2 nautical mile

and the ship has to alter course by 90° i.e. π / 2 radians

$$d = R \times \alpha$$

$$= 2 \times \pi / 2$$

$$= \pi \text{ nautical mile}$$

$$= 3.142 \text{ nautical mile.}$$

Now using degrees, $d = 2\ (57.3 \times \pi / 2) \ldots\ldots\ldots\ldots (v)$

To keep the distance d constant, the RHS of equation (v) has to be divided by 57.3

$$\text{Therefore, } d = 2\ (57.3 \times \pi / 2) / 57.3$$

$$= \pi \text{ nautical mile}$$

$$= 3.142 \text{ nautical mile}$$

$$\text{Hence } d = R\,\theta^\circ / 57.3$$

Now time taken i.e. $t = d / v$ ....(vi)

substituting the value of d from (ii) we get,

$$t = R\,\theta^\circ / 57.3\,v \qquad \text{(in hours)}$$

$$t = 60\,R\,\theta^\circ / 57.3\,v \qquad \text{(in minutes)} \ldots\ldots (vii)$$

$$ROT = \theta^\circ / t \qquad \ldots\ldots\ldots\ldots (viii)$$

Substituting the value of t from equation (vii) in equation (viii), we get

$$ROT = 57.3\,v\,\theta^\circ / 60\,R\,\theta^\circ$$

$$= 57.3\,v / 60\,R$$

$$= 0.96\,v / R$$

$= v / R$ degree per minute approximately.

PLANNING A CONSTANT RADIUS TURN

While executing a turn the ship has to travel some distance along an arc. The arc is drawn preferably with Radar or visually conspicuous object as center O and the distance to be passed from this point as radius R, taking into consideration that the resultant **Rate of Turn** is achievable.

The initial and final courses are now drawn tangential to the arc where the two tangent points are D and E respectively. The ship will travel along the arc DE while executing the turn.

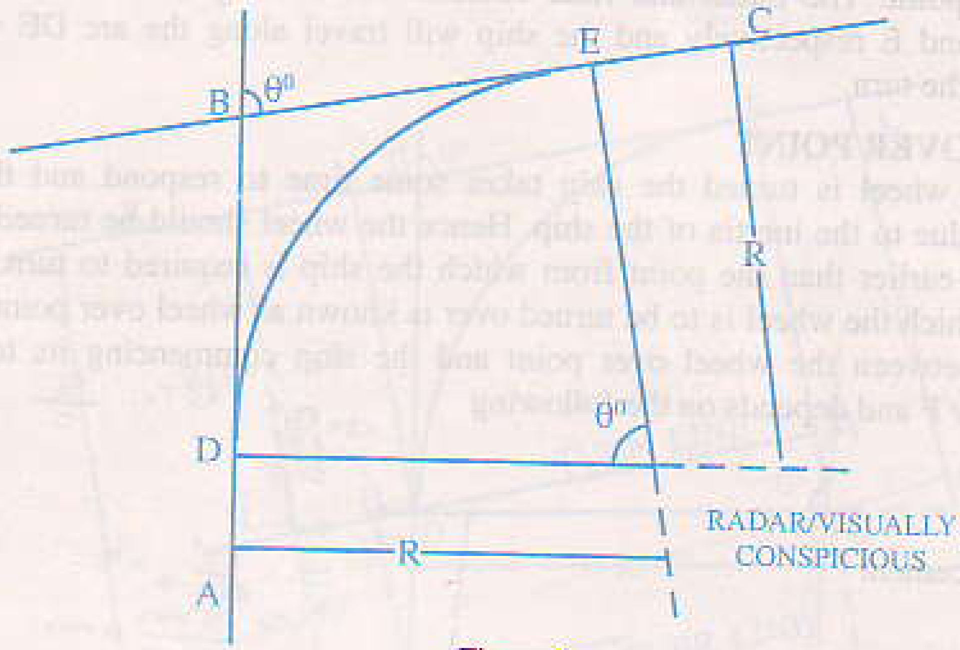


Figure 3

Conversely if the point O is not a radar or visually conspicuous i.e. it is an imaginary point, then the initial and final courses AB and BC are first drawn respectively. The radius R is now chosen conveniently, considering that the resultant ROT is achievable.

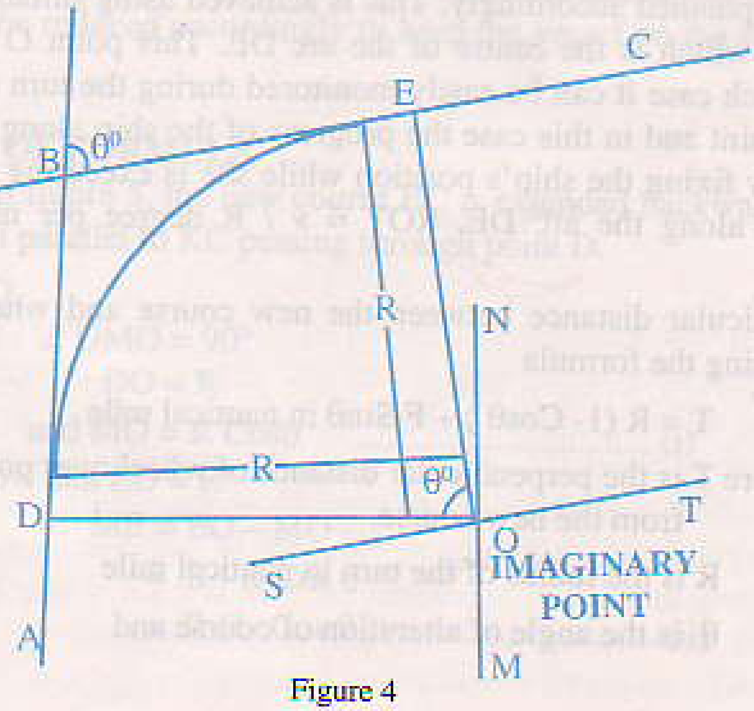


Figure 4

The two lines MN and ST are drawn parallel to initial and final courses respectively at a distance R and towards the center of the turn as shown in fig.4.

These two lines will intersect at point O and the arc DE is drawn with radius R from this point. The initial and final courses will be tangential to the arc at points D and E respectively and the ship will travel along the arc DE while executing the turn.

WHEEL OVER POINT

When the wheel is turned the ship takes some time to respond and this is primarily due to the inertia of the ship. Hence the wheel should be turned over at a point earlier than the point from which the ship is required to turn. This point at which the wheel is to be turned over is known as wheel over point. The distance between the wheel over point and the ship commencing its turn is denoted by F and depends on the following

- Length
- Beam
- Displacement
- Speed
- trim and
- type of the vessel.

PLANNING THE CONSTANT RADIUS TURN

As shown in figure 5, the ship is on her initial course AB and has to alter to new course BC, where the angle of alteration is θ°. It is not possible for the ship to take a sharp turn at point B and will actually travel along the arc DE, hence the turn must be planned accordingly. This is achieved using suitable radius R from the point O, which is the centre of the arc DE. This point O could be a land mark, in which case it can be easily monitored during the turn or it could be an imaginary point and in this case the progress of the ship along the turn is to be monitored by fixing the ship's position while she is executing the turn. For the ship to turn along the arc DE, ROT = v / R degree per minute should be achieved.

The perpendicular distance between the new course and wheel over point is calculated using the formula

$$T = R\,(1 - \cos\theta) + F \sin\theta \text{ in nautical mile}$$

where T is the perpendicular distance of wheel over point from the new course.

R is the radius of the turn in nautical mile

θ is the angle of alteration of course and

F depends on type and size of the ship and
is normally taken as 0.1 nautical mile for small ships,
0.15 nautical mile for large ships and
for very large ships it can go as high as 0.2 nautical mile.

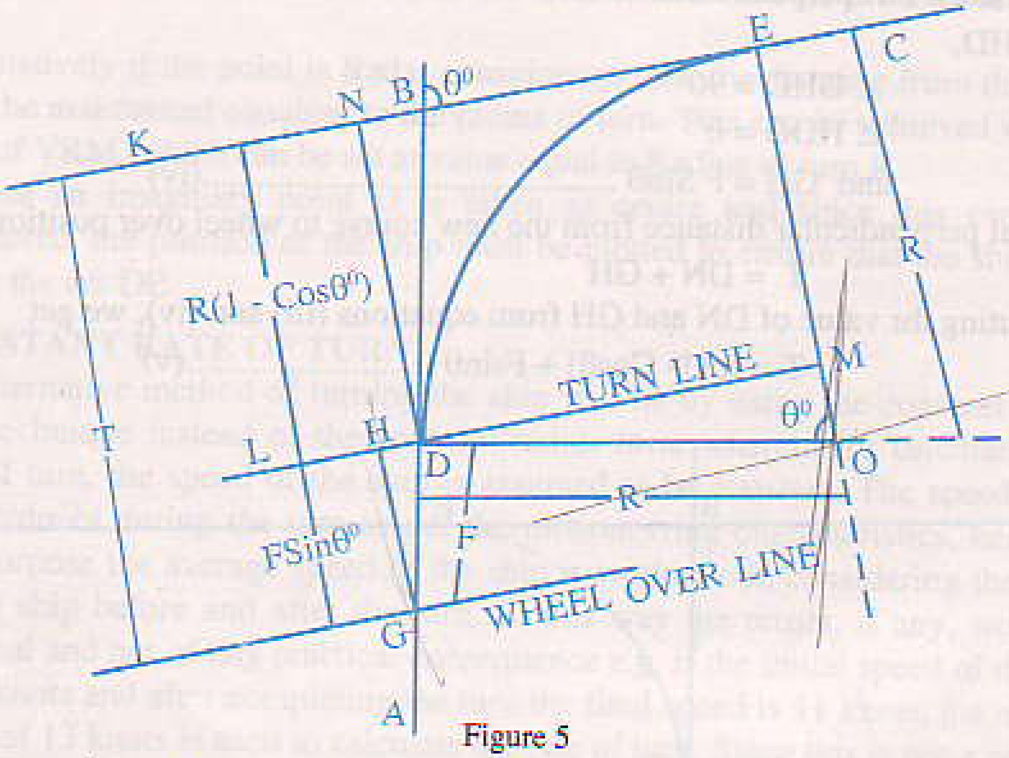


Figure 5

For convenience the radius R is chosen as 1 nautical mile, 1.5 nautical mile or 2 nautical mile so that calculating ROT becomes an oral exercise (ROT = v / R). Practically while executing the turn the speed of the ship reduces and therefore, the ROT has to be reduced accordingly to keep the vessel on the same track i.e. arc DE.

DERIVATION OF FORMULA

With reference to figure 5, the new course BC is extended backward to K and a line LM is drawn parallel to KC passing through point D.

Consider Δ DMO,

$$\angle DMO = 90^\circ$$

$$DO = R$$

$$\text{and } MO = R \cos\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

We also know that EO = R

$$ME = EO - MO$$

$$= R - R \cos\theta$$

$$= R(1 - \cos\theta) \quad \ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

From D draw DN perpendicular to KC meeting KC at N. The distance DN is the perpendicular distance of D from the new course.

Since KC and LM are parallel, the perpendicular distance between the two

i.e. $DN = ME = R\,(1 - \cos\theta)$ ……………..(iii)

From G draw GH perpendicular to LM.

In Δ GHD,

$\angle GHD = 90°$

$\angle HDG = \theta°$

and $GH = F\sin\theta$ ……………………………………..(iv)

The total perpendicular distance from the new course to wheel over position

$T = DN + GH$

Substituting thr value of DN and GH from equations (iii) and (iv), we get

$T = R\,(1 - \cos\theta) + F\sin\theta$ ………………………(v)

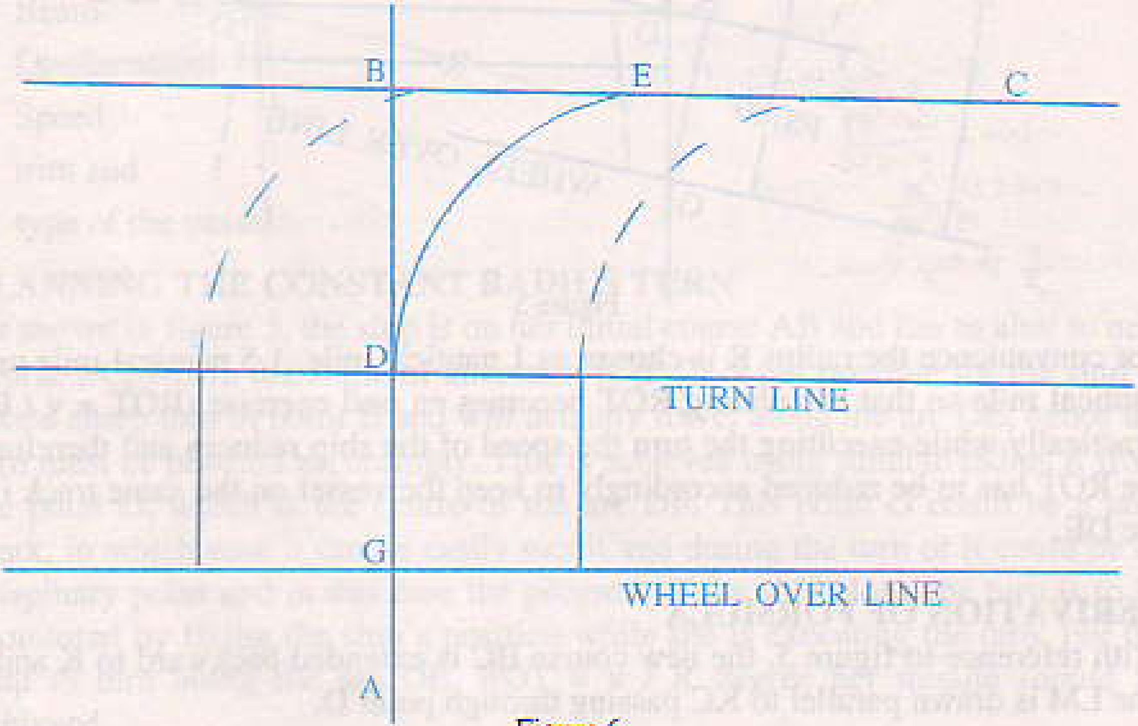


Figure 6

Due to current and wind the ship could have drifted either to port or starboard and may not be on the initial course line AB. In this case to execute the turn and to ensure that the ship finally comes on the new course line, the wheel over point has to be adjusted. To achieve this a line parallel to new course is drawn through the wheel over point G, referred to as the wheel over line, so that as soon the ship reaches this line the wheel must be put over as required. The ship will start turning as soon as it reaches the turn line i.e. a line drawn at point D parallel to the new course. The ship will now turn along the dotted lines and complete the turn on the new course line as shown in figure 6.

MONITORING THE TURN

In the fig 6, the point O is so chosen that it is either visible or Radar conspicuous and if both are not available then the point O may be an imaginary point.

Considering that the point O is visible then the relative bearing of the point should be maintain constant so that the ship remains on the arc DE during the turn.

Alternatively if the point is Radar conspicuous then the distance from this point must be maintained equaling to the radius of turn. This can be achieved with the help of VRM, which can be set at value equal to Radius of turn R.

In case an imaginary point O is taken as centre and since this cannot be monitored, the position of the ship must be plotted to ensure that the ship turns along the arc DE.

CONSTANT RATE OF TURN

An alternative method of turning the ship will be by using the constant rate of turn technique instead of the constant radius turn, wherein for calculating the rate of turn, the speed of the ship is assumed to be constant. The speed of the ship reduces during the turn as per the monouevring characteristics, hence for this purpose the average speed of the ship is worked out, considering the speed of the ship before and after the turn. In this way the errors, if any, would be minimal and not of any practical consequence e.g. if the initial speed of the ship is 15 knots and after completing the turn the final speed is 11 knots, the average value of 13 knots is used to calculate the rate of turn. Since this is not a constant radius turn, the track followed is the one shown in dotted line in figure 7, while if a constant radius turn is executed the track would be the one shown in bold. Practically the difference is only marginal.

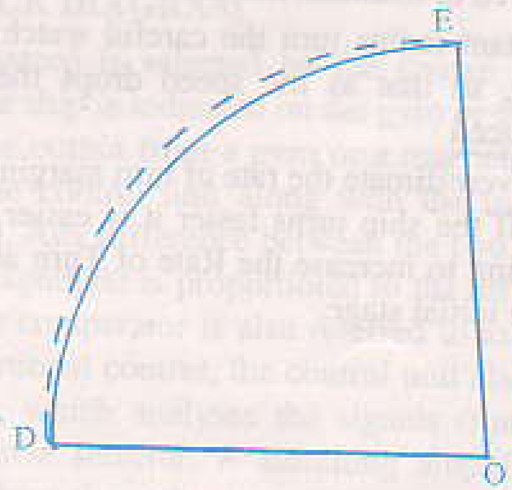


Figure 7

Thus to execute a turn either by the constant radius turn or constant rate of turn, the **Rate of Turn Indicator** is a very helpful equipment, but in either case the helm has to be adjusted by the helmsman to get the desired **Rate of Turn** and then to maintain it. It is, therefore, prudent to carry out a few practice turns in open sea before executing one in restricted waters.

On some modern ships the auto pilot is provided with a rate of turn control and on this control the required rate of turn can be set so that as soon as the ship reaches the wheel over line position, the new course can be fed to the auto pilot. The ship will now execute the turn with the help of autopilot, the wheel being adjusted according to the rate of turn fed to the control. The ship will also be steadied on the new course automatically.

ADVANTAGES

- The turn can be preplanned and the required rate of turn can be pre-calculated. Hence the execution of the turn becomes simple.
- The turn can be easily monitored while it is being executed.
- Since the turn is preplanned, the use of helm is minimized and thereby loss of speed during the turn is also reduced.
- Even if the ship has drifted to port or starboard. the turn can be easily amended so that on completion of the turn the ship is on the new course.

PRECAUTIONS WHILE USING THE RATE OF TURN INDICATOR

- The speed to be used for calculating the rate of turn is speed over ground and not speed over water.
- Initially a large helm is required to achieve the calculated rate of turn. The helm must be immediately eased as soon the rate of turn is achieved to the bare minimum required to maintain the rate of turn.
- In the case of constant radius turn the careful watch on the ground speed must be maintained, so that as the speed drops the rate of turn can be correspondingly reduced
- It is always safe to overestimate the rate of turn marginally rather than under-estimating it, since if the ship turns faster it is easier to reduce the Rate of Turn rather than trying to increase the Rate of Turn at a later stage if she is turning slowly at the initial stage.

CHAPTER VIII

AUTO PILOT

GENERAL

The autopilot is basically used when a ship has to steer a set course for a long time without alteration because any deviation from the set course is controlled electronically and automatically. This will not only relieve the helmsman from steering duties but is also more efficient because as soon as the ship deviates from the set course, corrective action is taken immediately using requisite amount of helm to bring the ship back to the set course. This is achieved by comparing the course to steer as set by the navigator with the ship's heading obtained from gyro or magnetic compass, any difference between the two will cause an error and correcting helm is applied to the rudder such that the heading is brought to the same value as the set course. With the use of autopilot over a long period of time, the average speed of the ship increases as the ship does not zig zag across the track and this will also ensure that ship's steering gear operates to a minimum. A good automatic steering system also reduces the fuel consumption. Since the manoeuvering characteristics of ship depends on the type of ship, length, beam and also varies with trim, loading and weather condition etc., certain critical controls have to be set optimally to obtain efficient automatic steering. The autopilot must have indicators to show whether the steering is on manual or autopilot and the change over switch must be on or near the steering panel itself.

SIMPLIFIED BLOCK DIAGRAM

The course to be steered is selected by the course selector knob while the present heading of the ship is indicated on the gyro or the magnetic compass. As shown in figure 1, the output from a gyro or a magnetic compass is coupled to the comparator in the control unit along with the input signal from manual course setting control. Any difference between the two signals causes an output error signal whose magnitude is proportional to the difference between the two signals and hence the comparator is also referred to as proportional control. In addition to the proportional control, the control unit also consists of derivatives and integral controls, which analyses the signals from the gyro or magnetic compass and the course selector. A summing amplifier is used to obtain a resultant error signal from these three controls.

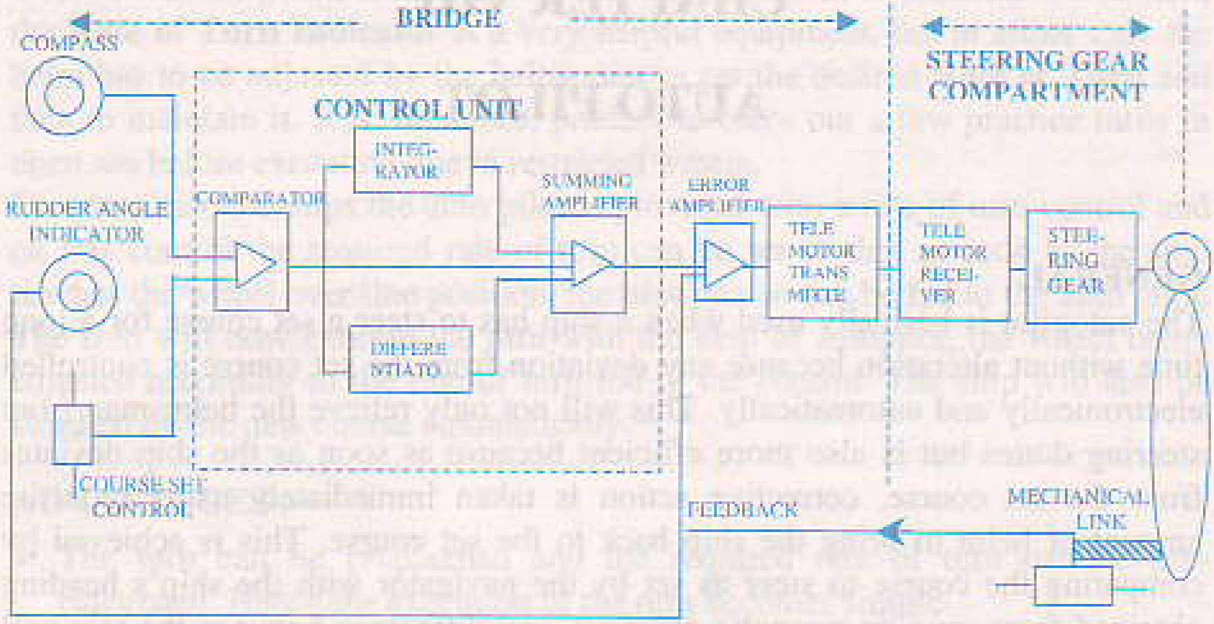


Figure 1
Simplified Block Diagram of Autopilot

This error signals is fed to the error amplifier, which also gets feedback signals from the rudder, consisting of rudder position and its movement. The output of the error amplifier is fed via telemotors to the steering gear unit and in turn operates the rudder. The telemotor has two units i.e. transmitter and receiver which are situated on the bridge and steering gear compartment respectively. There will be no output from the control unit when the difference between the two signals is zero and hence no movement of the rudder results.

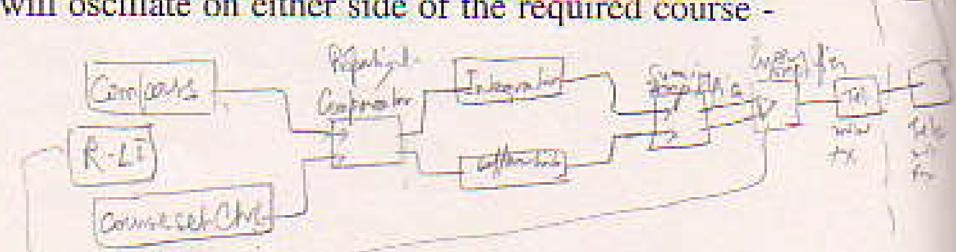
DETAILS OF CONTROL UNIT

In order to maintain the ship's course as accurately as possible, the helm must be provided with data regarding the ship's movement relative to the course to steer line. It is achieved by electronic circuits with the help of the following controls, which forms the heart of the control unit

- Proportional control
- Derivative control and
- Integral control

PROPORTIONAL CONTROL

The effect on steering when only proportional control is applied causes the rudder to move by an amount proportional to the off – course error from the course to steer and the ship will oscillate on either side of the required course - line as shown in figure 2.



When the ship has gone off course to port from the course to steer as shown in figure 2, an error occurs and helm has to be used to alter the course to starboard so as to bring the ship back on the set course.

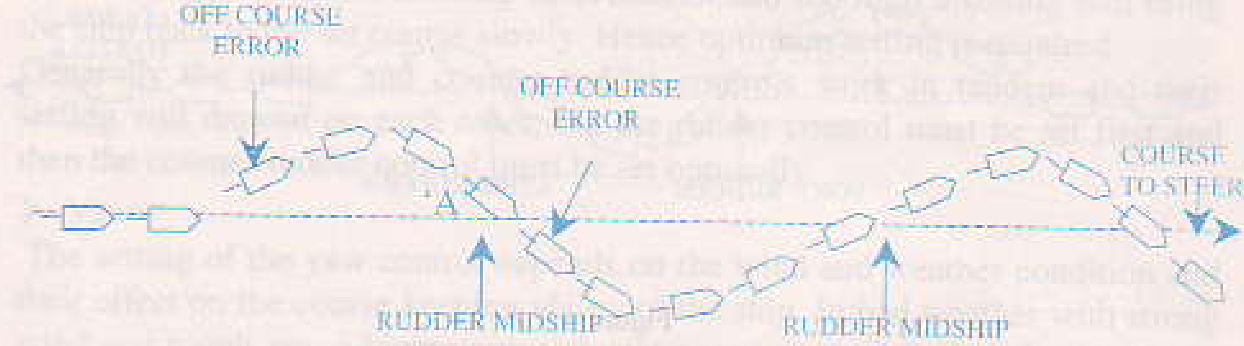


Figure2
Motion of the ship due to proportional control only

As the ship starts to return to the set course, the helm is gradually reduced and finally when the ship is back on the set course, the helm is removed. The rudder will be amidship as the ship approaches its course at point **A** causing an overshoot resulting in ship to go more to starboard than the requires course. Correcting data is now applied causing a port turn to bring the ship back to its original course line.

DERIVATIVE CONTROL

In derivative control the rudder is shifted by an amount proportional to the rate of change of ship's deviation from the course. As shown in figure 3, any deviation of course to port causing correcting starboard rudder to be applied. The rate of change of course decreases with the result that automatic rudder control decreases and at point **A,** the rudder will return to midship position as shown in figure 3.

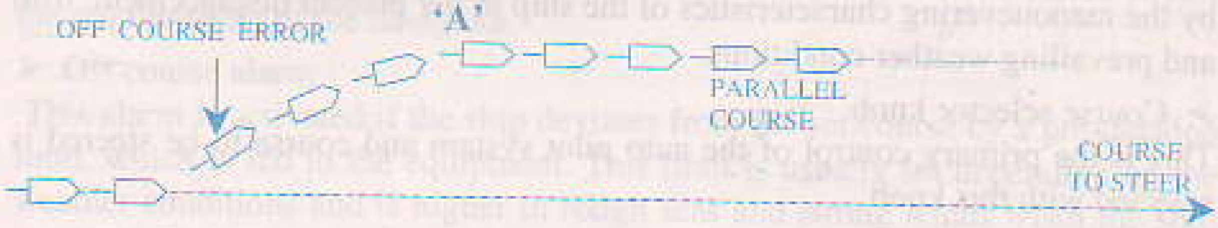


Figure 3
Motion of the ship due to derivative control only

The ship will now make good a course, which is parallel to the required course and will continue to do so.

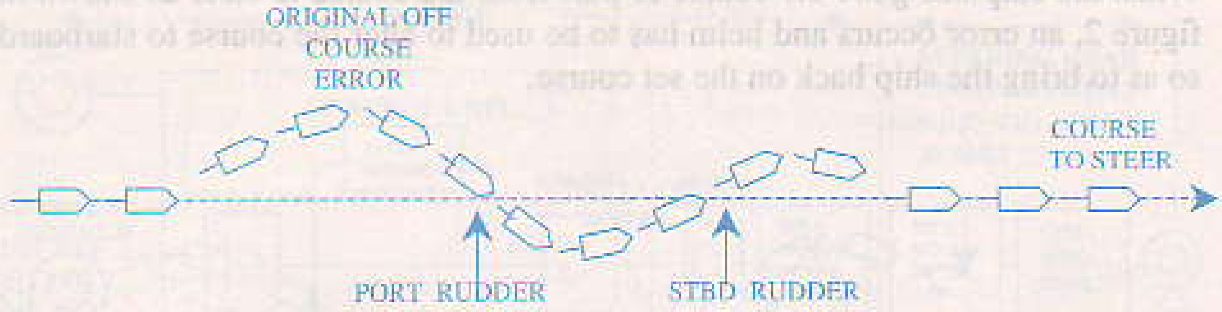


Figure 4
Motion of the ship due to combined effect

An ideal combination of both proportional and derivative control produces a more satisfactory return to course as shown in figure 4.

INTEGRAL CONTROL

There are certain errors due to design parameters of the ship like shape of the hull, bow going to port when ship is making a headway due to transverse thrust etc., which have to be corrected. Data signals are produced by continuously sensing heading error over a period of time and applying an appropriate degree of permanent helm is used for this purpose. The rudder used to correct the course will now be about this permanent helm instead of the actual midship i.e. permanent helm now acts as midship.

The output of these three controls is combined and the net resultant thus obtained drives the rudder, thereby maintaining the ship on the set course. Hence this type of autopilot is also referred to as PID autopilot

CONTROLS ON THE PANEL

Following are the critical controls and the setting of these controls is governed by the manouevering characteristics of the ship in her present displacement, trim and prevailing weather conditions

- Course selector knob

This is the primary control of the auto pilot system and course to be steered is selected with this knob.

- Rudder control

This control determines the amount of rudder to be used to correct the slightest amount of deviation from the set course. The higher the setting, the larger the rudder angle used to correct a course deviation and this may result in over correcting. Contrarily if the setting is low, less rudder angle is used to correct a course deviation and the ship will take a long time to return to the set course. Hence the setting has to be optimum so that the ship quickly returns to the set course with minimum overshoot.

- Counter rudder

This control determines the amount of counter action by the rudder to be used to steady the ship on the set course keeping the overshoot to a minimum. Too low a setting will allow the ship to overshoot and too high a setting will bring the ship back to the set course slowly. Hence optimum setting is required.

Generally the rudder and counter rudder controls work in tandem and their setting will depend on each other, but the rudder control must be set first and then the counter rudder control must be set optimally.

➢ Yaw

The setting of the yaw control depends on the wind and weather condition and their effect on the course keeping ability of the ship. In bad weather with strong wind and rough sea, a higher value should be selected while in calm weather a low value is preferred.

➢ Permanent helm

This control is used when the ship is being driven off course by cross winds. Rudder angle used should be just sufficient to off set this drift.

➢ Speed

The speed of the ship determines effectiveness of the rudder. The lower the speed, less effective is the rudder and vice versa. Speed input is usually given from the log and in case of log not working, manual speed can be fed.

➢ Rudder Limit

This control specifies the maximum amount of rudder to be used, when correcting the ship's head or when altering course on autopilot itself. In case the alteration of course is done on the auto pilot itself and the navigator intends to use helm of 10° only, this value of 10° will be specified as the rudder limit so that the ship will turn slowly to new course using a maximum helm of 10° only. If the ship overshoots on the other side, opposite corrective helm of only 10° will be used to bring the ship back to set course. This limit can be varied to suit the requirements of the navigator.

➢ Off course alarm

This alarm is activated if the ship deviates from the set course by a pre-decided limit, which is fed to the equipment. This limit is usually set depending on the weather conditions and is higher in rough seas and strong winds when the ship is more likely to deviate from the set course. In calm weather this limit is lower. This alarm also serves as a warning in case the autopilot fails and the ship deviates from the set course by the limits fed in.

➢ Synchronization control

This control temporarily disconnects the gyro repeater from the main gyro so that the heading of the repeater can be synchronized with the master gyro. This is usually not required to be done except when the gyro is switched off and restarted or for exceptional reasons the repeater has drifted off.

➢ Auto / Follow up / Non Follow up

This switch allows the navigator to choose between automatic steering or manual steering and in case of manual steering failure Non Follow Up system of steering may also be chosen.

➢ Dimmer

This is panel illumination switch and must be set so that the panel and controls are clearly visible at night without affecting the night vision of the Officer of Watch (OOW).

PRECAUTIONS

➢ Although as per paragraph 3.1 of Performance Standard laid down by IMO, change over from automatic to manual steering or vice versa is possible at any rudder angle, it is a good practice to change from automatic to manual or vice versa when the rudder is midship except in case of emergencies when it may be changed over at any angle.

➢ Regularly check the following

- The gyro repeater is synchronized with the master repeater.
- The setting of the controls are optimum and adjust if required.
- The off course alarm and
- Try out hand and emergency steering.

➢ If a close quarter situation is developing, the ship should not be left on auto pilot and instead manual steering should be used till the ship overcomes the close quarter situation.

➢ Maintenance should be carried out as specific in the manual.

It is important to note that autopilot is course keeper and not a helmsman. It should not be used under the following conditions

➢ In narrow channel

➢ At slow speeds

➢ During manoeuvring or in pilotage waters

➢ In areas of heavy traffic

➢ During heavy weather conditions

➢ While carrying out large alteration of course and

➢ In areas of poor visibility

In case of modern ships constructed on or after 1st September 1984 and above 1,00,000 tonnes gross, which by regulation are fitted with rate of turn indicators, large alteration of course can be made on the autopilot itself with the help of constant rate of turn technique. Relevant controls for this purpose are provided on the autopilot panel. When the ship is alternating course by a large angle with the help of constant rate of turn technique, the value of constant rate of turn to be used is fed to the autopilot with the help of this control. When the ship reaches the wheel over point on the original course, the new course is fed on the autopilot and the ship will execute this turn and steady itself on the new course using the constant rate of turn that has been fed. It is important to note here that the rudder limit is effective and if the value of rudder limit fed is so low that the desired value of rate of turn can not be achieved then this rudder limit should be increased.

CHAPTER IX

ELECTRONIC CHARTS DISPLAY AND INFORMATION SYSTEM

GENERAL DESCRIPTION

The chart is one of the basic requirements of a navigator and as soon as one thinks about navigation, chart is first thing that comes to his mind. Although the International Hydrographic Organization (IHO) was founded in 1921 with the basic aim to bring about the greatest possible uniformity in all nautical charts and related publications, the standardization of paper charts came about only in 1982 when the IHO issued chart specifications, which were to be used on all chart compilations **'as far as national practices and requirements permitted'**. Its member states are now producing the charts in conformity with these specifications.

Regional Hydrographic Commissions (R H C) were later established to decide on the scheming and production of international charts in their respective regions. They also formulated agreements for exchange of reproduction of material between member states.

ECDIS is the acronym for **Electronic Chart Display and Information Systems**. The electronic chart by itself is an image of paper chart displayed on a Cathode ray tube. When this electronic chart is interfaced with shipboard equipment such as navigational position fixing systems, gyro, speed sensors, Radar, ARPA etc., it offers certain advantages over paper chart and this electronic chart now in the form of ECDIS becomes a powerful navigational aid for improved ship operation and management.

The ECDIS has been developed to such a stage that it can now be used as a base for highly Integrated Navigational Systems (I N S). Today ECDIS is capable of presenting not only the chart, but also ship's planned route, position in relation to this route, as well as information from Radar/ARPA and navigational aids.

From the display point of view ECDIS is inferior to the conventional paper chart in terms of image resolution. A CRT has only 75 dots per square inch, while a paper chart has 1000 dots per square inch, however ECDIS offers considerable benefits, viz. its structure data allows the possibility of accessing detailed information from each object as and when necessary. All primary navigational tasks including sea room monitoring can be carried out from a single unit that too on a display with selectable scale and Radar interface in addition to own ship's position display along with position of all other ships and their movement in relation to fixed objects.

The basic requirement of navigation is not to rely on single position fixing system more so when coasting in critical areas. Hence in addition GPS and Radar provide the second position fixing system. By overlaying the Radar / ARPA picture, the comparison of other traffic in the area in relation own ship and other fixed objects gives tremendous advantage. Today ECDIS combines any number of individual navigational functions ranging from position fixing and charting to Radar, track and sea room monitoring.

ADVANTAGES OF ECDIS OVER CONVENTIONAL PAPER CHARTS

The ECDIS can be used in a more efficient manner than the paper chart. The navigator can do the similar job on the ECDIS and in fact more than what he does on the paper chart. Following points show that the ECDIS is far superior to the paper chart

- Position fixing at required intervals can be done without the indulgence of officer of the watch (OOW).
- Continuous monitoring of the ships position with respect to its planned track and available sea room.
- When the Radar/ARPA picture is interfaced with the ECDIS, targets acquired by ARPA can also be similarly monitored.
- If two position fixing systems are available, the discrepancy between the two positions taken by the two different systems can be identified by the ECDIS.
- Charts can be corrected and updated directly with the help of Floppy/CD
- Passage planning can be done on the ECDIS itself without referring to other publications since most of the information required for passage planning will be available on the ECDIS itself as supplied by the manufacturer.
- To facilitate easier passage planning, various alarms can be set and if any parameter is impeded, the alarm will activated.
- Progress of the passage can be monitored in a more disciplined manner, since other navigational data is also available on the ECDIS.
- Alarms can be activated to attract the attention of the OOW in case the ship drifts beyond certain limits from the planned track as well as when an alteration of course is reached or the ship enters critical areas.
- More accurate ETA can be worked out, considering the various effects of wind, current and tidal streams etc on different legs of the voyage.
- Anchoring can be planned more precisely with the ARPA information being interfaced with the ECDIS.
- With trial maneuvering being done on ECDIS, availability of sea room on the new course can be readily checked.

The above list is not exhaustive & includes only the main points. The workload of the OOW is much reduced and he can concentrate more on other aspects of navigation. However he should not develop an easy going or lethargic attitude, since the most important aspect is that the voyage is being recorded and can be reproduced as and when required. Hence errors, negligence etc will become evident and this should make the officer more vigilant.

CHART FORMATS

The data describing charts may be stored in Raster or Vector formats. In **Raster format** the information is stored in picture element (pixels), each pixel being a minute component of the chart imaging with a defined colour and brightness level. Pixels follow standard computer articeture and are normally aligned in rows and columns. Raster images are derived by video or digital scanning technique and results in the form of a photograph of existing paper chart similar to a facsimile chart. This is also referred to as raster chart display system (RCDS). In this system, the chart image is one single layer and hence no information can be taken away from the chart. Information can only be added in the form of layers viz. information from Radar/ARPA, GPS etc can be overlaid on this type of chart format.

In **Vector format** data is held as a series of instructions for defining and drawing a particular chart feature. This information is converted into screen image by the processor within the ECDIS. Since the data is stored as a table of chart information, vector system offers an intelligence that is not inherent with the raster system. Vector system also offers the ability to layer information and hence the user can have the flexibility as to what information should be displayed on the chart. In this system, the various chart information are stored as separate layers viz. depths, depth contours, cables & pipe lines, coastline features, isolated dangers, name of land marks & sea marks, nature of sea bed, chart boundaries on small scale charts etc are all stored as different layers and can be selectively displayed to the requirements of the user as well as other inputs like GPS, Radar/ARPA etc can be overlaid. Considerable effort is required to compile and check the data for vector charts, which is time consuming, where as it is relatively easy on the raster chart. Vector charts are also referred to as intelligent charts and they can be interrogated for information not displayed, but stored in its memory. Other information likes GPS, Radar/ARPA etc. can be overlaid and the chart generated by this method is called as Electronic Navigation Chart (ENC).

COMPARISION BETWEEN RASTER AND VECTOR CHARTS

RASTER CHARTS	VECTOR CHARTS
➢ The entire chart is stored as one single layer and therefore information stored cannot be displayed selectively.	Information is stored in layers and hence can be displayed selectively
➢ Customization is not possible.	Chart can be designed as per the requirement of the user i.e. customization is possible.
➢ Direct copy of paper chart	Computer generated chart.
➢ Chart appears cluttered.	Cluttering of chart can be avoided.
➢ Information can only be added.	Information can be added and subtracted
➢ Interrogation for more information is not possible.	Interrogation for more information is possible.
➢ Seamless charts not possible.	Seamless chart is a feature.
➢ GPS, Radar/ ARPA information, chart corrections etc can be overlaid.	This also has the same facility.
➢ Sensible rotation to any angle like head up is not possible.	Sensible rotation to any angle including head up is possible.
➢ Display regeneration takes time.	Display regeneration is faster.
➢ Safety depths, entering TSS etc. alarms is not possible.	Safety depths, entering TSS etc. alarm is possible.
➢ Same symbols and colours as that of paper chart.	Symbols and colours as per IHO publication S 52 App 2.
➢ Scale of the chart cannot be changed	Each chart can be viewed on different scales.
➢ Zooming facility is not possible.	Zooming facility is possible.
➢ Cheaper and simple to produce, hence easily available.	Costly and time consuming to produce.
➢ With recent IMO approval worldwide coverage is possible.	Worldwide coverage will take time.
➢ Memory requirement is higher.	Comparatively less memory is required.

➢ This is used as interim to vector charts Raster and only where ENC is not available.	With development of ENC, charts will be phased out
➢ During look ahead / review, other charts will be on different scale.	During look ahead / review, all the charts will be on same scale.
➢ Since chart is a single layer, no possible information can be lost.	Loss of an information layer is possible and a visual indication is given.

GENERATION OF ECDIS

The Electronic Navigation Chart (ENC) is the database standardized as to content, structure & format and is issued by the hydrographic office under the authority of the government. This ENC has to be in vector format since raster format is not suitable for ECDIS purposes and is modified with addition of updates and other data to form Systems Electronic Navigation Chart (SENC) as shown in figure 1. This is equivalent to an upto date paper chart.

The SENC may also contain additional information from other sources like recommended routes, list of lights, sailing directions, current atlas etc. to meet the needs of the mariner, thereby giving more information to the mariner to plan his passage and taking away the need to refer to other publications. When a chart is first displayed on ECDIS the information it shows is that available on SENC. This information can be modified by the mariner according to his specific requirements of route planning and monitoring based on the route, type of ship
etc.

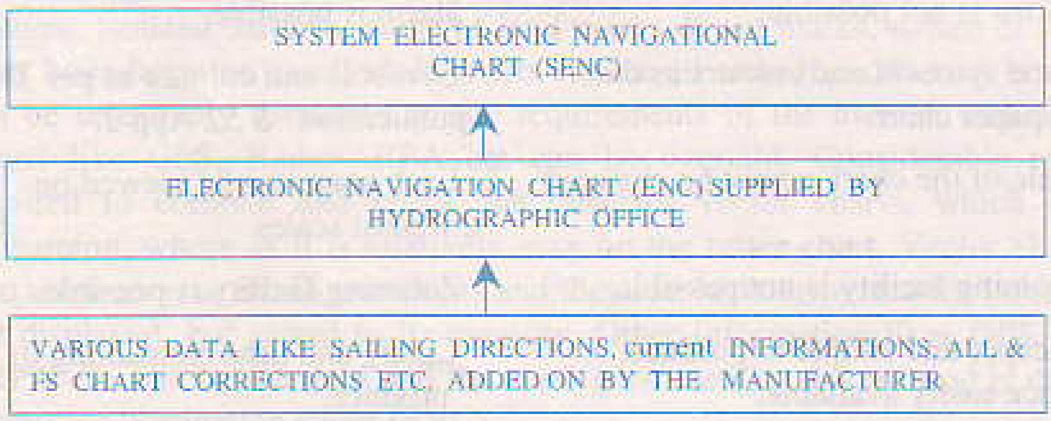


Figure 1

Various inputs fed to the ENC by manufacturer to form the SENC

The mariner can now actually design his own chart by displaying only selected information and taking away the unwanted data, thereby making a chart to meet his requirements. Since the information can be selectively displayed, there is a danger that certain information, which is actually required by the user, is deleted and this may make the chart unsafe. Hence the user has to be careful in designing the chart to his requirements.

While designing the chart to his requirement the mariner may take away certain layers of information, however there is a minimum level of SENC information; which cannot be deleted from the chart and this level is referred as **Display Base**. The user must remember that this information is **not sufficient for safe navigation**. This information is usually limited to coastline (high water), indications of isolated under water dangers with depths, traffic routing systems, buoys & beacons whether or not being used as navigational aids, scale, range, orientation & display mode, units of depth & heights.

When the SENC is first displayed, in addition to the above display base information, following information is also displayed- drying line, indication of fixed and floating aids to navigation, boundaries of fairways channels etc, visual and radar conspicuous features, prohibited and restricted areas, chart scale boundaries and indication of cautionary notes.

Additionally following information which is also available on the SENC can be displayed selectively as and when required - spot soundings, submarine cable and pipelines, ferry routes, details of all isolated dangers, details of aids to navigation, contents of cautionary notes, ENC edition date, last correction date, geodetic datum, magnetic variation, graticule and place names.

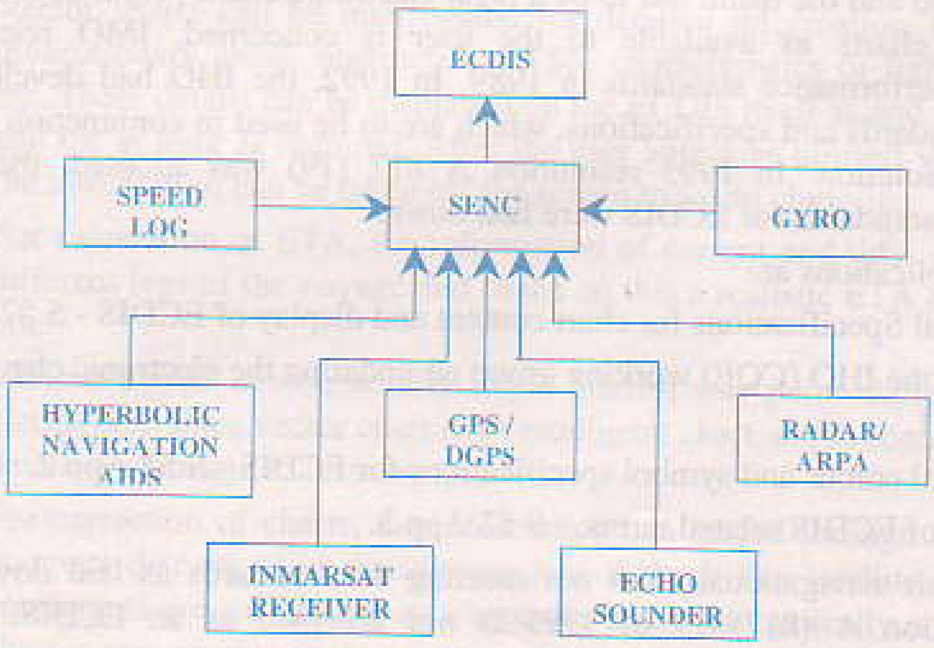


Figure 2
Various inputs fed to the SENC to be displayed on the ECDIS

There are certain special areas, which the ECDIS should detect and provide a visual / audible alarms if these areas are impeded during passage planning and monitoring. These are traffic separation zones, traffic routing scheme crossing or round about, traffic routing scheme precautionary area, two way traffic routes, deep water routes, recommended traffic lanes, inshore traffic zone, fairway, restricted area, caution area, offshore production area, areas to be avoided, military practice area, seaplane landing area, submarine transit lane, ice area, channel, fishing, ground, fishing prohibited, pipeline area, cable area, anchorage area, anchorage prohibited, dumping ground, spoilt ground dredge area, cargo transshipment area, incineration area and specially protected areas.

STANDARDISATION OF ELECTRONIC CHARTS

Standardization of electronic charts was a very complex problem. One single disc or floppy may contain chart information covering areas of responsibility of different hydrographic offices, hence the need for establishing **Regional Electronic Chart Data Base** (RECDB) arose, leading to a network of national data base.

The **RECDB** had to lay down

- the standard format of chart features
- format for exchange of data between hydrographic offices and
- format for updating regional and ship's data base.

The compilation of a nautical chart from source information is a highly specialized job and the result has to be a legal electronic chart. As far as the end product i.e. charts as available to the user is concerned, IMO released provisional performance standards in 1989. In 1992, the IHO had developed technical standards and specifications, which are to be used in conjunction with this IMO resolution. In 1995 resolution A 817 (19) was adopted, thereby performance standards for ECDIS were laid down.

The **IHO** publications are

- Provisional Specifications for chart content and display of ECDIS - S 52.
- Report of the IHO (COE) working group on updating the electronic chart- S 52 App 1.
- Provisional colour and symbol specifications for ECDIS - S 52 App 2.
- Glossary of ECDIS related terms. - S 52 App 3.

Any electronic navigational chart not meeting the standards as laid down in IMO resolution A (817) 19 of 1995 is not accepted as an ECDIS. This resolution also clarifies that ECDIS with adequate backup arrangement may be accepted as complying with upto date charts as required by V/20 of SOLAS 1974.

In December 1998, the IMO adopted amendments (ref T2 / 6.01) to the performance standards of ECDIS to include Raster Chart Display Systems, but only in areas where ENC data (i.e. vectorised format) is not available and that too to be used along with an appropriate upto date paper chart as back up. This circular of the IMO also reminds the mariner of the limitations of raster format of charts.

FEATURES OF ECDIS

- Route planning and monitoring

By virtue of SENC having information from sailing directions, recommended routes could be accessed. The mariner can plan out his own route by selecting the way points (i.e. alteration points being marked as way points), the start point being called as way point 0. From this point the cursor can be successively moved through various alteration points in order. A small window on screen will display the course and distance on the current track as well the total distance from the start point. This track can be checked for the requirements of under keel clearance, etc. Cross track allowance can be fed and the required under keel clearance on this cross track can also be checked. Similarly other critical parameters can be fed and if the passage does not meet the parameters, an alarm will be activated. Other legs of the passage can be planed accordingly.

- Critical passages can be checked with effect of wind and current as well as affect of other parameters on the progress of the ship can be monitored, thereby critical passages can be planned to precision.
- Vector charts can be interrogated for detailed information, like details of precautionary areas, obstructions, TSS, characteristics of lights and buoys, etc. These details can be displayed on the ECDIS itself as and when required and for as long as required. After the user appraises himself with the details the information can be taken off the screen to avoid cluttering.
- For calculation of ETA, the information of current and tides can be fed for different legs of the voyage and based on this a realistic ETA can be worked out.
- Various alarms can be set like depth alarms, way point alarms, cross track alarms etc., since vector chart is an intelligent chart, depth contours and other details are present in its memory.
- For correction of charts, the information can be fed through a floppy disc, compact disc or even directly on line through the satellite systems. The corrections are carried out as a separate layer automatically and a corrected chart is presented to the user.
- Similarly information received from the Navtex receiver can be directly fed and the chart appearing on the display can be corrected.

- Position of the ship can be directly plotted and continuously monitored from any position fixing system like GPS, DGPS, LORAN C etc. In fact it appears as a dot continuously moving as the ship moves. Any failure of position fixing systems is indicated by alarms and if alternative position fixing system is specified then the position fixing changes over to the other system.
- Position fixing can also be done by Radar and for this purpose a fixed object is identified and acquired by the ARPA. Bearing and distances from this object can now be plotted.
- An option is provided for fixing the position by two different systems so that the same can be compared. The user can use his discretion and update the position from any one of the two systems he chooses to rely on.
- Manual chart corrections are also possible and for this purpose various symbols and colour combinations are given.
- Other notes required by the master like VHF reporting points, engine maneuvering notices, calling master prior entering critical areas etc and even the night orders can be directly entered on the ECDIS itself. These notices can be amended while the passage is in progress.
- The colour of the display can be adjusted for day / night viewing.
- The waypoint tables for the present route or for any other route planned can be displayed as and when required.
- The information from ARPA can be superimposed on the chart and thereby critical manoeuvre and anchoring etc can be planned to precision. Trial manoeuvre can also be carried out on the ECDIS itself with the same limitations as that on the ARPA, hence an additional advantage of sea room monitoring
- Since the SENC is designed on the basis of certain scale requirements depending on the scale at which survey is done, if the chart is used at a scale not compatible to the scale of design, a visual warning is given on the ECDIS.
- The feature of zoom is also possible on the ECDIS. Unlike the magnifying glass, on zoom we can select a certain area and enlarge it to show features, which were not available on the normal scale in use. If viewed through the magnifying glass the same picture is enlarged without showing any extra details.
- Designing of own chart is possible whereby undesired information is taken off the chart and hence cluttering of information is avoided e.g. if names of the areas are not required, the same can be taken off the display. Similarly depth contours and depths beyond a certain specified minimum depth can also be taken off the chart. In fact all the depths can be taken off the chart. e.g. a ship with draft of about 12 meters can take away depths above 30

meters, but a fishing boat with a draft of only 2 to 3 meters will be most happy to take away depths beyond 10 meters. In this manner the charts can be designed to the requirements of the user.

- Most of the above features are not possible on raster format of charts. Hence though not specifically mentioned in resolution (A) 817 / 1995 of IMO, only vector formatted charts can be used as ECDIS since they would meet the requirements as laid down in this resolution. This did not go well with the paper chart manufacturers and Admiralty being the largest producer of paper charts tried to satisfy the IMO that raster format of charts was also good enough to be used for ECDIS although with limited purpose.

Any electronic chart system which does not meet the IMO specifications cannot be regarded as an ECDIS, but only as an Electronic Navigation Chart ie ENC. For any ENC to be legally accepted as an ECDIS it must meet all the specifications of IMO as per resolution no. (A) 817 / 1995, and as amended.

BRIEF DESCRIPTION OF ECDIS PICTURE SHOWN IN FIGURES 3,4& 5

Figure 3 shows a small portion of the ECDIS picture for Singapore area pertaining to chart number A2556. The right hand top corner indicates that GPS and ARPA presently interfaced with the ECDIS. UTC time and date are also indicated below this. The latitude and longitude i.e. 01° 11. 15 N and 103° 50.381 E respectively is obtained from GPS. This position is indicated on the chart at P where the single arrow head indicates the course steered i.e. 069.3° while the double arrow head indicates the course made good i.e. 055.5°. On the chart the dotted line behind the ship's position shows the path traversed by the ship and symbol 05:35 indicates the position of the ship at o5: 35 UTC.

On the right hand side below the ship's position, the course and speed made good and steered are indicated. The set and drift as well as the depth are also displayed. At the bottom right hand corner **VECTOR FIXED** means that this ECDIS has only vectorised charts, the range 5.55 nautical mile is the maximum diagonal range as displayed on the CRT and 1:30,000 is the scale of the chart.

The ECDIS has various feature which can be selected by different menus viz. **AHEAD, ROUTE, ZOOM** etc. For example, zooming into a particular area, select ZOOM and with the cross wires mark the area required to be zoomed. Similarly for route planning, select the ROUTE menu and with the help of sub – menu route planning is done. By selecting **ARPA menu**, all the acquired targets are superimposed on the ECDIS and are marked A1, A2 etc. as shown in fig.4. and by selecting the sub menu **Target table view,** CPA, TCPA, true course and speed etc. of all the acquired targets are displayed on the bottom of the chart as shown in figure 4. In this case the vector length chosen is 3 minutes.

The user can modify the chart as per his requirements e.g. consider the chart shown in figure 3 where all the information are displayed. If the user now wishes to remove some of the information, such as name of the places and depth above 30 meters, the resulting chart will be shown in figure 5

CHART UPDATING

The chart manufacturers supply the correction on Floppy or CD to update the charts on the ECDIS. These would be available to the navigator only in ports and is similar to the present system of notices to mariners for paper charts. Research and trials are in progress to facilitate on line chart correction by directly interfacing the ECDIS equipment with Satellite Communication System so that charts can be corrected even when the ship is on her voyage. The latest corrections for paper charts/ECDIS are being sent via **e-mail** so that the charts can be corrected manually even when the ship is sailing.

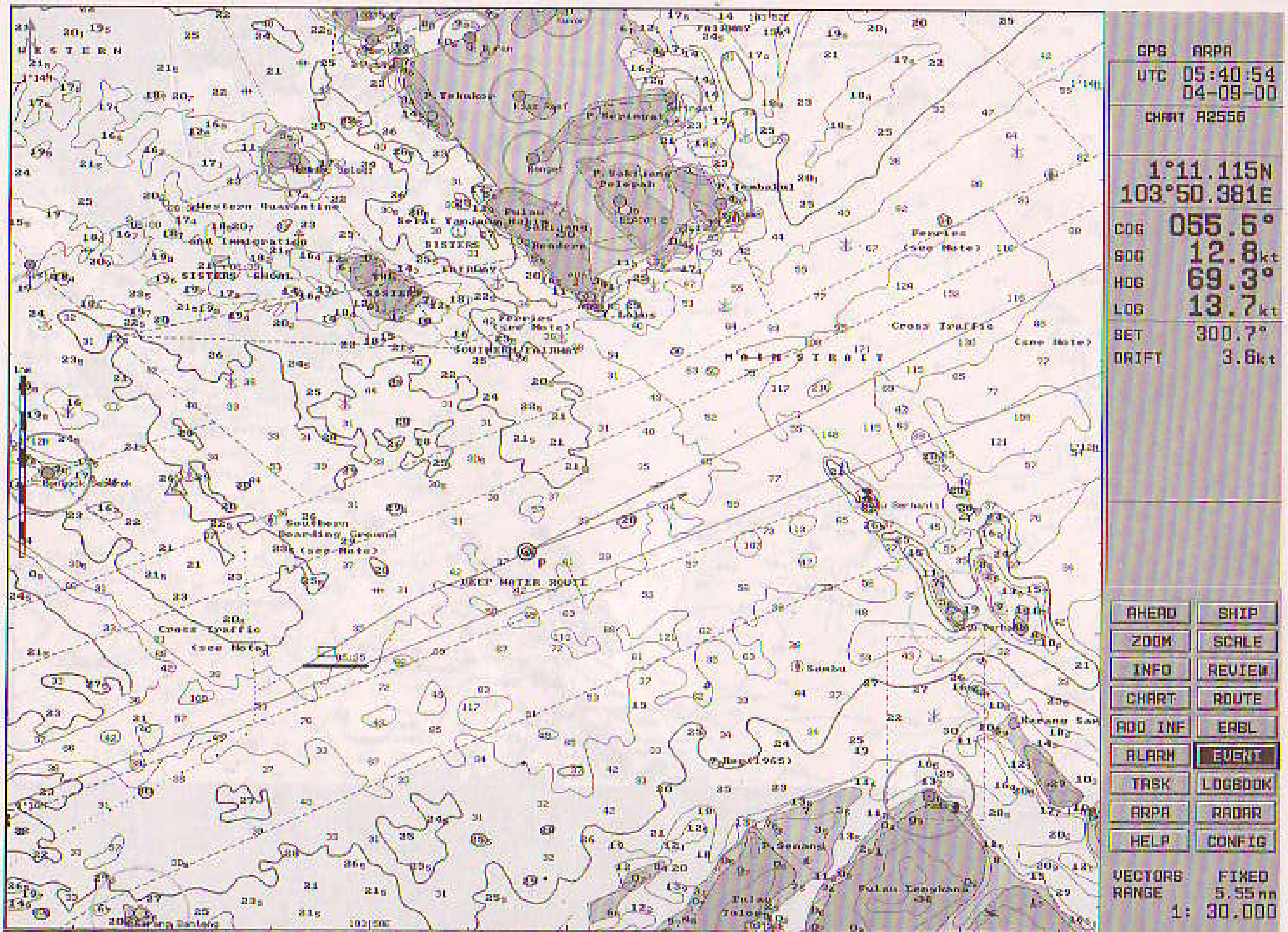
The navigational warnings, which are received by the Navtex receiver, can be directly displayed on the ECDIS. Dedicated software is used which processes these messages, arrange them in accordance with the area and present this information along with the relevant chart. Any freshly received message, which has not been read by the navigators, is indicated with a message marker. All these messages are stored in the memory and can be retrieved when required. Old and non - relevant messages are retained and can be deleted by the navigator, once he confirms that these are no longer required.

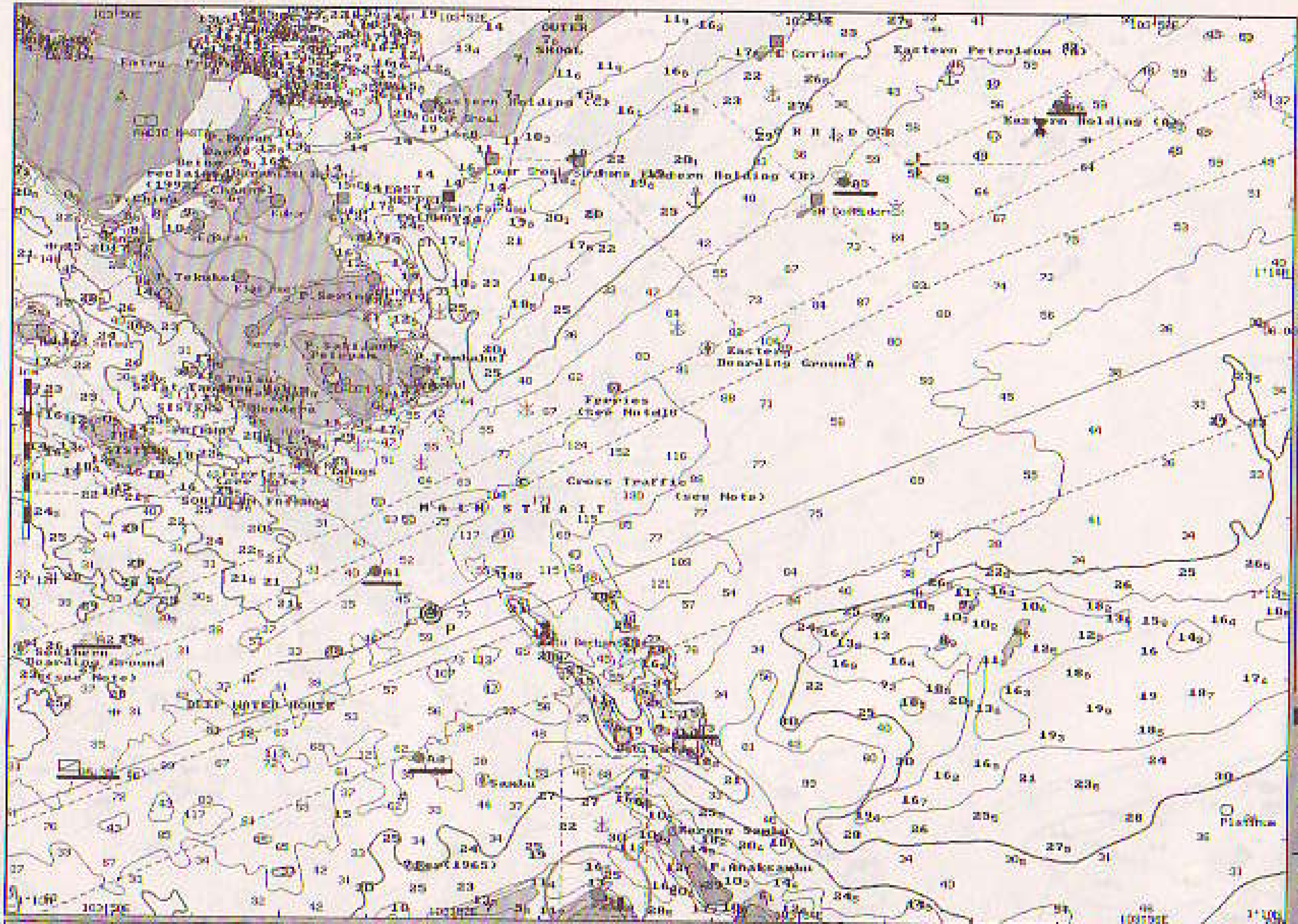
INTEGRATION OF RADAR/ARPA PICTURE WITH ECDIS

Radar/ARPA forms an integral part of navigation and collision avoidance not only in areas of restricted visibility but also in congested waters, coastal passages, approaches to port/pilot grounds, for anchoring purposes etc. This reduces the threat of collision & improves the safety of navigation. Radar video signals in the digital format are fed to ECDIS so that Radar picture can be overlaid on the ECDIS.

The advantages of overlaying the Radar/ARPA picture on the ECDIS are as follow

- Targets being tracked appear on the chart screen in their correct position with respect to coast line and their movement & alteration of course etc. can be anticipated.
- Although the Radar/ARPA picture is overlaid on the ECDIS, the positional input of the own ship continues to come from GPS/DGPS, unless navigator changes to Radar position. The coastline and other targets as displayed by the Radar/ARPA picture will show up on the correct range and bearing as the Radar picture may differ from that on the chart. A different colour is given to the coastline of the Radar picture so that it can be differentiated from chart picture.
- The Radar/ARPA picture can be recorded and stored so that it can be retrieved & replayed as and when required. These records can be used for investigation and training purposes.


GPS ARPA
UTC 05:40:54
04-09-00
CHART A2556
1°11.115N
103°50.381E
COG 055.5°
SOG 12.8kt
HDG 69.3°
LOG 13.7kt
SET 300.7°
DRIFT 3.6kt
AHEAD
SHIP
ZOOM
SCALE
INFO
REVIEW
CHART
ROUTE
ADD INF
EBL
ALARM
EVENT
TASK
LOGBOOK
ARPA
RADAR
HELP
CONFIG
VECTORS FIXED
RANGE 5.55nm
1: 30.000
DEPTHS IN METRES
WESTERN
MAIN STRAIT
DEEP WATER ROUTE
Cross Traffic
(see Note)
SISTERS' SHOAL
Western Quarantine and Immigration
Southern Boarding Ground
P. Tekukor
P. Semakau
Pulau Tekong
Pulau Jelang
Sambu
Figure 3



GPS	ARPA
UTC	05:45:53 04-09-00
CHART	A2556
ADD INFO	
	1°11.849N 103°51.850E
COG	055.5°
SOG	12.8kt
HDG	69.3°
LOG	13.7kt
SET	300.7°
DRIFT	3.6kt

Target table view

Target tracks	ON
Vectors	3min
ARPA Info	ON
Recording	ON
ARPA cursor	ON
ARPA ERBL	ON
UAIS Transponder	

-- Trial maneuvering --
Ship's model
Cancel trial man.
Trial manoeuvre

Number	A1	A2	A3	A4	A5	A6
CPA	-0.4	-0.8	1.4	0.8	-0.9	-0.6
TCPA	-0.3	-4.3	4.8	-1.8	19.9	27.3
Course	234.3°	232.4°	118.8°	0.0°	118.8°	119.0°
Speed	10.0	13.0	4.0	0.0	4.0	4.0
Range	0.41	1.90	1.68	0.90	3.00	4.82
Bearing	300.6°	264.9°	114.5°	183.6°	41.0°	48.3°
Bow X	-2.2	-4.6	5.1		-3.1	-2.1
TBow X	3.9	6.4	-22.8		37.0	38.5

Displaying the ARPA targets table

VECTORS 3 min
RANGE 7.41 nm
1: 40,000

DEPTHS IN METRES

Figure 4

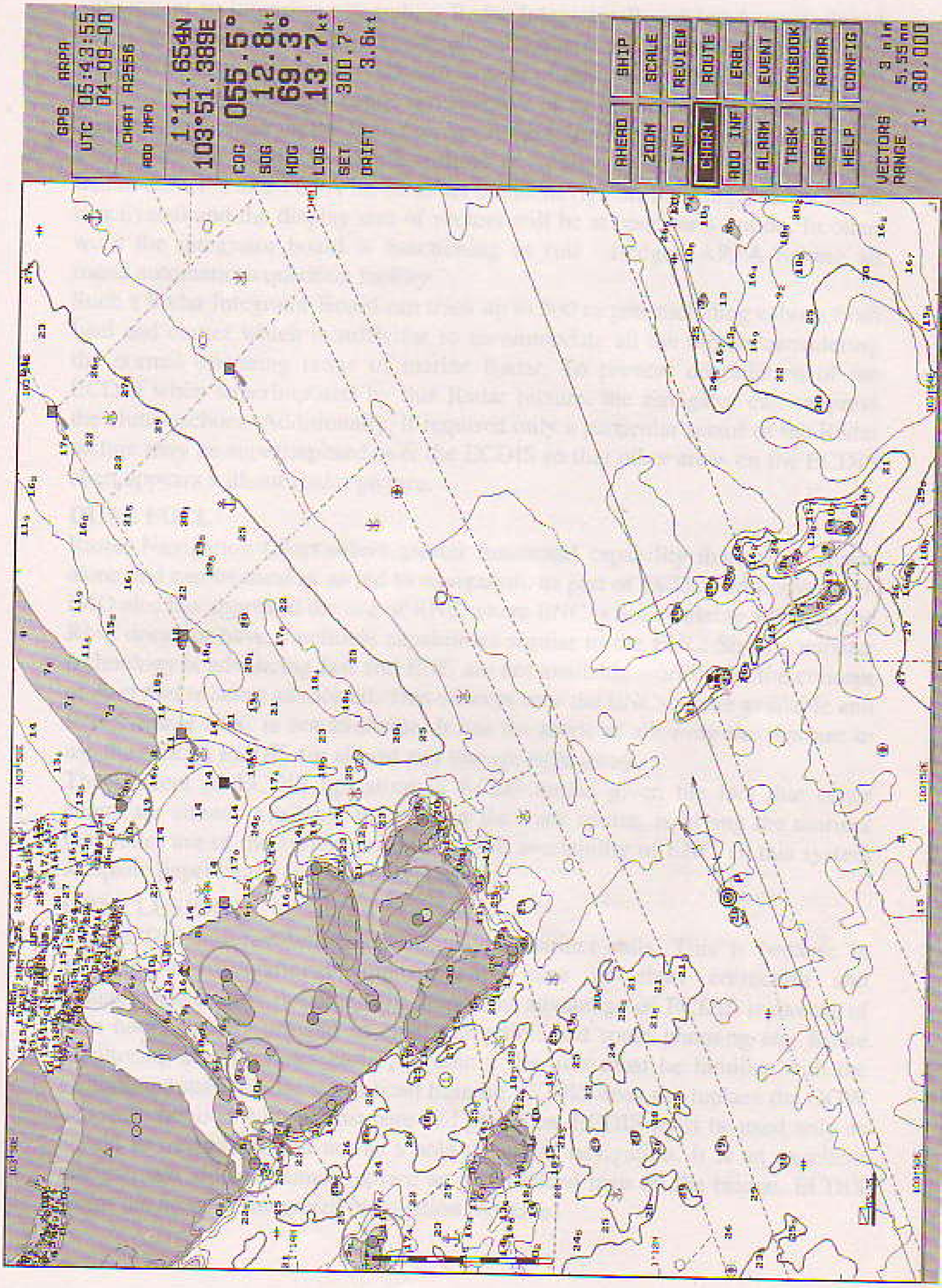

GPS ARPA
UTC 05:43:55
04-09-00
CHART A2556
ADD INFO
1°11.654N
103°51.389E
COG 055.5°
SOG 12.8kt
HDG 69.3°
LOG 13.7kt
SET 300.7°
DRIFT 3.6kt
AHEAD
SHIP
ZOOM
SCALE
INFO
REVIEW
CHART
ROUTE
ADD INF
ERBL
ALARM
EVENT
TASK
LOGBOOK
ARPA
RADAR
HELP
CONFIG
VECTORS 3 min
RANGE 5.55nm
1: 30,000
DEPTHS IN METRES

Figure 5

Subsequent to intensive research, a Radar Integrator Board has been designed and is interfaced with the Radar which will convert the Radar video signal into digital format and store them. The advantage of this board is that it will track all the targets **within Radar range irrespective of range scale being used**. When these targets appear on the Radar screen at the selected range scale, their CPA & TCPA etc. are readily available without any delay. In case of targets coming within the CPA and TCPA limits as set by the navigator, the danger target alarm is activated and the display size of vectors will be at operator's option. In other word the integrator board is functioning as full - fledged ARPA having all round automatic acquisition facility.

Such a Radar Integrator Board can track up to 500 targets including echoes from land and clutter which is sufficient to accommodate all the targets considering the normal operating range of marine Radar. To prevent degradation of the ECDIS when superimposed by this Radar picture, the navigator can suppress the clutter echoes. Additionally, if required only a particular sector of the Radar picture may be superimposed over the ECDIS so that other areas on the ECDIS chart appears without Radar picture.

DUAL FUEL

Raster Navigation Chart offers greater functional capability than paper charts alone and can be used as an aid to navigation, as part of ECDIS. Moreover now IMO also has approved the use of RNC where ENC is not available although the RNC does not have functional capabilities similar to the ENC. Since computer technology is advancing fast and ENC are not available worldwide, the concept of *dual fuel* is being advocated. This concept uses the ENCs where available and RNCs where ENC is not available. It has the merit of allowing the mariner to use the official ECDIS for almost any voyage right away.

The concept of ECDIS operating in RCDS mode, given the fact that raster charts are already available for most of the trade routes, is giving the mariner maximum use of the system prior to the full availability of ENC. In this system adequate paper charts is required as back up.

CONCLUSION

The ECDIS has revolutionized the way a mariner sails. This is because in addition to navigational improvements, ease of chart correction and maintenance is now possible. The important advantage of ECDIS is saving of man hours usually utilized in chart correction and route planning etc. Route monitoring also becomes easier, of course the user must be familiar with the ECDIS and may require specialized training. ECDIS does not replace the OOW and must be used with utmost care and prudence. ECDIS must be used only as an aid to navigation and not as a sole means of navigation. It is an excellent navigational aid but cannot replace an experienced man on the bridge. ECDIS forms the heart of Integrated Navigation Systems.

CHAPTER X

INTEGRATED SYSTEMS

INTRODUCTION

The advancement and adaptability of high power micro - processors in the marine industry has made the concept of integrated navigational systems a reality. Automatic control systems to monitor and maintain sensitive parameters within limits have been in existence for a long time and this allowed a single watch-keeping officer to have the overall control of the ship's propulsion systems, in addition to the navigational controls. The classification societies assigned a different class to this type of ship's viz. Unmanned Machinery Spaces or UMS.

DEVELOPMENTS OF INTEGRATED NAVIGATION SYSTEMS

With the advancement in ECDIS and programmable ship's steering control, the Integrated Navigation Control (INS) has actually come into existence. Although trials and research are still in progress, if present indications to go by, the INS will be fitted on board much faster than the seafarer can think about its implementation. The system promises improvement in navigational safety, saving manpower and efficiency of ship's operation as a transport unit in totality. The INS will help in reducing the factor of human error in causalities.

The main features which have contributed in making the INS a reality are

- The developments of ECDIS which itself has been a result of advancement in the field of micro - processors and its related equipment
- The development of GPS capable of continuously providing highly accurate ship's position data.
- The advancement of Radar based ARPA systems with capabilities like trial manoeuvers.

With these facilities it became feasible to introduce an INS which is capable of the following

- Continuously presenting the ship's position on Electronic Navigation Charts in relation to sea room available along with planned track and Radar scenario superimposed (i.e. ECDIS) and
- Automatic programmable ship's steering control

The INS based on modular concepts which allows a flexible change of a set of navigational facilities depending on ship's type and area of operation of the ship will have the three modules forming the integral part of the INS

- Navigational module
- Anti - collision module and
- Steering module

NAVIGATION MODULE

This module will take care of voyage planning, shop's position fixing on a continuous basis and ARPA plotting functions. This module will perform the following tasks

- Specifying the ship's route and sailing mode
- Dead reckoning by inputs from gyro and log
- Position and speed determination by signals received From GPS / DGPS
- Position fixing by inputs from terrestrial–based radio navigation systems
- Position and velocity determination using fixed Radar markers (along with ARPA)
- Automatic selection of radio navigation facilities on the basis of accuracy criteria
- Record and reproduction of cartographic information on a display
- Data logging in log book format
- Storage of navigational parameters for a given time
- Warnings in case of exceeding the prescribed depth, route cross track, approaching critical points including alteration of course etc. and
- Automatic correction of navigational charts

ANTI - COLLISION MODULE

This module works out the best possible action to be taken in case of close quarter situations on the basis of the following

- Collision regulations
- Sea - room availability
- Trial - manoeuver and
- Desired CPA

SREERING CONTROL MODULE

This module is dedicated to steering the ship and will perform the following functions

- Steering a given course, taking into account the ship dynamics, trim etc. and external conditions (winds, sea state and currents etc.)

- Automatic course alteration in accordance with planned track and
- Alterations for collision avoidance and subsequent track keeping

The INS regarded as an important part of full ship automation system with interface being provided for data exchange

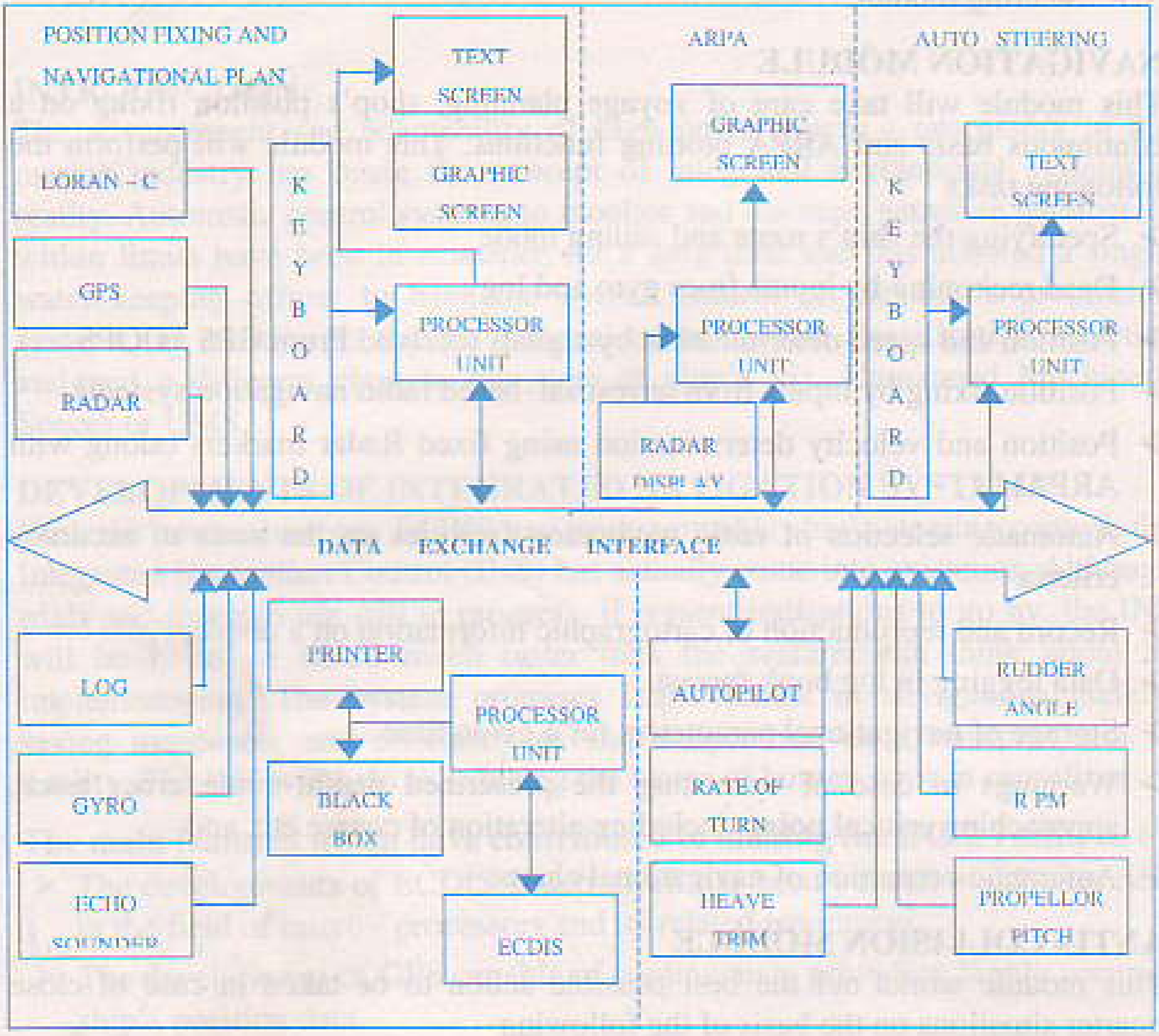
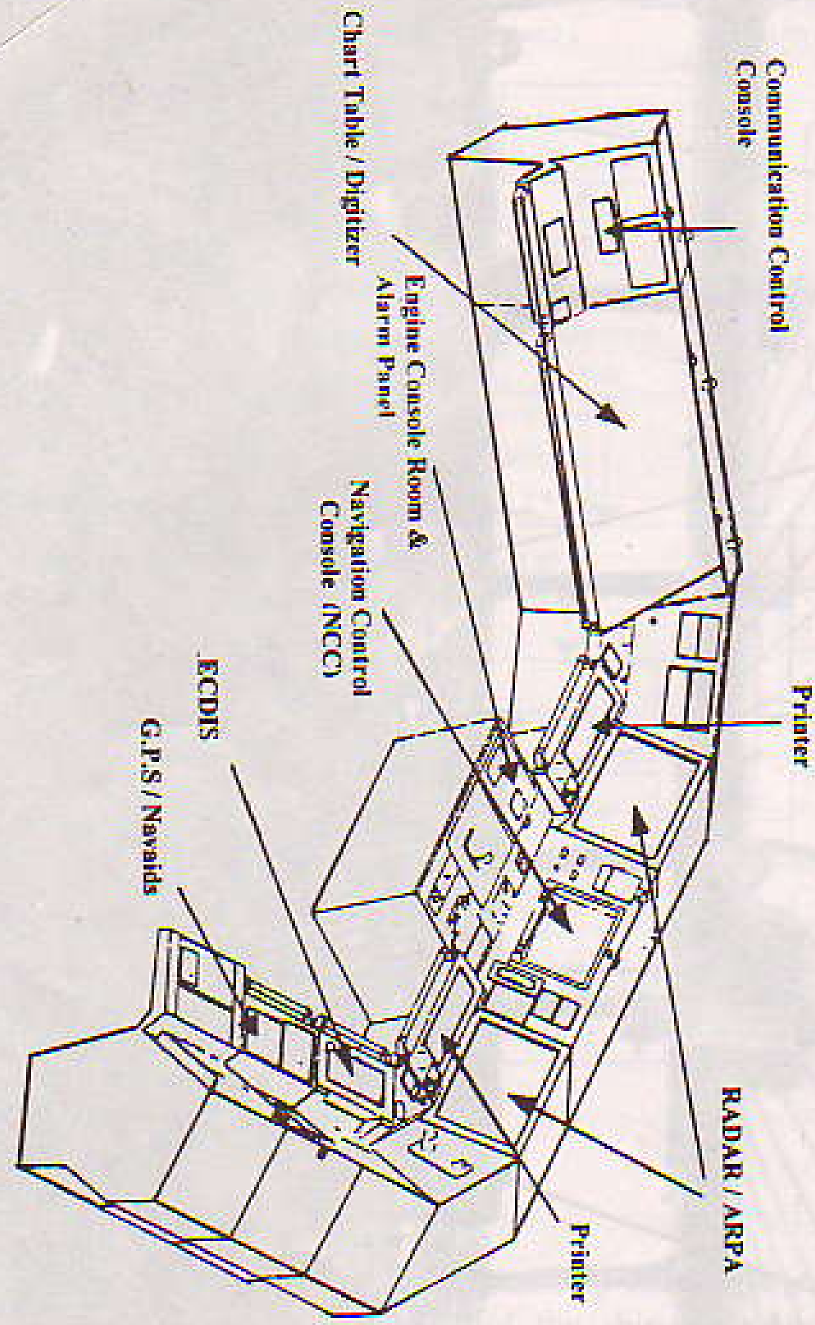


Figure 1
Block Diagram of INS

INTEGRATED BRIDGE SYSTEMS (IBS)

IBS is basically a combination of INS and other ship board systems, aimed at increasing safe and efficient management of the ship, reducing work load, providing centralised control and a black box i.e. data recording for later analysis. It should be capable of being of being operated by suitably qualified personnel



Communication Control Console
Chart Table / Digitizer
Engine Console Room & Alarm Panel
Navigation Control Console (NCC)
ECDIS
G.P.S / Navaids
Printer
RADAR / ARPA
Printer

The IBS should include the following (any two as per IMO)

- Passage execution
- Communications
- Machinery control
- Loading, discharging and cargo control and
- Safety and security

This system will also be based on modules and generally failure of any one module should not affect the functioning of other modules, unless they are dependent on the information provided by this defective module.

The equipment should be user friendly, giving prompts to the user as and when required. Alarms should be provided to indicate any malfunctioning and should be graded to indicate the order of priority. Generally visual and audible alarms are provided and audible goes off as soon as acknowledged, while visual alarm continues till the malfunctioning is rectified.

The basic difference between INS and IBS is that INS is a combination of navigational data and systems interconnected to enhance safe and efficient movement of the ship, whereas IBS interconnects various other systems along with the INS to increase the efficiency in overall management of the ship. In this sense the INS is specific in nature while IBS has a more generalised approach.

Vide resolution MSC.64 (67), adopted in Dec'96, the IMO has issued recommendations of performance standards for IBS and students are advised to refer to the same.

CHAPTER XI

GYRO COMPASS

GENERAL INTRODUCTION AND PRINCIPLE

The function of gyrocompass equipment is to provide an accurate non magnetic directional reference with respect to true geographic north. This directional reference is necessary for accurate navigation as well as for other equipment fitted in the modern ship such as Autopilot, Radar, ECDIS etc.

The nucleus of the gyrocompass equipment is an electrically driven gyroscope, which has a heavy well balanced wheel spinning at a high rate, above 20,000 revolution per minute (RPM) and has freedom of movement in three perpendicular axis i.e. free to turn about its spinning axis (A), its vertical axis (B) and its horizontal axis (C) as shown in figure 1.

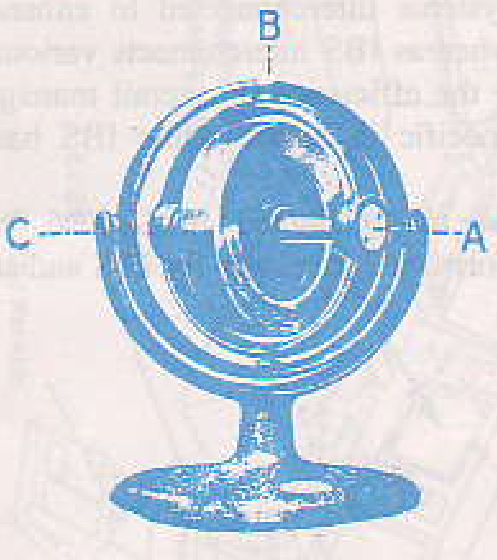


Figure 1
The three axes of freedom of the gyroscope

The whole system is balanced so that the centre of gravity is at the point of intersection of the three axes.

The following properties of gyroscope play an important role in the operation of of gyrocompass

- Gyroscopic Inertia or Rigidity in space and
- Precession

GYROSCOPIC INERTIA

It is that property of a gyroscope which causes it to maintain its position in space irrespective of any movement and to resist any force tending to turn its spin axis in a new direction.

The property of gyroscopic inertia is illustrated by rapidly spinning the wheel with it's base at an angle to the horizontal as shown in figure 2 and then bringing the supporting base to the horizontal position as shown in figure 3. The original direction of the gyro axle is not altered although the supporting base is made horizontal.

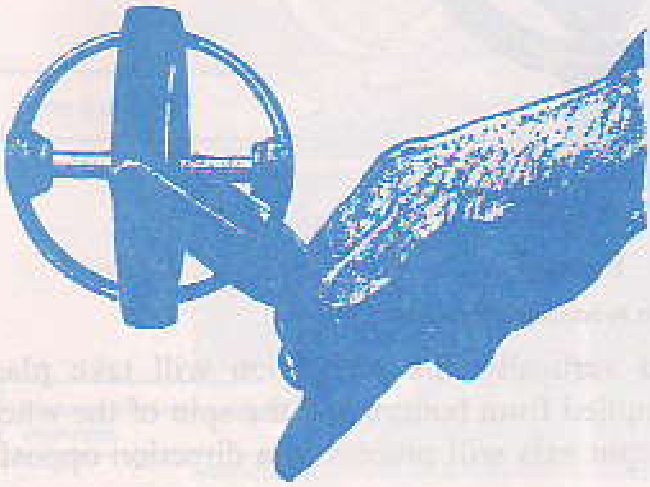


Figure 2

Gyro wheel set spinning with axis horizontal.

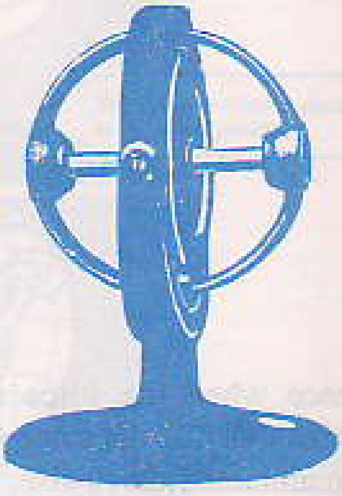


Figure 3

Axis remains horizontal when base is displayed.

PRECESSION

It is the angular displacement of the spin axis of the gyroscope when a torque is applied to the gyroscope. Hence when a torque is applied to it's spin axis the resulting movement will be in a direction at right angle to the applied torque, the angle being measured in the direction of the spinning wheel.

The property of precession is illustrated in figure 4, which shows that when a force **T** is applied to spin axis from top, it does not move in the direction of the applied force but moves at right angle to the applied force. The direction in which the spin axis will precess will depend on the following factors

- Direction of the spin of the wheel
- The point at which the force is applied to the spin axis and
- The direction in which the force is applied

In order to determine the direction in which the spin axis will precess when a force **T** is applied from top and the direction of the spinning wheel is clockwise, the force is apparantly turned by 90°in the direction of spin of the wheel and then made effective, hence the spin axis will precess towards **P** as shown in figure 4.

Figure 4

Precession in horizontal direction

Hence when the force is applied vertically, the precession will take place horizontally. If the same force is applied from bottom and the spin of the wheel is maintained clockwise, then the spin axis will precess in a direction opposite to **P**.

Similarly when the force is applied horizontally, the precession will take place vertically as shown in figure 5

Figure 5

Precession in vertical direction

Note -The diagrammatic explanation of the precession being in a direction of 90° from the applied torque is given in figure 6A and 6B

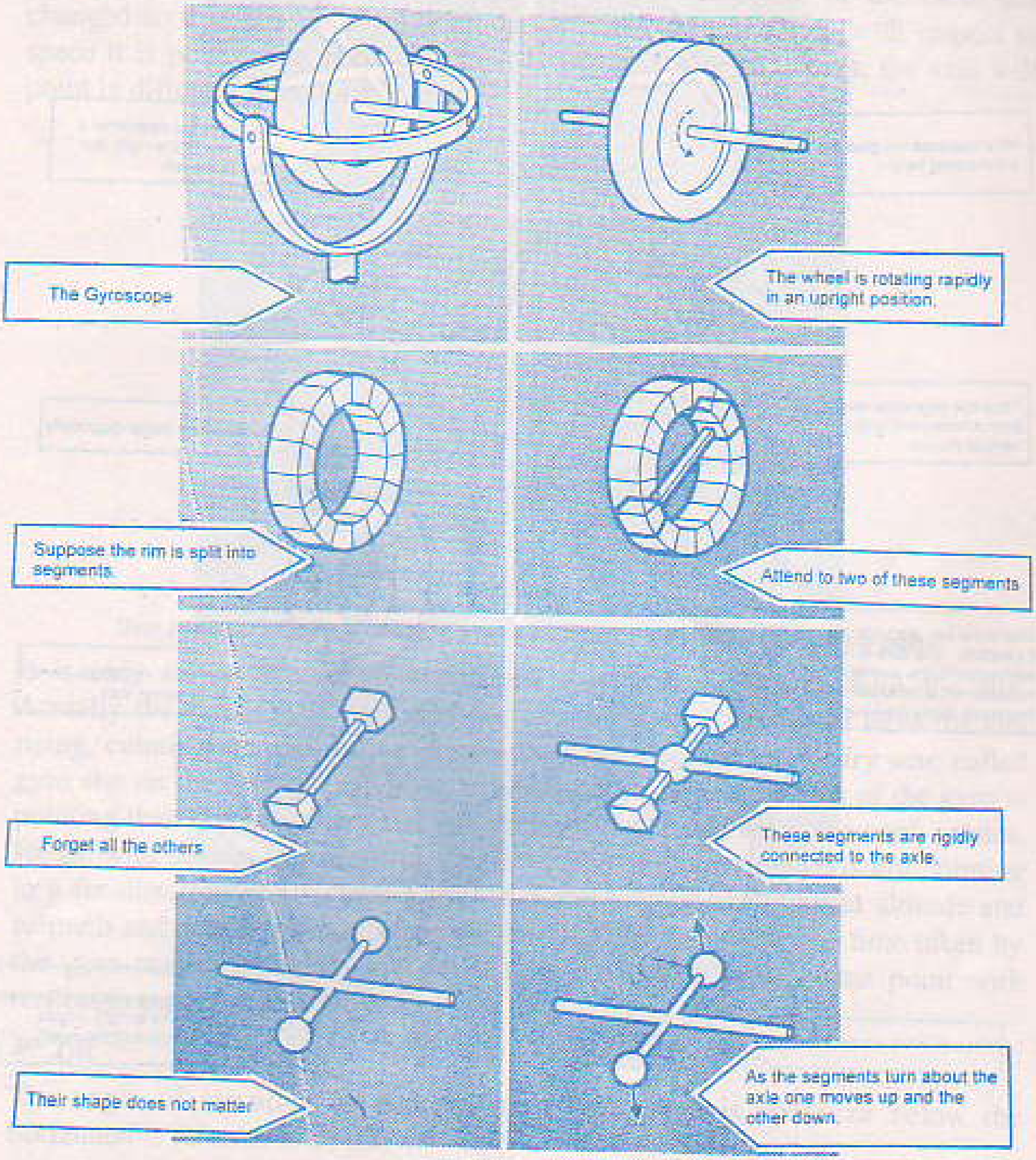
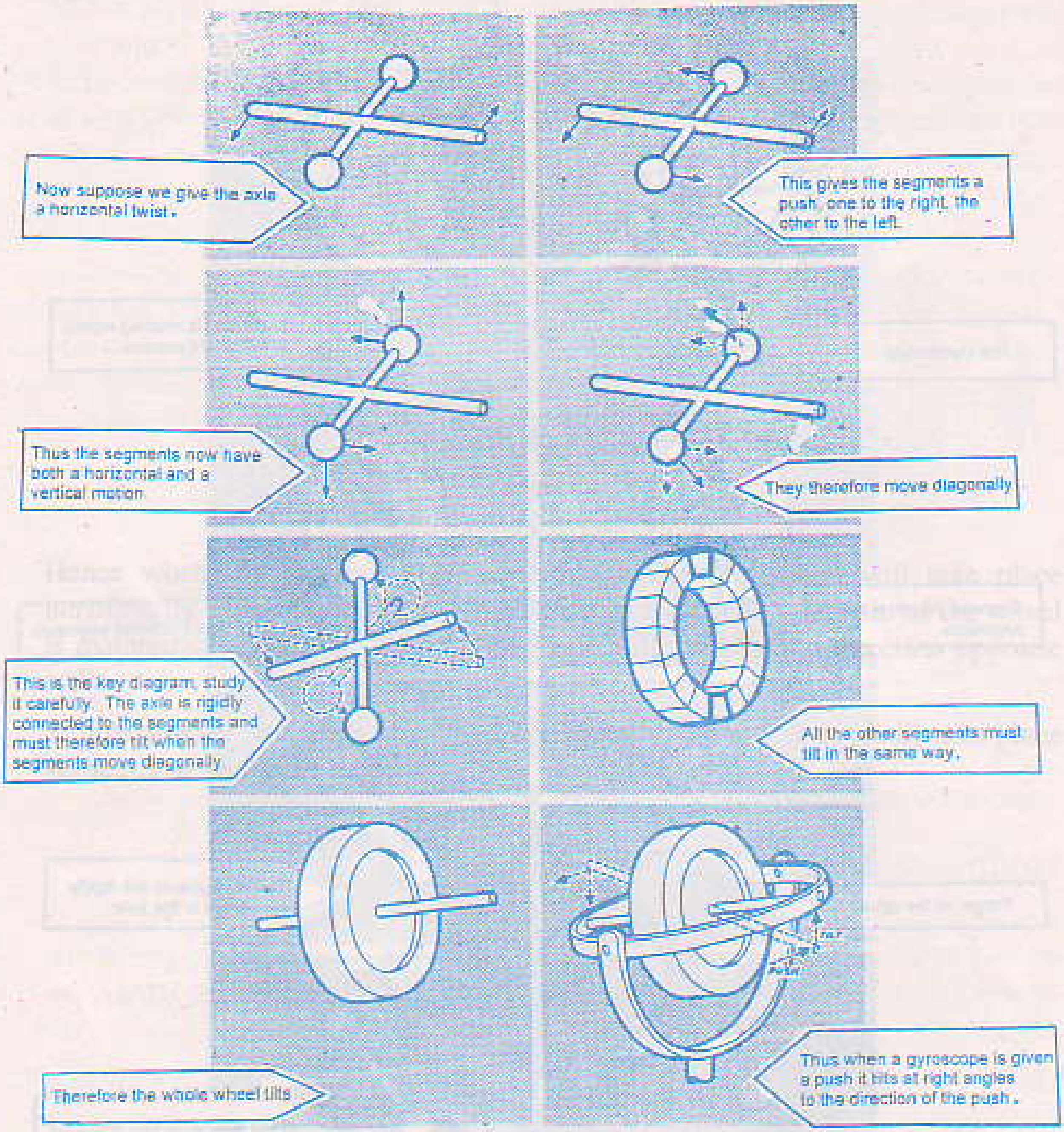


Figure 6A



Now suppose we give the axle a horizontal twist.
This gives the segments a push, one to the right, the other to the left.
Thus the segments now have both a horizontal and a vertical motion
They therefore move diagonally
This is the key diagram, study it carefully. The axle is rigidly connected to the segments and must therefore tilt when the segments move diagonally
All the other segments must tilt in the same way.
Therefore the whole wheel tilts
Thus when a gyroscope is given a push it tilts at right angles to the direction of the push.

Figure 6B

MOVEMENT OF EARTH'S SURFACE

The earth rotates around an axis from west to east and any point on the surface of the earth has same direction of rotation. The direction of spin axis of the gyroscope at position **A** on surface of the earth is set pointing towards North as shown in figure 7. As the earth rotates, the gyroscope also rotates and the direction of spin axis at position **B** with respect to North of the earth has changed so that it is no more pointing towards North although with respect to space it is pointing in same direction. Hence as the earth rotates, the axis will point in different directions.

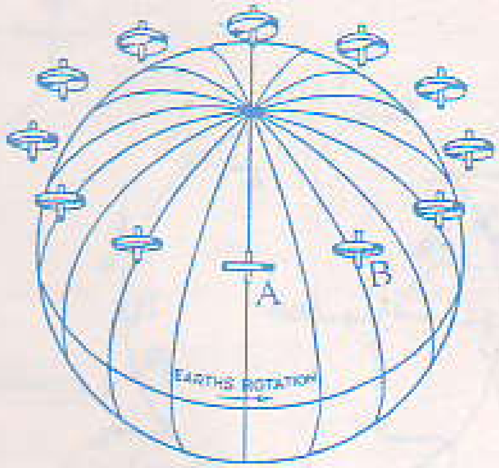


Figure 7

Gyro axis pointing to fixed direction in space but different directions with respect to earth.

It is easy for navigators to understand this when compared with the sun. Actually the sun is stationary and due to the earth's rotation we have the sun rising, culminating and setting. Similarly if we place an imaginary star, called gyro star on the celestial sphere in the direction in which the axis of the gyro is pointing then this imaginary star will rise, culminate and set as the earth rotates. Hence with respect to surface of the earth, axis of the gyroscope is not pointing in a fix direction but towards a gyro star and thereby changing in altitude and azimuth and said to be exhibiting **tilt** and **drift** respectively. The time taken by the gyro star to complete one revolution and return to the same point with respect to earth is one sidereal day.

➢ Tilt

The angle of elevation or depression of the spin axis above or below the horizontal is referred to as tilt.

➢ Drift

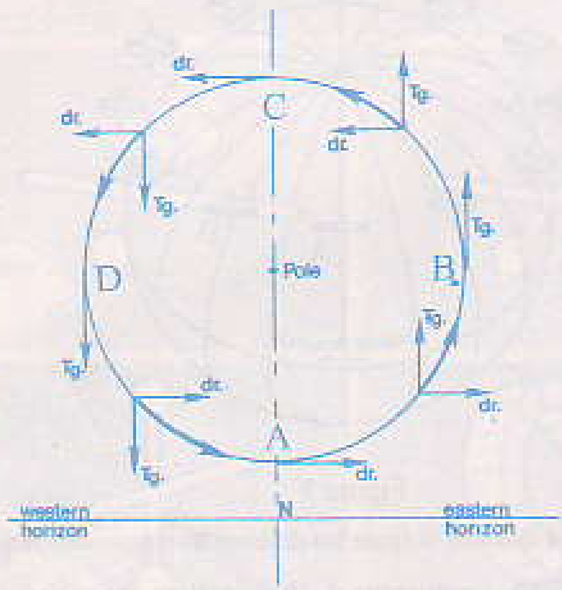
The movement of the spin axis in direction of azimuth is called as drift.

The rate of tilt and drift is given by the formula

Tilting = 15' Cos latitude x Sine azimuth per minute of time and

Drifting = 15' Sine latitude per minute of time

Assuming the gyro axis is initially pointing Eastwards on surface of earth and we know it will take one sidereal day to complete one revolution to return to same position pointing Eastwards, the path traced by the North end of the spin axis of a free gyroscope placed in North latitude initially set pointing in Eastwards shown in figure 8.



Tg = Tilt

dr = drift

Figure 8

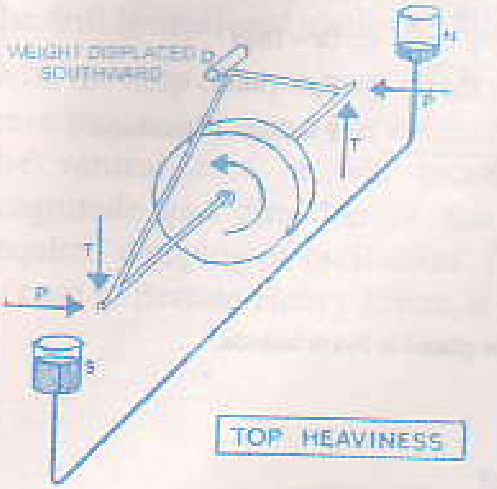
Path traced by North end of spin axis in North latitude

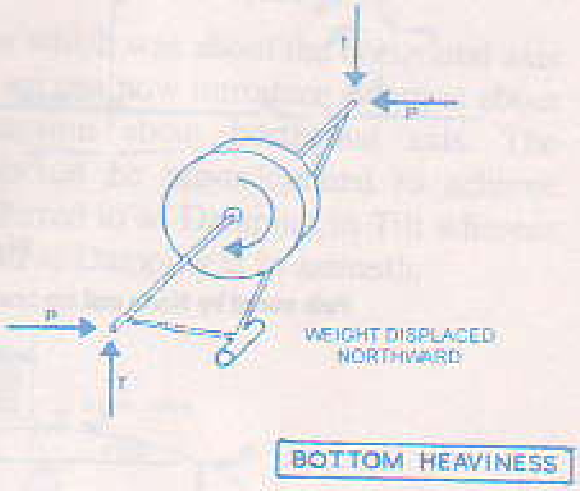
Consider the gyroscope at point A pointing Eastwards as shown in figure 8. As the earth rotates, relatively the gyroscope axis will increase in tilt & drift and follow the curve A, B, C and D. At B the drift will be zero and gyro will now only tilt. As the earth continues to rotate, the drift will now be in opposite direction till point C when tilt is maximum. From here onwards the tilt is reducing and at point D, the drift again becomes Eastwards to complete the circle back at A.

A gyroscope placed on the equator with its axis pointing Eastwards will experience only tilt and no change in azimuth, while a gyroscope placed at the poles with its axis pointing Eastwards will experience only drift and no tilt. If the gyroscope is placed on the poles with the axis pointing Northerly, there will be no tilt and drift with the rotation of the earth, but it will exhibit a turntable effect with its axis pointing towards celestial North pole.

GRAVITY CONTROL IN GYRO

The rotation of the earth gives us a free gyroscope, which has to be controlled with the help of precession and we have to use the property of earth's gravity and rotation to create the torque. If we place the gyro scope with its North axis pointing Eastwards, this axis will tilt upwards as the earth rotates and with the help of mercury ballastic or a fixed weight we can now create a top heavy effect which will provide us a torque.





T = Torque

P = Precession

Figure 9

Top heavy effect

Figure 10

Bottom heavy effect

This is achieved as shown in figure 9, where the rotor is moving in anticlockwise direction and the North end of the axle is pointing Eastwards, as the earth rotates this end tilts upwards, hence mercury from North bowl **N** flows to the South bowl **S** and as a result torque is applied to the upper end of the axle at **B,** which results in precessing the North end Westwards. A similar effect can be created by attaching a weight to the two ends of the axis, the weight being above the rotor as shown in figure 9. This is known as the **TOP HEAVY EFFECT.**

If we want the gyro axle to precess Westwards and the rotation of a gyro wheel in clockwise direction, then we must place the weight below the rotor as shown in figure 10. This is known as **BOTTOM HEAVY EFFECT**. Generally it has been noticed that, top heavy effect is used to control a free gyroscope.

The path of such a gyroscope as traced by it's North end when the gyroscope is placed in some North latitude will be as shown as figure11. Similarly if the gyro scope is placed in some South latitude, the path traced by it's North end will be as shown in figure 12 and when placed on equator it will be as shown in figure 13.

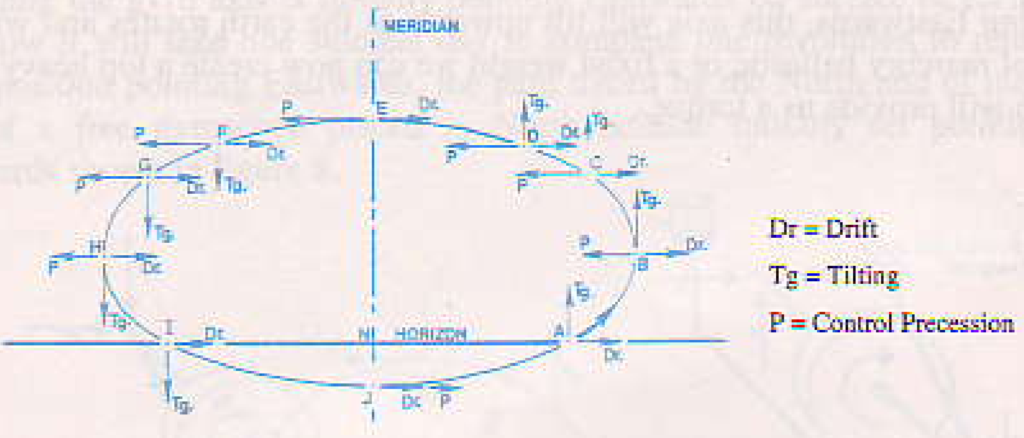


Figure 11

Path traced by North end top heavy gyroscope placed in North latitude.

Figure 12

Path traced by North end of top heavy effect gyroscope placed in South latitude

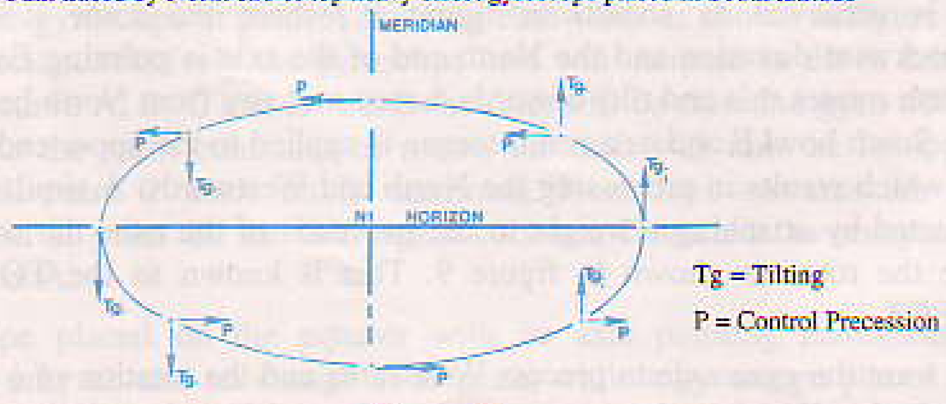


Figure 13

Path traced by North end of top heavy effect gyroscope placed on the equator

MAKING GYRO NORTH SEEKING

The requirement of a gyro is that it must settle down and maintain a fixed direction with respect to earth. This settling position should also be stable i.e. if the gyro is disturbed, it must return back to this direction.

The controlled gyro will not settle in a fixed direction in any meridian but will oscillate about the meridian. To damp the unwanted oscillation another torque perpendicular to the first one has to be introduced which will cause precession in the direction perpendicular to the original precession. In figure 11,12 &13, the drift is measured along the X-axis and tilt along the Y-axis.

With the help of top heavy effect the torque which was about the horizontal axis gave precession about the vertical axis. If we can now introduce a torque about the vertical axis, it will produce precession about horizontal axis. The magnitude and direction of this force should be pre-calculated to achieve required damping of oscillation. This is referred to as Damping in Tilt whereas in case of Bottom Heavy Effect, it is referred as Damping is in azimuth.

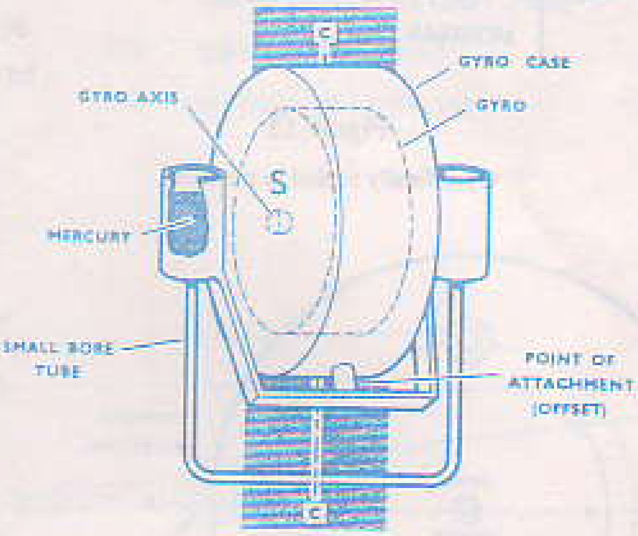


Figure 14

Point of attachment of the system of mercury offset from centre by 3 mm

To achieve damping in tilt, the point of application of the control force (i.e. torque about horizontal axis which was due to the top heavy effect) is offset slightly to the East of the vertical, resulting in a component of the same force producing a torque about the vertical axis, the resulting precession about the horizontal axis will ensure that the amplitude of oscillation is reduced and the gyro finally settles in the meridian.

The amount of offset in Sperry mark XIV Gyro equipment is 3mm as shown in figure 14 and the trace of the North end of the axis will now be as shown in figure 15, finally settling down in the meridian. The breakup of force in the two directions is as shown in figure 16. With reference to figure 15, the amplitude of each oscillation is reduced to 1/3[rd] of the previous oscillation and thereby resulting in the axis finally settling down in the meridian.

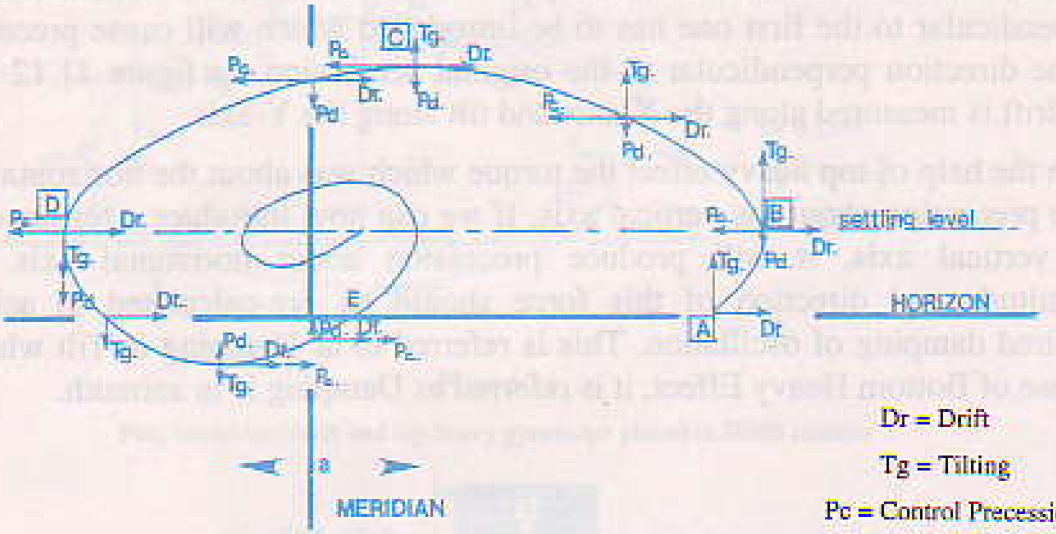


Figure 15

Gyro finally settled in meridian.

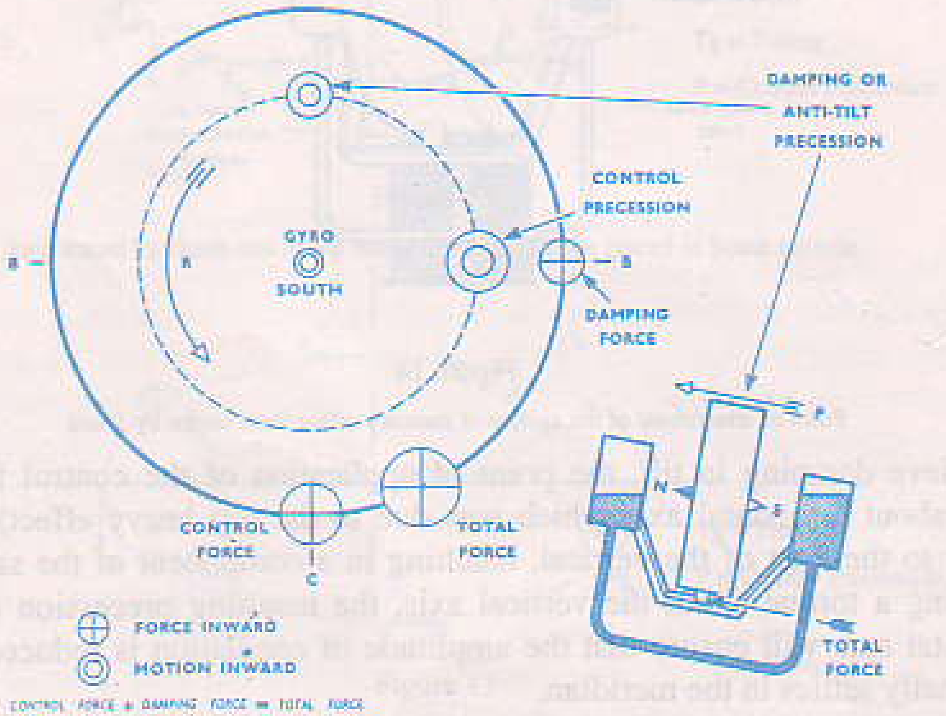


Figure 16

A small part of the total force is used for damping while most of the force is used to achieve gravity control

SPEED ERROR

A gyrocompass placed on a ship will behave and settle down as explained above while the ship is stationary. However when the ship is moving, the course and speed of the ship affect this gyrocompass. The error introduced is maximum on North – South course and reduces to zero on East - West courses. This is because the earth rotates from West to East and the movement of the ship in East - West direction only adds or subtract from earth's rotational speed. Whereas on North - South course the gyro axle will apparantely tilt North end up or South end up as the case may be. This northerly tilt causes the gyro to precess towards West and thereby settles West of the meridian. Similarly on southerly course it will settle East of the meridian. The error will increase with speed and latitude.

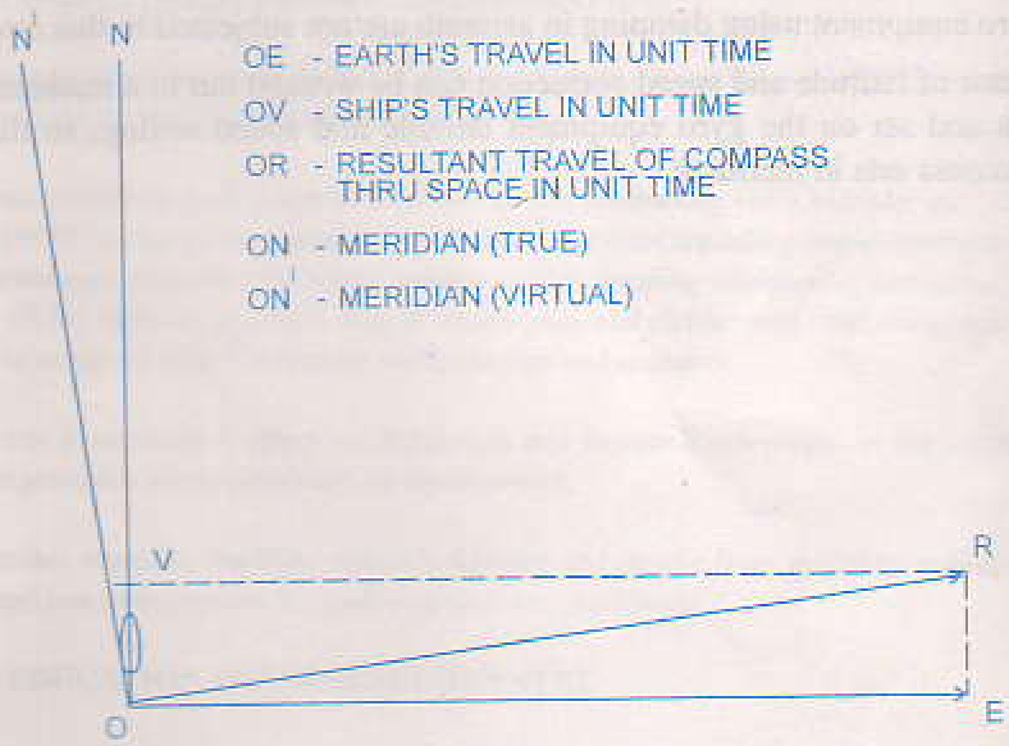


Figure 17

Effect of speed on gyroscope

With reference to figure 17, OV is the component of ship's course and speed in the northerly direction and OE represents the movement of earth in unit time, the resultant is OR.

When OV equals to zero, the gyrocompass settled at ON being 90° to OE.

When ship is moving and its component in northerly direction is OV, the resultant of OV and OE is OR, the gyro compass will settle 90° away from OR i.e. ON', being West of meridian ON. The angle N'ON will depend on OR and this in turn depends on component OV i.e. components of ship course and speed in northerly direction. Similarly if the ship has a course in the southerly direction, it will settle East of meridian. The angular difference N'ON will depends on

- Course and speed of the ship
- Latitude since higher the latitude, smaller the earth's rotational speed and hence greater effect on ship's speed.

DAMPING OR LATITUDE ERROR

In case of damping in tilt, the spin axis will settle a little to East or West of the meridian. This error is proportional to the tangent of the latitude and hence increases with latitude. It also depends on the design and construction of individual compass. This error is calculated and applied as latitude correction. The gyro equipment using damping in azimuth are not subjected to this error.

The factor of latitude and speed correction can be worked out in a mathematical formula and set on the gyro equipment latitude and speed setting, so that the gyrocompass sets in meridian.