NAVIGATIONAL AIDS

Modern Radio Aids to Navigation

DEPARTMENT OF TECHNICAL AND ECONOMIC COOPERATION

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C O N T E N T S

1. Radio Navigational Aids

1-1 General

Without road signs, automobiles cannot be driven on highways properly. Similarly, ships and aircrafts cannot be operated safely without knowing its exact position at any time. The position of a vessel had been determined in the midst of an ocean where no mountain or island can be pointed at by observation of the celestial objects, and the method is called astronomical navigation. Since it depends on an optical observation, it fails under poor weather when the sun or stars are hidden by clouds; and then estimation of the position of a vessel was possible only by means of calculation based on the previous observation and the direction and speed of the vessel. This is called estimation navigation. However, it is impossible to know the exact position by such estimation because of existance of a large error; and a new method of navigation was devised by utilization of radio wave in order to secure and improve operation of vessels under poor visibility. The range of effective utilization of radio navigation is very large practically with no limitation by weathwe condition such as fog or snow. An electronic equipment must be installed on ships or aircrafts corresponding to the ground facilities, but in this way the information for the position and bearing are available quite conveniently. The radio system used for such determination of the position, bearing and distance and detection of any obstacles is called Electronic Aids to Navigation or Radio Aids to Navigation and the navigation by such electronic aids is called radio navigation.

Radio navigation was started during World War I when marine wireless telegram was developing, as a means of direction finding by emission of non-directional medium frequency radio wave. Rotary beacon also appeared that was utilized by small boats having no direction finder. However, their accuracy was not satisfactory owing to the night error unless the boats were equipped with Adocock antenna.

Radio navigation made a great step forward since World War II owing to the military requirements. LORAN, DECCA, GCA (Ground Controlled Approach), radio-altimeter, and radar are some of them. Radio navigation continued to develop after World War II, and VOR(VHF Omni-directional Range), ILS(Instrument Landing System), TACAN(Tactical Air Navigation System), DME(Distance Measuring Equipment), Doppler Navigator, and LORAN-C are some of the development; and recently a system utilizing radio navigation satellite such as NNSS has been practically used.

While wireless telegram, wireless telephone and television are used for communication of the will, radio navigation is used for giving information to moving vessels concerning their bearing and position, and this makes its character somethat special.

Radio navigation is based on the basic characteristic of radio wave to propagate rectilinearly at a constant speed. Uitlization of SHF band and EHF band was developed in recent years, and many systems for radio navigation have been developed and put into practical use. Various receiving equipments are required to be carried by the moving vessels corresponding to the different systems of the ground facilities, but those on the vessels are the simpler the better. The variety of radio navigation systems that have been adopted till now are impossible to cover all of them by a single system, and several equipments are usually installed on vessels for different purposes. Besides, many systems of radio navigation have been shared by many kinds of vessels, and it is extremely difficult economically to change the system once adopted. Naturally, it is desirable that systems be adopted in common internationally, since ships and aircrafts serve internationally. Thus international discussions have been maintained since 1945 for unification or standardization of the radio navigation system.

International Meeting on Radio Aids to Marine Navigation, IMRAMN, was held in 1946 in London to discuss mainly on marine radio navigation, and the standard shown in Table 1-1 was agreed upon. As a result, equipment of direction finder became compulsory by the Convention of Safety of Life at Sea of 1948 for all of the ships of 1,600 tons or larger of grosstonnage.

Table 1-1 Standard by IMRAMN

distance	sea area	water depth	distance to dangerous object	accuracy required	time required
long	ocean	100 fms or larger	50NM or larger	± 1%	within 15 min
medium	coast	20-100 fms	3-50 NM	1/2NM-200m	1/2-5 min.
short	harbor	20 fms or less	3NM or less	± 50m	instantaneously

note: fms:fathom, a unit of depth, same as 6 feet

As for the marine radar, a resolution was adopted in the fourth extraordinary general assembly of IMCO (Intergovernmental Maritime Consultative Organization) in 1947 containing an enforcement of equipping all of the ships of 1,600 gross tonnage or larger with radars as a revision of the Convention of Safety of Life at Sea and further in 1971 in the seventh general assembly of IMCO a recommendation was adopted to provide a more strict standard for the radar at that time.

As for the international unification of the aeronautical radio navigation system, International Civil Aviation Organization, ICAO, has been promoting it since the organization in 1947.

Now ILS, GCA, SRE (Surveillance Radar Element), PAR (Precision Approach Radar), VOR, DME, Z Marker, CONSOL, and SSR (Secondary Surveillance Radar) have been adopted as the international standard for the international civil aviation system as a result. Although no definite classification according to the distance has been made owing to the different effective range of the aeronautical radio navigation equipment by the altitude, those with an effective range of 500 nautical miles or farther is called long distance system, while those with that of 100-500 nautical miles medium distance system and those with that of 100 nautical miles or shorter short distance system. Those for airports and vicinity are called terminal region system or landing system.

The accuracy of position determination is expressed usually by "value of error for 95% time probability". For example, "2 nautical miles or less of error by 95% time probability" means that 95 times of 100 determinations of position can be made by errors of less than 2 nautical miles while 5 determinations may be made by errors of 2 nautical miles or more.

Reliability is especially needed to the electronic aids to navigation for a safe operation of ships and aircrafts, and so most of the ground facilities have reserve equipment as well as in operation one. Many of the vessels have now been also equipped in duplicate. Especially aircrafts engaged in an international transportation business are compelled by law to have the equipments in duplicated. LORAN and DECCA can be used for marine as well as air navigation, but many of others cannot be used for both of the purposes. This is due to the large difference in the speed of the vessels. Because of the high speed of aircrafts, as compared with that of ships, direct reading of the informations of the position and bearing by the pilot is required. Unless a navigator is servicing besides a pilot, a direct indication of position and bearing to the pilot is necessary, the system of determining positions by use of a chart or numerical table is undesirable. The lower speed of ships allows the determination of the position by use of chart or tables practicable for navigation. Operation of aircrafts are performed under Air Traffic Control, ATC, and the electronic aids to navigation for aviation must have functions applicable for ATC.

(1) Maritime Navigational Aids

The equipment needed for the electronic aids to navigation is desirable, needless to say, to be less expensive and to be highly accurate and wide in effective range.

However, it is difficult for all of the requirements to be satisfied at the same time, and various units for the respective purpose are used according to the object.

The maritime radio direction finders don't require radio receiver to be equipped if they had medium wave wireless telegraph unit. However, in small fishing boats, a radio telegraph unit is lacking, and a rotary beacon for medium wave is utilized. A receiver which is able to reveive at 285-325 kHz is necessary, and a transistor radio costing 40-120 dollars will be sufficient. The precision is not particularly good, but it is sufficient for coastal fishery; thus utilized by many. With a direction finder, medium wave non-directional beacon and other radio stations can be utilized.

If a higher accuracy and a longer distance are desirable, DECCA or LORAN A is available, but an exclusive receiver will be needed. They are also suitable for an aircraft. The receiver for maritime purpose costs some thousunds dollars, but it may not be expensive if the improvement of operational efficiency is considered, and LORAN A receivers of a small type are widely used even by small fishing boats.

Omega system is used for a super-long distance, being developed mainly by the U.S.A. The system is reaching completion, and the eighth station is under construction in Australia. If the system is used world-widely, ships anywhere on the globe can determine their location, and the error is said to be some hundred meters.

Ramark and transponder are used for ships equipped with a radar. They give special indication to the radar picture and are used for improving the use of radar.

In foggy districts, course beacon or talking beacon that can be utilized by a receiver of some hundred dollars can be arranged for a coastal small fishing boat, and harbor radar in a large harbor or a narrow strait.

Table 1-2 List of radio navigation equipments

I. **navigation aids** (ground equipment) One that emits radio wave form the ground to be received by ships or aircrafts

1. unit indicating bearing only

name of equipment	item indi-cated	air or sea	equipment used	method or object of use	approximate effective range	accuracy	frequency used(band)	remarks
direction finding station	bearing from station	sea	transmitter and receiver, medium wave	radio waves are trans-mitted form ship to have the bearing determined and informed	daytime: 200 NM night: 50 NM	± 2°	medium wave, 410 kHz	very few at present after diffusion of direction finder
non-direc-tional beacon	"	sea	direction finder	(1) determine the bear-ing of the station by direction finder (2) obtain the position by bearings of two stations	daytime: 200 NM night: 50 NM	± 5° within	medium wave, 285-325kHz	often equipped along with a rotating pattern beacon
"	"	air	"	(1) ditto (2) instal-led along air routes for aircrafts deciding their route	daytime: 200 NM night: 50 NM	± 5° within	medium wave, 160-285kHz 325-450kHz	called NDB
rotating pattern beacon	"	sea	medium wave receiver	(1) count dot numbers from the standard time up to vanishing point (2) obtain two bearings	daytime: 200 NM night: 50 NM	± 2°	medium wave, 285-325kHz	can be used with a radio set cost-ing about 40 dollars
rotary beacon	"	sea	microwave beacon receiver	count dot numbers from the standard time until specified sound is heard	20 NM	± 2°	microwave 9,310MHz	receiver about two hundred dollars, used along with course beacon

name of equipment	item indi-cated	air or sea	equipment used	method or object of use	approximate effective range	accuracy	frequency used(band)	remarks
talking beacon	bearing from station	sea	microwave beacon receiver	(1) bearing can be heard as voices from station	20 NM	± 3°	microwave 9,310MHz	receiver about two hundred dollars, used along with course beacon
course beacon	spec-ified course	sea	microwave beacon reveiver	(1) know being on the right side by the rece-iving sign D(-••) or on the left side by U(••-)	10 NM	course width 2°	"	continuous sound on course, same receiver as above
VOR	bearing from station	air	VOR receiver	(1) determine bearing from station (2) installed along air route to indicate flight course to aircraft	125-200 NM	± 1.5°	VHF 108-118MHz	compose air route by this VOR
ramark	"	sea	Radar	(1) make bearing of station indicated on radar indicator (PPI) (2) define the position that is difficult by radar	30 NM	±2°(de-pends on the radar)	microwave 9335-9415 MHz	
CONSOL	"	sea air	medium wave receiver and direction finder	(1) determine bearing from station by counting dots (2) obtain two bearings	daytime: 1000 NM night: 2000 NM	±1/4°-±2°	medium wave 190-415kHz	first constructed in Germany but existing all over Europe
Localizer	speci-fied course	air	localizer receiver	aircraft landing aids equipment, described elsewhere				ILS
Glide Path	"	air	glide path receiver					

2. unit indicating distance from station only

name of equipment	item indicated	air or sea	equipment used	method or object of use	approximate effective range	accuracy	frequency used (band)	remarks
DME	distance from station	air	DME equipment	(1) radio wave transmitted from aircraft by DME equipment to receive responding signal and find the distance	100-200 NM (depending on the altitude)	±0.1%	UHF 960-1215 MHz	often along with VOR or ILS

3. unit indicating distance and bearing

name of equipment	item indicated	air or sea	equipment used	method or object of use	approximate effective range	accuracy	frequency used (band)	remarks
TACAN		air	TACAN equipment	(1) similar to a combination of VOR and DME	100-200 NM (depending on the altitude)	bearing ±1°, distance*	UHF 960-1215 MHz	mostly for military use, *±185m + 0.2% of distance measured
NAVARHO		air	NAVARHO equipment	(1) determine bearing and distance from station	1500-2500 NM	distance ±55 NM bearing ±4.°	low frequency, 90-110kHz	improvement being studied, for the error is too large

4. unit for determining position (hyperbolic line of position system)

The principle is utilized that the locus of points at equal distance difference from two points is a hyperbolas. The difference in distances from a pair of stations is obtained, and a similar difference is obtained from the other pair of stations; and the position is obtained as a crossing point of the hyperbolas. A special chart called LORAN chart or DECCA chart is required and a special receiver for the system is also needed.

name of equipment	type transmission	air or sea	transmission power	frequency used	effective distance	accuracy	remarks
LORAN A	pulse wave	air or sea	130 KW	1950, 1850 1900, 1759KHz	daytime: 750 NM night: 1500 NM	100NM to about 500m 600Nm to about 4000m	
LORAN C	pulse wave	air(sea)	1000-1600 kW	100kHz (90-110kHz)	daytime: 1200 NM night: 2400-3600NM	600NM to about 100m 1200NM to about 300m	
DECCA	continuous wave	air or sea	2 kW	70 - 90 110 - 130 kHz	daytime: 600 NM night: 390 NM	50 NM to about 5m 200 NM to about 60m	
DECTRA	pulse wave	air (sea)	50 kW	84 - 86 kHz	200 NM	1600 NM to about 5 NM	
OMEGA	pulse wave	air or sea	10 kW	10 - 14 kHz	5000-6000NM	1 NM	cover the whole globe by 8 stations
DELRAC	pulse wave	air or sea		10-14kHz	3000 NM	10 NM	

5. ground radar station Radar is arranged on the ground, the movement of aircrafts and ships are grasped, and indications and informations are given to the aircrafts going to land the airport or ships to arrive the port.

name of equipment	sea or air	frequency used (band)	range of utilization	method and object of use	remarks
Harbor Radar	sea	5600, 22500, 32500MHz	inside harbor harbor and 10-20 NM	inform present position of ships, conditions of course, harbor, and berth, and visibility	

name of equipment	sea or air	frequency used (band)	range of utilization	method and object of use	remarks
A R S R	air	1300-1350MHz	400 NM	grasp movements of aircrafts on and off the route and utilize them for air traffic control	
A S R	air	2700-2900MHz	50-100 NM	grasp movements of aircrafts in and around airport to use them for traffic control of landing and take off	
P A R	air	9000-9200MHz	10NM, angle 20°, incli- nation 6°	watch approaching course and approaching (descending) angle of aircrafts to secure their safety	
G C A	air	2700-2900MHz 9000-9200MHz	ditto	make landing guide to aircrafts equipped with ASR, PAR, and VHF communication unit; on traveling vehicle	ASR here is called SRE.
S S R	air	1030MHz		used in combination with ARSR or ASR, speci- fied marks are given to each of the images on the radar indicator (PPI) to identify specific aircrafts	responder is needed on the aircraft for response

6. equipment for instrument landing system

used for indicating aircrafts on landing approaching course and descending course (inclination) to the landing point; The following three kinds of equipment are called ILS collectively. Effective range 10 NM or less.

name of equipment	position	frequency used	use	remarks
Outer marker	3.9 NM from landing point (standard),	75 MHz	shows specified distance to landing point on runway.	Inner Marker may be installed in addition
Middle marker	3500 feet from landing point	75 MHz	ditto	

name of equipment	position	frequency used	use	remarks
Localizer	1,000 feet from end of runway	108-112 MHz	Indicate whether aircraft is approaching correctly on the extension of the runway or not. If not, the degree is indicated. In case of error by a building etc., directional localizer may be installed in addition.	The standard localizer is called clearance localizer to discriminate it from directional localizer.
Glide Path	800-1,600 feet inside from the landing point on the runway, 400-500 feet sidewise to the runway.	329-335 MHz	Indicate the course of descending approach inclination to the grounding point on runway. Usually 2.5-3°, with 2.5° standard. Show the degree of deviation up and down from the course.	
B L E U	ILS, radio altimeter, and magnetic induction cable are used in combination to be used in perfectly automatic blind landing.			

7. unit indicating the position

name of equipment	item indicated	air or sea	equipment for	method or object of use	effective range	accuracy	frequency used	remarks
Transponder	position	sea	radar	(1) Bright line indicated on the extension in the direction from the ship on the picture of radar indicator (2) indication of obstacle	30 NM	depends on the accuracy of radar	9335-9415 MHz	
Z Marker	position	air	Marker receiver	indicate position of NDB	12-15 sec. at 1,000 feet altitude and 120 knot speed.		75 MHz	

II navigation instrument carried by aircraft or ship

1. radar

	frequency used	range of angle	use
for ship	3100-3246 MHz 9300-9500 MHz	360°	Detection of ships, coastal line, islands, iceberg, etc. around a ship. effective range: 20-100 NM
on arcraft	5,350-5,460MHz 9300-9500 MHz	about 200° ahead	(for weather) mainly for watching weather conditions (cloud conditions) ahead, effective range: 150-180 NM

2. radio altimeter Used for determination of the height from the earth surface (ground or sea level). frequency used: 4,300 MHz, Used for calibration of barometric altimeter, confirmation of altitude in landing etc.

3. Doppler navigator (a kind of self supporting navigation equipment)

The position of aircraft is continuously indicated by a combination of doppler radar, navigation computer, and gyrocompass.

(1) Doppler radar (sensor)

Indicates the ground speed and deviation angle (the angle between the direction of the aircraft nose and actual ground running direction; 20° or larger not rare under jet stream) of aircraft

(2) navigation computer

The ground speed and deviation angle data from the doppler radar and the direction of the aircraft nose by the gyrocompass are input, while the anticipated flying course and the distance to the destination are set manually in advance; and the remainder of distance to destination and deviation from the course are indicated continuously.

These equipments must conform with the object of use. For example, an error of 10 mile is not a problem for a ship in an ocean but that of a mile is serious to a boat sailing along coast; even an error of 100 meter can be serious in entering a harbor through a narrow waterway. Thus suitable equipments should and can be selected according as needed.

(2) Aeronautical Navigational Aids

The object of aeronautical navigational aids is somewhat different from that of maritime navigational aids, conceptionally. Especially, owing to the increasing speed and traffic of aircrafts, the importance of these equipments are ever greater. Ships can select their course comparatively freely, but aircrafts flying under control must observe their course within certain limits of width and height of the course. NDB and VOR are used for indication of the specific point such as turning point, etc of navigational course. Therefore, equipment of ADF is a legal obligation of aircrafts conducting instrumental flying within controlled region.

ILS equipment for instrumental landing is important to aircrafts, for unlike ships anchoring outside port they cannot wait until the fog clears out. GCA and PAR are important for the same reason. Increase in traffic is great in recent years from helicopters to jet planes with a wide range in speed and altitude, and monitoring radars, such as ASR, ARSR, and SSR, are playing ever more important roles in their control. A summary of various radio navigation equipments is given in Table 1-2 as a list.

1-2 Direction Finder

Direction finder determines the direction of incident radio wave based on the characterestic of the rectilinear propagation of radio wave and are used extensively in various fields of marine, aircraft and ground facilities. Ships and aircrafts find their position for their security by determination of the directions of radio wave from two or more stations on the ground of known position. They can also ask a ground station equipped with a direction finder to find the azimuth of itself and get informed of the result. Rescue boats often hurries to the ship in distress maintaining its direction to that of the distress signal, and this is effective so long as the signal is continued. In fishery, direction finders are used by independent fishing boats returning to their mother ship, assembly to a fishing place, confirmation of radio bouys attached to the fishing nets or catches, etc. Besides, they are used in various fields of observing atmospherics and weather, watching radio wave, etc.

(1) principle

In propagation of radio wave along the ground surface, its magnetic field is parallel to the ground surface and perpendicular to the direction of propagation. Therefore, finding the direction of magnetic field is sufficient for finding that of the coming radio wave. When a loop (frame type) antenna is held vertical on the ground and rotated around its axis, an electric voltage is induced in it in proportion to the magnetic flux crossing it. The voltage induced will be the largest when the surface of the antenna is held parallel to the incident plane, while the least when perpendicular to it. Therefore, by finding the direction of the least voltage, the direction of the magnetic field is obtained and it shows also the direction of radio wave coming.

In Fig. 1-2, when radio wave is coming from N and the loop antenna is rotated, the induced voltage will be maximum when its surface coincide with NS plane but minimum at E or W direction. This is the same as with wave from S direction. Thus in actual azimuth determination one must decide whether the wave is from N or S. This ambiguity is resolved practically by synthesizing the output from 8 shape characteristic loop antenna (Fig. 1-1) with that of auxiliary vertical antenna to make cardioid pattern characteristic as shown in Fig. 1-2.

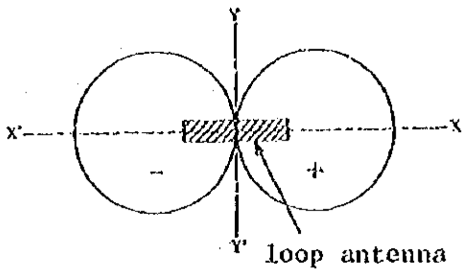


Fig.1-1 Directional characterristic of loop antenna

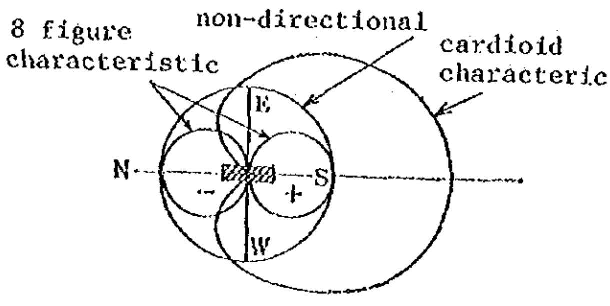


Fig.1-2 cardioid characteristic

Let E_1 and A_1 be the output of the vertical antenna and its amplitude,

$$E_1 = A_1 \sin \omega t \quad \cdots\cdots (1)$$

Let E_1 and A_1 be the output and amplitude of loop antenna,

$$E_1 = A_1 \cos \varphi \sin (\omega t + 0) \quad \cdots\cdots (2)$$

where 0 is the phase difference between the both outputs.

By adjusting the antennas so that $\theta=0$, $A_1=A_2=A$, the resultant output E is

$$E = A(1 + \cos\varphi) \quad \cdots\cdots (3)$$

having the cardioid characteristic.

(2) Structure

A direction finder is composed of an antenna, receiver, indicator and accessory equipments.

a. antenna

(a) loop antenna

A loop antenna is formed of a wire wound several times around a square, rectangular, circular, or various shaped frame to utilize the electromotive force generated as magnetic flux penetrates the coil. The directional characteristics are of an 8-shape as already explained. Its effective height he is expressed by the loop area $A(m^2)$, number of turns of coil N, and wave length $\sigma(m)$ as the following equation.

$$h_e = \frac{2\pi NA}{\sigma}$$

(b) Adocock antenna

Adocock antenna is used for eliminating the error which occurs when there is a horizontaly polarized component such as reflected wave by the ionosphere. By a group of vertical antennas, 8-shape characteristics are obtained. Its structure is shown in Fig.1-3 where vertical antennas AB, CD, A'B' and C'D' are connected by adjacent horizontal conductors with insertion of a coil between the middle points of the conductors to extract the antenna output.

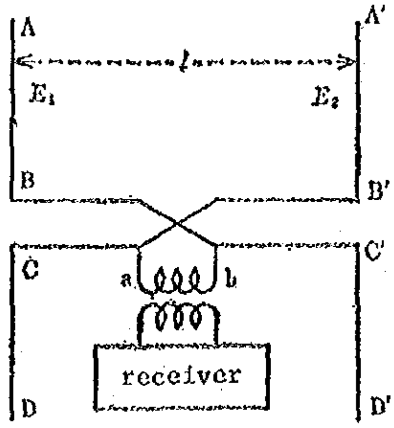


Fig.1-3 Adocock antenna

(c) goniometer

With a loop antenna or Adocock antenna, it is necessary to rotate it and find the minumum sensitivity point, a direct rotation of an antenna of a large size is difficult. Goniometer is a device for obtaining same effect as rotation of antenna without rotating it. This is accomplished by leading the outputs from two antennas arranged perpendicular to each other into fixed coils and finding the direction of mimimum output by rotating a search coil placed inside the fixed coils, whereby the angle of radio wave coming from can be determined.

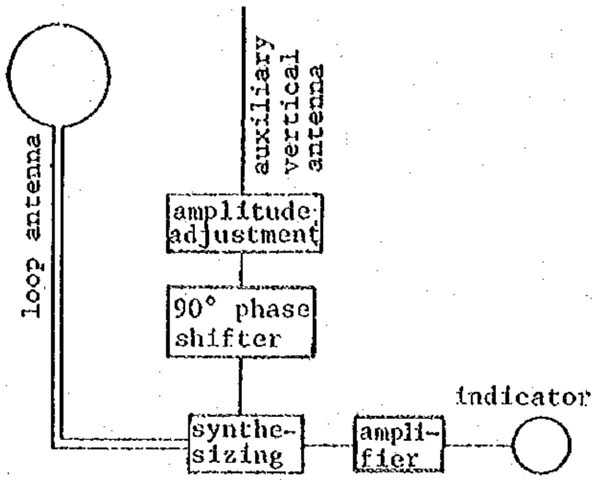


Fig.1-4 sense deciding equipment

(d) sense deciding equipment

This is a unit for obtaining cardioid characteristics by composition of the outputs from a loop antenna and auxiliary vertical antenna, and the diagram is shown in Fig.1-4. The amplitude of the vertical antenna output is adjusted and then its phase is shifted by 90° when it is impressed on the output from the by directional loop antenna of 8-shape characteristics. Three types of units for 90° phase shifting are used: by impedance insertion method, vacuum tube connection method, and a method utilizing the phase difference by the feeder line.

b. receiver

Receivers similar in construction to those for communication are used, and there is no large difference in the construction of the circuit. The performance can be described by the minimum detectable intensity of electric field and the width accuracy of measured azimuth. The strict conditions for the selectivity characteristics are required due to the narrower interval of frequency assignment.

c. indicator

(a) audio-type: The system for detecting the minimum point of sound with an ear receiver is useful when there exists fading of signal or radio wave transmission duration is short.

(b) visual system: Detection of minimal sensitivity point is carried out on a Braun tube by propeller-shaped picture.

(c) sea route meter system: A system using sea route meter in place of the Braun tube.

(d) total direction indicating system: The angle of incoming radio wave is read directly on a Braun tube oscillograph as goniometer or by the needle of a phase meter.

d. accessory equipments

Error correcting unit, testing oscillator, protecting unit for antenna input circuit, etc. are among the accessory equipments.

(3) errors

The errors in finding the direction can roughly be classified into the following:

ertor caused by the finder itself : This kind of errors are caused by an inclination of the loop antenna, imperfect 8 shape characteristics of the directional antenna (antenna effect), variance of the mutual inductance between the antenna coil of the goniometer and search coil depending on the rotation of the search coil, etc. They can be reduced small enough for practice by careful design and manufacture.

errors caused by adjacent disturbing objects : These errors are caused by structures on steel ships or aircrafts and are classified into quadrantal error, showing maxima at the directions of 45°, 135°, 225°, and 315° with the bow at 0°, and semicircular error showing maxima at two directions such as caused by a mast of ship (antenna or tower on land). They can be corrected by the correction curves as explained later.

error caused by propagation of radio wave: The velocity of surface wave is 0.2-0.3% larger on the sea than on the land. Therefore, in determining the direction of wave coming from the sea on the land, the wave is refracted away from the coastal line, causing an error in the direction. (coastal error) The error is nil when the incidence of wave is perpendicular to the coast, but it is the larger, the smaller the angle of incidence. Also the larger the error is, the higher the frequency of the wave.

A phenomenon is observed at night while determining azimuth with a loop antenna when the point of minimum sensitivity is obscure to be observed in a very wide range with fluctuation. This is called the night error and is caused by an inclusion of a horizontal polarized component by the reflection from the ionosphere, and determination of the direction with a loop antenna is difficult. Use of Adocock antenna is the only means for azimuth determination under the circumstances.

orror curve : The semicircular or quadrantal error is specific to the direction finder arranged on a ship and should be corrected by a correction curve prepared in advance.

An example of the correction curve is shown in Fig.1-5. The curve can be prepared by recording the angles on the compass and direction finder by receiving the radio wave from a small oscillator on a boat transmitted at a distance of about 1 km and every 5° or 10° with the ship at the center.

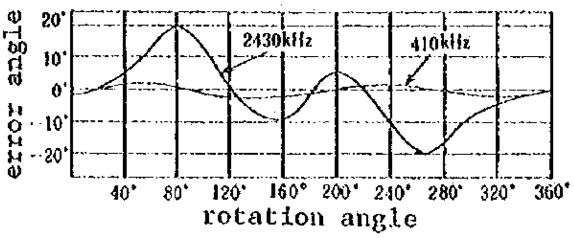


Fig.1-5 error curve

1. Direction Finder for Vessels

In Japan ships of 1,600 ton gross tonnage or larger engaged in international voyage (ships of less than 5,000 ton gross tonnage engaging in a coastal voyage are exempted from the obligation) are obligated by the Ship Provision Regulation, Article 146, to have a direction finder which must pass the official examination for the type approval. The conditions of the type examination are as follows:

Construction of the unit: The determination of azimuth shall be possible by waves A1, A2, and A2H of from 285kHz to 535kHz with an equipment enabling discrimination of a direction from one at 180° from it by means of sensitivity ratio, etc.

examination under rated environmental conditions: A sound mechanical operation with no abnormality such as failure, ignition, fuming, etc.

Width of azimuth determination: Within 6° for determination of azimuth of ground wave of 50μV/m electric field intensity under no external noise

error in azimuth determination: Within 1° for determination of ground wave of 1 mV/m electric field intensity or stronger in a place of small interference or disturbance.

signal to noise ratio: 10 dB or stronger for receiving a radio wave of 50μV/m electric field intensity at the maximum sensitivity azimuth under conditions of no external noise.

selectivity of a signal

passing band width: 2 kHz or more of the width with lowering of 6dB

amount of attenuation: 13 kHz or less of the width with lowering of 66 dB

spurious response: 40 dB or more

(2) Caution in provision

In providing a ship with a direction finder, the antenna shall preferably be placed on the center line of the ship in order to simplify the erroro characteristics. It is desirable also to place it as far from disturbing objects such as a mast, bridge, and communication antenna and as high as possible. After installation, the correction curve shall promptly be prepared and it should be constantly maintained accurate by calibration.

(3) Concrete example

The frequency band for an effective determination of the direction for vessels lies mostly within 200-4,000 kHz. A loop antenna is used. As indicating systems, an audio type by goniometer or rotating loop antenna, minimum sensitivity point detection type by deformation of Braun tube picture, or automatic indication type is used. Some units have an automatic error correction equipment attached.

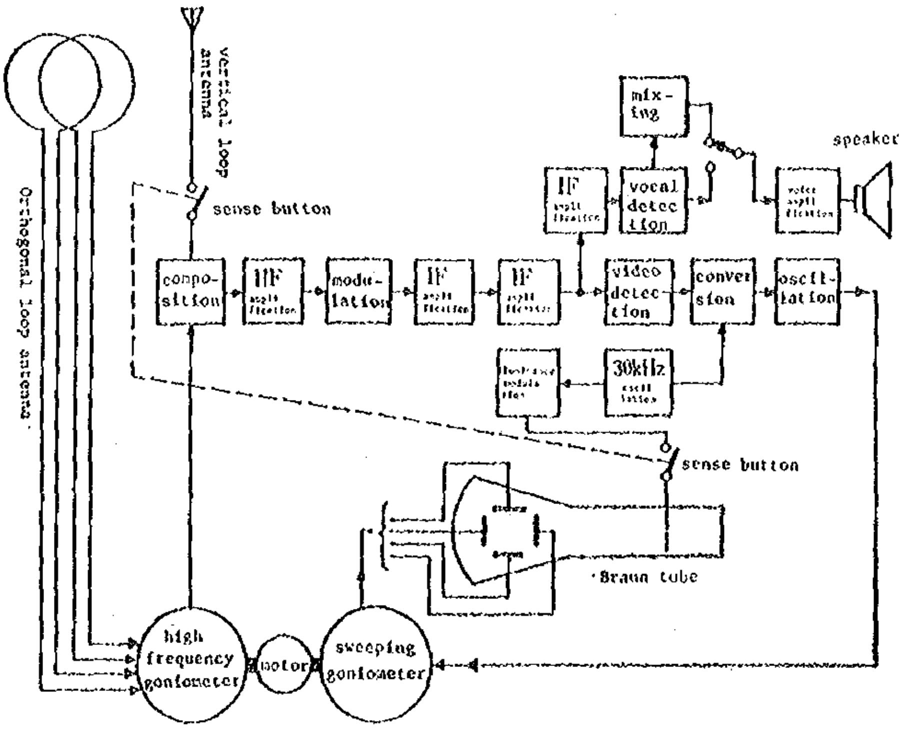
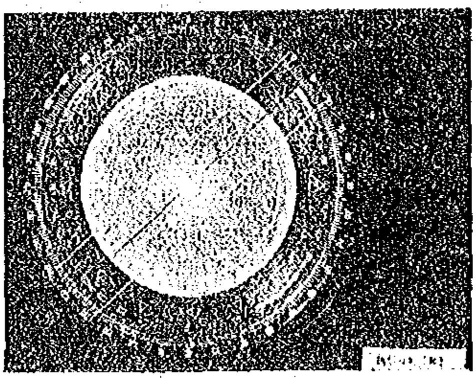
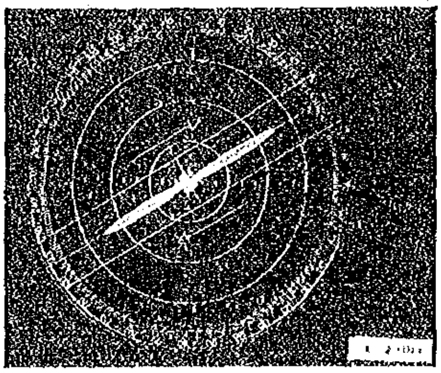


Fig.1-6 System diagram of visible direction finder

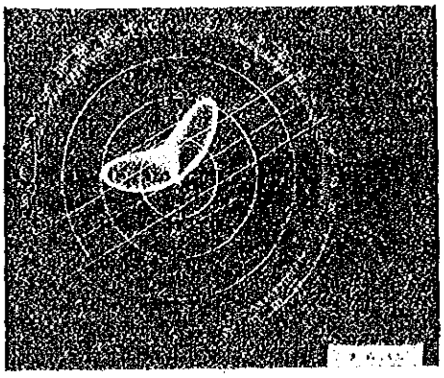
Direction finders by 27 MHz band have been developed in recent years to be used mainly in fishery, and they are good enough for practice by grasping the error caused by disturbing objects. Typical instruments are explained as follows:



without signal
(a)



direction finding
(b)



sense deciding
(c)

Fig.1-7 Propeller-shaped picture

a. Vision type direction finder

In this type of finder, the direction of incoming wave is indicated on the Braun tube as a propeller-shaped image, and the system diagram is shown in Fig. 1-6.

Instead of rotating the loop antenna, a high frequency goniometer is used, and output having an 8-shaped characteristic corresponding to the turning angle of the search coil and the direction of the incident wave is obtained by amplifying and detecting the output of the search coil with a receiver. The sweeping goniometer for indicating the incident direction on the Braun tube is directly coupled with the high frequency goniometer, and the sweeping output is maximum at the sound vanishing point showing the incident direction if the 30 kHz wave exciting the goniometer is inversely modulated by said output of 8-shaped characteristic, and conversely, the sweeping output is minimal at the point of maximum of the output of 8-shaped characteristic.

Accordingly, by rotating (about 15 times a second) both of the goniometers, the sweeping line appears circular (Fig. 1-7 (a)) in case of no signal, while a long bright line appears in the direction of least sensitivity on receipt of signal, a propeller-shaped picture (Fig. 1-7 (b)) without sweeping in the direction of maximum sensitivity being formed, and the direction of incident wave is found simply by reading the grading on the circumference for the direction of the bright line.

However, this is not enough for finding the true direction, and a sense deciding equipment is required. For decision of the sense, the input from the vertical antenna is composed with the loop antenna output after 90° phase-shifting, and cardioid characteristic is observed. The incident azimuth is decided by to which side the picture falls, (propeller picture) when the sense button is pressed. (Fig. 1-7 (c))

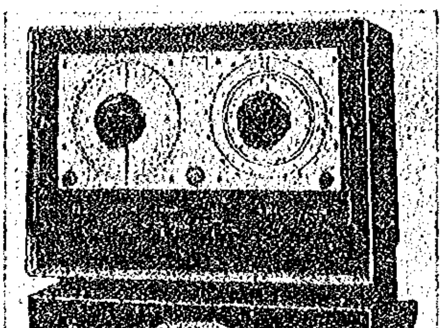


Fig.1-8 automatic direction finder

In addition, Braun tube type units using needle-shaped picture or trian triangular picture are avilable for sense determination.

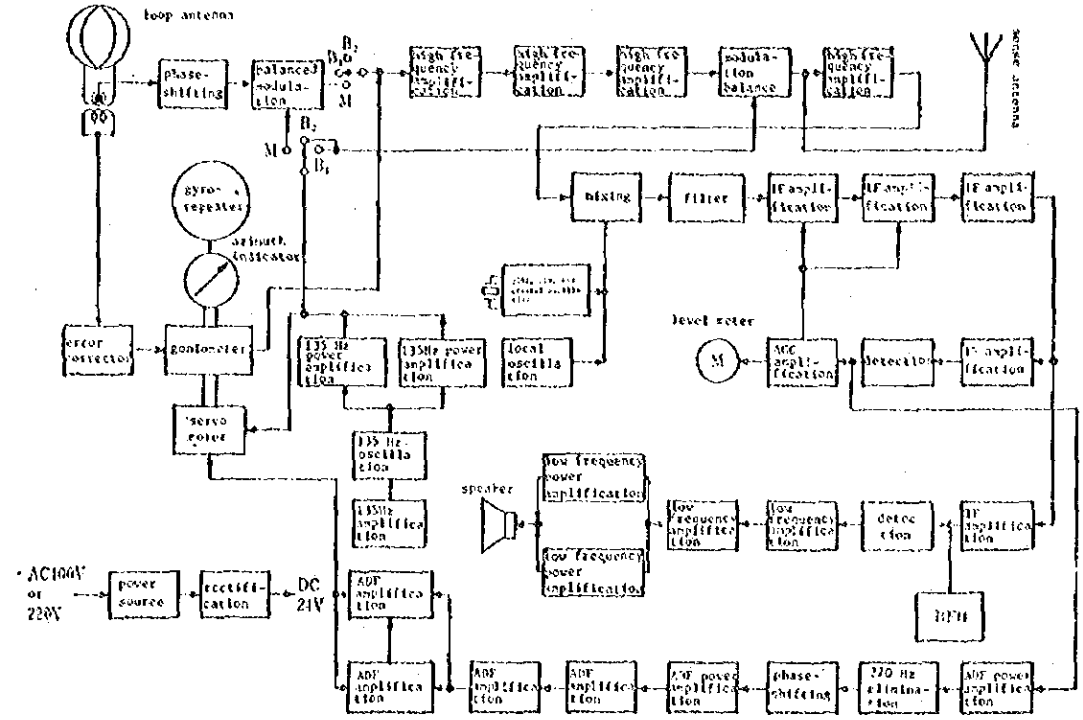


Fig.1-9 system diatram of meter indication-type direction finder

b. meter indication-type direction finder

This type of direction finder allows determination of azimuth within an extremely short time, for the needle of the meter shows the azimuth automatically simply by receiving the radio wave. (Fig. 1-8) The system diagram is shown in Fig. 1-9.

The loop antenna voltage undergoes balanced modulation of 135 Hz, after being shifted into the same phase as the vertical antenna voltage, to be composed with the latter. The composed high frequency voltage is detected after amplified, the dominant wave of 135 Hz only with elimination of higher harmonics is suitable phase-shifted, and impressed to the field coil of the motor after amplification. On the other hand, exciting current from 135 Hz oscillator is impressed to the other field coil of the motor; and thus rotating magnetic field is generated to turn the motor until the goniometer reaches an aural null.

Therefore, the stop point of goniometer indicates the azimuth of incident radio wave.

The error corrector corrects the quadrantal error automatically by insertion of inductance to the input terminal of gomiometer in series or in parallel.

The automatic direction finder shown in Fig. 1-8 is so constructed that it determines the azimuth through radiotelephony at distress frequency, 2,182 kHz, that is recommended by the Convention of Safety of Life at Sea, SOLAS.

2. Automatic Direction Finder (ADF) for airplanes

All medium wave direction finders for airplanes are automatic, and they are called Automatic Direction Finder, or ADF. When ADF is used on airplanes, the direction of the nose is taken as the standard, and the azimuth of the Non Directional Beacon, NDB, from the standard is measured automatically and indicated on the azimuth indicator.

(1) construction

ADF consists of an antenna, receiver, controller, and azimuth indicator. Fig. 1-10 shows an arrangement of two sets of ADF on an airplane, duplicate arrangement of ADF being obligated in large airplanes as with other electronic instruments for airplanes. The loop antennas and sense antennas are fixed at suitable positions of the body, but they are difficult to recognize in jet planes, for they are fixed inside body in order to minimize the air resistance. The controllers and azimuth indicators are placed at the pilot seat and navigators are placed at the pilot seat and navigator seat to be operated from either reading the magnetic azimuth of the nose and ADF azimuth simultaneously. Fig.1-11 shows the system diagram of ADF while Fig. 1-12 an example of ADF construction.

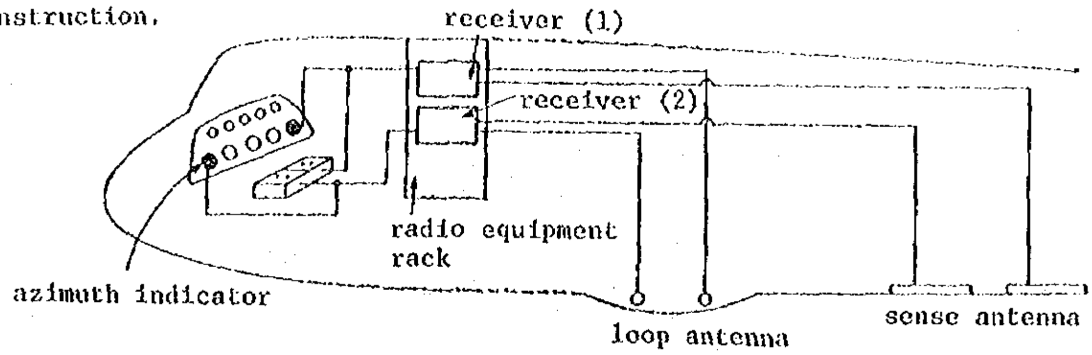


Fig.1-10 Arrangement of ADF

The frequency of NDB lies from 200 kHz to 415 kHz, but ADF can receive in the standard broadcasting frequency band, the usual range of receiving being 190 kHz to 1,750 kHz.

(2) Operation principle

It is of the same principle as in direction finders for ships that a rotating loop antenna driven by an electric mechanism and a non-directional sense antenna are used in determination of azimuth with ADF, but a change-over cardioid system is used in ADF in order to obtain azimuth indication automatically. The principle is shown in Fig. 1-13 where L is the plan view of the loop antenna whose directivity is 8-shaped. The sense antenna is non-directional, and its horizontal pattern is circular. The cardioid A in Fig.1-13

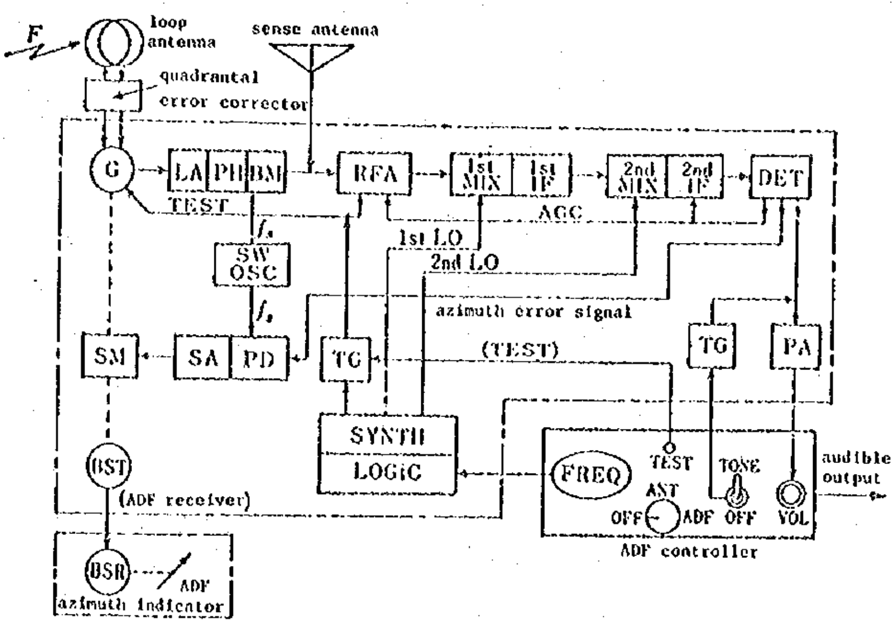


Fig.1-11 ADF system diagram

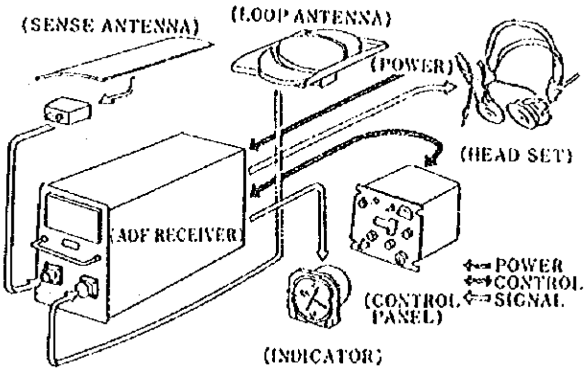


Fig.1-12 ADF construction

is obtained by composing the inputs both of the antennas after bringing their phases and amplitudes agreeable with each other. Then the output of the loop antenna is switched over and composed with the output of sense antenna after changing the phase of directivity by 180°, and cardioid B is obtained. In In other words, cardioid A and cardioid B are different from each other in the phase of output of loop antenna by 180°. Keeping the output of the sense

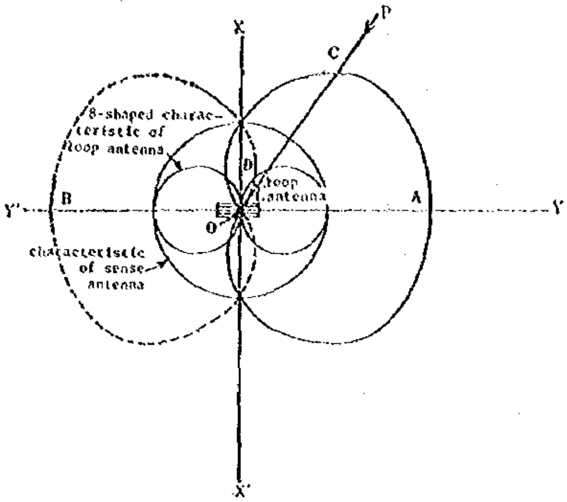


Fig.1-13 cardopod characteristic of ADF

antenna constant in this manner, and in the presence of left-right symmetric cardioid by switching of the loop antenna, an incidence of NDB radio wave from direction P will generates a voltage in proportion to the length OC in cardioid A, while a voltage in proportion to length OD in cardioid B, and there is a difference in the voltages induced between the both. In case of the radio wave coming from direction XO, that is the direction perpendicular to the loop antenna, the voltages induced are equal in either case of cardioid A and cardioid B. Therefore, by switching the output of loop antenna by some means to switch the cardioid characteristic continuously and by rotating the loop antenna automatically so that the output voltage of the both are equal, the indication of the azimuth towards a NDB is obtained by the angle of the loop antenna rotated.

Fig.1-14 shows an example of ADF system diagram. The loop antenna is rotated by a driving motor, and the switching of loop antenna output is made by low frequency balanced modulation. Fig.1-15 shows the relationship of phase in ADF. Assuming in the figure that the loop antenna is in the position of (1) and that the radio wave comes from direction P, the waveform of the voltage induced in the loop antenna is like [1]. The voltage is amplified in the next circuit and its phase is shifted by 90° to assume a waveform of [2]. The voltage waveform undergoes balanced modulation by a signal of 48 Hz like [3] from the low frequency oscillator. The balanced modulator uses twin triode, and one of the triodes works in the first half cycle if the amplitude of 48 Hz voltage from the low frequency oscillator is large, followed by working of the other triode in the next half cycle. The operation of the balanced modulator is as [4], and since the anode coil is attached in an opposite direction, the waveform in half cycle after the balanced modulator is reversed. Therefore, the output waveform of the balanced modulator is like [5]. Then the output waveform [6] of the sense antenna output voltage is composed with [5] so that waveform [7] is obtained. This is subjected to frequency conversion by superheterodyne system, and a signal waveform in 48 Hz like [8] is obtained by detection after intermediate frequency amplification. When the position of the loop antenna is different from (1) by 180° as shown in Fig. 1-15, (2), the waveform of loop antenna output [1] is also different from the case of (1) by 180°, and the output [5] of the balanced modulator is also different in the phase by 180° compared with the case of (1). Therefore, detection output waveform [8] is also different in phase by 180° from that of (1). In other words, what is clear from Fig. 1-15 is that the phase of detection output differs by 180° if the phase of radio frequency induced in the loop antenna differs by 180°. That is, the phase difference in radio frequency is converted into that of 48 Hz low frequency.

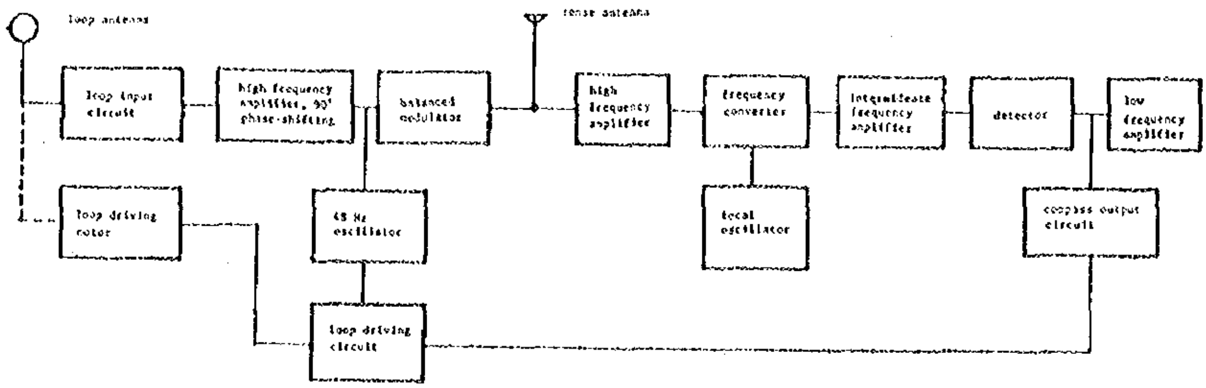


Fig.1-14 ADF system diagram

48 Hz two phase motor is used in ADF for rotating the loop antenna, and one of the motor coil is impressed with a radio wave from low frequency oscillator while the other coil is impressed with electric current [9] resulting from phase-shifting of detection output [8] by 90°. This is because two currents are needed for driving the two phase motor that are different in phase by 90° from each other. In Fig. 1-15 [9], the direction of rotation of the loop antenna in (1) is opposite to one in (2) because of the phase of the current given to the motor being opposite, and the motor stops turning

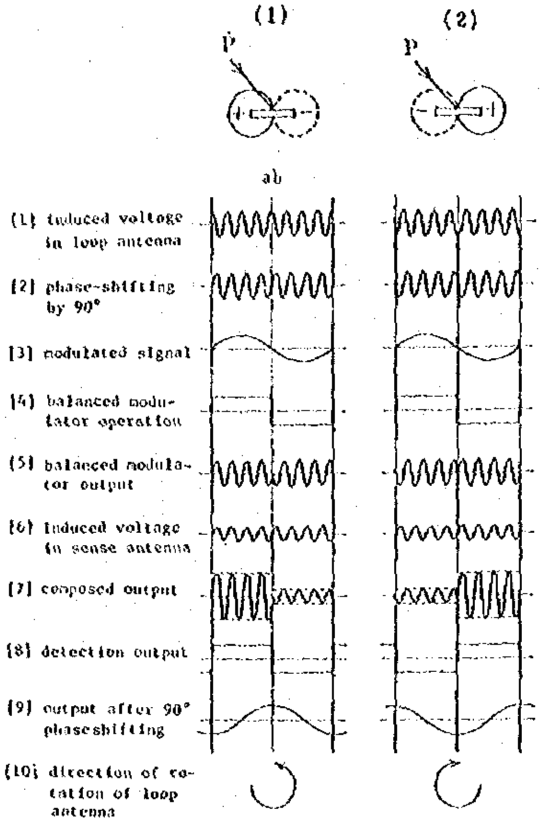


Fig. 1-15 Phase relationship in ADF

when the voltage induced in the loop antenna is zero. Indication of azimuth is made through transference of the loop antenna direction to azimuth indicator by self-synchronous mechanism.

(3) Error

The following causes of error in determination of azimuth by ADF can be enumerated:

(1) The structure of ADF itself,

(2) The position of ADF being installed,

(3) The position of NDB installed,

(4) The propagation characteristic of radio wave, etc.;

and these are similar to those in direction finder.

The accuracy of azimuth determination is provided to be 3° or less for the total of errors caused by the loop azimuth indicator, electric field intensity variation in the range of 100-10,000 μV/m, and quadrantal error correction mechanism. The quadrantal error caused by (2) above is about ±10-15%, and it is electrically or mechanically corrected so that the error is less than ±2% at the direction of the nose.

When an aircraft flies towards the direction of coming NDB wave, the azimuth indication of ADF is inverted as it flies over the NDB, but this does not necessarily take place right above NDB. Sometimes it takes place before or after arriving NDB, and this is caused by the directional characteristic in the vertical plane of the ADF sense antenna.

The threshold sensitivity of ADF is provided that the time needed for the indicator needle to turn by 175° under electric field intensity of 50μV/m is 7 seconds or less and that S/N under electric field intensity of 100μV/m and 1,000 Hz 30% modulation is 6 dB or more.

3. VHF Automatic Direction Finder for Airplanes

Two kinds of automatic direction finders are usually used for aviational aids: one carried by aircrafts for detection of NDB and the other for VHF band to be installed on the ground in airports for detection of radar signals from aircrafts.

Another type carried by aircrafts is VHF·ADF for VHF band radio wave that is used for aeronautical mobile communication, and is used to locate another flying aircraft during flight or a aircraft in distress during searching it. It is mostly needed by military aircrafts, especially searching and rescue aircrafts, and its civil use is rare. The following is VHF·ADF carried by aircraft that has been developed and used in the U.S.A. for military purpose.

VHF·ADF carried by aircraft that are used at present can receive amplitude modulated ro non-modulated wave of 225 MHz-400 MHz, determine the arrival bearing correctly and continuously, and make homing possible.

The unit consists of an ordinary receiver, directional antenna, indicating device, and controlling mechanism; and the receiver for communication by the aircraft is commonly used for the unit by switching with a relay so that duplication of instruments is avoided. The system diagram of the unit is shown in Fig. 1-16. The receiver is normally connected to the non-directional antenna, but in determination of azimuth it is switched over to the directional antenna by setting the selection switch to ADF when the relay operated the switching.

The directional antenna consists of a single element of slender rhombic shape and has feeding points at its both end of the cardioid directional characteristic. The connection of antenna is automatically switched from one end to the other of the antenna 100 times a second alternately.

As this way antenna pattern changes its phase by 180° at the same rate. AS a result the output signal from antenna is modulated by a rectangular wave of 100 Hz. That is, the signal level in antenna output assumes every half period of the rectangular wave of 100 Hz a value corresponding to each of the antenna patterns. The signal modulated by the rectangular wave passes a relay, and then is impressed to the receiver, and is demodulated to a rectangular wave voltage at the output of the receiver. The relationship of input levels of receiving wave from various directions is shown in Fig.1-17.

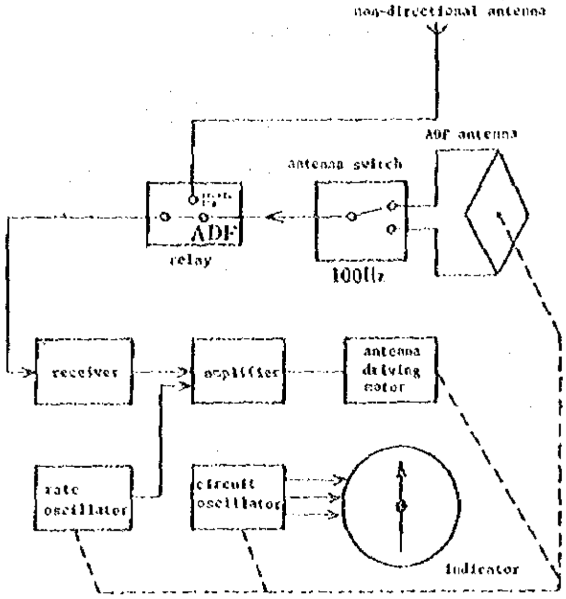


Fig.1-16 system diagram of VHF.ADF on aircraft

The output voltage of the receiver is impressed after passing a filter circuit and amplifying circuit on the antenna driving motor as control voltage for rotating antenna (directing it to direction X_0 in Fig.1-17) so that the signal outputs by the two patterns are equal to each other. This means that the control voltage is annulled, and any deviation of antenna from this position makes the antenna output signal unbalanced and a returning force to the equi-sensitivity direction is immediately generated.

The two cardioid characteristic patterns cross each other at two points and directions of equal sensitivity exist in two directions differing by 180° from each other. However, even if the antenna did stop at the reverse direction, the nose of aircraft is constantly changing by the action of wind and vibration and by steering, and the position of antenna cannot stay at a point, and a slight deviation would generate a restoring force to the stable normal position. Thus the incoming direction is indicated on the indicator at the pilot seat continuously with the nose direction as standard by transmitting the direction of equal sensitivity of the antenna by means of a syncro motor. Hunting and excessive deflection of the motor are avoided as the rate oscillator is connected with the antenna mechanically.

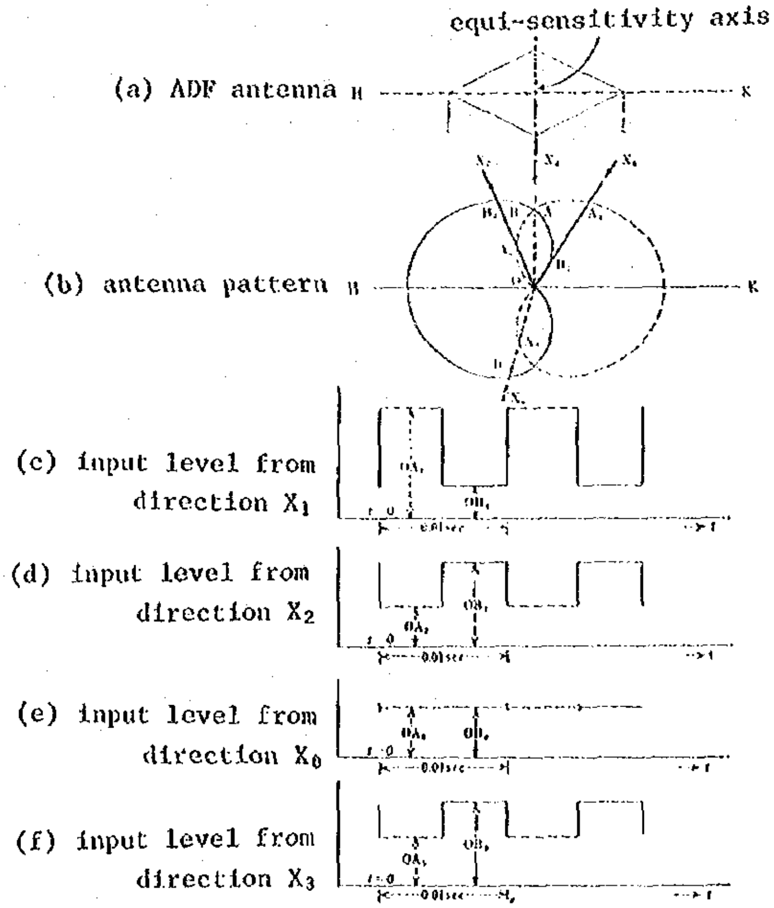


Fig.1-17 input levels from various directions

1-3 Radial Line of Position System

1. Maritime Navigational Aids

The maritime navigational aids of radial line position system used in Japan at present are: medium frequency non-directional beacon, and rotating pattern beacon with addition of the recently developed microwave beacon such as microwave rotary beacon, talking beacon, ramark, and course beacon. Development and improvement are under way aiming at a higher precision and easier handling,

(1) direction finding station

The first of the navigation aids with utilization of radio wave is the direction finding station. It determines the arrival bearing of the radio wave from ships by a request from ship and informs the azimuth determined at the station to the ship. Ships request two or more stations to find direction and know their position by cross bearing method.

This kind of maritime direction finding stations were established at the beginning of Showa Era, about 1925, successively all over Japan, but later on their utilization declined by arrangement of directional beacon and diffusion of maritime direction finder until they have disappeared. They belong to the past, but they are recorded in history as the daybreak of the radio beacon.

Table 1-3 representative examples of land direction finder

type	range of frequency	antenna used	sense antenna	indication system
low and medium frequency direction finder	285kHz-535kHz	diameter 2m, orthogonal single turn loop antenna	auxiliary vertical antenna	audio minimum sensitivity system or Braun tube picture system
time division type high frequency direction finder (KS 306 type)	3MHz-24MHz	height 6m, span 6m, four pole adocock antenna with matching transformer	6m high antenna arranged at the center of Adocock	direct vision by the needle picture on Braun tube
goniometer type high frequency direction finder (KS 329 type)	1.5MHz-23MHz	height 10m, span 10m, eight pole Adocock antenna with resistance matching box	composed by 8-pole Adocock antenna	direct vision by means of propeller-shaped picture on Braun tube and parallel use of audible minimum sensitivity
Braun tube goniometer type high frequency direction finder (PST-396 type)	1.35MHz-16MHz	height 8m, span 8m, 6 pole adocock antenna with matching transformer	composed by Adocock antenna	direct vision by needle-like picture on Braun tube

General direction finders placed on land are not much different in principle from those carried on ships, but their construction and circuit mechanism are largely different. The antennas used are of a large type because of no limitation in the space, most of them using goniometer system. The indicator is all direction automatic indication type, and some have audio indication in parallel.

Typical ones are summarized in Table 1-3.

Selection of the place for installation : Placing direction finders in an appropriate position is important to the error reduction in determination, and absence of any disturbing object near the direction finding station is ideal. Considerations for reducing undesirable effect of disturbing object to a minimum, if any, as far as possible must be made.

The conditions for establishing a direction finding station :

(a) Absence of steel tower, chimney, overhead line, railway, or metallic structure within the radius of 500m, of building and tree within that of 300m, and of antenna and metallic fence within that of 200m. All power lines, metallic pipings, and cables shall be buried at 1 m or more depth underground.

(b) Mountains shall desirably be 5 km or more apart, sea and large lake 1 km or more, cliff, valley and forest 500m or more, river and lake 200m or more.

(c) Surroundings within 400m approximately shall be flat and have uniform geology with good conductivity.

These are general requirements, and after all it is essential that a suitable place without trouble in direction finding be selected.

Placing antenna : Antennas must be manufactured in proper construction and accurate dimension and set firmly and vertically on the ground. The orthogonal antennas must be placed with special attention to the orthogonality of the two antennas in order to maintain electric balance.

(2) Non-directional Radio Beacon, Rotating Pattern Radio Beacon

These are both beacon for a medium distance of medium wave beacon band. Ships find the bearings from station by direction finder and medium wave receiver. Non-directional beacon had been the only and valuable beacon in Japan since it was first settled in 1932 at Kinkazan and other two places. After appearance of rotating pattern beacon shortly after World War II, ships dispensed with direction finder were enabled to find directions with inexpensive receiver only. And it became possible even for small boats to utilize the radio navigation aid. Thus the age of arrangement of various kinds of beacons from large ships to small boats was started. At present in the sea area around Japan, non-directional radio beacon stations are arranged so that two points or three points cross bearing determination (determinatiotion based on bearings from two or three stations) is possible, and the network is almost completed.

Non-directional beacon stations were placed side by side with direction finding stations, but according to the gradual decrease in the number of the latter, they are now placed side by side with rotating pattern beacon stations. Both of the beacons transmit signals 4-5 times an hour with their frequencies being kept identical with neighboring stations so that simultaneous determination of 2-3 stations may be possible.

The number of stations reached its maximum in 1969 to 51 in Japan, but it is decreasing somewhat. The number of stations in October, 1972 is shown in Table 1-4.

Table 1-4 List of medium wave beacon stations in Japan

non-derectional beacon station	11
rotating pattern beacon station	10 (one medium - short wave station inclusive)
non-directional and rotating pattern beacons side by side	30

Principle : Rotating pattern beacons transmit dots every 2 degrees by a combination of goniometer and orthogonal frame type antenna with 8-shaped directivity. (Fig.1-18) The first dot is transmitted at 2 degree of minimum sensitivity, and so ships can find their own bearing in degrees by counting the number of dots to sound-disappearing point with a receiver and then multiplying it by two.

Equipment : The radio equipment in rotating pattern beacon stations is now complete in the performance of beacon thanks to improvements in antenna system, automatic control, and signals transmitted and further in error correcting device etc. Recently emphasis is laid on improvement of reliability and remote control of station. Fig. 1-19 shows a standard construction of a beacon station.

(a) transmitter

frequency one frequency of 285-325 kHz

output A2 390 W (Fp) (rotating pattern beacon)

A2 300 W (Fp) (non-directional beacon)

(b) goniometer: single goniometer with primary rotary coil, direct connection to pattern board, built-in error correcting device

(c) beacon controller: crystal oscillation part (oscillating frequency 100 kHz, deviation $\pm 5\times10^{-7}$/3 months), signal transmitter (for non-directional beacon), control switching part

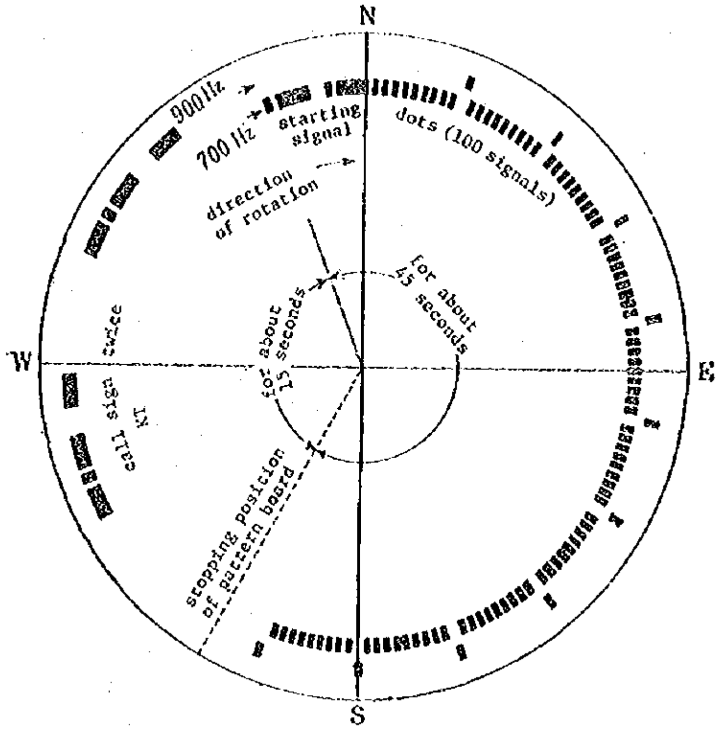


Fig. 1-18 pattern diagram of rotating pattern beacon

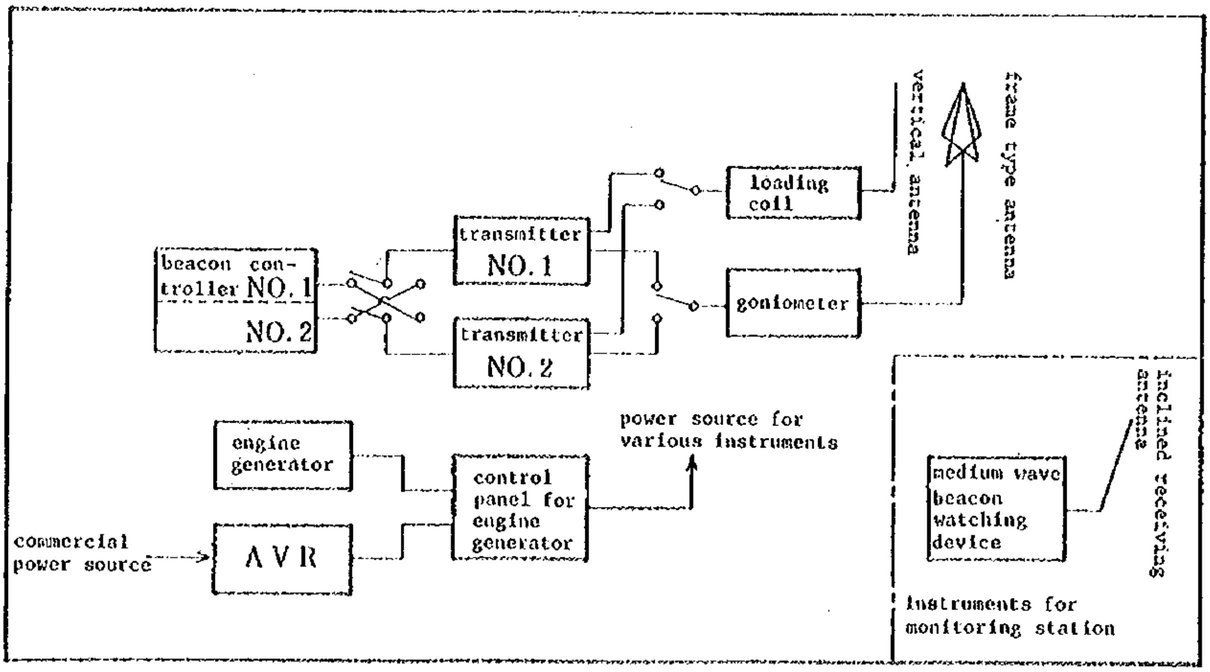


Fig. 1-19 construction diagram of medium wave beacon station

(d) engine generator: 11 HP, 1ϕ 200V, 6 VA

(e) antenna

frame-type antenna: triangle orthogonal frame-type (one side length: about 45m, 1,200m^2

vertical antenna: height 45m, steel pipe post

The frame type antenna in the initial stage was rectangular in shape (20m) with 2 turns, but the number of turns was reduced to single in order to minimize the variation in antenna constant and the shape was changed further into triangle considering the ground space and expense.

(f) error correcting device: So far as rotating pattern beacon stations are placed in a proper situation selected, the directions can be determined without error by counting the number of dots up to sound disappearing point and multiplication of the number of dots by two, but errors are often incurred otherwise in the range of a few degrees to 20 degrees as error peculiar to respective station. Correction tables based on error finding tests had been used for some time, but error correcting device is attached these days to the goniometer. The device is operated by adjustment of the rotation speed of either of the goniometer or pattenn board in correspondence with the correction table. It does not drive the goniometer as the same speed of pattern board, but drives the goniometer or the pattern board according to the error correction curve. Ships can dispense with the correction table by attachment of the device, but this has a drawback that the intervals between dots are not uniform. Essentially station arrangement to dispense with such correction is ideal, and recent trend of unattended station system by remote control is a large step forward, for it enables selecting a suitable geography for the station more freely, setting aside the problem of residential conditions of the maintenance personnel.

Transmitter, beacon controller, and power source among the equipments cited above are arranged in duplicate, for running and stand-by, and they are switched over automatically in case of trouble. The conditions of operation are reported to the monitoring station, and any lack in transmission of beacon or transmission of defective wave is avoided.

(g) item of report: transmitter (running or stand-by), power source (normal or spare), beacon controller (normal or fault), transmission output (normal or lower)

These reports are made by utilization of the modulation frequency of rotating pattern beacon without a separate momitoring link being arranged. That is, four modulation waves in an interval of 15 Hz each for nominal 700

Hz and 900 Hz (only for dots of every 20°) are prepared, and 16 items are reported as combination of the two kinds of wave.

(3) Microwave Rotary Beacon

This is a microwave beacon used as coastal beacon in comparatively short distance, and ships obtain the bearing in a manner similar to that in medium wave rotating pattern beacon by means of simple microwave receiver. It was first installed at Cape Ayarizaki (Iwate Pref. in Japan) in 1960 followed by Cape Heiizaki (Iwate Pref.). Their effective range is about 20 NM, but error correction is unnecessary and the finish of counting is clear unlike in minimum sensitivity method. Thus it seemed probable that it would develop as beacon for small boats, but the appearance of talking beacon that enables finding bearing directly through voice without counting made it transient. Transmission of beacon is constant without any pause as in other microwave beacons.

Principle: If radio waves of narrow horizontal beam are transmitted from two antennas rotating 150 times and 5/6 times every minute respectively and they are received at a certain point, the wave from the fast rotating antenna is received 180 times in 72 seconds while from the slow antenna once. Here, if the time of the slow antenna passing the base point (real north) is known by some means, the direction of the determining point is found by counting up the number of dots of fast moving antenna wave from that time to the time of receiving a signal of low speed antenna and multiplying it by 2. Actually both antennas are rotated with synchronization so that they come to the north simultaneously, and four dots of different pulse repetition frequency is transmitted from the high speed antenna immediately before the low speed antenna will come to the real north (from 352 degrees to 0 degree).

Fig.1-20 shows the condition of receiving at the determination point. In the figure, f_1-f_4 show the repetition frequencies of pulse.

f_1: 2 degree signal 600 Hz

f_2: 10 degree signal 750 Hz

f_3: signal for start of measurement determination (north signal) 1,200 Hz

f_4: measurement finishing signal 1,000 Hz

For determination of direction, one should count the number of dots immediately after the starting signal until the finishing signal for measurement is heard. The direction of the ship in the figure is 16×2=32 degrees. The 10 degree signal is transmitted for an easier counting of dots.

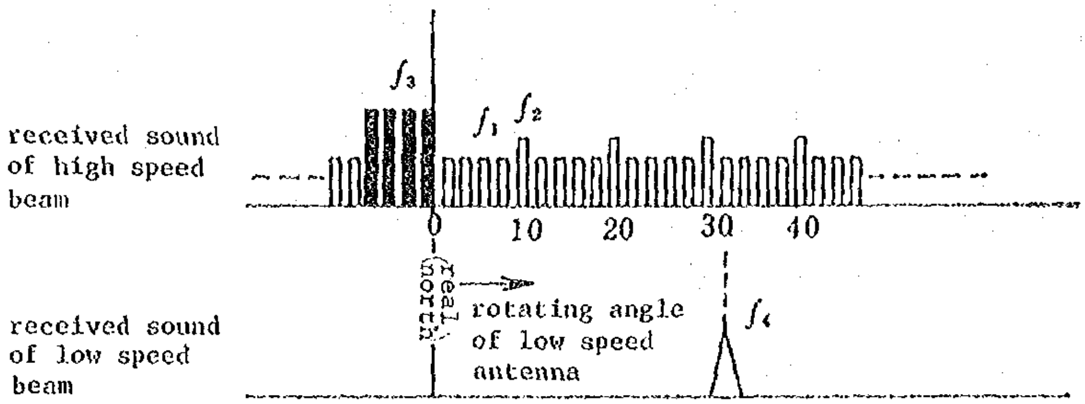


Fig. 1-20 receiving pattern and receiving sound

Equipment: Microwave rotary beacon stations are placed often in remote places owing to the propagation characteristic of the micro-wave and location of the vessels utilizing it, and so they are unattended and operated and maintained by remote control. An outline of the construction of their transmission equipment is shown in Fig. 1-21. Transmitters, one for high speed rotation and the other for low speed rotation, are installed and their ratings are as follows:

frequency 9,310 MHz
output P0 7 kW (Pp) (for low speed rotation)
P9 40kW (Pp) (for high speed rotation)
pulse width 1 μ sec
antenna horn antenna (high speed rotation)
parabolic antenna (low speed rotation)
horizontal beam width 2 degree (low speed rotation),
20 degree (high speed rotation)

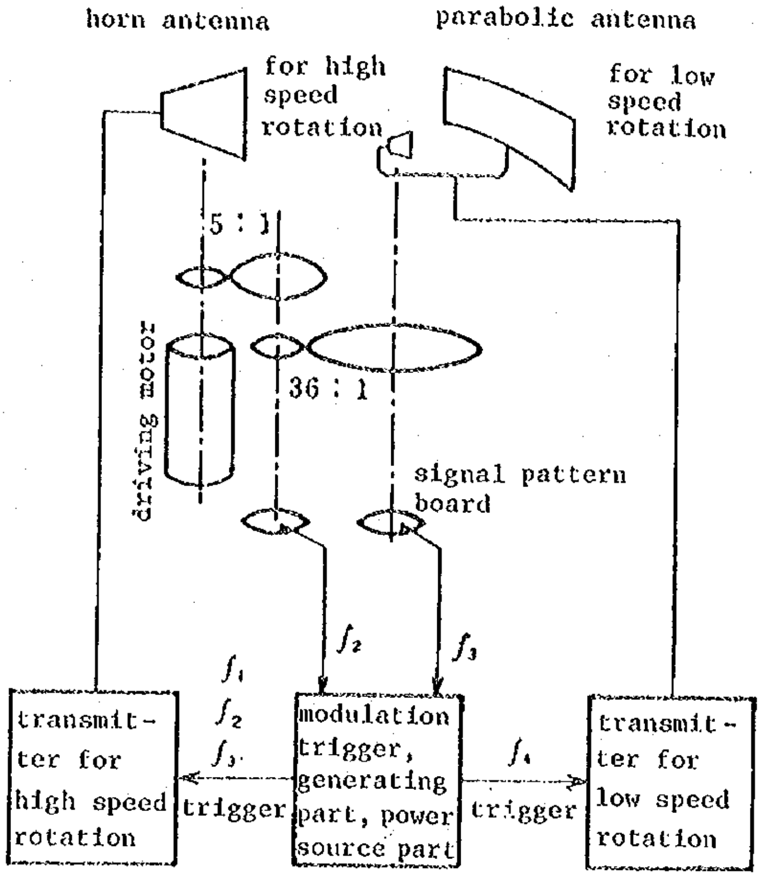


Fig. 1-21 System diagram of transmission equipment

Vertically polarized wave is used, to avoid interference by maritime radar wave which makes counting the number of pulses difficult.

Reveiver for microwave beacon : This is a direct detecting type of receiver in 9,000 MHz band to be used for any of the talking beacon and course beacon to be explained as follows in addition to being used for microwave rotary beacon. It is one of the effective radio navigation aids for small vessels such as fishing boats. It is so constructed that microwave after pulse width modulation (in the case of talking beacon) is directly detected by crystal, amplified by transistor amplifier, and demodulated by a low pass filter; and it is a portable receiver of small size and light weight. Fig. 1-22 shows its system diagram, and its specification is as floows:

range of frequency 9.2-9.4 GHz

directivity about 15 degree both horizontally and vertically

(horizontally non-directional with one for synchronous receiving)

minimum receiving sensitivity -50 dBm or less

video-amplifier passing band width about 600 kHz

audio-amplifier passing band width 300-4,000 Hz

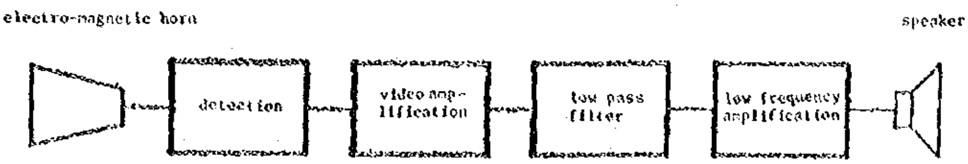


Fig. 1-22 System diagram of receiver for microwave beacon

(4) Talking Beacon

Determination of direction of the ship in counting dots by microwave rotary beacon has no difficulty of the width of aural null as in the case of medium wave, but the multitude of the kind of signals and the difficulty for unskilled operators to grasp the time of starting count, due to constant emission of the wave, cannot be ignored. It is ideal for crews of small boats to have a device that enables finding their direction through voice and by a simple operation, and appearance of this kind of beacon was waited for since early days. Talking beacon is just what they wanted and was installed at Kamo (Yamagata Pref.) and Ogi (Ishikawa Pref.) in 1964 for the first time in Japan. It is a kind of rotary beacon using microwave and depending on voice system, while the conventional one depends on the counting system. The difference is so epoch-making to those who use it that it is called a "light house of voice". 5 stations are operating including synchronous type at present, but the first opened Ogi and Kamo Stations were abolished due to the decrease in the number of ships utilizing them, leaving only one station, Hachinohe, so far as the station of single station system is concerned.

Principle : Similarly to the counting system already explained, radio wave of narrow horizontal beam width is transmitted by means of low speed rotary antenna, and the central direction of the beam is transmitted by pulse width modulation of voice. Therefore, ships can find their direction immediately by voice if they receive it with a microwave receiver. The antenna rotates at a slow speed of once every three minutes, but this is because directions in three digits must be transmitted every three degree in voice. This enables receiving information only once every 3 minutes, but an improvement was made by adding another antenna so that the two antennae are used as a pair back-to-back each transmitting direction signal differing by 180 degree in direction from each other. The second antenna works as a spare antenna, too. Thus direction information is available once every 1 minute and 30 seconds. Besides, the name of station and direction are alternately transmitted* by non-directive antenna for identification and preparation of determination (crude determination), so that the name of station can be received any time.

Equipment The station is unattended as in the case of microwave rotary beacon station, and the construction of equipment is shown in Fig.1-23.

(a) transmitter

frequency 9,310 MHz

output P3E 1 kw (Pp)

modulation system pulse width modulation

pulse width non-modulation pulse 8μsec

modulation pulse 8±6μsec

pulse repetition frequency 10 kHz

maximum modulation frequency 3,000 Hz

direction signal: every 3 degrees

(b) antenna

rotary antenna slot array shape

horizontal beam width 3 degree

vertical beam width 15 degree

rotation speed 1/3 rpm

fixed antenna slot shape

horizontal beam width 180 degree

vertical beam width 2 degree

plane of polarization horizontal

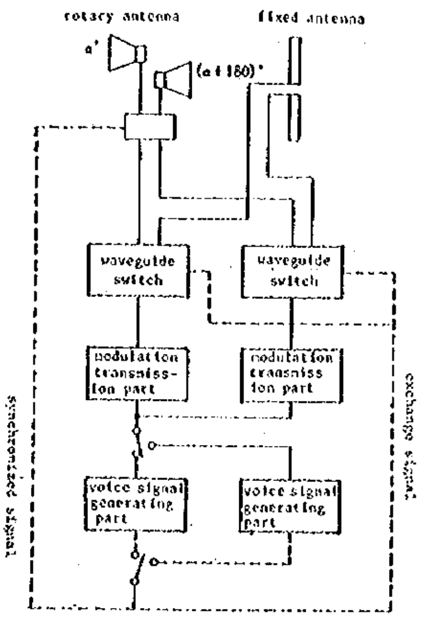


Fig. 1-23 System diagram of transmission equipment

(c) voice signal generating part This is an endles regenerating device using a magnetic drum synchronized with rotary antenna. It has 12 tracks and the names of stations are recorded in one of the tracks, the direction signal in 10 tracks, and the switching signal in the remaining one track. (Fig. 1-24)

* (example) Same (shark) (beacon identificationsignal of Hachinohe station), Same, 120, Same, 123, Same, 126, Same, Same, Same

The modulation transmitting part consists of 2 series, each being connected with a set of rotary antenna and fixed antenna. Therefore, even if one of the series is in trouble, the other series continues servicing, sending

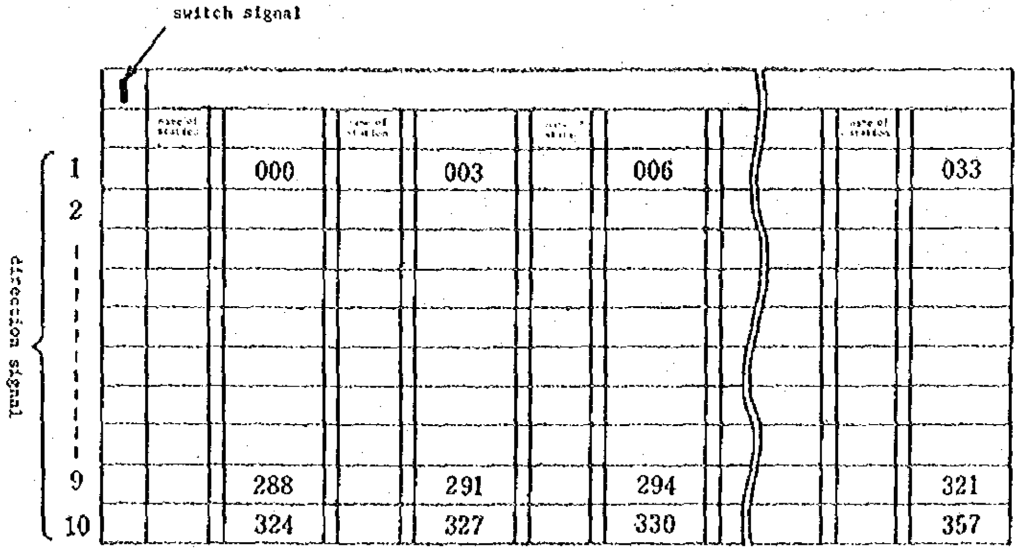


Fig. 1-24 magnetic drum recording diagram

direction information once in 3 minutes, in a half amount of the normal. A stand-by instrument is also arranged for the voice signal transmitting part.

(5) Synchronized Talking Beacon

This is a system for determining the position of a ship with high accuracy by means of determining directions of two to three talking beacons transmitted with synchronization.

"Regulating Line for Fishery of Japan and South Korea" was provided in Tsushima Strait in 1965, and a system was demanded whereby small fishing boats can find their position with high accuracy for their safety and efficient operation. This system was adopted, being considered satisfactory with installation of three stations. Later in May, 1972, another station was installed in Izuhara, south Tsushima; and four stations are operating at present.

Principle : The principle is similar to one for single station system, the following points being different for organization of the chain.

(a) The antennas in all of the stations are rotated with synchronization, so that ships can receive informations of station name and direction in succession by the wave transmitted.

(b) In order to increase the frequency of the information and improve the accuracy of determining position of ships by reducing the transmission time, three antennas rotating with difference of 120° respectively were installed and the station names and directions informed were abbreviated into codes.

(c) In order to facilitate determination of the position of ship, an exclusive chart was used with lines of direction from each of the stations being drawn.

Equipment: All of the stations are unattended and watched and controlled by the watching office.

(a) Transmitter

frequency	9,310 MHz
output	1.5 kW (Pp)
modulation system	pulse width modulation
pulse width	non-modulated pulse 8 μsec
	modulated pulse 8+6 μsec
pulse repetition frequency	10 kHz
maximum modulation frequency	3,000 Hz
direction signal	every two degrees

(b) Antenna

slot a-ray-type rotary antenna	
horizontal beam width	2°±10%
vertical " "	15° or less
rotation speed	1/3 rpm
plane of polarization	horizontal

Three series each are arranged for modulating and transmission parts, each connected to 3 antennas rotating with a difference of 120° respectively. Antennas in each of the stations are always rotated with synchronization so that they assume the same direction. However, in some small areas, waves from two stations are received simultaneously, making it impossible to utilize the system. This takes place on the line connecting the two stations and its extension and on the circle passing the two stations and the point viewing the two stations at 120 degree. Tsushima Stations were built with due consideration that such area is out of the usual fishing area.

Method of utilization Non-directional receiver must be used for receiving synchronized talking beacon. In order to avoid insensibility in some sea area due to reflection by the surface of sea, diversity receiving is adopted by using two slot antennas.

The names of station are called by abbreviations, red (North Tsushima), black (Middle Tsushima), blue (South Tsushima) and yellow (Izuhara); and directions are broadcasted every two degrees in figures of two digits.*

* (example) red 15, black 23, blue 60, yellow 85

Direction lines on the chart for talking beacon are numbered in colors each for the station, and ships can find their position as an intersection of two lines from two stations received or of three lines from three stations. (Fig. 1-25)

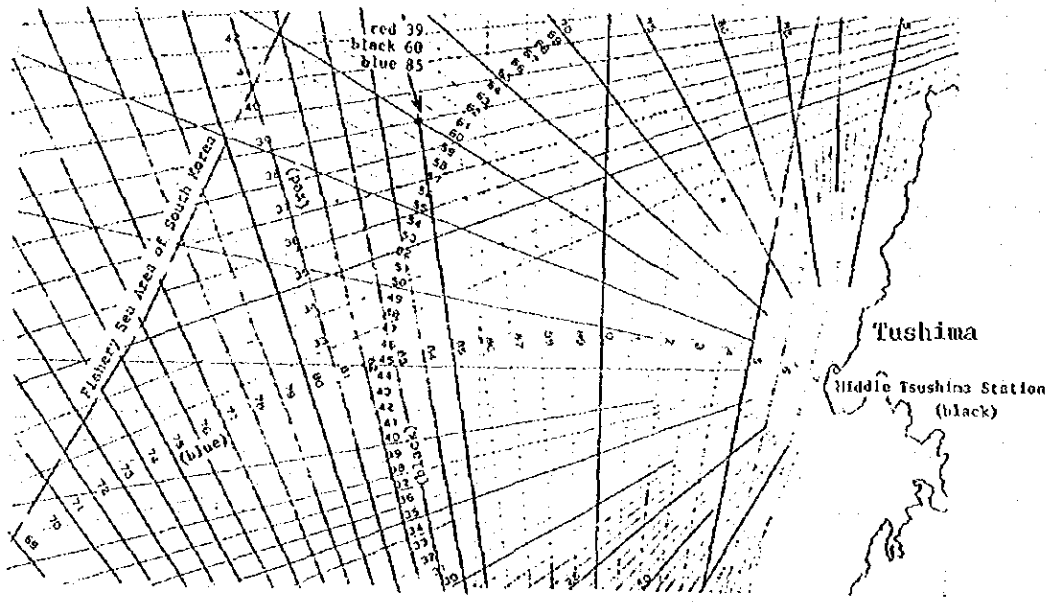


Fig. 1-25 Talking Beacon Chart

2. Aeronautical Navigational Aids

(1) AN system Range Beacon

AN system range beacon is also called 4 courses range beacon. Range means direction or flying course, and range beacon, formulating flying course by radio. When a transmitter output is connected alternately to one or the other of the two sets of adocock antenna that are mutually crossing each other perpendicularly, the radio wave is transmitted at one time with directivity in D_1 and the next time in D_2 in Fig.1-26 (a). The receiving sound of the wave is different by the direction from the antenna. That is, in direction r_1 intermittent sound is heard; for the wave from D_1 only is received; but in r_2 and r_4 directions the receiving sound is once strong and next weak alternatively, for the intensities of D_1 and D_2 are different from each other; and the sound is strong in r_2 when it is weak in r_4 and vice versa. In direction r_3 the intensities of D_1 and D_2 are equal, and the receiving sound is continuous and of a constant intensity. (Fig. 1-26 (b)) Therefore, aircrafts can fly correctly on the prescribed straight line course (on r_3, for example) by searching a line of constant and continuous sound. Assuming that direction

r_1 is direction zero degree, not only in direction 45 degree but also in directions 135, 225, and 315 degree, this is the same. Practically, this system is operated by intermittent transmission of signal N in Morse code (-·) on D_1 side and A signal (·-) on D_2 side so that both signals overlap on each other, the name of AN system being derived from here. The signals AN used enable to judge being on which side of the proper course, in case of flying off the course, by finding which of A or N is the stronger sound heard. Also aircrafts have to carry receivers only. The four courses should not necessarily cross perpendicularly with one another, and the course can be set in any direction as shown in Fig. 1-26 (c) by adjusting the input to each of the antenna elements.

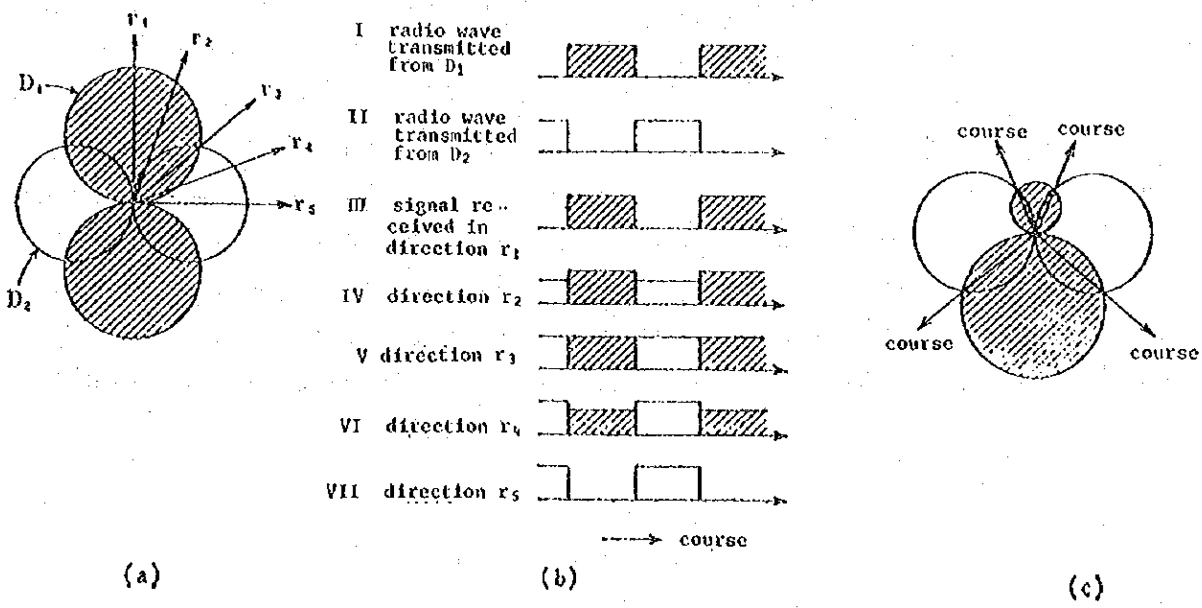


Fig. 1-26 principle of AN system range beacon

Range beacon uses frequency band of 200~415 kHz with a course band of 3 degree and effective distance of about 200 km. This system is not included in the ICAO standard and is expected to be abolished in the future.

(2) NDB

NDB is the abbreviation of Non-Directional Beacon and is also called Homing beacon. It is most extensively used as line of position system for long and medium distance, and ICAO (International Civil Aviation Organization) has adopted it as an international standard with provision of the technical standard. Its principle is the same as that of the one for ships, except that each of the beacon stations in a service area transmits radio wave of diferent frequency respectively, owing to the high speed of aircrafts, and aircrafts use ADF. Therefore, aircrafts flying towards a beacon station can fly just by setting the indicating needle of ADF to zero degree (direction of the nose); or they can find their position on the map if they receive beacons from station A and station B by means of two ADF.

Usually airways are provided by connecting the positions of NDB, and aircrafts fly towards an NDB and turn their direction when they pass over it to the next NDB.

NDB usually uses a frequency within 160-285 kHz and 325-405 kHz, transmitting a non-directional wave. The antenna power is 10-100 W for one of small power, 200-1,000 W for medium power, and several kilowatts for large power. Medium and large power units are used for airways, while small power unit for landing of aircrafts, being installed near airports. Antenna of T type or vertical type is used with a height of 30-50m, but one a few meter high of T type may be used in case of installing near runways. The antenna efficiency is of the order of ten and some %, and the effective range is limited usually within the area of the electric field intensity of 70-120 μV/m (37-42 dB), although this may depend on the extent of atmospherics, noise etc. The distance is dependent on the electric conductivity of the ground, and 100-500 km is usual in day time while somewhat shorter during night by the effect of sky wave that increases the error of ADF.

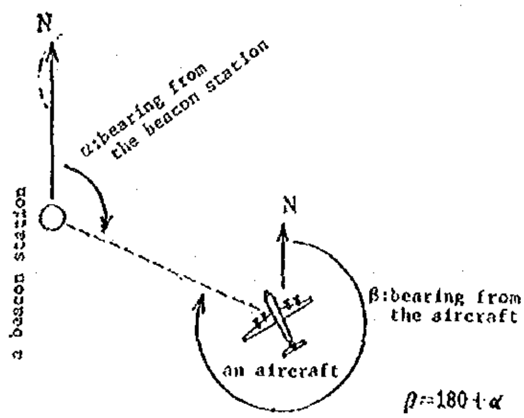


Fig. 1-27 Bearing from a beacon station and bearing from an aircraft

The transmitter is nearly the same as the one for medium wave wireless telegraphy, the kind of emission A2 using continuous carrier, and the modulation signal in 1,020 Hz according to the international standard. The carrier is constantly modulated by this 1,020 Hz frequency, and the station signals are transmitted twice every 30 seconds in Morse code by key operation of modulation sound. The station code (identification code) is composed of two or three letters of alphabet and operated by an automatic key unit, but the carrier wave is not suspended during the space between codes, and no ill effect is given to indication of ADF.

(3) VOR

VOR is an abbreviation of VHF Omni-directional Range, meaning a range beacon to all directions using VHF. Aircrafts can obtain their own direction viewed from ground stations in all directions by means of the radio wave transmitted from the stations in the system, and this is a superior function as compared with those of other range beacon. Besides, the error in direction is so small as ±1.5 degree, and the system is adopted as an international standard of ICAO, and construction in Japan is gradually increasing.

VOR uses frequency of 108-117.975 MHz and transmits a wave having signal in 30 Hz that changes its phase by the direction (variable phase signal) and the other wave also in 30 Hz with signal in the same phase in all directions (standard phase signal) simultaneously. (Fig. 1-28) (a)) Aircrafts can recognize their directions by comparing the phases of the signals. The variable phase signals are transmitted as non-modulated carrier by means of orthogonal adocock and goniometer with rotation of 8-shaped directivity 30 times every second. Thus the signals are received as if the carrier wave is subjected to amplitude modification by 30 Hz in the space, and the phase of 30 Hz wave changes according to the change of receiving position. The standard phase signal is transmitted non-directionally by modulating the same car carrier wave in low frequency of 30 Hz. The low frequency is used in a perfect synchronization with the rotation of goniometer, with adjustment so that the low frequency of the standard phase signal is at the maximum amplitude when the positive lobe of the 8-shaped directionality is directed right to the north. This way in zero degree (real north) the standard phase signal and variable phase signal are in the same phase, while in other directions the variable phase signal is maximum by a delay of some time after the standard phase signal comes to the maximum of amplitude. (Fig. 1-28 (b)) This amount of delay (phase differnce) shows the azimuth. Aircrafts find their bearing by detecting the phase difference. In order that the separation of the variable phase signal from the standard phase signal is facilitated, the main carrier wave subjected to amplitude modulation by an sub-carrier wave of 9.96 kHz frequency modulated by 30 Hz is used as the standard phase signal. In some case, rotation of dipole is resorted to instead of adocock to get rotary directionality.

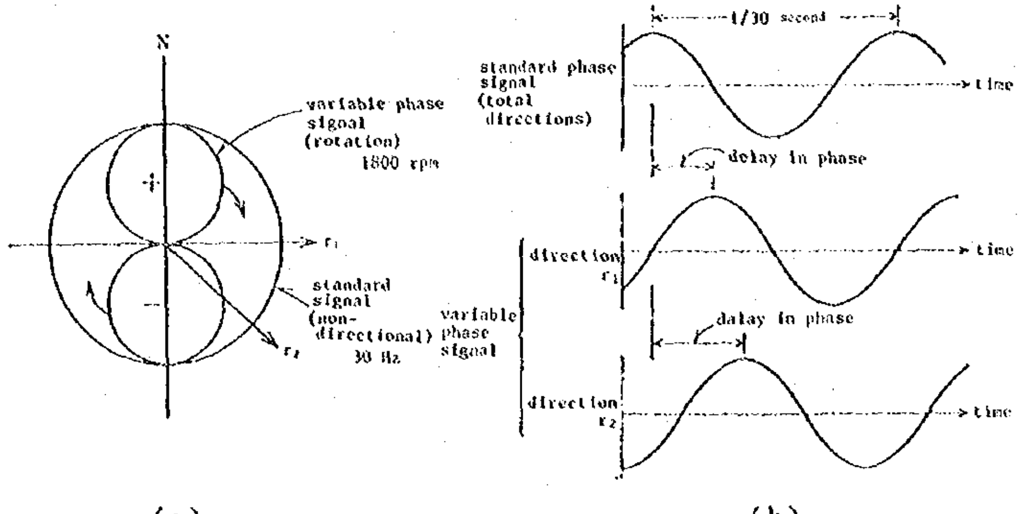


Fig. 1-28 principle of VOR

VOR is apt to give errors caused by the geography of the place of installation or wave reflecting objects, and full consideration is needed on the conditions of the surroundings. In some cases it is impossible to find a suitable place on the airway. Thus an improvement was made using the doppler effect. While the ordinary VOR is based on rotation of the directionality, doppler VOR rotates the emission source of wave at a speed of 30 times a second by placing the emission source on a circumference of circle of diameter of about five times the wavelength. When this is received on an aircraft, a doppler effect appears as a result of the change in relative distance and a wave is received that is frequency-modulated by 30 Hz. The frequency modulation gives the direction signal when it is frequency discriminated, for the modulation signal in 30 Hz varies in phase depending on the direction. The standard signal is emitted, similarly to VOR, from the fixed antenna at the center, as a carrier is subjected to amplitude modulation by the 30 Hz signal in synchrocization with the rotary antenna. Aircrafts receive both of the amplitude modulated wave (standard signal) and said frequency modulated wave (direction signal) and find their directions by detection of the phase difference in 30 Hz contained in each of the waves respectively. 108-117.975 MHz is used as the frequency for the carrier, and the frequency of the standard signal is set lower than that of the direction signal by 9.96 kHz, so that it is compatible with the ordinary VOR. Actually the direction signal is emitted, instead of by rotating the antenna, through successive feeding by a differential capacity distributor (similar to electrostatic goniometer and having 50 stators) of radio frequency to each of the 50 loop antennas placed on the circle of about five times the wavelength of the wave in diameter in an equal distance, constituting a condition equivalent to rotation of the oscillating source. Doppler VOR belongs to those of recent development, and the smaller error due to geography of the place of installation, etc., smaller error by polarization, no less accuracy in direction, etc., than by ordinary VOR can be enumerated as its characteristics.

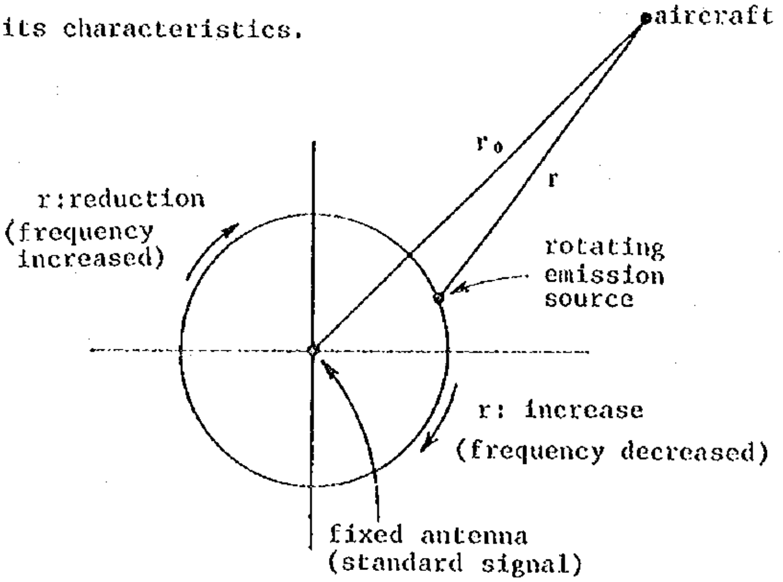


Fig. 1-29 principle of doppler VOR

(4) CONSOL

CONSOL was developed in Germany during World War II as navigation aids for aircrafts and ships and is used at present mostly in Europe. It is adopted as a temporary standard for long distance navigation aids by ICAO and has a characteristic that of indicating direction in high precision up to extremely long distance by means of A1 wave in the range of 200-415 kHz. Three vertical antennas are arranged on a straight line in an equal distance in CONSOL station as shown in Fig. 1-30. The distance AB and BC is selected in the range of 1.5-3 times wave length, but the following explanation applies to the case of three times. Of the electric currents fed on each of the antennas, the amplitudes for outside antennas A and C are set equal to each other and to 1/4 of that for B at the center. Letting the phase of the current fed on A be ahead of that of B by 90 degrees and that of C behind that of B by 90 degrees, the plan view of the directional electric field is as shown by the full line in Fig. 1-30. By reversing the relationship of phases of A and C, the directivity in dotted lines is given. By emitting the electric field in full line in dot signal and that in dotted line in dash signal alternately, dash sound can be heard at receiving point P_1 while dot sound at P_2 and con-

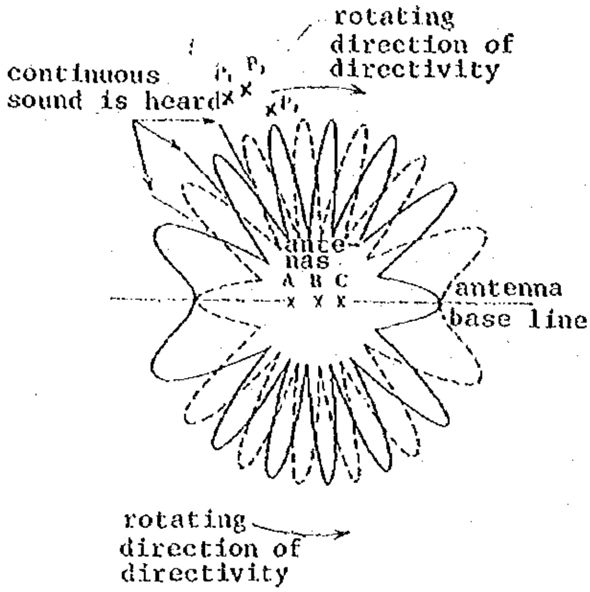


Fig. 1-30 directivity pattern
(at the beginning of rotation)

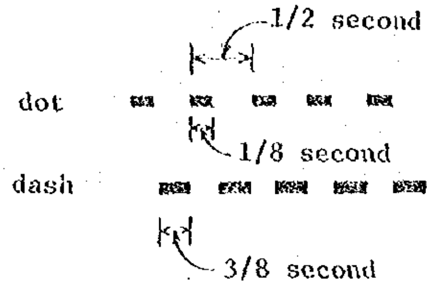


Fig. 1-31 keying

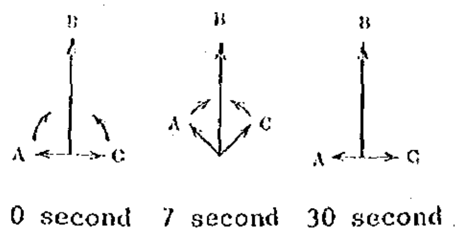
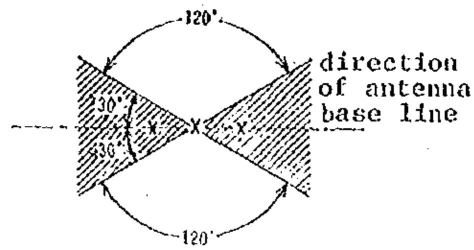


Fig. 1-32 rotation of phase vector of outside antenna in keying cycle



The hatched lines show regions of no effective use.

Fig. 1-33 effective angle of CONSOL

tinuous sound in the direction of P_3. This is similar to the case of AN system range beacon, except that the continuous sound is heard in 22 directions.
In CONSOL, dot-dash keying is maintained by changing the phases of outside antennas continuously and periodically by a rate of 180 degree in 30 seconds. This way the directional electric field rotates in the direction of the arrow in Fig. 1-30 with a change from dot to dash in 30 seconds. As shown in Fig. 1-31, the length of a dot is provided to be 1/8 second long and that of a dash 3/8 second; and the receiver can find his direction by counting the number of dots and dashes heard within 30 seconds of keying cycle. The total number of dots and dashes in 30 seconds should be 60, but practically, due to continuous sound being heard inbetween, about 56 are the maximum that can be counted, it is said. What is found by this method is the accurate data of direction within a certain sector, and the sector that one is belonging to (crude measurement) must be found by a direction finder etc.

1-4 Hyperbolic Line of Position System

It is extremely important for vessels on the sea and aircrafts navigation to know their positions. The hyperbolic navigation method is one of the radio wave navigation methods for this purpose and is based on the principle that the locus of the point which is definite in the difference of distances from the two fixed points becomes the hyperbola with the focie of these two fixed points.

The hyperbolic navigation methods are under study of various systems according to the frequency for use or the form of the transmission radio wave, but if roughly divided by the form of the transmission radio wave, they can be classified into the form of employing the pulse wave and the form of employing the continuous wave. The former typical ones are LORAN A and LORAN C and the latter typical one is DECCA.

1. LORAN A

The word LORAN is derived from the capital letters of the Long Range Navigation. The LORAN as commonly called is the LORAN A that is explained here and is called the standard LORAN, being the most prevalent at present. The LORAN has been kept developing form this LORAN A to the LORAN C via the LORAN B (It did not achieve implementation.)

The four transmission frequencies of 1,750 KHz, 1,850 KHz, 1,900 KHz and 1,950 KHz have been fixed worldwide as the transmission frequencies for use of the LORAN A, but in the neighborhood of Japan 1,850 KHz used to be employed and the LORAN network given in Fig. 1-34 has been established.

(1) Principle of the LORAN A

When the radio waves are transmitted simultaneously from the LORAN stations OF M and S_1 in Fig. 1-35, the radio waves reach at the same time any point on the PQ vertical bisection line of MS_1, because any point on the PQ line is at the equal distance from the both stations of M and S_1 and further, the radio waves propagats at a definite speed. Consequently, the difference in the arrival times is zero.

Now, when a vessel that was at the o point proceeds to the o' point, the radio wave of the S_1 station reaches the o' point earlier than that of the M station and so the time difference at this time is not zero, but has some value. At the example of 10m sec (10/1000 sec) the locus of the points where the difference of the arrival times from the both stations become 10m sec becomes as RS line in the drawing. The locus of the points where such arrival times difference becomes definte can be innumerably gained by changing

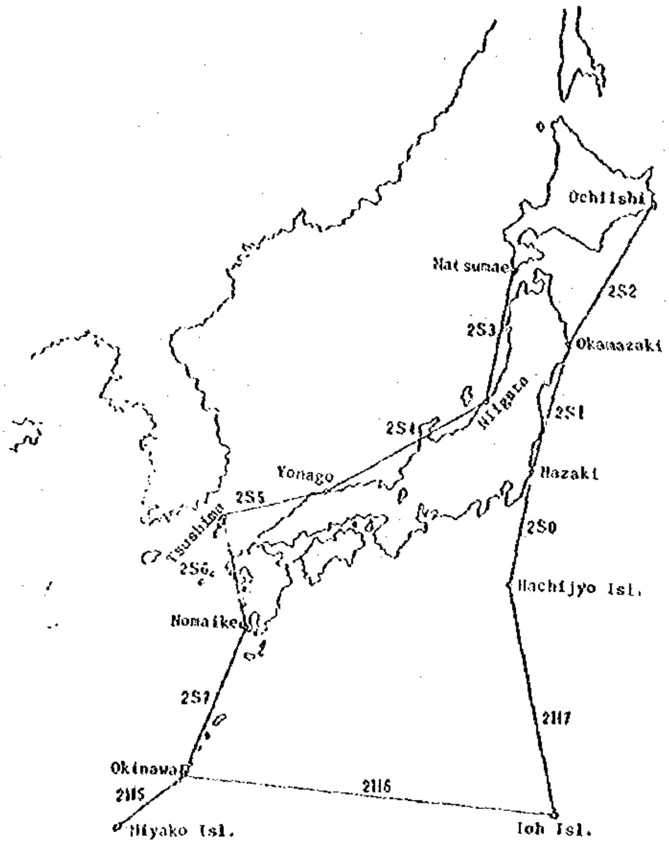


Fig. 1-34 LORAN network in the vicinity of Japan

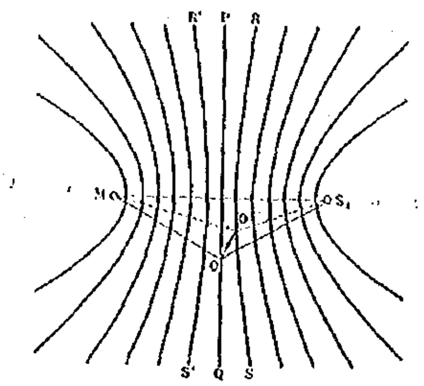


Fig. 1-35 Hyperbolic line group generated when simultaneous radio waves are transmitted from M and S_1

the time difference and Fig.1-35 is an example and finally the hyperbolic line group with the focie of the both stations of M and S_1 is obtained. The hyperbola is called the position line.

Therefore, by measuring the time difference of the arrival times of the radio waves from the both stations of M and S_1 on the vessel it can be known on which position line the vessel is located. However, as the position itself cannot be made clear at this time, one more LORAN station S_2 is installed as given in Fig. 1-36 and also from it the radio wave is transmitted. Then, by the both stations of M and S_2 one more hyperbolic group, i.e., position line can be gained and this time the time difference of the arrival times of the radio waves from both stations is measured. In this way, for instance, when it is made clear that the vessel is on the TU line, the vessel should be located at the point of intersection of the two position lines of RS and TU. Then, when position lines to be made by M_1, S_1 and M_1, S_2 are marked in advance on the chart (This is called the LORAN chart.), the vessel's position can be known by measuring the time difference.

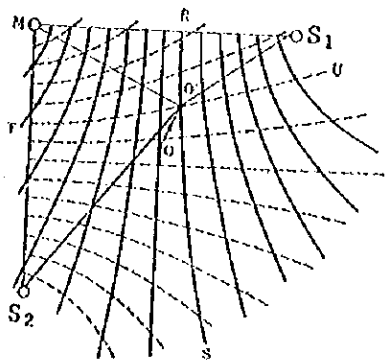


Fig. 1-36 Position lines network made from Master M (prinicipal station) and Slaves (sub-station S_1 or S_2)

In this way the hyperbolic navigation method requires two sets of combination of two stations. These three stations (One station is common as stated above.) are called the Chain.

(2) Transmission of the LORAN radio wave

As you may have noticed by Fig.1-36, there are in a set of the LORAN stations two symmetrical position lines that cause equal time difference, unless the radio wave of the M station and that of the S_1 station is discriminated. When, in Fig.1-35, the time difference on the RS line and that on the R'S' line become equal and it can not be discriminated on which position line the radio wave is even if the time difference is measured and as it is unfavorable for the radio waves to be transmitted simultaneously from the both stations, practically speaking, the M station first transmits the pulse radio wave and the S_1 station receives this pulse and by delaying by the time of the half of the pulse recurrence time plus a definite time transmits the pulse radio wave. In this case the M station is called the Master and the S_1 station is called the Slave station.

Assuming the pulse recurrence time to be T and the propagation time of the radio from the M station to the S_1 station to be β, this delaying time D μ sec is generally selected to be as follows:

$$D = \frac{T}{2} + \beta + \delta$$

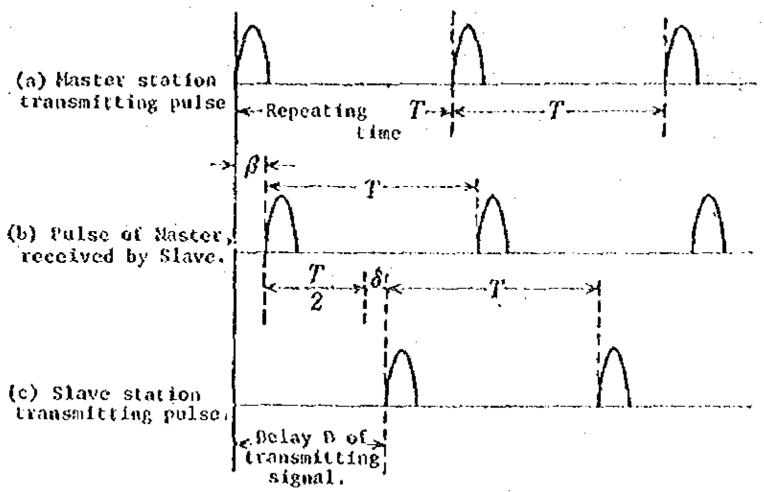


Fig. 1-37 Relations of time of transmitting radio waves from Master and Slave Station

However, δ is of a smaller integer number than (T/2 - 2β), being called Coding delay and 1,000 μ is generally employed.

It is Fig. 1-37 that illustrates these relations. When as (a) Slave station receives the pulse radio wave from Master with the recurrence time T, delay is caused by β as (b). When the half of the recurrence Time T/2 and the coding delay δ are added to this, the pulse radio wave transmitted from Slave is belated by D from the transmitted time of Master as shown by (c). Then, irrespective of where the reception point is, the radio wave of Slave surely reaches it later than that of Master and further, before the next arrival of the radio wave from Master and later than the middle of the Master radio wave duration. Thus, the discrimination between the radio wave from Master and that from Slave can come to be made possible.

As explained already, the two position lines must be gained in order to seek the position.

As the position line are fixed by a pair of Master and Slave, it is necessary to receive radio waves of two pairs of Master and Slave and fix them in order to seek for the position of the two lines. In order to discriminate the pair stations the specific pulse recurrence frequency is given to each pair of station. These frequencies are three kinds of 50 ms, 40 ms and 30 ms as bases, and are named respectively as S, L and H. Further, there are eight of those shortened by 100 μs with each of them, i.e., there are those from 50 ms to 49.3 ms, e.g., with S numbered from 0 to 7. Consequently, S_1 shows the recurrence cycle 49.9 ms and H_7 gives 29.3 ms.

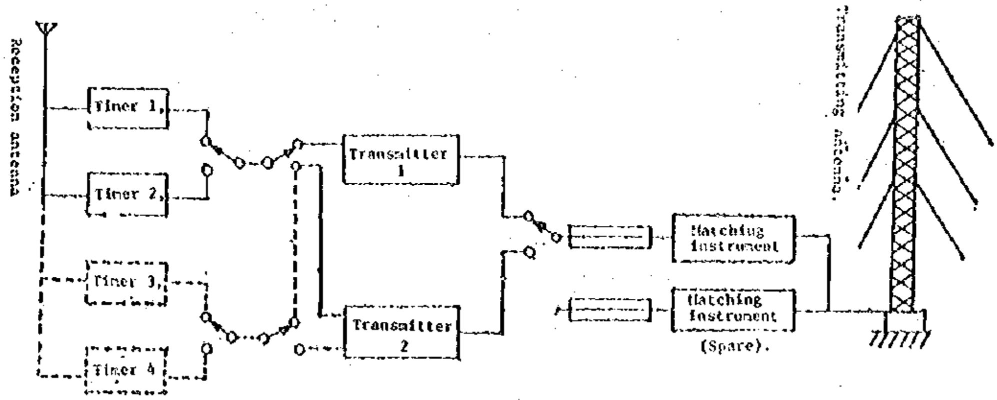


Fig. 1-38 Construction of the LORAN station (dotted line: the case of dual stations)

In the example of Fig.1-34, 49.9 m sec between Okamazaki (Master) and Ochiishi (Slave) and 49.8 m sec between Okamazaki(Master) and Hazaki (Slave) are used. The initial figure 2 here is the signal showing that the frequency is 1,850 KHz. When the recurrence frequency is changed, the asynchronous pulses other than the aimed even if the same frequency can be discriminated by disappearance on the braun tube of the LORAN receiver.

The outline of composition of the LORAN station is given in Fig.1-38. The transmitting station makes propagation frequency by dividing and multiplying station makes propagation frequency by dividing and multiplying 100 KHz from the timer and transmits in modulation by transmitting wave form (height 21 μs, 50% width 40μs) made by adding the trigger pulse to the wave shape forming circuit.

The timer is the portion that should be said to be the heart of the transmitting station. With the LORAN, Master and Slave shall be perfectly synchronous and must transmit the radio wave always with the definite time difference, necessitating the extremely accurate time control. This control unit is the timer and produce the pulse recurrence frequency which is made from output of the crystal oscillator. The oscillation frequency is 100 KHz, being of extremely high stability and the change is maintained at about 10^{-9} in short time and 10^{-7}-10^{-8} even in long time.

(4) Reception of the LORAN radio wave.

In order to measure the times difference on receiving the LORAN radio waves the measurements are performed with steps on the braun tube attached with the LORAN receiver.

As the pulse radio waves are transmitted from Master and Slave in the relations given in Fig. 1-37, the former half of one scanning is made to appear on the upper step and the latter half of the seanning is made to do on the lower step on the braun tube as given in Fig. 1-39 (a) and when the Master pulse is made to appear on the upper step, the Slave pulse is sure to appear on the lower step.

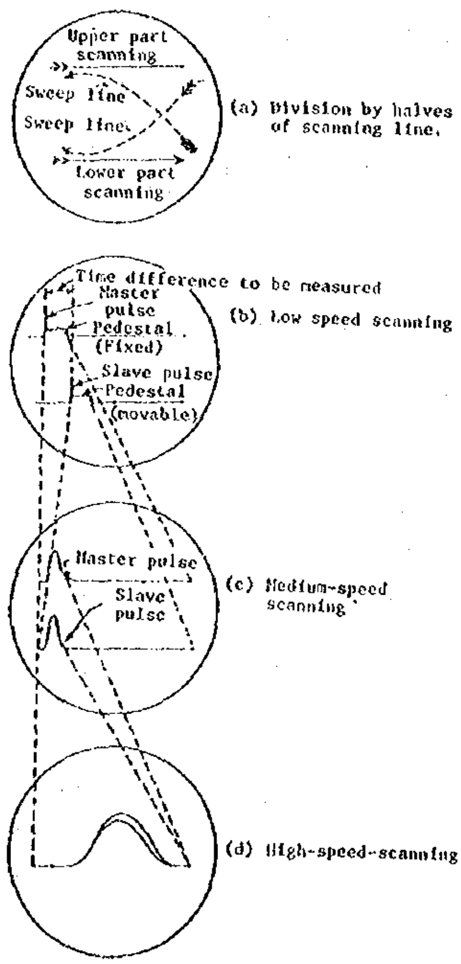


Fig. 1-39 Measurement of time difference

When the low speed sweep is taken place at the beginning, the Master pulse and the Slave pulse can be discerned as given in (b). The distance between the both pulses corresponds to the time difference, but in operation the time difference can be read when the both pulses are perfectly laid one on top of another.

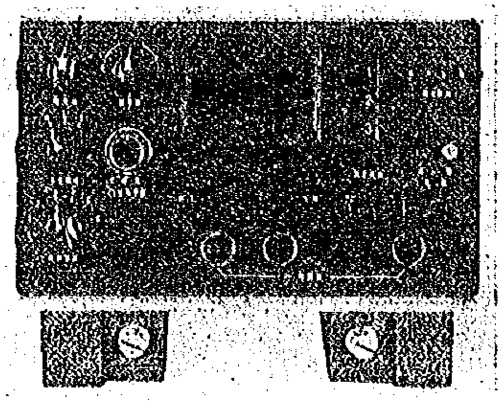


Fig. 1-40 An example of the LORAN receiver (LORAN A receiver)

The Master pulse is first put on the left end of the fixed stand (called a pedestal) of the upper step and then by moving the lower step pedestal the Slave pulse is made to set on its left end.

Next, as the sweep is made to be of medium speed, only the upper and lower pedestal portions are enlarged as (c) and when precisely matched and the high speed sweep is made finally, the heights of the upper and lower sweep lines becom equal as (d). When adjustment is performed so that the two wave forms are completely laid one on top of another and the accurate time difference is measured.

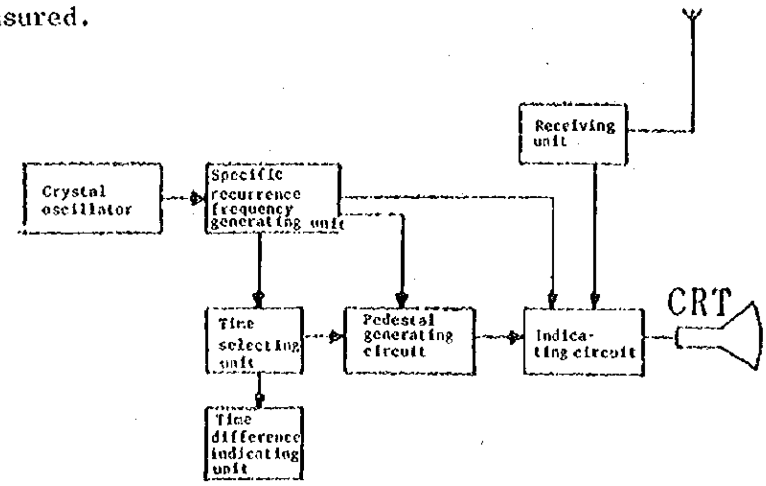


Fig. 1-41 Composition of the LORAN A receiver

Fig. 1-40 and Fig. 1-41 show an example of the LORAN receiver and the outline of the composition. The reception portion is the crystal control super heterodyne receiver and with a view to amplify faithfully the LORAN pulse the band width of the intermediate frequency amplifier is provided widely. The reception signal output is applied to the vertical axis of the braun tube

(CRT). The generating unit of the specified recurrence frequency is a demultiplying circuit and makes the rectangular wave of the specific recurrence frequency by dividing the output of the crystal oscillator. The sweep of the indicator face of the braun tube is made by this cycle and upper and lower sweep lines are provided by rectangular wave so that the received signal appears on the sweep line.

(4) Others

As the LORAN radio wave is the frequency around 2MHz as stated above, there are two propagation mode of surface wave (the mode of propagation on the land surface (or sea surface)) and the sky wave (the mode of returning to the earth reflected by the E layer or the F layer).
Fig. 1-42 shows this mode and the available mode among them is the surface wave and the one hop sky wave from the E layer. The intensity of the surface wave does not change in either day or night but is stable, and the available distance (i.e., the effective range) is said to be about 1,200 Km. (The peak antenna power of the LORAN radio wave is 130-160 KW and partly on the Pacific Ocean shore at Ochiishi 1,000 KW and at Okamazaki 800 KW).

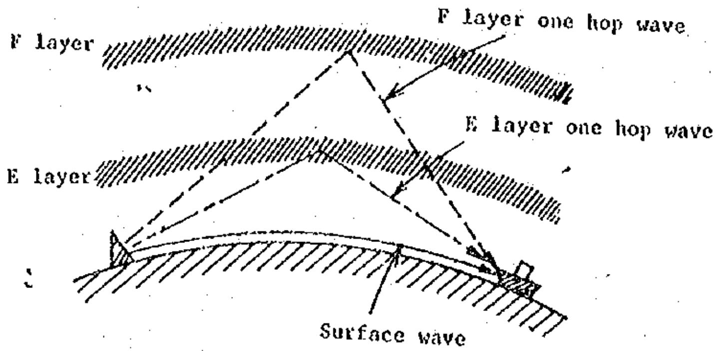


Fig. 1-42 Propagation mode of the of the LORAN radio wave

The sky wave becomes strong at night and the one hop wave of the E layer is said to be available up to about 2,500 Km, but as compared with the surface wave the sky wave is delayed by the length of the propagation route, causing an error. All the LORAN chart is provided about the surface wave, adjustment must be made to eliminate error when availing the sky wave. This adjustment value is described in the LORAN chart, but there is another type of LORAN, provided with a great deal of base line length (mutual distance between the LORAN stations) with a view to avail it far on sea and land, availing the fact that the propagation distance of the sky wave becomes longer in the night time. This is called SS LORAN (the Sky-wave Synchronized LORAN).

The measuring accuracy of positions with LORAN differs according to the relative positions of the measuring point and the LORAN station, but is ssid to be approximately from 900 m to 9,000 m.

2. LORAN C

(1) The process and principle of the development of the LORAN C.

The research of a system utilizing the low frequency to increase effective range with less number of transmitting stations and with high accuracy, starting from the LORAN A, had been kept proceeding in the U.S.A. The LF LORAN system utilizing low frequency has been kept researching as CYCLAN, NAVAGLOBE, FACOM and NAVARHO (combined system with the above-mentioned NAVAGLOBE and FACOM), but each of them was suspended research without satisfactory results. However, the research of CYTAC began on the basis of these technical heaps and here for the first time the basis of the LORAN C for use of the low frequency band of 90-110 KHz was established. CYTAC began operation by the American Coast Guard in 1958, when it was named as the LORAN C.

As stated above, the LORAN C has developed from the LORAN A and so there is no change in the principle, i.e., one chain consists of Master and is attached 2-3 Slaves and the similar position line of the time difference like Fig. 1-36 is made by the pulse radio waves, transmitted from Master and Slaves. These are the same as the LORAN A, but the following items are the points of great differ ence.

(a) The LORAN A transmits the so-called medium-short waves of 2 MHz band, while the LORAN C transmits the low frequency of 90-110 KHz (center frequency 100 KHz) with an antenna power of about 1,000 KW.

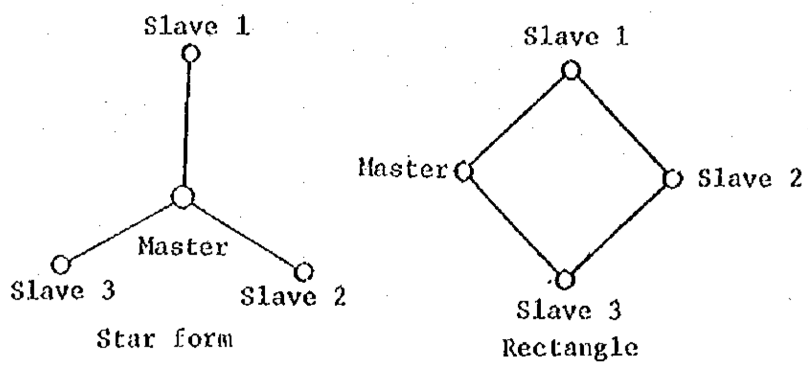


Fig. 1-43 Arrangement of the LORAN C station

(b) The time difference is measured with the LORAN A by piling up pulse wave forms of Master and Slaves, but with the LORAN C the precise measurement by comparison of the phase difference about the radio frequency of 100 KHz contained in that wave form is further made.

As a result of the above the effective range of the LORAN C is about

2,200 Km, about twice of the LORAN A when utilizing the surface wave. In the case of utilizing the E layer one hop sky wave the effective distance becomes over 4,000 Km which is also near two times and, though the measurement accuracies differ according to the synchronism error of the transmitting stations, the receiver error and error by radio wave propagation, the accuracies become better about 10-20 times LORAN A.

As the LORAN C network near Japan there are the LORAN C stations at Tokachita of Hokkaido, Iwo Isl. and Marcus Isl. and are operated by the United States Coast Guard.

(2) Transmission and reception of the LORAN C radio wave.

Master and each Slave are arranged so that they have a wide effective range and in the case of Master and two Slaves they are arranged almost similarly as the LORAN A, but in the case of having three Slaves they are arranged in a star form or vertically as given in Fig. 1-43. In either case larger the base line length is made, the larger the effective distance becomes and the accuracy of fixing position becomes favorable, but as the transmitting radio wave between Master and Slave must be synchronized for certain, its length cannot be so long as to make the receptions of the mutual stations difficult. The length is usually selected in the range of 900-1,300 Km.

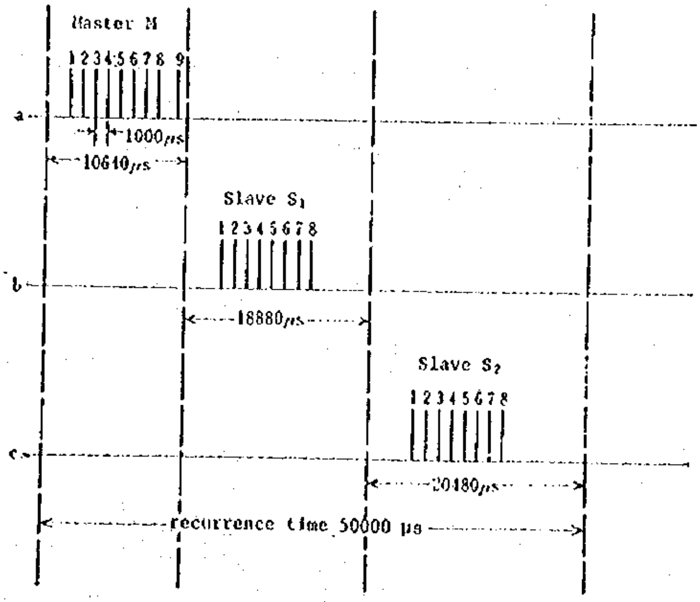


Fig. 1-44 LORAN C pulse transmission in case of the three stations

a. LORAN C pulse

The LORAN C transmits the pulse radio wave of the same frequency with both of Master and Slave. Though this is the same as the LORAN A, with the LORAN A the recurrence frequency of a pair of Master and Slave (e.g., M, S_1)

is different from that of another set of Master and Slave (M, S_2), while with the LORAN C the recurrence frequency of Master and Slave is all the same and the multiple pulse is employed for the transmitting pulse from Master and Slaves. Fig. 1-44 shows the transmitting instance in the case of Master and two Slaves. The employment of the multiple pulse is for increase of the mean transmitting power. Each station transmits eight pulses with an interval of 1,000 μ sec, but Master transmits the ninth pulse also with an interval of 600 μ sec or 1,300 μ sec with a view to visual discernment and to send to the receiver information about improvement of accuracy of this system, etc.

When the multiple pulse is transmitted from Master as (a) in the drawing, it begins to reach the Slave S_1 after a definite propagation time. After the initial pulse of Master reaches S_1, S_1 transmits a multiple pulse like (b), adding a definite signal delay time. Slave S_2 too transmits pulses with the method similar to S_1, but Slave signal delay is provided to be larger than that of S_1. Hence, there is no piling up of S_1 with S_2.

b. Cycle matching

The time difference is measured by piling up two pulse forms of Master and Slave with the LORAN A, but in addition to this with the LORAN C the exact time difference is measured by measuring the phase difference of radio frequency in the wave form. With this way it becomes possible to improve the accuracy.

The LORAN C pulse is, as given in Fig. 1-45, the wave form rising up in about 80 μ sec from zero to the peak value and the continuous time is about 250 μ sec if up to 10% of its amplitude is taken. However, as the sky wave is also mingled with the surface wave at the reception point, these discrimination must be possibly made in order to maintain the high accuracy. Though the one hop sky wave differs according to conditions, it has been made clear that the sky wave fortunately delays by 25~55 μ sec from the arrival of the surface wave. Then, with the LORAN C, as given in the drawing, the phase difference is measured in such a short time as the inital 2~10 μ sec of the surface pulse. This is called the Cycle Matching.

c. Reception of the LORAN C radio wave

There are 48 kinds of the recurrence frequency of the LORAN C pulse, but they are selected so as to be generally compatible with the LORAN A system. Consequently, even the LORAN A receiver is available if the transducer of transducing the 100 KHz LORAN C radio wave to the carrier frequency of the LORAN A channel should be provided. However, as it cannot perform the cycle matching like the LORAN C receiver, the accuracy becomes lower. Fig. 1-46

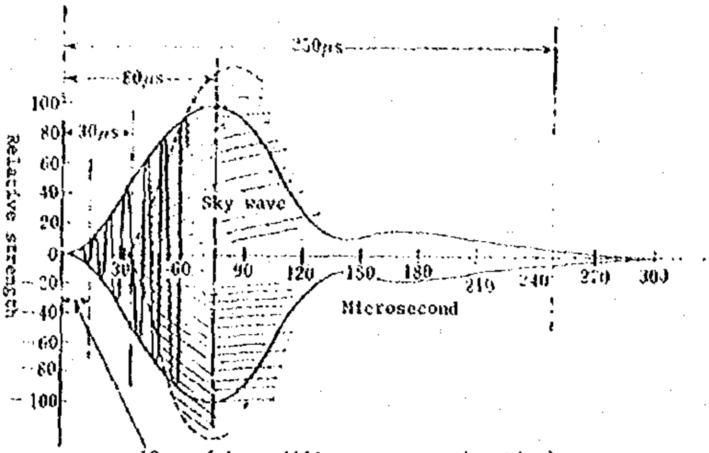


Fig. 1-45 LORAN C pulse

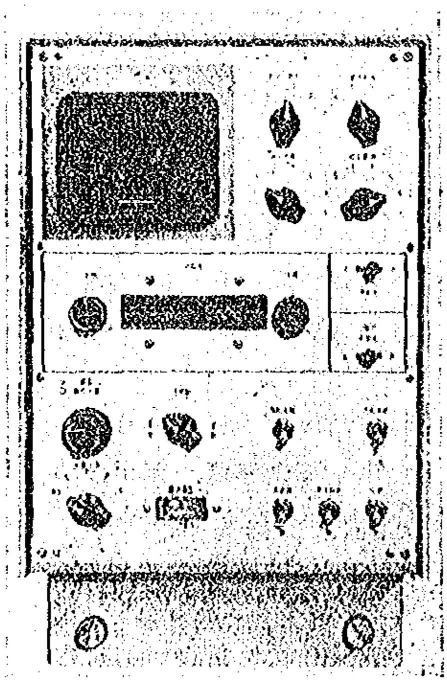


Fig. 1-46 An example of the LORAN C receiver

shows an example of the LORAN C receiver and its operation is briefly explained as follows:

(a) At first the pulse recurrence frequency of the LORAN C chain is chosen. The signal received appears stationarily on the Braun tube, but the pulse with different recurrence frequency disappears.

(b) It is synchronized with the Master pulse. These are two methods of availing the ninth pulse for visual discernment and the automatic method for this object.

(c) Synchronization of the Slave pulse is visually or automatically made.

(d) When the receiver is synchronized with the radio waves (including cycle matching) of Master and Slave, the position decision is done by the LORAN C chart, as the arrival time difference is directly indicated.

As stated above, with the LORAN C system the automatic measurement can be made and its result can be indicated continuously. Further, by the use of low frequency of 100 KHz and by also measuring the phase difference of radio frequency it can be considered as the mixed system of the DECCA to be stated later and the LORAN A.

3. DECCA

DECCA (Decca Navigation System) was developed in England. The name of DECCA came from the name of that company. It was particularly developed and became prevalent in the western Europe. It is the feature that the measuring accuracy is extremely high. The DECCA chain was constructed in Japan by the Maritime Safety Agency in Hokkaido and Kyushu and is currently in operation.

DECCA chain is arranged, as given in Fig. 1-47, so that Master and three Slaves compose a star shape and in the case of Hokkaido the arrangement is such as Master: Biei, Red Slave: Akkeshi, Green Slave: Wakkanai, Purple Slave: Oshamanbe. By transmitting radio waves from the respective station the hyperbolic position line is made, as given in Fig. 1-35, and this is the same as the case of LORAN, but its transmitting frequency applies 2MHz band with the LORAN A and 100 KHz with the LORAN C and in either case both of Master and Slave transmit the same frequency, while it employs the low frequency of near 100 KHz in the same way as the LORAN C, but the transmitting frequency of Master and each Slave are different and though each of transmitting radio waves of the LORAN A and C is the pulse, the DECCA receives the continuous wave. From the availing point of view the LORAN A and C can be said to be for use of the long range, while DECCA can be said to be for use of the medium and short range, the accuracy of which is favorable.

(1) Principle of DECCA

As given in Fig. 1-47, three Slaves with DECCA are discriminatingly called Red, Green and Purple. Three sets of position line are made by Master and each Slave and each position line is shown, as Fig. 1-48, according to the varied colors fo Slaves on the DECCA chart.

Now, the hyperbolic lines of position group, to be made by Master and Slave, are supposed to be indicated by Fig. 1-49. This form is the same as

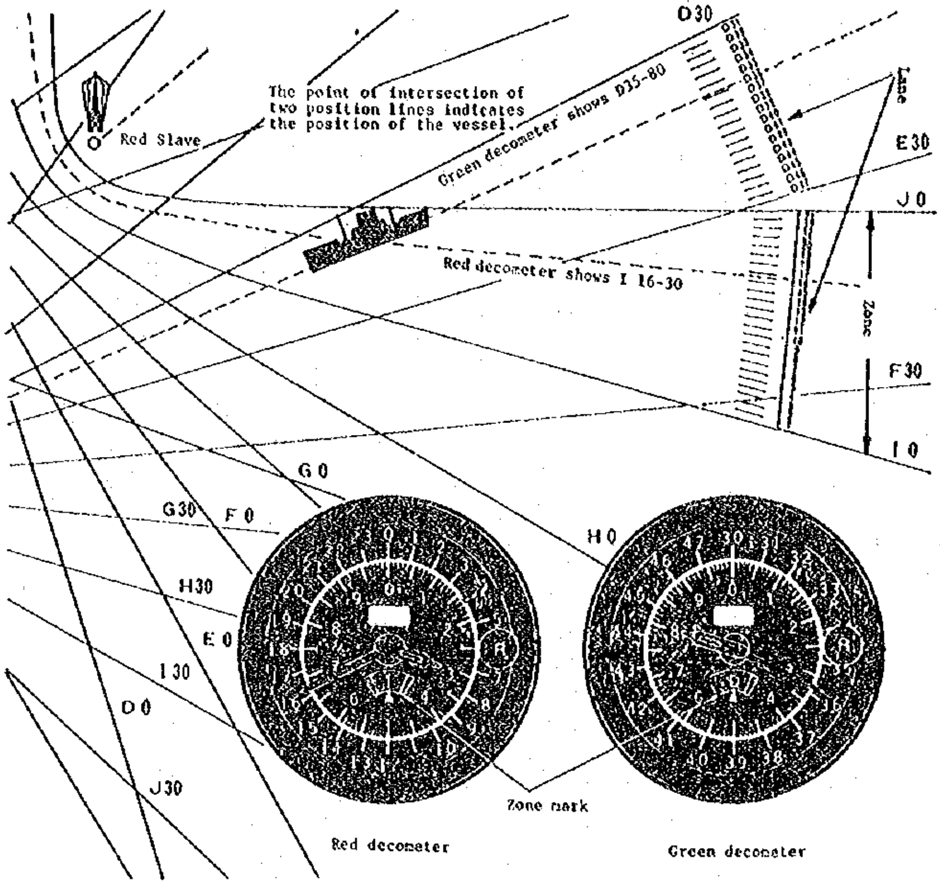


Fig. 1-48 DECCA chart and decometer of DECCA receiver

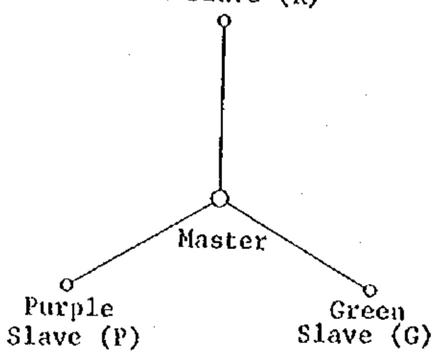


Fig. 1-47

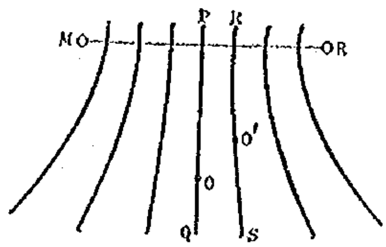


Fig. 1-49
Lines of Position of DECCA

the case of LORAN, but the different points are that this is a locus of points where the time difference from the both stations becomes definite, while this is a locus of points where the phase difference of the radio waves reaching from the both stations becomes zero with DECCA, but can be deemed intrinsically the same.

When the continuous waves of the same frequency and also of properly matched phase are transmitted, the interval of lines of position on the base line MR becomes $\frac{1}{2}$ wave length. There are points of the phase difference being zero on every $\frac{1}{2}\lambda$ on the bage line. The locus of each point of such a phase difference zero becomes the hyperbola like PQ or RS of the drawing.

Now, assuming the case that the vessel is at the point on the PQ line, when the phase difference of receiving radio waves from the two stations is measured, the result is zero. When the vessel proceeds to the O' point on the RS line, the phase difference at this time becomes also zero, but the phase amount increases by 360° than the case of the zero point.

Therefore, when the radio waves from the two stations are received on the vessel and if the meter to detect these phase differences is equipped there (the pointer revolves once by one wave length, i.e., 360°, this is called Decometer and is shown under Fig. 1-48), it can be found that the vessel is on the RS line, i.e., as the pointer makes one complete revolution when the vessel proceeds from Point O to Point O'. As the pointer makes one revolution by every passing of one position line, it is the reason that we can know on which position line the vessel is by the number of revolution when these revolutions are made so as to be integrated. When the vessel is between the position lines, the fractional distance can be found by finding what degrees the pointer designates.

At least one more set of hyperbola group is necessary to fix the position and as those are made by Master and Green Slave or Purple Slave, the position should be known in the above way and the position can be decided from that point of intersection. The decision of this position is the same as the case of LORAN.

(2) Transmission and reception of radio wave

Though it has been stated for convenience sake so far that Master and each Slave transmit the same radio waves, the different frequencies in the relation of simple integral ratio are practically transmitted, because reception cannot be discriminatingly made if these stations transmit the same frequency at the same time. In the case that the basic frequency is f (f is selected of about 14 KHz), as given in Fig. 1-47, each station transmits with the following frequencies: The figures in the paren theses are the examples at Hokkaido chain, being f=14.288kHz.

Master 6f	(85.725 kHz)
Red Slave 8f	(114.3 kHz)
Green Slave 9f	(128.588 kHz)
Purple Slave 5f	(71.438 kHz)

As the reception side must make the frequencies the same in order to

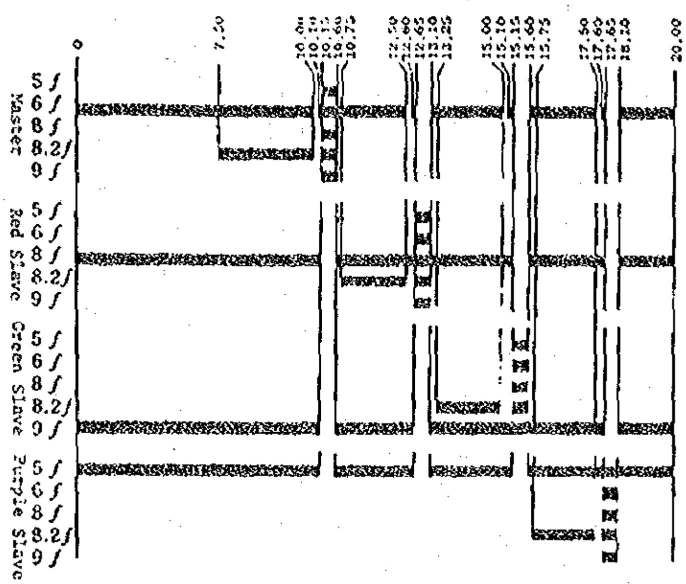


Fig. 1-50 Transmission of radio wave of DECCA

measure the phase difference, the respective frequency is suitable integrally multiplied in the receiver to be the same, which is called the comparative frequency.

(1) When reception is from Master and Red:

(Comparative frequency=24f) (6f of Master) × 4 ~ (8f of Red Slave) × 3

(2) When reception is from Master and Green Slave:

(Comparative frequency=18f) (6f of Master) × 3 ~ (9f of Green Slave) × 2

(3) When reception is from Master and Purple Slave:

(Comparative frequency=30f) (6f of Master) × 5 ~ (5f of Purple Slave) × 6

Further, the position line of the DECCA chart is drawn by this comparative frequency. The area between position lines adjacent to the phase difference zero of the comparative frequency is called Lane, or the area between similar position lines of the basic frequency is called Zone.

Alphabetic mark and figure are described to each position line in Fig. 1-48 and the interval of the alphabetic marks becomes Zone. There are the zone marks from A to J with position lines of each Slave and the figures between zones are, 0-23 with the Red Slave, 30-47 with the Green Slave and 50-79 with the Purple Slave and figures are different with each other. The interval of these figures is a lane and the figure is called the lane number. Fig. 1-51 shows a portion of the practical DECCA chart in which these position lines are described.

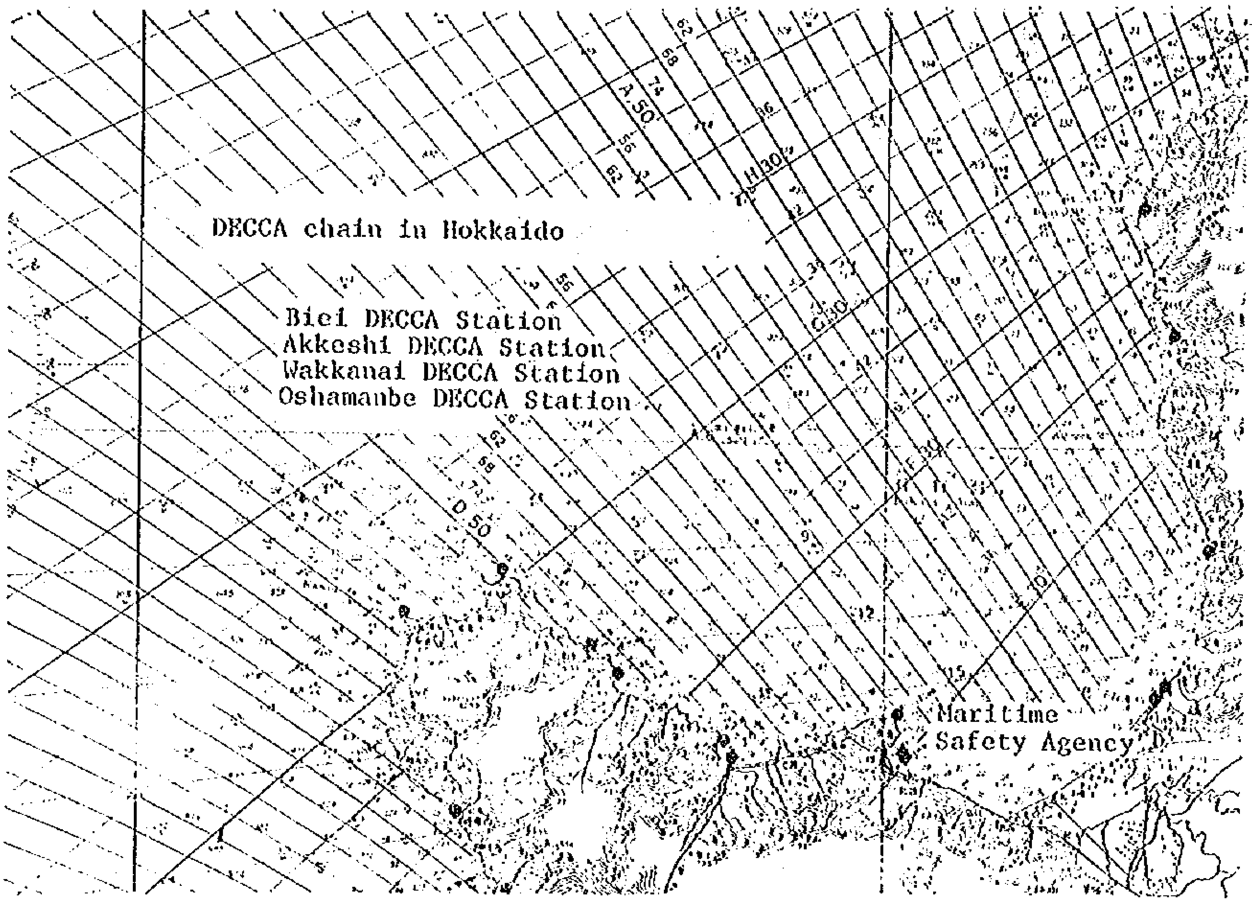


Fig. 1-51 An example of the practical DECCA chart

In the case of LORAN the pair stations are discerned by changing the pulse recurrence frequency with each station of the set, but in the case of DECCA the combination of one Master and two or three Slaves is called Chain and the discrimination of one chain from another is performed by changing frequencies. When a chain available with the DECCA receiver is selected, the radio waves of four (or three) stations among the chains become to be in the state of enabling constant reception.

Fig. 1-52 indicates the indicating portion of the DECCA reveiver and the lower three are decometers. There are clockwise a long needle and a short one. The short one makes one revolution when the phase difference changes by 360° and the long one moves one graduation in this while. This reading of decometer shows the position line of the DECCA chart.
When a vessel or aircraft moves, the needles of the decometer begin moving with the motion of the vessel or aircraft and so it is constantly possible for the reading and the position can be sought continuously.

The upper part in the center is called L.I. meter (Lane indication meter), which is to measure which lane in the zone is.

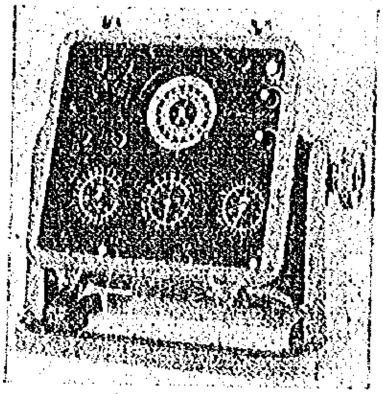


Fig. 1-52 DECCA receiver

The short needle of the decometer gives the phase difference of 0-360°, i.e., the position on one lane. The long needle moves only mechanically by one graduation per one revolution of the short needle. This relation can be considered completely the same when the long and short needles of the clock are reversed. Consequently, the long needle of the decometer must be set mechanically by finding out with a separate method to which lane the indication of the decometer belongs. As the width of one lane is 350-600m (This differs according to the Slave), it is hard to recognize lanes by position estimation. For this reason the L.I. meter is used. The L.I. meter can be considered as the decometer of zone. The width of one zone is about 10 kM on the base line and if the range is of this extent, it can be known by the chart before the departure, or it can be judged from the estimation of position. Signals to discern lanes are transmitted from the transmitting stations as follows:

(a) Master transmitts 5f, 6f, 8f, and 9f for from 10.0 sec to 10.6 sec per minute and each Slave transmits no radio wave.

(b) Following the above, the Red Station makes the similar transmission for from 12.5 sec to 13.1 sec and the other stations do not transmit any radio wave.

(c) The similar transmissions are made for from 15.0 sec to 15.6 sec by the Green Slave and for from 17.5 sec to 18.1 sec by the Purple Slave. During that time the other stations transmit no radio waves.

The above transmissions are performed for from 30.0 sec to 50.5 sec of every minute. Therefore, the transmission order of radio in one minute with the DECCA chain is as Fig. 1-52.

(3) Features of DECCA and their utilization

a. Because of utilizing the low frequency the attenuation on land and influence by mountains are little and it is available at the low altitude and complicated creeks.

b. Because of the phase comparison method by the continuous wave the accuracy is extremely high, and it is theoretically said to be the extent of six meters. The utilization of sky wave is impossible. In the night time this sky wave disturbs the accuracy and the accuracy is lowered, but even so, the error is about 750m at the distance of about 540 Km.

c. The effective distance is about 1,000 Km in the daytime and 600 Km in the night time.

4. DECTRA

DECTRA is the long range navigation aid system by high certainty, availing the LF band of 70-110 KHz and is the system of giving the aircraft the distance from the destination and the track to navigate along by availing the basic principle of DECCA and transmitting the continuous wave by keying and comparing the phase. This is operated at present in the North Atlantic Ocean. The error of track is below five nautical miles at the point of 1,600 nautical miles and the error in measuring distance is said to be below 5-10 nautical miles for all tracks. The word DECTRA consists of the capital letters of DECCA Tracking and Ranging.

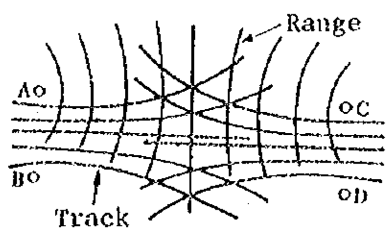


Fig. 1-53 Position line of DECTRA

According to the DECTRA system, as given by Fig. 1-53 as land facilities, Master and Slave (A and B or C and D) are arranged with the interval of 80-110 nautical miles at the right angle with the air route respectively at the both ends of the air route of 1,500, 2,000 nautical miles in length. By each of Master and Slave transmitting respectively the synchoronized radio waves, the hyperbolic position line group, called the tracking pattern, is made on the air-route and gives distance information from the center-line of the air route and by making the radio waves to be transmitted by the two Masters at the both ends of the air-route to have some definite phase relation with each other and making the hyperbolic position line group, called the ranging pattern, along the track and the distance information from the both ends of the air-route is given.

In order to provide the tracking position line, Master A stops its transmission for just a short time (0.5 sec) after transmitting the radio wave of frequency F_1 for about seven seconds, while Slave B transmits the radio wave of frequency F_1. This operation is repeated and Slave B shall have the frequency of its own oscillator synchronized with the radio wave of Station A during the time when Station A is transmitting waves. The same motion as this is also taken place with Master C and Slave D at frequency F_2. The receiver on the aircraft shall have the phase of frequency of its local oscillator synchronized with the radio wave of Master during the Master's transmission. While Master discontinues transmission and Slave makes transmission, the phase difference of the phase of the oscillator of the aircraft and the signal of Slave will be measured and let the traking decometer indicate the result.

Next, in order to provide the ranging position line, select F_1 of A Station and F_1 of C Station so as to be respectively multiples of $F_1 - F_2 = f$ (e.g., 185 Hz). F_1 is received by C Station and F_2 is gained by phase control of the frequency of the local oscillator of C Station. The receiver receives F_1 from A Station and F_2 from C Station and by measuring the phase difference of F_1 and F_2 the ranging position line is sought and let the decometer, etc., indicate it. Besides, there is a method of obtaining a distance by receiving either F_1 from A Station or F_2 from C Station, comparing it with the phase of output of the crystal oscillator of high stable degree, incorporated in the receiver and availing that the phase difference changes according to the navigating distance. This is usually called "single signal DECCA range" and the former is called "two signal DECCA range".

5. OMEGA

Omega is a similar hyperbolic navigation system as DECCA and LORAN. This system was proposed by Prof. J.A. Pierce of Harvard University who contributed to the development of the LORAN A and C. Since around 1957 experiments for development, centering by Navy Electronics Laboratory, U.S.A., were taken place. This system employs four waves of 10.2.kHz, 11.05kHz, 11.33 kHz and 13.6 kHz from among the radio navigation bands of 10-14 kHz. By the use of these ultra-low frequency and by that propagation feature the base line length among stations can be set at 5,000-6,000 nautical miles. Therefore, in order to cover the whole earth surface with this system it is enough for the eight OMEGA transmission stations to be set. Regarding the three stations among the eight stations, those at Hawaii, North Dakota and Norway was at first constructed for experimental operation but reconstructed for practical use. Regarding the other five stations practical stations are constructed lately respectively in Argentine in the South American area, in La Reunion Ils. (French ownership) on the east of Madagascar Ils. in the Indian Ocean in the Ocean area, in the North Western part of Melbourne in the Oceanian area, at Liberia and at the Shushi Bay on the northern part of Tsushima of Japan in the Far East area (Fig. 1-54). All of them except Australia station were completed in 1973 and it is scheduled to operate the eight stations in 1974. With a view to effectively avail OMEGA worldwide it is expected that the feeding power is 100-200 kW and the radiation power is around 10 kW. Consequently, it is necessary to expect the radiation efficiency to be about 10 % and the extremely large-sized antenna for use of the wavelength of about 30 km becomes is needed. The existing station such as Norway is installed the valley-span antenna in the valley of over 3 Km, availing the valley of depth of over 500 m. As a suitable valley was not available in the other North Dakota Sataion, an umbrella antenna is stretched on an iron tower of 450 m in height.

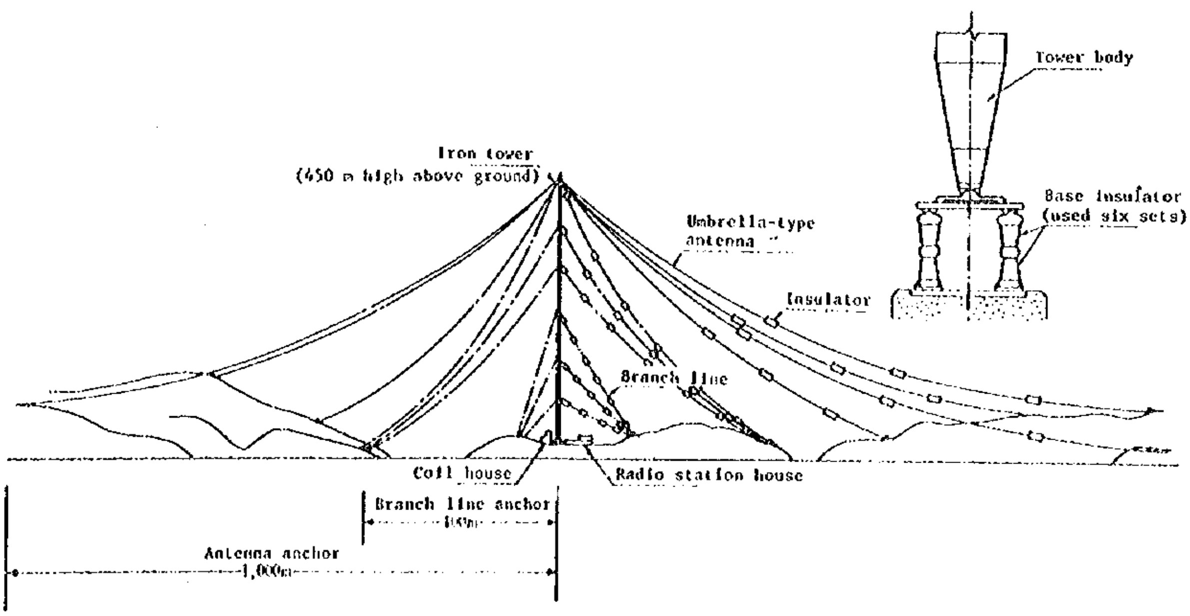


Fig. 1-54 Perspective drawing of OMEGA transmitting station

As the indoor facilities, a transmitter of 100-200 kW class, the time standard generating device consisting of four sets of atomic standard device, frequency composition device (consisting of the carrier oscillator, generator of element of mosulation wave and generator of multiplex wave form), all kinds of control device and an electric source equipment of 1 kW class are installed.

Signal Pattern In the case that the whole system is operated the waves are transmitted in accordance with the whole schedule, given in Fig.1-55, and this is repeated with the interval of 10 sec. This pattern just corresponds to what constitutes independently eight systems of OMEGA system of single frequency. Identification of each station can be done by the pulse length of the basic frequency and by the fact that the transmission time of the Norway Station is synchronized with the Universal Standard Time (UT) and 10.2 KHz was transmitted at every 10 sec from 00 sec of every hour and every minute at first.

In signal pattern a characteristic frequency (11-14 kHz) transmitted by each station besides four waves of the basic frequency for identification the station.

The receiver can make measurements by switching wave and measures with four frequencies by selecting suitable frequency or switching them by turns in respect of making it easy to discern the lane with the necessary accuracy.

The reason why the discernment of lane is possible is as follows:
As there is a difinite relation among four frequencies in the effective range, there are generated the following conformities in the four sets of position line groups.

a. No.3 lane of 10.2 kHz conforms to No.4 lane of 13.6 kHz. (24 NM)
b. No.9 lane of 10.2 kHz conforms to No.10 lane of 11.33 kHz (72 NM)
c. Consequently, No.9 lane of 10.2 kHz, No.12 lane of 13.6 kHz and No.10 lane of 11.33 kHz conform.
d. No.36 lane of 10.2 kHz and No.39 lane of 11.05 kHz conform (288 NM)

When the phase difference of reception wave of 10.2 KHz is measured in moving on the base line, it changes between 0°-360° at every 8 natical miles. Consequently, unless the navigator pursues that signal continuously, or confirms the lane number by finding his own position with accuracy of within 4 nautical miles by other navigation methods, the corresponding position line is not clear. However, when the position lines of 10.2 kHz and 13.6 kHz are pursued and combined, a postion in 3 lanes of 10.2 kHz can be decided and the ambiguity is generated at every 24 nautical miles on the base line. Further, when applying 11.33 kHz, the ambiguity appacars at every 72 nautical miles. From the phase difference of the frequency difference 0.28 kHz of 11.33 kHz and 11.05 kHz the width of discerning lane can be expanded up to 288 NW. In other words, when the approximate own position can be sought with an error of within 144 nautical miles, the accurate own position can be found.

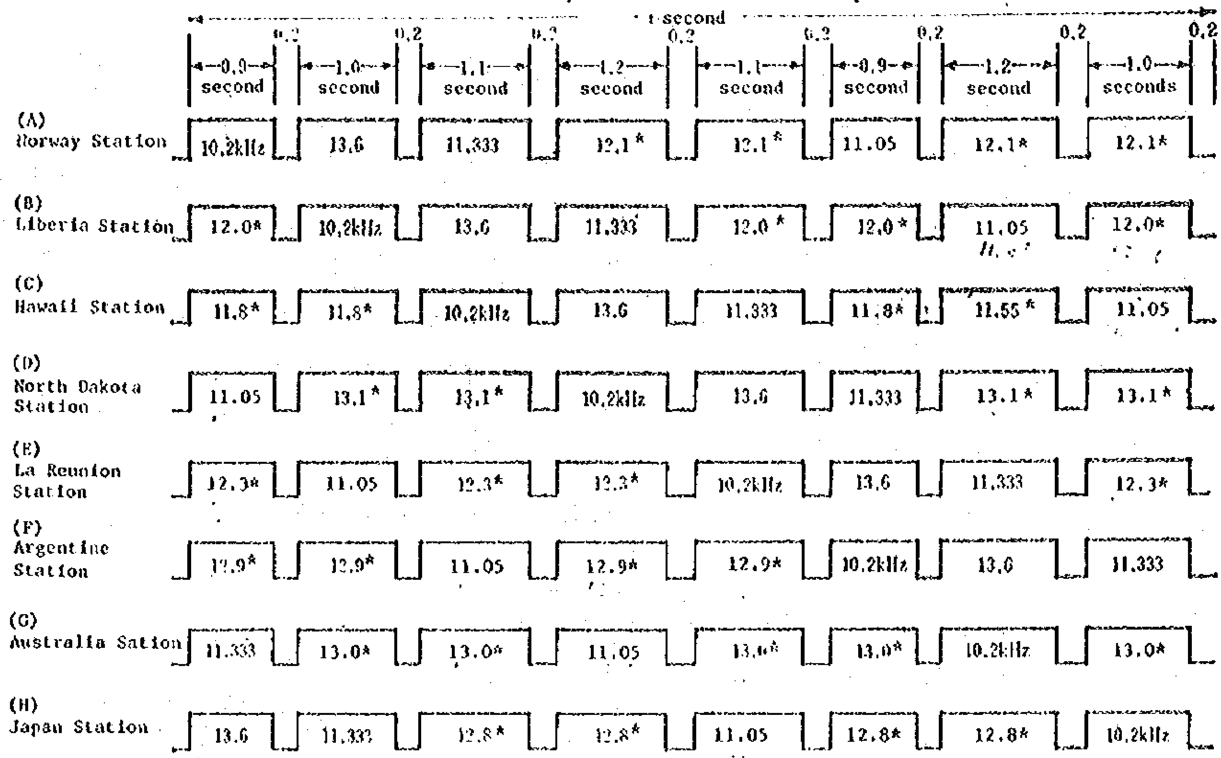


Fig. 1-55 OMEGA signal form (*identification of stations)

The standard deviation of reading the phase difference in the daytime is about 2-3 centi-lane in the Summer season and 4-5 centi-lane in the Winter season. Expressing this in 10.2 KHz, the 5 centi-lane is 0.4 nautical mile.

The receiver has been developed to the reception sensitivity of as extremely high as 0.01 μV.

It can be set to operate only during transmission time of the station from which the reception is intended and can compare the phase by memorizing the respective radio waves. The position of the measurer (vessel or aircraft) can be sought as the point of intersection of hyperbolic lines of the two sets. When the receiver is usually attached with the auto-tracking device and is set at the time, etc. of leaving ports, the automatic measurement of 4,000-5,000 nautical miles is available by no-man-operation by two pair-stations auto-tracking system and with providing a printer the measured data on the day, hour and minute measured can be indicated and printed digitally or in analogical figure expression.

Makers of receivers who developed OMEGA receiver in Japan became six companies. Fig. 1-56 and 1-57 show its one example.

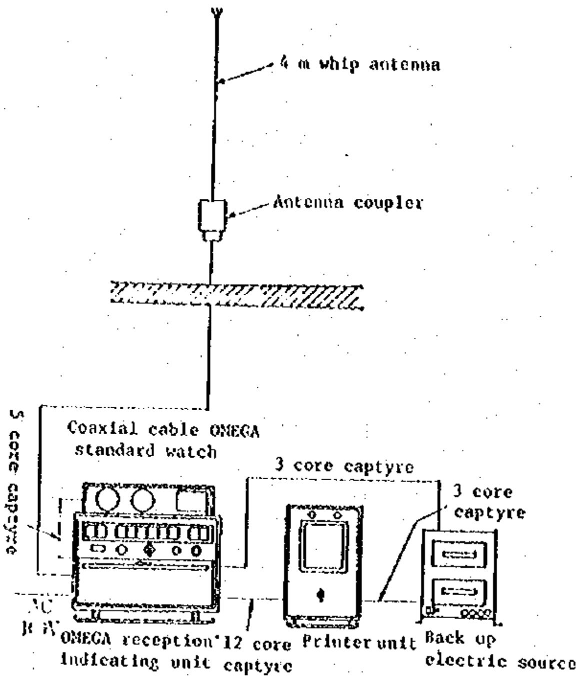


Fig. 1-56 Structure of OMEGA reception device

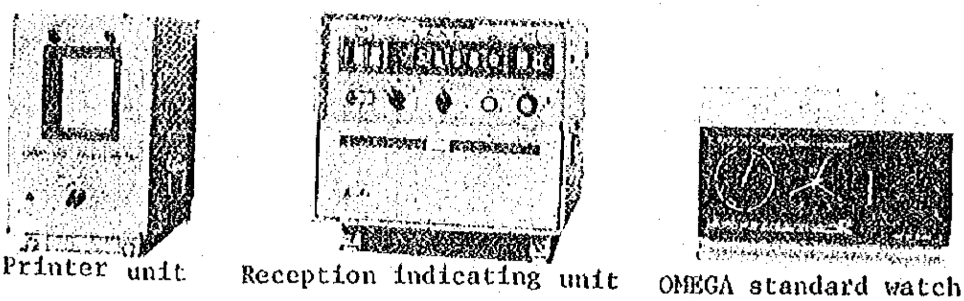


Fig. 1-57 Drawing OMEGA reception device

6. DELRAC

ELRAC is the abbreviation of Decca Long Range Area Coverage and is the navigation aid system for use of long range, availing the continuous wave of low frequency band of 10-14 kHz and taking the base line length between Master and Slave at about 1,000 nautical miles. The position of aircraft is decided by availing the principle of DECCA and by seeking in the same way as the general hyperbolic system from the chart given by Fig. 1-58 the point of intersection of the hyperbolic position line by the synchronized radio wave from a set of Master and Slave with the hyperbolic line from another set of Master and Slave.

With DELRAC at first the radio wave of the basic frequency F is transmitted for a definite period (5 sec) from Master M_1 and following it, the radio wave of the same frequency F whose phase is controlled by it is transmitted for five seconds from Slave S_1. The receiver on the aircraft holds the F signal from M_1 and compare it with the phase of F signal from S_1. On the basis of that phase difference the position line on which the aircraft is located is made to indicate with the decometer. In order to remove the unclearness of the position line that becomes always the problem with the phase comparison method by only comparing phase with basic frequency F, the signal of 4F/3, 10F/9 or of 28F/27 when in need, is in turn further transmitted for five seconds, following the transmission of F from Master M_1 and Slave S_1. The receiver makes beat frequences with these signals and the hold F and eliminates the umbiguity by seeking the position line of thrice, nine times or 27 times broader by signals of beat frequency of F/3, F/9 or F/27 when in need.

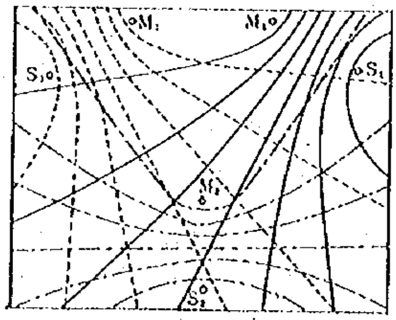


Fig. 1-58 Lines of Position of DELRAC

When the above measurement is carried out with the other set of M_1 and Slave S_2 or M_3 and S_3, the position can be decided by the point of intersectin of the two position lines. Each of these Master and Slave transits synchronized waves in turns and makes the plural decometers continuously indicate the position line by providing the holding circuit on the reception side.

The effective range of DELRAC covers over 3,000 nautical miles and the accuracy is said to be below 10 nautical miles with the probability of 95%, but it is said that the whole earth can be covered with about 12 sets of Master and Slave DELRAC land stations.

1.5 Distance bearing system

1. TACAN, VORTAC

TACAN is the abbreviation of Tactical Air Navigation system and has been developed with the military purpose in the U.S.A. It can obtain information of direction and distance simultaneously in comparatively high acuracy using radio wave of 962-1,213 MHz (It is said that the average error of direction is about ± 185 m + 0.2% of measured distance). There is an advantageous point that the aircraft can navigate by seeking distance and direction with one TACAN. The distance measuring part is the secondary radar and the mutual distance can be known by measuring time needed while the radio pulse returns between the two points. The transmitter on the aircraft repeatedly transmits a pulse pair of pulse width 3.5 μ sec, pulse interval 12 μ sec (In future also 36 μ sec will be used). When this pulse pair is received by the land station, the response of pulse pair is transmitted, by operating the transmitter with receiver output. This response pulse pair is received on the aircraft and the time difference with the previously transmitted interogation pulse pair is measured to indicate the distance. The delay time from the land station receiving the interrogation pulse to its sending the response pulse is set at a definite value in advance and the distance is indicater on the aircraft by correcting this value. The interrogation pulse pair is sent out about 30 times every second and as this repetition number can be changed within a certain range, the repetition number of its own interrogation pulse is changed and only the response pulse to be changed synchronizedly can be selected for measurement, even in the case that the response pulse to the other aircraft exists mixedly. In exploying the pulse pair it can be easily selected, even in noise and radio interference, if it be the definite interval pulse pair. The land station prevents the change in the transmitted power at the time when there is no interrogation pulse and is sending out the pulse pair of 3,000 pulse/sec with a view to indicating the direction (This is called skitter pulse) and when there is the interrogation pulse, it is arranged so that the specified one is synchronized with the interrogation pulse, becoming the response pulse. Consequently, aircrafts of over 100 have the function of measuring distance by the same land station. The interrogation pulse on the aircraft and the response pulse on land are arranged to utilize the separate frequencies and the interval of those frequencies is 63 MHz.

The directional indication is as similar as VOR, but employs the above mentioned response pulse or the skitter pulse instead of the VOR non-modulation carrier wave and applis the basic pulse as the standard phase signal. Now, when the radiowave of definite amplitude is transmitted with the antenna of Cardioid directivity of Fig. 1-59 (a) revolving at the speed of 15 revolutions/sec, the pulse radio wave, amplitude modulaed with 15 Hz, as in the same case with VOR, is received at the specified reception point. The phase of range indicating envelope (15 Hz) differs according to the directional angle and so when the basic pulse is transmitted at the time when the maximum directivity of Cardioid faces the right north and if the time delay between this basic pulse and the above-mentioned amplitude envelope line is measured at the reception point, this phase differece becomes its own directional angle from the transmission antenna. This is the rough measurement of direction. The standard pulse is the 12 pulse group having interval of 30 μ sec and each pulse consists of the dual pulse that has the interval of 12 μ sec. As given by Fig. 1-59 (b), these avail a portion of the skitter pulses.

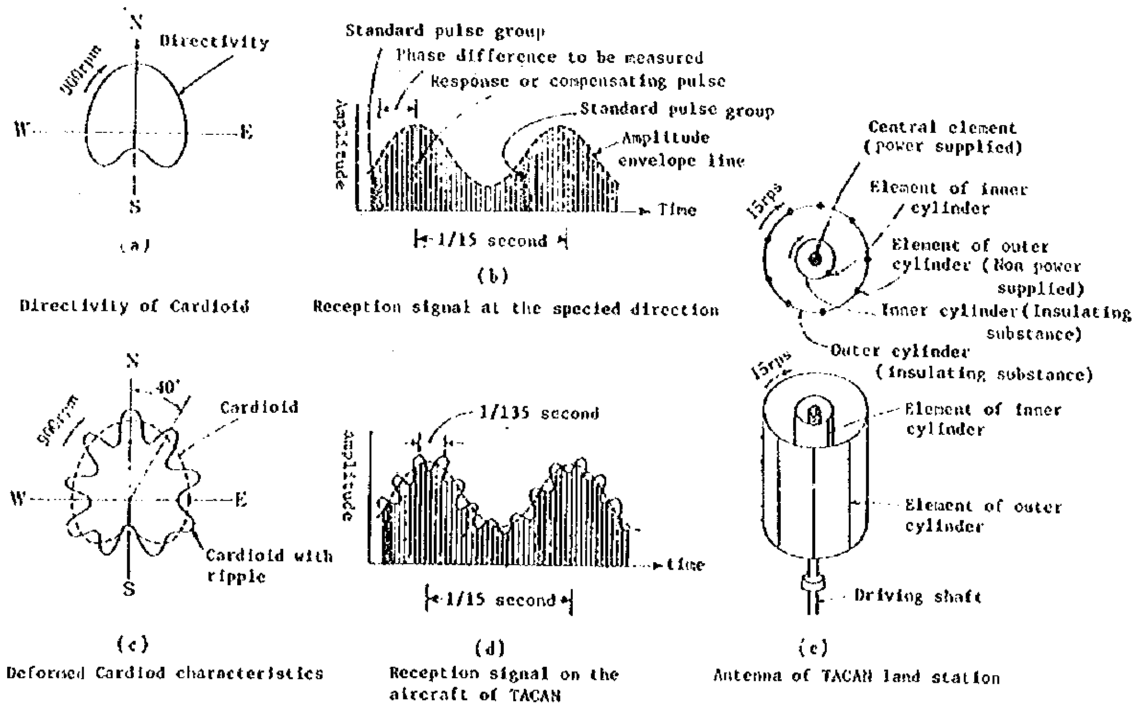


Fig. 1-59 Principle of TACAN direction measuring unit

TACAN uses the directivity as deformed as the actual line of Fig. 1-59 (c) to increase the directional accuracy. This is cardioid to which nine pieces of ripple are added at every 40°. At the reception point Cardioid gives 15 Hz, the ripple becomes 15 × 9 = 135 Hz. This ripple is 1 Hz at the directional angle 40°, i.e., the electric phase angle changes by 360° for the angle 40°

and the directional accuracy increases by nine times. The receiver on the aircraft selects 15 Hz by Cardioid and 135 Hz by the ripple and measures the respective phase. By putting these together it instructs the range finder the azimuth. The antenna of the land station is of the construction of Fig. 1-59 (c), supplying electricity to the central element and Cardioid by the element of the inner cylinder and the ripple by the elements (nine pieces) of the outer cylinder are formed.

What has the function of only the range measuring unit of TACAN is called DME (Distance Measuring Equipment), becoming the standards of ICAO and what was installed with TACAN and VOR at the same location is called VORTAC. By doing this way the aircraft having the equipment according to the ICAO standard can find out the azimuth with VOR and the distance with the DME equipment on the aircraft and the TACAN equipment on land. On the other hand the aircraft (chiefly military aircraft) equipped with only TACAN also utilize this.

2. DME, VORDME

DME (Distance Measuring Equipment) is almost the same as the distance measuring unit of TACAN (Refer to 1.5, 1st Paragraph) that was developed by the U.S. Navy after the World War II and is usually employed in conjunction with VOR (Refer to 1.3, 2nd Paragraph), having been adopted as the international standards of ICAO.

The aircraft can know the direction information with VOR and the distance information with DME, being able to continuously decide its position and distance against the land station.

In Japan, too, 12 VOR-DME stations and one DME station have been currently operated and such stations are expected to be installed in succession also hereafter.

DME system consists of the interrogater to be installed on the aircraft and the transponder to be installed on land. When the pulse radio wave of a certain frequency (The land stations have respectively their own specific frequencies.) is transmitted, the transponder on land receives it and automatically emits the pulse radio wave of the different frequency (The difference between both the frequencies of the transmission and reception is fixed at 63 Hz.). The aircraft can know the distance between it and the land station by measuring the time difference of its own transmission pulse and its returned reception pulse.

The frequency band for use is from 962 MHz to 1,213 MHz, using the interval of 1 MHz and can employ 126 as the X channel and 126 as the Y channel, totalling 252 channels.

Both of the interrogation pulse and the transponding pulse use the dual pulse of pulse width of 3.5 μs and it is discriminated by the dual pulse interval that that of 12 μs with both the interrogation pulse and the transponding pulse is X channel and that of 30 μs with the interrogation pulse and 30 μs with the transponding pulse is Y channel. In each case the frequency of interrogation pulse and the frequency of transponding pulse have definite combinations. It is possible for each of the land station to receive and transmit radio waves of definite frequencies that were decided for their respective station. The aircraft is equipped with DME airborne device that can transmit the radio wave of frequency for interrogation with 1 MH interval of this band and receive the radio wave of frequency for transponding crresponds to this.

3. NAVARHO

NAVARHO is an assisting system for the long range navigation by availing the continuous radio wave of 90-110 kHz of $\rho - \theta$ system and giving the aircraft information on the azimuth and distance from a land base point. The instrument is said to be able to be produced with the distance error of within five nautical miles and with the directional error of within 2° at the distance of 1,500-2,500 nautical miles.

NAVARHO land station arranges, as given by Fig. 1-60, three vertical antenna 1, 2, and 3 on the vertexes of a regular triangle with the length of one side being 0.4 wavelength, supply signal in turns by switching one pair in the order of 1-2, 2-3 and 3-1 with the same amplitude and the same phase in a short time (166.7 ms) and finally supplying signal simultaneously to the three antennas with the same phase. This cycle is repeated with the period of one secound. In this case with supply of signal to a pair of antenna three pieces of deformed 8-figure-shaped directivity of A, B and C, deflected respectively

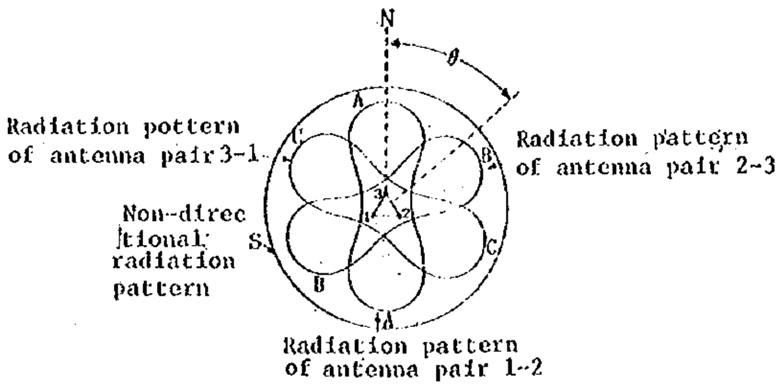


Fig. 1-60 Arrangement of antennas of Navarho land station and radiation pattern

by 60°, are obtained.

When these signals are received at the location of the magnetic direction 0, three pieces of pulse of A, B and C of different amplitude as shown in Fig.1-61, are received. As the magnetic direction of the reception point can be decided by comparative measuring of those amplitudes, the amplitude ratio is measured with connecting the ratio meter to the output of the receiver and further the direction meter is operated by this amplitude ratio.

The waves of two different frequencies are transmitted during the term of the S pulse of electric field of non-directional nature. The purpose of these pulses is to be the synchronous signal for discernment of each pulse of A, B and C, and to obtain information on distance. In order to measure the distance from the aircraft to the Navarho land station the crystal oscillator of extremely high stability of the extent of 10^{-9} is built in the receiver and the distance is obtained by comparing the phase of the S pulse with the phase of output to be obtained from the crystal oscillator. The reason of transmitting two different frequencies during the term of the S pulse is that if only one frequency of 100 KHz is transmitted same phase is gotton synchronized at every three km that corresponds to one wavelength and so ambiguity arises in the case of long range. By adding the radio wave of frequency different by 250 Hz and by measuring also the phase of the difference frequency that one wavelength becomes 1,200 km the ambiguity in measuring distance is eliminated.

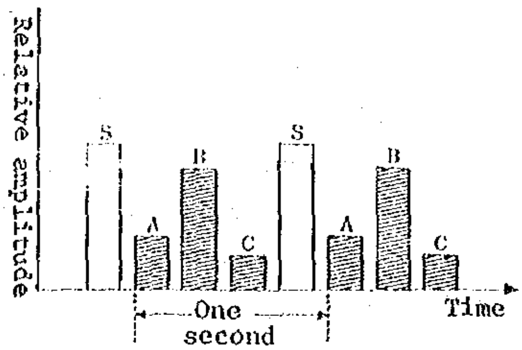


Fig. 1-61 Signal ratio at Direction 0

It is a fault that NAVARHO requires on the reception side the frequency standard of the high stability in measuring distance. In order to resolve this fault the following method has been proposed, i.e., NAVARHO-H that avails the hyperbolic position line made by difference of distances from two land stations, or NAVARHO-H·H that decides the position by the point of intersection of two position lines gotten by further measuring the distance between the one more land station and other.

1-6 Radar

Radar is the abbreviation of Radio Detection and Ranging and as shown by the words, it detects the target, or is employed to accurately decide the position of the target. Even in the case of the favorable field of vision the detecting distance is larger by radar than by visibility and the detecting accuracy of position is far more excellent. As also in the case of the particularly unfavorable case of vision of dark night, fog, snow, etc. it can be used in detecting the target with little influence of them, it has extremely high utilization value as navigation assistance for vessels and aircrafts.

(1) Principle

It avails the radio wave's nature of traveling straight ahead, with definite speed and that of reflection to decide the position of the target by measuring the distance and azimuth to the target.

The radio wave like light goes straight ahead with the speed of 300,000 km in one second and when there is an obstacle on its way, it has a nature of a portion of the wave returning by reflection. Consequently, the time needed from transmission of the radio wave to the reception of the reflected wave is the time needed in the radio wave returning in the distance between the transmitting point and the target. The distance to the target corresponds to the $\frac{1}{2}$ of the distance that the radio wave proceeded in this time, i.e. the fundamental of radar lies in measuring the elapsing time between the transmission of the radio wave and the reception of it.

As the direction of the target is the direction that the echo comes back, when the radio wave having sharp directivity is transmitted with scanning it around the radar equipment, it concentrates efficiently the radio waves to hit the target and at the same time can also seek the the direction of the target by the direction of the beam at the time of the echo comes back.

The usual radar employs the short time pulse repeated with a definite cycle in order to make it easy to measure the elapsing time from the transmission of the radio wave to its reception and to enable the receiver to emit instantaneously the radio wave of high output. When the pulse radio wave of high voltage of such short duration of time is transmitted, the strength of the echo returning by reflection on hitting the target becomes strong. The reception strength is remarkable lowered as compare with the strength of the transmitted radio wave, but as the repeat cycle of pulse is selected so that the reception is made before the transmission of the next pulse, the distance d(m) to the target can be measured from the following equation by measuring the time interval t(μs) until the instant (rising-up of the reception pulse) of receiving the echo from the instant (rising-up of transmitting pulse) of the transmission pulse being transmitted.

$$d = 150\ t\ (m)$$

With the practical radar the measurement of this distance can be directly read from that position by the image of the reception pulse on the fluorescent face of the braun tube with the electron beam scanning with a definite speed at the same time as the emission of the transmission pulse. When the scanning speed of the electron beam is changed, the interval of the both pulses that appear on the fluorescent face can be arbitrarily changed, even if the time interval between the transmission pulse and the reception pulse is definite and so switching can be made for easiest measurement according to the distance of the target.

In order to measure the direction of the target in the arbitrary direction the method is taken so as to receive the echo returning at every instant, as stated above, and to indicate it on the Braun tube, by matching the output with the direction of the beam. With most general radar there are many of those of the PPI display system (Plane Position Indication) that makes the position of the radar antenna to be the center of the Braun tube and indicates the position of the circumferential target by the polar coordinates, i.e., like a map shown by the directional angle from the right north and the distance to the target. Besides, the A-scope system of showing chiefly the distance to the target is frequently employed.

(2) Kinds

The radar is divided to the Primary Radar and the Secondary Radar according to the system. The primary radar is a radar system of receiving from the target the reflected radio wave and measuring the distance from the target. The secondary radar is a radar system that when the transmitted radio wave reaches the specified target, the equipment located there automatically transmits the same or different radio frequency and the position of the specified target is measured by reception of that radio wave.

The radar (Principaly the primary radar) was made research with the military purpose at the beginning and was equipped for use of shooting aircrafts, warships and ordinary vessel, navigation method or in many cases meteorology, but recently it became generally prevalent for use of vessels. It came at present to be equipped not only in almost all vessels of large size, but also in vessels of medium and small size. As for the land radar for maritime use there are harbor radars that are equipped with communication facilities alongside with the high resolution radar with a view to lead safely the navigation of vessels in harbors where there are much dense fog.

On the other hand the land radar for aerial navigation has two radars of the SRE (Surveillance Radar Element) to supervise the aircrafts around the airports with a view to lead their landing and to lead them to the entrance way and of the PAR (Precision Approach Radar) that is the radar of precision approach measuring for precision-measuring the position deflection of the aircraft from the final entrance way over the specified zone around the entrance way. Besides, there are, as land radars, the GCA (Ground Controlled Approach) that is combined device with the wireless telephone to transmit the approach instructions necessary for aircrafts, the Rapcon (Radar Approach Control) that is the surveillance radar to supervise the constant movements of aircrafts within the control area, the ASDE (Airport Surface Detection Equipment) that is the high resolution radar to make sure the airport control by detecting positions of aircrafts and vehicles running on runways and the leading ways, and others. Further, there are the meteorological radar for aircrafts of investigating the weather conditions over the air-route or its neighborhood in order to fly avoiding thunder, storm, etc.

1. Shipboard radar

The radar for the vessel is employed by vessels chiefly navigating on sea to make navigation officers decide the safe and effective course by investigating the movement of other vessels and positions of obstacles or by seeking its own relative position with the shore, buoy, beacon, etc.

The features of the radar for the vessel are:

[1] The performance can be fully displayed satisfactorily even when the vessel encounters bad weather and makes remarkable rollings.

[2] It has the high resolution for detecting the targets in the neighborhood.

[3] The measurement of distance can be at any time switched according to the distance of the targets.

[4] The antenna and other equipment are of enough small-size to be equipped in the limited space in the vessel.

The frequencies used for shipboard radar are 3,000 MHz (S band), 5,000 MHz (C band) and 9,000 MHz (X band), but most of radars employ at present radio waves of frequency of 9,000 MHz because of the small size of the antenna and propagation features of the radio wave. Optional circuit of FTC (Fast Time Constant) to make less the difficulty of seeing the picture reflection of the reflecting signal by rain and snow and the device of the STC (Sensitivity Time Control) to eliminate the unwanted reflecting wave from waves on the adjacent sea surface.

(1) General

The radar for the vessel is used as a kind of navigation instrument and is made to be simply operated and understood about the condition of the surrounding sea at a glance by navigation officers of even without knowledge of the radio equipment. That is, as given by Fig. 1-62, the Braun tube is employed as the indicating instrument, and is PPI system to indicate the pictures reflection, centering its own vessel like a map. The radar for the vessel usually uses the pulse wave and indicates on the Braun tube the distance converted from the time of the transmitted pulse coming back reflected by the target. As shown by Fig. 1-63, the same antenna is employed for the pulse transmission and the reception of the reflected pulse and by switching the transmitter and the receiver electronically the antenna is always connected to the receiver except when the pulse radio wave is being transmitted.

As the radio wave must be emitted around the ship, the antenna is revolved continuously in the same direction and on the horizontal surface. From the necessity of indicating the right position by matching the direction of the antenna at every instant with the distance to the target in that direction, the revolving synchronous device sending directional data of coinciding always the direction of the sweep line, as given by Fig. 1-62, with the direction of the antenna is employed between the antenna and the indicator.

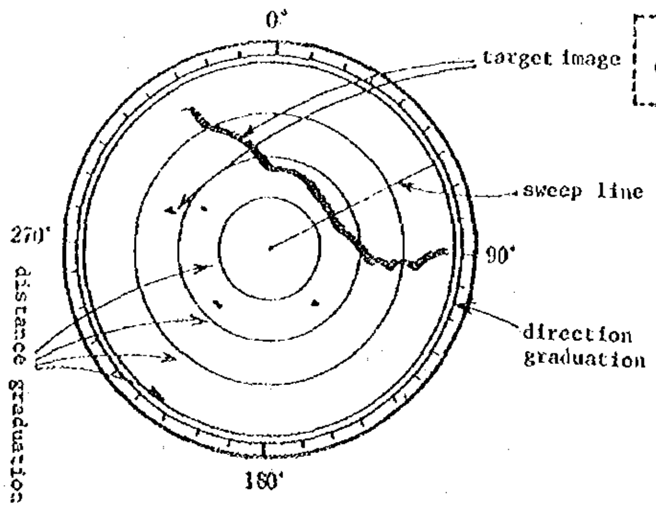


Fig. 1-62 PPI display

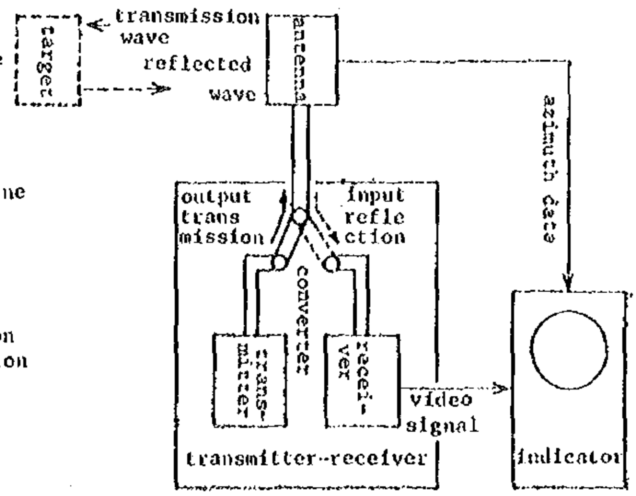


Fig. 1-63 Fundamental construction of a primary radar

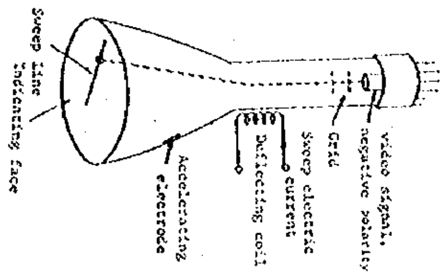


Fig. 1-64 Explanation of Braun tube

Now, the method how the time of the transmitted radio wave coming back by reflection, is converted to the distance and indicated on the Braun tube is considered here. When the saw-tooth shaped electric current like Fig. 1-65 (b) is applied to the deflecting coil of the Braun tube of Fig. 1-64, the electron beam sweep line is indicated as one line from the center of the Braun tube to the circumference, as given by Fig. 1-65 (a). When as given by Fig. 1-65 (c), the reflected pulse received after some time delay from the transmission is applied as negative polarity to the cathode of the Braun tube after amplifying as the picture signal, the bright point is obtained at the position of S_1 - S_3 according with the sweep time t_1 - t_3 of the saw-tooth shaped wave applied to the deflecting coil. On the other hand the time needed until the time that the transmitted pulse coming back by reflection on hitting the target is 12,4 μ sec for the target located one nautical mile far in view of the speed of the radio wave being definite at about 300,000 km every second and as the reflection pulse of the target at the arbitrary distance is received belatedly by this ratio, it can be indicated on the Braun tube as expanded or shortened as Fig. 1-65 (a) (b), by adjusting the sweep time of the saw-tooth shaped wave. Consequently, with the practical radar for the vessel the cycle of the sweep electric current is provided to be switched by the delayed time of the reflected pulse, i.e., the distance to the target. The switching is of about 4 - 6 kinds, i.e., as the measuring distance by radar is only about max. 40 nautical miles in view of the propagation characteristics of the radar radio wave, the delay time of the reflected pulse of this time is 12.4 × 40 μs. Consequently, the cycles of the sweep electric current of changing ranges at e.g., 40 nautical miles, 20 nautical miles, 8 nautical miles, 4 nautical miles and 1 nautical mile are respectively 496 μs, 248 μs, 99.2 μs, 49.6 μs and 12.4 μs.

Further, by revolving mechanically the deflecting coil or by letting the sweep electric current run to the deflecting coil with revolving electrically the sweep direction of beam, the sweep line moves radially from the center

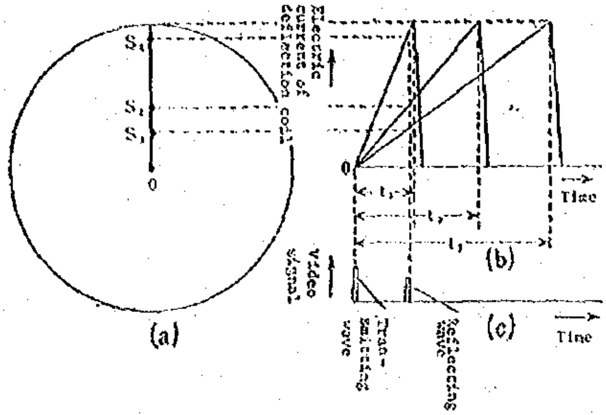


Fig. 1-65 Indication of reflecting·pulse

of the Braun tube continuously and when it is synchronized with the antenna, the targets in the surroundings can be all shown on the Braun tube.

(2) Composition of the instrument.

The radar for the vessel consists of three principal parts, as given by Fig. 1-66 (a).

[1] Antenna (Scanner)

[2] Transmitting and receiving unit

[3] Indicator.

Further, the electric engine generator (or transistor inverter) is added according to the kind of the electric sourse of the vessel.

In the case of the samll-sized radar the transmitter and receiver are incorporated separately with the scanner and the indicator. As shown by Fig. 1-66 (b) there are many units that consist of two units of the scanner and the indicator.

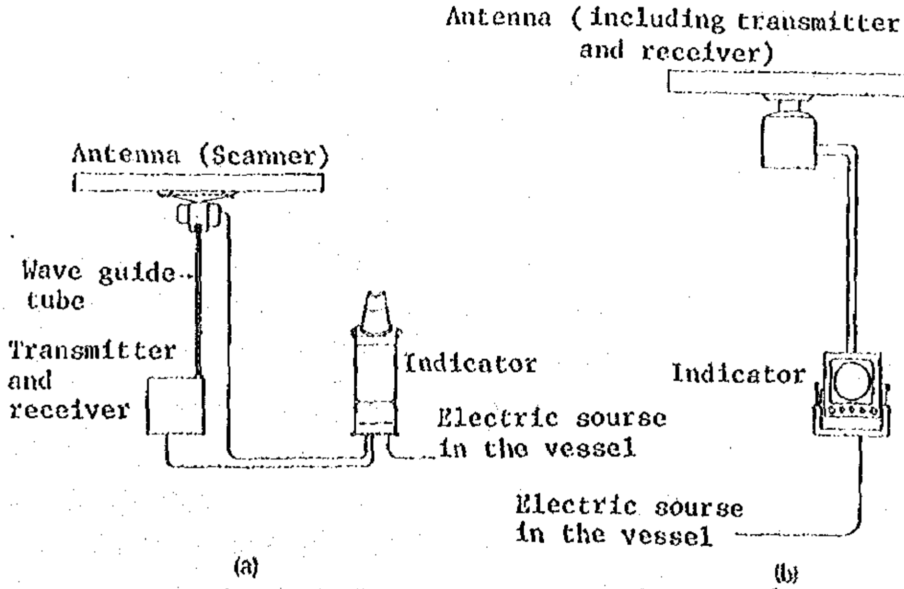


Fig. 1-66 Composition of radar for vessel

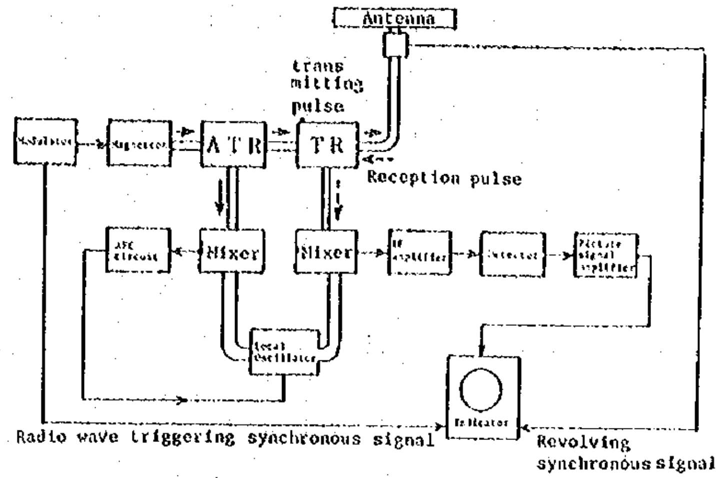


Fig. 1-67 Circuit composition of radar for vessel

The simpler and typical circuit composition of radar for the vessel is as Fig. 1-67.

a. Antenna (Scanner) Most of the conventional one is the type of the common use for transmission and reception, called the electromagnetic hone attached with the revolving parabolic reflecting mirror, but the radar revolving-type slot antenna of small type and light weight is recently used in many cases. There is also that of small-type, separating transmission and reception with heaping the slot antenna of revolving type by two steps, thus omitting the switching circuit of transmission and reception. As the revolving synchronous mechanism, large-size radar employs the selsyn and adopt servomechanism in many cases. Small radars use the resolver systems.

The former transmits the directional signal of the scanner to the indicator by use of the synchro-transmitter of the scanner and by use of the synchro-receiver of the indicator and the latter transmits the direction signal of the scanner electrically as the change of magnetic field of the deflecting coil.

b. Transmitter and Receiver The magnetron for use recently is the same kind with almost all the makers. There are in many cases 2J55 for the large-sized radar, 2J42 for the medium sized rada and 9M10 for the small-sized radar. Among the TR tube and ATR tube there are the small-sized radars that omit the ATR tubes and AFC (Automatic Frequency Control) circuit is also in many cases omitted, as the stability of the magnetron and the klystron have become favorable.

c. Indicator The braun tube of afterglow nature is employed and besides the relative bearing measurement plate, ship heading marker and direction carsor, the STC for curbing sea surface reflection, FTC for curbing reflection, FTC for curbing reflection of rain and snow are used with almost all the radars. There are many cases of large-sized radars which have such accessories as the true direction equipment connected with the gyro compass, off-center device and magnifying equipment of the central part and there are some attached with the plotter device to check the picture of the Braun tube.

(3) Performance

The performance of the radar for the vessel is generally expressed by the following elements:

[1] Max. detecting distance. This is the max. distance to be able to be detected by radar and is decided by transmitting power, antenna gain, min. receivable power of the receiver.

[2] Min. detecting distance. This is the min. detecting distance to be able to be detected by radar. It is decided by the pulse width and the recovery time of the TR tube.

[3] Distance resolution. This is the faculty of separatly indicating two targets in the same direction and is expressed by the least distance between the two targets to be recognized seperately. This is almost decided by the pulse width.

[4] Directional resolution. This is the faculty of separately indicating two targets at the same distance and is expressed by the angle that the targets form. This is decided by the horizontal directivity characteristics of the antenna.

[5] Distance accuracy. This is the faculty of indicating how well the measured distance matches the actual distance and is decided by the design of the distance graduation generating circuit.

[6] Directional accuracy. This is the faculty of indicating how well the measured direction matches the actual direction and is decided by the revolving mechanism of the antenna and the revolving synchronous mechanism.

The general standards and performances of radar for the vessel sold currently on the market are as per Table 1-5.

Table 1-5 Standards and performances of radar for vessel

	Large-seized radar	Medium-sized radar	Small-sized radar
Antenna power	40 - 50 kW	20 - 30 kW	3 - 10 kW
Antenna size	6 - 8 ft	4 - 6 ft	4 ft
Pulse width	Two stepped switching of 0.1 - 0.5 μs	Ditto to the left	0.1-0.5 μs
Pulse recurrence frequency	Two stepped switching of 2,000 Hz - 500 Hz	Ditto to the left	2,000 - 1,000 Hz
Beam width (horizontal)	1 - 1.5°	1.5 - 2°	2° or so
Beam width (vertical)	15 - 20°	15 - 20°	15 - 20°
Max. detecting distance	40 - 50 nautical miles	30 - 40 nautical miles	20 nautical miles or so
Min. detecting distance	20 - 30 m	20-30 m	20 - 30 m
Distance resolution	About 20 - 30 m and 70 m	Ditto to the left	40 m
Direction resolution	Within 2°	2° or so	Over 2°

(4) Recent trend of radar

The design of the radar for the vessel has been at present almost completed and the following items are currently proceeded.

[1] Improvement of the circuit system to simplify further the various kinds of circuit.

[2] Decreasing weight and size by introduction of solid states.

[3] Rationalization of combined wiring and simplification of maintenance by adoption of the printed wiring.

[4] Transferring to the slot type for height decrease of the scanner and improvement of the performance of the antenna.

With a view to spread the radars to the vessels of smaller-size cost reduction and development of the supermini-type radar are being proceeded. In the case of the large vessel on the contrary the design for equipping two sets at the same time has been made so as to decrease troubles, caused by disorders in navigating in the ocean.

2. Air-borne Weather Radar

The most important problem in the civil aviation is to enable the passengers always to enjoy the flight safely and comfortably and at the same time to carry on the economical flight. Consequently, in the case of flight over the area where there is an area with such regional unfavorable conditions as bad weather and particularly thunderous cloud, if such things can be known prior to the arrival there, passengers can make safe flight without as less discomfort as possible by flight avoiding the unfavorable area and by earlier decision of the air-route on the basis of the previous knowledge of the far distant condition, the shortening in time and saving of fuel can be attained and economy can be improved. In this sense the airboune weather radar is the most effective means to know in advance the thunderous cloud, dense cloud, etc. and has become indispensable to the modern aircrafts. Particularly even in the night or cloud and fog the forward conditions can be grasped for certain. By the radar picture the extremely instinctive information can be gotten as compared with that obtained by the other instruments, so it can be used for observation of the forward topography and also help prevent collision.

As the radar for aircraft is used to know the weather, topographical condition of the forward route of the flight, the radar antenna must be placed at the place of good visual command as the seat of the pilot. Since radar control and observation are made by the pilot, the radar antenna is attached in radome of the nose of the plane and the picture indicator and the control device are attached by the seat of the pilot.

The radio frequency of the radar for weather must be appropriate to detect weather conditions according to the object and to give the excellent resolution to the topographical observation. The currently employed frequency is roughly divided to two kinds. One is of 5,400 MHz, 75 kW and another kind is of 9,375 MHz and about 40 kW. The attenuation quantity of radio wave by rain and the propagation loss in the air is less with 5,400 MHz than with 9,375 MHz. From the stand point of long range detection 5,400 MHz is more excellent than the latter. When to observe through the rainy area the stronger or denser cloud in the forward route, the aircraft with 5,400 MHz is more suitable in consideration of the time of getting to that location. On the other hand in the case that there is no raining area in the near side and there is the rainy area in the forward route or in the case of observation desired until little rain the radar with 9,375 KHz displays a satisfactory performance. Further, when the antennas of the same size are employed, as the beam width is in proportion to the wavelength, 9,375 KHz has higher resolution, having the advantage of finding out the crevice of rain zone and dense cloud. From these points it can be said that 9,375 KHz is suitable for the low-speed plane.

1-7 Coastal Navigation Aids

1. Course Beacon

Course beacons or microwave beacons used as guiding signals in habor areas as well as narrow waterways are intended for the guidance of small ships instead of large ones as in the case with Ramark to be described later. The signal sent out from a transmitting station via two different radio waves is received by a microwave beacon receiver; as a result, any ships will be able to reach their destinations if they plot the course along a line where the beacon is heard as a continuous tone. In Japan course beacon systems were set up at Fushiki and Shinminato (Toyama Pref.) for the first time in 1960, and the number of them was increased to 6 in 1970 for augmenting the intended effect. However, it was due to the decreased number of ships utilizing the beacons that 2 stations were put to disuse; thus 4 stations are operated now.

The beacons are very effective as a means of pointing out the line for ships to make port on if they are used in harbors where their characteristics are suitable for serving the purpose; and more efficient if they are used in combination with talking beacons.

(1) Prinicíple

When directional pulse modulated waves are emitted from two adjoining directional antennas as shown in Fig. 1-68 (a) in such a manner that a code signal A and a code signal N will be sent out by turns, these signals are heard as a continuous tone if they are received in the direction of 0° (it has

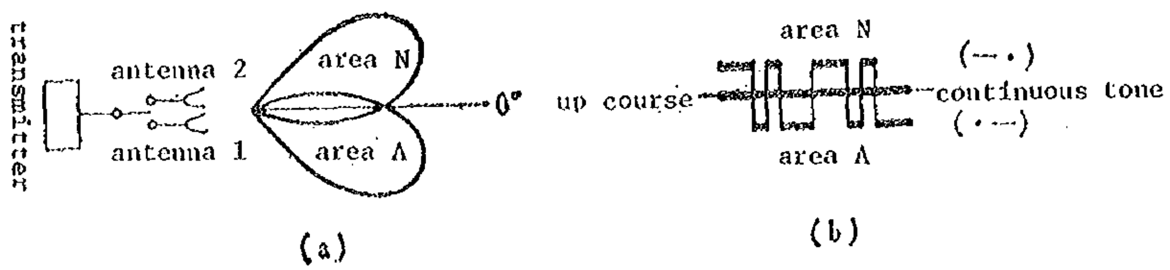


Fig. 1-68 Principle of course beacon

been set up in common with the course direction) because electric fields produced by these waves are equal, and it becomes known that the navigation is on the route. (Fig. 1-68 (b)) Moreover, it can be seen that the ship is either in the area A or N depending on the code signal that can be heard, nemely, A or N.

(2) Equipment

Ratings of the transmitter.

Transmitting frequency:	9,310 MHz
Output:	P1 7 kW (Pp)
Pulse width	1 μ sec.
Pulse repeat rate	1,000 p.p.s.
Antenna	Electromagnetic horn
Directivity on horizontal plane	About 60° or 15°
Directivity on vertical plane	About 4°
Course width	1° or less
Transmitting signal	One of A-N, D-U or B-V

2. Harbor Radar

The first harbor radar system was set up at the port of Le Harvre in France in 1948. In Japan harbor radar stations installed at Kushiro Port in November, 1961 and at Osaka Port in April, 1964. One of the features of Japanese systems is the use of highly efficient radar beams with a millimeter frequency band (14 GHz band is used recently) as the primary main radar and with the frequency band of 5,000 MHz as the secondary one on the other hand the frequency bands of 9,000 MHz and 3,000 MHz at radar stations in Europe. The reason for this is that it has been aimed to detect accurately the whereabouts of ships in harbors by the use of the equipments of high resolution power.

Harbor radar systems, which are set up ashore in harbor areas to assist ships to keep navigating, help those ships continue sailing safely without reducing operation efficiency when visibility is poor because of fog and rain by giving to them necessary information on navigation through VHF, medium or short wave radiotelephone after making out the situations of harbors and waterways precisely with highly efficient largesized radars. The radar systems have been installed at Kushiro and Osaka Ports that are frequented by fogs and they have fully been playing an importand role during foggy days which occur more than 80 times a year. Furthermore, a radar chain made up of 3 harbor radar stations (at Honmoku, Kannonzaki and Urayasu) is in operation, which is called Tokyo Bay Traffic Advisory Service System, to secure safety and efficient shipping service in the Tokyo Bay where there is particularly much traffic.

An advantage of the harbor radar system is its complete true motion indication system. In other words, radar system in ships can detect only the relative motion of other ships because the radar itself is moving, and cannot judge other speeds and travelling courses quickly. Furthermore, the shipboard radar cannot detect the existence of ships hidden behing the bend of a narrow waterway. On the other hand, the harbor radar system can detect each movement of ships on the basis of date obtained from their reports of entry into and departure from the port; in addition, all other data such as ship's names. It can also exercise surveillance over ships at anchor as well as berths without interruption. Therefore, it can provide those ships with information necessary for navigation much more timely than the case with shipboard radar systems because it is completely familiar with the positions of known buoys, breakwaters, and those of reefs as well as sunken ships.

Giving Osaka Harbor Radar Station as an example, the capacity of the radar system in use is as follows:

	Radar with millimeter wave	Radar with centimeter wave
Working frequency	32.6 GHz	5,589 MHz
Transmitting power	30 kW	40 kW
Pulse width	0.02 μs/0.04 μs	0.05 μs/0.2 μs
Repetitive frequency	5,400 p.p.s.	2,700 p.p.s.
Measuring distance	2 m ~ 10 km	50 m ~ 40 km
Horizontal beam width	About 0.2 degree	About 0.5 degree
Indicator	16 inches	16 inches

Although the frequency bands of 24 GHz and 32 GHz are used at first at Kushiro Station and at Osaka Station respectively now as a highly resoluble primary radar, another with the frequency band of 14 GHz, with which high efficiency can be expected even with centimeter waves, is set up at Honmoku Station and Kushiro Station. The reason is that it is particularly important to operate harbor radar stations when the precipitation of rain and snow is heavier, but the radar system may not demonstrate its capacity enough as occasion demands because millimeter waves that have short wavelengths are attenuated by fast degrees. The capacity of radar with a centimeter frequency band is as follows:

	Radar with the frequency band of 14 GHz
Working frequency	14.15 GHz
Transmitting power	40 kW
Pulse width	0.1 μs
Repetition frequency	2,998 p.p.s.

Measuring distance	50 m - 20 km
Horizonatl beam width	0.25°
diametter of the Indicator	16 inches

Other than the capacity above, harbor radar systems are equipped with electronic cursors as those which are different from shipboard systems in general. The radar system with a cursor is used to measure electronically the position of a ship asking for information on the display surface of the indicator (PPI) and the distance from a specified point can be measured by linking the point (e.g., a lighthouse near the entrance of a breakwater) and the ship with a bright line. Stopping the normal sweep about 30 times per second, another sweep for the cursor is carried out, using separate deflecting circuits. As to the revolution of the electronic cursor, the same principle as the resolver is used, and the measurement of distance is based on the principle of variable range marker. In addition to this, transponders may be used to make it less difficult to identify the specified ship by means of the harbor radar system in a habor where a number of ships are observed.

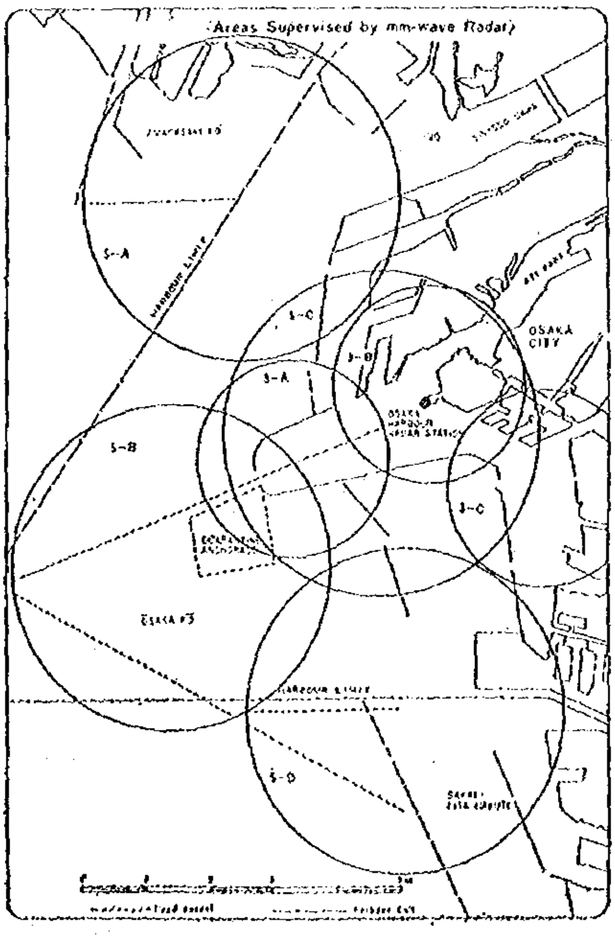


Fig. 1-69 Monitoring areas of the harbor radar system in Osaka.

3. Ramark

Ramarks, which differ in features from microwave beacons mentioned above, are intended for the guidance of ships equipped with radar systems. Radio waves with the same frequency as that of shipboard radar are emitted from Ramark stations so as to give overlapping images onto the shipboard radar PPI (Plan Position Indicator) with the configuration of the circumstances. It is therefore an advantage on the part of the shipboard radar system that a beacon can be utilized without adding another sort of equipment. Ramarks are suitable for use in the following cases, and able to play a similar role to that of a lighthouse when visibility is poor, so that the azimuth can directly be detected.

(a) In the case of open sea navigation, beacons confirming the azimuth at the distance that the radar system cannot detect the land configuration.

(b) In the case of the coast line built up by a wide flat low land, beacons confirming the place where the radar system cannot clearly detect the land configuration.

(c) Despite the fact that the radar system can detect the land configuration, beacons confirming the spot where the coast line is too vague and indistinguishable because it is congested with capes, islands and mountains.

(d) Beacons guiding in such places as harbors and narrow waterways.

In Japan ramark systems were set up at Kannonzaki (Tokyo Bay) for the first time in 1960, then at Inubozaki, Shionomisaki, etc.; now totalling up to 6 stations. It covers an area within 20-30 nautical miles and is operated without interruption.

(1) Principle

The frequency band used for shipboard radar in use is nearly almost 9,000MHz, and 9,375 MHz as a center frequency. If pulse waves are emitted from a revolving antenna while wobbling the frequency within the range of 9,375 ± 40 MHz so that radar pulse with the frequency band of 9,000 MHz may all be received, a bright line (azimuth marker) will be obtained on the PPI from the center to periphery upon receipt of them through the antenna. In order to wobble the transmitting frequency, saw tooth voltage is added to the repeller of a klystron. The wobbling frequency is determined according to the horizontal beam width of radar, the number of the revolution of the antenna, the band width of a intermideate frequency amplifier, and the number of pulse repetitions. The frequency is about 50Hz in this case. The reason why the pulse is modulated is to increase the receiving efficiency of radar and give the code of a station (chain lines or dotted lines). The bright line of Ramark appears on the PPI only when the antennas of ramark and radar system face each other and when the wobbling frequency corresponds with the receiving frequency of the radar. If the bright line appears continually on the PPI, the line and blips of other ships overlapping one another may endanger navigation itself. In view of this, it is so determined that reception should be made once every 30 seconds at the speed of ships, and that the speed of revolution and the horizontal directivity of the antenna of a Ramark system are fixed upon consideration of shipboard radar sources.

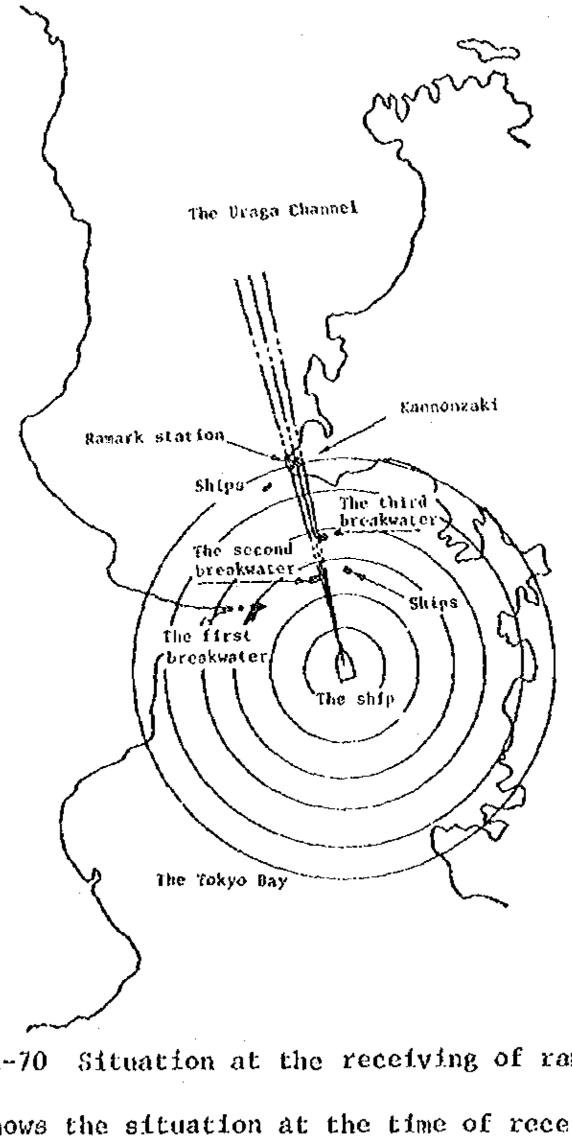


Fig. 1-70 Situation at the receiving of ramark

Fig. 1-70 shows the situation at the time of receiving Ramark. From the bright line of Ramark and the blips indicating the land, not only the azimuth but also the position of a station have become known. Two to three streaks of bright lines appear in Fig. 1-70, but the number of the lines differs according to the directivity, the speed of revolution of both the antennas of ramark and radar system and wobbling frequency.

(2) Equipment

Ratings of the transmitter:

Transmitting frequency:	9,375 ± 40 MHz
Output:	P9 0.6W (Pp) (At 9,375 MHz)
Pulse width:	2μ sec.
Pulse repetition rate:	250 kHz
Wobbling frequency:	50Hz or 60Hz
Antenna:	Pillbox type
Directivity on horizontal plane:	About 55 degrees
Directivity on vertical plane:	About 2 degrees
Number of revolution:	About 2 r.p.m.
Plane of polarization:	Horizontal

The directivity on vertical plane is acute, to reduce the interference caused by the masking effect on radar when ships are approaching the station.

4. Obstruction Indicating Transponder

Since it is difficult to find out which one is a true target blip on a shipborard radar screen, the purpose of this system is to give to the ships using radar systems with the frequency band of 9,000 MHz widely used now information about the locations of specific targets, e.g., lighthouses, light beacons and buoys accurately on the radar screens with the use of marks such as dashed lines from them as shown in Fig. 1-71. This is also a secondary radar that, upon receipt of radio waves from shipboard radar systems, is sending back the radio waves with 9,375 MHz ± 40 MHz to the radar systems in ships.

What makes a difference between the transponder and the ramark system is that the latter keeps emitting radio waves at all times and indicating the azimuthal line, while transponder sends out 6 pulses of 5μs only when it has received the radar pulse from a ship, indicating the position of the transponder station. It also features that the range of utilization is limited to about 6 nautical miles, so that it will be used as a beacon for confirming specified spot along the coast or in an inland sea, such as sunken rocks and light buoys; and that antenna power required is as small as 20 ~ 30 mW.

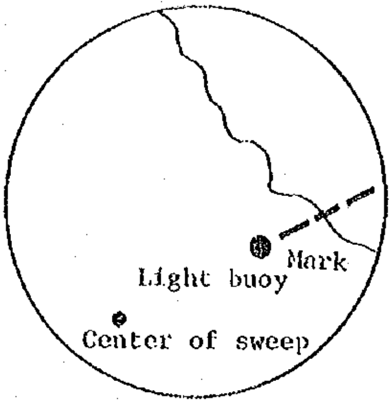


Fig. 1-71 Radar blips by transponder

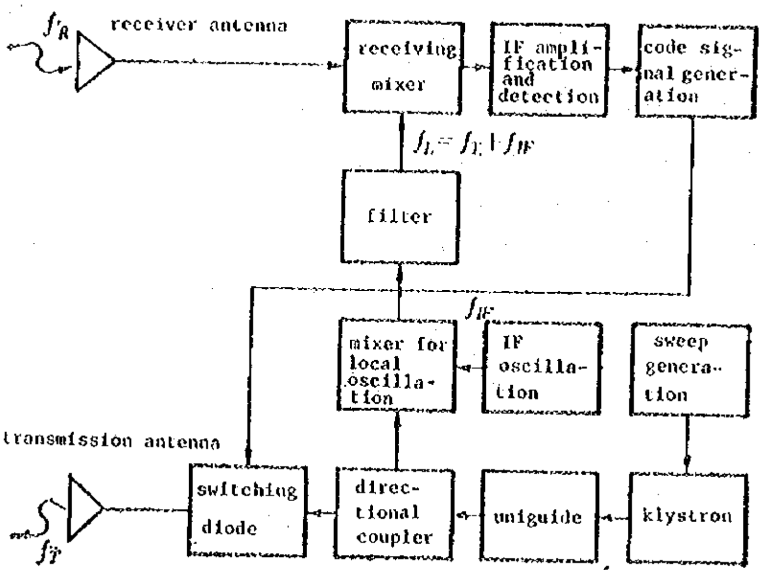


Fig. 1-72 Construction of transponder

In Japan, transponder stations were installed and operated recently in Tokyo Light Buoy in the Tokyo Bay and at Merabana on the Boso Peninsula in Chiba Pref.

Principle : After receiving pulse signal of about 9,000 MHz from a shipboard radar system by the use of a receiving antenna and mixing them with local oscillating output so as to obtain IF (Intermediate Frequency) signal, the transponder produces 6 pulses having specific width by driving the code signal generator with the IF signal as a trigger. On the other hand, it produces saw tooth waves for wobbling the oscillating frequency of a klystron in sweep generating circuits, carries out the oscillation with 9,375 ± 40MHz and sends the output to switching circuits through a uniguide. To the switching circuits said code signal pulse has been added, so the output from the klystron is pulse-modulated before being transfered to an antenna for transmission and sent out. Furthermore, the output from the klystron is partly split by a directional coupler and added to the mixer, then mixed with the output of the oscillator of intermediate frequency in the receiver to produce an local oscillation signal. The construction of a transponder is shown in Fig. 1-72.

1-8 Navigational Aids at the Airport

1. ILS (Instrument Landing System)

ILS or Instrument Landing System is an international standard system named by the International Civil Aviation Organization (ICAO) as one of the aids for the landing of aircraft. In other words, it is a radio navigation system for the guidance of aircraft; giving a guide to them in horizontal and vertical directions immediately before or during their descending; and sending information about the distance to the standard point for landing to the aircraft. The ILS, which is different from GCA where aircrafts are guided to landing according to the instructions given by radio from the ground station by use of blips on the ground radar screen (SRE and PAR), is a system in which pilots themselves receive directional radio waves indicating a landing course from the ILS transmitter on the ground by the use of the ILS receiver installed in the aircraft, and have an indicator called a "cross-pointer" displaying the output of the receiver, then make landing by adjusting the deflection of flight course. Therefore, the system is very valuable when visibility is poor, and so being installed at main airports.

The ILS set up on the ground consists of the following 3 units of equipments:

1) VHF localizer and its monitor.
2) UHF glide path and its monitor.
3) VHF marker beacon and its monitor.

Other than the aforementioned, an LF/MF locater beacon is used as a supplement to the ILS when coming in for landing.

On the part of aircraft utilizing this system, it is required to be equipped with a receiver and an indicator corresponding to three types of transmitters. The localizer is the equipment giving instructions regarding a horinzontal direction towards the landing strip while the glide path is the one instructing a landing route on a vertical plane towards the landing strip.

The marker beacon is the beacon giving instructions as to the distance to the landing point to the landing strip; and consists of outer, middle and inner (often omitted) markers.

(1) Outline of equipment

The general specifications of those transmitters above have been tabulated in Table 1-6 below, and the arrangement of them is shown in Fig. 1-73.

Table 1-6 Outline of ILS transmitters

Classification		Radio frequency (MHz)	Antenna power (W)	Modulation and others
Localizer		108 - 112 (Horizontally polarized wave)	200	90Hz, 150Hz, Identfying code, sound signal
Glide path		328.6 - 335.4 (Same as above)	10 - 20	90Hz, 150Hz
Markers	Inner marker	75 (Same as above)	2 - 5	3,000Hz, dots (6 dots/sec.)
	Middle marker	75 (Same as above)	2 - 5	1,300Hz, dots, dashes, (6 dots/sec. 2 dashes/sec.)
	Outer marker	75 (Same as above)	2 - 5	400Hz, dashes (2 dashes/sec.)

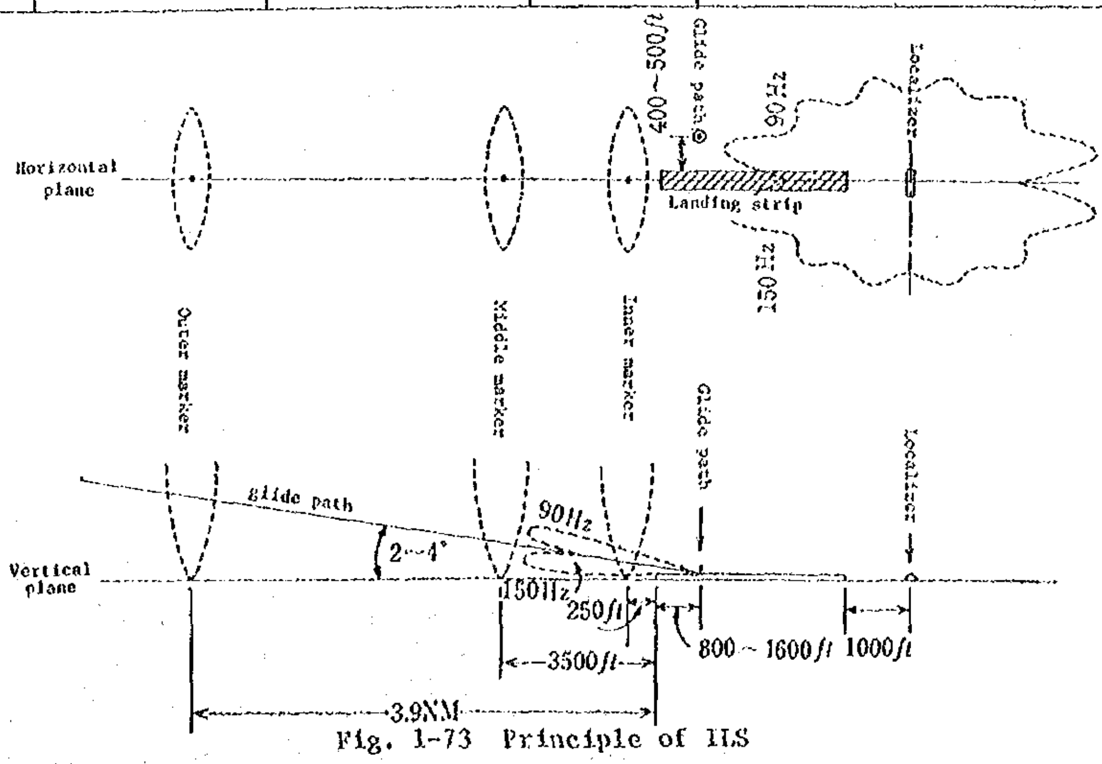


Fig. 1-73 Principle of ILS

Localizer : The localizer transmitter consists of a unit which transmits VHF carrier components modulated with 90Hz and 150Hz of an AC generator by carrier antenna; and another which transmits extracted side band components by side band antenna. As to the antenna system, 8 loops are arranged in a row at a right angle to the course, and they are divided into two, namely, a pair of carrier antennas in the center and 3 pairs of side band antennas located at the outside. The feeding power and the space of each pair of antennas are adjusted according to a specified ratio, in order that, when looking at the antennas from the coming-in side of the runway, total electric field pattern becomes as shown in Fig. 1-73; in other words, the electric field with modulated components of 150Hz is stronger on the right and the one with 90Hz is stronger on the left, but the strength of both components is equal on the central line. To make such radiation pattern, the phases of side band components of either 90Hz or 150Hz from the side band antennas is adjusted to become antiphase of carrier components of 90Hz and 150Hz from the carrier antennas. If this is considered by the indicator of the localizer receiver, the deflection of a vertical needle is in proportion to the difference in depth of modulation (DDM) between two waves.

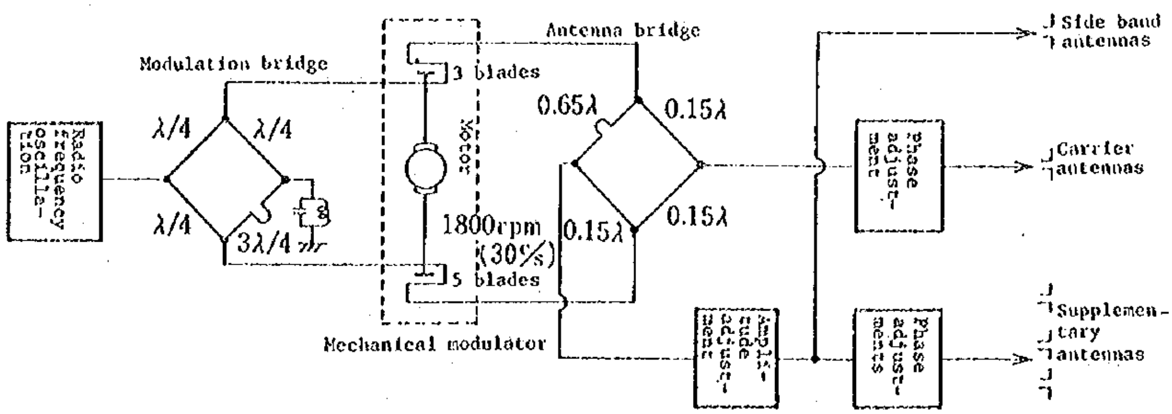


Fig. 1-74 System chart of glide path

Glide Path : The glide path transmitter mechanically modulates the output of the UHF oscillator with 90Hz and 150Hz utilising resonant and non-resonant circuits as shown in Fig. 1-74, and separates it into carrier components and side band components with bridge circuits, and feeds them to each antenna. In addition to this, the transmitter supplies to the supplementary antennas a part of side band components with specified phase and amplitude modification to make the glide path straight. The antenna system is composed of 3 pairs of transformed dipole antennas and attached to a pole about 10 meters in height, and a pair for carrier waves is put in the center, another for side band is put on top and another for supplementary is put about one tenth lower than that for carrier (This is called Null Reference type). The glide path is thus set up with these antennas system, and directional pattern is composed in such a manner that the modulated components with 150Hz is stronger under the glide path, and the components with 90Hz is stronger above the glide path. By use of the indicator of the glide path receiver, a vertical needle is displaced up or down according to the difference in depth of modulation (DDM) between two waves.

Marker beacon, locater beacon: The marker used in ILS transmits VHF directional radio waves of a fan beam, and makes the spot recognized by aircraft passing over it. Transmitting antennas are composed of two half-wavelength dipoles which are set at the height of a quarter wavelength above the counter-poise. The marker receiver in aircraft distingushes the beacon by audible tones and the colors of display lamps (inner, middle and outer markers are white, orange and purple, respectively).

The locater beacon is also called a compass locater, which is a low or medium frequency NDB to lead to the outer marker.

(2) Future prospects and new equipment

The usual ILS above belongs to the category I, but there are ILS's be-longing to the categories II and III internationaly recognized. Their classif-ication is as follows:

Category I: This is an ILS which gives instructional information up to a point where the localizer course crosses the glide path over the horizontal plane of height of 60m (200ft), that includes the ILS basic point (a point selected 500-1,000ft from the comingin side of the runway). According to this category, the minimum weather conditions can be reduced to 200ft in the height of clouds and 1/4 mile in visibility.

Category II: The difference from the provisions above is that the height of the horizontal plane has been changed from 60m (200ft) to 15m (50ft). The minimum weather conditions are 100ft in altitude and 1/4 mile in visibility.

Catergory III: This is an ILS giving instructional information from the coverage limit point of the ILS onto the runway with aids of supplementary units, if required. In other words, it is for use in all-weather flying, but is still in the stage of development with auto-pilot.

On the part of transmitters considering the difference of require-ments between categories I and II, category II is more rigidly defined than category I regarding (1) DDM error by the vertical polarized wave components (localizer only) of horizontal polarized waves; (2) DDM error due to the deflection of the course line; (3) frequency tolerance of modulation tone of 90Hz and 150Hz; and (4) the shift of the course line (localizer only).

Now, let us briefly describe the new directional localizer. This system has been included in the international standard because the ordinary localizer has broad directivity and consequently reflected waves from terminal buildings or hangars interfere the course, thus produce disturbances such as warp and undulation. The localizer in this system which has been set up recently on an extension line of the runway C at the Tokyo International Airport is provided with antennas of wave-guide type with a sharp directional array about 50ft ahead of the conventional clearance array, and transmitting carrier frequency higher by 8kHz than that of clearance type (taking frequencies for both cases at ± 4kHz above and below the nominal channel frequency). Since the radiated electric field of the wave guide system is stronger within a narrow sector including the front course as shown in Fig. 1-75, only its signal is detected. The back course and omnidirectional clearance characteristics is maintained in normal values by the radiated electric field by the clearance system. This wave guide is set up in such a way that 18 vertical half wavelength slots are placed to face the runway at regular intervals of 1/2 wavelength.

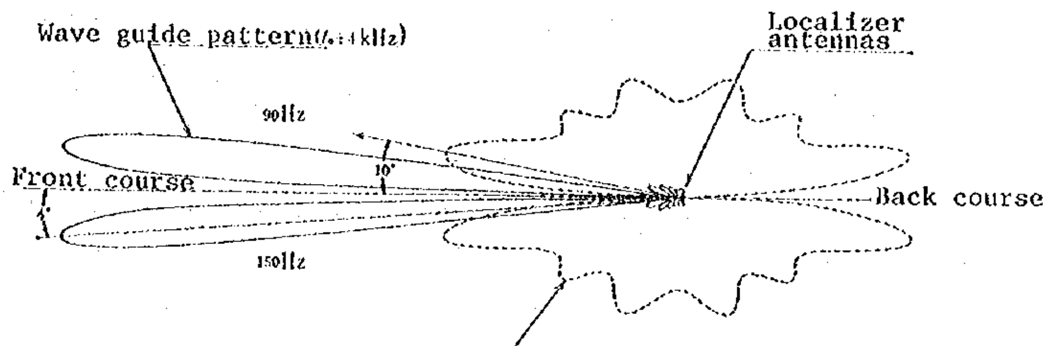


Fig. 1-75 Directional localizer

2. GCA, ASR (SRE), PAR, RAPCON

GCA (Ground Controlled Approach) is a landing aid for the guidance of aircraft to the specified runway safely and accurately even in a moonless night without being influenced by poor visibility with the use of radar system set up on the ground. The GCA VHF or UHF radio telephone to be used for communication between aircraft and the ground and two sets of radar systems, namely, search radar system or surveillance radar element (SRE) and precision approach radar system (PAR). This equipment is normally mounted on a trailer and as a moving unit or stationary one, which depends on the conditions of installation at an airport.

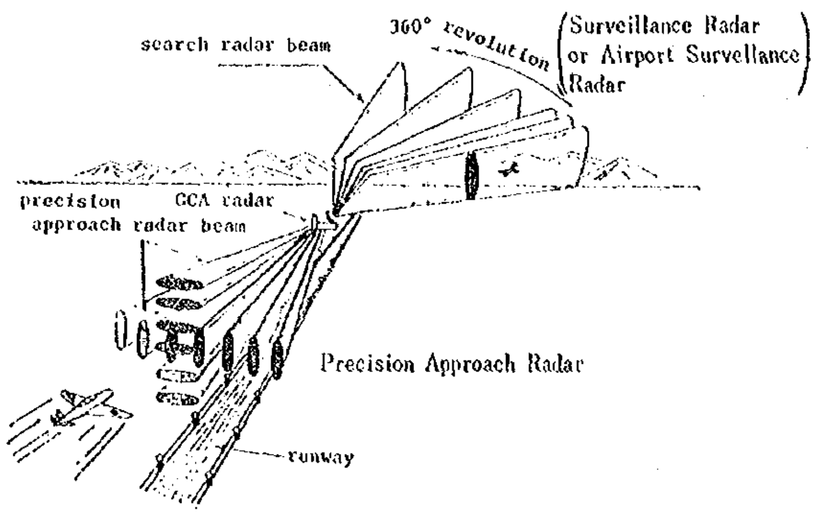


Fig. 1-76 Principle of GCA

There are two steps for guiding aircraft to landing by the use of GCA. In the first stage, the search radar system watches aircraft flying in the vicinity of the airport under the Air Traffic Control (ATC), with VHF or UHF radio telephone so that they will not collide with each other, and instructs them to take up a landing position one after another. In the second stage, the aircraft that has taken the landing position is instructed to follow a right course, that is, on the approach line to the runway in the horizontal plane and on the glide path in the vertical plane; and guided to the position below clouds where the pilot can recognize the runway.

For the guidance in the second stage, the precision approach radar system, a radar system scanning the horizontal plane with fan beams that have sharp horizontal directivity; and the other scanning the vertical plane with fan beams that have sharp vertical directivity, are used, for it is required to know how much the aircraft is deflected to the left or right from the approach line, or upward or downward from the glide path.

In the case of landing guidance according to the GCA method, no equipment for instrumental landing is necessary on the part of aircraft. Moreover, it reduces by far the technical burdens of pilots caused by unfavorable conditions at the time of landing, and it also becomes possible to control quickly and precisely the increased number of aircraft within a control area.

The search radar system of the GCA above is aimed at monitoring and guiding aircraft within the radius of 30-50 km centering the airport to the effective range of the precision approach radar (roughly 20 km in the direction of the runway), and it is also called an Airport Surveillance Radar (ASR). Normally, aircraft is guided from an airport to another by the LORAN, VHF Omni-directinal Range Distance Measuring Equipment (VOR-DME), Non-Directional Beacon (NDB) and so forth; and then go into the effective range of the ASR; then communicate with the control tower without interruption.

The ASR is equipped with a plane position indicator (PPI) by which the position of aircraft (azimuth and distance) is under surveillance at all times; therefore air traffic controllers are to instruct the aircraft to take a landing position, using radar systems and VHF radio telephone for communication, but also inform them about a variety of requirements for landing in order to lead them safely to the guiding range of the PAR.

This indicator has been so constructed that one can clearly recognize the aircraft to be guided, even when many aircraft are flying simultaneously in the neighborhood of the airport, by obtaining identifying signals from a Direction Finder (VHF/DF) which utilized transmitting waves of VHF telephone from aircraft. Furthermore, there is a Moving Target Indicator (MTI) which indicates only moving targets such as aircraft. As to the gain adjustment of receiver, TAGC, Sensitivity Time Control (STC), Fast Time Constant Circuit (FTC), etc. are carried out for the purpose of supressing noise caused by thunder, clouds, fog and the like. The ASR in Japan uses approximately 2,800MHz and 600kW.

Aircraft monitored and guided by the ASR to take a landing position are given instructions through the PAR (Precision Approach Radar) how to come in for landing. In the PAR, scanning in a horizontal direction with fan beams having narrow horizontal directivity is electrically switched over to the one scanning in a vertical direction with fan beams having narrow vertical directivity one after the other. The PAR also gives instructions to aircraft while monitoring whether it is flying along the designated course or not, by use of echos gotten by horizontal and vertical scanning on the Expanded Position Indication (EPI) in which a scanning angle is expanded as shown in Fig. 1-77.

The PAR used in Japan is about at 9,100MHz in frequency and 35kW in transmitting peak envelope power.

Aircraft flying by instruments, although they are under control during navigation as to a flying route, are to be instructed to go along with the admission control from the landing airport when they have approached the airport within the range of a designated distance. The admission control is carried out for the purpose of guiding aircraft safely in order to landing; e.g., instructing them to keep flying above the specified course while waiting their turn. In the opposite way, aircraft ready to take off are also to receive take-off permission, taking into consideration the space of time left between them. It is called radar admission control that admission controllers control the landing and take-off of aircraft as looking at PPI blips according to the GCA method, and the system used for this is called Radar Approach Control System (RAPCON). Though the RAPCON is not different from the GCA in view of their functions to be fulfilled, radar scanning blips signals are transferred to the PPI in front of controllers in the control tower through cables. As a search radar system, its power for transmission is 2,500-5,000kW, which is rather large. An Air Route Surveillance Radar (ARSR) is seen to be used some time; its effective search range is wide.

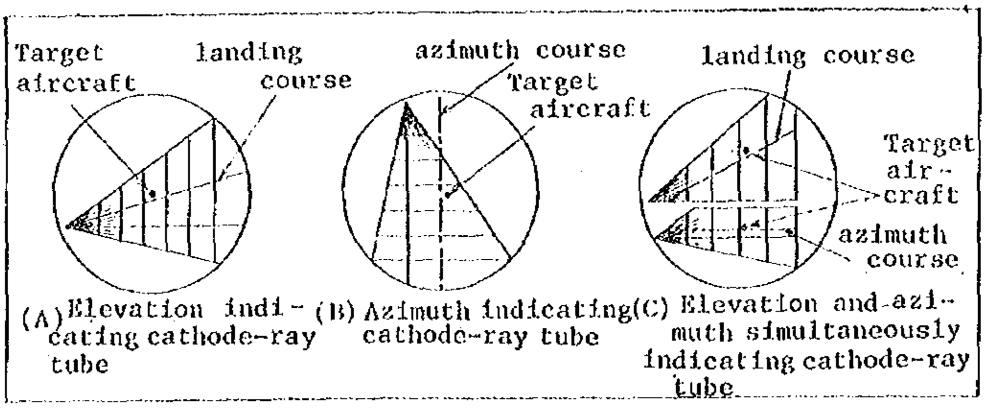


Fig. 1-77 Indication of PAR

3. ARSR (Air Route Surveillance Radar)

With the appearance of jet-propelled aircraft, the speed of airliners has increased to a greater extent, and not a few of them fly at more than the sound speed (Mach). On the other hand, the number of aircraft is increasing year after year. As a result, time intervals between the take-off and landing of aircraft tend to be shortened and proper control over the departure and arrival of them affects safe and effective operation of airports.

Consequently, it is necessary to monitor the movement of aircraft accurately flying on various airline routes at a long distance in a wide range for the purpose of carrying out safe and efficient control, and the surveillance radar is called ARSR.

The ARSR is, in view of its purpose, set up in a high place for excersizing surveillance over a wide area. In case the place where the ARSR is set up is a long way off the control center, normally the scanning images of the ARSR are relayed through microwave circuits to that control center where automatic control and direct surveillance are fullfilled.

The most important thing in this kind of radar is the maxium search distance, and efforts have been made to increase such capacity. As the wavelength for use, microwaves (e.g., 1,300MHz band) of comparatively longer wavelengths are used so as to minimize attenuation due to the absorption by the wave propagation midium and irregular reflections. The effective area of an antenna and directional gain determining the maximum search distance are made as large as its construction permits. Peak envelope power for transmission is about 2,000-5,000kW. If the power for transmission exceeds 5,000kW, the window for supplying power from a transmismission tube to a waveguide will be damaged by heat produced by induction loss, so it is technically difficult to increase power. As a transmission tube, a magnetron or klystron or platinotron is used.

Another way to increase the maximum search distance is to reduce the minimum receivable power. For this object the noise figure and passing band width of a reveiver must be small.

In Japan, the ARSR with 1,340MHz in frequency and 2,000kW in power was set up by the Civil Aviation Bureau, Ministry of Transportation, at Hakone in 1964, and microwave relay circuits with 6,000MHz band were constructed between the station and the Air Traffic Control Center in Higashikurume.

Another equipment was later set up at Sangunsan (Kyushu) and expected to be set up in Choshi and Okinawa.

4. ASDE (Airport Surface Detection Equipment)

A radar system called ASDE is aimed at detecting and searching, when visibility is poor, aircraft and motor vehicles running on guidance passages and the runway so as to secure airport control and make it efficient. The radar system used as ASDE requires not so long effective distance to cover, but on the other hand, excellent resolving power. Targets are moving in the extremely close proximity to each other on the ground, unlike in the air, so it is desirable to distinguish aircraft from vehicles, and recognize the types of aircraft. Therefore, the radar for ASDE requires resolution of about 1-2m. There is not much difference between this radar system and ordinary radar systems equipped with PPI indicators, yet consideration has been taken to obtain high resolution.

The equipment with 24GHz and 35GHz have been developed in the United States and United Kingdom, respectively. 24GHz is used in Japan. Since reflection and the absorption owing to waterdrops become larger because of high frequency, it is so arranged that reflected waves from raindrops are removed by the use of circular polarized waves.

5. SSR, IFF

A Second Surveillance Radar (SSR) has been developed from Identification Friend or Foe (IFF) utilized for the recognition of allied aircraft during the World War II. Specified group of pulses was used to indicate allied aircraft; besides effort was made to keep the IFF secret, but its principle was quite simple. The IFF used during the war was never completed, but it became reliable after the development of advanced methods such as Mark X IFF, meeting economical requirements particularly for commercial use; as a result, it has begun to be used to make air traffic control. In Japan, it has been set up at Haneda Airport, etc. as a ground facility and utilized for the automatization of control.

In the SSR system, a interrogation pulse is sent out from the ground at first to monitor aircraft recognized in the control area, and the aircraft sends back pulse waves with different frequency as a responding pulse on receiving the pulse from the ground. Since the energy of the pulse waves sent back is large as compared with that of reflected waves, a very clear image appears on the radar screen. If a certain code for recognition is given to the responding pulse, it is possible to find out individual aircraft. Therefore, the equipment is effective to expand the available range of radar and can be made into a useful means from the viewpoint of air traffic control in order to minimize the number of aircraft whose position is unknown; or avoide collision with each other, and maintain a precise difference of heights. The automatic transmission of navigational information will be realized in the future with the equipment of more advanced type.

(1) Principle of SSR

Radar pulse energy propagating in space rapidly attenuates. As a result, a group of small bright dots begins to appear on the radar screen when it becomes the same level as that of noises. Radar energy attenuates in proportion to a square of the distance from a target and the reflected wave becomes weak in proportion to the fourth power of the distance from a target. Since the energy of the SSR signal makes only one-way trip from aircraft to the ground, so energy attenuates in proportion to a square only.

The antenna of an interrogator on the ground is placed on the primary radar antenna. In the standard method waves with frequency of 1,030MHz are transmitted and those with frequency of 1,090MHz are sent back from a transponder in the aircraft. If a double pulse as shown in Fig. 1-78 is transmitted from the interrogator, a coded group of pulses from the transponder returns to the ground where they are decoded. The normal radar pulse appears on the PPI as a dot while the blip of the transponder appears as short lines on the same location as that of radar pulse. This is because the beam width of the SSR is so wide that they appear slightly earlier than the true position of the aircraft and remains slightly later than its true position. (Fig. 1-79)

In the mode shown in Fig. 1-78, A and B are normally used to ask for the the type of aircraft, flight number and other needed items for air traffic control, and C for altitude information, but use of D has not been decided yet. Other than the modes above, modes 1, 2 and 3 are used for military purposes. Mode 3 has the same pulse duration as that of mode A for civil use, thus it is called 3/A and commonly used for military as well as civil use.

The code pulse from the transponder is composed of 15 pulses with 2 pulses in the beginning and at the end of each line, and these 2 pulses are called framing pulses,which have a pulse interval of 20.3 μs and they are basic pulses for decoding. Between the framing pulses there are pulse positions in which 13 of them each having the pulse width of 0.45 μs may be set at intervals of 1.45 μs, and the information is obtained whether the pulses are located there or not. These pulses for information are 12 because the pulse position at 10.15 μs from the first framing pulse is designated in only technical standard for the protection of possible future use, and 2^{12}=4096 items of information can be composed. In addition, there is a pulse for recognition at 4.35 μs behind the second framing pulse. The pilot sends out this pulse by operating the transponder upon request of the control officer on the ground.

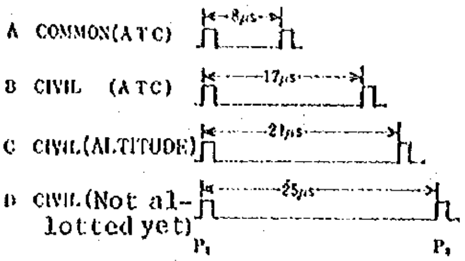


Fig. 1-78 Interrogator mode

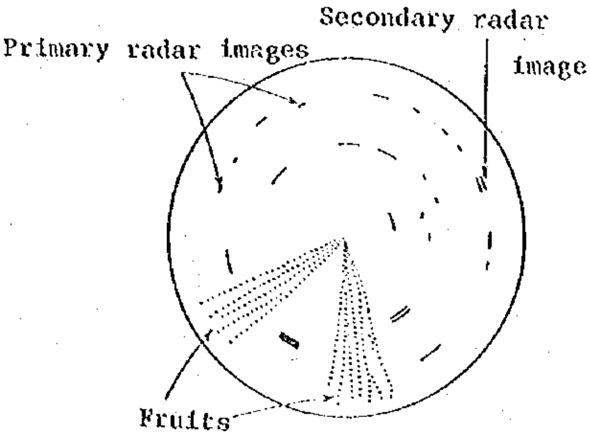


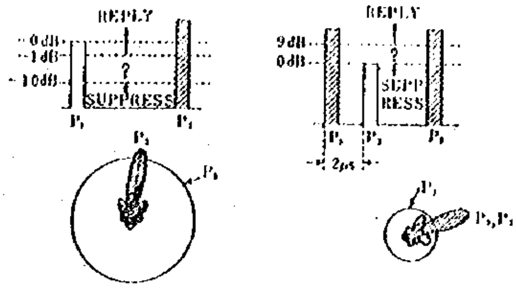
Fig. 1-79 Display on the SSR radar screen

(2) Side lobe suppression

In an area near to the SSR, the transponder replys to interrogating signals sent out from the side lobe or back lobe of the interrogation antenna.

Since the reply obtained from those other than the main beam is displayed as a signal obtained from the main beam, true position of aircraft cannot be detected. As the method for suppressing replying to the side lobe, ICAO has set up the side lobe suppression as shown in Fig. 1-80 as its standard. In this case, the P_1 and P_2 of the interrogator pulse is radiated by the directional antenna, and the third pulse is put in between two pulses so as to radiate it from the omnidirectional antenna. In this method, the transponder will not reply when the omnidirectional pulse reaches the level of the largest side lobe pulse.

The phenomenon known as fruits occurs when the pulse of the transponder that has replied to a station is received by another station. Interference appears in the form of random bright dots, but it is possible to erase using video circuits in the ground station.



ICAO Regulation 3 pulse method

Fig. 1-80 Side lobe suppression

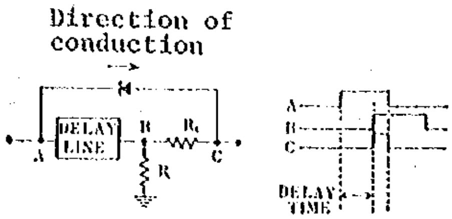


Fig. 1-81 Diode coding circuit

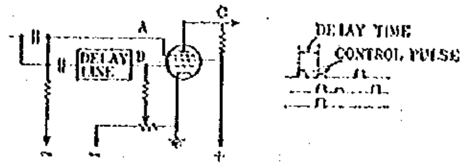


Fig. 82 Basic side lobe suppression circuit

Circuit shown in Fig. 1-81 is used to obtain a double pulse. Input is supplied to a delay circuit, but it does not come out to point C instantly because of the polarity of the diode. After coming out of the delay circuit, it appears at points B and C. When input pulse stops, C has a higher potential than A, and electric current flows to the diode whereas voltage drop occurs at R, and at the same time, opposite voltage is produced at C.

The side lobe suppression is given by selective demodulation of amplitude circuits as shown in Fig. 1-82.

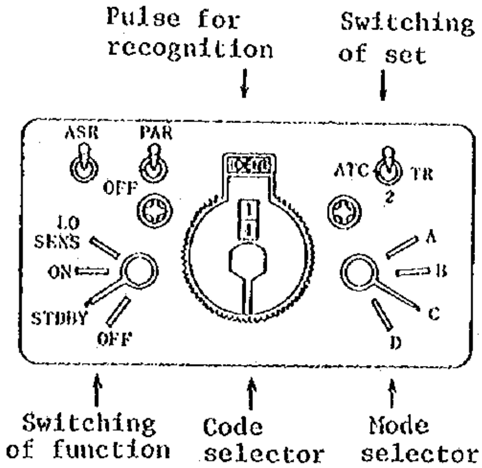


Fig. 1-83 Transponder control panel

(3) ATC transponder

ATC (Air Traffic Control) transponder is the airborne equipment replying to the SSR as mentioned above.

The standard transponder controller is shown in Fig. 1-83. On the left there is an ON-OFF switch, and no voltage is applied to vacuum tubes at STDBY, and the sensitivity of a receiver is lowered at LO SENS. The code selector sets the code required. The mode selector selects the interrogator pulses from ABCD. IDENT is used when the pulse for recognition is transmitted.
At present, SSR is being utilized together with ASR, but PAR is expected to be

used with SSR in the future.

The basic circuitry of transponder is shown in Fig. 1-84. IF and RF circuit of the ATC transponder resemble the DME circuit; Transmission and receiving are at 1,090MHz and 1,030MHz, respectively. IF is 40 MHz and a single stabilized oscillator is used for the transmitter and the local oscillator. The pulse detected and amplified enters a spike-eliminator and pulses of less than 0.3 μ sec of width are stopped to prevent noises. The decoder is set to reply to the designated interrogator code. The same input is supplied to the side lobe suppression circuit, which is an amplitude selection circuit. The output of the decoder is supplied to a keyer and then supplied to an encoder which makes a pulse row to produce the specified code. The sensitivity of a receiver will be lowered if reception is made 1,600 times per second while the automatic overload control circuit is counting pulse number. Furthermore, on counting the number of encoder pulse number, the sensitivity will be lowered if the average power exceeds the fixed value. Despite the lowered sensitivity, it is so arranged to reply to strong pulses in the vicinity of interrogator.

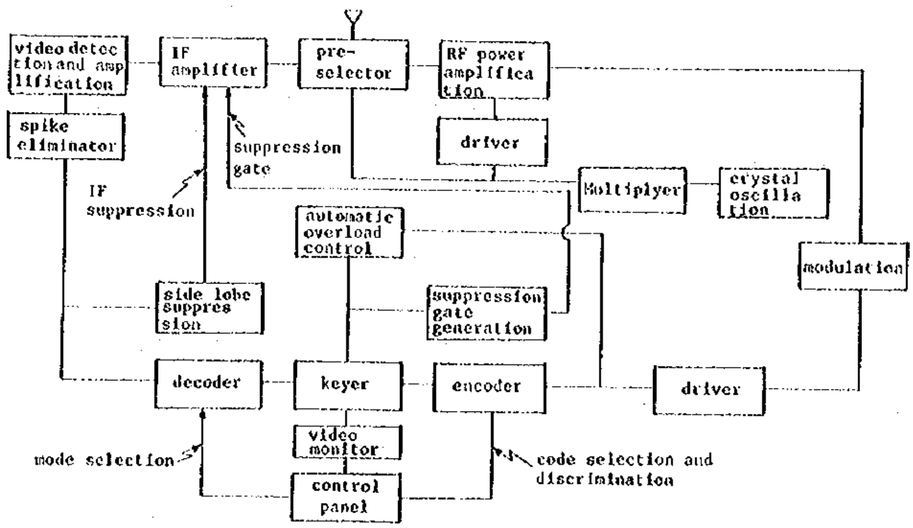


Fig. 1-84 Transponder system diagram

According to the code selected by the pilot, the keyer actuates the encoder and makes a row of pulses to be sent to the modulator. This pulse row becomes RF pulse row and radiated after amplified. The keyer actuates suppression gate pulse generating circuit and terminates the function of the receiver while transmitter is working

6. 3-Dimension Radar

A radar surveillance system employs two kinds of radars to obtain the

distance to a target, its azimuth, and information about its height by means of scanning performed mechanically. In other words, azimuth and distance are obtained on one indicator of the search radar system and when its height is required, the height and distance is obtained on a separate indicator by scanning beams in a vertical plane on which the target lies.
For instance, the GCA is composed of a search radar and a precision approach radar.

However, when it is necessary to cope with the higher speed of aircraft and simultaneously control a number of aircrafts, single radar system is required to obtain quickly the information about the azimuth, distance and height of a target. For this purpose, a 3-dimension radar system has been studied in many countries in the world whether it is for military or non-military use. However, there has still been no established system developed. The 3-dimension radar system will be classified into 3 categories according to the arrangement of beams.

(1) Single beam scanning system. (2) Multi-beam scanning system.
(3) Multi-beam non-scanning system.

Since these beam arrangements can be combinded independently in azimuth and elevation, theoretically 9 types of beam arrangement may be considered, and if V beam system that has been considered since the beginning of the devevlopment is included, there are 10 types of arrangements.

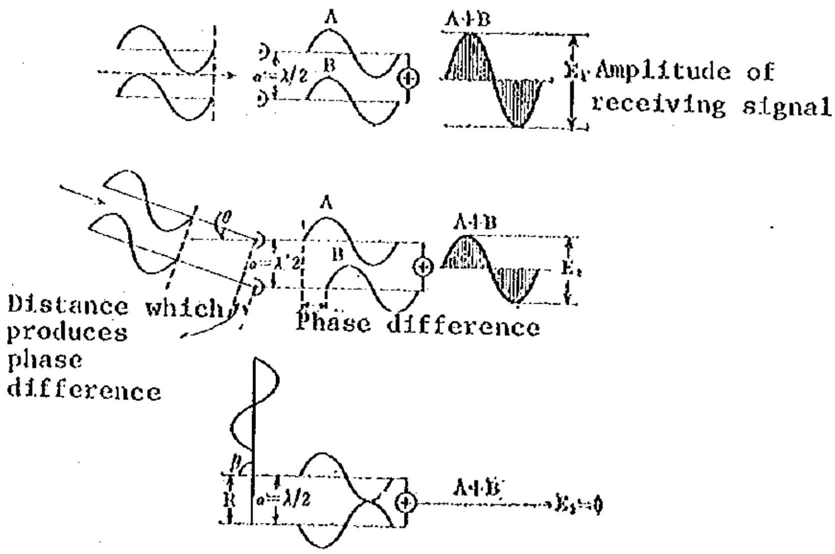


Fig. 1-85 Characteristics of 2 element array (λ/2 interval)

On the other hand, scanning methods are classified roughly into two:

mechanical scanning and electronic scanning. Phase scanning and frequency scanning are employed for the electronic scanning.

In the phase scanning, the feeding phase of each element of the linear array antenna is changed in such a way that the direction of the main beam is scanned, and Fig. 1-85 shows the simple case with the array antenna composed of 2 elements and its characteristics. The frequency scanning is same as the phase sanning in principle and the relative phase of feeding is controlled by changing the frequency.

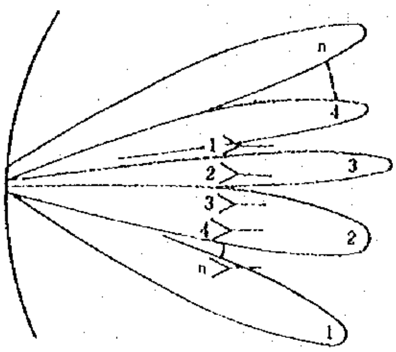


Fig. 1-86 Multiple beams by Defocused Horn

The methods for making multple beams in the multiple beams non-scanning system are following 3 ones:

(1) Defocused Horn. (2) Luneberg lens. (3) Multiple beams for reception.

The Defocused Horn as shown in Fig. 1-86 forms the multiple beams by setting the same number of primary radiators as that of beams at the focus of a parabolic antenna and the direction of the primary rediator is diversified.

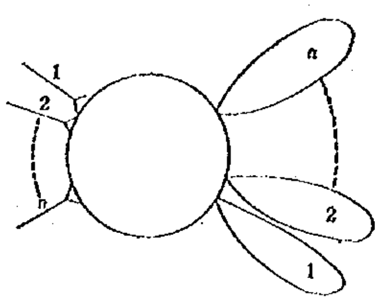


Fig. 1-87 Multiple beams made by Luneberg lens.

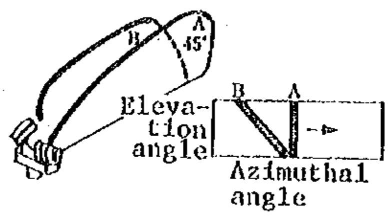


Fig. 1-88 V-beam method

The Luneberg lens as shown in Fig. 1-87 provides the multiple beams by placing radiators as many as the number of beams on the Luneberg lens.

In the case of multiple beams for reception, multi-beams are produced by supplying the output of each element of the array antenna to a delaying matrix. However, the demerit of this type is that it requires receivers as many as the number of beams.

Let us describe the representative methods of 3-demension radar.

V·beam method : This method has long been in use, where the height of a target is computed by measuring the time required for the target to be caught by beam A until it is caught by beam B. Two beams are arranged in a V shape with an opening angle of 45°, and they are broad in the elevation direction but sharp in the azimuthal direction.

Single beam mechanical scanning method : This type of scanning method has been employed for the air traffic control radar system at Brussels Airport in France, and it is a 3-dimension radar in the earliest generation. This uses the scanning method of the primary feeder for a parabolic antenna in a saw tooth wave shape in the direction of elevation and the prabolic antenna is revolved mechanically in the direction of an azimuthal angle.

Single beam frequency scanning method : This is an electronic scanning method put to practical use for the first time. Although normal revolving scanning is performed in an azimuthal direction, beams are scanned utilizing the variation of electric lengths between the elements of the array caused by the change of transmitting frequency in the direction of a elevation angle.

This method was developed by Hughes Company, U.S.A., and it can work out the compensation against the pitching of vessels electronically and quickly and it needs no mechanical stabilizer.

Single beam phase scanning method : Normal revolving scanning in the direction of an azimuthal angle and single beam phase scanning in the direction of elevation angle are performed. In this case, one set of phase shifter is necessary for each element of the array and so a large antenna is required.

Single beam frequency-phase, phase-phase scanning method : Frequency or phase scanning is applied to the scanning in the direction of an azimuthal angle, taking advantage of the quickness. The antenna is not driven mechanically at all. An experemintal manufacture has already been announced by Hughes Company. It requires an antenna system in an enormous scale, but is prospective if it is reduced in size.

Multi-beam mechnical phase scanning method : This is the method of scanning an antenna mechanically in the direction of an azimuth angle while scanning pencil beams in the direction of elevation angle by phase shift.

Multi-beam phase-phase scanning method: Employing the principle that the distribution of beam shapes can freely be selected, with transmitter-receiver channels individually set up in a plane, the scanning is performed electronically.

Multi-beam mechanical non-scanning method: By distributing multi-beams without scanning in the direction of elevation angle and with ordinary revolution in the direction of an azimuthal angle, this method is used as standard 3-dimenion radar systems in the United States and the United Kingdom.

Multi-beam for reception method: Making normal revolution in the direction of an azimuthal angle and making out a number of beams in the direction of a elevation angle with the process of receiving phases, it has been manufactured trially in Japan.

1-9 Doppler Navigator

The Doppler navigator is a radio navigational aid used for self-supporting navigation of high precision, employing a Doppler radar system on the part of aircraft to measure directly and continuously its speed against the ground and drift angles by the use of the Doppler effect. In other words, aircraft flying over the ocean or polar regions not covered enough by navigation aid facilities such as radio beacon stations and radio navigation stations on the ground, can estimate the present and future positions. This airborne equipment obtains a distance by integrating the speed against the ground and a course line by the addition or subtraction of nose angle and drift angle with the aid of a computer. Therefore, it is possible to know the deflection from the course and the distance to the destination, if information about the positions of take-off or a fixed point and the destination is presetted. Fig. 1-89 shows the construction of Doppler navigator.

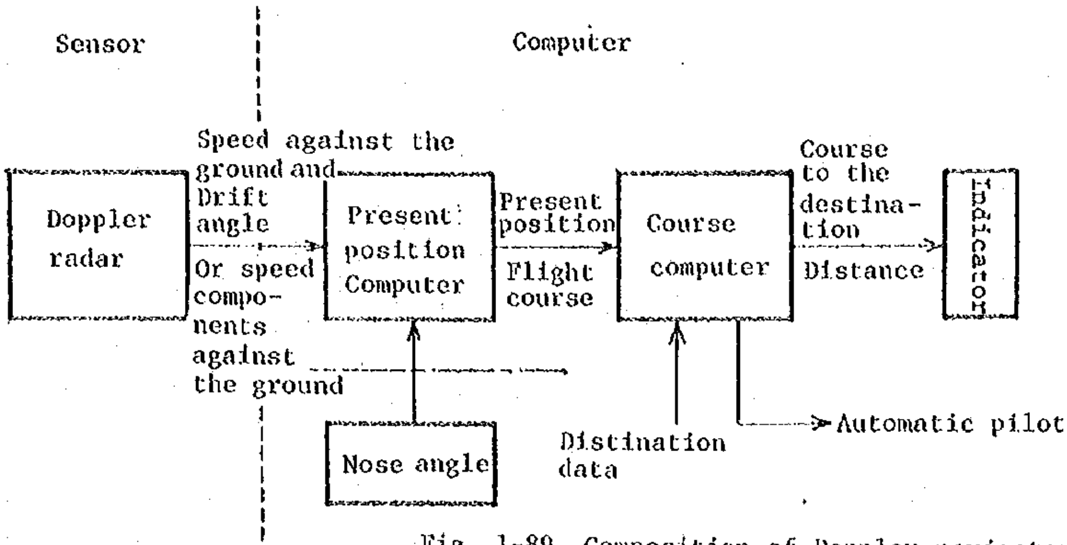


Fig. 1-89 Composition of Doppler navigator

1. Doppler radar

If the source of a wave, e.g., sound waves and radio waves, makes its way to a observer with certain relative speed, the frequency observed is higher than that at the source of the wave and vice versa, i.e., if it is going away from the observer, the observed frequency becomes lower. This phenomenon is known as the Doppler effect. In this case, the frequency difference (Doppler frequency) is in proportion to the relative speed. For example, in case the transmission with frequency f_t is made along a flight course of aircraft flying at a speed of v, the Doppler frequency f_d obtained by the reflected wave from the target on the flight course is:

$$f_d = \frac{c + v}{c - v} f_t - f_t = \frac{2v}{c - v} f_t \fallingdotseq \frac{2vf_t}{c} \text{ (Propagation speed } c \gg v)$$

As shown in Fig. 1-90, when f_t is transmitted to the ground with an angle γ against the flight direction, the speed of the aircraft against the ground V_g is $v = V_g \cos \gamma$ where v is a speed component in the direction of a beam. Therefore, the following is obtained from an equation above.

$$f_d \fallingdotseq 2V_g \cos \gamma \, f_t/c = 2V_g \cos \gamma/\lambda$$

If γ and λ are constant, V_g can be obtained by measuring f_d. Moreover, when γ=90°, f_d=0, and in the case of front beam f_d becomes positive and for back beam negative. To obtain a drift angle, at least 2 beams need to be transmitted in the direction of the nose.

In this case, if the antenna is installed in such a way that beams are symmetrical, and when there is no side wind both directions of the nose and flight course coincide with each other, and the Doppler frequency difference on the left and right is 0. If there is a side wind, the direction of the

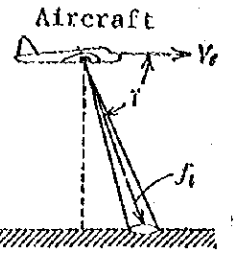


Fig. 1-90 Principle of Doppler radar

nose is displaced from that of flight course to produce a drift angle, and the Doppler frequency on the left and right produces difference in proportion to the drift angle. If by detecting the frequency difference and revolving the antenna with use of a servomechanism, then arranging the beams to be symmetrical against the flight course and making the frequency difference 0, the drift angle can be obtained from an angle formed by nose direction and an antenna direction.

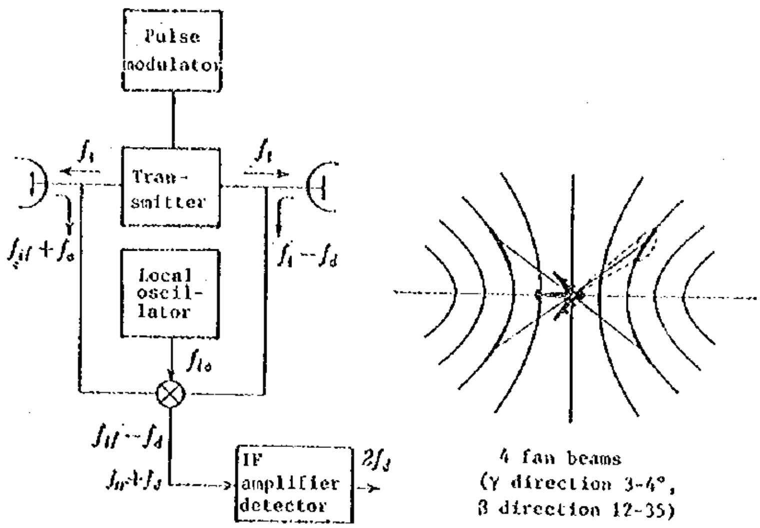


Fig. 1-91 Pulse incoherent method

Continuous wave method, pulse method and frequency modulation method are used for the Doppler radar system. Transmission power is often in watt order, and working frequency bands are 8 GHz or 13 GHz. Since sharp directivity is required, a slot (planar-array or linear-array) lens or parabolic antenna is used. The number of beams is 2-4, but 4 beams switchover method is employed frequently to reduce the error according to flying postures. (Janus method)

The description of the representative pulse method and CW-FM method is given as follows:

(1) Pulse incoherent method

As shown in Fig. 1-91, 4 beams in two pairs, namely, a pair composed of front right and back left, and another composed of front left and back right, are sent out by turns. In this case, the Doppler frequency f_d is not the difference between transmitting and receiving waves, but to be made between receiving waves of front beam and back beam. For this, transmission frequency needs not to be stabilized, and obtained doppler frequency is twice as large. In addition to this, even if there are variations in pitch angles and roll angles, 2 beams offset the error with each other within a small range of angles. Moreover, the drift angle can be obtained by revolving the antenna around the vertical axis and comparing the f_d of two pairs of beams transmitted by turns and directing them so as to make the frequency difference 0. Thus the computation becomes simple. The problem is that reception may become impossible in ase of the overlapping of reflected waves and transmitting pulses resulting from the special relation of pulse repetition frequency and height. (Altitute hole) To prevent this effect, measures are taken to change the pulse repetition frequency or to change modulation method.

(2) CW-FM method

This method is aimed at measuring the Doppler frequency by modulating the transmission frequency with a certain frequency and utilizing side bands produced by the modulation. The method is superior to the CW method whose drawbacks are that there occurs power leakage or reflection by the vicinities; but it has a deffect of an altitude hole with some modulation frequency. The description of the equipment installed on large-sized jetliners on international routes is given as follows: Fig. 1-92 is a system chart indicating the function of a sensor. Microwaves of 8.8 GHz from a transmitter are sent out from the planar array antenna 5 times every second by turns by a beam-switch, so that beams in 4 directions are formed. Reflected waves having Doppler shifts are received by the same antenna and sent to a tracker of a receiver after being converted to approximately 500 kHz. These waves are introduced to the corresponding tracker 1-4 by a sequencer which operates sychronously with the beamswitch of the antenna. The role of the tracker is to seperate the Doppler frequency from the reflected waves. Each piece of information from 4 trackers are transferred to a flag actuator to indicate that this system has been locked and then the off-flag is put down. On the other hand, 4 Doppler frequencies obtained from the trackers are mixed into various method by a combiner, and synthesized into 5 different signals. Three of them are signals for the speed against the ground: f_x correponding speed

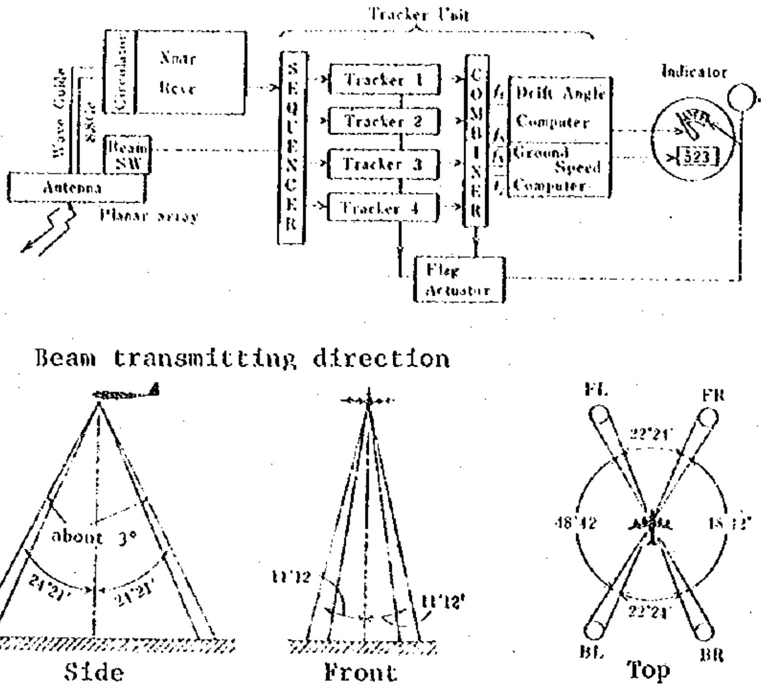


Fig. 1-92 Functional system chart of sensor

component of flight course f_y, f_z corresponding right angle and vertical directions respectively. They actuate the indicator through the computer and servo systems. The 4th signal (f_L) is for the drift angle. The 5th is for checking the functions. If the surface is flat e.g. on the sea, it sends back only small amount of effective reflected waves, and so sea-level bias error correction circuit is provided in order to minimize errors. In addition, the sensor stops relying on the reflected waves when the instruction may be inaccurate beacuse the Doppler frequency cannot be found out of the reflected waves. Then last value obtained while the equipment was operaing normally, is displayed on the indicator. (In this case, off-flag alarm lamp is actuated)

2. Navigation computer

Navigation computer integrates the speed against the ground gotten by the output of the Doppler radar and an angle formed by the nose direction and an actual onward direction, in order to get the present position. As to the input of computer, the output from the gyrosyncompass of aircraft is also required.

If the distance and the direction to the destination are put in the computer in a certain place before departure or after taking-off, the aircraft will be informed of the residual distance to the destination and the onward direction after that.

The output can be combined with auto-pilot, but reliability in that case has not been confirmed yet.

The reliability of the Doppler navigator is quite positive with actual results of navigation data. With the progress of selfsupporting navigators, it seems that pilots' load will be reduced while the safety of navigation will be increased.

1-10 Radio Altimeter

As an height indicating instrument for the aircraft flying horizontally at a constant altitude, barometric altimeters have been used. They indicate the height above sea level, and in cases where height from the ground is needed, radio altimeters are used. The latter are used in limited fields such as flying above land of a complicated geography at low altitude or as a clue in finding a change of the atmospheric pressure.

Radio altimeters using 440 MHz and those using 4,300 MHz are available at present, but the former will not be used in the near future. Two types of instruments, FM and pulsed types, are used, the former being of a comparatively large size and high accuracy, while the latter being simple and light weighted.

1. FM Radio Altimeter

As shown in Fig. 1-93, radio wave frequency modulated by a modulation

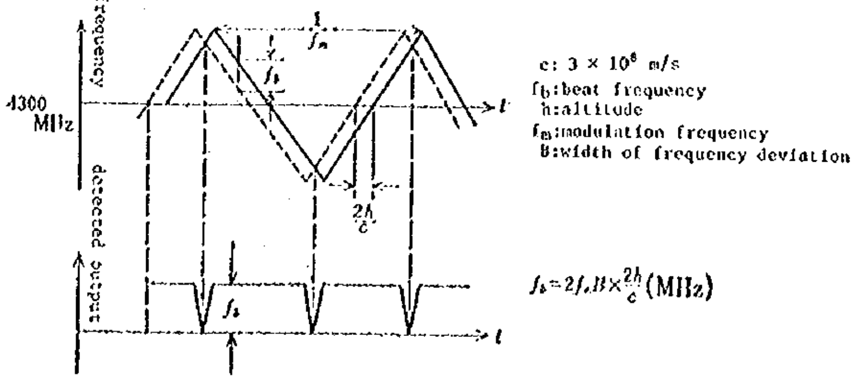


Fig. 1-93 principle of FM radio altimeter wave of triangular waveform generates a frequency deviation proportional to the length of the time for propagation, after propagation to and from the ground surface. Thus the altitude can be found by determination of the frequency difference between the outgoing and reflected waves.

2. Pulsed Radio Altimeter

In this type of instruments, similar to the radar, altitude is found by measuring the time needed for pulses to go and back to the instrument. For use in low altitude or when high accuracy needed, the width of pulses must be as small as possible. 0.01 μsec pulse width is the smallest with the instrument developed up to the present, but even this cannot give a higher accuracy than $0.01 \times 10^{-6} \times 3 \times 10^{8}$m = 3m theoretically. The advantage of this type over FM type is of light weight.

1-11 Navigational Aids using Artificial Satellite

At Applied Science Laboratory of Johns Hopkins University the doppler shift of the radio wave from Sputnik No.1 of U.S.S.R. was found when they received the wave from it in 1957 and they proposed the possibility of determining the position of the receiver from the doppler curve of a satellite with known orbit. The proposal was accepted by the U.S. Navy and was studied until its practical use was started. The method, however, is for military purpose, for positions can be obtained only once every 1-2 hours and the receiver is expensive. Thus a system of navigation satellite for civil use is being studied and developed by NASA and in many countries.

The navigation satellite system can roughly be classified into two types, passive and active. This means whether the radio wave is emitted from the user or not, and said system by U.S. Navy is representative of the passive type.

In case of the active type, the location determination center is the ground station controlling the satellite so it has the convenience of data processing with large computers, and the burden on the users can be lightened. However, the users who want to know their positions must equip themselves with a unit having a function of communication or data transmission repeated by the satellite. This means that the determination is made by the radio wave from the user, and it is impossible that more than one user would utilize the system unless time sharing or frequency sharing. This system has the limitation of the number of users.

However, considering the anticipated number of users and the burden by the users, the active type seems more expectative of realization.

The determination of position of moving body is based on determination of that of a satellite of known orbit. The reverse of tracking an artificial satellite from a known point on the ground is applied, whereby unknown position on the ground or in the air is found. The method is devided into two cases, that is, one is radio wave emitting type from the moving body and the other is not emitting type.

NNSS system belongs to the non-emitting i.e. passive system, and it has been developed for military purpose by the merit of being free from detection by enemies. This method is based on computing the own position by the moving body itself from the orbit data of the satellite and data of observation.

On the other hand in case of moving body emitting radio wave, the moving bodies are not required of equipments of high grade, but it is necessary to give either the satellite or the base a sufficient computing power. The former method is avoided due to lack of reliability and economical reason, and a system using a geo-stationary satellite with communication function will be expected, so resulting in somewhat a lower accuracy, speaking in terms of principle.

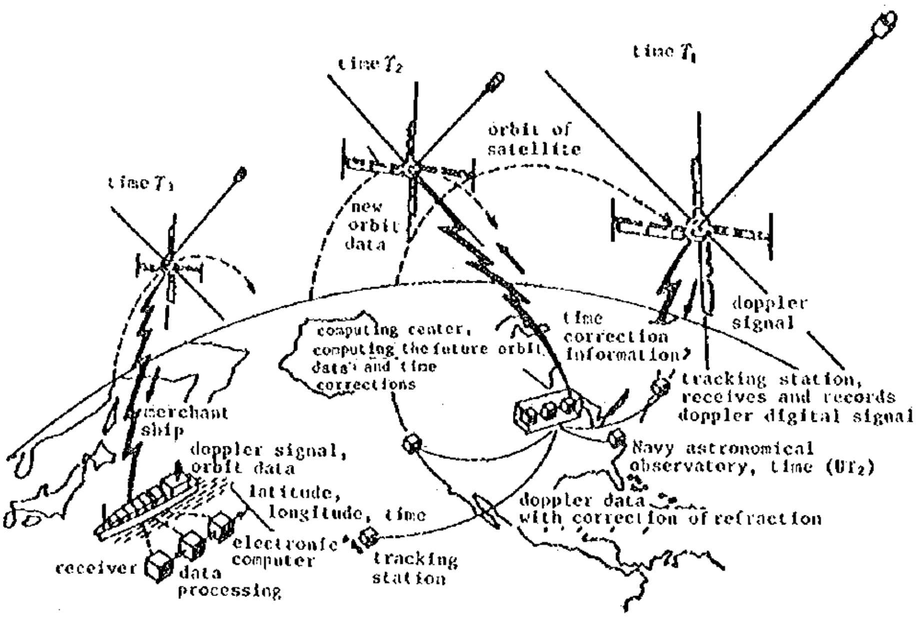
Therefore, it is probable that a system in which position is computed in the moving body will be adopted for special or limited uses while a system having a ground facility for computation with utilization of communication facilities will be used for general use. Recently, the latter is in the lime-light as AEROSTAT and MARSAT programe. The satellites are expected to be used for facsimile transmission, communication of voice and data, position determination for search, radio location and weather information, etc. However, complications are expected ahead until it is put into practice, for many problems, not to speak of the technical ones, in organizations, operation, finance, and other field must be solved.

1. NNSS (Navy Navigation Satellite System)

The navigation system using artificial satellite has the merit similar to that of astronomical navigation and radio navigation while the drawbacks the latters are offseted. The inconvenience in the conventional system of the different ground systems at different sea areas are overcome by NNSS, and navigation throughout the world by a single system is possible, finding position with almost a uniform accuracy at any point of the world. The system was developed for military purpose and is used as such, but a part (about one sixth of the information) of the knowhow was opened to civil utilization since 1967.

(1) Summary of NNSS satellite

Although the detail of the satellite is not open to the public, the appearance is something like the drawing in the right upper part of Fig. 1-94, and its control of inclination is by gravitation. The weight is said to be about 60 kg and was launched by a Scout rocket, being comparatively of light weight.



The tracking station (in U.S.A.) measures the doppler frequency of the radio wave from the satellite and sends the data to the computing center. The computing center computes the orbit forecast data of the satellite and sends them to the satellite via information transmission station to be memorized in the satellite. Ships determine the doppler frequency of the radio wave from the satellite and receive the orbit data so this enables them to obtain their position.

Fig. 1-94 Conceptional diagram of NNSS

The transmitted radio waves are 399,968 MHz and 149,988 MHz, and the frequencies are exactly in the ratio of 8 to 3, made by the same crystal oscillator of ultra-high stability. The stability of frequency is better than 10^{-11}, and the transmission power is said to be 1.25 W for 400 MHz band and 0.8 W for 150 MHz band.

These waves are phase-modulated as shown in Fig. 1-95. The lead and lag in the modulation waveform are in balance so that no ill effect is given to determination of the doppler frequency. The modulation speed is 1,103 bits (1 bit in 19.662 ms, in the figure indicated in 20 ms) in every 2 minutes.

The accuracy of time signal is ± 200 μs against standard time and that of interval is within 10 μs by the observation of Naval Astronomical Observatory in Washington, DC.

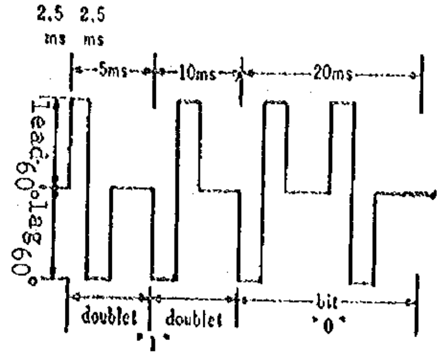


Fig. 1-95 modulation waveform in NNSS

The 6 orbit data are shown by 9 data (time of perigee, average motion, perigee parameter, eccentricity, semimajor axis, ascending intersection point latitude, Greenwich latitude, sine and cosine of inclination angle), and they are repeatedly transmitted every 2 minutes with addition of the rates of variation of perigee parameter and ascending intersection point latitude made by perturbation.

These values for orbit calculation are calculated in the computer center with the tracking data measured by four doppler tracking stations shown in Fig. 1-94 placed in the U.S.A., and the forecast data for coming 16 hours are prepared. The latter data are transmitted, by the orbit information transmission station attached to two of the tracking stations, to the satellite to be stored in the core memory in it and broadcasted successively.

(2) Receiving equipment and determination principle of NNSS

A receiver and an electronic computer for calculating the position are needed to be installed in ships. A conceptional diagram is shown in Fig. 1-96. The reason why two frequencies in integral ratio are used for transmission from the satellite is correction of the error by refraction by the ionosphere, but the measurement error of 400 MHz band being within the permissible range (0.3 NM maximum), merchant ships are inclined to omit the receiving circuit for 150 MHz band in the the dotted line of the figure in order to make the reveiver cheap. The receiver includes a pre-amplifier of high frequency, and the receiving circuit is of a phase synchronization system to mix the received frequency with 400 MHz (and 150 MHz) of a highly stable crystal oscillator to form a beat frequency about 32 kHz (12 kHz), and count and integrate the beat between the time signals from the satellite.

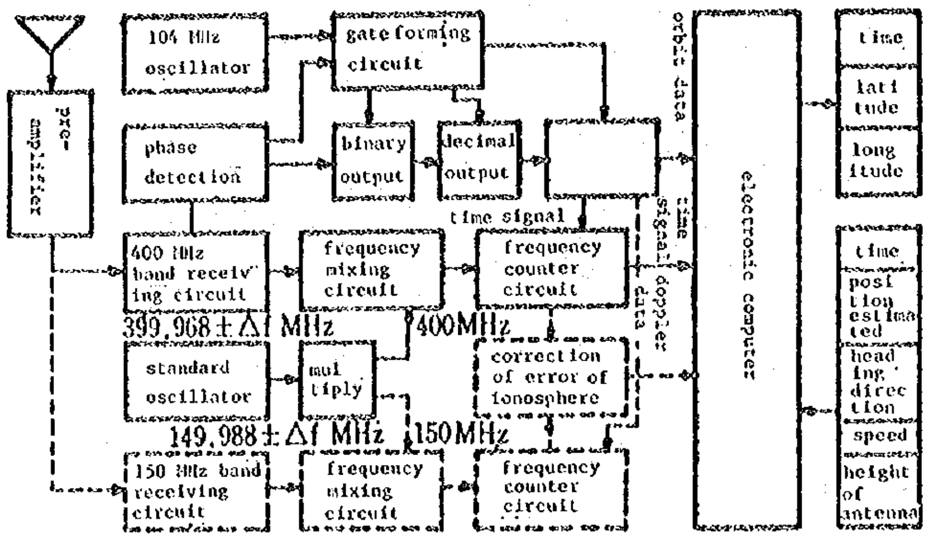


Fig. 1-96 receiving equipment for NNSS

The orbit data extracted for navigation are printed in decimal number or put into computer.

Said integrated count shows the difference of distance in 2 minutes beween the satellite and the ship, and a hyperboloid of revolution can be constituted with the two adjacent points where satellites transmitting time signal as its foci. Therefore, the position can be obtained from the intersection of the two hyperboloids and the surface of the globe.

(3) Position determination by NNSS

In NNSS, the satellite moves and so the positions of the hyperboloid foci are not always the same. Therefore, determination calculation is needed using an electronic computer.

For NNSS, 4 satellites are sufficient, but five are on the orbits. The orbit period is about 107 minutes, and considering the range of satellite being visible and the period of rotation of the globe, the radio wave from the satellites can be received about 25 times a day, but actually, due to deviation of satellites from the orbit and other reasons, 10 and some times a day for position measurement is the average in an ideal case.

As an example, at Electronic Navigation Laboratory a receiving equipment of single wave of 400 MHz band gave an accuracy of less than 0.3 NM if poor results of the satellites passing right above are omitted, while another by Seikomaru which installed the equipment for the first time on board seems to have obtained an accuracy of less than 0.5 NM if poor data from high elevation are excluded. The performance of the equipments in the market which receive simultaeously 150/400 MHz, is said to be better by 10 times than the above.

1-12 Precision Position Fixing System of Short Range

1. HIFIX

HIFIX (DECCA HIFIX) is one of the systems of the BACCA series to be used usually for a short distance of 9~70 km. Therefore, the accuracy of position determination is far higher than what was given for LORAN or DECCA, and is several tens of centimeters. For this reason, it is used in surveying, such as hydrographical survey, geophysics, construction, etc.; and recently it is going to be used in determination of the speed of ships.

As imagined from the field of utilization, the instrument is simple and portable, can be set within a short time, and is designed for a simple operation.

(1) principle of HIFIX

HIFIX is constituted, as shown in Fig. 1-97, by a Master station and two Slave stations, and the three stations form position lines of hyperbola of zero phase difference as in the case of DECCA. The transmitted wave, however, is a continuous wave near 2 MHz. Therefore, the frequency band used is near to LORAN A.

For determination of position, the radio wave is received by a receiver for HIFIX from the Master and Slave stations, and the position is obtained by detection of the phase difference and using the chart. This is not much different from the case of DECCA.

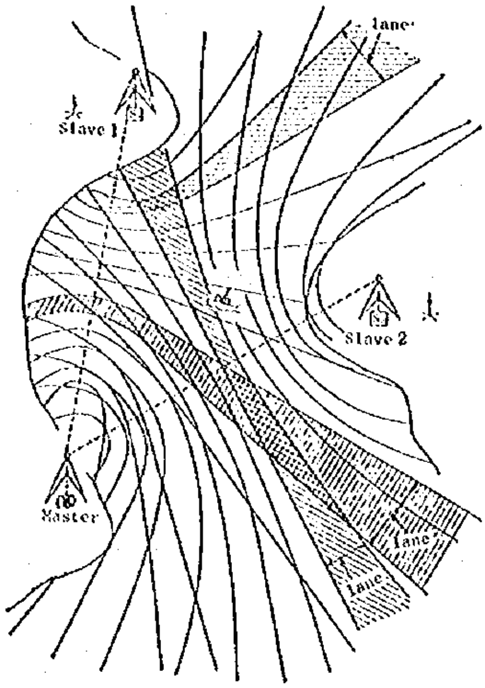


Fig. 1-97 Constitution of HIFIX station and position lines

(2) Transmission of radio wave in HIFIX

The Master and Slave stations transmit radio wave near 2 MHz in the sequence shown in Fig. 1-98. The sequence is controlled automatically by the timer contained in the Master station, and the basic principle of the system is as shown in Fig. 1-99.

In the figure, the three oscillators are oscillating continuously, but the output passes the gate circuit only when the gate is open. The gates are opened and closed by the timer which opens gates No.1 and No.2 at first for 0.1 second, and the output from OSC1 and OSC2 are impressed on the mixer. Therefore, the beat of the output frequency is

$$2,032.080 - 132.140 = 1,899.94 \text{ kHz}$$

This frequency is lower than that forms the hyperbolic position line by 60 Hz, and is used for synchronization of the transmission frequencies of the Slave stations; and it is called trigger frequency.

After 0.1 second, the timer closes gate 2 and opens gate 3, and the output frequency of the mixer is

$$2,032.080 - 132.080 = 1,900 \text{ kHz}$$

which is the frequency for forming the position line. The transmission time of the Master station is 0.3 second as shown in Fig. 1-98, and after this time,

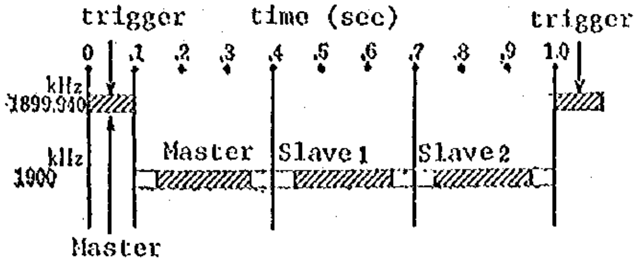


Fig. 1-98 Transmission of HIFIX radio wave

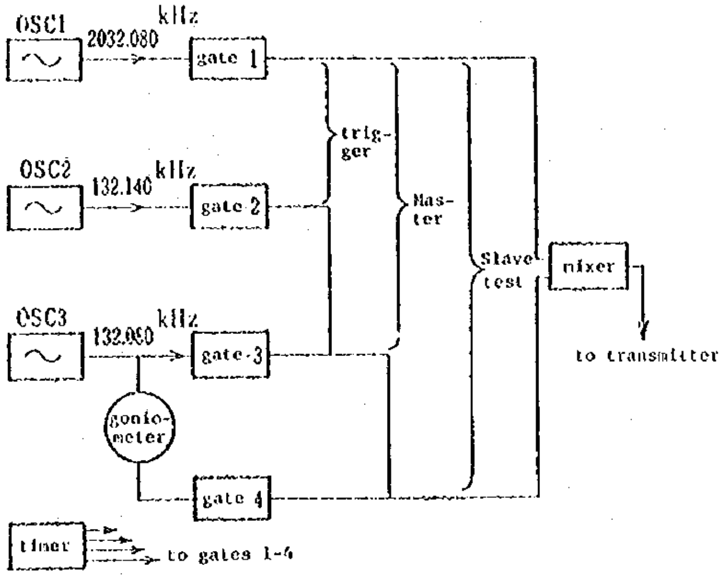


Fig. 1-99 System diagram of radio wave transmission from Master station

gates 1, 2 and 3 are closed and transmission from the Master station is suspended. This is followed by transmission from Slave station 1 for 0.3 second and further by one from Slave station 2 also for 0.3 second in 1,900 kHz. Thus the total of the time for a sequence is 1 second, and this is repeated.

Transmission from the Slave station 1 is made with a time lag of 0.3 second after receiving the trigger from the Master station and that of Slave station is made with a time lag of 0.6 second.

Hifix can also be used in circular position line system by installation of the Master station on the ship itself. Such a configuration is shown in Fig. 1-100, and it corresponds to determination of the distance from the ship to the Slave stations by the hyperbolic position line system where the distance from the ship to the Master station is kept at zero. The position of the ship is determined from the intersection of the two circular position lines, and this is one of the variations of the hyperbolic position line system.

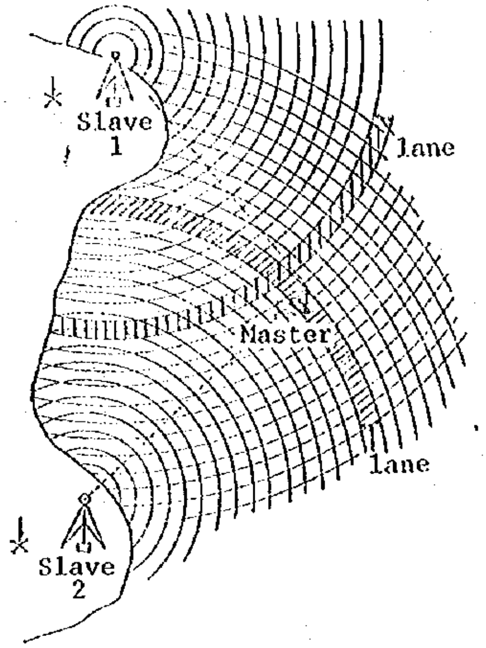


Fig. 1-100 Circular position line system of Hifix

In hyperbolic position line system, many ships can be served simultaneously as in the case of LORAN or DECCA, but in circular position line system, ships equipped with the Master station only can be served. However, the accuracy of determination is better and the range of determination is larger in the latter system.

(3) principle of HIFIX receiver

Fig. 1-101 shows the system diagram for the basic principle of the receiver for HIFIX. When the switch of the antenna input circuit is put on to OP, the trigger signal from the Master station and the position line signal from the Master and Slave stations are converted into a certain intermediate frequency, IF, by heterodine OSC and the mixer. These IF is amplified by the amplifier while the trigger signal of it operates the timer circuit. The timer controls the gates for the detection circuits for Slave stations 1 and 2.

Therefore, the series of signals transmitted in the sequence of the Master, Slave 1 and 2 stations can be compared by phase discriminators 1, 2 and 3 and servo-goniometers G_1 and G_2. That is, the phases of the position line signals from each of the stations are compared with that from the Master station, and the phase differences are converted into the count number of the lane and indicated in the detecting circuits for Slaves 1 and 2. The indication can be made down to 1/100 of lane, and extremely precise position determination is made. Fig. 1-102 and Fig. 1-103 are examples of HIFIX receiver and indicator part respectively.

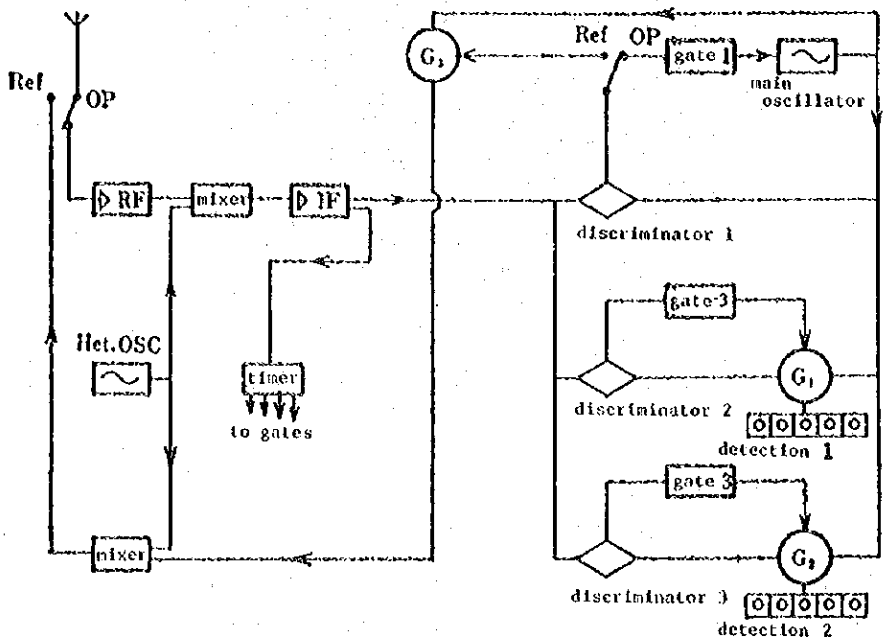


Fig. 1-101 System diagram of HIFIX receiver

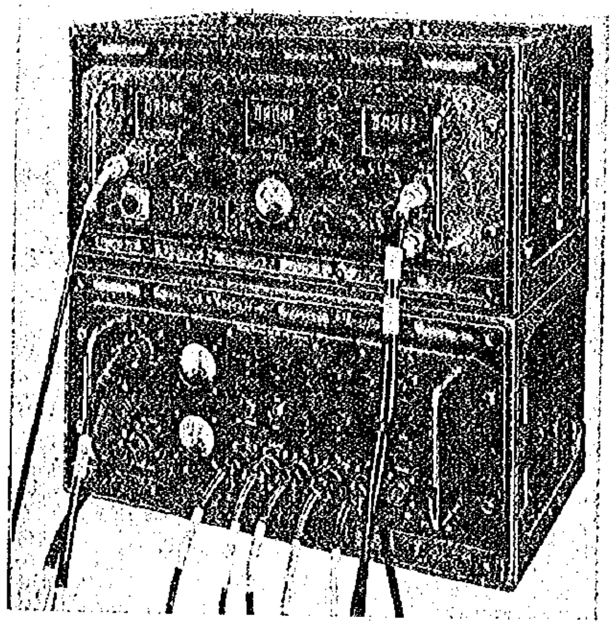


Fig. 1-102 HIFIX receiver

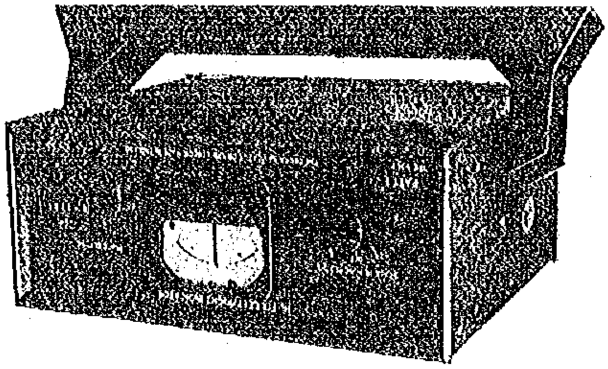


Fig. 1-103 HIFIX indicator

2. Ship Position Fixing System for Survey

This is a kind of secondary radar to be used for obtaining the position of a surveying ship in hydrographical survey with an extremely high precision. Radio wave of 3,000 MHz band is mostly used, and the operation can be continued even under bad weather with a small portable unit, and it is very simple and efficient as compared with the conventional position determination by optical methods. Hydrodist, Autotape, etc. are among those used in practice.

The performance of these ship position fixing systems are shown in Table 1-7.

Table 1-7 Various kinds of ship position fixing system

		Hydrodist	Autotape
Manufacturer		Tellurometer Limitd	Cubic Corp.
date developed		—	March, 1964
type of transmission, carrier frequency, antenna power	station on board	F2, F3 2920MHz 0.1W 2977MHz 0.1W	F2, F3 2970MHz 0.1W
	station on land	F2, F3 2953MHz 0.1W 3010MHz 0.1W	F2, F3 2915MHz 0.1W 2925MHz 0.1W
modulation frequency	station on board	1498.468kHz 1483.483kHz	1498.486kHz 1498.49kHz 1498.5kHz
	station on land	1348.621kHz	1496.486kHz 1495.986kHz 1483.501kHz
range of determination		—	0 - 9999.9 m
determination accuracy		—	$\pm$ (0.5×10^{-5})
sea ares of possible determination		40 km max	200 m - 50 km

(1) Hydrodist

This is a kind of waterway distance meter which is used extensively in the U.S.A. and Europe. For measuring the distance only, a principal oscillator (Master station) and a remote oscillator (Slave station) are used. Radio wave of about 2,800 MHz is emitted from the principal station first after frequency modulation with pattern frequencies (A 1498.4 kHz, C 1483.483 kHz, D 1348.621 kHz), it is received by the Slave station, and a radio wave of a higher frequency than 2,800 MHz by 33 MHz is sent back to the Master station after modulating with a modulation frequency 1 kHz apart. Therefore, the output signal of the intermediate frequency amplification stage in the receiver of the Master station becomes amplitude modulated by 1,000 Hz, and this is detected to obtain the AC part of 1,000 Hz which is impressed on the X deflecting plate of Braun tube with simultaneous impression on the Y deflecting plate after 90° phase shifting to make a circular locus on the Braun tube. On the other hand, in the Slave station, the 1,000 Hz AM (amplitude modulation) signal obtained as output of intermediate frequency amplification stage is detected and led to the pulse forming circuit to generate pulse voltage at the instant of the leading edge of the 1,000 Hz wave, and the pulse voltage is used for simultaneous FM (frequency modulation) of klystron. Detection is carried out in the Master station with a frequency discriminator, and detected signal is led to the first grid of the Braun tube and a bright point is indicated on the circular locus by brightness modulation. This gives the distance by the angle of the bright point from the zero degree point.

In case of determination by the A pattern frequency, 360° on the circular locus on the Braun tube of the equipment in the Master station corresponds to 200 m both ways and 100 m one way, and determination of 100 m or shorter can be made. In case of determining a distance longer than 100 m, D pattern frequency is used, while longer than 1,000 m, C pattern, both in the Master and slave stations. The delay in the phase of the received modulated wave compared with the wave from the Master station is shown by the equation

$$\frac{2\ell}{c} \cdot P_m = \frac{2\ell}{c} \times \frac{2\pi c}{\lambda_m} = 360 \times \frac{\ell}{\lambda_m/2}$$

where ℓ is the distance between the Master and Slave stations, P_m the angular velocity of the modulation wave $(=\frac{2\pi c}{\lambda_m})$, λ_m the wave length of the modulation wave. Therefore, by dividing 360° into 100 equal parts, the reading of the distance meter gives $100\frac{\ell}{\lambda_m/2}$, and since λ_m=200m, the reading of the distance meter is ℓ m.

For obtaining the position of a surveying ship, two Master stations are placed on board, and two Slave stations A and B on suitable points on land of exactly known position. By operation under these arrangement as explained above, the distance AS and BS from the two Slave stations to the ship are obtained as shown in Fig. 1-103 (a); and by drawing circles on the map with the radii equal to the obtained distances centering the Slave stations, the position of the ship is obtained as the intersection of the circles. In actual hydrographical survey, two equipments in the Master stations and two in the Slave stations are used, so 4 waves are necessary. Both in the Master and Slave stations, antennas are connected directly or through cables with the main body consisting of transmitting-receiving parts and measuring parts. The standards of the equipment are as follows:

maximum distance determined	40 km 40 km
carrier frequency	2,800 - 3,200 MHz
power emitted	0.1 W

simultaneous transmission and receiving possible between Master and Slave stations.

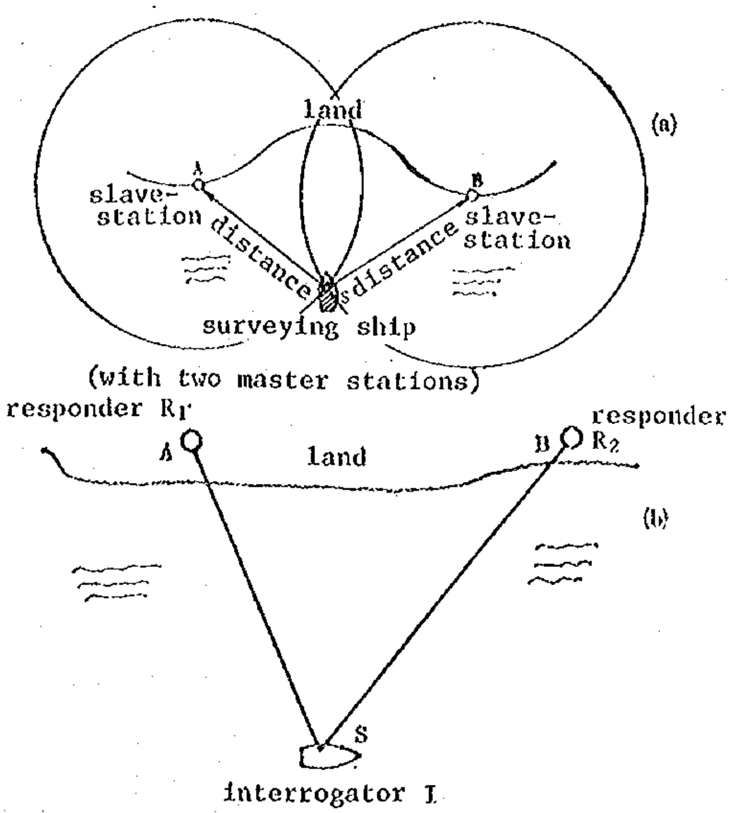


Fig. 1-103 Determination of ship position by Hydrodist or Autotape

(2) Autotape

This also is a kind of small and convenient distance meter to be used in hydrography, similar to Hydrodist.

While Hydrodist uses two Master station equipments and requires four radio waves, Autotape one Master station equipment and three radio waves; and the distance measured is obtained directly in numerical indication. As shown in Fig. 1-103 (b), two points A and B are selected on the coast whose positions are accurately known, and two stations, responder R_1 and responder R_2, are fixed there; while interrogator is arranged on surveying ship S. The distances SA and SB can be automatically measured by determining the delay in phase of the signal emitted from S to A and B and sent back to S, between signal emitted and signals sent back from A and B respectively, and the position of the ship can be found, like the case of (a). of Fig. 1-103, as the intersection of two circles centering at A and B and having radii equal to the distance respectively.

The interrogator emits carrier waves of 2,970 MHz which is phase modulated once every second (the interval between siganls: 1/3 second) by three kinds of modulation frequencies, 1.5 MHz, 150 kHz, 15 kHz, through switching circuit respectively. It is received by each of the responders, phase detected and modulated by the output of detector, so R_1 sends the carrier wave of 2,925 MHz, and R_2 sends 2,915 MHz, back to the interrogator after phase modulation with the same modulation frequency as is received.

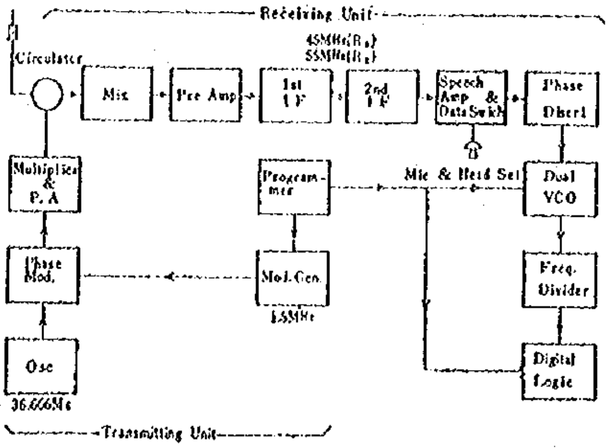


Fig. 1-104 Block diagram of the interrogator

By the interrogator, the radio wave from the responders is received through circulator, as shown in Fig. 1-104, and a part of the transmission output is added to the mixer at the same time; so that transmitter functions also as a local oscillator. The phase of the transmitted radio wave and that of the returning wave from the responder are compared and detected by the phase discriminator, and the frequency of the dual voltage control oscillator is controlled by the voltage generated by the phase difference, so that numerical indication is made by the digital logical circuit through frequency divider. The telephone for communication between the interrogator and two responders can be used by turning the switch of Measure-Talk, and the distance can be determined automatically. A summary of the standard of the unit is said to be as follows:

Maximum distance measured	50 km
carrier frequency	3,000 MHz band
output	0.1 W

Similar instruments to Autotape are developed in Japan by Anritsu Dempa Industries Ltd., (AUTO FIX position determination equipment), and by Shimada Rika Industries, Ltd.

1-13 Wave Height Meter

This equipment is arranged on a flying boat to be used mostly for finding the height of wave, so that the flying boat can judge during flight if the surface of the sea is good for alighting. For this reason, the instrument should be small and of light weight, naturally can be used under bad weather, and an accurate determination of wave heitht of 2-3m must be made during flight at high speed and various altitude. The principle lies in emission of radio wave in 24 GHz frequency band vertically against the surface of the sea to reveive the reflected wave and detect the Doppler frequency caused by the difference in the path due to roughness of the surface. The principle of operation is shown in Fig. 1-105 (a) and (b).

In the figure, the radio wave is emitted from the aircraft flying at speed V with an acute directionality against the surfave of the sea, and the reflected wave is received. Letting the frequency of wave transmitted be f_t, that of wave received f_r, wave height h, and virtual speed of up-down motion of wave v, the received frequency undergoes Doppler shift (Δf) due to the change in the path of propagation according to the progress of the flying boat. Namely

$$|f_t - f_r| = \Delta f$$

where $\Delta f = \frac{2vf_t}{c}$, $v = \frac{dh}{dt}$ therefore,

$$\Delta f \propto \frac{dh}{dt}.$$

And so, assuming that the flying boat flies horizontally and that the beam hits the surface of the sea vartically, doppler shift is irrelative to the wave length, wave speed, the flying course with relation to the direction of the wave, etc. Assuming vertical hitting of beam against the surface of the sea,

$$h \backsim \int_{t_0}^{t_1} \Delta f dt = F$$

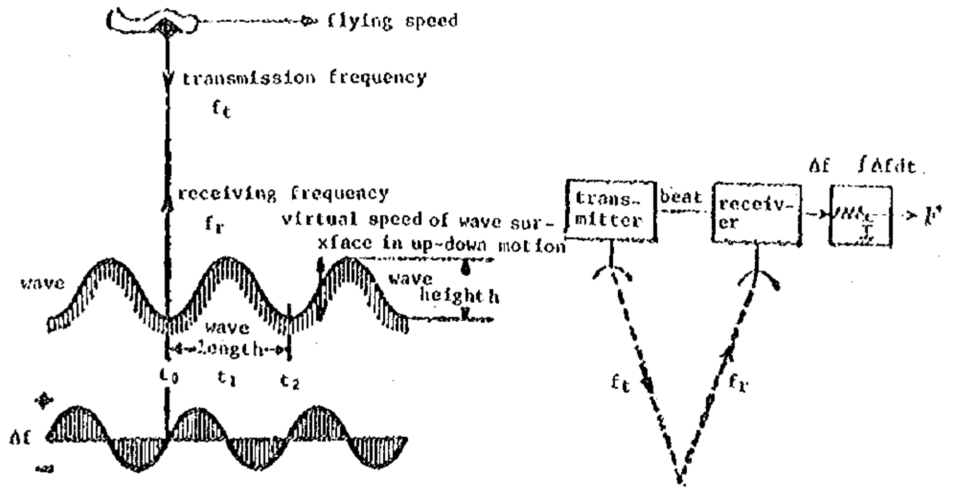
So the height of the wave can be obtained by integration of the Doppler shift from t_1 to t_1 (or to t_2) by means of the integration circuit of the receiver. The output of the integrating circuit F is given by

$$F = \frac{2h}{\lambda}$$

and therefore, wave height is $h = \frac{F\lambda}{2}$.

Therefore, the height of wave is irrelative to the flying speed, wave length, wave speed, and the relation of the direction of the wave to the flying route.

As to the directionality of the antenna, owing to the need of determining the wavelength of up to the wave of several meter, the width of the beam hitting the surface of the sea must be limited within 1 m. Assuming a flying altitude of 50 m, this makes the width about 1.5° or less; and this is achieved by using millimeter wave and parabolic antenna.



(a) (b)

Fig. 1-105 principle of wave height meter

The conditions of reflected wave vary considerably depending on the conditions of the surface of the sea and is also very weak, so that the reception is affected by leakage of the transmission wave, leakage within

Table 1-8

characteristic / type	type	central frequency (MHz)	range of determination (ft)	accuracy	weight (lb)	transmission power	antenna	pulse width	frequency deviation width
AN/APN -22	FM	4,300	0-40 40-20,000	5% ± 2ft 5% ± 2ft	30	10-100W (average)	horn		± 30 MHz
AN/APN -141	pulse	4,300	0-5,000	30 ft	9	2-1kW (peak)	horn	0.01 μsec	

the instrument, and reflection by the neighborhood. For this reason, the transimssion wave is frequency modulated and at the same time a part of the output is shifted and used as well as local frequency. In this case, the modulation index of FM in IF is decided by the phase difference between the receiving signal and FM of local oscillation, the modulation index being zero when there is no phase difference and twice when the two phases are opposite to each other. Thus the FM phase of the reflected wave from sea impressed on the receiver is the almost opposite phase to the local oscillation and raise the modulation index of IF, while the disturbance of leakage etc. is mostly in the same phase and lower the modulation index.

By extracting one of the side bands of IF frequency modulated in this condition, doppler shifted signal from the surface of the sea can be received without ill effect of disturbing waves such as leakage. Such a system is called FM-CW system (the system diagram is shown in Fig. 1-106). is used in the present unit.

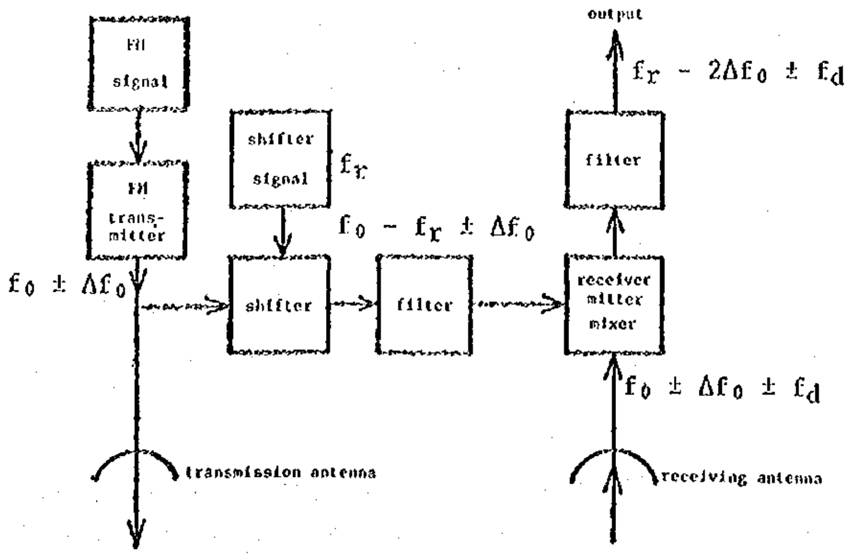


Fig. 1-106 FM-CW system diagram

2. Conventions in Relation to Radio Communications

2-1 General

The utilization of radio waves has been controlled by the International Telecommunication Convention for years, and its revised version in Montreal in 1965 is one in force now. The Radio Regulations attached to the Convention which were partially modified in 1963, 1966 and 1971 are the standing regulations. The Regulations prescribe the assignment of frequencies from 10kHz to 275GHz to various services, namely, fixed service, broadcasting service, mobile service, fixed satellite service and so forth. The Regulations also provide an international frequency registration system, in which those countries concerned (authorities in charge of telecommunications) shall give a notice to the International Frequency Registration Board (IFRB) when the use of a frequency may cause interference to foreign radio stations, when the frequency is to be used for international radio communications, or when protection whith international approvals is required. The IFRB considers the received notification according to the specified standard of judgment, and registers the use of the notified frequency if its judgment is affirmative. Moreover, the Regulations provide the standards relating to the tolerance of frequency that radio stations transmit, the strength of spurious emission and occupied band-windths for the effective utilization of frequencies. The Comité Consultatif Internationale des Radiocommunications (CCIR) acts as an advisory organ for the study of technical matter regarding telecommunications.

In Japan the utilization of radio waves is domestically controlled by the Radio Law, the Broadcast Law as to broadcasting and other special laws in connection with their utilization by ships and aircraft. It is so prescribed in the Radio Law that a license shall be obtained from the Minister of Posts and Telecommunications to establish a radio station. The Law further provides the technical standards of installations which should be observed by radio stations; procedures according to which communication should be conducted, that is, the regulations for operation; and a qualification system for those who are to operate the radio equipment. The Radio Regulatory Bureau and the Regional Radio Regulatory Bureau of the Ministry of Posts and Telecommunications are charged with the business of doing qualification screening for radio stations, and the Radio Regulatory Council is to provide advice and suggestions on the formulation of regulations and the matter relating to licenses for broadcasting stations in compliance with the requests made by the Minister of Posts and Telecommunications. In order to strive for the rational use of radio waves, the Radio Technical Council considers technical matter as requested by the Minister of Posts and Telecommunications. Furthermore, the Radio Research Laboratory of the Ministry of Posts and Telecommunications is doing wide research work about radio waves.

Installations at radio stations must be manufactured in such a manner that they conform to the technical standards provided in Chapter 3 of the Radio Law and the Ordinance of the Ministry of Posts and Telecommunications issued on the basis of a mandate given by the Law. The frequency to be used by a radio station is designated by the Minister of Posts and Telecommunications at the time of obtaining a license. The frequency to be designated is examined according to the frequency allotment list as provided by the Radio Regulations, in consideration of the existing state of frequencies used at home and abroad, and upon international registration as occasion demands, before being allotted to the radio station. The frequencies for use in mobile services in the ocean and air have been considered and arranged in a plan in advance from the nature of the services. Most part of the plan for assignment has been made on an international scale at international conferences. The contents of the plan are included in an appendix to the Radio Regulations and the annexed document 10 of the International Civil Aviation Organization (ICAO). The plan of frequency assignment for broadcasting has also been formed. Although European countries have their own plan with one accord, there is no internationally recognized convention relating to the frequency assignment for broadcasting in Asia, and the plan of assignment laid by Japan has been made from an independent standpoint of Japan in consideration of the existing state of frequencies used in countries around Japan. As for other kinds of services, there is a plan of assignment for them in view of their forms and the assignment is carried out according to that plan for each station. However, there is no such a plan for a certain type of service, so the allotment of frequencies is determined case by case whether it is appropriate or not according to the table. The allotment of frequencies must be conducted so as not to give interference to the existing stations.
As there are several types of interference, namely, co-channel interference, interference of near-by frequency, blocking effect, cross modulation, intermodulation, spurious, etc., one or all of them must be taken into consideration as occasion demands. For this reason, the number of frequencies that can be allotted is quite limited if radio stations with the same frequency band center around the same district.

2-2 International Law of Radio Communications

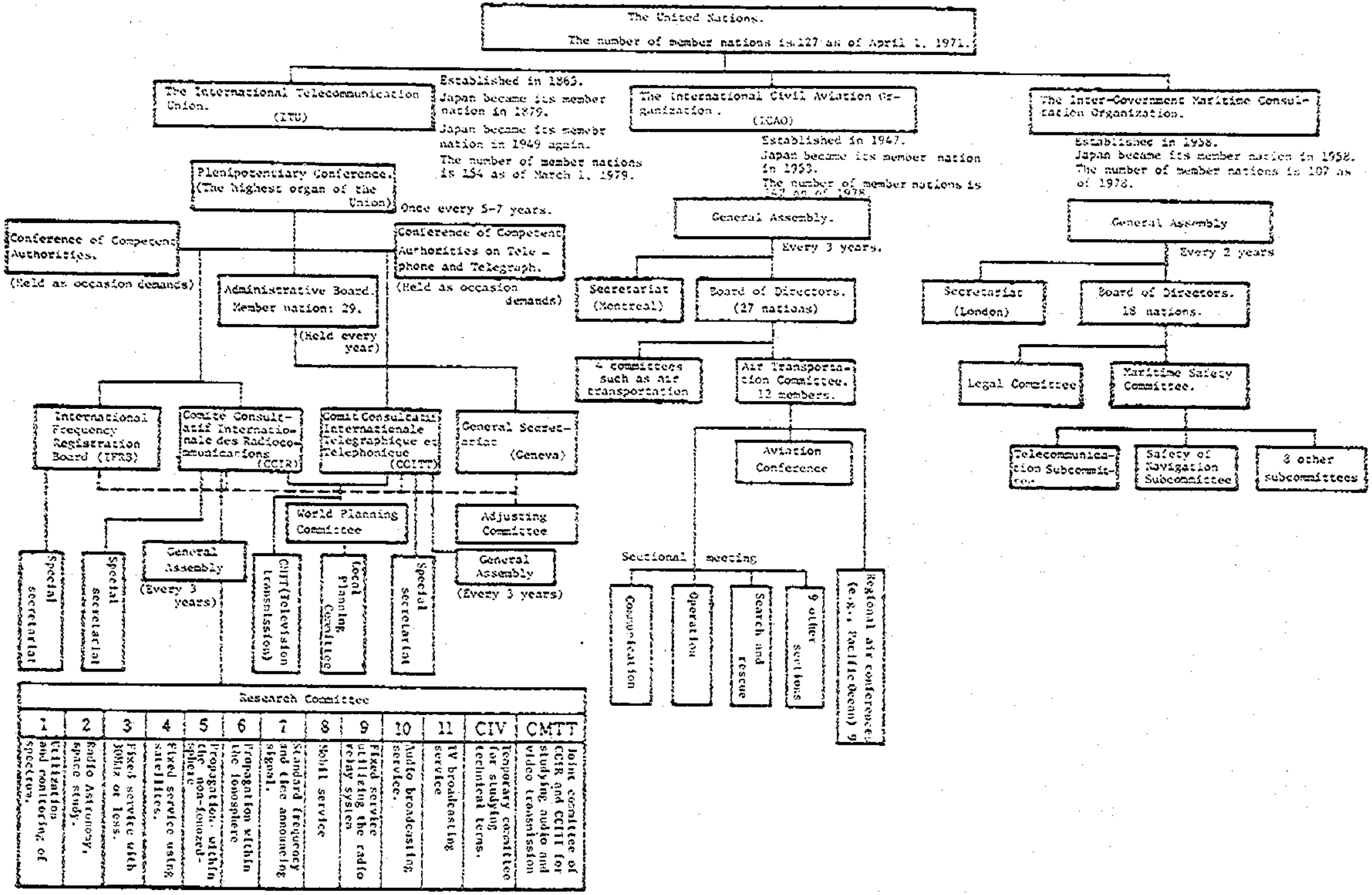
1. International Telecommunication Convention

An international convention relating to radio communications dates back to the International Telegraph Convention Paris in 1865. After the World War II, a new order became firm by the International Telecommunication Convention Atlantic City in 1947, which were partially revised in Buenos Aires in 1952 and in Geneva in 1959. International organizations relating to telecommunications are shown in Fig. 2-1.

Contents of the Convention: As provided in the International Telecommunication Convention, the member nations organize the International Telecommunication Union (ITU). The Union placed in Geneva holds a plenipotentiary conference as the highest decision-making organ, the conference of competent authorities of telecommunications belonging to the Union (the Ministry of Posts and Telecommunications in Japan), and an administrative board that acts as substitute for the plenipotentiary conference between sessions. Moreover, as the permanent organs of the Union, it has a secretary-general; the International Frequency Registration Board (IFRB) constituted by five members; the Comité Consultatif Internationale des Radiocommunications (CCIR) and the Comité Consultatif Internationale Telegraphique et Telephonique (CCITT) as advisory organs. The Convention also provides the general provisions relating to radio communications, and stipulates for the telecommunication networks and equipment required for telecommunications to be installed under the best technical conditions, and that the wisest measures should be taken to operate and maintain the equipment. In addition, it includes special provisions relating to radio communications in which it provides the general rule for limitting the number of frequencies and the spectrum width at a minimum required.

2. Radion Regulations

The Radio Regulations have been enacted on the basis of the International Telecommunication Convention and attached to it. The existing Radio Regulations were settled at the regular conference of competent authorities in Geneva in 1959, and partially revised to include the provisions for space radio communication service in 1963, air mobile service on air lines in 1966, maritime mobile service in 1967 and space radio communication service in 1971. The description of the main point is given as follows:



The United Nations.
The number of member nations is 127 as of April 1, 1971.
The International Telecommunication Union. (ITU)
Established in 1865.
Japan became its member nation in 1879.
Japan became its member nation in 1949 again.
The number of member nations is 154 as of March 1, 1979.
Plenipotentiary Conference. (The highest organ of the Union)
Once every 5-7 years.
Conference of Competent Authorities.
(Held as occasion demands)
Conference of Competent Authorities on Telephone and Telegraph.
(Held as occasion demands)
Administrative Board. Member nation: 29.
(Held every year)
International Frequency Registration Board (IFRB)
Comite Consultatif Internationale des Radiocommunications (CCIR)
Comit Consultatif Internationale Telegraphique et Telephonique (CCITT)
General Secretariat (Geneva)
World Planning Committee
Adjusting Committee
Special secretariat
Special secretariat
General Assembly (Every 3 years)
CMTT(Television transmission)
Local Planning Committee
Special secretariat
General Assembly (Every 3 years)
Research Committee
1 Utilization and monitoring of spectrum.
2 Radio Astronomy, space study.
3 Fixed service with 30MHz or less.
4 Fixed service using satellites.
5 Propagation within the non-ionozed-sphere
6 Propagation within the ionosphere
7 Standard frequency and time announcing signal.
8 Mobil service
9 Fixed service utilizing the radio relay system
10 Audio broadcasting service.
11 TV broadcasting service
CIV Temporary committee for studying technical terms.
CMTT Joint committee of CCIR and CCITT for studying audio and video transmission
The International Civil Aviation Organization. (ICAO)
Established in 1947.
Japan became its member nation in 1953.
The number of member nations is [illegible] as of 1978
General Assembly.
Every 3 years.
Secretariat (Montreal)
Board of Directors. (27 nations)
4 committees such as air transportation
Air Transportation Committee. 12 members.
Aviation Conference
Sectional meeting
Communication
Operation
Search and rescue
9 other sections
Regional air conference (e.g., Pacific Ocean) 9
The Inter-Government Maritime Consultation Organization.
Established in 1958.
Japan became its member nation in 1958.
The number of member nations is 107 as of 1978.
General Assembly
Every 2 years
Secretariat (London)
Board of Directors. 18 nations.
Legal Committee
Maritime Safety Committee.
Telecommunication Subcommittee
Safety of Navigation Subcommittee
8 other subcommittees

Fig. 2-1

Terms and definition: The terms classified into 3 categories, namely, the general terms, terms for radio system and for services and stations in addition to technical charasteristics, and the terms relating to space tele-communications were largely introduced by the revisions in 1963 and 1971.

For example:

Earth station : a station installed on the surface of the earth or in the main part of the troposphere of the earth, which aimed at exchanging communication whith the following stations;

- one or more than two space stations, otherwise
- one or more than two stations of the same type as above utilizing one or more than two passive satellites or objects in space.

Space station: a station outside the main part of the troposphere of the earth or launched to get rid of the troposphere, or installed on the object outside the troposphere.

Geostationary satellite: a satellite having a circular orbit on the equator line of the earth and revolving in the same direction with the same cycle as the earth and rotating around the same axis as the earth.

The orbiting path of a satellite that it should be positioned in order to become a geostationary satellite is called a 'Geostationary Satellite Orbit'.

Other than those mentioned above, radio astronomical stations, satellite communication system, geostationary satellite service, mobile satellite service, broadcasting satellite service, earth search satellite service (including meteorological satellite service) and the adjustment of distances have newly been defined.

Frequency band assignment: According the Radio Regulations, radio waves have been defined as electromagnetic waves with 3,000 GHz or less of frequency, and at the same time frequency band assignment from 10 kHz to 275 GHz has also been determined. Part of frequency bands from 40 GHz to 275 GHz has been allotted to the radio astronomical station service and space communication service in line with the revision of the Regulations in 1971. The Regulations provide the method of assignment common to all areas in the world and a slightly different one by areas, namely, the 1st area (Europe and Africa), the 2nd area (America) and the 3rd area (Asia and Oceania). Furthermore, it provides exceptional cases to cope with special necessities by countries. The use of radio waves is so ordained by the Radio Regulations that it must be subject to what they allot in the fields of maritime mobile, air mobile and space services, and fixed service except for the case in which there is clearly no possibility for the service to interfere with foreign radio stations.

Special provisions for special services : One of the important provisions in the Regulations is that the establishment and use of a broadcasting station installed in a ship or aircraft outside the territory of a nation, or on a floating object in the air (including an audio broadcasting station or TV broadcasting) are prohibited. In the field of air mobil service, the Regulations provide that different frequencies should be used for the R-service in which the safety of navigationa and its normalization are aimed at; and the OR-service in which objects other than the aforementioned are aimed at, and that the electric field intensity suitable for the area should be used as to aeronautical beacons. In the field of maritime mobile service, the Regulations provide provisions detailed according to purposes of employing frequency bands, while reserving the strength of electric fields required for beacons on the surface of the sea. As for the fixed service, the use of double-side band radio telephone with less than 30 MHz has been prohibited since January 1, 1970.

In the field of space service, the position relation if the space radio communication service and the ground radio communication service use the same frequency band at less than 1GHz in addition to the selection of frequency; the limitation of power on the stations for surface service; minimum elevation angle; and the standard of power density are prescbribed. The space station is to be equipped with a device which can immediately suspend the emission of radio waves by instructions given by remotely control.

Notification and registration of frequency : Notification is to be made to the International Frequency Registration Board (IFRB) whenever the use of a frequency may interfere the radio service in foreign countries; when it is used for international radio communications; when international approvals are required. The IFRB will consider the received notification with the specified standard of judgement and register the frequency if it fits the conditions prescribed.

As for the space station, a country who is going to establish a satallite communication system shall, prior to the application for the allotment of a frequency, follow the procedures in 3 steps, namely, the announcement of information beforehand, registration for adjustment, and notification. In other words, the specified items of information must be submitted to the IFRB anytime by the time the adjustment procedures start from the time of 5 years before the commencement of the operation. Moreover, investigation is to be required between the authorities concerned prior to the notification of registration in making an allotment of frequency to the earth station with the frequency band which is commonly shared by the geostationary space station and the earth station; or more than 1GHz commonly shared by the space system and earth communication system.

Management of interference : Detailed provisions are provided for the frequency tolerance of transmitted radio waves, the tolerance of spurious emission and permissible frequency-band width. Furthermore, an international monitoring system is set up so as to make it easier to enforce the Regulations.

Management of radio stations : No transmitting station shall be established and operated by an individual person or firm without a permission given by the country it belongs to. At the same time, the station must be distinguishable by a call sign or other means. The Director-General of the Union shall publish International Frequency Lists, Call Sign Lists, Station Name Lists and Maps of Coast Stations. Operation of radio station transmission work on ships and aircrafts must be conducted by operators bearing certificates verified or supplied by the government that the radio station belongs to.

3. Additional radio regulations

This regulations also is attached to the International Telecommunication Convention, providing the handling methods of telegraph and telephone, and rates as well as the method of settlement.

4. Safety of Life at Sea Convention.

The convention concluded in London in 1960 is in force now. In its Chapter 4 Radio Telegraph and Telephone, provisions stipulate that all ships shall be equipped with radio installations, and that the construction of the equipment and the methods of operating them shall conform to the provisions.

5. International Civil Aviation Organization Convention

The appendix 10 provides radio installations, their construction, frequencies, and operation. The International Civil Aviation Organization (ICAO) has been set up in Montreal of Canada, and the radio communications section under its standing Aviation Committe has its conference as occasion demands to debate the revision of the appendix.

A P P E N D I X

1. Inertial Navigation

Inertial navigation is a method of navigation based on Newtonian physics to be applied to the movement of ships and aircraft. The equation of the Newtonian physics is well known.

$$F = M\alpha$$

Where F is force, M is mass, and α is acceleration.

Or speed is $V = \frac{ds}{dt}$, where s is distance and t is time.

Acceleration $\alpha = \frac{dV}{dt} = \frac{d^2s}{dt^2}$

$$\therefore \quad s = \iint \alpha \, dt$$

$$V = \int \alpha \, dt$$

Therefore, if the acceleration component of a mobile body such as aircraft or ship is measured and integrated by time, its speed will be obtained. If the speed is integrated by time, the distance that the object has moved will be obtained. Since the moving body is actually in motion in 3 dimentions, the measurement and integration of acceleration must be performed in terms of 3-dimension components as shown in Fig. 1. The inertial navigation method looks quite simple in principle, but it is necessary to keep the accelerator ant the supporting table stable, maintain its x axis in the direction of gravitation, and make data calculation. However, that method of navigation actually has been put to practical use in the fields of military missiles, aircraft and ships as the result of research and degelopment work, so utilized in civil aviation is expected. The inertial navigation is a completely selfsupporting navigation method and its merit is characterized by the fact that it does not require radio waves.

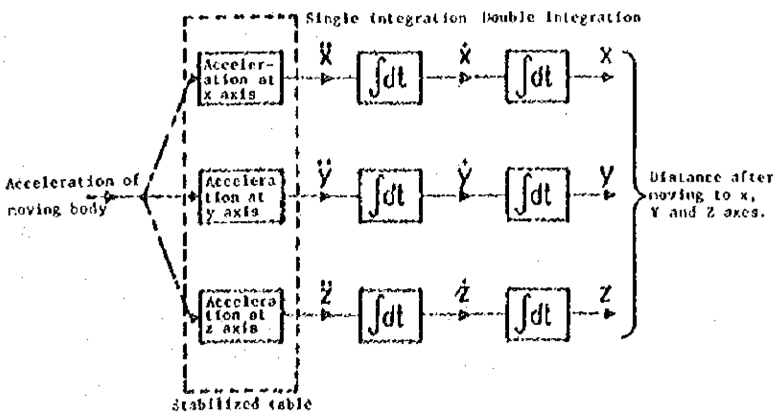


Figure of the principle of inertial navigation

JICA