INTERNATIONAL MEETING ON RADIO AIDS TO MARINE NAVIGATION.

An International Meeting on Radio Aids to Marine Navigation was held in London from 7th to 27th May 1946.

Delegates from the following countries attended : Australia, Belgium, Canada, Denmark, Eire, Finland, France, Greece, India, Italy, Netherlands, Newfoundland, New Zealand, Norway, Poland, Portugal, South Africa, Spain, Sweden, United Kingdom, U.S.A., U.S.S.R. and Yugoslavia.

Vice-Admiral J.D. Nares, the President of the Directing Committee of the International Hydrographic Bureau was invited to attend as an observer, and was present at three of the earlier meetings.

The following extracts from certain papers read during the meeting, or presented thereat, are reproduced by permission of the Chairman, Sir Robert Watson-Watt, on behalf of the British Ministry of Transport and the Admiralty.

J. D. N.

FIRST SERIES.

I.—A technical appreciation of the various Radio Aids to Marine navigation.

(Document No. 28)

PART I.

INTRODUCTION.

1. This document is based on the report of a technical committee representing the Government Departments concerned in the United Kingdom and their scientific research establishments.

2. It summarises the properties of those systems of radio navigational aids which have a possible application to marine use.

3. Part II summarises the principal characteristics of the various systems. These are divided into two groups.

TABLE 1.—*Systems of known performance,* i. e. those which are at present in use (such as Medium Frequency Direction Finding) and those which have been used in operations during the recent war.

TABLE 2.—*Other systems,* i. e. those which have been used in experimental trials and those of which the general principles have been demonstrated or which exist only " on paper ", and for which the figures of performance are known incompletely.

4. Fuller details of the systems are given in Appendices 1 and 2. Appendix 1 gives further details of the system in Table I of Part II ; appendix 2 of those in Table II.

5. This document should be read in conjunction with document No. 8* which discusses the basic navigational problems to which radio aids are applied, and with document No. 30 which outlines the trends of development of radio aids to marine navigation.

6. Reference should also be made to document No. 29 which describes the problems of frequency allocation which arise in connection with radio navigational aids, and document No. 34 which sets out the band widths desirable for each system.

7. No attempt is made in this document to discuss the economic factors which will affect the adoption of any particular system.

PART II.

CHARACTERISTICS OF THE SYSTEMS OF RADIO AID TO MARINE NAVIGATION.

1. Tables I and II summarise the principle characteristics of the various systems.

2. In studying the tables the following *Explanatory notes* should be borne in mind.

NOTE 1. An "elementary" system means the simplest version of the system capable of giving a position line only.

NOTE 2. All distances, except where stated, are in nautical miles (one nautical mile = 1.85 kilometer).

NOTE 3. Under " Performance ", the accuracy of the various systems is given on a statistical basis. Under 50 % zone (columns 8 and 11) and 95 % zone (columns 10 and 12) are given the range of error or inaccuracy, within which 50 % and 95 % of all observations will lie. Except when stated, ***inaccuracies refer to a position line and not to a fix.***

NOTE 4. In column 15, " Possible marine use ", the letters O, L, C and P have the significance : O = Ocean aid ; L = Landfall aid ; C = Coastal navigation aid ; P = Pilotage aid. These terms are more fully discussed in document No. 8.

NOTE 5. The characteristics given in Table I relate to the systems ***as at present used.*** They take no account of possible modifications. The characteristics in Table II are in some cases conjectural.

(*) Not reproduced.

Part II. — TABLE 1

NAVIGATIONAL AIDS OF KNOWN PERFORMANCE (5)

FIGURE IN BRACKETS REFER TO THE EXPLANATORY NOTES (Part II, par. 2).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
						PERFORMANCE									
						DAYTIME			NIGHT TIME						
Reference Letter in Appendix 1	SYSTEM	GENERAL METHOD	FREQUENCY BAND (General) (8)	No. of channels required for elementary system (1)	Power of transmitting system (9)	Range (2) (over sea)	Limits of inaccuracy (3) 50 % Zone	Limits of inaccuracy (3) 95 % Zone	Range (2) (over sea)	Limits of inaccuracy (3) 50 % Zone	Limits of inaccuracy (3) 95 % Zone	REMARKS on Performances	Is accuracy controlled mainly by the shipborne equipment	Possible Marine Use (4)	GENERAL REMARKS
(a)	M.F. D/F shipborne	Loop Type D/F	250-600 kc/s	1	»	300 miles	1°	3°	25 miles	1°	3°	Ground ray only	Yes	L.	Reliable only within ground ray range.
(b)	M.F. D/F shorebased	Adcock D/F	300-600 kc/s	1	»	500 miles	0.7°	2°	100 miles 100-500 miles over 500 miles	0.7° 1.4° 0.7°	2° 4° 2°	Applies to a good site	No	O.L.	Two-way communication channel necessary.
(c)	M.F. D/F shorebased	Loop Type D/F	300-600 kc/s	1	»	300 miles	0.7°	2°	25 miles	0.7°	2°	Ground ray only	No	L.	Two-way communication channel necessary.
(d)	ROTATING M.F. BEACON	Rotating loop aerial C.W. or M.C.W.	300 kc/s	1	1.5 kw.	300 miles	1°	3°	25 miles	1°	3°	Ground ray only	No	L.	
(e)	GEE	Pulse, time difference	20-85 Mc/s	1	300 kw. (peak)	100 miles	0.3 % of range	0.8 % of range				Day and night the same (6) (7)	No	L.C.	Range depends on height of transmitter aerial.
(f)	STANDARD LORAN	Pulse, time difference	1,750-1,950 kc/s	1	100 kw. (peak)	600 miles	0.2 % of range	0.6 % of range	0-500 miles 500-1,200 miles	As for daytime 0.3 % of range	0.9 % of range	(6) (7)	No	O.L.C.	
(g)	DECCA	C.W. phase comparison. Multiplicity of frequencies.	80-150 kc/s	2	2 kw. (C.W.)	300 miles 300-1,000 miles	0.02° lower but useful accuracy obtainable	0.05°	0-75 miles 75-200 miles over 200 miles	Effectively as for day. Appreciably poorer than for day. Serious errors due to possibility of " lane slipping " at ranges over 250 miles.		Full performance figures not yet available. (6) (7)	No	O.L.C.P.	Use as Ocean or landfall aid awaits completely satisfactory system of Lane Identification. Pilotage facilities limited to within about 50 miles from centre of chain.
(h)	CONSOL	Mod. C.w. Rotating equisignal pattern.	200-500 kc/s	1	2 kw. (C.W.)	1,500 miles	0.2°	0.6°	25-50 miles 300-500 miles	As for daytime 0.5°	1.7°	At night bearings are subject to bias as well as fluctuations shown. (7)	No	O.L.	Minimum range of 25 miles within which the system cannot be used.
(i)	RADAR (shipborne) to U.K. specification	Pulsed radar, P.P.I. display.	9,000-10,000 Mc/s	1	30 kw. (peak)	Minimum range = 50 yards. Discrimination = 50 yards in range. — = 2° in bearing.				±25 yards	±50 yards 1°	On largest scale bearing accuracy.	Yes	C.P.	Merchant ships radar to the U.K. specification.
(j)	RADAR (shipborne) Type 268	Pulsed radar, P.P.I. display.	9,000-10,000 Mc/s	1	30 kw. (peak)	Minimum range = 500 yards. Discrimination = 200 yards in range. — = 2° in bearing.					± 100 yds ± 3°	On largest scale bearing accuracy.	Yes	C.	Type of P.P.I. radar set at present on loan to merchant ship.
(k)	RADAR BEACONS	Pulsed responder beacon.	9,000-10,000 150-200 Mc/s	1 or 2	10 kw. 30 watts (peak)	Performance controlled substantially by the shipborne radar.							No	C.P.	Requires additional receiving equipment in the ships.
(l)	LEADER CABLES	L.F. Induction field	20 c/s — 5 kc/s	1	about 1 kw.	Range of 400 yards off the cable. Course relative to the cable can be determined to an accuracy comparable with the steering limitations.							Yes	P.	Vulnerability of cable to displacement largely overcome by modern methods.

OTHER SYSTEMS

PART II. — TABLE 2

FIGURE IN BRACKETS REFER TO THE EXPLANATORY NOTES (Part II, par. 2).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
						PERFORMANCE									
						DAYTIME			NIGHT TIME						
							Limits of inaccuracy (3)			**Limits of inaccuracy** (3)					
Reference Letter in Appendix 2	SYSTEM	GENERAL METHOD	FREQUENCY BAND (General) (8)	No. of channels required for elementary system (1)	Power of transmitting system (9)	**Range** (2) (over sea)	50 % Zone	95 % Zone	**Range** (2) (over sea)	50 % Zone	95 % Zone	REMARKS on Performances	Is accuracy controlled mainly by the shipborne equipment	Possible Marine Use (4)	**GENERAL REMARKS**
(a)	L.F. LORAN	Pulse, time difference	180 kc/s	1	100 kw. (peak)	1,500 miles	0.3 % of range	1.0 % of range	3,000 miles	No sufficient data		»	No	O.L.	Has had experimental trials.
(b)	P.O.P.I. (General)	C.W. Phase comparison. Time multiplex.	Any	1	»	Would depend on the region of the frequency spectrum chosen. Accuracy comparable with DECCA should be possible.						»	No	O.L.C.P.	General principles have been demonstrated experimentally. All four functions will not usually be fulfilled by one ground installation.
(c)	P.O.P.I. 3-element beacon	C.W. Phase comparison. Time multiplex.	200-500 kc/s	1	2 kw. (C.W.)	1,500 miles	0.7°	2°	0-100 miles 100-500 miles 500-1,500 miles	As for day time 1.5° 0.7°	 4° 2°	»	No	O.L.	General principles have been demonstrated experimentally.
(d)	FLETCHER SYSTEM	C.W. Phase comparison. Frequency multiplex.	Any	1	»	Would depend on the region of the frequency spectrum chosen. Accuracy comparable with DECCA should be possible.						»	No	O.L.C.P.	Principles have been demonstrated. All four functions will not usually be fulfilled by one ground installation.
(e)	LONG RANGE H.F. SYSTEMS	Rotating polar diagram, probably equisignal.	3-20 Mc/s	1	»	750 miles or over	0.3°	1.0°	750 miles or ever	0.5°	2°	Less accurate at ranges below 500 miles.	No	O.	Subject to the vagaries (fade-outs, etc.) and advantages of H.F. communication. Have had experimental trials in Germany.
(f)	VERY LOW FREQUENCY DECCA	C.W. phase comparison. Multiplicity of frequencies.	10-35 kc/s	2	of the order of 100 kw. (C.W.)	150 miles	0.03 miles	0.1 miles	150 miles	As for day time		»	No	O.L.C.	Transmitters would require elaborate aerial systems.
						Ranges of 1,000 miles or more	Long range (day and night) performance not known, but night approach 1 % of range (95 % Zone). Performance at intermediate ranges is uncertain.								
(g)	RADIO LIGHTHOUSE	Rotating modulated beacon.	3,000-10,000 Mc/s	1	»	Optical, say 25 miles	1°	3°	As for day time			Performance figures based on timing by stop-watch. (See appendix 2 and docum. 30.)	No	C.	On paper only. Accuracy slightly lower than that required for Coastal Aid (4). Intended for small coastal shipping.
(h)	V.H.F. PILOTAGE AID	C.W. phase comparison **or** pulse, time difference.	20-200 Mc/s	1 — 3	»	50 miles	0.01°	0.02°	Day and night performance similar.				No	C.P.	On paper only.
						The figures quoted refer to the reported accuracy of the German ERIKA system. The actual performance would depend on factors not yet accurately known.									

NOTE 6. In systems defining hyperbolic position lines (e. g. Gee, Loran, Decca, etc.) the coverage of an "elementary" system consists of two sectors of about 120° wide centred on the right bisector of the base line.

NOTE 7. Performance data for hyperbolic systems are given for a course 30° from the normal to the base line. For these systems accuracy falls off at the edge of cover and for complete information on performance the appendices must be consulted.

NOTE 8. It has not been found practicable to include in the Tables themselves any simple statement as to the band width required for each system. The band width required depends in many cases on the nature of adjacent transmissions and on the degree of specialisation permitted in the receiver. In the case of pulse systems a proper measure of the total band width occupied must take into account the possibility of using the same band several times over by the use of several different pulse recurrence rates. This subject is further discussed in document No. 34. The problems of frequency allocation are discussed in document No. 29.

NOTE 9. The power quoted in column 6 of the Tables is the power generated by the transmitter. It is not necessarily the power radiated in all cases.

3. Figures in brackets in the tables, e.g. (6), refer to these notes.

MEDIUM FREQUENCY DIRECTION FINDING (Shipborne).

1. General description of the system.

1° The collector system normally employed in ships is of the loop type, either rotating or a fixed pair with a goniometer.

2° This apparatus is capable of taking bearings on any suitably situated transmitter and can be designed for any frequency band in the range 15-1,000 kc/s. Commercial equipment is normally limited to covering the Beacon bands and the International Distress Wave, say, 250-600 kc/s.

2. Facilities and limitations.

1° The equipment provides a line of bearing relative to some fixed point in the ship, on the selected transmitter. To convert to a true bearing the ship's heading must be taken into account ; where repeater compasses are fitted this can be done automatically.

2° The directional properties are affected by the metallic masses of the ship in a manner similar to a magnetic compass and must be calibrated (just as a compass must be "swung") and corrections applied. These corrections may be changed by changes in the ship's superstructure or, unlike a magnetic compass, by the freeboard.

3° Bearings can be taken on another ship's transmitter, which is useful in the case of distress signals and also in the fishing industry. Measurement is completely controlled from the ship.

3. Operation and presentation.

1° Presentation on most commercial instruments has been by means of a bearing pointer and scale, set by an aural minimum method. It is usually necessary to resolve an ambiguity of 180° in a separate operation.

2° Automatic presentation, either by scale or pointer or by cathode ray tube, is quite possible. These systems, however, are usually more seriously affected by the presence of interference than are aural systems.

3° In any case it is necessary to read the call sign of the transmitter in order to use the bearing. This call sign is sent in slow morse on most "Beacon" transmitters.

4. Accuracy and range characteristics.

1° The accuracy on a pure ground wave signal is limited only by the instrument and the effects of the ship. The standard of accuracy which can be obtained is of the order of $\pm 1°$ for 50 % of observations and $\pm 3°$ for 95 % probability.

2° The ranges within which this condition can be realised are usually taken as 100 miles by day, but may be 2 or 3 times this range, and 25 miles by night.

5. **Complexity.**

1° The measuring equipment is fitted in the ship, this *can* be quite simple in character but to obtain the best results a first quality instrument must be provided.

2° The shore equipment is simple, only a medium frequency transmitter being required.

MEDIUM FREQUENCY DIRECTION FINDING (Shorebased).

1. **General description of the system.**

1° There are two systems in general use :—

a) Large Loop type collectors ;
b) Adcock type collectors.

2° The frequency band used is 375 to 500 kc/s.

2. **Facilities and limitations.**

1° The system provides a line of true bearing from a fixed point ashore to the vessel requesting the bearing.

2° Such a bearing can be provided for any ship carrying a Medium Frequency transmitter and receiver and is independent of the rig, etc., of the ship, provided adequate power is radiated. All measuring is done ashore, the answer only being passed to the ship. This greatly simplifies operation and the equipment in the ship.

3. **Operation and presentation.**

No special operation in the ship is required and the bearing is presented in the form of a morse or R/T signal, usually morse.

4. **Accuracy and range characteristics.**

1° The accuracy and range characteristics depend on the system adopted and can best be seen from the following table.

Suitability of site	Sector in which data applies	ADCOCK				LARGE LOOPS			
		Day		Night		Day		Night	
		Range in miles	Limits of inaccuracy 95 % zone	Range in miles	Limits of inaccuracy 95 % zone	Range in miles	Limits of inaccuracy 95 % zone	Range in miles	Limits of inaccuracy 95 % zone
GOOD.........	360°	0-500	2°	0-100 100-500 500 and over	2° 4° 2°	0-300	2°	0-25	2°
FAIRLY GOOD...	270°	0-500	4°	0-100 100-500 500 and upwards	± 4 ± 6 ± 4	0-300	2°	0-25	2°

2° These figures assume careful installation, calibration and maintenance.

5. **Complexity.**

1° Shore equipment comprises standard fixed aerial direction finding systems together with radio communication equipment.

2° A continuous watch must be kept during the operating period.

3° Shipborne equipment requires nothing but a transmitter and a receiver operating on the communication channel.

ROTATING M. F. BEACON.

1. **General description of the system.**

This system comprises a continuously rotating closed loop aerial fed from a C. W. transmitter. A characteristic signal (or signals) is emitted when the zero of the polar diagram lies along some specified direction (or directions). The beacon operates in the region of the

M.F. beacon band ; the only existing rotating M.F. beacon in Great Britain (Orfordness) uses a frequency of 288.5 kc/s. and a power of 1.5 kw. The speed of rotation is once per minute.

2. **Facilities and limitations.**

The system gives a line bearing from the beacon. Two occasions of minimum signal are heard during each rotation. Thus it is possible to make two determinations of bearing per minute so long as the beacon is radiating the required signals. Resolution of the 180° bearing ambiguity is not provided for in the signals emitted.

3. **Operation and presentation.**

Observations are made by timing the interval between the characteristic zero marking signal and the instant of reception of minimum signal with the aid of a stopwatch which for convenience may have a dial calibrated directly in degrees of bearing.

4. **Accuracy and range characteristics.**

The accuracy and range characteristics are essentially similar to those of a shore-based M.F. loop type direction finder, providing account is taken of the possible errors of making the time measurement with a stop-watch. Thus the day and night ranges are as for loop type M.F., D.F. viz., 100-300 miles by day and 25 miles by night. Within these ranges the accuracy obtainable can be given as a 1° for 50 % of the observations and 3° for 95 % of the observations.

5. **Complexity.**

1° The beacon comprises a medium powered transmitter (1.5 kw.) and a rotating loop aerial together with automatic keying arrangements. The driving mechanism for the loop aerial must be capable of giving essentially uniform speed of rotation.

2° The receiving equipment required is extremely simple, comprising only a receiver covering the required frequency band and a stopwatch.

GEE.

1. **General description of the system.**

1° Gee is a system of radio position finding which can be used by an unlimited number of ships and aircraft simultaneously. Three ground stations sited about 70 miles apart are employed to obtain a fix, two stations only being required for a position line. These ground stations radiate a steady succession of pulses, which are received in the craft and displayed on a cathode ray indicator. The time interval between the arrival of a pulse from the central or Master station and a pulse from each of the slave stations is measured on this indicator. Hence, the lines of position generated by each pair of stations are hyperbolae with the stations as foci.

2° The system operates in the band 20-85 Mc/sec. All stations of one chain are on the same radio frequency and selection of chains is by change of receiver tuning in the craft. It is possible to operate a number of neighbouring chains on the same radio frequency and to identify these chains by employing different pulse recurrent rates, but this has not yet been done. A further check of chain identity is by coding of the master station transmission.

3° The permanent ground stations radiate pulses of 5 microseconds duration rising in 3/4 microsecond with a peak amplitude of 300 kw. Master stations radiate 500 pulses per second and slaves 250 per second.

2. **Facilities and limitations.**

1° The equipment may be operated in two ways, viz :—

(a) To determine the position of the craft at a chosen instant. This position being known 1 minute after the observation is made.

(b) To enable the craft to home to any point by travelling along Gee position line. Arrival at the chosen point may be determined by intersection with another Gee position line or by landfall.

2° Sector Coverage. The coverage of an elementary Gee system consisting of 2 stations only comprises two sectors of about 120° wide centred on the right bisector of the base line.

3. **Operation and presentation.**

Presentation is on a cathode ray indicator on which pulses from Master and slave stations are aligned by operation of control knobs and switches. After alignment the pulses are cleared from the time base and replaced by calibration markers closely resembling a ruler. Two numbers are thus obtained and plotted on a chart over printed with a hyperbolic lattice. The fix obtained refers to the instant of alignment of the received pulses, a time which should be noted. The process of resolving and plotting the fix may be completed at leisure and normally takes about one minute.

4. **Accuracy and range characteristics.**

1° For surface craft a range of 100 miles from any station of a chain is normal with a transmitter aerial height of the order of 300-400 ft. above sea level.

2° Accuracy of position line is about ± 0.3 % of range from the mid-point of the baseline for 50 % probability and about ± 0.8 % for 95 % probability.

5. **Complexity.**

1° The equipment carried in the craft consists of two boxes 9" × 12" × 10" and 9" × 8" × 18", weighing 70 lbs. total, and consuming 250 watts of 80 volts, 1000 cycles power.

2° An alternative equipment operating from 230 volts, 50 cycles power is available; this uses an additional unit to supply power weighing another 70 lbs. approximately.

3° The installation contains about 35 valves.

4° Ground station equipment. Permanent Gee ground stations consist of a pulse transmitter and in a slave station additional timing equipment. Assuming 100 % spare equipment all the technical gear can be housed in a building about 20 feet by 60 feet.

5° Simple aerial systems are mounted on a mast which can be from 100 to 300 feet in height according to the nature of the site and the coverage required. It has been found that the system can be operated satisfactorily with a two man watch system. This means that there must be a total of six technical men per station but only three need be highly skilled.

STANDARD LORAN.

(Ground wave synchronised)

1. **General description of the system.**

Loran is a long range navigational aid employing pulse transmitters sited 200 to 600 miles apart to provide hyperbolic position lines as in Gee. The stations operate in pairs and it is necessary to obtain reading from two pairs of stations to determine a fix. The stations radiate pulses of 50 microseconds duration with a peak power of 100 kw. at a recurrence rate of 25 pulses per second. The radio frequency employed is about 2.0 Mc/sec. and selection of chains is by change of recurrence frequency. Sixteen recurrence rates and three radio frequencies are provided giving a total of 48 channels, which are sufficient for global coverage. The whole of the North Atlantic and most of the Pacific Ocean are already covered.

2. **Facilities and limitations.**

1° The equipment provides position lines only, which may be combined, allowing for distance run, to obtain a fix.

2° Care must be taken during interpretation of the display, owing to the multiple skywave signals received, particularly at night. Training of operators must be thorough. Stations must be sited near the coast.

3° The sector coverage for each pair consists of two sectors of about 120 degrees centred on a line normal to the centre of the base line.

3. **Operation and presentation.**

Presentation is similar to Gee but only one pair of stations is visible at a time. The time interval between arrival of pairs of pulses being measured by means of a cathode ray tube and calibration marks. The readings are plotted on charts overprinted with hyperbolic lattices.

4. **Accuracy and range characteristics.**

1° The range of the system over the sea is approximately 600 miles by day. At night the range is increased to 1200 miles by the use of sky wave signals.

2° The accuracy can be expressed as a percentage of range but is different for ground and sky wave reception by a varying factor dependent upon the distance off the normal.

Daylight accuracies :

For 50 % readings, on ground wave reception, ± 0.2 % of range.
For 95 % of readings, approximately ± 0.6 % of range.

Night time accuracies :

For night-time the figures are the same as for daytime up to approximately 500 miles. From 500-1200 miles the accuracy will be : for 50 %, ± 0.3 % of range; for 95 %, ± 0.9 % of range.

3° These figures apply within 30° of the normal to the base line. At the edge of cover (60° off the normal) the inaccuracy at night is about twice as great.

5. **Complexity.**

Three forms of equipment are available, two intended for use in aircraft and the third for ships :—

AN/APN-4 (Aircraft set) : Two units 9" × 12" × 18" and 9" × 8" × 18" weighing 70 lbs. and using 250 watts at 80 or 115 volts, 400 to 2000 cycles. Interchangeable with Gee. This equipment uses 43 valves.

AN/APN-9 (Aircraft set) : Single units 9" × 12" × 18" weighing 35 lbs. Power supply 225 watts, 80 or 115 volts, 400 to 2000 cycles.—This equipment uses 35 valves.

DAS-2 (Ship set) : Constructed in more robust fashion than airborne equipments. Operates on 50 or 60 cycles power supply. Size approximately 24" cube. This equipment uses approximately 45 valves.

6. **Ground equipment.**

1° The technical equipment at a Loran ground station is similar to that employed for Gee, and can easily be contained in a building 20 feet by 60 feet.

2° Te transmitting aerial can be supported by a 105 or 120 foot tower with, where possible, a 300 foot earth mat system. A similar or slightly smaller aerial system is required for the Loran ground receiver.

3° A station crew must provide four men per watch of whom two must perform continuous tube monitor watching.

DECCA NAVIGATOR.

(*M.F. Decca*)

1. **General description of the system.**

1° The Decca Navigation System consists of a chain or a number of chains of transmitting radio beacons, each chain consisting of a master transmitter and two or more slaves controlled by the master transmissions. These stations are placed at intervals of 50 to 60 miles. The system is at present operated in the low frequency band (80-150 kc./sec.). Transmissions consist of steady unmodulated C.W. with a transmitter power of the order of 2 kilowatts. Each beacon has its own frequency, the frequency of the slaves being related to that of the master in a simple ratio such as 4:3 or 3:2 and the signals are locked in phase.The user, by means of a multi-channel receiver measures the phase difference between the master-slave pairs of transmitters at the Lowest Common Multiple Frequency or "comparison" frequency of each pair. It is possible to relate this phase difference to a distance difference between stations and the receiver, so enabling one to locate the receiver on one of a number of hyperbolic lines of position or "lanes" for each station pair. The lanes can be computed and drawn in as a lattice on a standard navigational chart.

2° A "chain" of three stations is necessary to give a "fix". In some circumstances a fourth station in the same chain is necessary to give 360° coverage.

2. **Facilities and limitations.**

1° Decca provides a continuous means of plotting the instantaneous position and movements of the ship and aircraft relative to the radiation patterns. In its present form it suffers from a high degree of ambiguity. Since it is a continuous reading device, this can be partly overcome if it is required to navigate only from a known position inside the service range of the stations, and to remain inside this area. However, in the event of temporary failure of transmission service or receiving equipment, or in the case of the user entering the system from outside the service range there is no means within the system of setting up the receiver to give the correct plot.

2° A system of " lane identification " to resolve this ambiguity is still in the development stages.

3° The system is affected by the presence of sky waves, the accuracy of the received signals and their stability being successively more disturbed as the range from the beacons is increased.

4° There is some evidence that mountainous land in the vicinity of the receiver can have an adverse effect on the high accuracy of the radiation pattern—similarly some limitations may be imposed on the siting of beacons for the same reason ; this matter is still to be investigated fully. The coverage of a pair of stations is limited to a zone approx. $\pm 60°$ about the right bisector of the base line, the base line extensions being useless for navigation.

3. Operation and presentation.

In the receiver the phase difference between signals from a pair of stations as measured at the comparison frequency is shown on the phase meter or " decometer ". This meter has geared counter dials connected so that it can integrate the movements in the radiation pattern in terms of " lanes " as shown on the chart. Once the receiver is switched on and warmed up, and the counters are set to the appropriate whole number of lanes corresponding to the receiver's position on the lattice of the chart, then the indicator meter will automatically record the movements in terms of lanes and fractions of lanes. The receiver includes test facilities to ensure that the radio frequency channels are all in correct alignment and also that the signals are all being received correctly at any instant.

4. Accuracy and range characteristics.

1° Along the base line between the stations the width of one lane corresponds to one half wavelength at the comparison frequency. The overall instrumental accuracy is about 0.02 lanes, which corresponds to about 10 yards of position on the base line.

2° Because of the divergence of the pattern the corresponding values at 100 miles and 200 miles are in the region of 40 and 80 yards, respectively with normal station separation. This does not take into account any distortion of the radiation pattern due to secondary or reflected signals such as can appear in the vicinity of mountainous terrain. Nor is it certain that the propagation conditions over all parts of terrain will permit the limits of the instrumental accuracy to be achieved.

3° In daytime, within a range of 300 miles, 95 % of the observations are accurate to within four or five times the instrumental accuracy and 50 % within one or two times the instrumental accuracy as specified above. Useful but reduced accuracy may be obtained at ranges exceeding 300 miles up to the order of 1000 miles.

4° At night the incidence of sky waves has a very appreciable effect on the accuracy obtainable except at the shorter ranges. At ranges up to 75-100 miles the effects of the sky waves are likely to be inappreciable, and between 75-100 miles and 200-250 miles appreciable. Beyond 250 miles there is a possibility of the occurrence of " lane-slipping " (a convenient expression to describe the phenomenon of the irrecoverable loss of one or more lanes due to interference phenomena between ground and sky waves). This possibility becomes serious beyond about 300 miles. Precise performance figures, particularly relating to night-time, are not at present available.

5. Complexity.

1° A Decca chain will consist of three or more transmitting stations with fair sized aerial systems. The control gear at each station is fairly complex to build but it is almost entirely automatic in operation. In addition it is necessary to provide a remote receiving station to act as a control on the accuracy of the radiated pattern. No continuous manual operation is involved at the transmitters, a station watch of two men being required.

2° A special multi-channel receiver of high sensitivity is required. This would contain 35-40 valves if used on a 3-station chain, and 45-50 valves for use on a 4-station chain, with additional valves when a method of " lane identification " is in operation.

CONSOL.

1. **General description of the system.**

1° The Consol Ground Station radiates dot and dash signals and a position line can be determined by making a count of the dot and dash characters heard during the transmission period of one minute. By reference to a map overprinted with the Consol lattice it is possible to establish that the observer is accurately located on one of five alternative position lines in each coverage sector of 120 degrees, those position lines being located approximately 20° apart. Should the observer be in doubt on which position line he is located all bearings except the correct one can be eliminated by taking a rough bearing of the ground station with the D/F loop, the accurate value of the position line being established from the dot and dash counts. The observer can then establish his position by reference to two independently operated Consol Ground Stations.

2° Frequency Band	200-250 kc/s.
Channel Spacing	2 kc/s.
Ground Transmitter Power	2 kw. C.W.

2. **Facilities and limitations.**

The Consol Radio Navigation system provides long distance bearing indication by the reception of dot and dash signals on any type of medium frequency communication receiver suitable for C.W. reception. Consol provides navigation facilities up to distances of about 1,500 miles over the sea and 1,000 miles over the land under favourable conditions. The coverage area comprises two sectors of 120° centred on the normal to the aerial system. The type of position lines are great circles. The number of ground stations required for a fix is two. Lattice charts are not essential as the position lines are in the form of great circles. The minimum range of Consol is 25 miles within which the system is not usable.

3. **Operation and presentation.**

1° Operation is very simple and demands only elementary training. Presentation is aural reception of dots and dashes. Counting of 60 characters comprising dots and dashes and referring to a map overprinted with the Consol lattice enables a position line to be located. Lattice charts are not essential as the position lines are in the form of great circles.

2° To determine such a position line will take about a minute and a fix about three minutes. There are five ambiguities in each sector of 120° which are resolved by D.R. or loop bearing.

3° An automatic recorder is being developed which will record the counts for several hours without attention.

4. **Accuracy and range characteristics.**

1° Daytime accuracy :—

50 % of readings, 0.2° at the normal, and 0.4° at edge of cover.
95 % of readings, 0.5° at the normal, and 1° at edge of cover.

2° Night-time accuracy : At night-time when there is appreciable sky-wave present owing to the difference in the radiation pattern for ground and sky-waves bearings receive a mean shift towards the normal in addition to fluctuations about the mean. Random errors are liable to be largest in the region where ground and sky-waves are of comparable amplitude. Present indications are that at ranges of the order of 350-450 miles, which is approximately the range at which the sky-wave will be equal to the ground wave, the performance will be as follows :—

Fluctuations about the mean :

50 % of readings : 0.2° near normal rising to 1.5° at edge of coverage ;
95 % of readings : 0.8° near normal rising to 5° at edge of coverage.

3° The bias or error of the mean, will be zero at the normal rising to 3° at edge of coverage.

5. **Complexity.**

1° Any suitable receiver can be used, preferably with a high selectivity characteristic, e. g., crystal gate I.F. The estimated power consumption is 120 watts. The receiver bandwidth is 0.2 kc/s approximately.

2° The aerial used is "T", inverted "L" or vertical wire. A D/F loop may be required to resolve ambiguities.

3° Ground station comprises three vertical mast radiators spaced in line about 1.5 miles apart and fed throught transmission lines from a centrally located 2 kw. transmitter. With the transmitter is associated a control unit which distributes the power in appropriate amplitude and phase to the three aerials, keys the transmissions and rotates the field pattern electronically in accordance with the cycle of operation.

4° Aural signals are received from distant located monitor which enables the station operator to adjust manually the phase of the transmissions to provide the correct directional characteristic.

P.P.I. RADAR.

(Shipborne)

1. General description of the system.

1° A P.P.I. radar set carried by the ship can be of great assistance in navigation and pilotage, by giving a plan view of all objects in the neighbourhood of the ship. For really satisfactory assistance in the pilotage of close waters, radar capable of high discrimination is required, and will be provided by a prototype set meeting the U.K. Performance Specification. (See document No. 35.)

2° Since, however, many ships will be fitted with Naval Type 268 sets, it is necessary to refer to the principal characteristics of this type also.

	U.K. Specification	Type 268
Frequency bands in Mc/sec.	9425—9525	9320—9475
Pulse width	0.2 microseconds	0.75 microseconds
Pulse rep. freq. (P.R.F.)	1,000 p. s.	500 p. s.
Peak power	30 kw.	30 kw.
Minimum range	50 yards	500 yards
Aerial beamwidth horizontal	2°	4°
Aerial beamwidth vertical	35°	17°
Aerial speed	20-70 r. p. m.	22 r. p. m.
D.C. Power required	4 kw.	5 kw.

2. Facilities and limitations.

1° Plan displays, with scales ranging from 1:30,000 to 1:600,000, the largest scale facilitating discrimination between numerous objects in close waters, and the smallest permitting ranging on distant land (Type 268 has, 1:100,000 to 1:1,000,000). The minimum range of perception of small objects is 50 yards (Type 268-500 yards), with provision for countering the effect of sea-wave clutter (not in Type 268). Discrimination between objects lying 50 yards apart in range or 2° apart in bearing at the same range (Type 268—200 yards and 4°).

2° Except in the vicinity of recognisable land features radar is unable to indicate absolute position without ancillary devices, which must be provided in certain positions if the full advantage of radar is to be obtained.

3° Where power supplies and maintenance staff are available, radar or radar beacons can be used. For estuary navigation buoys arranged in geometrical patterns and fitted with special reflectors to increase the detection range, have been found very satisfactory. A pentagonal or hexagonal cluster, of corner reflectors (each of 2 foot side) is found to have a service area of about 5 miles radius when mounted at a height of 12 feet.

3. Method of operation and presentation.

The prototype set will have all the essential controls (whose number will be as small as possible) at the main display on the bridge, and the main panels will run unattended ; thus no radar operator will be required (Type 268—operator is required at the mains panels). Means will be provided for monitoring the performance of the radar from the main display (not provided in Type 268). An auxiliary display whose purpose is to facilitate comparison between the radar picture and the chart will also be available with the prototype and is considered to be an important aid to pilotage Type 268 provides a second display exactly similar to, and controlled by the main display.

4. Accuracies and range characteristics.

1° When using the largest scale, the position of the ship can be determined with reference to a nearly buoy or ship with an accuracy of ± 25 yards for 50 % of readings, and approximately ± 50 yards for 95 % (Type 268—having no strobe ranging unit when fitted in Merchant ships gives approximately ± 100 yards). When using the smallest scale, position can be determined relative to distance with an accuracy of ± 200 yards for 50 %, ± 300 yards for 95 % (Type 268—approximately 500 yards).

2° The following ranges have been obtained on trials with equipment similar to the U.K. set (aerial height 52 feet).

	50 % Chance	95 % Chance
2nd Class buoy	2 ½ miles	1 ¾ miles
1,000 tons ship	6 ½ —	5 —
10,000 tons ship	13 —	10 —
20 foot slope	7 ¼ —	5 ¾ —
100 foot cliffs	12 —	10 ½ —

(Range performance for type 268 is similar).

Bearing accuracy ± 1°, for 95 % readings (Type 268 ± 3°).

5. **Complexity.**

Some effort has been devoted in the prototype set to making the equipment easy to service. Any high performance radar must necessarily be relatively complex, however, and indeed some of the measures for ease of maintenance involve added complexity (e. g. monitoring system). The aim was to make a radar which could run for, say, 1,000 hours without servicing ; this is no doubt possible, but it cannot be said to have been achieved yet.

6. **Details of the pilot model prototype radar set developed at the Admiralty Signal Establishment to meet the U.K. Specification.**

1° Aerial.—Single cheese 5 foot wide by 3 inches high ; Horizontal beam width ± 1°; Vertical beam width ± 20° ; Rotational speed 20 to 70 r.p.m. variable for trials ; Ahead contact making over 1/2° ; Astern contact making over 15° approximate.

2° Main Panels :—

1. *Modulator VX*-4024 : Hydrogen Thyratron with discharge line ; Pulse length 1/4 microsecond ; Pulse power 150 kw. balanced output ; Repetition frequency 1,000 p.p.s. ; Motor alternator 220 volts D.C., 180 volts, 500 c/s A.C.

2. *R.F. Head :* Magnetron CV 353, delivering approximately 35 kw. pulse; T/R cell CV 221 ; T/B cell VX 363 ; Local oscillator 723 A/B Later to be VX 5001 ; Signal crystal CV 253 ; A.F.C. crystal CV 253 ; Four valve A.F.C. unit and four valve I.F. head amplifier incorporated in chassis ; Forwards and backwards power metering included.

3. *Power Pack :* Provides supplies for all the units, except filament voltages and the E.H.T. for display. Incorporates main I.F. amplifier, with outputs at I.F. for the two displays. Instantaneous Automatic Gain Control (I.A.G.C.) and Swept Gain both provided for trials.

4. *Control Unit :* Incorporates motor alternator starter and carbon pile voltage regulator, automatic delay unit for bringing on H.T. to the modulator, blower for the magnetron and the waveguide drying, automatic monitoring selector and amplifier.

5. *Main display :* Cathode ray tube CV 254 (9 inch diameter). Three scales : 2,000 yards, 15,000 yards and 45,000 yards. Linearity better than 1 %. Calibration rings at 1,000 yards intervals. Ranging ring giving accuracies of 40 yards, 100 yards and 300 yards depending on the scale in use.

I.F. gain and video sensitivity controls both provided for trials.

Coil rotation by means of a servo system employing magslips and a velodyne motor. Accuracy expected 1/2°.

6. *Auxiliary display :* Divided into two units, one display unit containing only the circuits and controls which cannot conveniently be separated from the cathode ray tube and the other unit containing the remaining circuits. The display unit is suspended above the chart table, and the P.P.I. picture compared with the chart by means of a semi-silvered mirror. Circuits basically similar to the main display, except that the range of the P.P.I. is continuously adjustable from 2,000 yards to 70,000 yards.

3° Automatic monitoring.—A system is proposed by which 20 monitoring points throughout the equipment are automatically selected, and displayed as a row of vertical lines of the main display. This should facilitate quick location of a fault.

4° Performance monitoring.—A Monitor consisting of a pulsed spark gap source and a receiving crystal is placed near the aerial on the astern bearing. The video pulse resulting from the spark gap is gated and measured and the pulse from the crystal is also measured, giving an indication of receiver sensitivity and transmitter power respectively. These quantities, electronically multiplied, give the overall performance and can be used to control the display, switching off if performance is too low.

5° WAVE GUIDE DRYING.—The method of keeping the inside of the waveguide dry is to maintain a continuous current of air through it, drawn from cold outside atmosphere, and to heat the waveguide along its length so as to keep the air always above dew-point. Preliminary tests indicate that this will be satisfactory.

RADAR BEACONS.

1. General description of the system.

1° A responder beacon, which by means of a distinctive signal enables the radar set to determine the range and bearing of a particular point on a coastline, is an important ancillary to navigational radar in facilitating landfalls and identifying coastlines or landmarks. The basic principle of such a beacon is that the radar transmitter pulse is received and used to trigger a second transmitter on the same frequency or a different frequency. The use of a different frequency makes for complication of the radar but facilitates the separation of beacon responses from normal echoes.

2° Two beacons are in existence, Type 952 and AN/CPN-6 (U. S.) :—

	Type 952	AN/CPN-6
Beacon receiver frequency	X-band Wide band	X-band Wide band
Beacon transmitter frequency	157-187 Mc/sec.	9.310 Mc/sec.
Beacon transmitter power	30 watts	10 kw. (approx.)
Aearial beamwidth	180°	360°
Form	Portable	Fixed installation
Power supply required	Battery or 80 v. 2.000 c/s., 80 v. 500 c/s., 230 v. 50 c/s.	115 v. or 230 v. 50 or 60 c/s.

2. Facilities and limitations.

Both beacons receive pulses in the whole X-band and reply on a spot frequency. With Type 952 a separate receiver is required to work in conjunction with the radar. With AN/CPN-6 either a method of switching the receiver frequency or a separate receiving head is required. Three response codes are available in Type 952 ; in AN/CPN-6 the number is about sixty. With Type 952, the response arcs on the radar P.P.I. become very wide at short ranges ; with AN/CPN-6 this effect is much less, being partly controllable by the radar gain control. Of the two, Type 952 is much the simpler to operate, adjust and maintain. The traffic handling capabilities of Type 952 is of the order of 6 ships for interrogation ranges less than 4 miles and 50 ships for greater ranges. CPN-6 will handle approximately 12 ships at ranges less than 4 miles and 100 ships at greater ranges.

3. Method of operations and presentation.

When the response is selected for display on the P.P.I. it appears as a number of concentric arcs (the number depending on the response code), the middle of the arc corresponding to the bearing of the beacon. The range of the nearest arc is greater than the true range by a fixed amount, due to delays inherent in the system.

4. Accuracies and range characteristics.

1° The range accuracy of the response, when due allowance is made for the inherent delay, is determined by that of the radar. In Type 952 each set is adjusted to give a delay of + 400 yards at minimum range. This delay will increase with increase of range up to a maximum of + 25 yards. The AN/CPN-6 has an inherent fixed delay, which varies from set to set, between 650 and 1,350 yards ; in addition the delay will increase by a maximum of + 400 yards from maximum to minimum field strength.

2° The bearing accuracy is somewhat lower than that of the radar, particularly at short ranges, and fixes are most accurately obtained by taking ranges of two or more beacons. The bearing accuracy of Type 952 at long range is approximately ± 1° and ± 5° at 1/4 of the maximum range.

3° The bearing accuracy of Type AN/CPN-6 at long range is ± 1° and ± 2° at 1/4 of the maximum range for 50 % probability.

4° The range of location of the beacons is approximately the optical range between the aerials.

5. **Complexity.**

1° *Type 952 :*

Dimensions	17" × 11" × 8".
Weight	25 lbs. for T/R box.
(Battery model)	35 lbs. for battery box.
(Mains model)..........	80 lbs.
Number of valves........	10.
Number of operators.....	None, except for an occasional routine maintenance.

2° *Type AN/CPN-6 :*

Dimensions	Two cabinets, each : 49" × 17" × 24".
Weight	530 lbs.
Number of valves........	53.
Number of operators.....	None, except for frequent routine maintenance.

6. **Test equipment.**

The following test equipment is also required for setting-up and maintenance :—

1° *Type 952 test equipment :*

Dimensions	20" × 8" × 11".
Weight	70 lbs.
Number of valves........	20.

2° *AN/CPN-6 test equipment :*

Dimensions	36" × 17" × 24".
Weight	120 lbs.
Number of valves........	35.

LEADER CABLES.

1. **General description of the system.**

1° Leader cables were in use from 1918-1926. They fell into disuse due to the inadequacy of the available techniques.

2° The simple system consists of a cable laid on the sea bed along the centre of the channel to be marked and energised with alternating current from one end of the cable and using a sea return. A ship can follow the cable detecting the cable field with suitable coils, the resultant signals from the Fore and Aft, Thwartships and vertical components of the field being amplified and used to indicate the Relative Heading (with respect to the cable), the ship's "offset distance" laterally from the cable in terms of the depth of water over the cable, and the "Hand" of the cable (i. e. on which side of the ship it lies).

3° Existing gear uses single frequencies in the band 70-90 c/s. Maximum requirements may be for single frequencies up to 5 kc/s. Cable currents are from 0.5 to 10 amperes.

2. **Facilities and limitations.**

1° The equipment gives instantaneous heading and "offset" position relative to the cable, direct to the Pilot and/or Quartermaster, making it possible to make good an accurate course parallel to the cable, to correct for cross-wind and tide, and to appreciate immediately major changes in cable course. No special charts are needed. Shore radar and an R/T Link can unable warning of other vessels and obstructions to be given. Light temporary cables are simple to lay.

2° Danger of damage to and dragging of the cable can be minimised by multi-cable technique, such as using two cables to mark the channel limits and by the known technique of self-burying cables.

3° The cable insulation governs cable length and current, and indication of "distance run" is being developed.

3. **Operation and presentation.**

1° A small display unit shows relative course and offset distance on two 3-inch cathode ray tubes to the Pilot and/or Quartermaster. Repeater units can be used if required.

2° Control is by ON/OFF switch only. All adjustments to the gear are pre-set.

4. **Accuracy and range characteristics.**

Existing gear was designed to meet specific limited requirements. Maximum offset range, at least 25 yards with 0.7 amperes cables current in 4 fathoms depth, with course accuracy better than the steering capacity of a small craft at 15 knots. Offset ranges of 400 yards have been obtained. The maximum depth of water is substantially greater than 18 fathoms. Offset range is a function of depth of water and cable current. Accuracy increases in shallow water and is constant along the cable in a constant depth.

5. **Complexity.**

1° *Ship Gear.* Portable, in steel boxes 22" × 7" × 10". Maintenance is routine only, no special operator is required, the training requirements are small. The detectors are mounted on a suitable spar near the ship's " pivotal point " and well clear of masses of steel ; the gear is easily set up.

2° *Shore Gear.* A suitable generator driven off electric mains or petrol generator. Normal routine maintenance, remote monitoring of the cable current is required.

LOW FREQUENCY LORAN.

1. **General description of the system.**

1° This is development of the standard Loran working on a frequency of 180 kc/s to provide cover at greater ranges over both land and sea. The system is in the experimental stages only but shows great promise. The pulse transmitted is much longer than in standard Loran, being of 300 microseconds duration with a rise time of approximately 100 microseconds, peak power used to date has been 100 kilowatts.

2° The skywave trains are much shorter in duration than standard Loran partly because F echoes are absent and multiple E signals are small at this frequency, and in general the interpretation of the display is somewhat simpler. For this reason it has been suggested that the stations should be sited in triplets rather than pairs, and that a new design of receiver should be produced providing for the simultaneous observation of the two position lines obtainable from a triplet. In this way an instantaneous fix would be obtained, as distinct from a " running fix ", the fix or position being known about one minute after the observation is made.

3° The transmitted bandwidth is approximately 10 kc/s. Sixteen pulse recurrence frequencies are provided, which should be ample for global coverage.

2. **Facilities and limitations.**

Interpretation of the display calls for some skill but should be simpler than in the case of the standard Loran. Training must be thorough.

3. **Operation and presentation.**

Similar to Gee and standard Loran. Cathode ray tube indicator with calibration marks. Time measurements plotted on charts overprinted with hyperbolic lattices.

4. **Accuracy and range characteristics.**

1° Recent trials in America have shown that ranges of at least 1,500 miles by day and 3,000 miles by night may be obtained over water, whilst ground wave ranges over land are about 75 % of the daytime range. This means that stations may be sited inland.

2° Daytime position line accuracy working on ground ray for 50 % chance is 0.3 % of range from the mid-point of the station base line, 95 % readings will be within 1 % of the range.

3° Night-time figures for operation on skywave only are not yet available.

5. **Complexity.**

1° Trials were conducted using standard Loran indicators fitted with radio frequency converter units. These are very small (approximately 6" cube). To obtain full use of the system a new receiver should be designed. This would be 20 % more complicated than equipment now in service.

2° Owing to the low frequency employed high transmitter aerials are required with large earth systems.

POST OFFICE POSITION INDICATOR P.O.P.I. (General).

1. **General description of the system.**

1° P.O.P.I. is a navigational aid of the continuous wave type. It employs time multiplex to avoid the use of the several frequencies normally associated with continuous wave navigational aids. The time sharing feature of P.O.P.I. is its main characteristic.

2° It can be used at any frequency at which is is possible to generate phase-stable oscillations, that is, from very low frequencies, through the medium frequency band to the V. H/F band.

3° The band width of the transmission and the band width required in the receiver is of the order of a few cycles and is dependent on the rate at which the multiplex is operated. Even for the fastest aircraft the switching need only take place a few times each second.

2. **Facilities and limitations.**

1° It can be arranged to give position lines or fixes at long or short distances. No method is contemplated for ground and sky wave separation.

2° One ground installation would be required to give a position line and two to give a fix.

3. **Operation and presentation.**

1° The transmission consists in sending dashes of radiation from certain fixed points. In the simplest case this involves the switching of the transmitter output to each radiator in turn. In more difficult cases it would necessitate the control of the phase of the radiation from two transmitters spaced a considerable distance apart.

2° The reading is presented upon a pointer instrument.

4. **Accuracy and range characteristics.**

The accuracy-range characteristic will be similar to other continuous wave aids using a comparable frequency and base line, except that it may be better than those systems using more than one frequency.

5. **Complexity.**

1° The transmitting equipment is a C.W. transmitter provided with a special crystal drive, an output switch and special monitoring facilities.

2° The receiving equipment is fed from a communications receiver and consists of a special low-frequency-attachment.

POST OFFICE POSITION INDICATOR (P.O.P.I.) 3 ELEMENT BEACON.

1. **General description of the system.**

1° The P.O.P.I. 3 element beacon system provides position line information from a single ground beacon by C.W. phase comparison methods. Three transmitting aerials are set up at the corners of a triangle of sides 0.5 wavelength and are energised in turn. A fourth aerial, which may be placed at any convenient point in the neighbourhood, radiates a signal displaced by 83 1/3 c/s to provide a beat signal in the receiver. The phase of the transmissions from the two ground aerials, whose base line normal is closest to the point of observation is compared at 83 1/3 c/s.

2° It is proposed to operate the beacon in the band 100-500 kc/s.

2. **Facilities and limitations.**

1° A position line of great circle bearing from the station is given directly on a scale and pointer instrument. No attempt is made to separate ground and sky waves.

2° Two stations would therefore be required to give a fix.

3. **Operation and presentation.**

1° The output of a 2 kw. transmitter is switched in turn to each of the three radiators ; a second 2 kw. transmitter feeds the heterodyne aerial continuously. In the mobile craft a standard receiver feeds the dashes of 83 1/3 c/s to a switching and meter unit which displays the phase difference between the dashes as the bearing from the beacon.

2° If the position is not initially known to within 120° the possible ambiguity may be resolved by a check reading on one of the other pairs.

4. **Accuracy and range characteristics.**

1° The instrumental accuracy of the system is of the order of 2/3 of a degree.

2° The accuracy-range characteristics will be similar in many respects to a fixed station Adcock direction finder. The accuracy of 95 % of the readings is expected to be :—

Day-time	0—1,500	miles	over sea	± 2°.
Night-time	0— 100	—	—	± 2°.
	100— 500	—	—	± 4°.
	500—1,500	—	—	± 2°.

5. **Complexity.**

1° The beacon consists of two 2 kw. continuous wave transmitters driven from a special crystal oscillator, a special switch for distributing the output of one transmitter to each of the three aerials in turn, and equipment for monitoring the phase pattern of the transmission.

2° The receiving equipment is a special low frequency attachment to a standard receiver.

FLETCHER PHASE COMPARISON BEACON.

1. **General description of the system.**

1° The " Fletcher " proposals are a modification of the single-sideband, two aerial type of phase comparison system such as was used in the German " Erika " apparatus. It must be noted that to determine a position line by phase comparison two quantities must be transmitted ; in " Erika " and " Decca " separate simplex channels are employed for these quantities, whilst in P.O.P.I. a time division multiplex is employed.

2° The " Fletcher " proposal is for a frequency multiplex i. e., several adjacent frequencies are used on one transmission band of the order of 1 kilocycle or less wide. On such a multiplex system it becomes possible to incorporate a separate channel for " Lane identification " (resolution of ambiguities) so that a " rough " and a " fine ", or " vernier " system is always available.

2. **Facilities and limitations.**

1° The system provides position line together with resolution of ambiguities and can, theoretically, be adapted to almost any phase comparison aid, but certain difficulties and limitations must be noted.

2° In order to keep the band occupied to reasonable proportions it is necessary to multiply the " Lane identification " frequency before making a phase measurement, this implies that any slight phase error introduced before this multiplication, i. e., in transmission and reception, has a much exaggerated effect on the result presented.

3° The relative amplitude of the various frequencies received would probably require careful adjustment, to avoid apparent demodulation of one channel by a strong component from another.

4° These difficulties are likely to be more severe if an attempt is made to use the system on base lines of 30-100 wavelengths, than if shorter base lines are used.

5° Considerable care will be required to avoid non-linearity both of phase and amplitude and harmonic distortion in the receiver, since it is clear that any harmonics generated from a frequency F could distort the phases of the frequences nF that are transmitted for comparison purposes.

3. **Operation and presentation.**

In operation the set would be tuned in to the required beacon and the position would be present on direct reading phasemeters. One meter could be switched for "fine" or "coarse" patterns, or two separate meters could be provided. More elaborate presentation is clearly possible if required.

4. **Accuracy and range characteristics.**

The accuracy and range characteristics will be the same as for any other C.W. phase comparison system on the same frequency and using the same base-line. See the data on Decca, Consol, P.O.P.I., V. L/F Decca and V. H/F Pilotage Aid.

5. **Complexity.**

Additional channelling equipment must be added at the transmitter and receiver.

LONG RANGE NAVIGATIONAL AIDS IN THE H.F. BAND.
NEW FORMS OF PILOTAGE AID IN THE V.H.F. BAND.

The systems falling under the above headings will be discussed in greater detail in Document No. 30 entitled "Future Trends of Development of Radio Aids to Marine Navigation".

VERY LOW FREQUENCY DECCA.

1. **General description of the system.**

1° The system would resemble the normal "Decca" system but two or more *pairs* of stations, giving position lines, would be used rather than a triplet. This would ensure good "cuts" over a wide area.

2° The frequencies used would be in the range 10-35 kc/s.

2. **Facilities and limitations.**

1° The system is intended to provide navigational cover over large distances. It provides a continuous indication of position but suffers from the drawback that a number of ambiguities must be resolved (Lane identification) although these may be fewer than in the normal Decca system.

2° No method is available to separate ground wave and sky wave, and this may impose certain limitations.

3. **Operation and presentation.**

1° The presentation would be in the form of a phase-meter of the continuously revolving type, provided with counters to record the number of revolutions performed.

2° These counters would be set initially to the correct position, by the use of a departure fix or otherwise. Thereafter it is necessary only to read the meters and to refer to a latticed chart to obtain position.

3° The efficient operation of the instrument must be checked, by the devices built into it for this purpose, at fairly frequent intervals.

4. **Accuracy and range characteristics.**

There is considerable difficulty at the moment in stating the range accuracy characteristics, but the following points should be noted :—

(a) In the range where the ground wave is always predominant, probably up to 100-150 miles the accuracy may be expected to be rather less than with the present Decca system, i. e. say $\pm$ 0.1 mile for 95 % chance ;

(b) It appears that the "sky" or ionospheric wave is much more stable than had been thought, waves incident at points separated by a few wavelengths receiving almost equal treatment ; whether this will be true with waves of different frequencies has yet to be proved. If the possibility of dispersion is ignored, then it seems that the best accuracy of position line that can be provided by such a system working on sky wave, at ranges of a few thousand miles, may be *in the order of* $\pm$ 1/2 % of the range for 70 % of readings, and $\pm$ 1 % for 95 %.

(c) The errors to be expected in the intermedial zone where ground and skywaves interfere are not at present assessable, but may, theoretically, exceed the ambiguities of the instruments. This zone will shift according to the time of day and year.

5. **Complexity.**

1° Special ship-borne equipment, of fair complexity, is required as for the normal Decca. It seems at the moment that the receiver will not be suitable both Decca systems.

2° The shore equipment will be very large and expensive (compared with a V. L/F transmitter such as Rugby), but in this connection the considerable coverage hoped for must be considered.

RADIO LIGHTHOUSE.

1. **General description.**

1° The general idea behind this suggestion is to provide a radio analogue to the visual lighthouse which would in its immediate vicinity provide to as large a variety of types of craft as possible guidance similar to that provided by a visual light. Many suggestions have been put forwards ranging from a rotating talking U. H/F beacon to an omnidirectional U. H/F beacon with directional receiving equipment on the vessel. The proposal favoured by the Development Sub-Committee is of the rotating beacon type in which a position line is given by timing characteristic signals. The rest of this description applies to the particular system favoured by the Development Sub-Committee.

2° The beacon consists of two aerial systems rotating at different speeds radiating very narrow beams of energy. Bearings may be obtained by measuring the time interval between the reception of signals from the two beams as they pass over the ship. The equipment employed in the ship may be of the simplest possible consisting only of a receiver and head telephones. The simplest form of timing is by means of a stop watch, but more elaborate schemes may be developed to provide continuous records of bearing on a dial or on a paper recorder. This flexibility of type of equipment is considered to be an essential feature of the scheme in order that the beacons may be of use to all types of ships ranging from smallest fishing vessels up to the largest liners. It is proposed to use a wavelength in the centimeter region where narrow beams with convenient rotating structures are possible. Power would be of the order of 100 kw. peak.

2. **Facilities and limitations.**

Bearing lines from the beacon are given by timing methods. Bearings could be obtained at intervals of the order of one or two minutes depending on rate of rotation of aerials. Utility of such a device and the possibility of use of very simple receiving equipment can only be judged by experiment. The system could probably be fitted in lightships subject to the necessity of fitting a gyro compass to permit azimuth stabilisation.

3. **Methods of presentation.**

1° The type of presentation employed may be graded according to the size of ship and type of facility required. A few examples are given :—

(a) Simple receiver with stop watch ;

(b) Compass card automatically reset each time beams pass over the ship.

(c) Automatic paper recorder giving continuous record of bearing.

2° No special charts are required.

4. **Accuracy and range.**

1° Range is substantially optical.

2° Accuracy will depend partly on timing methods employed. Simple counting methods without the aid of even a stop watch or metronome would give an indication of general direction. Use of a stop watch could give an accuracy of $\pm 3°$ for 95 % probability, and an aerial speed of the order of one revolution per minute.

With more elaborate (e. g. electronic) timing mechanisms, accuracy of a fraction of a degree would be possible, but then questions of the constancy of rate of rotation of the beacon and accuracy of polar diagram would arise.

5. **Complexity.**

1° Receiving equipment might vary from a simple battery operated unit employing one or two valves to an automatic equipment with a maximum of possibly 15 valves.

2° Shore installation would be of the same order of bulk and complexity as a large ground control radar equipment.

2.—Hyperbolic Navigation

by J. Stewart.

(Document No. 15)

1. Development leading up to hyperbolic system.

All radio navigation systems which use fixed reference points on the earth's surface must use either distance or bearing from these reference points at the basis of operation. Until recently only baerings were used for this purpose and these were measured by ordinary loop or Adcock D.F. systems. Recently, however, developments have taken place which enable the bearing of the observer relative to a fixed station to be determined by means of a characteristic variation with azimuth of the signal from a fixed beacon, providing the system known as an "omni-directional range". In addition, the development of means of measuring radio-frequency phase and the establishment of radar technique have provided a tool for the measurement of the distance of the observer from the fixed radio reference point. This follows from the fixed constant velocity of propagation of radio waves in air (3.10^5 km/sec.), so that the distance between the two points can be determined by the measurement of the time of propagation of radio waves between the two points.

It is to be noticed at the outset that only time *differences* can be measured, hence it is necessary in any distance-measuring system to establish at the observing station a reference point in time from which all time intervals are measured. One means of doing this is embodied in the principle of secondary radar or the radar beacon. In this, a pulse of radio-frequency energy is transmitted from the observer, received by the ground beacon, retransmitted with, possibly, a fixed known time delay by the ground beacon transmitter and, finally, received by the observer. The time difference between the originally transmitted pulse and the finally received pulse is equal to twice the time taken to traverse the distance between observer and beacon, plus the fixed delay at the beacon. In this way, the distance from the beacon can be determined.

This system has received considerable attention and has been used quite extensively, but is subject to certain very serious limitations of which by far the most important is its liability to saturation, that is, the beacon's inability to handle more than a limited number of signals from interrogating observers. A second disadvantage is the necessity for each observer to carry a transmitter as well as a receiver. This transmitter must be maintained accurately on its operating frequency, since the tuning of the beacon receiver is fixed and this presents some difficulty in many cases.

2. Hyperbolic systems.

The type of system now under consideration is that in which signals are sent out simultaneously or with a fixed time difference from two fixed stations. If the time difference between these signals is measured at the observing point a line of position is established. This line of position is not such a simple curve as the concentric circles which (effectively) form the lines of position to the radar beacon system mentioned above or the radial straight lines of the omni-directional range. It is, in fact, a hyperbola whose fundamental property is that the distances of the point tracing out the hyperbola from two fixed points (the foci) differ by a constant quantity. Such a system is therefore referred to as a hyperbolic system and it is such systems which will be discussed in the more detailed papers following this one. There are, however, certain general features applicable to all hyperbolic systems which will be discussed here.

3. Accuracy of hyperbolic system.

In any hyperbolic navigation system, two ground stations are required to establish a position line and hence it is necessary to use either 3 or 4 ground stations to obtain a fix. It is only possible to use 3 stations provided one of these can be used for the determination of two hyperbolic position lines.

Charts can be constructed showing families of hyperbolae each corresponding to a fixed difference in distance, superimposed on a map of the area concerned. The network of intersecting sets of hyperbolae is known as a lattice. Apart from permitting a fix to be obtained, an assessment of the accuracy of the fix may be made from a lattice chart, since the probable error of a position line is proportional to the spacing of adjacent lattice lines. In any pair of stations it is common practice to employ a " master " station and a " slave " station which uses the emissions from the " master " to synchronise its own emission. Similarly, a 3-station chain has one master and two slaves.

The spacing for the hyperbolic lattice lines for equal measurements of time difference is not constant but increases as the observer approaches the extensions of the base line joining a pair of stations, and hence the accuracy falls off in these directions. In practice, therefore, the coverage of a pair of stations is limited to two sectors of 120° about the mid-bisectors of the base line and situated on either side of the base line. To obtain all-round cover it is the practice to employ a four station chain, using a central station as master and three slaves whose bearings relative to the master are spaced approximately 120°. To obtain a fix at any point the master and two slaves are used. At distances which are large compared with the station separation, the position lines approximate to radial lines through the mid-point of the line joining the two stations concerned. Hence, in a 3-station system the position lines will tend to cut at an acute angle at distances great compared with the spacing of either pair of stations. In such circumstances, while the position line accuracy may still be reasonably high, the accuracy of the fix in a direction towards and away from the ground stations may well be rather low. As a very rough approximation, it might be said that the position line accuracy varies inversely as the distance from the ground stations and the radial accuracy inversely as the square of this distance. To achieve higher accuracy it is necessary either to increase the base line, i.e. the station separation, or alternatively, to use two pairs of stations so situated that the position lines cut at more nearly right angles. Both of these expedients have been employed in practice.

Hyperbolic systems are capable of giving a much higher position line accuracy than any D.F. systems or omni-directional ranges and the fixing accuracy, in so far as it depends on the angle of cut of position lines, is not subject to any more stringent conditions than a D.F. system. Hence, on the score of accuracy alone a hyperbolic system shows a considerable advantage over a straight-forward D.F. system or, indeed over any system involving the measurement of angles with stations situated at the mid-points of the lines joining the pairs of hyperbolic stations. If we now add to this the very important features that the ground stations of a hyperbolic system do not require to be interrogated by the observing ship or aircraft and that they are not restricted, as in the case of a D.F. system, to handling only one aircraft at a time, but in fact, are capable of being observed by an indefinitely large number of craft, it is clear that they are possessed of a number of very attractive features.

4. Types of hyperbolic navigation systems in use or projected.

Several different systems of hyperbolic navigation have been proposed or used so far. The earliest use of such systems involved radar technique in so far as the ground stations transmitted pulses of radio frequency energy and the time differences between reception of pulses of radio different ground stations was measured by the observer. Such systems are Gee and Loran, the former developed in this country, the latter in United States of America. Gee operates on a sufficiently high radio frequency to allow the allocation of a relatively wide frequency bandwidth and hence permits the use of narrow pulses. This gives adequate accuracy with a relatively short base line but ground wave range is limited at these frequencies to about 200 miles over sea and less over land. Loran operates on a frequency near 2 Mc/s per second, so as to achieve ranges of the order of 700 miles using ground waves only. Recent developments in Loran using a frequency of 180 kilocycles/seconds have shown promise, but this system has not yet passed beyond the experimental stage.

The next method of time measurement involves measurement of the phase difference between radio frequency waves sent out from the pairs of ground stations. The most highly developed system using this technique is the Decca navigation system which is capable of very high accuracy. The P.O.P.I. system, while effectively of this type, uses such a small station separation that the hyperbolae degenerate into radial straight lines, although it is possible that future developments of the P.O.P.I. technique might lead to increased station separation and a genuine hyperbolic lattice.

Another possible scheme for time measurement is the measurement of the phase difference between sinusoidal modulations of the radio frequency transmissions from the ground stations. This system has not been used in practice.

Advantages and disadvantages of hyperbolic systems.

The advantages of hyperbolic systems lie mainly in the considerable accuracy which can be achieved, the absence of transmitters at the observing points and the unlimited handling capacity. These advantages are all of extreme significance.

The disadvantages of hyperbolic systems are largely concerned with economies rather than technique in so far as a chain of at least three and possibly four stations is required to give a fix and the signals from these stations must be maintained in synchronism. This latter operation, if carried out manually, requires a constant watch to be maintained at each of the slave stations or, if carried out automatically, necessitates continuous monitoring to ensure against possible slipping of synchronisation due, for example, to momentry loss of the synchronising signal due to bursts to interference.

In addition, in pulse systems up till now, the presentation as will be described in the subsequent papers, has taken the form of pairs or triplets of "blips" displayed on a cathode ray tube and has involved the counting of calibration markers in order to determine the hyperbolic lattice coordinates. This is not so complicated as it sounds and becomes very easy after a little practice. It is, nevertheless, such a constantly reiterated criticism that thought has been given to the elimination of this disadvantage and it is now considered that an automatic Gee system to obviate "blip" matching and calibration marker counting, together with a computer to permit navigation along a pre-determined track can be achieved.

C.W. systems provide direct pointer indication of the lattice coordinates but possess a disadvantage not shared by the pulse systems, in that the reception of sky-waves which will have travelled a considerably longer distance than the direct ground waves, will render the fix inaccurate or possibly, useless. Such sky-waves normally appear at night and at ranges of the order of 200-1,000 miles depending on the operating frequency of the system concerned. This sky-wave interference, is, of course, not peculiar to hyperbolic systems, but is almost universally troublesome. It is mentioned here, however, to indicate that hyperbolic systems are not inherently immune.

5. **Conclusion.**

This paper has striven at generality. Most of the features involved will be treated in greater numerical detail in the subsequent papers on individual hyperbolic systems.

3.—Charts for radar and position fixing systems

by Commander E.G. Irving, O.B.E., R.N.

(Document No. 25)

RADIO AND RADAR CHARTS.

1° In recent years the rapid advances in Radio and Radar development have made available to the mariner a number of new aids to navigation. Full advantage of these aids can only be derived by using them in conjunction with charts of some description and this has involved chart producers in the dual problems of designing special types of chart and in modifying or adopting existing charts for the purpose. Certain types of radio aids were, of course, in use before the war, e.g. direction finding stations, but these could be used well enough with existing charts and no special cartographic problems were involved.

2° The four principal types of radio aids which were developed during the war years are Gee, Loran, Decca and Consol. Operation of Gee and Loran involves measuring with great accuracy the time interval between the reception of short pulses emitted from shore radio stations. A master station transmits a number of uniformly spaced pulses each second and a slave transmitter emits a corresponding series of pulses which are kept accurately synchronised with those from the master station. The time difference between the reception of a master pulse and the corresponding slave pulse establishes a line of position along which all time differences for this pair of station are equal. For any other time differences there are other corresponding lines of position. The master station controls two or more slaves and for each master-slave pair there is a series of lines of position which the mariner uses for fixing himself. It is the business of the cartographer to plot these lines of position on existing charts or charts specially produced for the purpose, to number them with their respective time differences in microseconds and to provide suitable means for their identification.

The Decca system involves the accurate measurement of phase differences as opposed to time differences but produces similar families of hyperbolae as position lines to Gee and Loran, and the work required in the preparation of a Decca chart is from the cartographer's angle the same as that for Gee and Loran.

The Consol system involves the accurate measurement of bearings from three or more shore stations. The problem involved is the relatively simple one of plotting lines of true bearing over the chart and a number of maps have been produced for this. This system has not been extensively used by this country for Surface Navigation, and no special marine charts have been produced for it.

3° For the Gee, Loran and Decca systems the lines of position would on a plane surface be hyperbolae. On a chart they will approximate to hyperbolae but their exact shape depends on the projection employed for the chart. It is the business of the computer to provide the cartographer with the necessary data for plotting these lines, i. e. by giving enough cutting points on the graticule engraved on the chart to enable them to be drawn. The exact geographical positions of the shore stations, the distance between master and slaves and the speed of transmission of the radio waves are obviously matters of importance. Where the stations of a chain are all in one country which has been covered by a regular trigonometrical network, e. g. the United Kingdom or the United States, the actual and relative positions of the stations can be found without difficulty since the existing triangulation will certainly be accurate enough for this purpose. If the stations lie in different countries whose individual trigonometrical networks have been connected, the positions of the stations, as derived from these different networks, must obviously be adjusted into sympathy with each other. These cases present no great difficulty but some trouble has arisen and may arise again in the future when stations have of necessity to be located on small and isolated islands, as in the Pacific.

Methods of determining geographical position all depend on the assumed verticality of the plumb line at the place of observation. Considerable plumb line errors are known to exist in various places and these errors may be found and compensated for in large countries by taking astronomical observations in widely spread positions which are nevertheless connected by triangulation. On small isolated islets this cannot be done and some error from this cause may often be anticipated. Fortunately, judging from results obtained in the Pacific, the errors are not likely to be serious from a navigational point of view. It is possible, and indeed probable, that radio will eventually enable us to establish the true positions of such islets with a greater accuracy than has yet been possible.

The work of computation required for these so-called "Lattice" charts is considerable since the number of cutting points required for plotting the lines of position is very large, especially in the vicinity of the stations themselves where their curvature is greatest. One method of reducing the amount of computation is to make use of the conical orthomorphic projection, one of the properties of which is that small circles on the earth's surface are correctly represented by circles on the chart or map. A series of arcs is drawn with each station as the centre and curves joining the intersections of arcs of constant difference of radius are the required lines of position. This method does indeed eliminate a lot of the computation but it can only be used with accuracy where the arcs make a good cut with each other, i. e. not too far from the stations, and it adds, of course, considerably to the draughtsman's work. Also, the chart produced is not a projection liked by the navigator since courses cannot be laid off as straight lines, though for short distances the errors involved are not large.

4° The data provided by the computor cannot always be used as it stands. For example, our large scale charts of the coasts of Normandy are, of course, based on French hydrographic surveys and these in their turn are based on the French national trigonometrical network. Latticed versions of these coastal charts were required for the Normandy invasion but the radio stations, for which the lattice had to be drawn, were located in the United Kingdom and the positions used by the computer were based on the Ordnance Survey of Great Britain in which Airy's figure of the earth is used. A correction, which will bring the geodetic positions of the French network into sympathy with those of the Ordnance Survey of Great Britain, is obtainable in the Straits of Dover area from the direct visual connection which has been made across them but, apart from this, since the French system is based on a different figure of the earth, there is a variable discrepancy increasing in value as you proceed away from the Dover-Calais area. To bring the graticule of our charts of Normandy into sympathy with the Ordnance Survey triangulation of Great Britain, a good deal of investigation into the former was required and in effect a large part of it had to be re-calculated on Airy's figure. From this the necessary adjustment was found and a bodily shift of the graticule of each charts was made so that the computer's data could be directly applied. This discrepancy is not of ordinary navigational significance as it does not amount to more than a few seconds of arc and it would not be appreciable on small scale charts showing both sides of the channel.

In this connection it may be mentioned that in mid-Atlantic simultaneous fixes by Loran are, under good conditions, obtainable from both sides, i. e. from a Loran chain with stations in the Faroes, Hebrides and Iceland and from a chain on the other side with stations in Canada, Newfoundland and Greenland. It has been satisfactory to note that good agreement has been generally obtained between these independent fixes and, though admittedly only small scale charts have been used, it provides what is perhaps the first direct evidence that the relative positions of the Eastern and Western Hemispheres have been established with reasonable accuracy. Comparative fixes taken between one of the Position Finding systems, in this case Decca, and Sextant Angle fixes in a recently re-surveyed area has shown that this system promises sufficient accuracy to provide substantial assistance in Hydrographic Surveys, where visual fixing is either difficult or impossible owing to weather conditions.

The drawing of the lines of position, i. e. the lattice, presents no particular difficulty but it should be emphasised that a great deal of care is necessary, particularly on small scale charts. When the cutting points on the graticule have been plotted, the lines are drawn in with the aid of wooden splines which can be adjusted to the required curvature and weighted down. In the vicinity of the shore stations, which are foci of the hyperbolic systems, the curvature of the lines is, of course, greatest and cutting points at close intervals are required. As distance from the stations increases, the lines tend to become straight and their linear separation increases. Unfortunately there is no mechanical method of accelerating the drawing procedure since there is a different set of hyperbolic curves corresponding to every master-slave pair of stations and in point of fact the work of the draughtsman is the largest and longest item in the production of a lattice chart. As a rule not more than two draughtmen can be employed at once on a particular chart and it may be mentioned that on an average their work and that of the cartographer may occupy 2 or 3 weeks, depending on the size and scale of the chart.

Owing to the multiplicity of the lattice lines and the necessity of distinguishing those belonging to different pairs of stations and the lines themselves from others required on the chart, e. g. meridians, the lattice has to be overprinted in suitable distinctive colours and the normal procedure is to draw the original lattice on a number of tracing paper impressions of the chart and these are reproduced by photo-litho for the colour plates.

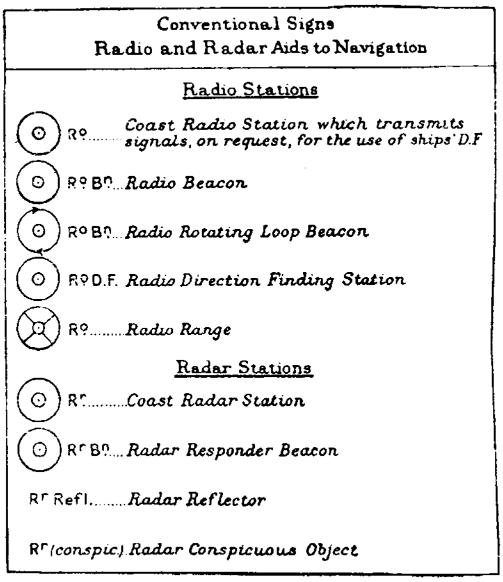
In the case of the long range aid, Loran, the ground, i. e. direct, wave from the shore stations is receivable in ships up to distances of 500-700 miles and the lattices on Loran charts are computed and drawn for these ground waves. Sky waves, reflected from the ionosphere, can however be received up to 1,400 miles and much thought has been given as to the best way of making the lattice chart suitable for their use also. The present method is to show the necessary corrections, i. e. for converting sky wave readings into ground wave readings, in small " windows " evenly distributed over the face of the chart. Whether this is the best possible method is open to doubt but alternatives, such as a separate series of charts, with a sky wave lattice, would involve a great increase in our work.

I have said that there is no great *difficulty* in the cartographic and drawing aspects of the work on these charts but it is necessary to emphasise the great *volume* of work which the future may call for if, as there is a possibility, practically all small scale ocean charts, medium scale coastal charts and larger-scale approach charts have to be produced in a new form with some type of radio aid data added. The British Admiralty publishes some 4,000 navigational charts covering the whole world and perhaps two-thirds of these would ultimately be affected. In this connection it is also necessary to emphasise the desirability of a settled policy for radio aids on a long term basis with the radio stations fixed once and for all and a general acceptance of a particular system if not to cover the whole world, at least to cover agreed areas. Even a change in the position of a transmitting station of a few hundred yards for technical reasons would involve the scrapping of all charts latticed for that station. Only by adopting a settled policy will it be possible to avoid waste of effort.

5° Reproduction of lattice charts does not involve any special technique but with the three or four coloured overprints great care in registration is required. Even the thickness of a lattice line may represent a considerable distance on a small scale chart and this possible source of error must be carefully guarded against. In the case of lattice charts, however, we have had to depart from our general ruling that all essential matter should be shown on the black plate of the navigational chart so that exact registration of colours, if colour overprints are used on the latter, was not a matter of great moment.

In this connection there is another matter of considerable concern to us. We are naturally expected to see that charts are sold to the public at an economic price, i. e. a price that bears a reasonable relation to the costs of compilation and production even if it does not cover the actual costs of the survey. It may be that latticed charts will in the future supersede ordinary charts for navigational purposes. There is the obvious advantage that the mariner wants as much information as he can get on his chart and he does not wish to have to refer to a second chart of the same area for fixing his position. Nevertheless, it has to be admitted that a lattice tends to overcrowd with detail an already crowded chart and there are always difficulties in the hand correction of a coloured document. Even if these difficulties can be accepted or surmounted and the mariner is content with latticed versions of charts only, we are still faced with the fact that charts of this type cannot be economically produced without a very considerable increase in cost, and shipping companies and other customers may not take kindly to the consequent increase in price.

6° In addition to the charts required for the radio aids I have mentioned, we are now being faced with the problem of modifying them possibly for use with another navigational aid, Radar. On the ordinary navigational charts the emphasis is naturally placed on a design suited to human vision and on objects which are useful as visual aids, e. g. lighthouses, radio masts, beacons, etc... Some of these objects may not necessarily be conspicuous or even visible on the Plan Position Indicator whilst others may show up very well. In particular the general topography, that is, the relief afforded by high land, as shown on many of the older charts where hill forms were often rather roughly indicated by "hachuring" cannot easily be correlated with the picture in the P.P.I. It is quite certain, however, that the mariner does not wish to be bothered with two charts of the same area, i. e. one in all respects suitable for visual navigation, the other suitable for radar navigation. It will be necessary to find a reasonable compromise suited to both requirements. In general this will probably be achieved by paying more attention to the mapping of topographical detail than in the past. An experimental chart has been produced in which the hill work was not only contoured but layered in colour so that differences of height are distinguishable by gradations of the tint. The difficulty in this is that it adds vastly to the work of compilation, to the costs of production and so in the end to the price of the chart itself. A solution along these lines may be found in the future but it is possible that essential requirements will be met by more accurate contouring and simpler modifications than those involved in the use of colours.



It is obviously desirable to be able to project the P.P.I. picture, adjusted to scale, onto the chart. The projected image is not very bright and not too easy to see simultaneously with the mass of detail (principally soundings) already on the chart. In the experimental chart referred to, the soundings were printed in pale grey and the result was certainly good as far as the P.P.I. was concerned but this was somewhat at the expense of the clarity of the soundings and fathom lines in the relatively dim light the navigator may have to work in.

Any wholesale change in the general design of navigational charts can obviously only be undertaken on a very long term basis and it is safe to say that for many years to come the mariner will in most cases have to make use of existing charts and correlate his P.P.I. picture to them as best he can. Experience has at least shown that this can generally be done without much difficulty.

7° Much consideration has been given to the question of symbols and abbreviations for radio aids on charts. As a tentative measure, a standard symbol is being adopted for all types of radio aid, followed by an abbreviation which will indicate its nature. Full details of such aids cannot usually be found space for on a chart and it will be necessary to consult the Admiralty List of Radio Signals for them. In view, however, of the increasing importance of these aids the symbol will be embellished with a circle in colour, thus making them as distinctive on the charts as lighthouses with their light flares.

Attached to this paper are the conventional signs for Radio and Radar Aids to Navigation which have been provisionally adopted pending international discussion and agreement.

8° The Navigator must appreciate the limitations of the various Radio Fixing Systems and should invariably treat them as an AID whilst the normal guiding principles and precautions of navigation should not be neglected.

Very little practice is required in the use of latticed charts and some personal experiences in their use, particularly Decca charts, may be of interest. In the case of this system, it is essential to know approximately the ship's position as it is not yet possible to determine initially the lane through which the ship is passing, but once the ship is fixed by celestial or terrestial observations or other means, the equipment will automatically keep the lane number up to date.

Accuracy is of a high order, as has already been remarked in this paper, and a continuous record of the ship's track can be recorded, and positions obtained at any moment.

The dials are not difficult to read and one operator can read both dials simultaneously. The large decimal pointer may be read to a hundredth part of a lane, which is in the order of 10 yards on a scale of 1/25,000 at a distance of 30 miles from the stations.

Decca and similar aids can be used for homing on to a pre-determined position ; during the trials previously mentioned, using a portable Decca set in a small motor boat, a completely untrained coxswain was able to negotiate the narrow entrance of a small boat harbour across a 4 knot tidal stream in very choppy water purely by following the movements of the pointers. This property is a valuable asset to the mariner, who can select for himself "leading lanes" as opposed to visual leading lines and navigate through channels and into ports without, if the need arises, seeing any shore marks, since the discrimination of the Decca system gives adequate accuracy.

9° Only by a substantial measure of agreement between nations can a chart, which may be considered an international document, give that information the mariner will require on his various voyages throughout the world.

4.—The Gee Navigation System.

(Document No. 16)

The Gee system was developed during the war primarily for air operations but it has since been employed extensively by naval vessels around the British Isles and formed the basic navigational aid for ships taking part in the invasion of Europe.

Principle.

1° Gee is a system of position finding, on the sea or in the air, by reception of radio signals from transmitting stations of known position. Gee stations emit steady successions of pulses (short, sharp signals) which travel out in all directions at the speed of light ; Basically the stations operate in pairs and a navigator finds his position by receiving pulses from two pairs.

2° Position lines are obtained by measuring accurately the difference in time of arrival of synchronised signals from the specially erected shore stations.

In practice, reference is made to two pairs of stations simultaneously and the point of intersection of the two position lines is the fix.

3° The system consists of a chain of stations having three or four separate transmitters sited up to 80 miles apart that emit a continuous series of synchronised radio pulses from omni-directional aerials.

4° All stations of a chain operate on the same radio frequency and all but the central station, known as the Master (A), time their transmissions by reference to the Master's pulse. These other stations are known as Slaves (B, C and D).

5° All Gee systems operate on radio frequencies 20 and 85 Mc/s. The use of these relatively high frequencies has many advantages. In particular it results in the reception of pure ground wave signals free from the difficulties and possible errors caused by sky waves at lower frequencies. The band is also sufficiently high to avoid many forms of static interference, especially those which affect all medium and low frequency communication in rain or snow.

All radio navigational aids which do not employ pulses (normally known as C.W. aids) suffer from errors caused by reflections from buildings, hills, aircraft, etc... Thus there are severe siting restrictions for such systems making them either unusable or dangerous in hilly districts. Gee, however, suffers to no degree from such errors since all measurements are made from the front of a pulse and the indirect signals, since they have travelled further, must arrive some time later.

6° The time differences of arrival of corresponding pulses from the separate stations in the chain may be measured in the receiving equipment to within a microsecond (a millionth of a second) making use of a cathode ray tube display.

7° The loci of points having constant time differences can be calculated mathematically and it is shown that these lines form a family of hyperbola about the master and slave station as foci, as with the Loran navigation system.

8° By means of a Gee receiver the time difference can be determined and the ship's position established as being on the corresponding position line.

9° In practice in operating the receiver the same sequence of events takes place simultaneously between the Master Station's signal and another slave's signal and so a second position line is obtained, the intersection of the two position lines being the ships position.

10° It is to be noted that signals are not distorted by passing near or over land ; and no appreciable errors are caused by reflections from land or other ships as measurements are made from the leading edge of a pulse and such indirect signals, since they have travelled further must arrived some time later. Signals, are, however, weakened to some extent by passing over land ; and reception may be seriously impaired if land obstructs the optical path between transmitter and ship. But the stations are sited to give the maximum coverage to the desired ship and aircraft services.

11° Suitable delays are introduced at the slave stations to ensure that pulses are always received in the same order for case of interpretation.

12° Some chains have a third slave station so that in certain areas it is possible to obtain a third position line to give a better cut.

Coverage.

13° Operational results show that for a transmission path chiefly over sea, satisfactory reception at a range of 100 miles is normal, while workable signals are frequently obtained at 150 miles.

14° The coverage for aircraft depends to a very great extent upon the nature of the intervening terrain, but reception is usually possible to 400 miles at 15,000 feet and to 200 miles at 5,000 feet.

Charts.

15° The Gee lattice is superimposed on the standard navigational chart for naval use. For standardisation between services the AB equal time differences are printed in Red, AC in green and AD in mauve to make up the appropriate lattice for the area.

Accuracy.

16° The positional accuracy of the systems varies with the location of the receiver relative to the stations. An experienced operator can normally be expected to obtain readings

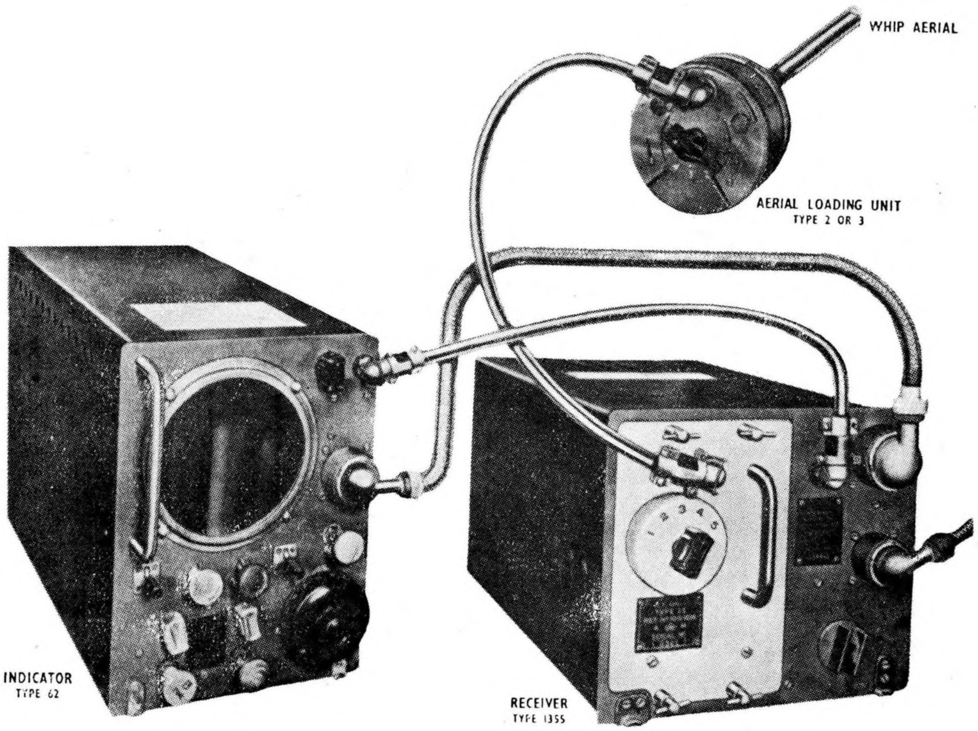

WHIP AERIAL
AERIAL LOADING UNIT
TYPE 2 OR 3
INDICATOR
TYPE 62
RECEIVER
TYPE 1355

Fig. 3.1

to ± 0.01 units and the error to be expected can be estimated by inspection of the lattice lines. The greatest accuracy is on the base line between the master and slave stations where 0.01 of a unit corresponds to about 100 yards. At a distance from the stations the position-line accuracy is highest along the bisector of the base line with a falling off of accuracy towards the base line extension where the readings become ambiguous and of no value to the navigator. In considering the accuracy of a position line at varying ranges from the centre of the Gee system it may be determined by 0.3 % of range for 50 % zone, and 0.8 % of range for 95 % zone. These figures are based on operational experience.

The range to which Gee signals can be received depends to a very great extent upon the nature of the intervening terrain, but reception is usually possible to 400 miles at 15,000 feet and to 200 miles at 5,000 feet.

Installation.

17° The receiver and indicator are not bulky measuring 9 in. × 8 in. × 18 in. and 9 in. × 12 in. × 18 in. respectively and their joint weight being 70 lbs. It has been found practical to fit this equipment in all classes of ships where suitable power supplies can be made available—i. e. about 270 watts at 80 volts, 1,000 cycles per second or 230 volts, 50 cycles per second.

The aerial unit consists of either a vertical 5 foot metal rod and support or a single wire vertical aerial 8 feet to 12 feet in length, which should be sited clear of screening by any of the ship's superstructure.

The receiver and indicator are the same for both ships and aircraft.

Operation.

18° The Gee system has successfully passed through all the stages of extensive operational research and the shipborne equipment can therefore be said to satisfy the most stringent requirements for reliability.

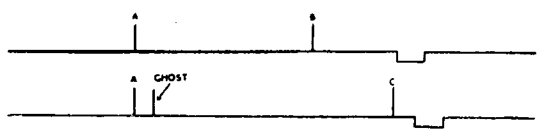


Fig. 3-2

19° The manipulation of Gee equipment is found to be quite simple after a few hours practice and the knowledge that the indicator will provide the correct answer or none at all is found to give added confidence to the navigator. A navigator should be able to obtain a fix and plot his position within a minute, the two position lines being obtained simultaneously.

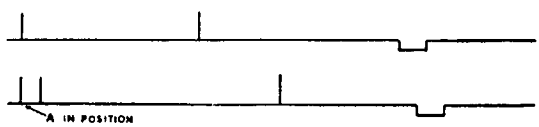


Fig. 3-3

Let us follow the operator's actions as he goes through the motions of taking and plotting a fix. The first picture seen is as fig. 3-2 and the Master signal, or " blip " as it is usually called, is recognised by the fact that it occurs on both traces and always is vertical alignment. One of the Master blips is followed by a ghost whose purpose is to identify the two slave blips. The slave following the single pulse is the " B " while that following the ghost is the " C ". The Master signal is commonly known as the " A " blip.

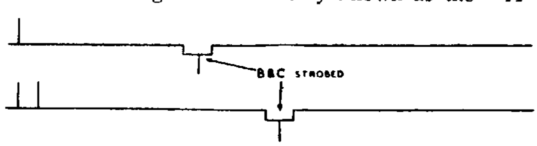


Fig. 3-4

By means of the oscillator control which very slightly changes the repetition frequency of the time base, the pulses are caused to drift across the tube face until the two " A " blips are at the left hand side of the picture with the " A " ghost on the lower trace. Having positioned the " A " correctly, the " B " will always be to the right on the top trace and the " C " somewhere to the right on the bottom.

The Gee operator is basically required to measure the distance between the top A and the B, and between the lower A and the C. To enable him to do this to a sufficiently high order of accuracy, four small sections of the picture are selected or "strobed" and then amplified out to fill the whole tube. The sections of the main picture that must be strobed are naturally those occupied by the four signals. So there are four strobes ; two are fixed at the left side of the picture covering the A blips, while the B and C strobes can be moved on to the slave pulses by the operator. The position of the moveable strobes is indicated by a kink in the trace which is placed astride the required signals (see fig. 3-4). Note that the Slave blips have now been inverted.

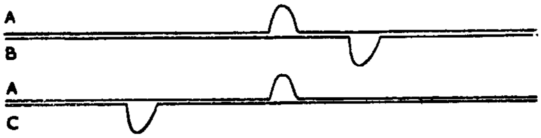


Fig. 3-5

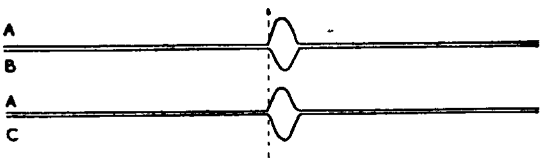


Fig. 3-6

At the touch of a switch, the picture is now changed to show the four signals on the fast time base (fig. 3-5). Once more using the strobe controls, all four signals are brought into vertical alignment. Since the A blips already satisfy this condition, it is only necessary to place the left hand edges of the B and C blips against the corresponding part of their respective A blips. This instant of pulse alignment is the time of the fix which has yet to be resolved.

The alignment of the pulses effectively stores the information of the two readings, so that it is now possible to replace the received signals by a system of electrical calibration pips. Figure 3-7 shows the strobe and main time bases with calibration pips. While in the strobe position, the two decimal readings are obtained and the whole numbers are taken from the main time base. The intersection on the Gee lattice chart of the two lines whose values correspond to the two readings and plotting can all be performed in well under a minute.

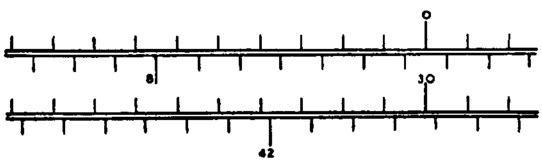


Fig. 3-7 a

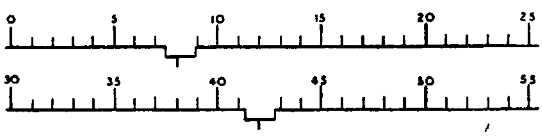


Fig. 3-7 b

Future operation.

20° Design work is being undertaken in both U.S. and U.K. which should eliminate the need for counting calibration pips when taking a reading. It should then be possible to obtain direct readings on a calibrated scale after lining up the signals.

21° Since Gee and Loran employ similar techniques it is hoped to be ultimately possible to produce a common receiver for both systems. These systems are widely used for both sea and air navigation and the wide coverage that already exists merits the contemplation for such a combined scheme.

5.—Loran(*)

by C.C.E. Bellringer.

(Document No. 17)

1. General.

1° Loran is similar to Gee in its basic principles and as the name implies, is a Long Range Navigational Aid. Loran is intended mainly for marine navigation and long flights over the sea. It employs pairs of pulse transmitting ground stations which are spaced up to 600 miles apart, according to the nature of the terrain and the navigational cover required.

2° The master station radiates first, and is followed by the slave station after a fixed delay. Each pair (i. e. Master and Slave station) is selected by means of a recurrence frequency switch on the receiving equipment.

3° The pulses are received and displayed on a cathode ray indicator, from which the operator can determine the difference in arrival time between the two pulses.

4° The line along which the difference in arrival time of two pulses is constant is called a line of constant path difference, and is a hyperbola. Thus for each pair of stations there is a family of hyperbolae, and the position of the aircraft can be determined by taking a path difference reading from two pairs of stations. It should be noted that the two path difference readings, i. e. position lines, are not taken simultaneously as in Gee, but one after another with a short time interval. With good reception conditions, the observations can be made and the plotting completed in from 3 to 6 minutes.

5° The radio frequency used for Loran is approximate 1,900 kilocycles/sec. and this permits the use of E-Layer reflections to increase the night time range of the equipment.

2. Ground stations.

1° A Loran ground station consists of a receive-timer unit, a transmitter unit and two aerial systems. Master Station signals are received at the Slave Station and are retransmitted after a known and accurately monitored time delay. The transmitters produce a pulse of 50 microseconds duration with a peak power of 100 kw. at a recurrence of 25 cycles per second. The transmitter is, however, quite small as the mean power output is only about 600 watts.

2° The aerials in common use consist of a quarter wave element supported from a 105 foot tower. The earth mat for the transmitter aerial consists of 120 radial wires 300 ft. long, whilst that employed for the receiver aerial uses the same number of 150 ft. radials.

3° The radio frequency is such that ground wave propagation over land is very poor and hence ground stations should always be sited very near to the coast.

3. Shipborne and airborne equipment.

1° The latest Loran equipment for shipboard use is the DAS-3 which operates from a 230 volts A.C. power supply. It has approximate dimensions 12" × 18" × 18" and weights 100 lbs.

2° There are two forms of airborne equipment AN/APN-4 and AN/APN-9, which may also be employed on ships. AN/APN-4 comprises two units about 9" × 12" × 18" with a total weight of 70 lbs, and consumes 270 watts of 80 volts, 1,000 cycles. This equipment is mechanically interchangeable with a Gee airborne set and can use the same mounting trays, cables and power supply.

3° AN/APN-9 comprises one unit 9" × 12" × 18", with a total weight of 35 lbs, and consumes 225 watts of 80 volts, 1,000 cycles.

4° The operating procedure for all types of sets is very similar to Gee, except that an additional control is provided to balance the amplitudes of the signals arriving from the two ground stations. When the amplitudes are balanced the front edges of the pulses are matched by superimposition. After alignment, the signals are cleared from the traces and calibration markers are presented and counted.

(*) NOTE : See figures of the above article "Loran—The new radionavigator".

5° The fact that sky waves are present means that each direct pulse is followed by a number of pulses arriving by reflection from the ionosphere. Thus some skill is required in identification of the correct pairs of pulses required for obtaining a position line.

6° Position lines are plotted on special charts overprinted with hyperbolic lattices in colour. Pairs of stations are selected by reference to these charts in order that the best angle of cut may be obtained for fixing.

4. Operational characteristics.

1° Loran provides service up to a range of 700 miles by day over sea and 1,400 miles by night. Over land the ground wave ranges are very poor being around 200 miles or less for rough terrain. The sky wave signals are unaffected however, by land, and a belt extending from 300 to 1,200 miles from the stations is covered at night.

2° The accuracy of a position line obtainable from a pair of Loran Stations is proportional to the length of the base line of the pair and varies with location within the coverage area, but may generally be taken as 1/2 % of range from the mid-point of the base line.

3° During the war the whole of the North Atlantic and most of the Pacific was covered by Loran and the operational utility of the system has been well proved.

5. Effect of interference.

1° Systems employing pulse transmission together with cathode ray tube displays have inherent advantages under all forms of interference. These advantages arise as follows :—

(a) Very large peak powers may be transmitted ;

(b) The human eye can detect the required signal even in the presence of very close grained interference of greater amplitude than the signal.

2° It is possible to operate the Loran airborne equipment in the presence of atmospheric static of peak amplitude many times greater than the incoming Loran signals. As an illustration of this point, range and accuracy of Loran were quite unaffected by monsoon conditions in the Indian Ocean at times when all M/F and H/F communications were completely wiped out.

6. L.F. Loran.

1° L.F. Loran is a variant of the standard Loran system working on the low radio frequency of 180 kilocycles, in order that much greater ranges may be obtained over both sea and land. As yet, L.F. Loran is an experimental system but it has been subjected to over a year of trials.

2° Recent trials of the system in America have shown that ranges of at least 1,500 miles by day and 3,000 miles by night may be obtained over water. These trials have also shown that the accuracy of position line is about 0.3 % of range from the mid-point of the Station base line.

3° The sky wave trains are of shorter duration and in general, the display of pulses on the cathode ray tube is somewhat easier to use, than is the case with Standard Loran. As a result of the simpler nature of the sky wave signals, stations may be sited in triplets to provide an "instantaneous" fixing service to aircraft or ships carrying a suitable indicator. No such indicator has yet been produced but the design would be similar to that used in Gee. Standard Loran aircraft equipment may be used for obtaining "running" fixes, by the addition of an RF Converter Unit.

4° The pulse used is approximately 300 microseconds long, with the rise time of about 100 microseconds. The transmitted bandwidth is of the order of $\pm$ 10 kilocycles/sec. and PRF selection is employed to provide for operation of sixteen chains on a single radio frequency channel. A rough survey shows that the greater part of the globe may be covered with twelve chains of stations.

6.—The Decca System of Radionavigation

by Mr. G.J. BURTT.

(Document No. 19)

Introduction.

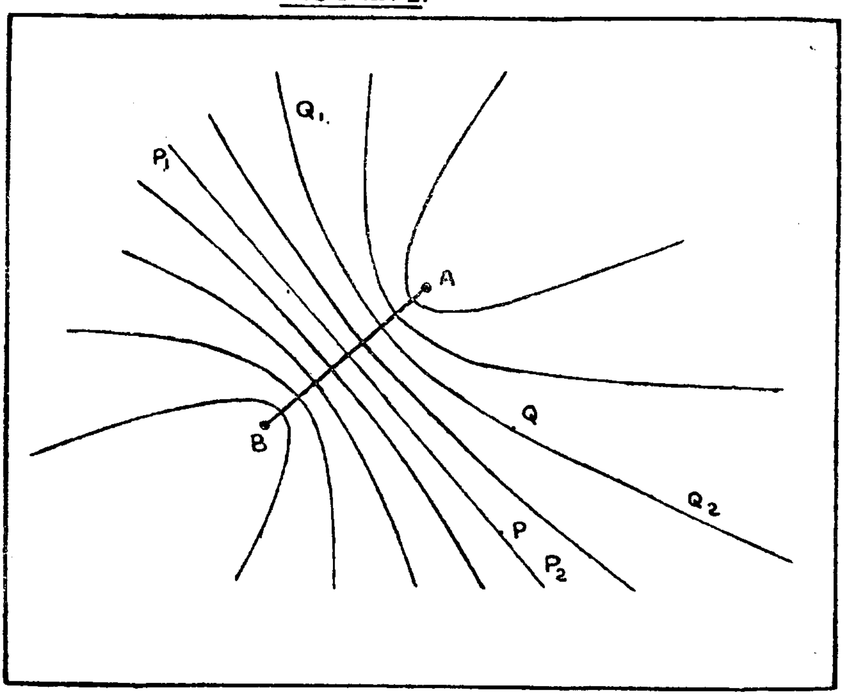
The Decca system of radio navigation consists of a number of transmitting beacon stations at fixed positions on shore, and special receiving equipment to be carried in the ship or aircraft by means of which the navigator can determine his position relative to these beacons. In order to interpret the results given by the receiving equipment it is necessary to use special charts. These are normally standard navigational charts on which are superimposed a lattice of lines of position which are numbered and which can be directly related to the figures obtained from the receiver.

Basic principles.

The basic principle employed in Decca is that which can be described as the " hyperbolic " system and is common also to the Gee and Loran systems. Referring to figure 1, suppose that A and B are two radio beacons sending out simultaneous synchronised signals. An observer with suitable equipment at a position P (on the line P1, P2, the perpendicular bisector of AB) would receive the signals from A and B simultaneously. At a point Q, however, where the radio path AQ differs in length from the path BQ, the signals will be received with a time interval corresponding to the difference in path length between AQ and BQ, divided by the effective velocity of propagation of the radio waves. If the observer at Q moves so that the time difference remains a constant, then it can be shown mathematically that the point Q follows a hyperbola such as Q1, Q2, and a whole series of lines such as Q1, Q2 can be drawn, each corresponding to a different time interval. If A and B were stations on the surface of a flat earth, then the lines would from a " family " of hyperbolas with A and B as the foci. In actual practice, it is a matter of straight-forward mathematical computation to produce the correct series of lines on any standard type of map or chart used in navigation.

In systems such as Gee and Loran, the signals sent out by the beacons are " pulse " time signals, and the observation made at the receiving position is a direct measurement of

FIGURE. I.



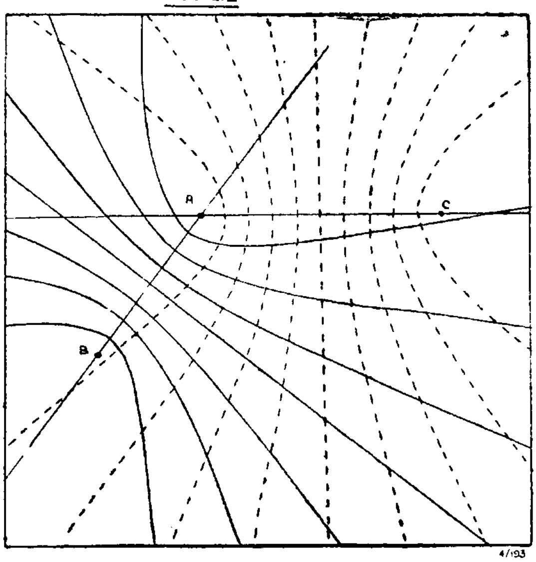
time. In the Decca system, however, the signals from A and B are steady continuous waves which are accurately " locked " together in phase, and the measurement of path difference at the receiving position is made in terms of wavelengths and fractions of a wavelength of the radiated signals.

In practice, in order to be able to identify the signals from each separate station, it is necessary to operate each station on a different frequency, but the frequencies of each pair bear a simple numerical relationship to one another, such as 3:2 or 4:3 and the maintenance of a steady phase synchronisation between the stations is a matter of frequency multiplication and phase control well within the capabilities of modern radio engineering practice. In making use of such a pair, the signals are received using a multi-channel receiver and are then frequency multiplied to bring them to a " lowest common multiple " frequency which is referred to as the " comparison frequency ". The phases are compared at this comparison frequency and the lattice of lines drawn on the chart are based on the wavelength corresponding to this frequency.

The transmitter system.

A pair of stations such as A and B will only assist the navigator by defining a " line of position ". To define a " fix " it is necessary to have at least one more pair of stations. This is normally done by adding a third station C as shown in figure 2 and thus producing two pairs AB and AC with two series of intersecting lines of position. The A station is referred to as the " master " station and B and C are the " slave " stations. It is possible to employ more than two slave stations in order to extend the area of navigational cover provided, bearing in mind that a separate receiving channel is required for each station in the " chain ". The use of three slave stations extends the coverage to a full 360°. The normal spacing between stations is of the order of 50-60 miles, and from a study of the geometry of figure 2 it is clear that to provide the optimum cover in any particular sea area it is desirable to site the master station A somewhat inland from the line BC of the two slave stations.

FIGURE. II

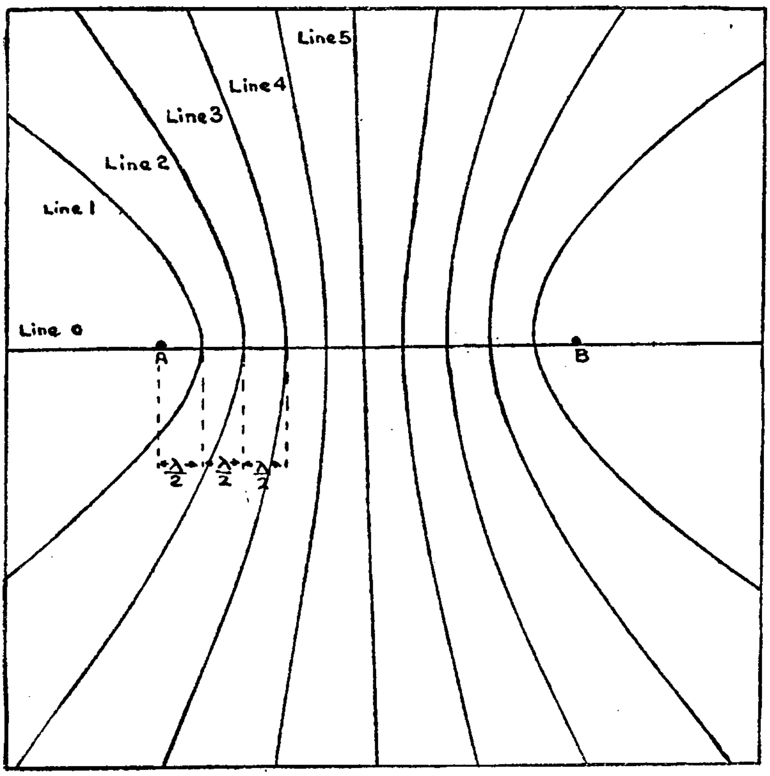


The system at present is operated in the low frequency band (80-150 kilocycles) and as a result of this, it is not essential to site the stations close to the shore line, since the attenuation of signal strength at these frequencies is not serious over land. The local siting conditions for the transmitters are not very critical, but it is desirable to avoid broken hilly country and to keep well clear of overhead telephone lines and power cables. The transmitters used are of a nominal power output of about 2 kilowatts, but owing to the low efficiency of any reasonable sized aerial that can be built for these frequencies, the power radiated is probably not more than 100 watts. It is essential that the aerial system should be non-directional, and the most satisfactory type is probably a single vertical mast radiator with symmetrically disposed top loading.

At the master station there is a crystal controlled transmitter with a frequency stability of a high order. At the slave station there is a receiver tuned to and receiving the master signal. The output from this receiver is then multiplied and divided in frequency to give the correct value for the slave transmitter and is then amplified to form the transmitter "drive". Thus the slave stations are driven by the master transmissions and are automatically locked in phase.

The system is self controlling in that once the relative phase between master and slave has been adjusted manually at the slave station, an automatic phase control circuit in the slave input equipment will hold the phase to the set figure. Nevertheless as an additional safeguard it is considered desirable to set up a monitor receiver station for each master-slave pair. This monitor is set up some distance from the slave (mid-way between master and slave is a suitable position), and is linked to the slave by telephone line. If then the monitor is manually operated, the stability of the phase reading can be passed to the slave station for comparison with the manual phase control setting. It is possible to dispense with manual watchkeeping at the monitor and to obtain a remote indication of the monitor station reading via a land line linking the monitor phase meter readings automatically to the slave station.

FIGURE III



The setting up of the pattern of equiphase lines is a matter of adjusting the phase of the slave station output. If one imagines an observer moving along the base line from master station to slave, then at positions spaced at half a wavelength (at the comparison frequency) there will be conditions of equal phase. It has been accepted as a convention that the phases at the master position shall be equal, and thus the base line extension at the master station and will be an equiphase line. This is achieved by adjustment at the slave station. Then at distances of one half, one, one and a half, etc., wavelengths from the master, the base line will be intersected by equiphase hyperbolas. These are numbered 1, 2, 3, etc., the base line extension through the master station being line O. Figure 3 illustrated this point. The zones between successive lines of equiphase are referred to as "lanes".

The receiving equipment.

The receiving equipment consists of a multi-channel receiver—with a separate channel for each transmitter station in the chain being used. Following the receiver channels are the frequency multiplying circuits and the phase discriminator circuits feeding the phase meters or " decometers ".

In the shipborne equipment at present in use, the receiver has three channels, a master and two slaves, and operates two " decometers ". The channels are narrow band, and are designed to ensure a high degree of phase stability over long periods. Provision is made in the equipment for checking the alignment of the circuits and for an instantaneous check that the signals are being received correctly. Apart from this there are practically no controls. The equipment requires a simple receiving aerial with a height of 15 feet or more—the higher the aerial the better.

When the receiver is operating in the service area of a pair of stations, then the " decometer " operating off the appropriate channels will indicate the phase difference of the signals at that point, measured at the comparison frequency. This phase difference will vary almost linearly with the movement of the receiver across the " lane " between two equiphase lines. Instrumentally the phase measurement can be made to an accuracy of about 3° to 5°, thus giving the position in the " lane " to about 2 % of the lane width. The phase meter itself cannot indicate which lane the observer is in, it can only show very accurately where he is in any particular lane. Since the lane widths are narrow (they vary from something of the order of a third of a mile close to the transmitters to three miles or so at three hundred miles range) it is evident that the system suffers from a high degree of ambiguity. However, each decometer has a set of counters geared to the phase meter, and so the instrument can integrate its movements in the phase pattern. Thus each meter is set up when the position of the ship or aircraft is known to the extent of the number of the lane in which it is situated. The counters can be set to the correct whole numbers from the chart, and the phase meter will automatically indicate the fraction of the lane. Thereafter the equipment provides a continuous record of the movements and position of the ship or aircraft throughout the whole time it is in the service area of the stations.

In the event of a temporary failure of the transmitter system, or a breakdown at the receiver, there is no way of setting up the decometer counters again until the position is once more known to the accuracy of a lane width. Similarly, for a ship entering the service area of a Decca chain from outside there is no means of identifying the correct lane number unless the ship's position is sufficiently accurately known by other means. A system of " lane identification " to overcome these difficulties is in course of development at the present time, but has not yet been incorporated in the system on an operational basis.

The receiver equipment is so constructed that it is insensitive to large differences in strength of signal, and so can be used with equal accuracy very near to one station and remote from the other of the pair. It is possible to use the receiver in any sector around a pair of stations without getting a false result.

Range and accuracy.

Before proceeding to a statement on the range and accuracy of the Decca system two points should be mentioned. The first is that the results given by this system depend upon the measurement of the wavelengths of radio signals. Since the frequencies of the signals can be determined to within very small limits, this means an accurate measurement of the velocity of propagation of the radio waves. Using the present series of frequencies which lie in the band 80 to 150 kilocycles, three entirely separate sets of measurements have indicated that a velocity of propagation obtains which is rather lower than the figure normally accepted (2.9925×10^{10} cms/sec. instead of 2.9977×10^{10} cms/sec.).

The second point is that this system depends upon a comparison of the difference between the wavefronts of signals from widely separated stations and the calculated patterns of lines on the charts assume that these waves travel by the most direct great circle paths. The pressure of any secondary or reflected wave with a path different from that of the direct wave will cause an error in the phase measurement, and will produce to the user the effect of a distortion of the lattice of lines.

Secondary or reflected waves can occur because of reflection of the signals by prominent land masses. As far as the marine use of this system is concerned we have practically no evidence of this effect. If proper precautions are taken in the siting of the stations, the effect should be negligible.

Reflected waves, however, can and do occur due to the existence of the ionosphere, and the presence of these " sky waves " has a pronounced effect on the useful range and accuracy.

The instrumental accuracy as experienced with the system is such that a line of position can be observed to within 2 % of the lane width. This means that close up to the base line between the stations a movement of the order of 10 meters could be recorded. As the range from the stations increases, the lanes increase in width, producing a falling off in positional accuracy. It must also be borne in mind that an accuracy in fix also depends upon the angle of intersection of the two sets of position line. The lane width also depends upon the sector of the pattern relative to the base line of the stations. The accuracy is highest near the perpendicular bisector of the base line, and falls off to zero on the base line extensions. In order to make a comparison with other methods of navigation the following figures are quoted as the accuracy of line of position in terms of a bearing from the centre point of the base line, and refer to the area about the perpendicular bisector of the base line.

Two figures are given in each case, one the accuracy to be expected with 95 % of the observations and the other the accuracy on 50 % of occasions.

Under daylight conditions the errors up to ranges of the order of 300 miles are probably not more than four to five times the instrumental inaccuracies and this would give an equivalent bearing accuracy of the order of 0.05° for the 95 % case and 0.02° for the 50 % case.

Beyond 300 miles in daylight there is very little data on which to base any results, but in the limited experience available it is known that useful results were achieved on ranges up to 1,000 miles, and at that range the instrument was still operating on the signals and giving the correct answer within the limits to which it could be checked.

The night time figures are based on rather less information than is available for the short and medium distance daytime figures. They are also based on observations at fixed stations on shore rather than actual navigational trials in ship and aircraft.

At ranges of up to 75-100 miles, the effects due to " sky wave " are small, and the accuracy is comparable with that obtained in daylight. At ranges of 100 up to 200 or 250 miles, the sky wave signal has an appreciable effect. It is inadvisable to quote on insufficient evidence, but it can be expected that the error will be of the order of three times that of the comparable daytime figures. When ranges of 200 to 250 miles are reached, the effect of the sky wave signals may be expected to cause much larger errors. At a range of 300 to 350 miles, the sky wave becomes comparable in strength with the direct wave. Under such conditions there is an appreciable probability of the error building up to such an extent that a whole " lane " can be falsely gained or lost. At the present state of investigation it is difficult to estimate the range at which this would happen frequently enough to become important, but the indications are that " the system will have a useful night time range of the order of at least 300 miles ".

The radio frequency requirements.

Each chain of a master and two or three slave stations require a set of frequencies which are related to one another in a simple numerical ratio such as 6:7, 8:9. The transmissions are unmodulated continuous waves and thus the interference to other users should not be serious. As far as the requirements of the Decca system are concerned to be free from interference from other transmissions of comparable power output it is necessary to be clear by 2 kilocycles from other users employing uninterrupted continuous waves. Where the transmission carrier is broken by keying, it can be tolerated to within 200 cycles of the Decca frequency. The system is very insensitive to random or short period interference even at a level much above that of the Decca signals. The observed effect is to make the phase meter needles fluctuate quickly but no permanent error is introduced.

At the present time it is necessary to use a separate receiver equipment with each chain in use, since each chain will employ a separate set of frequencies. However, a receiver with frequency band switching and with a band width of the order of 200 cycles is under development, for use on several sets of frequencies. It has been predicted that four sets of frequencies with a separation on the corresponding stations of 0.45 % of the nominal frequency in each case, and a separation from other users of 0.35 % of the nominal frequency, could be used for world wide coverage without causing mutual interference.

The application of the system.

Subject to the satisfactory introduction of a system of " lane identification ", it is considered that the Decca system would be of material use to shipping at medium distances from the coast and when making a landfall. It has an immediate application for coastal navigation and for short and medium distance ferry services. Also, within a range of 50-75 miles from the stations of the chain it could be used for pilotage in narrow channels, and as an aid in marine survey.

7.—The Consol Navigation System

by CARADOC WILLIAMS.

(Document No. 13)

SUMMARY.

The paper describes in general terms the operation of the Consol Navigation System. An estimate is made of the capital cost of the ground beacon and the number of personnel required for its operation. Range and accuracy characteristics for both day and night operation are stated. On the Consol system the use of receivers with narrow band characteristics can do much to alleviate the problems of noise static and interference. Some devices are under development to facilitate the process of making character counts and to record and plot the character counts continuously.

1. Introduction.

1° The German system which was formerly known as Sonne has now been in service for a considerable time and the development of a British system embodying detailed improvements is nearly complete. Precise figures for operation will be given later in this paper.

2° Consol provides long distance navigational aid facilities for ships and aircraft using automatic transmitting beacons on the ground and a standard M.F. receiver in the vessel or aircraft.

3° The system radiates dot and dash signals and a position line can be determined by making a count of the dot and dash characters heard during the transmission cycle. By reference to a map or chart overprinted with the Consol lattice, it is possible to establish that the observer is accurately located on one of six alternative position lines in each coverage sector of 120 degrees, these position lines being located approximately 20 degrees apart. Should the observer be in doubt on which position line he is located, all bearings except the correct one can be eliminated by taking a rough bearing of the ground station with the D.F. loop, the accurate value of the position line being determined by the dot and dash counts. The observer can establish his position by reference to two independently operated Consol ground beacons.

4° It is anticipated that tables may be substituted for charts at a later date, if found to be suitable.

2. General description.

1° Consol provides bearing indications of a ground beacon up to distances of about 1,500 miles over the sea and 1,000 miles over the land, under favourable conditions. The coverage area comprises two sectors 120 degrees wide centred on the line normal to the aerials. The ground beacon consists of three vertical aerials spaced in line approximately 1.8 miles apart. These are energised through transmission lines from a medium frequency continuous wave transmitter delivering a total power of about 1.5 kw. to the three aerials.

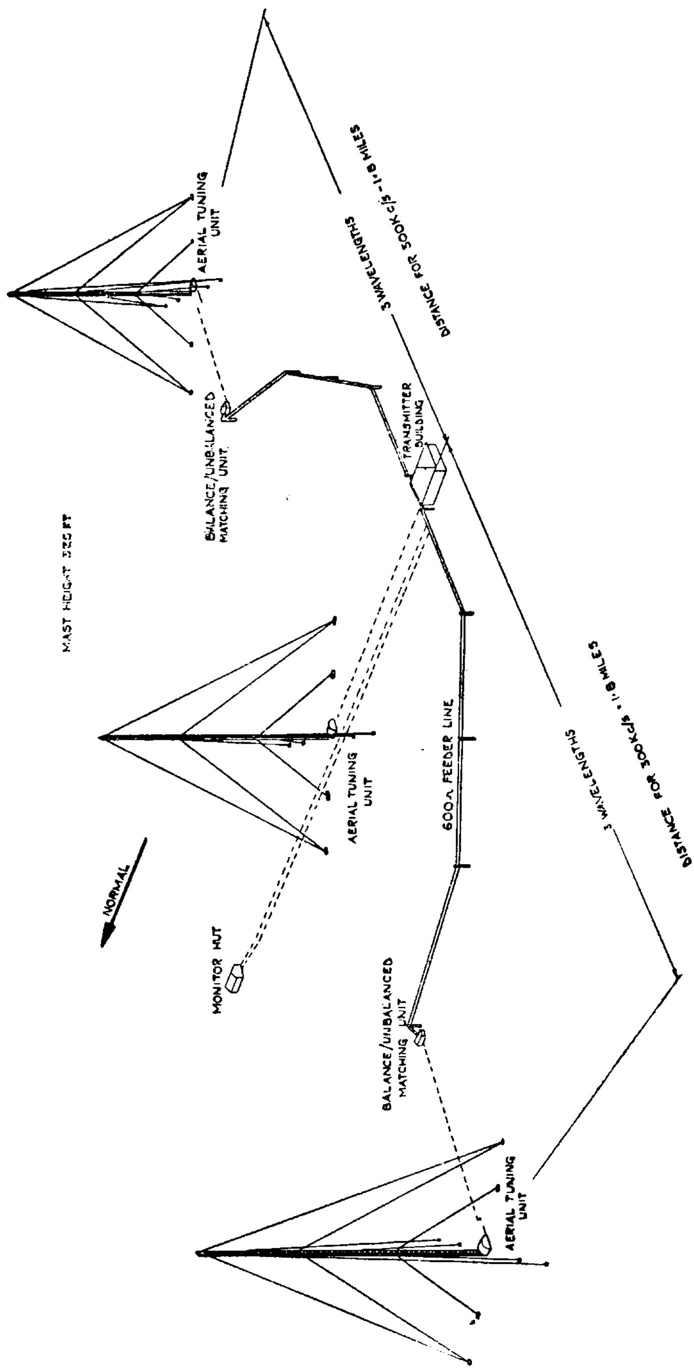
3. Frequencies.

1° The German stations were designed to operate on fixed frequencies between 260.Kc/s. and 500 Kc/s. All stations have been dismantled with the exception of one beacon at Stavanger, Norway being operated on 319 Kc/s. under allied control. There are also two beacons in Spain, one at Lugo operating on 303 Kc/s. and the other at Seville operating on 311 Kc/s.

2° A station using British designed equipment is now being erected at Bushmills, Northern Ireland and will operate on 263 Kc/s. This station will provide navigation coverage on the north and mid-Atlantic sea and air routes and its back coverage will provide good fixing facilities with the Stavanger beacon in the sea areas around the British Isles. It is proposed that future British Consol stations will operate at fixed frequencies in the band 263 Kc/s. to 415 Kc/s. The minimum acceptable spacing between channels will be of the order of 2 Kc/s.

4. Cycle of operation.

1° The complete cycle of operation of German beacons takes 2 minutes. During the first 56 seconds omni-directional C.W. transmission takes place from the centre aerial, the



DIAGRAMMATIC LAYOUT OF CONSOL STATION.

commencement of the cycle being taken up by the station identification code. After a break of 3 seconds, the keying cycle of 60 dot and dash characters commences during which time the observer makes a count. This cycle takes 1 minute, the dot period being 1/6 second duration and the dash period 5/6 second duration. This is followed by a break in transmission for one second, after which the cycle recommences. It will take from 6 to 8 minutes to get a fix from two beacons.

2° The first British prototype station will operate at twice this speed, the cycle being completed in 1 minute. During the 30 seconds keying cycle 60 characters are transmitted, the dot period being 1/12 second and the dash period 5/12 second. It will be possible to get a fix from two beacons in 3 to 5 minutes. It is proposed on later British stations to reduce the total time cycle to 40 seconds, thus reducing still further the time taken to get a fix.

5. **Ground equipment.**

1° The ground beacon shown in figure 1 comprises three vertical mast radiators about 300 feet high and associated radial earths, aerial matching units and transmission lines, a building locating the transmitter, the phase control and keying equipment, power supply equipment and remote automatic monitor receiver connected by lines to the main building to enable the duty operator to check and adjust the characteristics of the transmissions. The transmitter and control equipment will be duplicated in order to ensure a 24 hour service of operation.

2° It is not possible to estimate the cost of a Consol ground beacon without due consideration of the location of the site; transport problems, cost of excavations; availability of power supply, etc... Where the conditions are favourable in these respects, it is estimated that the capital cost of a station laid out to provide a 24 hour service will be of the order of £15,000 to £20,000.

3° Full operation of a Consol station deriving its power supply from outside sources could be maintained by a one man watch, although two men per watch is recommended. This economy in man power is being effected on British stations mainly by the provision of remote control facilities to the station operator for tuning and adjusting the aerial matching units from the transmitter building.

6. **Receiving equipment.**

1° The only equipment required in a ship to receive Consol signals is a standard type of communications receiver and standard D.F. loop. The automatic volume control should be switched off when receiving these signals. The operation of Consol involves tuning the receiver to the ground beacon, identifying the station code, taking a bearing with the D.F. loop if required, making dot and dash counts and then referring to the Consol chart.

2° Any type of M.F. aerial may be used for the normal reception of Consol signals. A single vertical wire or a top loaded inverted "L" or "T" aerial will be satisfactory.

7. **Accuracy and performance.**

1° The bearing accuracy of Consol over water or over land in daytime when there is negligible sky wave transmission is considered to be good. Near the line normal to the station 50 % of observations are likely to be within 0.2 degrees and 95 % of observations are likely to be within 0.5 degrees. At 60 degrees to the line normal to the station 50 % of the observations are likely to be within 0.4 degrees, and 95 % of observations are likely to be within 1 degree.

2° At night the system is subject to error due to multiple path propagation, that is the effect of simultaneous reception of ground wave and sky wave signals at the receiving point which will under certain conditions compromise the accuracy of the system. The accuracy at night is dependent on a number of characteristics, for example :—

(a) The distance of the receiving point from the beacon ;
(b) The value of reflection coefficient of the waves returned by the E layer ;
(c) The angle the position line subtends to the normal line of the beacon.

3° The night accuracy of Consol is the subject of scientific investigation by the Radio Research Board and the Ministry of Supply. It has been established that when observations are made in the vicinity of the normal line to the beacon, the errors are exceedingly small, the average errors being of the order of 0.2 degrees for all distances from the beacon. Accuracy is always the lowest at the edge of coverage, that is at 60 degrees to the normal. At distances between 350 and 450 miles where the two signals have comparable amplitude, maximum error is present, the errors decreasing at greater and lesser distances. In this region of maximum error the effect is to produce a bias of the mean (systematic error) increasing from zero at the normal line to 3 degrees at the edge of coverage. Present indications are that the scatter of bearing about the mean in this region are :—

50 % of readings within 0.2 degrees near the normal line rising to 1.5 degrees at the edge of coverage ;

95 % of readings within 0.8 degrees near the normal line rising to 5.0 degrees at the edge of coverage.

At distances greater than 500 miles, the sky wave signals become the major component and the accuracy will improve with increase of distance from the beacon. If second hop sky wave is present in addition to the first hop this will be liable to compromise the accuracy to an amount at present unknown. It will be of interest to remark that the change of bearing due to sky wave transmission is such as to shift the average readings nearer to the normal line. When a great deal more is known about the night propagation conditions at these frequencies, it is not improbable that some kind of corrections could be applied to the observations in order to give appreciable improvement in the accuracy of the system at night. It can be stated that the statistical data so far collected and analysed does show some very interesting tendencies to follow regular laws predicted by the theory of propagation at medium frequencies.

8. **Noise static and interference.**

1° This paper would not be complete without giving some consideration to the performance of the system in regions of high noise level or in the presence of other sources of interference.

2° The maximum distance of operation of the Consol system has been stated in paragraph 1-2° and these apply where the static noise level is not high. Where static noise levels are high, the maximum distance of operation of the Consol system will deteriorate accordingly. If the average static noise levels of the areas concerned can be given with reliability for both day and night, then the maximum distance of operation of Consol beacons set up in these areas can be readily predicted. It should be mentioned that bursts of static during the counting cycle may interfere with the taking of observations and may thereby increase considerably the time required to obtain a fix.

3° An important characteristic of continuous wave systems is that they can operate on a very narrow bandwidth, for instance, Consol beacons could be spaced at 2 Kc/s. or even less without mutual interference. From the point of view of interference from unwanted transmission and noise sources, a very great deal can be achieved by narrowing the bandwidth of the receiver to a few hundred cycles by the incorporation of crystal gate filters in the intermediate frequency circuits or by narrow band filters in the audio stages. Since the noise level is proportional to the square root of the bandwidth of the receiver, a very great deal can be done to minimise the effects of all sources of interference, by the use of receivers which incorporate narrow band selectivity characteristics.

9. **Ancillary equipment.**

1° The operational use of the Consol system calls for no equipment additional to the M.F. receiver and the D.F. loop. It has been considered that ancillary recording devices may be of value to facilitate the use of the system for particular applications.

2° An automatic counter system is proposed which will totalize the dot and dash counts received during one cycle and present these continuously on an indicator. No serious technical problems are expected to realise this.

3° An automatic recorder is proposed which will receive the Consol signals and record on a chart continuously. The equipment may be left unattended for many hours during which time a continuous record of the position lines are made and the navigator can plot his track and locate his position at any time from the data recorded. This recorder is under development.

10. **Conclusions.**

The Consol system provides within the limitations described an accurate and reliable long distance navigation aid, for which no special equipment is required by the user. Only a small amount of practice is required to use the system. The ground beacons are not expensive, having regard to the service they can provide within the coverage area and the cost of maintaining the stations is likely to be low.

8.—The P.O.P.I. Navigation System

by Caradoc Williams and C.D. Smith.

(Document No. 18)

SUMMARY.

The paper describes a beacon system for long distance navigation called P.O.P.I. (Post Office Position Indicator). It operates in the M.F. band and a single beacon provides bearing indications to the observer on a scale and pointer meter. Two independently operated beacons are required for a fix. It operates on the principle of phase comparison of signals from spaced radiators. The basic principles have been demonstrated successfully and a prototype system with omni-directional characteristics is being developed. General information concerning the transmitter and receiver equipment is given. Range and accuracy characteristics are estimated from known data on other systems.

1. **Introduction.**

It is the purpose of this paper to describe a long distance navigation system which is, as yet, in the early stages of development. This is called P.O.P.I., an abbreviated term for the Post Office Position Indicator. This system has been invented by the British Post Office Engineering Department, who have successfully shown the possibilities of the scheme by demonstration of the basic principles on a very low power experimental installation. The further development of the system is being carried out in the U.K. by the Ministry of Supply, who are to design and erect a prototype installation on which full scale trials can be conducted. The possible applications of the system to marine navigation would be "Ocean Aid" and "Landfall Aid".

2. **General description.**

1° P.O.P.I. is a beacon system from which bearings may be obtained up to distances of 1,500 miles or more. Each beacon will operate on a separate frequency in the M.F. band and in order to provide ocean coverage two or more beacons would be sited to provide good position line cuts over the area of operation. The system is based upon the comparison of phase of signals from two or more spaced radiators which are transmitting phase locked signals. The loci of point of constant phase difference will be a family of hyperbolae having their foci at the aerials. In the P.O.P.I. system the radiators are spaced a half wavelength apart and in the most elementary form, that is the two radiator system, ambiguity will arise either side of the base line. By increasing the spacing between the two radiators to greater than half a wavelength, greater accuracy of bearing will be realisable, but the number of ambiguities will increase.

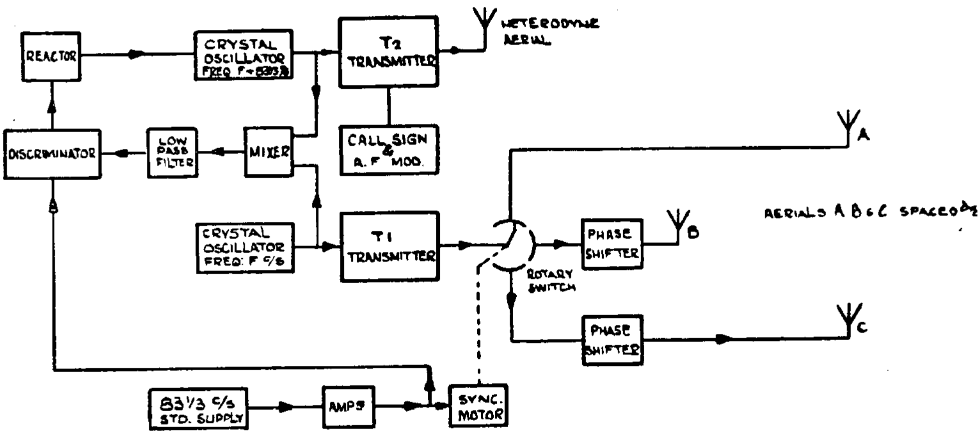
2° The system which is in development will comprise three radiators located at the apices of an equilateral triangle of half wavelength side. This arrangement is being adopted in order to provide a beacon with omni-directional characteristics. The radiators are used in pairs for the purpose of comparing the phase of the transmissions as in the case of the two element system, but the choice is made of that pair whose normal to the base line lies closest to the receiving point. By this means each pair of radiators is only used over that sector where the accuracy is greatest and in circumnavigating the system six such sectors are encountered. Each sector occupies 60° of arc and if all three radiators are fed in phase there will be 180° electrical phase change between the transmissions for each 60° of arc.

3° It has been stated that lines of constant phase difference consist of a family of hyperbolae with the aerials as their foci. At distances from the station greater than a few wavelengths (that is say 3 or 4 kilometers) the hyperbolae became substantially straight lines and therefore lines of constant phase difference are great circles lines radiating from the beacon.

4° There appears to be no technical objection to spacing the radiators many wavelengths apart, except that this will increase the complexity of the installation and the equiphase lines will no longer be great circles, but hyperbolae. It is considered that adequate accuracy without ambiguities will be realisable by using the short base system of half wavelength spacing.

5° In practice the three aerials will be energised in turn from a continuous wave transmitter and the phase difference of these three transmissions can be most easily compared if they are converted to a low audio frequency. It can be shown that provided the heterodyne oscillator producing the audio frequency is very stable, the phase difference which exists at the transmitting frequency will be maintained at this lower frequency. The heterodyne oscillation is provided by radiating from an additional aerial at the ground station a C.W. signal differing by the required audio frequency from the original radio frequency. In this manner, the audio frequency is rigidly controlled from the ground and appears at the output of the second detector of the receiver.

6° It will be apparent that in order to identify the signals at the receiver as originating from any one of the three ground radiators a switching system synchronised with the switching of the ground radiators has to be embodied in the receiver equipment. The manner in which this is realised will be described later in the paper. At present it is sufficient to state that the signals are separated out by this switching system and the great circle bearing of the beacon will be read directly from a scale and pointer meter.



P.O.P.I.—Transmitting equipment.

3. Frequencies.

To those familiar with the propagation characteristics of radio waves, it will be realised that the reception of signals at great distances must be dependent upon either a ground wave propagation path or a sky wave path, in the latter case the signals being reflected back to the ground receiving point by the ionosphere. At certain critical distances from the ground beacon, both ground and sky wave signals will be received simultaneously and at distances where the ground and sky wave signals are comparable in amplitude it is to be expected that the errors of the system will be at their maximum. Therefore, it is desirable that a part of the radio frequency spectrum, should be chosen which will give the best possible ranges by the ground wave and for this purpose it is considered desirable to use either medium frequencies or low frequencies. In practice it is proposed that the P.O.P.I. system should operate in the band 100 Kc/s. to 500 Kc/s. This band will provide good long distance performance by day or night and over sea or over land.

4. State of development.

1° It has been stated in a previous paragraph that the principles of operation of the system have been successfully demonstrated by the Post Office Engineering Department. This has been achieved by setting up an experimental two aerial installation working on 749 Kc/s. using very small aerials and radiating power of only a few milliwatts. Obviously, the operating range of such a system is only a few miles. A receiver has been set up in a vehicle and it has been possible to take approximate bearings successfully within the neighbourhood of the station.

2° Considerable further development work is now being carried out by the Ministry of Supply to produce a higher power prototype system using two kilowatt transmitters. Much further development of circuits and equipment will be required to realise this.

3° On the receiver side development is proceeding on circuit technique in order to improve the instrumental accuracy of the equipment and in order to produce prototype designs of receivers suitable for use in ships or in aircraft.

5. **Transmitter equipment.**

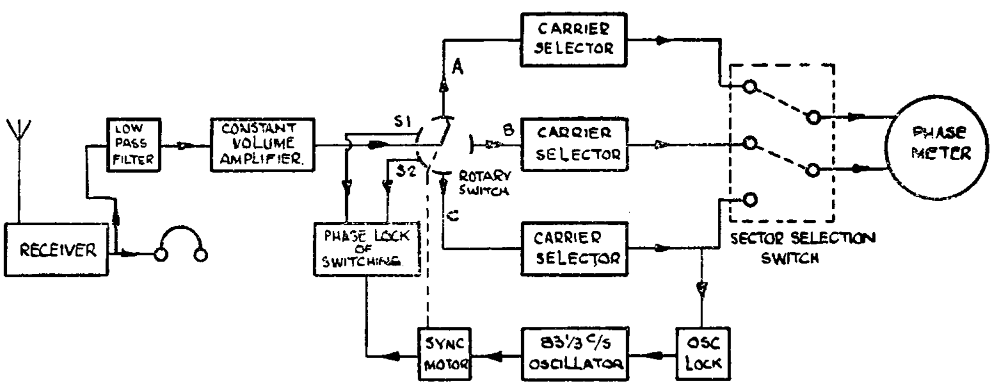
1° A schematic diagram indicating the general features of the transmitter equipment is shown in figure 1. The installation comprises two 2 kilowatts transmitters with crystal drive unit and automatic frequency locking and phase stabilising arrangements ; motor driven rotary switch which supplies the power to the aerials, coaxial transmission lines, aerial matching units and three 150 ft. vertical insulated masts working as self radiators ; a fourth subsidiary aerial of similar construction which radiates the heterodyne transmission and lastly monitoring equipment.

2° The three phase locked aerials will be located on the corners of a triangle as indicated in paragraph 2-2° and for a frequency of 300 Kc/s., the aerials will be located 500 meters apart. The location of the fourth subsidiary aerial is not important, but it should be located several wavelengths away from the other aerials.

3° The two transmitters will be controlled in frequency from separate crystal drive sources and if the transmitter feeding the phased aerials operates at frequency f, the second transmitter will operate at frequency f + 83 1/3 cycles per second. Automatic frequency control equipment is associated with the crystal drive units in order to ensure that the difference frequency between the two transmitters is accurately maintained at 83 1/3 cycles. The switching motor will be driven by a synchronous motor at 5 5/9 cycles (15th sub-harmonic of 83 1/3 cycles), using the 83 1/3 cycles source for frequency control. The full power of the transmitter will be switched to the three main aerials in turn.

4° Each aerial will have a matching unit at its base which will tune the aerial and provide impedance matching to the coaxial transmission lines.

5° A simple receiver aerial will be located at a point equidistant from the three transmitting aerials and will be used in conjunction with the station monitoring equipment for checking the phase of the transmissions from the three main aerials.



P.O.P.I.—Receiving equipment.

6. **Receiver equipment.**

1° A conventional type of medium frequency receiver is used to receive P.O.P.I. signals but certain ancillary equipment will be connected to it. It is desirable to use a narrow band receiver in order to derive the full advantage of good signal to noise ratio, since the P.O.P.I. transmissions occupy only a narrow band of frequency. A block diagram of the receiver circuits developed by the Post Office Engineering Department is shown in figure 2, but it is expected that considerable deviation from these circuits may be necessary in order to achieve the accuracy which will be required from the prototype equipment.

2° The signals from the phased aerials and the heterodyne aerial are received simultaneously and the 83 1/3 cycle beat frequency signal at the receiver output has the same phase characteristics as the radio frequency transmissions. Thus during the switching cycle of the ground transmission, three successive audio signals are received, displaced approximately in time by 0.2 seconds, whose relative phase depend upon the relative phase of the signals from the individual radiators of the ground beacon.

3° The signals from the receiver output are fed through a low pass filter and amplifier to a rotary switch which is locked in synchronism with the switching operation on the ground. These interrupted signals are then converted to continuous signals in the carrier selector units prior to feeding them into a suitable phase meter. The phase locked switching operation is achieved by driving a rotary switch at 5 5/9 r.p.m. from the 83 1/3 cycle locked signal by means of a synchronous motor. The conversion of the interrupted signals to continuous signals will be carried out by more accurate methods than hitherto and the circuit arrangement to perform this function are still under development.

4° The technique of presenting bearings on a meter has yet to be fully developed. It is proposed that great circle bearings will be displayed directly on a scale and pointer meter with central pivots to give a 360 degree bearing scale. Two methods have been proposed for development either of which may be adopted. The first is a null method using phase meters which would be servo controlled. The second uses phase discriminator circuits and a D.C. indicator similar to that used in the Decca Navigator.

5° The receiving aerial can be of any type suitable for the reception of M.F. signals, that is a vertical wire or an inverted " L " or " T " aerial.

7. **Range and accuracy characteristics.**

1° Until a prototype station has been erected on which long range trials can be carried out, it is only possible to estimate the range performance of the system. From data collected on the Consol and Decca systems, it is expected that 1,500 miles over water and 1,000 miles over average land will be obtainable. The narrow band characteristics of the receiver will provide advantages compared with the Consol system, by greater ability to work through high static noise of interference levels.

2° Resulting from improvements in circuit technique, it is hoped that the instrumental accuracy of the measurement of phase will be of the order of 2 degrees. This corresponds to an accuracy of measurement of bearing to ± 2/3 degree.

3° The accuracy range characteristics will be similar in many respects to a fixed station M.F. Adcock Direction finder. The accuracy of 95 % of observations is expected to be within :—

(a) Daytime	0—1,500 miles	± 2°.
(b) Night-time	0— 100 miles	± 2°.
	100— 500 —	± 4°.
	500—1,500 —	± 2°.

4° Errors will be at their maximum at night due to the higher reflection coefficient of the E layer at these frequencies. When the ground and sky wave signals are comparable in amplitude the errors are greatest and this will take place between 350 and 450 miles, the errors becoming smaller at greater and lesser ranges. Errors are expected to be very small near the normal to a pair of aerials and will increase with increasing angle from the normal line. With the P.O.P.I. three element system no bearing line is greater than 30 degrees from the normal of a pair of radiators and this will lead to greater accuracy of bearings derived from sky wave than other systems which depart up to 60 degrees from the normal.

8. **Conclusions.**

1° P.O.P.I. is a system which will offer the facility for determination of bearings and fixes beyond the normal ground wave range.

2° Instantaneous bearing and track indications will be available on a scale and pointer meter.

3° The basic principles have been shown to be sound but considerable further development is in progress in order to improve the accuracy of the system.

9.—Corner reflectors.

Extract from " Identification for Marine Navigational Radar ".

by A.G. Bogle B.E., A.M.I.E.E.
(Admiralty Signal Establishment Extension, Witley)

(Document No. 22)

The basic element of a corner reflector array is a right tetrahedron with its equilateral surface removed—the shape obtained by diagonally cutting a corner off a hollow cube. This element has the property that radiation falling on it from a point inside its solid angle is

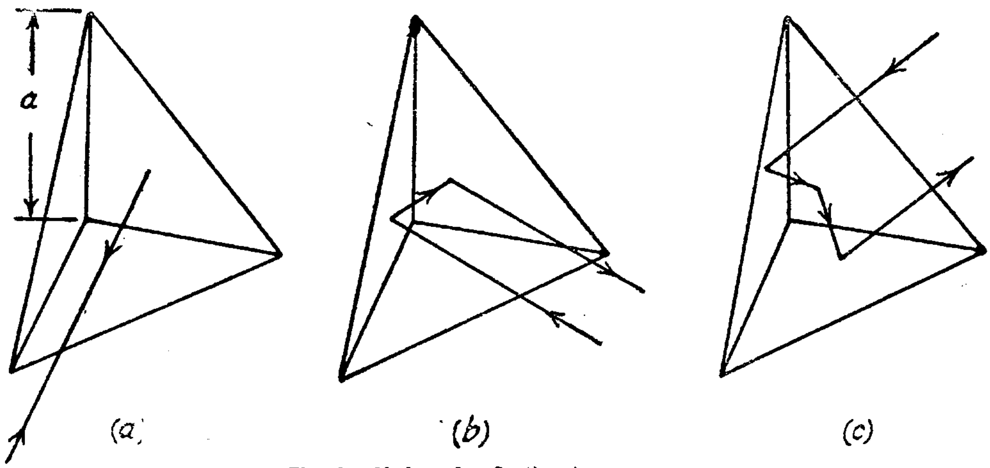


Fig. 1.—Modes of reflection in a corner.

reflected back in the direction from which it came, provided that the three surfaces are accurately at right angles and that deviations from flatness are small compared with the wavelength of the incident radiation. Reference to figure 1 will show how this direct

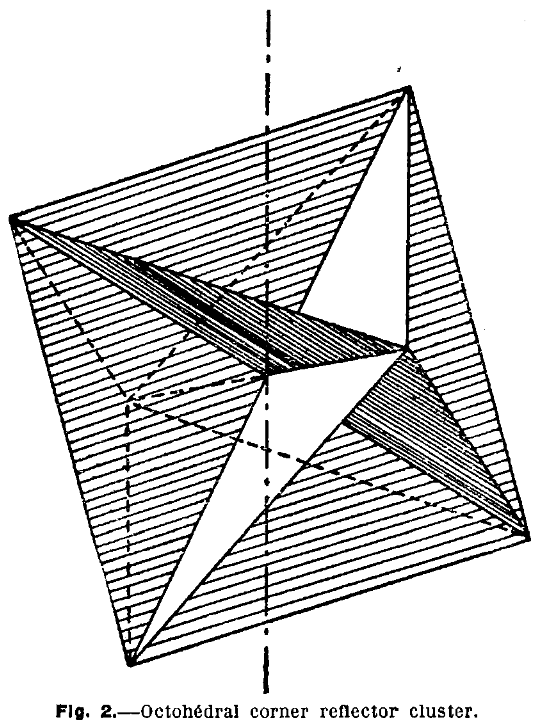


Fig. 2.—Octohédral corner reflector cluster.

reflection is achieved, and it is clear that this causes the corner to have a large gain compared with a target which gives uniform scattering of the incident radiation. The power reflected from such a corner is $\frac{5.2A}{\lambda^2} \times$ the power reflected from a single half-wave dipole, where A is the projected area of the open face of the corner, λ is the wavelength of the radiation, and the radiating point lies within the solid angle of the corner.

Two arrangements have been tried, each giving approximately all round cover from a group of corner reflectors. The simplest mechanical construction is that shown in figure 2 where it is seen that three flat plates, intersecting so that each is perpendicular to the other two, create eight hollow tetrahedra, six of which can be made use of for horizontal cover by mounting the structure with the remaining two apertures horizontal. A second arrangement which was tried is that shown in figure 3. Here five of the basic tetrahedral elements are mounted separately in a pentagonal cluster.

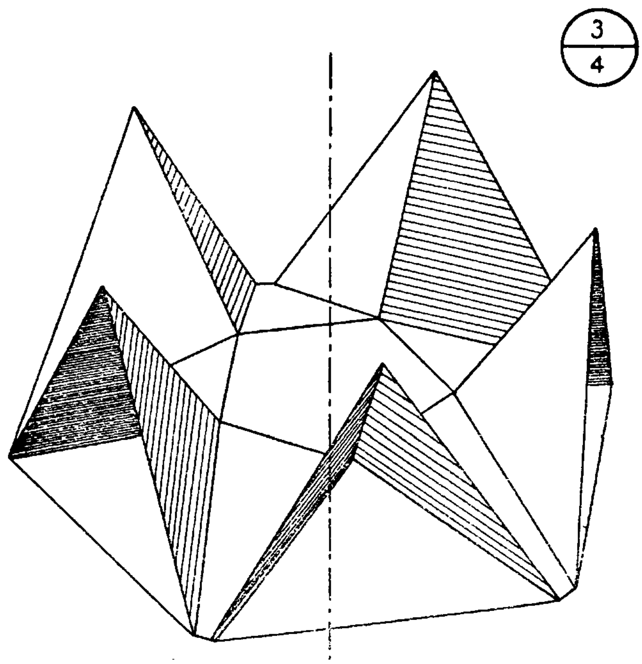


Fig. 3.—Pentagonal corner reflector cluster.

The second arrangement is a little easier to make with the required accuracy, and should give slightly the better performance ; in practice, however, it seems to have no marked advantages and the first arrangement is preferred as being mechanically simpler and potentially lighter.

The corners used in trials with 3 cm. radar had dimension "a" equal to 60 cm., and when made up into eight-sided units had a weight of about 70 lbs. These units, when mounted on second-class buoys, increased their radar detection range from 6 kilometers to 16 kilometers. Even more important than the gain in detection range is the fact (indicated in the curves of figure 5) that when fitted with corner reflectors the buoy can always be detected in rough sea conditions, where sea clutter swamps the echo from a normal buoy, and so renders it useless for radar pilotage.

For the purpose of giving clean identification of a point, as distinct from increasing the range of detection of a buoy, it is necessary to use a number of corner reflector clusters in a recognisable pattern. Trials have been carried out with patterns of four clusters arranged in the form of a T, and it is found that this gives a clear mark, not very likely to be imitated by a fortuitous gathering of other reflecting objects. If the spacing of the buoys is 330 meters the pattern is clearly recognisable at all ranges from detection range ; a narrower spacing tends to make them merge together at maximum range, a wider spacing is more difficult to recognise and more liable to confusion by adjacent craft, etc... With the optimum spacing the identification is almost always clear and unambiguous but the possibility of interference by other reflecting objects calls for some care in observing the pattern.

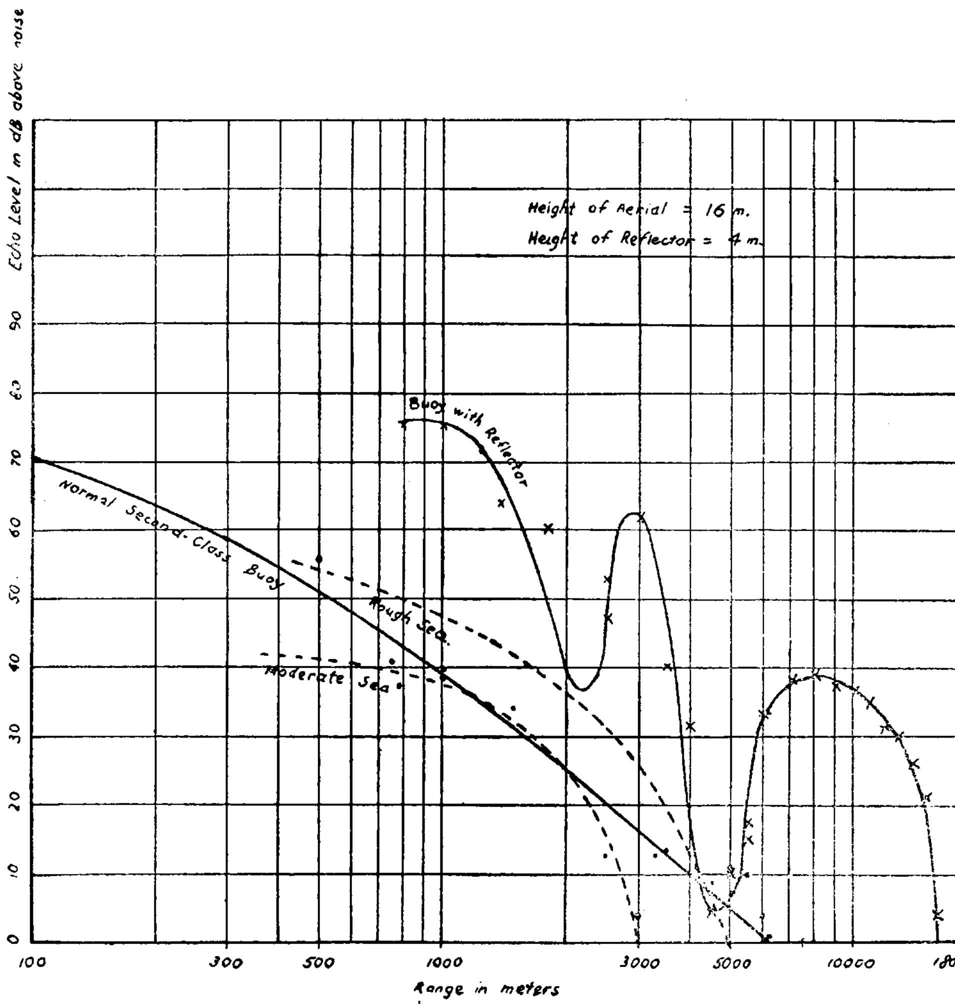


Fig. 5.—Variation of Echoes and Sea clutter with Range.

It is obvious that corner reflector clusters, in spite of the fairly high accuracy of manufacture required, will be cheaper than any electronic device, and if suitably designed should have a long reliable life with no more maintenance than a periodic inspection for mechanical damage. Their simplicity and reliability can hardly be equalled by any other device. Provided that the radar has the good range and bearing discrimination already regarded as essential for pilotage the use of reflectors involves no complication. The reflector patterns are, of course, less reliable, and useful when used with radars of lower performance.