C.W. RADIO AIDS TO HOMING AND BLIND APPROACH OF NAVAL AIRCRAFT*

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SUMMARY

A brief historical account is given of the development of c.w. homing beacons for use by the Fleet Air Arm. The equipment at present in use on aircraft carriers and at naval air stations is described. The method used to compensate for changes in direction of the ship's head so that the beacon always transmits the correct homing information is detailed. The factors affecting the choice of a particular type of homing aid are discussed.

An account is given of experiments with a Lorenz type of beacon for blind approach to aircraft carriers. The present equipment is described.

The paper concludes by emphasizing that the requirements for fully automatic homing, approach and landing set a problem for the future that may require separate solutions for shipborne and land-based aircraft.

(1) HOMING BEACONS

(1.1) Historical Survey

(1.1.1) Early Experiments.

The navigation of a naval aircraft when it has left its parent carrier introduces problems additional to those encountered by civil and shore-based military aircraft. A torpedo- or bomb-carrying aircraft may be away from the carrier for as long as seven hours, flying several hundred miles over open sea with little prospect of obtaining a position fix. During this time the ship itself may have steamed a hundred miles or more, and, moreover, may have altered its mean line of advance in order to engage the enemy, and therefore may not be in the position anticipated by the pilot of the aircraft. The endurance of carrier-borne fighter aircraft is not as great, but they are invariably single-seater aircraft, so that navigation is an additional burden for the pilot, whose physical and mental faculties may be affected by combat fatigue. In such circumstances the use of conventional navigational methods is unsatisfactory, and there is an obvious need for a simple homing aid.

In June, 1932, development of a rotating radio-beacon system using metre waves was initiated. The range originally required was 50 nautical miles at an aircraft height of 5 000 ft. H.M. Signal School (now Admiralty Signal and Radar Establishment) developed a transmitter using a silica magnetron operating at a wavelength of about 3½ m, and a quench receiver was produced by the Royal Aircraft Establishment for the waverange 3–4 m. Either a sonic or supersonic modulation could be applied to the transmitter, the received signal being made audible in the latter case as the beat frequency between the supersonic modulation frequency and the quench frequency of the receiver. The transmitter was installed in Southsea Castle, and fed a vertical half-wave aerial with a parabolic-section reflector of horizontal aperture approximately $1 \cdot 2\lambda$, composed of 30–40 half-wave vertical rods. The transmission was directed along a fixed bearing. The choice of an aperture of $1 \cdot 2\lambda$ was a compromise between the requirements for providing a reasonably sharply defined beam and an aerial size suitable for accommodation in a ship.

The first air trial in May, 1933, showed that the required range was easily obtained, and the bearing arc over which signals were audible was found to be 45°. It was decided to reduce the wavelength progressively, with the object of reducing the size of the transmitting aerial, and trials were carried out on 2·75 m, 2 m, and finally, in September, 1933, on 1·5 m. This was the limit of the valves available at the time for use in the experimental receiver.

Equipment was then developed by the Admiralty Research Laboratory to rotate the aerial system at exactly one revolution per minute. The beam was made to pass through true north exactly on the minute, and an observer in an aircraft, on hearing the signal reach its maximum intensity, referred to a watch. Before the aircraft left the aircraft carrier, this watch had its second-hand synchronized with a master clock controlling the rotation of the aerial, and the observer was informed of his aircraft bearing relative to the beacon, whence the correct homing course could be deduced as the reciprocal of this bearing. When this system was put into general use, an average operator could determine his homing course to an accuracy of ± 5 deg.

First trials with a rotating aerial in March, 1934, showed a reduction in effective range compared with that obtained when flying a fixed course. This was due to the difficulty of distinguishing between presence and absence of the signal, owing to the high noise output of a super-regenerative receiver at low input-signal levels. It was therefore proposed to key the modulation in half-second dashes, but this suggestion was never adopted. Early in 1935 the beacon was re-erected on a 50-ft tower at Eastney Fort East (Portsmouth). The speed of rotation of the aerial system was doubled experimentally, but it was found that with a rate of approach of 115 knots (usual at that time), one revolution per minute was sufficient for successful homing. At close range, difficulty was experienced in obtaining a sharply defined maximum without skilful adjustment of the quench receiver. One suggestion to overcome this difficulty was that alternate revolutions of the aerial system should be at reduced transmitter power, but this was not put into effect.

(1.1.2) Shipborne Equipment.

A complete equipment, known as type 72X, was installed in an aircraft carrier at the beginning of 1936, and by mid-1940 several ships and certain Royal Naval Air Stations ashore had also been fitted. A naval type NT52 silica magnetron was used, delivering 30 watts in the frequency range 206·5–218·5 Mc/s, with its anode supply modulated at 20 kc/s. The tuned circuit consisted of a pair of lecher rods, the output being fed through a resonant line to a fixed end-fed half-wave vertical aerial. The beam was obtained by fitting a solid parabolic-section reflector behind the aerial, and rotating round it. The transmitter and aerial system were mounted at the top of the foremast in a hut consisting of a steel platform with canvas-covered plywood sides. The modulator, power supplies, and control table were mounted in an office near the base of the mast. The control table regulated the speed of rotation of the reflector from a precision chronometer, and compensated for changes in the ship's course in the manner described in Section 1.2.1.3.

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In the above-mentioned ships, the best site had been selected for the beacon. In the later aircraft carriers, priority of position on the mast was given to radar, and the homing beacon had to occupy a lower position on the foremast at a height of about 100 ft above the sea. This meant a complete redesign of the aerial system, so that the radiating element, reflector, and transmitter, could all rotate bodily round the mast, which, at this point, was 16 inches in diameter. The modified equipment was known as type 72DM, and its aerial system and gyro-control circuits are described in Sections 1.2.1.2 and 1.2.1.3 (type 72DP). The primary standard controlling the aerial speed was a chronometer fitted with electrical contacts, as in type 72X. The transmitter was also redesigned, using a pair of naval type NT58 valves (equivalent to Marconi-Osram type DET12) in a self-oscillatory circuit. The frequency stability and power output were thereby improved. An extended frequency range of 182·5–218·5 Mc/s was also provided. Type 72DM was fitted in several ships and gave useful service during the early stages of the war.

As the war developed, the number of flying personnel in the Fleet Air Arm increased rapidly, and it was therefore decided to facilitate training by simplifying the interpretation of the beacon signal, although it was appreciated that by so doing it was made easier for the enemy himself to use the beacon. In its simplified form the beacon defined true bearings around the ship by transmitting characteristic modulations, thus avoiding the use of a synchronized watch. The modified equipment is known as type 72DP, and is described in Section 1.2.1.

(1.1.3) Airborne Equipment.

The first receiver produced by R.A.E. for use with the Series-72 beacons was a four-valve quench receiver with a tuning range of 206·5–218·5 Mc/s. The receiver was known as type R1110. Later, an alternative model covering the range 182·5–206·5 Mc/s was introduced. The h.f. oscillator was an acorn triode, and standard battery triodes were used for the quench oscillator (frequency approximately 19 kc/s) and the two stages of a.f. amplification. The h.t. supply was derived from a 120-volt dry battery. The aircraft was fitted with a ¾λ rod aerial.

In the summer of 1938 consideration was given to the development of a replacement for the R1110 receiver. This was necessary as more beacons were coming into operation, and the poor selectivity of the quench receiver restricted the number of transmitting channels available. Furthermore, the Naval Staff requirements were now altered, satisfactory homing being required from 100 miles range down to within one mile of the aircraft carrier. The R1110 was neither sensitive enough for reliable reception at the maximum range, nor could it be desensitized satisfactorily for accurate homing at short ranges. Other improvements of detail were also required. A new receiver, the R1147, was put into service at the beginning of the war. This was of superheterodyne type and covered the frequency range 180–220 Mc/s; it used seven valves, including three acorn pentodes and one acorn triode. The intermediate frequency was 25 Mc/s with a bandwidth of 500 kc/s (to allow for transmitter frequency variations); and a beat-frequency oscillator operating at 20–23 kc/s provided an audible tone from the 20-kc/s modulation on the received signal. The signal/noise ratio was improved by using a sharply-tuned stage of amplification at the supersonic frequency.

Power units operating from 12-volt or 24-volt batteries were provided, the h.t. supply being obtained from a motor generator delivering 20 mA at 200 volts. The power input was 36 watts. The total weight of the receiver, power unit, and remote control unit was 24 lb. A ¾λ rod aerial was fitted.

A new superheterodyne receiver was introduced to work with the carrier and modulation frequencies of type 72DP, which, for operational reasons, were different from those of type 72DM.

(1.2) Equipment at Present in Use

(1.2.1) Type-72DP Beacon.

This is a metre-wave beacon with an aerial system rotating at 1 r.p.m. The carrier wave is modulated at a medium radio frequency. As the beacon sweeps through each true bearing, a modulation is automatically transmitted which is characteristic of that bearing. The rotation of the aerial is stabilized in azimuth, corrections being applied to compensate for alterations in the ship's course. An average operator can determine his homing course to within ± 7½ deg, which is considered adequate for all practical purposes. The aerial system and transmitter are designed to revolve round the foremast together, and the control circuits and power supplies are located in an office in the "island" of the aircraft carrier.

(1.2.1.1) *Transmitter.*

The transmitter covers a frequency range of 200–250 Mc/s and is modulated at a medium radio frequency. Both the carrier and modulation frequencies are crystal-controlled. The carrier crystal resonates at one thirty-sixth of the desired signal frequency, the oscillator being followed by a frequency-trebling stage, two stages of frequency doubling and a further trebler. There are two stages of amplification at the signal frequency, each using a pair of disc-seal triodes in an earthed-grid circuit. Earthed-grid amplifiers have been used in v.h.f. receivers to obtain an improved signal/noise ratio, but their use in transmitters has been limited. There would appear to be distinct advantages in their use as driven stages in v.h.f. transmitters, by virtue of their stability and the elimination of neutralizing adjustments and controls. The grid forms a screen between the anode and filament, the input and output circuits being coupled only through the medium of the anode-space current. The circuit is inherently stable because the driving circuits and amplifying valves are effectively in series across the output circuit, the phase relationships between the driving and amplified voltages being such as to provide negative feedback. As some of the driving power appears in the output circuit it becomes necessary to modulate both the amplifier anode and driver voltages to obtain full modulation. A more powerful modulating stage than would normally be required has been provided to do this. Three beam-tetrodes (type CV124) in parallel constitute the modulator. These are driven by a crystal oscillator using a further CV124 valve. The power delivered to the aerial at 80% modulation is 35 watts throughout the specified frequency range.

The power supplies for the transmitter are derived from a 400-volt 50-c/s three-phase supply and are housed in panels situated in the type-72DP office. Valve rectifying circuits are used to produce the requisite d.c. supplies, which are then fed to the transmitter through mast cabling.

(1.2.1.2) *Aerial System.*

The aerial system and transmitter are mounted on a sectional aluminium casting known as the pedestal unit. A vertical half-wave centre-fed dipole, set at the focus of a solid parabolic-section reflector of horizontal aperture 1·6λ, is mounted at the front of the casting, and the transmitter is bolted to brackets at the back. The two are joined by a short length of screened twin feeder. The reflector is made in four sections to facilitate hoisting and to enable it to pass through the 2 ft 6 in square hatch in the floor of the hut. Fig. 1 shows the horizontal polar diagram of this aerial. The rotating part of the pedestal unit is driven by a three-phase synchronous motor supplied through cables running up the mast. The various supplies required by the transmitter are fed through slip-rings and brushes.

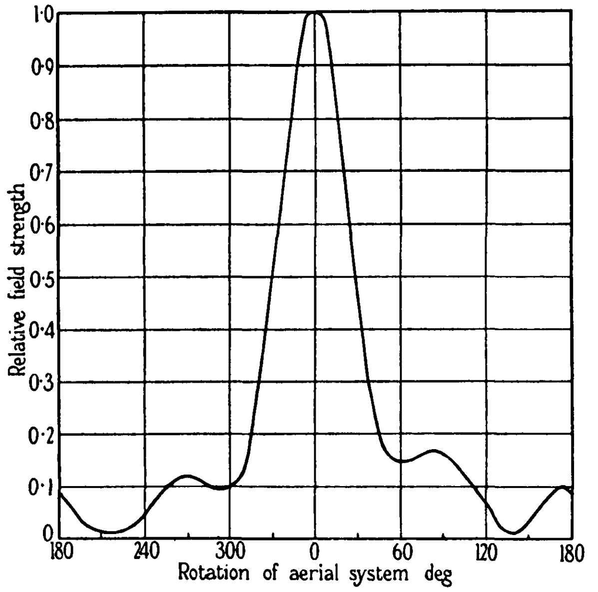

Fig. 1.—Horizontal polar diagram of type-72DP beacon aerial.

The pedestal unit is installed in a hut at a height of about 100 ft above the sea. This unit is based on a circular steel platform 10 ft in diameter fixed at the intersection of the tripod legs of the foremast. The sides are of canvas-covered plywood, and the roof is also made of wood, with a copper lining on the underside. Cables and waveguides serving equipment installed higher up the mast are fed through the hut between the mast and a cylindrical copper screen which connects the pedestal unit and the copper ceiling of the hut electrically. A vertical wooden ladder is provided on the outside of the hut to enable personnel to reach the top of the mast.

(1.2.1.3) *Control Circuits.*

The object is to rotate the beacon so that the desired bearing information is transmitted always in the same true direction from the ship irrespective of any alterations in its course.

To achieve this object, a control table is installed in the type-72DP office. A diagram of this unit is given in Fig. 2. The d.c. motor, running at 3 000 r.p.m., drives the rotor of an alternator. This is a three-phase two-pole machine giving a 50-volt 50 c/s output which is conducted through mast cabling to the synchronous motor in the pedestal unit of the aerial system. When fed with a 50-c/s supply this motor rotates the aerial system once per minute. The d.c. motor also drives, through reduction gearing, a selsyn transmitter which is connected to a corresponding receiver in an automatic modulation-control unit. Thus the speeds of rotation of the aerial system and of the modulation controller are locked together at a nominal 1 r.p.m. when the ship is on a steady course.

The stator of the alternator is designed to rotate and has a balanced cylindrical form with a uniformly distributed star-connected three-phase winding brought out to slip-rings. If it is necessary to reduce the speed of rotation of the aerial system to correct for the ship turning to starboard, the stator of the alternator is rotated in the same sense as its rotor, thereby reducing the frequency of the supply sent to the synchronous motor driving the aerial system. Similarly, if an increased aerial velocity is required the alternator stator revolves counter to the direction of rotation of the rotor. The stator is driven through a non-reversible worm gear from the chaser motor, which is a series motor with two independent field windings permanently connected to the d.c. supply and energized in opposition. There are two sections of resistance in series with each field winding. Short-circuiting one field winding and a section of resistance causes the motor to rotate, its direction of rotation depending on which winding is short-circuited. Any change in the ship's course is introduced into the differential gear (see Fig. 2) by a step-by-step motor driven from the ship's gyro-compass system, and causes the carriage carrying the intermediate wheels to be displaced. This closes contacts in the field circuits of the chaser motor, which then rotates in such a direction as to bring back the carriage of the differential gear to its original position.

In the older type-72DM beacon, where homing courses were derived by reference to a watch (Section 1.1.2), it was necessary for the speed of rotation of the aerial system in space to be exactly 1 r.p.m. and for the beam to pass through the north bearing exactly on the minute. For this purpose a chronometer was fitted in the control table. This controlled the speed of the d.c. motor accurately at 3 000 r.p.m., and also started the aerial system automatically on the north bearing at "zero seconds."

The method of control outlined in this Section works very well, the azimuthal stabilization of the aerial system being accurate to within ± ½ deg, and there can be no cumulative error.

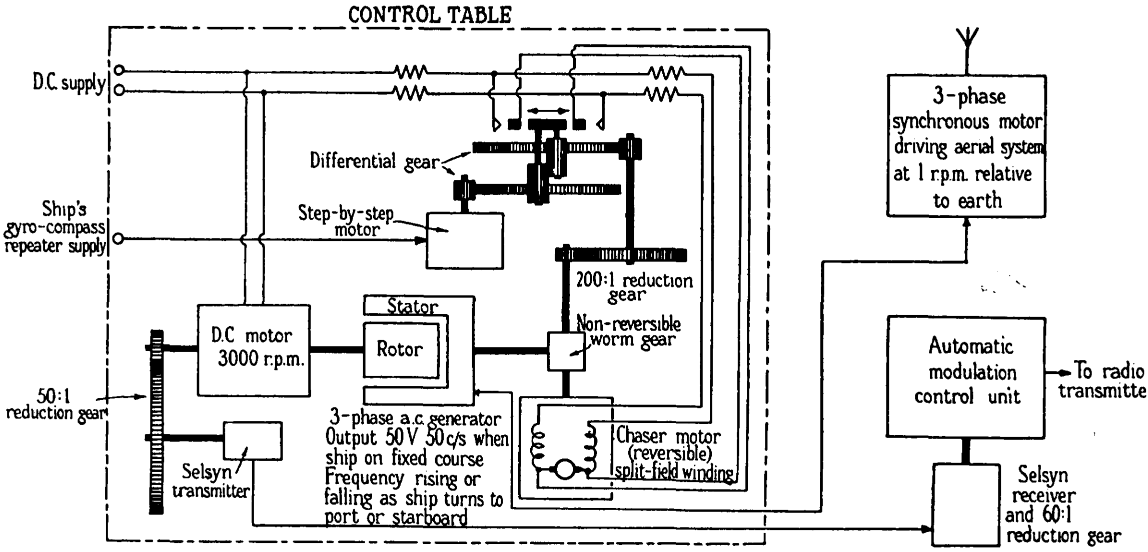

Fig. 2.—Type-72DP speed-control system.

(1.3) Factors affecting the Choice of a Homing Aid for use in a Naval Air Arm

Many methods have been demonstrated or proposed for radio beacons and other aircraft homing aids. Several of these are adaptable to shipboard use. This Section deals with some of the considerations involved in the choice of a suitable system for naval application.

(1.3.1) Adaptability to Shipborne Installation.

The suitability of any beacon system for use on ships is mainly determined by the size and spacing of the required aerial system, together with possible aerial-siting restrictions. The close spacing of the aerials, dictated by the relatively small size of the ship, makes the use of a true hyperbolic navigational system impracticable. It is generally impossible to find a site clear of interfering metal structures, and for this reason rotating beacons with narrow beams in azimuth are preferable to omnidirectional beacons or rotating beacons with wide azimuthal polar diagrams, because the interfering structure is less frequently irradiated.

Experimental investigation has shown that the horizontal polar diagram of a rotating directional aerial system is distorted on certain bearings relative to the ship by the proximity of masts and other parts of the ship's structure. This distortion may produce an apparent widening of the beam which, if asymmetrical, will introduce a bearing error that is a linear function of the asymmetry of the beam. Owing to the low order of accuracy of beacons like type 72, this distortion is not serious except on those relative bearings where one or other of the side lobes of the aerial is considerably increased in magnitude. It is possible on such bearings for the amplitude of the subsidiary beams to approach the magnitude of the main beam, and under such conditions the apparent beam width of the beacon aerial has been observed to be anything up to twice the normal width. Nevertheless, it has been possible in practice to use sites for the beacon which are far from ideal without seriously affecting its performance. The reasons for this inconsistency are that an aircraft homing on the beacon does not normally maintain a constant bearing relative to the ship's head (due to the turning of the ship), and, moreover, the observer can exercise a certain amount of control. He will know when bearings obtained from the beacon are liable to be faulty because an abnormal beam-width will be received, and he can either reject such bearings, or alternatively reduce the gain of the receiver, to obtain the maximum discrimination between the main beam and subsidiary beams.

All systems installed in a ship must be stabilized in azimuth to compensate for changes in ship's head. With the aerial apertures normally used, the beam width in the vertical plane is wide enough to make correction for rolling or pitching of the ship unnecessary.

(1.3.2) Ease of Operation and Reliability in the Aircraft.

In any homing system, responsibility for correct operation is divided between the ship or ground personnel, and the aircraft personnel. It is important that as little responsibility as possible should rest with the aircraft, particularly in the case of a single-seat fighter. The ship should be responsible for transmitting correct information, and the interpretation of that information into a homing vector or on-course indication in the aircraft should be simple, or else automatic. With the beacons now in use a homing bearing is provided aurally once a minute when required. The pilot does not have to perform a d.f. operation, and his vision is not distracted. He may listen on the beacon and r.t. communication channels simultaneously if he wishes. The aircraft equipment is a light and reliable receiver using a simple omnidirectional aerial, and the only requirement in siting this aerial is that it should give as good an all-round view as possible.

Whilst aural presentation has been used up to the present time, there are certain advantages to be derived from visual presentation of the homing course. The information may be continuously displayed (preferably on a meter) for attention by the pilot at his convenience. One centre-reading meter can be used to provide on-course indication of both the homing and final approach paths. Such an instrument can be adapted to control an automatic pilot if required. Visual presentation has the following implications:

(*a*) The speed of rotation of the ship's aerial system must be greatly increased above that at present in use (to at least 60 r.p.m., say), or a system such as the v.h.f. omnidirectional radial-track guide adopted, to facilitate continuity of presentation at the receiver.

(*b*) The aircraft equipment is more complicated.

(*c*) An ideal site is required for the aerial system, otherwise the rejection of faulty bearings, normally accomplished by the observer, will have to be done automatically, with consequent increase in weight and complication of the airborne equipment.

(*d*) An effective a.v.c. circuit will be required in the receiver, because the reduction of receiver gain as the aircraft closes range, which is normally done manually, will have to be accomplished automatically. With the present speed of rotation of the aerial system, such an a.v.c. circuit would involve either large time-constants or, alternatively, the radiation of a special omnidirectional signal to control the receiver gain. The problem would be simpler with higher speeds of aerial rotation.

A further point to be considered in relation to the ease of operation of a beacon system is that of its traffic-handling capabilities. It should be possible for an unlimited number of aircraft to home simultaneously from different directions. With the systems described there is no limit to the traffic-handling capacity of the beacon, but with responder-type beacons handling capacity is limited, and becomes an important consideration if continuous presentation, or the control of an automatic pilot, is required.

(1.3.3) Frequency and Propagation Considerations.

The advantages in the use of a frequency between 200 Mc/s and 1 000 Mc/s for the homing beacon are:

(*a*) A suitable beam width can be secured with small aerial size.

(*b*) Effective optical ranges are obtained which, in the past, have corresponded roughly to the aircraft's field of operation.

(*c*) The rapid falling-off in the strength of the ground wave reduces the risk of the presence of the aircraft carrier being revealed to enemy surface vessels.

For a given size of transmitting aerial, the higher the frequency used the narrower the beam width obtainable. The minimum usable beam width, for a given aerial rotational speed, is limited by the maximum permissible transmission speed of bearing information. A beam width of 35–45 deg to the half-power points in the horizontal plane is suitable with the rotating beacon in use.

Since the aerial system is not normally stabilized in the vertical plane, the aerial polar diagram must be wide in this plane, and is usually equivalent to that of a half-wave or full-wave vertical dipole. It can be shown that, for a constant horizontal beam width and a ship's roll of ± 30 deg, the effective gain of a directional aerial (i.e. the aerial gain at the limit of ship's roll) is optimum if the vertical beam width of the aerial system is of the order of that of a half-wave vertical dipole. Reducing the vertical beam width decreases the effective gain very little below this optimum value until the beam width is the same as for a full-wave dipole. Thereafter, further reduction of the beam width results in a rapid decrease in effective gain.

Fig. 3 shows the position of the maxima and minima in the

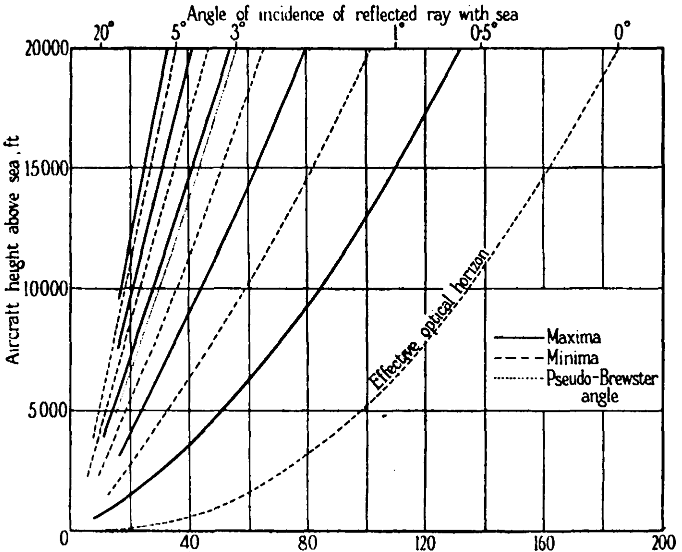

Fig. 3.—Theoretical positions of maxima and minima in the vertical plane for the type-72DP beacon, with aerial height 25λ and vertical polarization.

vertical polar diagram of the type-72DP beacon as fitted in British aircraft carriers. These maxima and minima are due to interference between the direct and sea-reflected waves. The first minima, i.e. those occurring at the smaller angles of elevation, are the most pronounced, and produce a change in received power of the order of 10–15 db. The presence of these minima is a factor that must be considered when deciding the optimum frequency for a beacon system, because, for a given height of transmitting aerial, the number of minima increases with frequency, while the elevation angles of the minima decrease with increase of frequency. Any change of aerial height, as can be effected by roll and pitch of the ship, varies the elevation angle at which the maxima and minima occur. For all frequencies above about 800 Mc/s such vertical motion of the beacon aerial can be expected to interchange the positions of the maxima and minima, and thus a receiving aerial at a given height and range may operate from time to time in a minimum of the radiation pattern. The consequent limitation in the reliable range of the beacon is more serious at the lower elevation angles, where the minima are more pronounced. Similarly, motion of the aircraft through the vertical pattern of the beacon aerial involves fluctuations of the received signal, which are more extreme for small angles of elevation, and more rapidly occurring for larger elevation angles or for higher frequencies. Another source of fluctuations in the received signal is the variation in the wave reflected from an irregular sea. This variation may accentuate the maxima and minima, or erase them. This causes a continual fluctuation of the received signal even when the transmitting aerial is stationary. These fluctuations increase with signal frequency, and they have been observed to be stronger at the larger elevation angles of the aircraft.

The limitations of the airborne equipment are an important factor in the choice of a frequency for a beacon system. Since the aircraft receiving aerial must have an omnidirectional characteristic, it will be limited to a simple half-wave vertical aerial or equivalent. It becomes more difficult to produce an efficient receiving system as the frequency is raised because the efficiency of such an aerial decreases as the frequency is raised, and because, in addition, the receiver input voltage required to produce a given signal/noise ratio increases with frequency. Theoretical calculations for the frequency band 200–1 000 Mc/s show that, assuming a constant transmitter power and a constant transmitting-aerial aperture in terms of wavelength, the overall efficiency of a beacon system is highest at the lowest frequency and is progressively reduced as the frequency is raised. If the horizontal dimension of the transmitting aerial is kept constant, with corresponding reduction of the beam width for increasing frequency, the overall performance of the system can be maintained substantially constant for frequencies up to 500 Mc/s, but there is a progressive falling-off in efficiency for higher frequencies. The vertical dimension of the transmitting aerial cannot be held constant with increase of frequency, because the vertical gain of the aerial system must be restricted for the reason stated previously. With increased airspeeds, it becomes necessary to mount the aircraft aerial under the aircraft's skin, where space limitations are a factor in favour of using the higher frequencies.

(1.3.4) Security.

There is generally no special security objection to operating the beacon whenever an aircraft is away from the aircraft carrier, because the presence of the ship is already revealed within effective optical distances by its radar and v.h.f. radio-telephony transmissions, but methods may be adopted to reduce the probability of detection by the enemy. Two such methods, applicable to the type of beacon at present in use, have been suggested. The first provides "time" security by restricting the transmission to one revolution of the aerial system when requested by an aircraft. The second provides both "time" and "area" security by restricting the duration of the transmission and also confining it to the sector in which the interrogating aircraft is flying. Both systems work automatically, but they require a radio transmission from the aircraft, besides affording little improvement in security in the event of several aircraft homing simultaneously.

It is usual to facilitate reception by modulating the carrier, owing to the low absolute stability of v.h.f. oscillators. A signal with supersonic modulation is no more readily detected by an ordinary search receiver than an unmodulated one, whereas an audio-frequency modulation would be apparent over the whole bandwidth of the receiver. A low supersonic frequency was used for the type-72DM beacon to reduce the risk of spurious radiation at the modulation frequency in the event of the feeder system becoming damaged in action.

Once an enemy appreciates that a certain radio navigational aid is being used, he may either navigate on it himself, jam it, or radiate a similar transmission with the object of misdirecting users. The use of a synchronized watch makes it more difficult for the enemy to find the bearing of the beacon and use it without an airborne v.h.f. direction-finder. Beacon systems requiring very accurately measured lengths of aerial, transmission line, matching sections, etc., are disadvantageous because it is difficult to change frequency to avoid jamming. Characteristic signals may be transmitted by the beacon at intervals to identify the transmission from a particular ship.

(2) BLIND-APPROACH BEACONS

Deck landings on an aircraft carrier are made with the aid of visual directions from a deck-landing control officer who is stationed at the approach end of the flight deck. Pilots approaching the carrier at a height of 200 ft must sight this officer within at least 100–200 yd, according to the speed of the aircraft, and, at this distance, the aircraft must be correctly positioned for landing. When an aircraft carrier moves through mist or fog it leaves behind it an area of improved visibility for a distance of about 400 yd. This constitutes a track which is normally visible from heights up to several hundred feet. Hence a visual landing can still be made in foggy weather, provided the aircraft can locate this track. In such weather conditions there is therefore a requirement for a device that will enable the aircraft to fly towards the carrier from astern, along the projected fore-and-aft line of the ship, and it is preferable that such a device should give an aural indication of the approach path because during the approach the pilot must watch for the deck-landing control officer.

(2.1) Experimental Investigation of Blind-Approach Systems

A preliminary investigation of possible approach methods was started early in the war. It was considered that a simple approach aid would be provided if an aircraft could be directed into the approach zone behind the carrier so that it might fly towards the ship at a height of, say, 200 ft with some prospect of sighting the flight deck. A modification to the homing beacon type 72 (see Section 1.1.2) was tested. It was arranged that the beacon signal should be interrupted by the transmission of the morse letter K (— - —) as the beam crossed the stern of the ship. This letter occupied an arc of about 6 deg, i.e. one second in time. An aircraft close to the ship had only to increase the gain of its receiver until the beacon was heard continuously and to note the time when the letter K occurred. From this, the fore-and-aft line of the ship was derived. The gain of the receiver was then reduced to obtain the true bearing of the ship, and an orbit made until the aircraft was brought astern of the ship as indicated by the reception of the letter K at the maximum of the beacon signal. The aircraft could then turn in for the final approach. The results obtained were sufficiently encouraging to justify investigation of the problem of providing a final approach path instead of merely defining the final approach zone.

The Lorenz-type interlocking beam appeared to be the most promising system. A small 200-Mc/s transmitter was constructed, consisting of an RL16 triode driving two RL7 pentodes with separate output circuits. These valves were grid-modulated from a 20-kc/s oscillator so that the signals might be heard on the type R1147 homing-beacon receiver (see Section 1.1.3). Each valve fed a separate vertical ¼λ aerial mounted in a common corner-reflector. The energy was switched from one aerial to the other in a dot-dash sequence by keying the screen-grids of the output-stage valves from a multivibrator. This method of keying was ideal in so far as key-clicks were negligible, but it was realized that the use of separate output stages increased the difficulty of maintaining equal power in each aerial. It was considered that if this arrangement were adopted it would be essential to use an automatic monitoring system, capable of compensating for any change in amplifier gain or feeder loss, in order to avoid alterations in the direction of the equi-signal path. Before introducing such a complication it was decided to experiment with a single output stage and aerial switching, with which there would be less likelihood of an unwanted change in the direction of the beam.

At the same time, the aerial system was changed to two Yagi arrays in order to obtain a sharper equi-signal beam than was possible with the largest corner-reflector that could be accommodated in the restricted space available on the ship. Each Yagi array consisted of a vertical folded dipole with one reflector and four directors, and they were installed symmetrically about the fore-and-aft line of the ship at angles of about 30° to it. The two overlapping radiation patterns were obtained by a method of feeder-line switching, using a standard Post Office relay, similar to that which had been developed by T.R.E. for the radar beam-approach equipment known as "Babs Mk. I." The relay was operated from a multivibrator and d.c. amplifier for a period of ⅛ sec, every second. Fig. 4 shows the aerial feed and switching arrangement. The two pairs of contacts on the keying relay are shown at S1 and S2. In the position illustrated, S1 (open) reflects a low impedance at the point C and a high impedance at B. At the same time S2 (closed) presents a high impedance at D, and the point B is loaded with the impedance of only the "dash" aerial, which is thus energized. Similarly, when the switch positions are reversed, the "dot" aerial is energized. The trimming capacitors C3 and C4 are provided to adjust the effective lengths of the lines CS1 and DS2 to be ¼λ when the contacts S1 and S2 respectively are closed. Capacitors C1 and C2 adjust the effective lengths of the lines CC1 and DC2 to be ¾λ when the contacts S1 and S2 respectively are open.

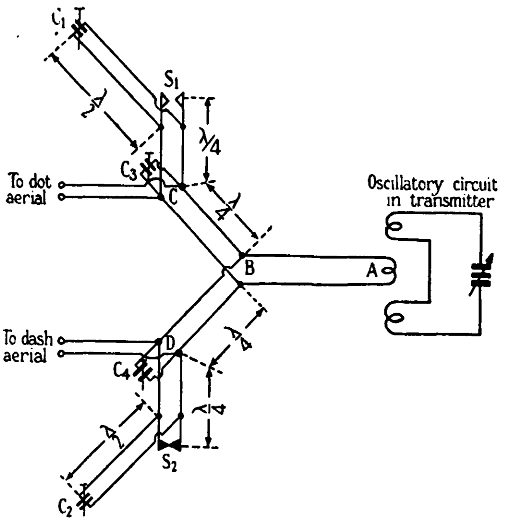

Fig. 4.—Experimental aerial-switching arrangement.

Satisfactory blind approaches were made during trials of this method, although key clicks were stronger than had been anticipated, and care was necessary to avoid the spurious approach paths caused by the side lobes in the radiated pattern.

Further improvement of the system was not undertaken, for, at this time, the homing and blind-approach services were moved to a higher frequency consequent upon the introduction of the type-72DP homing beacon. A sufficient number of trial flights had been made to demonstrate the feasibility of a Lorenz system of approach for shipboard use, and the following technical requirements for the present-day equipment had been formulated:

(*a*) The use of a transmitter with a driven final stage and single output circuit.

(*b*) Formation of the desired radiation pattern by relay-operated switching in the r.f. feeders.

(*c*) The aerial system should provide a radiation pattern free from strong side-lobes, and having a normal equi-signal beam width of 1–2 deg, with provision for increasing this to 5 deg if the ship's yaw is excessive.

(2.2) Requirements of a Shipborne Lorenz-Type Blind-Approach System

Apart from the technical requirements mentioned in Section 2.1, the following basic requirements apply generally to any shipborne Lorenz-type blind-approach system for use in the Navy.

(2.2.1) Mechanical Considerations.

The mechanical requirements of the transmitter and aerial system are more stringent than would be necessary for an equipment ashore. Great extremes of temperature are experienced by shipboard installations. There is much strain from vibration and the shock of gun-fire. The aerial system is invariably subjected to salt spray and icing conditions, and must be small so that it may be installed as close to the flight deck as possible and yet offer no obstruction to flying.

(2.2.2) Stabilization.

If the effects of the ship's pitching are to be avoided without resort to aerial stabilization, the aerial system must have a broad vertical polar diagram. Stabilization against roll is not required because, with aircraft flying at the low altitudes concerned and with the low mounting position of the transmitting aerial in the ship, roll has relatively little effect on an approach path with a divergence of the order of 2 deg. The ship's yaw has the greatest effect on the approach path, and it may cause the direction of the beam to shift as much as 5 deg. When yaw is prevalent it should therefore be possible to increase the equi-signal beam width, so that the aircraft's approach track is not influenced by the yaw. Roll and yaw are normally small when the carrier is heading into wind for the purpose of landing aircraft, and they are usually negligible in foggy weather, when the sea would be calm.

(2.2.3) Maximum Range.

As the aircraft uses the equi-signal beam up to a minimum range of about 200 yd, it is essential that the aircraft receiver should be fitted with an efficient a.v.c. circuit. The power radiated by the approach beacon should be the minimum consistent with achieving the required maximum range, in order to avoid overloading the receiver a.v.c. circuit. The maximum range, therefore, should be no greater than is necessary to allow sufficient time for a high-speed aircraft to locate and settle down on the correct approach course before reaching the control zone of the deck-landing control officer. A maximum approach-beacon range of about 10 sea miles is considered adequate for a naval aircraft flying at a height of 1 000 ft.

(2.2.4) Standardization with the Homing Beacon.

The primary use of the approach beam is to guide single-seater aircraft, and it is therefore imperative that the size and weight of the airborne equipment should be reduced to a minimum. For this reason the same aerial and receiver should preferably be used for the homing and blind-approach services. If this aim is to be achieved, the carrier and modulation frequency ranges, the frequency stability requirements, and the plane of wave polarization must be identical for the two systems.

(2.2.5) Provision of a Glide Path.

In the past it has been considered that satisfactory blind approaches may be made, over sea, if the aircraft's position is determined in the horizontal plane by beacon signals and in the vertical plane by altimeter readings. The introduction of a stabilized glide path has therefore not been attempted for shipboard installations.

(2.3) Description of Equipment at Present in Use

(2.3.1) Type 93.

This is a Lorenz-type beacon radiating dashes to the right of the equi-signal approach path and dots to the left.

(2.3.1.1) *Transmitter.*

The transmitter provides an output of about 3 watts in the frequency range 200–250 Mc/s, the carrier being modulated at a medium radio frequency. Both the carrier and modulation frequencies are crystal-controlled, the crystal for the carrier frequency oscillating at one thirty-sixth of the required signal frequency. Four stages of frequency multiplication are used, the final stage using two Marconi-Osram type-DET12 valves in a push-pull frequency-trebling circuit. These valves are plate-modulated by a modulator amplifier consisting of two type-CV1501 beam tetrodes in parallel. A single-valve timing circuit is included, operating a Post Office relay which actuates, in its turn, the aerial phase-switching relay. This provides the interlocking dot-dash keying sequence. The dot-dash ratio is about 1 : 7, and the keying speed once per second. The transmitter derives its supplies from 230-volt 50-c/s mains.

The blind-approach and homing beacons operate on the same carrier frequency, but different modulation frequencies are used for the two services, the pilot selecting the required channel on his receiver according to whether he requires the homing beacon or the approach beacon.

(2.3.1.2) *Aerial System.*

The aerial system consists of three vertical folded $\frac{1}{2}\lambda$ dipoles spaced about $0\cdot4\lambda$ apart in line, and mounted $\frac{1}{4}\lambda$ in front of a flat wire-frame reflector approximately 10 ft wide and 5 ft high. The phase-switching unit for producing the alternating radiation pattern is mounted on the back of the reflector. The whole assembly is fitted at the stern of the aircraft carrier immediately under the flight deck.

The equi-signal beam has a normal divergence of 3 deg, but provision is made for varying this between the limits 1 deg and 5 deg. Aircraft flying at a height of not more than 5 000 ft and at an angle of elevation from the beacon between 1 deg and 60 deg are able to detect the equi-signal path up to ranges of 10 miles from the ship. A horizontal polar diagram of the aerial is given in Fig. 5.

Fig. 6 shows the connections between the three dipole aerials and the phase-switching unit. It will be noticed that each dipole is provided with a balanced matching line consisting of two $\frac{1}{4}\lambda$ tubes hard-soldered into the base of the aerial stub at one

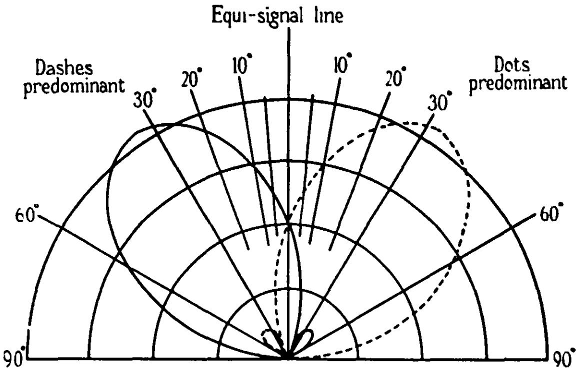

Fig. 5.—Horizontal polar diagram of type-93 aerial.

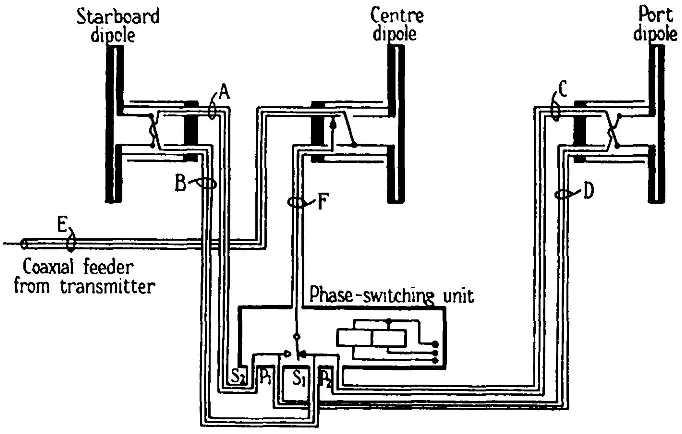

Fig. 6.—Type-93 aerial-feeding arrangements.
Cables A, B, C and D are identical in length.

end, and connected to the dipole aerial at the other. The power from the transmitter is fed through the cable E to the matching unit for the centre dipole, the cable being led through a slot in the upper tube and connected to the lower tube at a point representing its correct terminating impedance. The tuned line is thus excited and the aerial energized. An adjustable tapping point on the upper tube is connected through a section of telescopic feeder F to the centre contact of the phase-switching relay, which connects alternately to S2, P1, or S1, P2, depending upon which way the relay is energized.

The cable A, which is connected at one end inside the starboard aerial to the lower side of the balanced line, and hence to the lower half of the dipole, is connected at the other end through the phase-switching unit to cable D, which is connected inside the port aerial to the upper side of the balanced line, and hence to the upper half of the dipole. Therefore, if power is fed into these aerials through the relay contact and the junction of cables A and D, the current flowing into the two side aerials will be in antiphase, since these cables are of the same length. Similarly, if the relay contact is over to the other side, power being fed to the aerials through cables B and C, the currents in the two aerials will still be in antiphase, but each will be in the opposite phase from that obtaining when fed through cables A and D.

It should also be noted that by cross-connecting the cables as shown, and making the lengths (A + D) and (B + C) electrically equivalent to an exact number of wavelengths, the side aerials are prevented from acting as radiators parasitically excited by the centre aerial.

The adjustable tapping point in the centre-aerial matching unit controls the beam width by altering the amplitude of the currents in the side aerials. The length of the feeder line F determines the phase relationship between the currents in the side aerials and that in the centre aerial. This is so adjusted that the currents are in quadrature. The phases of the currents in the side aerials thus differ by angles of + 90° and − 90° from that in the centre aerial, and their fields add or subtract from that due to the centre radiator. With the aerial spacing adopted, and the presence of a reflector, this phase relationship results in the horizontal polar diagram shown in Fig. 5. When the phase-switching relay is energized at the required keying speed, the radiated energy will alternate between the two lobes in an interlocking dot-dash pattern.

During the short period taken by the keying relay to change over, the field due to the centre aerial is maintained. This greatly reduces trouble from key clicks.

(2.3.2) Type 93S.

This is type 93 adapted for shore station use by removing the reflector from the aerial system, thereby giving both the approach path and its reciprocal. The aerial is mounted at a height of at least 8 ft above the ground on the centre line of the low-visibility runway, about 600 ft from the up-wind end. The usual siting restrictions for approach beams have to be observed.

In addition, standard R.A.F. marker beacons are provided. These have a power output of 30 watts on a frequency of 360 Mc/s, and therefore require additional receiving equipment in the aircraft. The inner marker is sited on the centre line of the runway, 450 ± 50 ft from the approach end. It carries a 1 700 c/s modulation keyed at six dots per second. The outer marker is sited on the centre line of the runway, 9 450 ± 300 ft from the approach end. It carries a 700-c/s modulation keyed at two dashes per second.

The maximum range of type 93S is about eight miles.

(3) CONCLUSION

This paper has described the past experience in the sphere of c.w. aids to homing and blind approach of naval aircraft. Little can be said of the future except that the ultimate aim is fully-automatic homing, approach and landing. The paper shows that only the fringe of the problems involved has been explored, but sufficient has been said to show that the naval problems differ from those involved in such an aim for shore use only. For example, the relatively small size of runway, the proximity of the aerials to the runway, the problems of stabilizing the aerials for ship's roll, pitch and yaw, and the fact that the aircraft has to land some 50 ft above the electrical ground plane, are major factors applicable only to the design of a system for ship use; whereas important factors in the design of a system for shore use, such as the effect of obstructions in the main path of the beam, the variation in conductivity and permittivity of the ground, and the effect of ground contours on altimeter readings are of little or no importance if the system is to be used only at sea. The ultimate solution of the shore problem may involve techniques, such as the use of marker beacons or the induction field of leader cables, that would be difficult or impossible to apply at sea; on the other hand, methods considered inapplicable on shore, such as the use of altimeters to control the aircraft's height, may be quite satisfactory if used in the solution of the ship problem. It is thought, therefore, that the development of an automatic blind-approach and landing system for shore runways may not be an intermediate step in the evolution of a shipborne system, and, since the trend of present ideas appears to be in a direction away from carrier requirements, the naval problem may have to be solved separately.

(4) ACKNOWLEDGMENT

Acknowledgment is made to Marconi's Wireless Telegraph Co. Ltd., who developed the type-93 equipment.