O.U. 5327(2).

W/T RECEIVING HANDBOOK.

CHAPTER II.

DIRECTION-FINDING IN SHIPS.

Revised February, 1928.

This revised chapter replaces that dated August, 1924, all copies of which are to be dealt with in accordance with Paragraph 28, Page 3, of Form O.U. 24.

The fact of its insertion is to be noted in the space provided on the Receipt Form inside the cover, which will also act as a table of contents.

The instructions contained in O.U. 6105 " Handbook for Calibration of D/F Set " are to be cancelled, but the forms contained therein are to be used for " Records of Calibration " until existing stocks are exhausted.

O.U. 6105 will not be reprinted and after stocks are exhausted ships are to make out their own forms (*vide* specimen in Paragraph 44).

ADMIRALTY
(Signal Dept.).
N.I.D. 8559/27.

REVISED CHAPTER II.

DIRECTION-FINDING IN SHIPS.

The theory of direction-finding is treated thoroughly in the W/T handbook, and will not be touched upon here. The theoretical considerations, however, which affect the design of apparatus and the handling of the gear are discussed shortly, chiefly as an explanation of the various errors which are met with in practice. Since all ships are fitted with untuned aerials, the question of tuned aerials has been omitted entirely, as also has any reference to D/F at shore stations.

I.—Theoretical Considerations in D/F as affecting Arrangement and Design of Apparatus.

1. **The System.**—The system of D/F generally employed in ships in the Navy is the Bellini-Tosi system, with two crossed aperiodic aerials, one in the fore-and-aft line of the ship and one athwartships. Exceptions to this are :—

(*a*) The single rotating frame coil, mounted on a collapsible mounting, fitted in H.M.S. "Furious" as an experiment.

(*b*) The fixed or rotating frame coils fitted in some submarines where Bellini-Tosi loops are obviously impracticable.

(*c*) The experimental rotating frame coil outfit to be fitted in "Queen Elizabeth" and "Revenge" which is in course of production.

The selection of the Bellini-Tosi system for general Service D/F is based upon the following considerations, where, except that frame-coil reception is essential for wavelengths below 300 metres, it holds distinct advantages over other methods :—

(*a*) It is the only system which employs aerials of a size comparable with the metal masses, guns, funnels, etc., of the ship. This is necessary to prevent the effect of any one mass of metal being excessive. For example, with a frame aerial near a gun, the apparent bearing is very greatly influenced by the training of the gun. With large aerials, an average effect from the whole ship is obtained and local irregularities in the distribution of metal are relatively of less importance.

(*b*) It has no heavy structure which must be rotated to obtain a bearing.

(*c*) It has a great range.

(*d*) Errors due to the ship are, if the set is accurately installed, always quadrantal, and as such they may be corrected automatically.

As regards the aerial circuits, the question arises as to whether the circuits should be tuned or untuned. (The term "aperiodic" is usually applied to the latter, but it is not strictly accurate.)

The advantages of the former for a definite wavelength under fixed conditions are of much importance :—

(*a*) The tuned circuit gives, naturally, greater sensitivity, and consequently great ranges are obtainable.

(*b*) Currents in the tuned loops are so large that those set up by the direct action of the waves on the amplifier itself are negligible in comparison and, consequently, errors from this source are reduced to a minimum.

The advantages, for ship work, however, are outweighed by the disadvantages, which may be summarised as follows :—

The two aerials on board ship can be made identical, but even then one will receive better than the other, and the only method of correction for the greater efficiency of the one is to reduce this, by means of resistance, to that of the other. The amount of resistance will vary according to the wavelengths and this will obviously lead to complications where rapid wave-changing is essential.

Balancing the two aerials is a delicate matter and cannot be carried out hurriedly. This consideration alone would suffice to secure the adoption of aperiodic or untuned aerials.

2. **Determination of Direction.**—The principle involved in direction-finding is that of collating, by some means, the amplitudes of the E.M.F.s due to signals as received by the two aerials simultaneously. As will be shown under the theory of the radio-goniometer, this is accomplished by rotating a "search coil" connected to the receiving gear, in the magnetic fields produced by the induced currents in the two aerials, until a position is found where one of a choice of two conditions is satisfied; these limiting conditions being that signals are a maximum or that signals are a minimum.

It is extremely difficult to settle on the exact position of a flat maximum, and the method adopted in the Navy has been to find the point of minimum or, if possible, zero signals. This is done directly, if the zero is sharply defined, or by the means of equal strengths round a minimum if zero cannot be obtained. The manipulation, then, of the set is to rotate this search coil for zero signals in the receiver; the direction of the transmitting station under these conditions will be discussed later.

3. **Errors.**—It has been proved by experiment that, on board ship, if the fore-and-aft and athwartship aerials are made the same size, then the directions as observed would tend to crowd towards the fore-and-aft line, the error being a maximum when the actual bearings are on the relative quadrantal points and vanishing when the correct relative direction is ahead, astern or abeam.

This error—*quadrantal or calibration error*, as it is called may be removed completely by reducing the size of the fore-and-aft aerial, or by reducing its efficiency by adding impedance, or by a combination of the two.

A consideration of this point leads to the view that all the metal structure of the ship may be regarded as a virtual loop aerial in the fore-and-aft line, which adds its effect to the actual fore-and-aft aerial, thus making it really too big in proportion to the athwartship one. In practice, therefore, the athwartship aerial is made as large as conveniently possible and the fore-and-aft one reduced until practically all the quadrantal error is eliminated. The final adjustment is made by adding inductance in the office.

That the aerials are of different sizes means that in all probability they will both have different natural frequencies. If the two loops are widely different in LC value from that of the signal to be received, the currents produced in the loops will be almost in quadrature with the incoming voltage and, therefore, in phase with each other. Also, the value of the current reached in each loop will be almost exactly proportional to the voltage applied to that loop by the incoming wave divided by its impedance. If, however, one loop happens to be in tune with the incoming wave, the current in this loop corresponding to the voltage impressed by the incoming wave will be greater out of all proportion to the current in the other loop, which is not in resonance, and an error similar to quadrantal error will result owing to the disproportional field of the resonant loop, but in this case varying with the wavelength. It can, of course, be avoided by choosing suitable values for aerials and wavelengths. This is sometimes called "*Loop tuning* error," and is most important where cables are employed. The capacity of the cable becomes part of the condenser which tunes the loop.

4. **Lack of Symmetry Error.**—This is due to either or both of two factors. Firstly, unequal dimensions of the loops themselves, which would result in unequal impedance in the two halves, measured from the apex to the mid-point of the field coils of the goniometer. This may be termed "permanent" lack of symmetry.

Secondly, what may be called "inductive" lack of symmetry is caused by the unsymmetrical distribution of metal conductors, guns, searchlights, etc., which may have more influence on one half than the other.

Consideration of the following equation may serve to show the importance of the question of symmetry.

The circuits can be shown diagrammatically as in Fig. 1.

It may be shown that the conditions for zero signals are

$$\frac{M_1E_1}{L_1} = -\frac{M_2E_2}{L_2}$$

E_1 and E_2, being vectorial quantities representing the E.M.F. produced by the incoming signals in each loop, this implies that

CIRCUIT DIAGRAM.

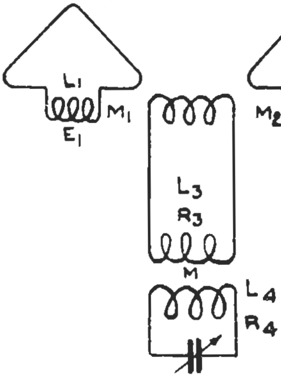


FIG. 1.

the currents in the two aerials must be strictly in phase with each other. The plane of one aerial must, therefore, bisect accurately the surface of the other and, further, since currents are produced in all stays and metal structures, these must be arranged symmetrically about the aerial system or the resultant E.M.Fs. will be out of phase and a blurred zero will result.

So far as accuracy of bearings is concerned there is no disadvantage in the loops having very different sizes, provided that :—

(*a*) each is symmetrical with respect to the primary winding of the goniometer to which it is connected;
(*b*) the plane of one aerial accurately bisects the other.

These errors are progressive as the signal strength is increased and with weak signals they may not be apparent. It is, therefore, important always to calibrate on strong signals, since, if errors under these conditions can be eliminated or nearly so, with normal signals their effect must necessarily be small and perhaps inappreciable.

If a ship has been calibrated on weak signals, however, lack of symmetry error may have been present but too small to be observed. When a strong signal was being received, however, the error would become appreciable.

5. **Vertical Component, or Antenna Effect.**—Vertical component is due to the electrical constants of the two sides of a loop not being equal which causes a lack of balance in the antenna currents, to earth, down the two sides of the loop. This results in two minima not being 180° apart.

It is essential to test each loop separately and preferably at a short wavelength, *e.g.* 450 metres, where the antenna currents are greatest.

The effect of vertical component is chiefly blurred zero, *i.e.*, not a perfect silence for any position of the search coil.

6. **Land and Night Effect.**—Land effect is an elusive error and no satisfactory explanation can be laid down. The errors may be attributed to distortion or tilting of the wave front, due to various causes.

It must be remembered that what is actually measured is the direction of the horizontal component of the resultant magnetic field. What is actually required is the line of motion of the waves.

Over salt water these two are at right angles and, therefore, the goniometer measures the required direction.

Over land, however, and under abnormal atmospheric conditions, another component makes its appearance and combines with the true horizontal component, giving a resultant no longer at right angles.

If the currents produced by these components are in phase the result is an inaccurate bearing; if, as is vastly more probable, the currents are not in phase, the quality of the zero will be spoilt.

The distortion of the wave front may be attributed to refraction and reflection at the earth's surface.

If the line of bearing of the transmitting station cuts the coast at an acute angle of 20° or less, the bearing will probably be unreliable. This is also the case where high land intervenes. The effect of valleys is remarkable and it is often found that bearings are drawn towards the axis of a neighbouring valley.

Night effect may be attributed to the distortion due to patches in a layer of the atmosphere in different states of ionisation and consequent refraction of the waves. It has the effect of making the zeros "woolly" due to the second component already mentioned, and this may give a sign that reliance cannot be placed upon bearings taken under these conditions.

There is nothing, however, to warn the observer of land effect except the consideration of the track of the wave when laid off on the chart.

7. **Personal Error.**—Some operators are better than others at taking accurate and rapid bearings. Some have a definite bias of a degree or so to one side of the true bearing or the other. To what this may be attributed is obscure, but difference in the sensitivity of the two ears may be the cause. It is possible that the operator subconsciously listens more acutely with the ear towards which he is working the goniometer handle. In this case, if one ear is less sensitive than the other, his apparent minimum position will be drawn towards the less sensitive ear. Careful selection of operators and constant practice is the only way to make D/F thoroughly reliable.

8. **Unexplained Errors.**—These may be caused by an error in the compass. A gyro-compass may take up a permanent error of a few degrees at sea, and hence should be compared fairly frequently with a magnetic compass. Readings of a magnetic

compass should always be corrected for variation and deviation, and may be incorrect due to lag of the card if ship is swinging.

9. **Bearings of Aircraft.**—Bearings taken of aircraft with trailing aerials are liable to error due to the directional effect of the aerial. The error is a maximum when the aeroplane is flying at right angles to the line joining the D/F receiver to the aeroplane. It is a minimum when the aeroplane is flying directly towards or away from the receiver.

The reason for this effect is believed to be due to the horizontally polarised waves which are set up by the trailing aerial of the aeroplane.

10. **Convergence.**—Since bearings taken by W/T are great circle bearings, before putting them on to a Mercator's chart a "$\frac{1}{2}$ convergence" correction should be applied, if the distance is great.

Convergence in minutes = difference of longitude in minutes multiplied by sine middle latitude.

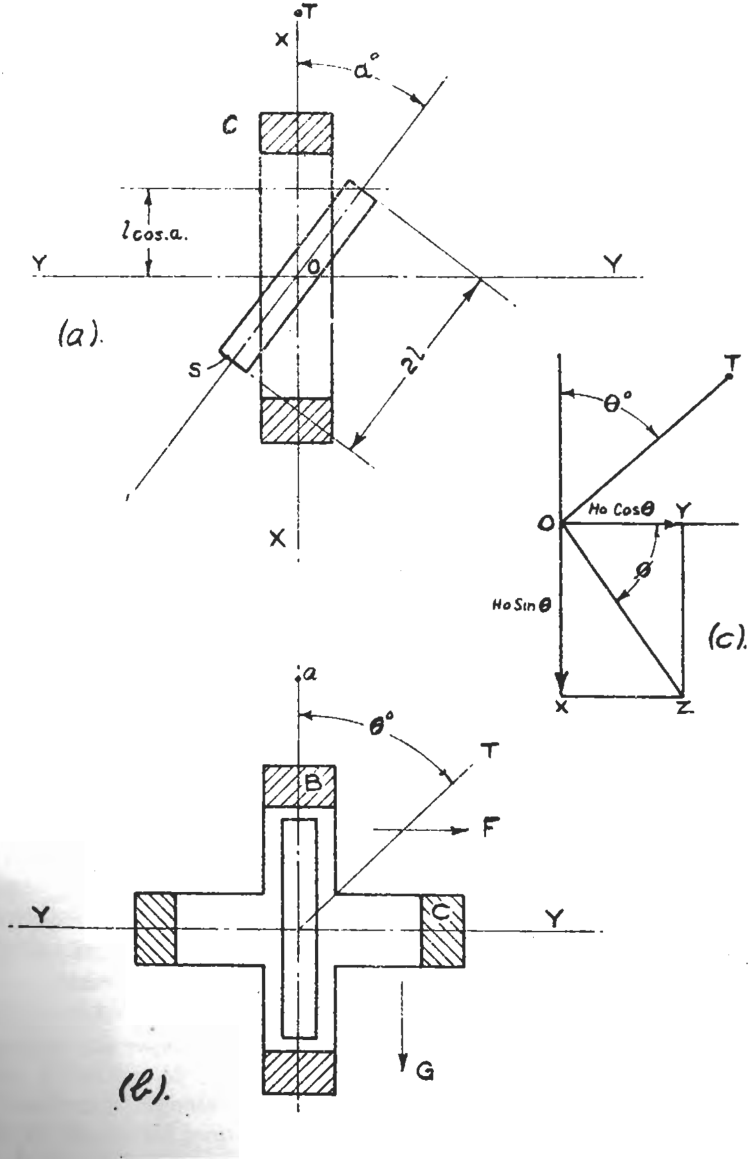
In the Northern hemisphere half of this convergence is added to the W/T bearing when the ship is West of the station and subtracted when the ship is to the Eastward. In the Southern hemisphere the converse applies.

11. **Theory of the Radiogoniometer.**—Suppose the movable search coil in Fig. 2 (a) has a horizontal length $2l$ and height h, and suppose it is to be acted upon by the single field coil C and that it can revolve about an axis perpendicular to the plane of the paper. Also suppose the field to be uniformly distributed and the rotating coil to be wholly in that field (a condition which for one field coil is entirely hypothetical). Then, considering only the top half of the coil which is above O, the alternating flux due to the coil C will be $Hh1$, when the plane of the search coil coincides with that of the field coil C. In this position the maximum flux due to the field H, the direction of which is parallel to the axis OY, passes through the search coil. Since H and h are constant, it is clear that when the search coil is rotated so that its axis makes any other angle a with the direction OX, the flux passing through the coil will be proportional to $l \cos a$. The E.M.F. produced in the coil is also then proportional to $l \cos a$ and is zero when $a = 90°$.

The signal strength will also, therefore, be a sine function of the angle the plane of the coil makes with that of the inducing coil.

It will be clear now that, if the fluid coil be replaced by some distant transmitting station, the signal strength received will be proprotional to $\cos a$, where a is the angle the plane of the search coil and the direction of the transmitter subtend at the axis of the search coil.

INFLUENCE OF FIELD COILS ON SEARCH COIL IN RADIO-GONIOMETER.



Thus it is a maximum when the plane of the search coil coincides with the direction of the transmitter and zero when it is at right angles to it.

Above, only a single aerial circuit has been taken into account with only one field coil. In the radiogoniometer there are two aerials and field coils acting simultaneously upon a single search coil. In the goniometer, the field coils are so arranged that the field obtained is actually uniform and the dimensions of the search coil are such that it does move wholly in this uniform field.

In this case the argument, which was hypothetical for one single coil, is by construction strictly valid for the radiogoniometer.

It has just been shown that when the transmitting station lies in the plane of one of the directional aerials, say in the direction *a* in Fig. 2 (*b*), the signal in the movable coil is a maximum when its plane coincides with the field coil corresponding with that aerial. The magnetic field is then at right angles to the plane of the movable coil; let this be denoted by the arrow *F* and let its intensity be called H_0. There is no field due to the coil C, since this coil is at right angles to the direction of the incident wave. Supposing the transmitter be moved round into position *T*, so that it now makes an angle θ with the coil *B*. Sending then with the same signal strength, the magnetic field due to the coil *B* is less than before and is equal to $H_0 \cos \theta$, while the field due to *C* is equal to $H_0 \cos (90 - \theta)$, and has the direction denoted by the arrow *G*.

These two fields being at right angles, owing to the coils being perpendicular, the resultant field, *H*, is :—

$$\begin{aligned} H &= \sqrt{(H_0 \cos \theta)^2 + (H_0 \sin \theta)^2} \\ &= \sqrt{H_0^2 (\cos^2 \theta + \sin^2 \theta)}. \\ &= H_0. \end{aligned}$$

∴ the resultant field has a constant value, and is independent of the direction of the transmitting station.

To obtain the direction of the resultant field, let *OY* in Fig. 2 (*c*) represent the magnetic field due to coil *B* both in magnitude and direction and *OX* that of coil *C*. The resultant is then obtained by completing the parallelogram.

If the angle *YOZ* be called ϕ it is easy to see that $\phi = \theta$

$$\begin{aligned} \text{since } \tan \phi &= ZY/OY = OX/OY \\ &= (H_0 \sin \theta)/(H_0 \cos \theta) = \tan \theta. \end{aligned}$$

Therefore the resultant field *OZ* is at right angles to *OT*, which is the direction of the transmitting station. This means that for maximum signals the inclination of the search coil to the plane of the aerial loop is the same as the relative bearing of the transmitting station, since in this position it is at right angles to the magnetic flux.

If a pointer be fixed to the search coil in the plane of the coil this will point to the direction from which signals are emanating.

As a matter of fact, the position of minimum signals is always looked for when direction-finding in practice, so that in this case the pointer is arranged at right angles to the axis of the search coil. The pointer will then give the direction of the station when the minimum signals are heard in the receiver.

In some cases the aerials are set diagonally, in which case the pointer will be set at 45° to the maximum position.

The coupling of the search coil to the field coils is constant provided that the instrument is accurately made.

12. **Errors in Radiogoniometers.**—There are two principal sources of error from which a goniometer may suffer. These are (1) inaccuracies in the magnitude and direction of the magnetic fields produced in the field coil windings, and (2) the presence of electrostatic forces between the several windings which tend to produce appreciable capacity currents within the instrument, with the result that zeros become blurred. The following tests are simple to apply, and should be resorted to when there is any reason to suspect defects in the goniometer itself :—

(*a*) The electrical axes of the two primary windings should be exactly at right angles. To test this the Buzzer Tester for D/F, Pattern 7465 is used. This instrument will be detailed later. Break the beam aerial circuit and record the two zeros. Repeat the operation for the fore-and-aft aerial. The four points obtained should lie 90° apart to within $\frac{1}{2}$°.

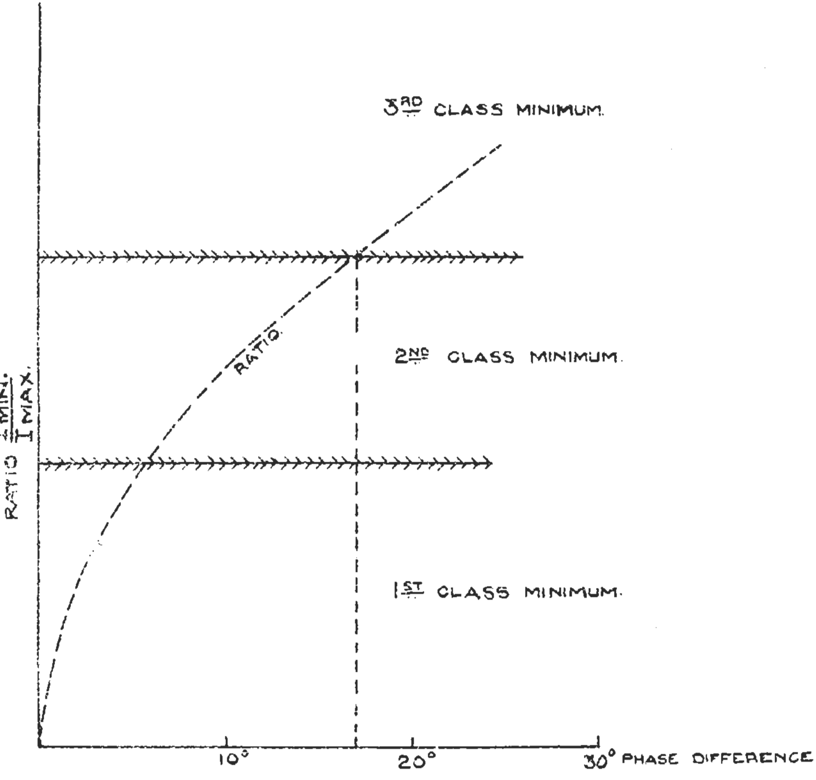
(*b*) For equal currents the field coils should produce magnetic fields of equal strength. To test this join the field coils in parallel and record the position of the two zeros obtained with the buzzer tester. Reverse the connections to one field coil and again record the zeros. The four points thus obtained should lie midway between those previously obtained (in (*a*) above) to within $\frac{1}{4}$°. Any goniometer which satisfies these tests is almost certainly reliable.

Blurred zeros are the result of current out of phase with the main E.M.F. Capacity currents inside the goniometer will, therefore, cause this effect. Tests have proved that even on waves as short as 130 metres no harmful effects due to capacity in the windings need be anticipated from the Service goniometer.

13. **Quality of Zeros.**—Bearings taken when zeros are blurred or where there is insufficient decrease of signal strength at the minimum point, are useless and should never be accepted. It is useful, therefore, to establish a rough scale by which the quality of the results may be judged as to their reliability. Zeros may be perfect, or the minima may be divided into three categories, first, second and third class. The quality on this scale should be reported at the time of taking the bearing.

(*a*) *Perfect Zero.*—This has the property that, no matter how far the amplification be pushed, there is a position of

RELATION BETWEEN SIGNAL STRENGTH & QUALITY OF ZEROS.



silence, and the greater the amplification the more sharply will the silent position become defined.

(*b*) *First class minimum.*—Here the rate of variation of signal strength round the minimum is sufficient to allow of its being read to 1° accuracy. As a general rule, increased amplification does not hold any advantage.

(*c*) *Second class minimum.*—The position of minimum signals is ill-defined, and a bearing correct only to 2 or 3 degrees can be taken. In this case decrease of amplification is sometimes of assistance.

(*d*) *Third class minimum.*—Here the minimum is so ill-defined that a bearing cannot be taken. Possible causes of this condition are :—

(i) Effect of other aerials.
(ii) Unsuitable D/F system.
(iii) Atmospheric effects. This, however, is an unlikely source when bearings are taken by day over sea and at less than 100 miles range.

Note.—Perfect zero is only obtainable when the currents in the two halves of the goniometer are exactly in phase. The quality of the minimum depends upon the phase difference of the currents in the two loops. The curves shown in Fig. 3 are the result of actual experiment. The results may be taken as applying to all sets. The angle ϕ is the phase difference calculated from the constants of the circuits used, and the curve is plotted for the four classes of D/F results. The dotted curve shows the corresponding ratio of minimum to maximum signal strength.

$$\left(\text{Ratio of signal strength} = \frac{\text{I min}^2}{\text{I max}^2} = \frac{1 - \cos\phi}{1 + \cos\phi}\right)$$

It will be seen that, for reliable results, the strength of minimum signals should not exceed about $3\frac{1}{2}$ per cent. of that of maximum signals. This would correspond to a phase difference of the currents in the two loops of about 17°.

14. Sense Finding.—The instruments so far described point out the line of bearing upon which the transmitting station is situated, but do not determine the " sense." That is, they do not show whether the minimum selected shows the true direction or its reciprocal. To determine the sense, an instrument is added called an " Eliminator, reciprocal bearing " or a " Sense finder." The manipulation of this instrument will be detailed later, but the principles involved will be briefly given here.

For sense finding, the effect of a vertical aerial is utilised combined with that of crossed loops.

Suppose an E.M.F. is induced into the search coil due to a signal being received on crossed loops such that it is equal to

$$E' \sin\omega \sin\alpha.$$

where a is the angular movement of the search coil at the zero position; and suppose, say from a vertical aerial, an independent E.M.F. is constantly superimposed on the search coil and represented by

$$E'' \sin (\omega t + \phi),$$

ϕ being the difference of phase. Now, if by some means this second E.M.F. be made equal in amplitude to and in phase with the E.M.F. due to the crossed loops, it may be utilised to indicate the direction from which the waves are coming. For the total E.M.F. in the circuit is now

$$\text{Sin } a \, E' \sin \omega t + E'' \sin (\omega t + \phi) = E.$$

or, since the amplitudes and phases are equal,

$$E = E' \sin \omega t \, (\sin a + 1) \qquad . \quad . \quad . \quad . \quad . \quad (1)$$

Hence, when $a = 90°$, the expression becomes $2E' \sin \omega t$, and when $a = 270°$, it becomes 0.

That is to say, that there is only one zero as the search coil is rotated, and so this can be used to show the sense.

That the phases of the two E.M.F's are the same is an absolute essential to the principle, but if the amplitudes are very nearly equal a reduction of signal strength will occur when a is 270° although zero is only obtained when the amplitudes are exactly the same, for, referring to equation (1)

if $E' \neq E''$ then

$$\text{if } a = 90° \; E = E' \sin \omega t \left(\frac{E''}{E'} + 1\right)$$

$$\text{if } a = 270° \; E = E' \sin \omega t \left(\frac{E''}{E'} - 1\right)$$

So much for the theory. It indicates that to eliminate the ambiguity of reciprocal bearing it is necessary to have an E.M.F. which satisfies the following conditions :—

(*a*) It can have its amplitude varied at will.

(*b*) It is independent of, but of the same frequency as, the E.M.F. in the crossed loops due to the incoming waves.

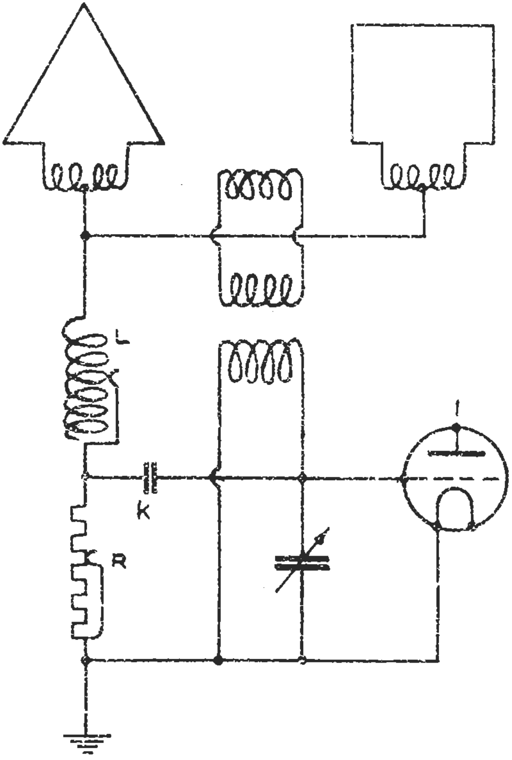
(*c*) It must be exactly in phase with the E.M.F. in the crossed loops.

The circuit employed is shown in Fig. 4.

In virtue of the fact that the loops possess an appreciable capacity to earth, a current is produced by the incoming waves through the resistance R and in the inductance L. Therefore across the resistance there is an E.M.F. whose amplitude may be varied by the value of R and its phase may be adjusted by varying the inductance L. This E.M.F. is transferred to the grid of the receiving model via the condenser K.

The grid is supplied therefore with two E.M.F.s. One that is due to the ordinary loop effect and the position of the search coil and the other one independent of the direction of the transmitter but of the same frequency as, and capable of being brought

SENSE FINDER CIRCUIT.



into phase with, the first. The amplitude of the latter may be adjusted to that of the former. Thus the conditions required for sense finding are satisfied. In practice, R is varied in four steps and L is varied according to wavelength. In D/F systems which employ a frame coil, the antenna or vertical effect is sometimes of insufficient magnitude to be employed for sense finding.

In this case a separate aerial is used and its effect combined with that of the loops.

15. **Effect of Resistance on D/F Circuits.**—Suppose the mutual inductance between the search coil, L_1, R_1, and the tuner circuit L_2, R_2, C in Fig. 5 be M and the E.M.F. in the search coil circuit be E. Then a consideration of the current in these circuits

THEORETICAL DIAGRAM.

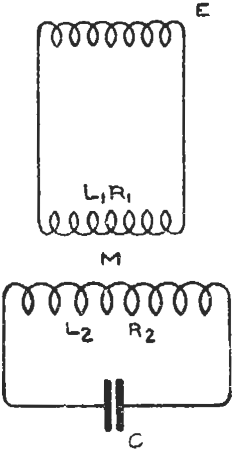


FIG. 5.

shows that (a) the aperiodic circuit reduces the effective inductance of the tuned circuit by an amount which is proportional to the coupling; that is, L_2 is reduced to

$$L_2\left(1 - \frac{M^2}{L_1 L_2}\right)$$

and (b) the effective resistance of the tuned circuit is increased by an amount proportional to the resistance of the aperiodic circuit and to the square of the ratio $\frac{M}{L_1}$. In other words, it is increased from

$$R_2 \text{ to } R_2 + R_1 \frac{M^2}{L_1{}^2}.$$

That is to say that if $\frac{M}{L_1}$ is small, the resistance of the aperiodic circuit is not important. If the coupling is tight, the resistance of the search coil circuit must be reduced as much as possible.

From this we may deduce the following conclusions :—

(*a*) The resistance of the last tuned circuit must be kept as low as possible.

(*b*) The resistance of the search coil may not be ignored, especially on short wavelengths, because it is tightly coupled to the tuned circuit.

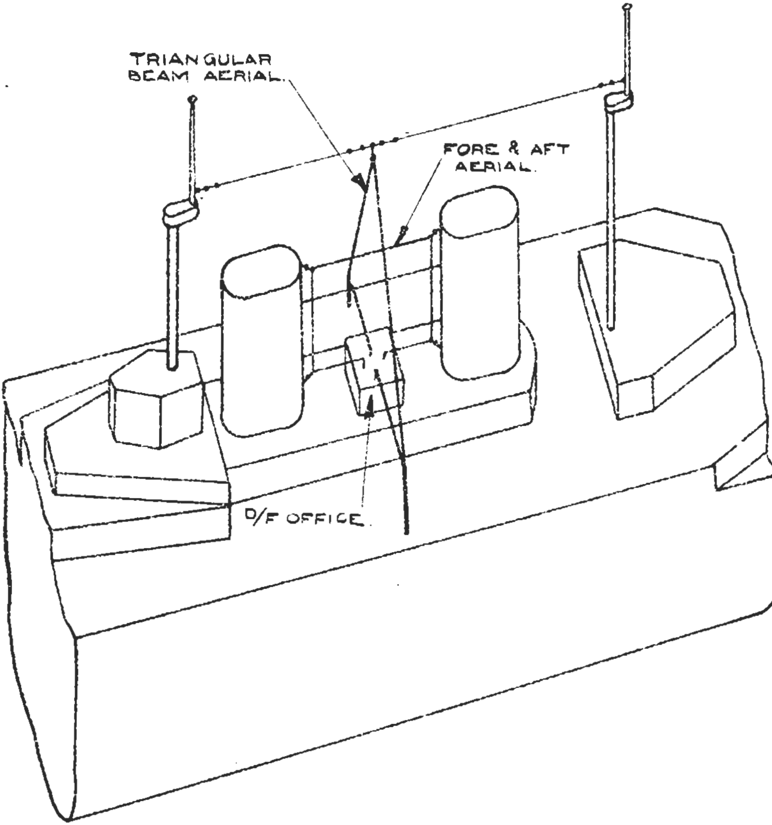
(*c*) The resistance of the aerial, within limits, is of small importance, provided that both the loops have the same resistance. Phosphor-bronze wire is just as good as copper, therefore, for making D/F aerials.

16. **Position of the D/F Office.**—It is often difficult or impossible in a ship to provide an office near to the position most suitable for the D/F aerials. An advantage of this system of direction-finding lies in the fact that the office may be placed below armour and connected to the aerials by cables. In order that no errors in deviation be introduced by the remote position of the office, the two pairs of wires from the aerial to the office must satisfy two conditions, viz., there must be no mutual induction between them; and, secondly, the total E.M.F. in each pair due to the direct action of the wave must vanish. This is not difficult to achieve, but two new factors are introduced. The first and principal one is the capacity per foot length of the cable used, and, second, its power factor, which is of greater importance in the case of tuned aerials. With the circuit used in the Bellini-Tosi system, the capacity of the cable is shunted across the goniometer field coils. That is to say, that only a portion of the current circulating round the loops is available to affect the search coil. The higher the frequency, the greater becomes the shunting effect.

Under ordinary circumstances and for untuned aerials, the most suitable goniometer to use is one in which the field coils have an inductance equal to that of the aerials. It may be noted, however, that the shunting effects of the cable capacity are reduced by reducing the inductance of the goniometer Thus, when employing long cables, it becomes worth while to use a goniometer of which the field coils have an inductance less than that of the aerials. In the Service, goniometers of inductance 20 mics. are used, and it is found that the cable capacity may then amount to as much as 1·35 jars before trouble is experienced on waves of 450 metres and above, even though the loops be of very different inductance. Nevertheless, the effect of putting equal capacities across the goniometer windings if the loops are of different inductance, will be to make the automatic correction of quadrantal errors at all frequencies impossible. If E is the E.M.F. in the two loops L_1 and L_2, and C the ratio of the currents in the field coils of the goniometer L, then

$$\frac{E}{C} = \frac{L_1 + L\,(1 - \omega^2 L_1 C)}{L_2 + L\,(1 - \omega^2 L_2 C)} \text{ (approximately).}$$

TYPICAL D/F. AERIAL RIG.



That is, the value E/C varies with the frequency. Waves incident from the same direction, but of different frequency, have the same value for E, but different values for C, and therefore appear to come from different directions.

By using the special low inductance goniometer mentioned, it is possible to have the aerials identical, and then there is no limit to the length of the cables, except loss of signal strength.

There is the danger, however, that this extra length of lead may bring the loop circuit nearly into resonance with the wave being received. In practice, however, cable having capacity of 1 jar per 100 feet is specified, and at present the length must be limited to 150 feet.

II.—Description of Apparatus.

17. **Aerials.**—The aerial system consists of two crossed loop aerials, one in the fore-and-aft line and the other athwartships. The latter, if truly at right angles to the electrical centre-line of the ship and symmetrical to it, receives no re-radiation from the ship, since the latter induces equal and opposite currents in this aerial.

On the other hand, the fore-and-aft aerial receives signals direct, but, in addition, signals re-radiated from the ship. It is necessary, therefore, to reduce the sensitivity of the fore-and-aft aerial, by some means, until its response to signals coming from the fore-and-aft line is equal to that of the athwartship aerial to signals arriving from the beam. This has been explained earlier.

If the aerials are so adjusted, the bearings will be accurate, since the incoming signals will always produce, in the radio goniometer, a field in the direction of their source.

It will, therefore, be apparent that, for perfect accuracy, the beam aerial must receive no signals from the ship. This is obtained by rigging the beam aerial carefully in the athwartship line, and by choosing a site for the D/F aerials so that no masses of conductor asymmetrical to the fore-and-aft line of the ship are in positions to induce currents in this aerial.

The method of balancing the aerials is given under the instructions for calibrating the set. The beam aerial is, as a rule, of triangular form, and as large as possible.

It is generally necessary to fit a triatic stay as in Fig. 6 in the centre line of the ship, passing over the office, in order to support the beam aerial. This stay should be at least 15ft. below the main aerial and if possible 30 ft. above the funnels, and should be broken up into 60 ft. lengths or less with rigging insulators. The lower ends of the beam aerial are run through aerial insulators, Patt. 5678. The other ends of the beam aerial are secured to the inboard ends of wire outhauls by means of which the aerial is hauled out on each beam to stump masts or booms. The booms (if fitted) should be prevented from moving fore and aft by means of insulated wire fore-and-aft outhauls. The ends of the aerial are taken in horizontally to the deck insulators, Patt. 1719, on the roof of the office.

The beam aerial is then hauled out equally on each side and accurately aligned on the beam by the fore-and-aft outhauls to the booms. These are then fixed so that if at any time the outhaul has had to be eased in, the aerial can be replaced in its correct position by hauling the outhaul taut.

The fore-and-aft aerial is considerably smaller than the beam one, and is generally in the form of a triangle or rectangle supported from the triatic stay, or between a funnel and bridge (*e.g.*, "Nelson"). The size will vary with different ships. The loop should be vertical and exactly in the plane of the centre line of the ship and may be suspended by four insulators, Patt. 5678.

The fore-and-aft aerial must be kept absolutely rigid, and to enable this to be done, bottle screws should be fitted in this aerial close to the deck insulators. By this means this aerial can be rigged bar taut. When inserting these bottle screws, Patt. 1108, the aerial lead must not be broken, but must be firmly attached to each end of the bottle screw, thereby forming a loop. This is done in order that the circuit from one deck insulator round the fore-and-aft aerial may be made with an unbroken aerial wire.

In submarines, frame aerials are used at present and are sometimes set to 45° to the beam and fore-and-aft lines, but rotating frame coil outfits are under trial.

18. **Deck Insulators.**—D/F offices in many cases are fitted at a distance from the base of the D/F aerials, the aerials being connected to the D/F receiving apparatus by means of special lead-cased cable, Patt. 6895, and a special deck insulator group designed for the purpose and described as Insulator, Deck, Group N. This insulator consists of the following component parts :—

	No.
Patt. 7457, Box for four insulators for D/F aerials	1
Patt. 7458, Conductor, central, 11-in., $\frac{3}{8}$ in. dia. -	4
Patt. 7459, Shield for Patt. 7458 Conductor, Central - - - - - - -	4
Patt. 7600, Insulator, porcelain, terminal, $\frac{3}{8}$-in. bore, $4\frac{7}{8}$ in. high - - - - -	4

The method of fitting Group N insulators is illustrated in Fig. 7. The height and nature of the mild steel stand depends on the position in which the Patt. 7457 Box is mounted and on the local arrangements of the D/F aerials. The actual position in which the deck insulator is fitted depends on the type and class of ship, but must always be at the point of intersection of the bases of the fore-and-aft and beam loops.

In connecting up the cables, care must be taken that the two cores of each twin are connected to opposite and not to adjacent insulators, so that the fore-and-aft loop will use one

INSULATOR DECK - GROUP N. METHOD OF FITTING.

SCALE:- 1½ INCHES = 1 FOOT.

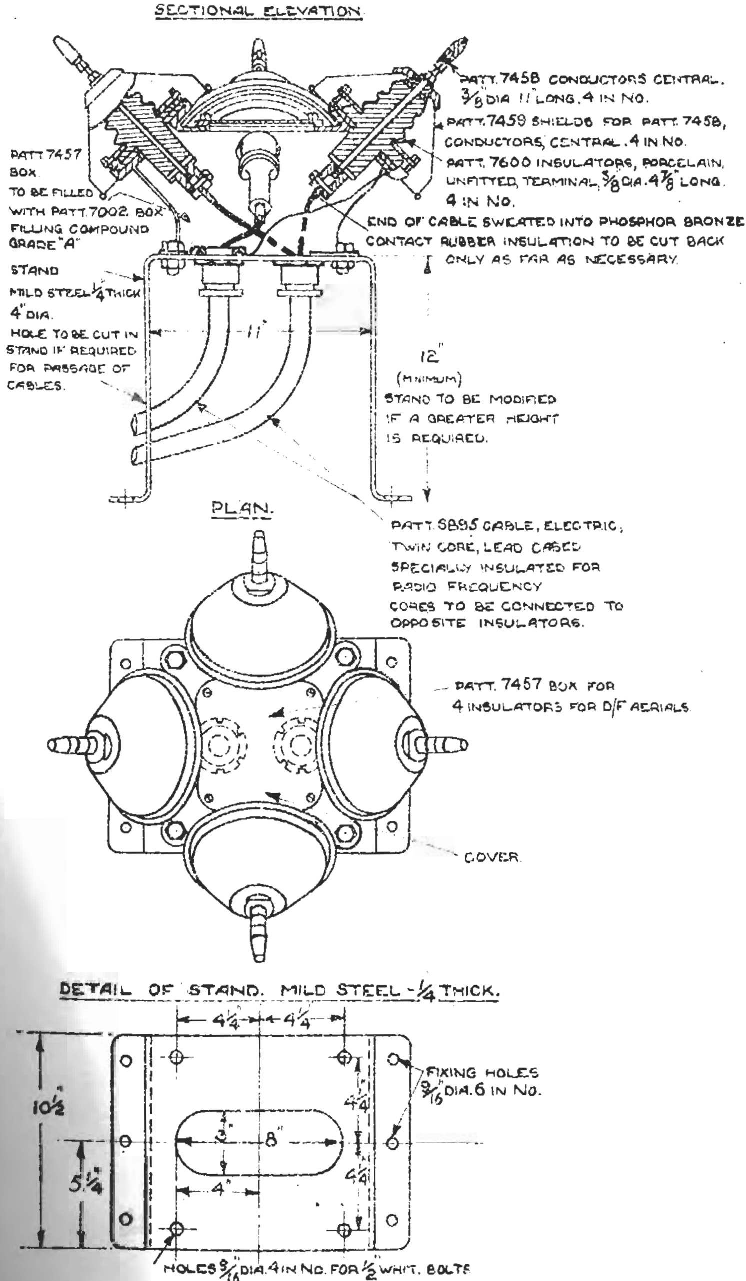


FIG 7.

MODEL OUTFIT S.D. — WIRING DIAGRAM.

	PATT	DESCRIPTION		PATT	DESCRIPTION
1	325	INDUCTANCE ADJUSTABLE Nº 3.	8	2279	CONDENSER Nº 13 ADJUSTABLE (MICA).
2	7209	SWITCH, 6 POLE, AERIAL SAFETY (ONLY ALLOWED IF TYPE 36 IS FITTED).	9	2186A	CONDENSER Nº 7 ADJUSTABLE (AIR).
			10	5478	AMPLIFIER MODEL M.D.
3	1549	SWITCH, C.O. UNENCLOSED, 2 POLE, 5 AMP.	11	6957	NOTE MAGNIFIER Nº 9.
4		RADIOGONIOMETER, S.23.	12	5869	TRANSFORMER FOR TELEPHONES 5/1.
5	6896	ELIMINATOR, RECIPROCAL BEARING FOR D/F.	13	7275	CONDENSER, FIXED (IN BOX) 4 JARS. 400 VOLTS D.C. TEST.
6	2181	INDUCTANCE ADJUSTABLE Nº 1 (TUNER LARGE)			
7	8286	INDUCTANCE 8000 MICS FOR D/F.	14	2328	SWITCH TELEPHONE, D.P. SINGLE WAY.

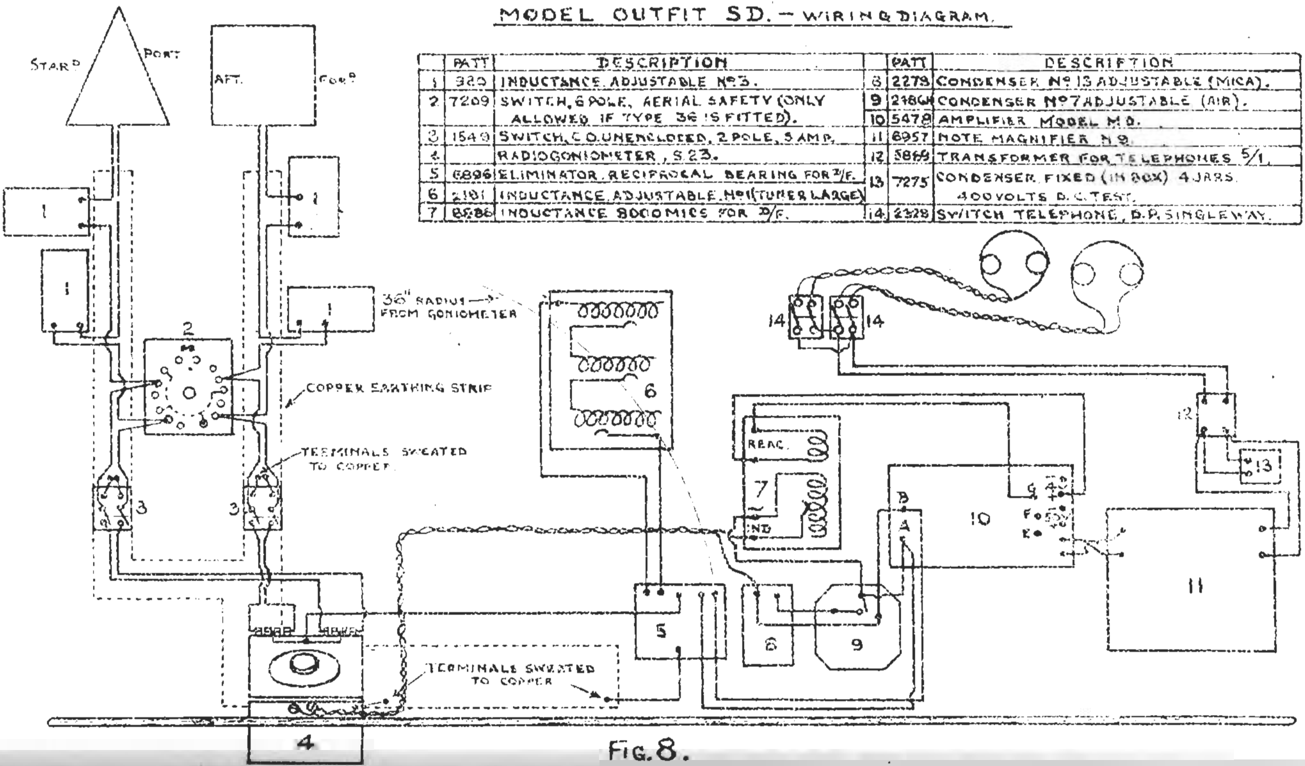


FIG. 8.

Maiby & Sons. Photo-Litho

twin cable and the athwartship loop the other. In the D/F office or bay the Patt. 6895 cables are brought to a terminal block with earthing clamp, Patt. 7131.

The fitting of one Insulator, Deck, Group N entirely replaces the obsolescent method of fitting four separate Insulators, Deck, Group G.

19. **Interior Fittings of the Office.**—A tuned search coil circuit for Model-Outfit SD has been tested in comparison with the present untuned circuit, and although for wavelengths above 2,000 metres there is no marked difference between the two circuits, below 2,000 metres the tuned circuit is definitely the superior as regards signal strength. As the aerial system in some ships is small, every means of increasing signal strength is an advantage. It has therefore been decided to adopt the tuned search coil circuit, and all ships fitted with Model-Outfit SD are modifying their wiring accordingly. The approximate positions of the various instruments inside the office with the necessary connections are shown in Fig. 8.

The leads from the four Patt. 1719 Deck Insulators or Terminal Block Patt. 7131 consist of bare copper wire, No. 10 S.W.G., the two leads from one aerial being led together along porcelain cleats, Patt. 4879, and the two leads from the other aerial being led along another line of insulators to the outer terminals of the coils in the radiogoniometer; in both cases through two small inductances L_3. Inductances L_3 must be placed well clear of earth, not too close to one another, and at least three feet from the radiogoniometer. Their use will be explained later.

All these leads from the aerials must be carefully run with particular attention to the following points :—

(*a*) All connections must be good. (Soldered wherever possible.)

(*b*) The lengths of wire in the two aerial leads must be equal and symmetrically spaced with respect to the other leads and to earth.

(*c*) Mutual induction between the two aerial leads must be avoided.

(*d*) Wires must not be clipped to any wooden object, but must be carried in porcelain insulators ½ in. clear of bench and walls.

(*e*) The aerial leads must be as far away as possible from the receiver gear, and must not run past the latter.

(*f*) The ends of the aerial leads to the goniometer must, at first, be left long enough to enable the coils to be reversed if desired.

A gyro-compass repeater or bearing receiver must be installed in the operator's office unless a gyro-driven goniometer scale is fitted. The receiver dial should be placed on the bulkhead in clear view of the operator. Other office communications required are :—

(*a*) A buzzer to remote control, main and 3rd offices.
(*b*) A telephone to bridge or exchange.

The D/F goniometer should be placed 1 ft. clear of earth and 3 ft. if possible, from the tuned receiving circuit and is let into the top of the bench with its top slightly tilted forward so that the operator can readily turn the search coil and read off from the scale.

The present receiving set for D/F is known as Model SD in surface vessels and Model SA in submarines.

20. **Correcting Inductances.**—The correcting inductances L_3, variable from 0 to 20 mics, already mentioned, are inserted in the office, one in the foot of each leg of each loop, and at least 3 ft. away from the goniometer. These inductions are used to vary the sensitivity of the loops for purposes of balancing them. They should be fitted with their axes at right angles to one another so as to avoid mutual inductance. (*See* Figs. 20 and 21.)

21. **Buzzer Tester for D/F, Patt. 7465.**—This instrument has been designed to act as a check on any direction-finding set. Its object is to detect any fault in either the aerial system or the goniometer. The instrument is shown in Fig. 9.

A diagram of the circuit of the buzzer tester is shown in Fig. 10. To induce the external magnetic field of the instrument and thus eliminate any possibility of obtaining an audible signal in the telephone due to direct action, otherwise than through the aerial system, which would tend to produce an imperfect zero, the whole of the inductance of the buzzer tester is concentrated in a toroid.

It will be seen that by coupling the aerials in the manner shown in Fig. 10, the E.M.F.'s induced in the two loops are precisely equal and independent of any small movements of the aerial wires or the wires which pass through the toroid.

If the two D/F loops were of identical dimensions the buzzer zero, with both loops connected, should be at 045 deg. precisely, and any change from this position would indicate a fault in the aerial system. In most ships, however, the loops are not identical; the zero will, therefore, not be at 045 deg. but at some other point in this region. This point should remain constant as long as the aerials are in order.

The resistance and capacity of the circuit of the buzzer tester have been adjusted so that the tuning is sharp (at above 970 metres) and the signals of sufficient strength to give a sharply defined zero when using amplifier Model MD. One dry cell Patt. 4976 is sufficient for this, but two cells will be supplied with each Model-Outfit SD and space is allowed for them in the box containing the buzzer tester.

PATT. 7465. BUZZER TESTER FOR D/F.

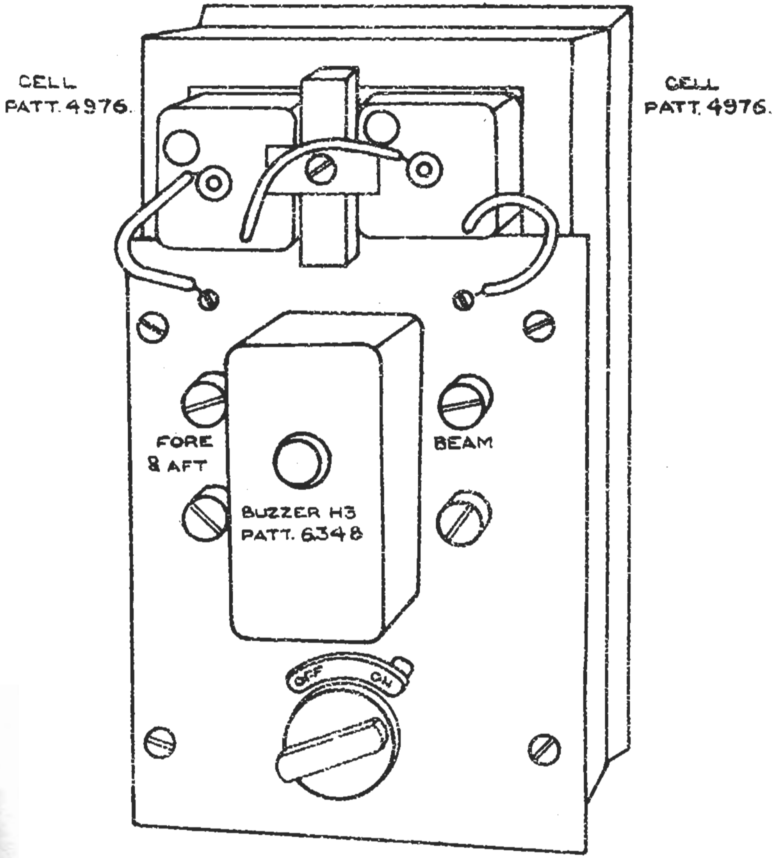


FIG. 9.

DIAGRAM OF CONNECTIONS OF BUZZER TESTER FOR D/F (PATT. 7465).

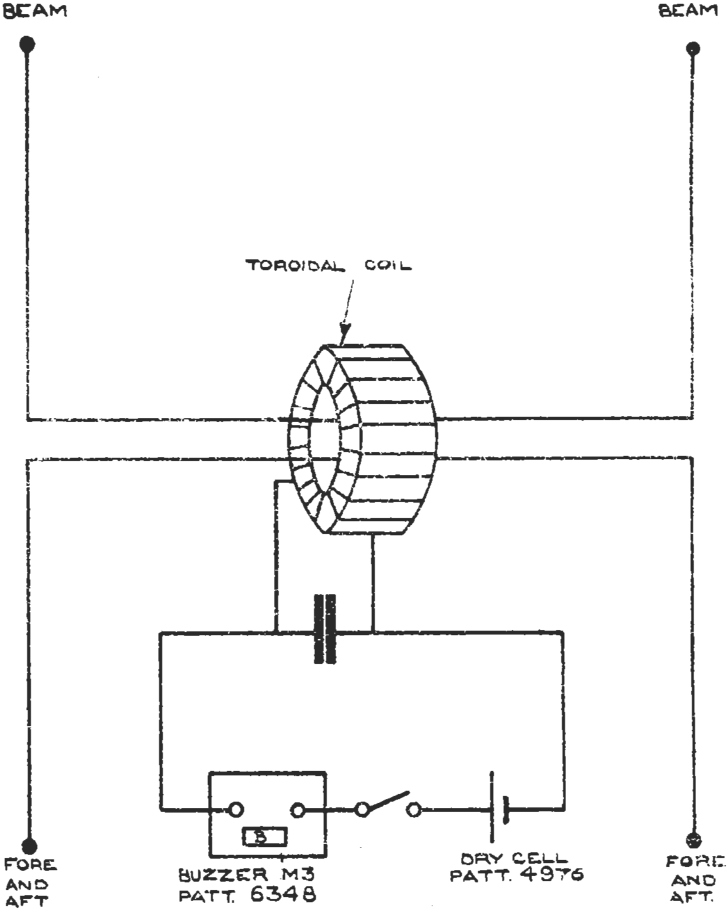
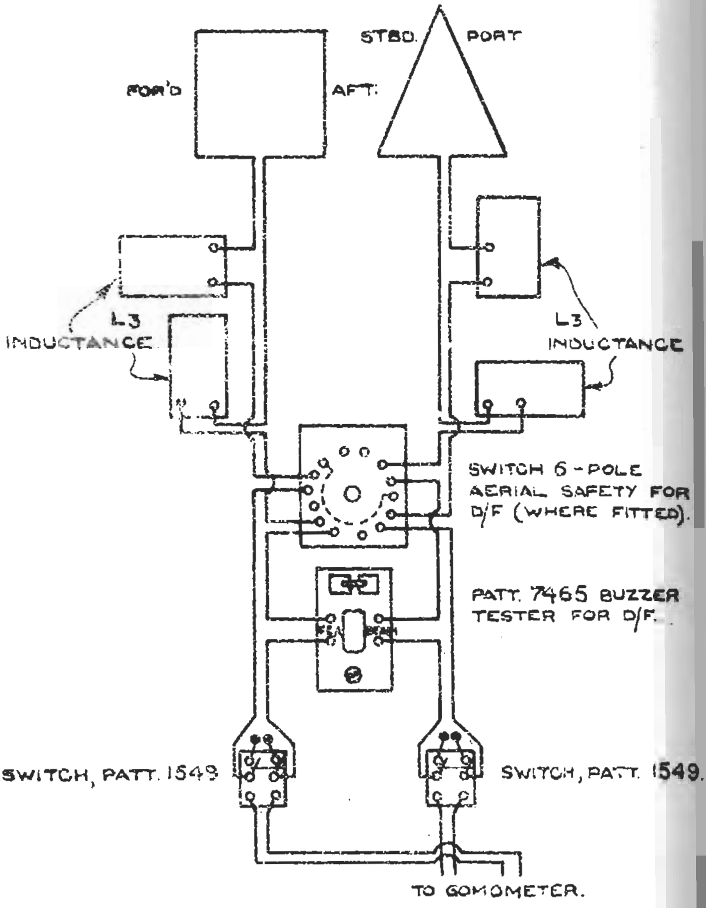
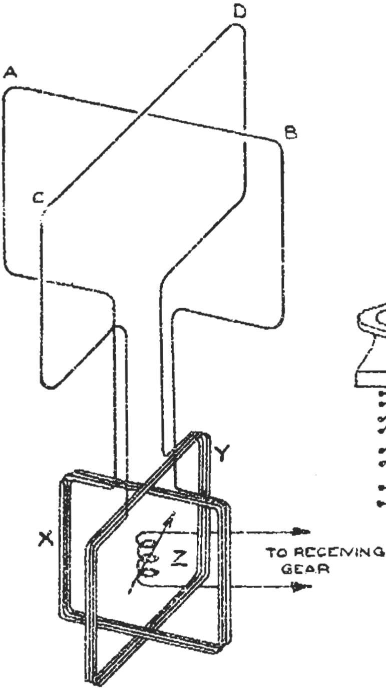


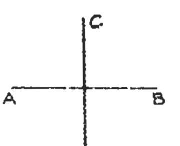
DIAGRAM SHOWING HOW TO CONNECT PATT. 7465 BUZZER TESTER FOR D/F IN CIRCUIT OF MODEL-OUTFIT SD.



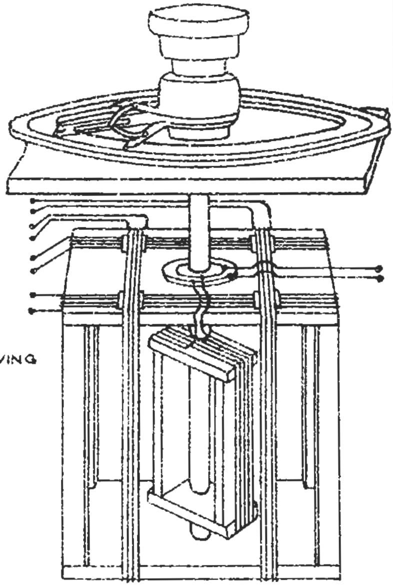
RADIOGONIOMETER.



RADIOGONIOMETER



(a)



(b)

The buzzer tester is connected in the circuit of Model-Outfit SD as shown in Fig. 11. It is important that the buzzer should be shunted by a Patt. 5056 "Shunt, 100-ohms, for Buzzer" and this shunt is therefore incorporated in the buzzer tester as a component of Patt. 7465.

22. **Radiogoniometer** (*see* Fig. 12).—By means of this instrument the line of the transmitting station is found. It consists of two field coils set very accurately at right angles to each other, each receiving current from one of the loops. The two coils are divided into two halves, the inner ends being brought out to two terminals which may be short-circuited and earthed as required. A coil, known as the search coil, is set in the middle so that it may be rotated horizontally at right angles to its axis in the fields of the two coils. The greatest care must be taken not to damage, strain or distort this instrument in any way, as upon its accuracy depends the whole success of the installation. The framework of older pattern instruments is very liable to warp in a damp atmosphere. The principle upon which this instrument works has already been described.

The pointer is divided into three, the centre one holding a sliding pivot for two equal links which are fixed symmetrically to pivots on the outer legs. (*See* Fig. 13.) If one of the outer

GONIOMETER POINTER. ANGLING DEVICE.

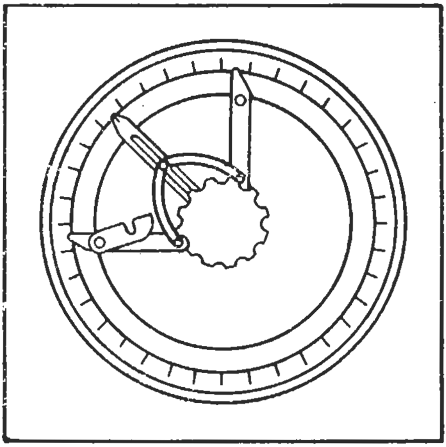


FIG. 13.

legs is then clamped at a position giving a convenient strength of signal and the handle turned till the other leg is at the opposite side of the minimum at the same strength, then the centre leg automatically bisects the angle and gives the position of the minimum. With the original radiogoniometers, only relative bearings can be read off the scale, and to convert these relative bearings to true gyro bearings, reference to the gyro-repeater in the D/F office is necessary.

This cumbersome process is eliminated in the new Radiogoniometer S25 now introduced, which is fitted with a gyro-driven scale worked off the gyro system of the ship.

The accuracy of the gyro scale must frequently be checked with the master gyro.

The following gyro-driven radiogoniometers are now being issued to certain ships concerned :—

Patt. No.	*Description.*
7450.	Radiogoniometer S25. 20-mics.
7452.	Radiogoniometer S25. 230-mics. (S/ms. only.)

A wiring diagram showing how the Radiogoniometer S25 is connected to the gyro-system of the ship is shown in Fig. 14.

The following additional instruments to those shown in Fig. 8 are required for use with the Radiogoniometer S25 :—

Patt. No.	*Description.*	*Number.*
7454.	Condenser Unit for shunting small motors	1
7455.	Coupling, Flexible, spare, for Radiogoniometer S25 - - - - - - -	1
7467.	Motor for Radiogoniometer S25 - -	1
7058.	Resistance, 13·6 ohms, 1·1 amps. - -	1

A general view of the Radiogoniometer S25 with the necessary additional instruments is shown in Fig. 15.

23. **Inductance for D/F.**—This, in conjunction with a No. 7 condenser, forms the tuned receiving circuit and is connected to Amplifier MD. It consists of a variable inductance having five tappings and is tuned by means of a No. 7 condenser joined in parallel across it. The rough values of the tappings are 450, 1320, 2725, 5030 and 8500 mics. For receiving C.W. the heterodyne unit K5 should be used. This obviates any change of note as the search coil is rotated. But for quick searching a reaction is embodied in the inductance 8000 mics. This enables the amplifier to be used as a self-oscillating heterodyne receiver. Leads beyond the search coil must be non-inductive so as to avoid picking up extraneous signals. They should be wired as close together as possible, the only wiring to be used for this purpose being two cables, Patt. 611 or Patt. 482, twisted together.

A new Tuner A41 is being introduced to replace the 8000 mics. inductance and a diagram showing the method of connecting this instrument in the circuit is shown in Fig. 16.

24. **Eliminator, Reciprocal Bearings, Pattern 6896** (Fig. 17).—The method of using the instrument is described hereunder. Fig. 18 shows the method of connecting up the eliminator. The casing of amplifier MD must be carefully insulated to avoid a short circuit through the grid potentiometer when the " B " terminal is earthed.

RADIO-GONIOMETER S 25.

DIAGRAM OF CONNECTIONS FROM GYRO SYSTEM TO MOTOR DRIVING SCALE.

NOTE:- THE COMMON LEAD FROM THE GYRO-COMPASS SYSTEM MUST FOLLOW THROUGH TO THE COMMON LEAD OF THE MOTOR (COLOURED DARK BLUE) WHEN THE SWITCH IS CLOSED. THE CORRECT CONNECTION OF THE OTHER LEADS MUST BE ASCERTAINED BY TRIAL.

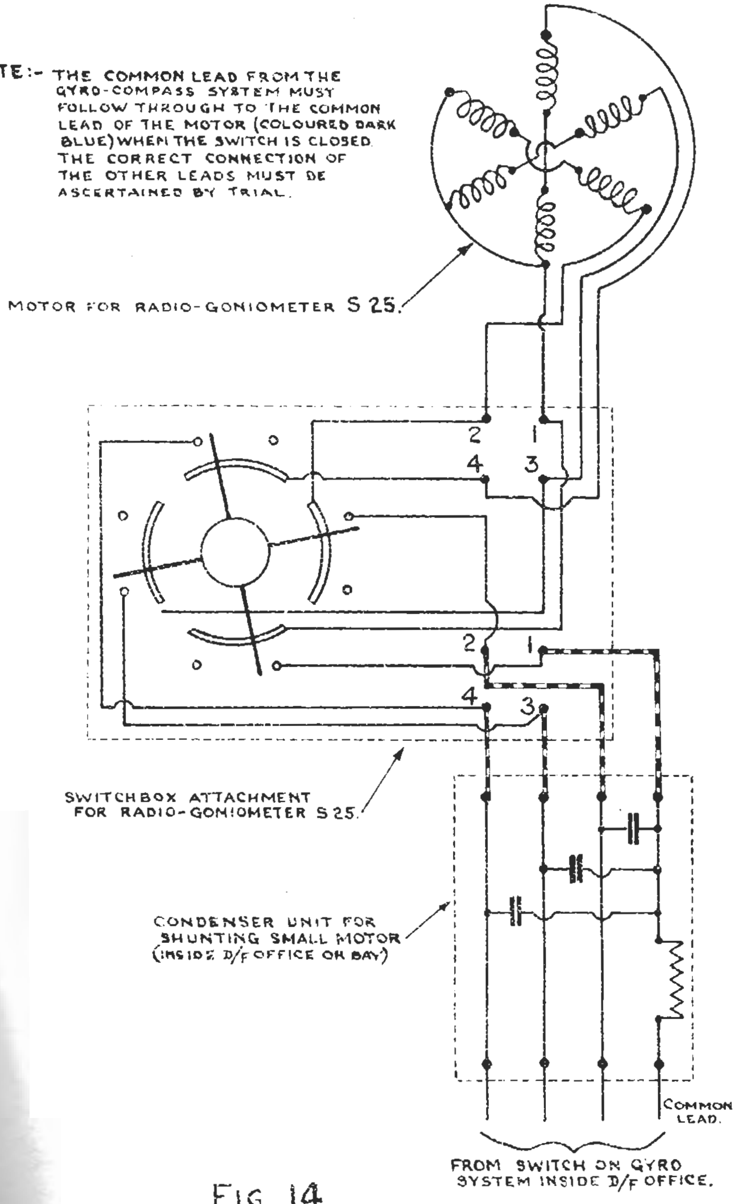
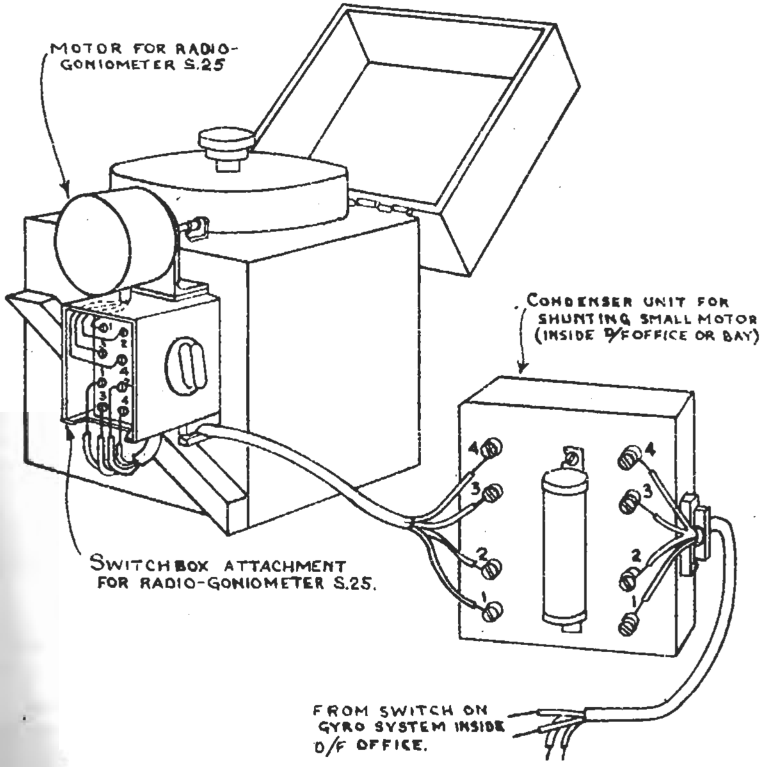


FIG. 14.

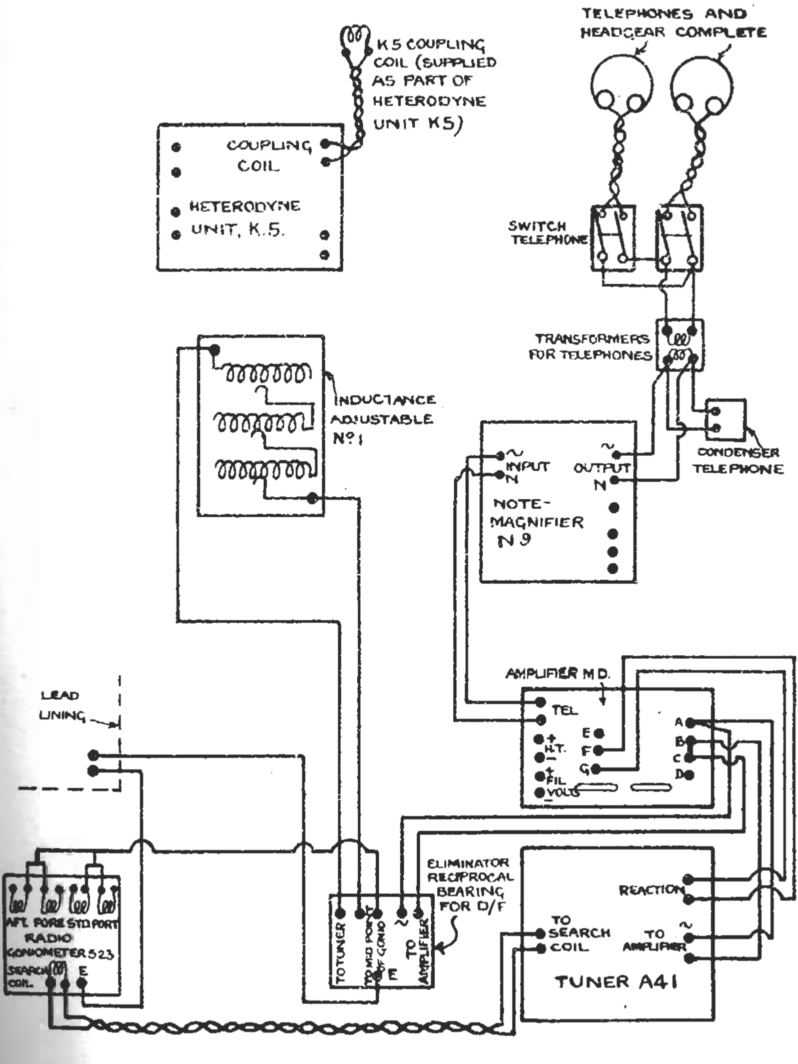
RADIO-GONIOMETER S25.

POSITION OF INSTRUMENTS.



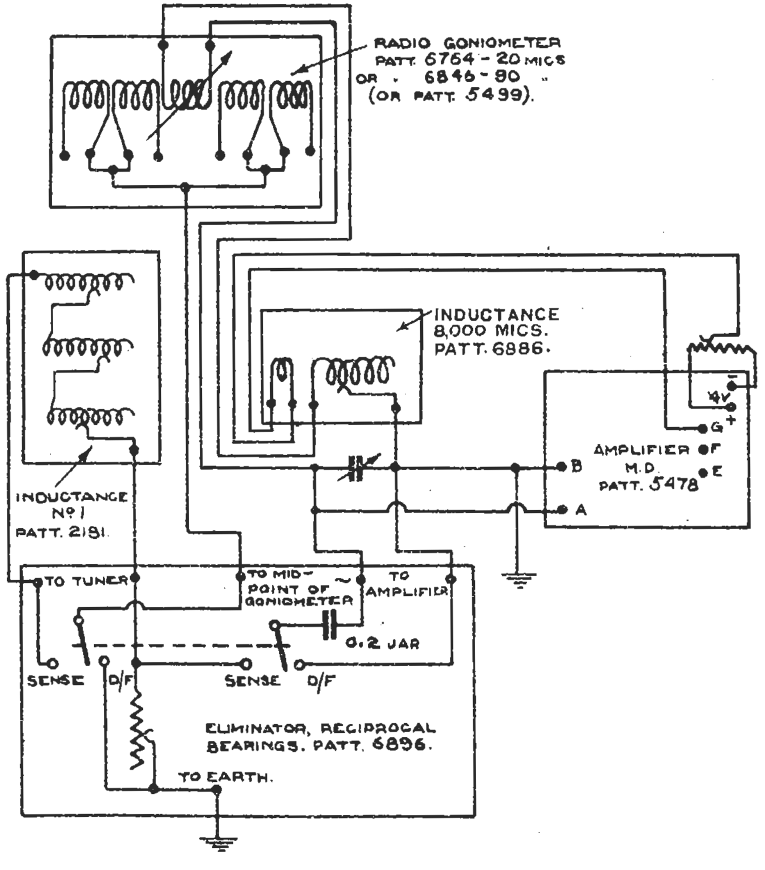
MODEL - OUTFIT SD.

METHOD OF CONNECTING TUNER A41 IN CIRCUIT.



ELIMINATOR RECIPROCAL BEARINGS.

WIRING WITH MODEL OUTFIT SD.



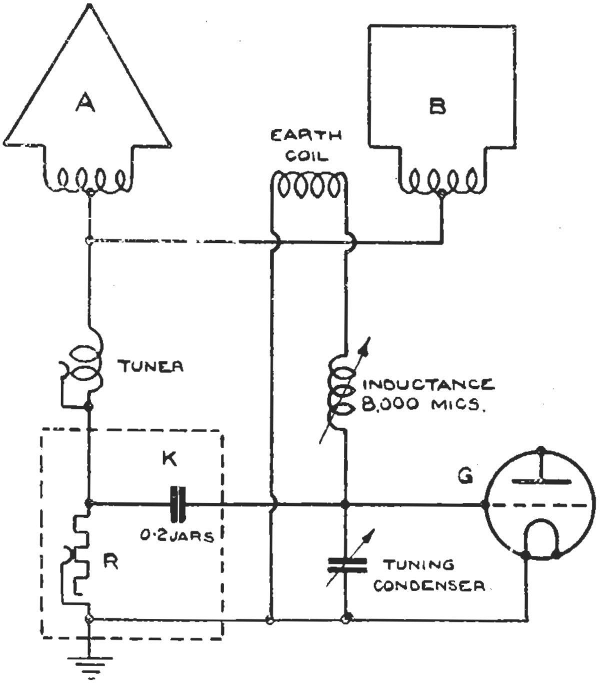


FIG. 17.

As explained earlier the action of the instruments depends on the combination of the vertical and loop effects of the D/F aerials :—

(a) *Antenna Effect.*—The antenna effect of the two loops is applied to the amplifier through a tuning inductance and a variable non-inductive resistance, the resistance being coupled by means of a 0·2 jar condenser to grid and filament of the first valve of the amplifier. For a given value of the tuning inductance and resistance the voltage thus applied to the valve will be constant.

(b) *Loop Effect.*—The voltage induced in the search coil is applied to the amplifier in the ordinary manner. With the search coil placed so as to give maximum signal strength, the voltage thus applied will be opposite in phase to that applied when the search coil is 180° from this position (*i.e.* at the other maximum).

(c) In combining these two effects it has been shown that the applied voltage due to antenna effect will be approximately in phase with one maximum search coil voltage, and 180° out of phase with the other maximum. Hence, when the plane of the search coil is perpendicular to the resultant field of the goniometer coils in one position, the total voltage applied to amplifier will be a maximum, and when the search coil is rotated through 180° the applied voltage will be a minimum.

The best results will be obtained when the maximum value of the voltage due to search coil equals that due to the antenna effect, and the value of the latter can be adjusted by altering the values of the resistance and the variable inductance.

(*d*) *Tuning.*—It will be clear from the foregoing that the whole sense effect depends upon the phase relationship of the two applied voltages. This relationship will be found to be correct when the aerial is de-tuned from the incoming wavelength. "Sense" could be obtained if aerial were tuned either to a shorter or to a longer wavelength, but it is more efficient to keep down the loading in the aerial circuit, *i.e.*, to keep to the shorter wavelength. As the aerial tuning approaches resonance with the incoming wave the signal strength increases, but the "sense" effect diminishes owing to the current coming more nearly into phase with the voltage. *If too much inductance is inserted* and aerial is loaded to the longer wavelength, *the sense will be reversed.*

In calibrating the D/F set with the eliminator switch to D/F, the goniometer pointer is set to read off the bearing of the transmitting ship or its reciprocal, when the signal strength is zero. On changing over to "sense," the search coil is rotated until the maximum is found, and in this position the pointer will be at right angles to its position when the zero was found. An arrow will therefore be marked on the handle at right angles to the pointer (when set) so that it will indicate which to choose of the original bearing and its reciprocal. It will be obvious that the correct choice will depend on the way the search coil terminals are connected up and can only be tested by calibration. In Radiogoniometers S25, an adjustable arrow is provided for indicating sense, which is to be set on initial calibration. This pointer must not be moved subsequently without due cause; apparent reversal of sense may be due to mis-tuning the sense-finding circuit.

The accurate bearing must be obtained with the eliminator switch to D/F, the "sense" position only being used as described above.

III.—Testing.

25. **Procedure.**—Make all connections as shown in the diagrams, but leave the inductances L_3 at zero position. Switch on the Buzzer Tester, Patt. 7465, and valves of the amplifier. Then connect the telephones to the amplifier direct and see that signals are received.

26. **Setting the Pointer of the Goniometer.**—When signals are satisfactory, the pointer attached to the search coil of the

goniometer may be set in its correct position relative to the search coil.

Assume that the two aerials are arranged, one called the fore-and-aft aerial in the plane of the fore-and-aft line of the ship, and the other called the beam aerial exactly at right angles to this. Then the pointer of the goniometer can be set as follows :—

(1) Open circuit the beam aerial circuit.

(2) Excite the fore-aft aerial by means of the Buzzer Tester.

(3) Find the search coil position for zero signals.

(4) Set the pointer to the zero of the scale and clamp it in that position.

(5) Check setting, to be satisfied that it has been tightened up without moving; note that zero also occurs at 180°.

An additional test now is to disconnect the fore-and-aft aerial and excite the beam aerial, in which case the zeros should be obtained at 90° and 270° respectively. **When these tests** have been complied with, **the direction-finding pointer reading** for zero signals from any **station gives the direction relative to** the ship's head (0°). These respective zero readings, when one aerial is disconnected and the other excited by the Buzzer Tester, provide a ready method of resetting the pointer, if it is accidentally moved at any time. These zeros should always be within 1° of their correct positions.

Note that there are two zeros to be found for every station. Thus, for instance, if a station be found to give a zero at 30° there will be a similar zero for it at 180° + 30° or 210°. Thus, a pointer reading of 30° only means that the station in question is on a line drawn through the ship at 30° to the centre line of the ship. This is obviously the same as saying that the station is on the line drawn at 210° to the fore-aft line of the ship.

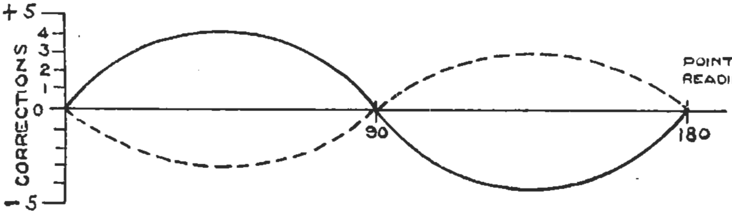
With both aerials connected the minima should be at 45° and 225° approximately.

27. **Trials on Signals.**—In the case of a set which can be tuned to a long wave it is best to select a station like Daventry or Eiffel Tower for preliminary trials. Care should be taken to disconnect the main aerial entirely, then tune in to the station selected and take a rough bearing by turning the search coil handle through the position of minimum signals, taking a reading on each side where the signals appear to be of equal strength. The mean of these readings gives the apparent bearing of the station relative to the ship, provided the pointer has been set by the buzzer zeros as indicated above. Add the reading of the ship's head to the mean of the direction-finding pointer readings and the result is the W/T true bearing of the station.

NOTE.—All bearings, &c., are taken from 0° to 360°, and any magnetic variation or deviation should be applied in those cases where the magnetic compass is used. The difference between the W/T bearing of the station and the true bearing from the chart gives the correction plus or minus to the W/T bearing to give the true bearing.

This correction should be approximately zero at 0°, 90°, 180°, or 270° relative to the ship. Take a few bearings of stations all round the compass, work out the various corrections and plot them against their pointer readings. They should lie on curves similar to that shown in Fig. 19.

CURVES OF CORRECTION.



Curves of Correction :—Full line indicates that fore-aft aerial is too powerful, increase L_f.

Dotted line indicates that fore-aft aerial is too weak, reduce L_f.

FIG. 19.

The curves may be negative between 0° and 90° and positive between 90° and 180°, but provided the aerials are correctly connected it should not be possible for a station which is really on the starboard bow, say, to appear to be on the port bow. As a rule the effect of the ship is to drag the bearing into the fore-and-aft line. If the bearing appears to be dragged from one side of the ship to the other the causes should be sought in a faulty connection of one aerial, and it will probably be necessary to reverse the connection of one aerial at the direction-finding box.

CURVE OF CORRECTIONS SHOWING CASE WHERE FORE-AND-AFT AERIAL IS RECEIVING TOO STRONGLY.

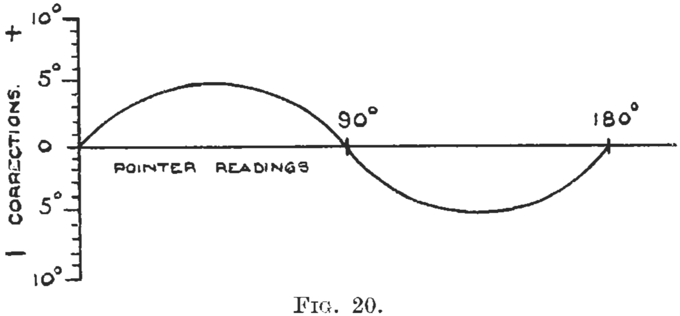


FIG. 20.

It is probable that a curve of correction similar to that shown in Fig. 20 will be obtained, and consideration of this curve will show that in this case the bearings are being drawn into the fore-and-aft line, indicating that the fore-and-aft aerial has too much effect on the result, hence the effect of the fore-and-aft aerial must be reduced. This can either be done by reducing the size of the fore-and-aft aerial or by introduction of inductance into it, such inductance not being influenced by external signals, nor influencing the search coil of the direction-finding box. A curve in the opposite sense, *i.e.*, one that is negative in the first quadrant, indicates that the beam aerial is receiving too much signal and inductance may be introduced into it to reduce this effect.

In many cases curves will not cross the zero line exactly at 0°, 90°, or 180°, but if it is only, say, 10° or 15° out, the errors can still be practically eliminated.

28. **Correction of Errors.**—When the approximate curves for the aerials alone have been obtained inductance L_3 should be introduced into the aerial which is receiving strongest signals until observations show that the error at 45° or 135° has been reduced to zero. The errors at 0°, 90° and 180° should still be zero, hence complete, or nearly complete correction has been obtained. Correction by L_3 above is entirely satisfactory for spark signals, but is not necessarily so for C.W.

In the case of C.W. perfect correction for ships' errors may have been obtained by use of L_3, but after this has been done it may be found that the note of a C.W. signal alters when the search coil is rotated. If this alteration of note is serious it will be difficult to take accurate C.W. bearings owing to the difficulty of obtaining a satisfactory equality of strength between signals of different pitch.

The change of note is due to the change in the effective inductance of the search coil caused by changes of its mutual inductance with the two aerial circuits as it is rotated. There would be no change if the two aerials were similar in all respects, but in the present case the inductance of one may be considerably greater than that of the other. If the change of note is always most noticeable on the shorter C.W. waves, and if found to be annoying, steps must be taken to remedy matters. This may be accomplished by the use of a separate heterodyne.

29. **Relation between Wavelength and Deviation.**—The current which flows in an untuned loop depends upon the E.M.F. induced and the impedance of the loop. The former increases uniformly with the frequency. Also, provided the resistance of the loop is small, the impedance increases uniformly with the frequency so that wavelength will not affect the deviation. So much for the loop effect. In the case of a vertical aerial, however, this is not so, for here the current increases with the frequency until resonance is reached and then falls off again. To capacity current, the vertical effect already discussed is due, and these currents we now see from the above will cause deviations which will

not be constant, but will vary with the wavelength. As the wave becomes shorter, below a definite limit as shown clearly in the curves, the error increases. The effect of appreciable capacity currents is, however, not so much to cause bearing errors, but to spoil the zeros altogether so that a bearing cannot be taken. Their presence may be recognised by the following characteristics :—

The zeros are poor as in every position of the search coil there will be some E.M.F. produced in it. A position of minimum sound is all that can be found and even this is difficult to locate.

The minima are most indefinite for short waves and when signals arrive from the beam.

The deviations as deduced from the positions of the minima are not quadrantal.

The **deviations vary with the wavelength**. They increase with the frequency.

The curves, Figs. 21 and 22, reproduced, were actually taken in "Queen Elizabeth" and "Barham," and show very clearly the variation of the necessary value of L_3. It is thus necessary to have different fixed values of L_3 for all waves.

L_3 is divided into two equal halves in order to maintain the symmetry of the loop.

When calibrating, a curve should be made out similar to those shown in Figs. 19 and 20.

30. **Aerial and Instrument Mutual Inductance.**—When a station is erected, the two aerial systems which include the two fixed coils in the radio-goniometer must be free from mutual inductance except that introduced by the search coil. If mutual exists then it must be eliminated.

First determine whether there is any mutual between the two fixed coils of the radio-goniometer. This may be done as follows :—

(*a*) Disconnect one aerial, say "E–H" and remove its leads as far away as possible from any of the leads of the other aerial "A–D."

(*b*) Connect together terminals "F–G," and have a wire ready to connect together terminals "E–H." Set the buzzer to any convenient wave, tune the one aerial and carefully set the search coil to the position of zero signals. Now connect together terminals "E–H," keeping search coil fixed, note if buzzer can now be heard. If buzzer can now be heard then there is mutual between the two fixed coils. The reason for this will be clear when "E–H" is open circuited, then, even if there is mutual between it and "A–D," "E–H" cannot react back in any way. Directly "E–H" is shorted, however, energy is transferred from "A–D" to "E–H," and this transferred energy reacts back on the search coil, thus causing the buzzer

H. M. S. BARHAM.

GRAPH SHOWING INDUCTANCE NECESSARY IN LOOPS TO CORRECT QUADRANTAL ERROR AT VARIOUS WAVELENGTHS.

(NOTE:– ON 450 METRES MAXIMUM L_3 (80 MICS) LEFT 7° OF ERROR UNCORRECTED, AND ON 310 METRES, 14°).

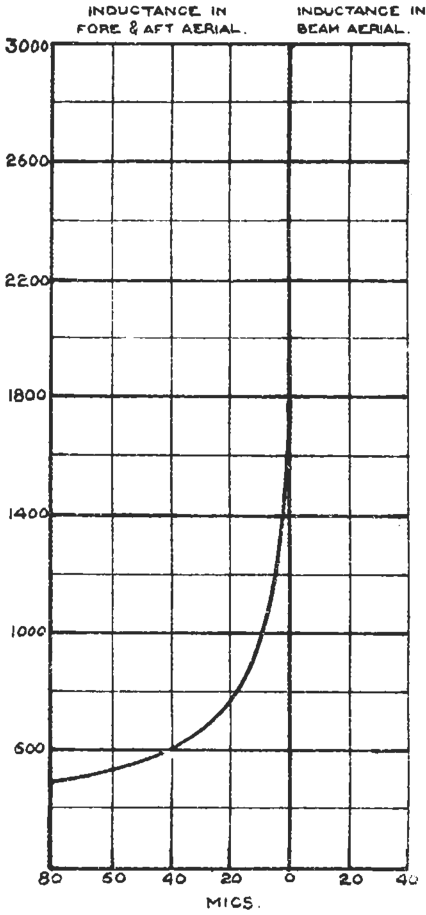
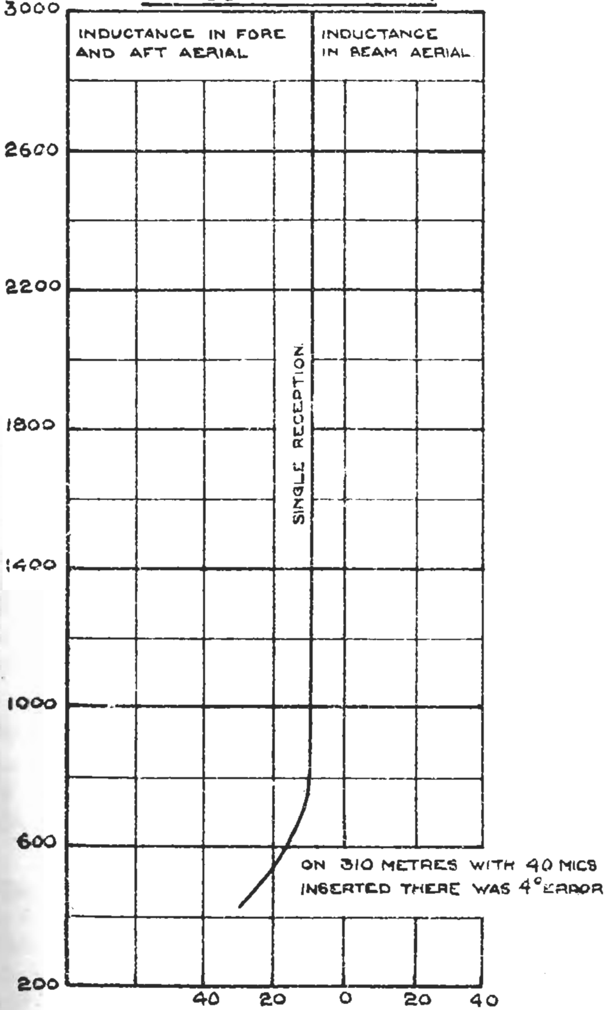


FIG. 21

H.M.S. "QUEEN ELIZABETH."

GRAPH SHOWING INDUCTANCE NECESSARY TO CORRECT QUADRANTAL ERROR ON VARIOUS WAVELENGTHS.



to be heard with the search coil in the same position as that which gave inaudibility with " E–H " open circuited. To eliminate mutual between the two fixed coils, the wires forming one of the coils must be bent. To do this leave " E–H " shorted, and bend the wires of " E–H " until a zero is obtained. Care must be taken that the search coil is not moved in any way or any of the wires of "A –D." The above tests should be made with the wires to the aerials and condensers either temporarily or permanently fixed in their final positions. This kind of mutual should seldom occur as instruments are carefully adjusted before sending out—but shocks in transport may introduce a little.

31. **Mutual between Aerial Systems.**—Re-connect both aerials to the radio-goniometer, and having set the Buzzer Tester to any convenient wave, balance the two aerials. Now take the Buzzer Tester and set it to the same wavelength as that on which the aerials have been balanced. Place the mutual close to one of the aerials as far from the office as possible. By the help of a ladder one should be able to get it within a foot of the wires. Assume that the frame is being held close to aerial " A–D."

Disconnect this aerial from the radio-goniometer and listen on aerial " E–H." If the buzzer can be heard, then re-arrange the frame so that the buzzer is inaudible. When this has been done, disconnect " E–H " and connect up " A–D." Set the search coil to the position of maximum signals. Connect up aerial " E–H," then if the buzzer remains audible, there is mutual, but if the buzzer is inaudible there is no mutual between the two aerial systems. If the aerials have been put up correctly at right angles to one another, then this mutual is present in the leads, and should be corrected.

If the amount of mutual is not large it may be neglected, but if large it may be eliminated by bringing one of the leads connected to " A " or " D " in proximity to one connected to either " E " or " H." A re-test for mutual inductance between the aerial circuits need only be made every few months.

Aerial mutual may be due to the beam aerial not being exactly abeam. The ship herself is a good directional receiver in the fore and aft line, and unless the beam aerial is really at right angles to this effect, the ship's effect will not be neutralised on the two sides of the beam aerial. Hence the beam aerial will have mutual to the ship and thence to the fore-and-aft aerial.

The effect of the mutual is to introduce errors at 0°, 90° and 180°, whilst at 45°, &c., its effect is negligible. The presence of large mutual should, therefore, be evident on the calibration curves.

IV.—Calibration.

32. **General.**—The calibration of a D/F installation consists of four parts :—

1st, the application of tests to instruments inside the D/F office.

2nd, the adjustment of aerials until they are correctly balanced.

3rd, a swing through 360° to determine the curve of corrections.

4th, a correction for variation of wavelength.

The first stage may be completed in harbour. The second third and fourth stages must be done at sea.

33. **Instrument Tests.**—The following Tests should be made and satisfactory results obtained, before proceeding to swing the ship. They are designed to ensure that no error can be due to instruments inside the D/F office.

They should be applied in the sequence indicated :—

(*a*) During erection.
(*b*) Whenever new instruments or aerials are installed.
(*c*) Whenever unsatisfactory results are obtained.

Test.	Fault.	Cause.	Remedy.
Examine aerials and plan of ship to see that each aerial lies in a vertical plane, and that the two planes are strictly perpendicular.	Planes not perpendicular.	Booms, deck insulators, or point of attachment to triatic stay misplaced.	Correct, as far as possible, and draw attention to what cannot be rectified.
Test insulation resistance of each aerial to earth with a megger.	Insulation resistance less than 1 megohm.	Probably deck insulators.	Wipe surfaces with cloth. If possible, wash with distilled water and leave to dry.
Test insulation resistance between any point in one aerial and a point in the other. (Remove earths from goniometer.)	Resistance less than 1 megohm.	Leakage across switches or surface of goniometer.	Wash surfaces with very diluted ammonia followed by distilled water.
Test insulation of amplifier and batteries to earth with filament disconnected.	Resistance less than 1 megohm.	Acid on battery supports.	Wipe clean all insulators, supports, &c.

Test.	Fault.	Cause.	Remedy.
Disconnect both ends of search coil and try to receive signals on amplifier and tuned circuit alone.	Signals heard -	Imperfect screening of amplifier by W/T office.	Find a more suitable position for amplifier and tuned circuit (*e.g.*, far from window or door).
Trace aerial leads inside office from deck insulator to goniometer.	Zeros in wrong quadrant.	Aerials connected to wrong terminals of goniometer.	Correct aerial connections.
Break beam aerial circuit and receive any loud 600-meter signal on F and A aerial alone.	No position of search coil in which there is complete silence.	"Vertical" or unsymmetrical capacity to earth of two sides of loop.	Increase distance between aerial wires and metal structures.
Repeat above, using beam aerial alone with fore-and-aft aerial broken.	Ditto.	Ditto.	Ditto.
Break beam aerial circuit and receive any loud signal on F. and A. aerial. Set pointer so that one zero is at 0°.	Opposite zero not at 180°.	Direct coupling between goniometer primary circuit and amplifier circuit.	Rearrange leads and instruments. (If possible, at least 3 ft. between goniometer and any other instrument.)
Break F. and A. aerial circuit and receive any loud signal on beam aerial.	Zeros 180° apart, but not at 90° and 270°.	Primary windings of goniometer not perpendicular.	New goniometer.
Excite F. and A. aerial alone with buzzer tester. Break beam aerial circuit. Zero is at 0°. Then make beam aerial circuit.	Zero no longer at 0°.	Mutual induction between the aerials.	Alter aerials until F. and A. aerial lies in the plane of symmetry of the beam aerial.
Test quality of zero on suitable station, *e.g.*, Paris spark 2,600 metres.	Poor zeros -	Rotating magnetic field in the region of the aerials.	Make certain main aerial and any neighbouring aerials are not influencing the D/F aerials.

Test.	Fault.	Cause.	Remedy.
Test ohmic resistance of aerial circuit, all switches in the circuit, L_3 inductances and field coils of goniometer. Connect bridge megger to the inner terminals of the field coils. Remove common earth lead.	High resistance (more than one ohm). The fact of increasing the resistance of the circuit is similar to inserting L_3 inductance and therefore erroneous bearings will result.	—	Examine all contacts on switches, at terminals, and on L_3 inductances.

34. **Sea Trials.**—For the remaining trials, which must be conducted at sea, the following requirements should be borne in mind :—

(*a*) *Position of Ship.*—The ship should not be less than four wavelengths from land, or from the transmitting station, which may be either a ship or a shore station. The transmitting station must be clearly visible from the ship, so that its relative bearing may be taken at any time by pelorus or equivalent device. Four wavelengths is the minimum distance at which it is safe to work. But it is advisable to carry out the calibration at the greatest distance at which the transmitting station can be clearly seen.

(*b*) *Synchronising the Visual Bearing with the D/F Bearing.*—Direct communication between the D/F office and the bridge is required. When a satisfactory reading is obtained in the D/F office, a pre-arranged signal is immediately sent to the bridge and the correct relative bearing of the transmitting station at that instant is recorded; this relative bearing is passed to the D/F office immediately.

All readings, whether satisfactory or otherwise, should be recorded in the D/F office.

(*c*) *Power.*—It is desirable that the transmitting power should be sufficient to give a strong signal without excessive note magnification.

(*d*) *Other aerials* should be insulated.

(*e*) *Movable Metal Structures.*—These should be housed in their normal sea positions.

The calibration of D/F apparatus can also be carried out with ships on passage. The simplest method of doing this is to station the transmitting ship at least four miles on the bow of the ship being calibrated. The quadrantal error must then be eliminated, the aerials being adjusted, if necessary. When this has been done both ships should alter course 90° together to bring the transmitting ship on the other bow of the receiving ship. A final adjustment can then be made on a second quadrantal point.

Both ships should then alter course together 15° at a time towards the original course, and beyond it, until the transmitting ship is on the quarter of the receiving ship. Both ships should then resume the original course together.

Each course should be steered for at least five minutes.

By this means the apparatus will be calibrated for relative bearings from 045° on one side through right ahead to 135° on the other side, and in the normal ship it may be taken for granted that the errors on reciprocal bearings are equal. If the quadrantal error is eliminated on both bows the error on other bearings should not exceed 1°.

The total time taken depends on the time taken to eliminate the quadrantal error, but, in a ship which has been previously calibrated, should not be more than three hours from the time the transmitting ship is in station on the bow of the receiving ship.

Instead of laying down a programme for the transmitting ship it will usually be found more convenient for the receiving ship to direct the transmitting ship, by means of the appropriate operating signal, to transmit when required. Care must be taken to insulate the transmitting aerial as soon as the signal has been made.

More information is required on the subject of permanent correction of error for all wavelengths, both with regard to heavy ships and cruisers.

35. **Adjustment of Aerials.**—The fore-and-aft loop has a smaller area than the athwartship loop. The exact adjustment of the aerials is carried out when the relative bearing of the transmitting station is 045°, and this bearing should remain steady until the aerials have been correctly balanced.

Examples :—

(*a*) Relative bearing of transmitting station by :—

Pelorus - - - - - -	045°.
D/F bearing - - - - -	039°.

Fore-and-aft aerial should be reduced.

(*b*) Relative bearing of transmitting station by :—

Pelorus - - - - - -	045°.
D/F bearing - - - - -	052°.

Fore-and-aft aerial should be increased, or, if this is not practicable, beam aerial should be reduced.

Every endeavour should be made to adjust the aerials so as to obtain an accurate balance on the quadrantal point without the use of L_3 inductances. The adjustment of aerials is fairly critical, however, a matter of one foot of wire completely altering the direction of the bias, and it may be found necessary to use a small amount of L_3 inductance to obtain the final adjustment for an exact balance.

A wavelength of about 1,740 metres should be employed for this part of the calibration.

The error in D/F bearing towards the fore-and-aft line of the ship increases as the wavelength employed decreases; therefore, if the aerials are left slightly unbalanced, the bias should be towards the beam in order to ensure that the L_3 inductances will be capable of correcting the balance on the shorter wavelengths, *i.e.*, down to 450 metres.

36. **Curve of Corrections through 360°.**—Having adjusted the aerials on the quadrantal bearing, the next step is to make a swing through 360° in order to obtain a "curve of corrections."

Any convenient wavelength may be employed for this part of the calibration, the aerials being balanced by means of the L_3 inductances for the wavelength in use before the swing is commenced.

Simultaneous D/F bearings and relative bearings by pelorus are taken during the swing; and providing this swing is carried out reasonably slowly, there is no necessity for the ship to be steadied periodically. The 360° swing can be commenced from the direction in which the ship's head lies during the adjustment of the aerials. A rate of swing of about 6° per minute can be maintained if inter-communication between the D/F office and the bridge is sufficiently rapid, but this rate should not be greatly exceeded.

37. **Correction for Variation of Wavelength.**—This part of the calibration is carried out with the ship steadied so that the transmitting station bears 045°.

The commencing wavelength should be 450 metres, and the initial error on this wavelength noted, after which the L_3 inductances should be adjusted so as to obtain an accurate balance. The values of L_3 inductances used must be noted.

This process is repeated on 600 metres and then every 200 metres upwards until a point of constant error is reached. Time may not permit of corrections being made on all these waves, in which the more important wavelength lying between 600 metres and the point of constant error should be used.

For wavelengths below that on which the aerials were originally balanced the error will be towards the fore-and-aft line, and for those above, towards the beam line.

The point of constant error varies with the class of ship, but will be found to be approximately between 1,100 and 1,700 metres.

So far as is known at present, the "curve of corrections" obtained during the 360° swing should be similar for all wavelengths, provided the aerials have been correctly balanced by the insertion of the necessary amount of L_3 inductance, for the particular wavelength in use. This should be verified, however, as opportunity offers.

38. **Gyro Repeater in the D/F Office.**—The method of calibration obtained above does not involve the use of the gyro repeater. However, in the normal use of D/F an error in the gyro repeater means an error in the final D/F bearing. It is, therefore, very important that the repeater should be frequently checked against the master gyro.

The reliability of the gyro repeater in the D/F office should be made the object of a special series of tests. It is good practice to check the repeater at the beginning of each watch, and after large alterations of course.

Some ships are supplied with a gyro-driven scale on their goniometers, in which case no gyro repeater is provided but the above remarks apply equally well to the gyro-driven scale on the radiogoniometer.

39. **Effect of other Aerials on D/F Bearings.**—It is desirable to know whether the main aerial has any effect on D/F bearings. This can only be found by trial. It is best done in harbour when the ship's head is fixed, and may be done by the ship's staff.

For example, one of the transmissions from Daventry on 1,600 metres can be utilised. Bearings are taken every two minutes in the D/F office while the main aerial is tuned for reception first on 600 metres, then 1,100 metres and so on by steps up to 3,500 metres, including 1,600 metres.

A record should be kept of the wavelengths (if any) at which :—

(*a*) The zero becomes blurred.
(*b*) The zero (or minimum) shifts.

The same sort of experiment can be made for other wavelengths and for any other aerials sufficiently near to the D/F loops to be suspected of affecting the bearings.

In most ships it has been found that the main aerial has a distinct effect on D/F bearings. It is therefore essential to insulate the main aerial inside the W/T office when taking bearings.

Any aerial connected to a receiving set listening out on the same wave as that on which a D/F bearing is being obtained, but with the valves of the receiving models switched off, appears slightly to affect the quality of the zero inasmuch as their sharpness is reduced, but the average of several series of readings, taken with :—

(*a*) Aerials tuned to same wavelength and valves switched off;
(*b*) Aerial insulated;
(*c*) Aerial earthed,

all give the same results. The main aerial has most effect on the quality of the zeros, hence the necessity of insulating it inside the main office whilst bearings are being taken.

40. **Intercommunication between Ship Calibrating and Transmitting Station.**—In order that the D/F calibration may be carried out efficiently and without delay, it is essential that the transmitting station should be under the control of the ship calibrating, the latter giving the necessary instructions to the former as to changing wavelength and periods of transmissions. A definite wavelength, say 1,740 metres, should be established for intercommunication between ship and station during the calibration.

41. **Programmes.**—(*a*) The following is a specimen of the programme which should be submitted to the Captain of the ship in advance.

PROPOSED PROGRAMME FOR D/F CALIBRATION OF *H.M.S. "Berwick."*

Position of Ship.—Ship to be approximately 5 miles off, and in sight of Rame Head W/T Station by 0900 on 27th February, 1928.

This distance should be maintained throughout the calibration. It may be reduced slightly if visibility is poor, but a satisfactory calibration cannot be carried out if the distance is less than 3 miles. Intervening land should be reduced to a minimum.

Part I. Balancing Aerials.—Ship to be stopped, with station bearing Red (or Green) 45. This bearing to be held within 3 degrees on either side if possible.

Time required: about 45 minutes.

Part II. Swing for Curve of Correction.—Ship to be turned slowly through 360° at about 6° per minute.

Time required: about $1\frac{1}{4}$ hours.

Part III. Correction for Change of Wavelength.—Conditions as for Part I, preferably with the station on the same bow as in Part I.

Time required: about 45 minutes.

Bearings.—Throughout Parts I, II and III *relative* visual bearings of the station will be required. "Stand by . . . stop" will be passed to the bridge for each bearing and the bearings should then be passed to the D/F office as soon as possible.

(*b*) The responsibility for applying for the services of a station to act as transmitting station for a calibration rests with the calibrating authorities, and the following is a specimen of the signal which should be made to the appropriate authorities and repeated to the station concerned:—

"Request Rame Head W/T Station may be relieved of normal duties at 0830 Sept. 12th to act as transmitting station for D/F calibration of "Queen Elizabeth" and that watch may be set on 1740 metres at that time."

Communication between ship and station should be established about half an hour before the calibration commences. The station should maintain constant receiving watch on the wavelength ordered in the signal throughout the calibration, the transmitting wavelength being altered as ordered by operating signal from the ship calibrating.

It is essential that the station keep a good look-out for instructions in order to avoid delays.

42. **Accuracy of Calibration.**—Any D/F calibration is accurate only for the particular radiogoniometer and aerials which were employed for that calibration. Large structural alterations in the vicinity of the D/F aerials will also affect the accuracy of the calibration.

A.A. guns, booms, &c. in close proximity to the D/F aerials should be in their normal housed position during calibration.

43. **Specimen Copy of Report of Calibration.**

REPORT OF CALIBRATION OF W/T DIRECTION FINDING SET—
MODEL OUTFIT SD.

H.M.S. "Berwick."

1. *Date.*—27th February, 1928.

2. *Place.*—Underway 3·8 miles off Rame Head W/T Station.

3. *Weather Conditions.*—Very good.

4. *Calibrating Officers.*

5. *General Description.*—All preliminary tests were carried out satisfactorily.

(*a*) The aerials were balanced on a relative bearing of Red 45 on a wavelength of 2,400 metres, the fore-and-aft aerial being adjusted as requisite.

(*b*) Data for the "Curve of correction required due to change of wavelength" were then obtained on wavelengths of 2,400, 1,740, 800 and 600 metres. The point of constant error is approximately 1,100 metres. A graph showing the corrections required is attached.

(*c*) The swing for "Curve of correction" was then carried out on 2,400 metres and the results obtained are shown plotted on attached drawing.

It is not considered that any corrections to observed bearings are required except as shown over the arcs Red 90 to 135 and Green 45 to 90.

6. *Accuracy.*—For wavelengths of 600 metres and above the maximum error by day is unlikely to exceed 1° plus or minus, provided that the corrections referred to in para. 5 (*b*) and (*c*) are applied and that the local conditions are the same as those obtaining during calibration.

Radiogoniometer S 25, Serial No. R 19, was used during this calibration and the values of the aerial resistances were as follows :—

Insulation Resistance :	Infinity.
Continuity :	0·36 ohms.

7. *Sense Finding.*—Sense finding was found practically on all wavelengths.

The use of the Pattern 511 Tuner in the sense circuit is desirable on some wavelengths, but care must be taken not to insert too much inductance in this circuit or a reversal of sense will result.

44. Specimen of Calibration Record Form.

H.M.S............

WIRELESS DIRECTION FINDING SET—RECORD OF CALIBRATION.

On every occasion of calibration of the W/T Direction Finding Set, a record of all readings taken is to be made in duplicate in the following form. The duplicate copy is to be forwarded with a copy of the Calibration Report to the Admiralty.

RECORD OF CALIBRATION OF W/T DIRECTION FINDING SET.

H.M.S. at

Date.

Transmitting Station.

Wavelength.

Correction to Cabinet Watch.

Time.	Goniometer Readings.	Relative Bearing of Transmitter by Pelorus.	Error in D/F.	Remarks. To include (*a*) Wavelength. (*b*) Quality of Zero.

45. **Weekly Tests.**—Tests of D/F installation to be carried out once a week, also before a D/F exercise and before proceeding to sea :—

Zero Tests.—(*a*) Listen out for strong signals on any wave; break the beam aerial and receive signals on the fore-and-aft aerial only. Zeros should be at 0° and 180°.

(*b*) Make the beam aerial switch and break the fore-and-aft aerial and receive signals on the beam aerial only. Zeros should be at 90° and 270°.

Resistance Tests.—(*c*) With a bridge megger measure the resistance of each aerial circuit, inserting the megger between terminals F and G, and B and C, on the goniometer in turn, the earth leads being disconnected from these terminals.

The resistances found should be compared with the resistance measured during calibration. Any increase in the resistance will probably be due to dirty or faulty contacts and D/F errors will result. Special attention should be paid to the contacts on the L_3 inductances. The resistance of these inductances should increase uniformly to a maximum of about 0·07 ohms.

Insulation Tests.—(*d*) Remove the earth connections from the goniometer and measure the resistance of each aerial to earth and the resistance between aerials.

The resistances should be, in each case, at least 1 megohm. Low insulation resistance is usually caused by dirty insulators.

(*e*) Measure the resistance to earth of both filament and anode batteries when disconnected from the model and from the charging circuit.

The resistances should be, in each case, infinity. Low insulation resistance is usually caused by dirty insulators or leakage of acid.

V.—Reports.

46. **Reports.**—H.M. ships are to forward to the Director of Navigation, Admiralty, monthly reports as to the results of bearings obtained by D/F. Blank reports are not required.

Reports are to be rendered by all ships carrying a navigating officer down to, and including, flotilla leaders and sloops.

These reports are chiefly of use for checking the reliability of D/F bearings taken by shore stations and also of D/F bearings taken by ships themselves.

Reports are to be rendered on Form S. 1201, "Report of D/F Bearings."

Lizard D/F Station is at present the only Naval Shore D/F Station and H.M. ships should take every opportunity of obtaining bearings from this station, especially when a few hours North or South of Ushant. When possible bearings should be obtained over a period of several hours. The results are specially useful when reliable fixes can also be obtained.

In order to minimise the danger of undue reliance being placed on incorrect bearings obtained by D/F installations fitted in ships, it should be borne in mind that errors are liable to occur due to :—

(*a*) Aerial wires in the ship other than those fitted for D/F.

(*b*) Atmospheric effects (*e.g.* at night).
(*c*) Pointer slipping.
(*d*) Errors in gyro repeaters or compass of comparison.

Of these, (*a*) and (*b*) nearly always result in blurred zeros. This should generally be realised, as it affords a valuable means of recognising doubtful bearings.

Only those bearings which were reported by D/F office as reliable should be included on Form S. 1201; *i.e.*, only cases in which accuracy was anticipated. If the quality of the zero is anything but first-class, the fact should be noted in remarks column (*see* paragraph 13).