## CHAPTER 10 - HF DF

In March and April 1932 trials were carried out on "Concord" with a rotating screened frame-coil on the roof of the spotting top, with the topmast removed, (HYR Sept '32 p 19). The coil was rotated by an ARL remote control system.

> "From 16-1000 kHz bearings were good throughout, maximum error $2\frac{1}{2}$ degrees, a great contrast to the state of affairs when the topmast is in position. Above 1000 kHz the deviation begins to increase and the usual error curve changes form, becoming tilted. This change is very marked at 1875 kHz, when the wavelength is approaching the total length of the ship. Then with increasing frequency the blurring of the minima becomes worse and the deviation increases (to 20°), the error becoming approx semicircular at 3 MHz (ie positive and negative maxima at 90° and 270°), and again at 4 MHz but reversed in sign from that at 3 MHz.
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> For some frequency about 3.6 MHz (83 m = 270 ft) the error is again quadrantal, this frequency becoming apparently a critical frequency for the ship. A similar effect was found in Subm L22 at about 7.5 MHz (40 m = 130 ft). In both cases the critical wavelength is rather more than half the length of the receiving ship. Above 5 MHz a single-turn coil was compared with the frame coil and above 10 MHz only the former gave minima. The curves at these frequencies are very irregular and it appears from this that the ordinary realm of "ship effect" is quite left behind, and that now the error is produced by re-radiation from portions of the superstructure near the coil. It is probable that minor alterations in the rigging will considerably alter the curves obtained at these high frequencies. It may be noted that the differences between the two sets of curves may be due to the rigging of a triatic stay prior to the trials using the single-turn coil."
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> "With the frame coil, nominally balanced, the antenna effect was thought to be so large in comparison with the loop effect that no minima were observable. With the single-turn coil and a balancing condenser to earth on one of the 'balanced' feeder leads at the input to the receiver, the minima could be adjusted to 180° apart. But it was shown that the pick-up in the feeder leads, though they were encased in earthed lead tubes, was by no means negligible and therefore is a great element of uncertainty as variations in the capacity to earth will considerably alter its effect."

This extract summarises very well the position of HF DF in 1932.[27a]

In November 1933 extensive shore-effect trials were done in Plymouth Sound, for frequencies up to 55° kHz, (HYR Mar '34), the effect being up to 4°, but not greater than about $\frac{1}{2}$ degree out near the Eddystone Lighthouse.

(27a) 'Night Errors in Direction Finders' J F Coales JIEE 71, p 497 '32 'Wireless Studies of the Ionosphere' E V Appleton 71 p 642 '32. 'Errors in DF Calibration due to the Shape and Orientation of the Tr Aerial' J F Coales JIEE 73 p 280 '33. 'A Radio Compass' C E Horton and C Crampton 73 p 284.

The situation in 1937 was similar to that given above for 1932 and is detailed on the following page taken from ref 37.

"In 1938 an opportunity arose of conducting experiments on an aircraft carrier having no masts or rigging at all. It was found at 25 ft above the deck that the effect of the hull alone can cause very large errors with equivalent blurring due to quadrature components. There were however few cases in which the errors were so large or varied so rapidly that the df bearing was valueless, or in which blurring was so bad that no minimum could be found. Both these conditions occurred in practice in ships with normal superstructure and rigging. At sufficient height above the hull and superstructure the secondary field due to the hull alone will not be so large as to cause prohibitive errors on any frequency in the hf range. So the other major limiting factor in siting the hf df aerial is the proximity of linear re-radiators, particularly the mast itself on which the aerial is mounted. Whipple(37) calculated the re-radiation of a vertical conductor in relation to the incident field and found that the thickness of the conductor was not a major factor at the quarter-wave resonance, and then the secondary magnetic field at deck level diminishes nearly inversely as the distance from the base of the structure; at a distance equal to the height of the structure the field is very nearly equal to the primary field. But at a height above deck equal to one and a half times the height of the quarter-wave structure, the field ratio is one-third and the error is then not greater than $20^{\circ}$. For a conductor in the $3\lambda/4$ mode the effects are smaller, and in choosing suitable sites the $\lambda/4$ mode effects are decisive."

(37) C Crampton, Radio Convention Paper 'Naval Radio Direction Finding' JIEE Part 3A No 11 p 132 Mar '47. See also supporting papers:- Crampton, Whipple and Mugridge 'Errors of HF DF caused by Reradiation from a nearby Mast' p 815: Crampton, Struszynski, Marshall and Wooley 'The Performance of HF DF in Various Types of Ships' p 798: R T P Whipple 'Measurements of Reradiation due to the Hull' p 168: S de Walden et al 'Development of CRT DF' p 823: Griffith and Rosinski 'The Extension of DF Techniques to VHF' p 727. Struszynski and Marshall, 'Symmetrical Screened Transformers for DF' p 857.

**(3.2.1) Siting Conditions and Site Errors (for Normally Polarized Electromagnetic Wave, i.e. Electric Vector Vertical).**

A good deal of experience had been accumulated before the recent war on the performance of h.f. direction-finders of the simple loop type installed in various positions in various kinds of naval vessels. Experience up to that time, as well as a limited amount of theoretical investigation, had led to the belief that the top of a tall, or if possible the tallest, structure in the ship—generally one of the masts—was the best position for the h.f. direction-finder aerial from the point of view of minimizing errors due to the surroundings. With the aerial in such a position the site errors were still by no means negligible: they were fairly small and varied with frequency, and with different relative bearings, in some simple way up to about 2 Mc/s. They then reached 30°, or more on some frequencies, and varied in an increasingly erratic manner as the frequency was increased. At the higher frequencies the errors become if anything a little smaller than on the lower ones, but the number of maxima and minima in the variations with the direction round the ship increases. In some circumstances more than one true bearing will give the same d.f. bearing. Fig. 7 shows a typical destroyer as fitted in 1937 with the h.f. direction-finder aerial at the foremast head, together with the curves of corrections found necessary for the frequencies 2·5 Mc/s, 6·0 Mc/s and 13·0 Mc/s. In Fig. 8 is shown a destroyer with the aerial fitted in the second-best position, on the mainmast as high as practicable consistent with other requirements in the ship. The correction curves for this case on 2·41 Mc/s, 9·39 Mc/s and 11·6 Mc/s are also shown. The degradation in performance as compared with that for the aerial in the foremast position is apparent. At this stage of development shipborne h.f. direction-finding was relatively poor, and to a large extent the results were unpredictable even under the best siting conditions. It had not been thought worth while to attempt sense-finding. It was clear that a better understanding was needed of the magnitude of errors that could be caused by typical parts of the ship such as a mast, a funnel, the ship's communication aerials, and the hull of the ship. This was all the more necessary and all the more urgent with the growing
importance of radar which claimed the best sites

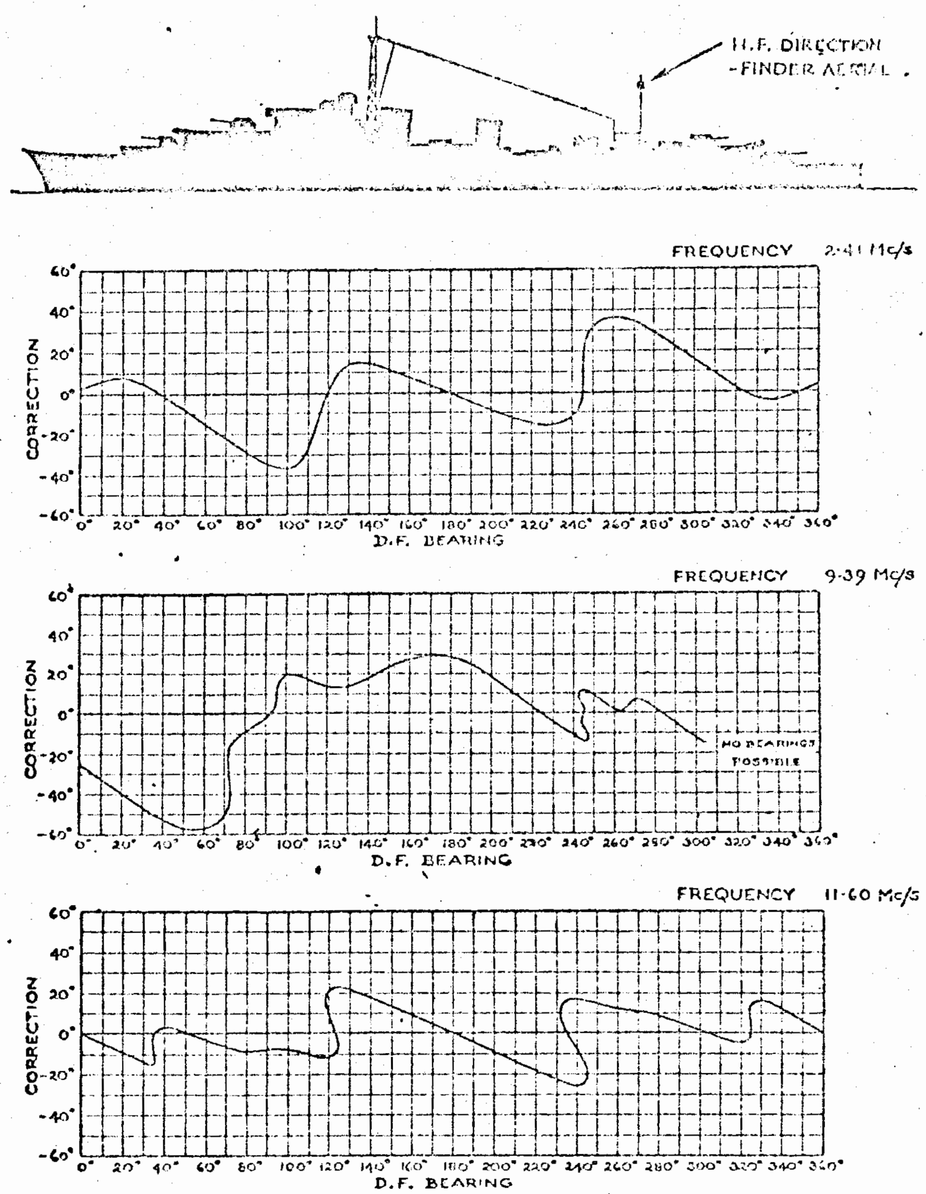


**Fig. 8.**—Site aft for h.f. direction-finder aerial in a destroyer, and corrections needed.

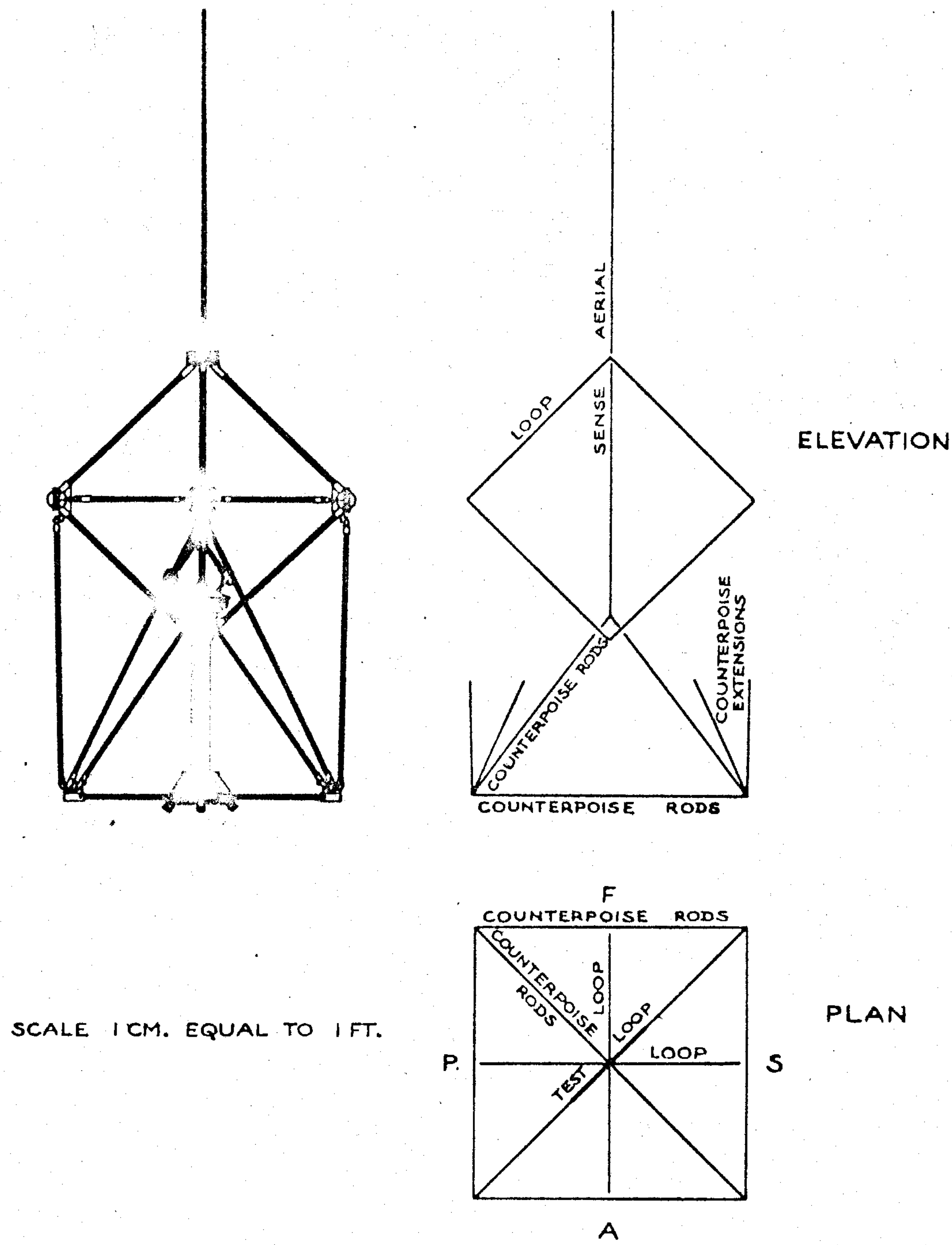


FIG. 18. CONSTRUCTIONAL DETAILS OF STANDARD H/F D/F AERIAL FOR SHIPS

The aerial is therefore usually sited on a mast which is at least 30 ft high. For reasons of performance and mechanical convenience a fixed crossed aerial of screened Bellini-Tosi type was used. Extreme precautions were necessary to avoid:-

a. Induction of unwanted emf's from the magnetic field of currents induced by the incident radiation in the supporting mast. The aerial must be symmetrical about the mast supporting it and about any metallic structure running through the aerial system and extending above it, eg the sense aerial. If the latter is displaced 2 in. from the axis errors of $30^\circ$ on some frequencies would result. The limbs of the df aerial are of course electrostatically screened.

b. Unbalance in the two members of the aerial and feeder system, the length of the latter being up to 130 ft. To achieve this the feeder cable's characteristic impedance and propagation co-efficient must be specified to closer tolerances than normal; and the direct pick-up by the feeders must be small ie solid screening.

c. The induction of unwanted emf's in the loop from the electrostatic field existing at the top of the supporting mast.

d. Transfer of unwanted emf by electrostatic coupling in the balanced hf transformers.

To obtain sense a non-directional vertical aerial is needed in the usual way for collecting the comparison emf. This aerial must be mounted on the central axis of the df aerial system. At the resonant frequencies of the support mast the secondary field can induce emf's in the sense aerial whose magnitude is many times that due to the incident field; sense finding is then obviously impossible. Struszynski pointed out that in the sense aerial of Fig 16 the mast voltage is applied in a capacitive bridge circuit consisting of the capacitances of the two members of the dipole to the mast and to ground. The counterpoise size and the size of the sense aerial are made such that the bridge can be balanced by the provision of a small adjustable capacitance from the lower member of the sense dipole, the counterpoise, to the mast. So the resultant current through the coupling coil joining the two arms of the sense dipole is small; a remarkable achievement.

The sensitivity was adequate for the operational requirements. Taking the minimum sensitivity as 50 microv./metre at 3 MHz and 7 at 20 MHz for a 10 dB signal/noise ratio, the powers which must be radiated to develop these fields at 50 miles over the sea are 0.3 and 0.5 watt respectively from a vertical dipole. With care in calibration of the pick-up factor over the frequency range it was found possible to make excellent estimates of the distance away of the radiating German submarine. The first sets were fitted in 1941: the ASWE file ref is FI/DIR, and FS/Nutbourne for sidelights on early work (1932).

This solution of the very difficult problem of 'huff-duff' on ships was one of ASE's more important tasks both before and during the last war.
Mr C E Horton, head of the DF section until Nov '37, believed Britain was ahead of any other country in df at the outbreak of the war, and this was confirmed by German admissions after the war that their work on df before 1939 was inadequate, and that they had experienced difficulties in locating the positions of their U-boats during the war.

> "It was not the result of a single invention by an individual but was the final outcome of the tenacity of a few individuals working at a time when resources were hard to come by and the scientist a lowly personage in the hierarchy. The technical problems on shore and even more on shipboard were formidable. This was where the real difficulty lay, not in appreciating the operational value of the thing when done . . . Progress was really conditioned by the rate of solution of technical problems."

Shore sets could operate from one hundred to three thousand miles. In 1940 Prof P M S Blackett suggested that hf df sited on the coast should be used to locate U-boat positions. Shore based stations were built to cover the Western Approaches.

The fundamental problems of hf df on board ship having been solved for the aural-null method, work started early in 1941 on visual presentation of bearings on a cathode-ray tube, to facilitate rapid reading and interpretation of bearings by unskilled operators. The first experimental equipment using a twin channel receiver developed in 1940 by the Plessey Co was fitted on HMS Culver in Oct '41. In 1942 a number of installations after the prototype were already in service use. By 1943 the improved equipment became the standard naval shipborne direction finder FH4(37). Its great value was that it showed the scale of attack and the bearings of the U-boats. The escort vessels could then dispose themselves to the best advantage before the U-boats began to attack(38). It was adopted for shore-station use with an Adcock aerial system.

Mr Crampton finally remarks:-

> "There were many examples of the use of FH3/4 for navigational, rendezvous, homing of aircraft to carriers and tactical purposes, particularly the latter, in all classes of escort vessels during the Battle of the Atlantic and on northern convoy routes. Its importance was equal to that of radar in these particular applications, and it is interesting to note that because of this it was able to reclaim the best site, at the top of the tallest mast, in certain classes of vessel. One instance of its use worth recalling was that made in bringing ships of the Home Fleet into position for attacking and destroying the German battle-cruiser Scharnhorst in December 1943."

A further programme was the development of vhf-df(37) for fitting in aircraft carriers, where it proved extremely valuable for the navigation and safety of aircraft, particularly in the Pacific theatre.

(38) Guy Hartcup, 'The Challenge of War' David & Charles 1970, p 67.