SECRET

NAVAL SHIPBORNE RADAR

NOTES FOR EXECUTIVE OFFICERS

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MARCH 1946

PREFACE

The notes in this pamphlet are intended to supplement the user and executive officers courses in radar given in HMS COLLINGWOOD. They do not cover the whole field of Naval Radar, the principal omissions being IFF and interrogators, and airborne radar. The present system of IFF has little military value today and is under review. Airborne Radar is not dealt with in HMS COLLINGWOOD.

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Chapter I

HISTORICAL INTRODUCTION TO NAVAL RADAR

1 Radar was the outcome of researches carried out since the year 1924 on reflections of radio waves from the ionosphere.

2 It had long been appreciated that objects in the path of a radio beam reflected back a little of the energy and as early as 1922 Marconi forecast the radiolocation of ships. The first practical sets for military use were the "Chain Home" stations erected just before the war by the RAF on the east coast.

3 The first naval sets were fitted in 1938 in Rodney and Sheffield for the detection of aircraft. These were the first type 79 airguard and many of them in almost their original form are in the fleet today having given reliable and valuable service all through the war.

4 For a time, this was the only type of set fitted in ships and it was consequently made to perform a variety of functions later performed by separate sets. Early in the war, design was started on a set for range-finding purposes with guns and it was at the same time realised that the 79 as an airguard set had many inherent dis-advantages and needed replacement by a more suitable design.

5 Development then proceeded along functional lines; the air-guard type 281 was in time added to the fleet, but never completely replaced 79 which was found to give superior performance against high flying aircraft. Both sets are now rendered obsolescent by the introduction of 960, fitting of which is commencing with Vanguard.

6 Gunnery sets began with the 282/5 series operating on the then very short wavelength of half a metre. These sets were continually improved but were never more than emergency sets awaiting the development of the very much better 274, 275 series. Though these latter sets have now gone into production, fitting has only proceeded very slowly. A number of 274 main armament sets were fitted in BPF ships and proved very satisfactory.

7 The development of surface warning equipment began with the fortunate invention in about 1940 of the resonant cavity magnetron valve. This, enabling radar wavelengths to be reduced to a few centimetres, made possible the detection of surface objects. Without the use of such short wavelengths long range surface detection would have remained impossible. The first surface warning sets, the 271/2/3 series were fitted in Western Approaches escort vessels and proved so valuable that their use was extended to all ships. These sets underwent two major modifications during the war both centring round an improved magnetron transmitter valve. The series is at present represented by 277 and 293. Because of its superior surface performance and ability to produce a narrow beam, the use of the magnetron was extended to gunnery sets and all modern gunnery sets (274, 275, 262, 931 etc.) use centimetre wavelengths.

8 As an interim measure small ships were fitted in 1940 with an aircraft radar ASV modified for use with a simple masthead aerial. A descendant of this set, type 291, is still fitted to most small ships and gives a moderate amount of combined air and surface cover. The set was also used successfully by submarines.

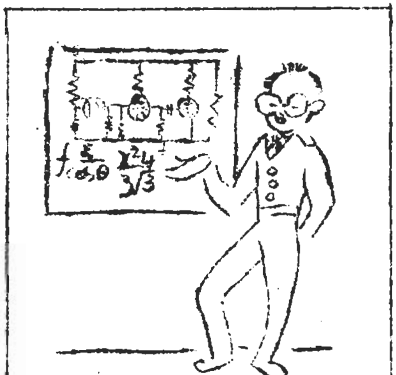
9 Recent additions to the naval series include a spotting set, Type 931, for use with main armament set Type 274, and an auto follow set type 262 for use with close range weapons.

10 Naval radar is grouped and named as follows:

AIRGUARD - Air warning radar (e.g. 79, 281 and 291 in destroyers).
SEAGUARD - Surface warning radar (e.g. 277).
POINTER - Target indication radar (e.g. 293).
RANGER - Gunnery radar (e.g. 285, 274).

Chapter II

PRINCIPLES OF RADAR - HOW IT WORKS



"Radar - How It Works."

1 This description is confined to pulse modulated radar only, as this system is exclusively employed in naval equipment.

2 When a radio wave strikes an object (any object, whether conductor or non-conductor) a little of the radio energy is reflected back, just as an object in the path of a light ray will reflect back a little light.

3 If therefore a radio transmitter T sends a signal such that it is received at B a little of the energy will be reflected back and will eventually reach T where it can be detected on a radio receiver. As radio waves travel at a known and finite speed it is only necessary to measure the time interval between the transmission of the original signal and the reception of the reflected signal, in order to calculate the distance between transmitter and the reflecting object.

4 Were transmission from the station to be continuous the received echo would also be continuous and in the absence of special modulation there would be no means of identifying the respective waves

and therefore no way of measuring the reflection time. An early system of radar adopted this method using frequency modulation of the signal but this system is not used in naval radar and will not be referred to again.

5 The method used of identifying the outgoing and the reflected signals is to transmit a brief pulse of energy, so short that the transmitter has stopped sending by the time the reflected signal is received. Both the transmitted pulse and the reflected (which will have the same characteristics of duration and wavelength as the original) will in practice be received on the same receiver and a display device incorporated at its output to measure the time interval between them and convert it into distance.

6 . The simple Radar set consists therefore of the following essential units:-

(a) Transmitter (including the modulator)
(b) Receiver
(c) Display Panel.

and is required to yield three items of information in order to determine the position of an object, namely, range, bearing and height. Of these range and bearing can be found with considerable accuracy. Height presents a greater problem.

RANGE

7 Range is obtained by simply measuring the time interval between the two pulses, the outgoing and the reflected. It is measured along the time base of a cathode ray tube.

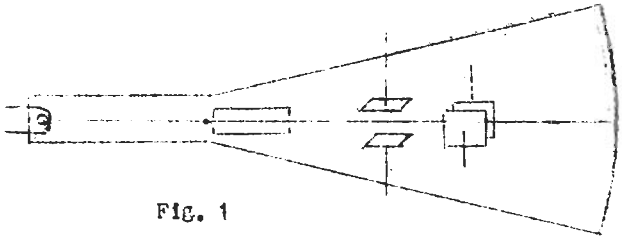


Fig. 1

8 A cathode ray tube consists of a hollow conical glass tube which has an electron producing gun at the narrow end. Electrons are projected in a fine beam to the wide end of the tube where they strike a chemical surface which glows under their impact. The beam is focussed to be as fine as possible and when it is at rest the tube face (the screen) shows a fine bright spot.

9 This electron beam consists of negative particles of electricity and can therefore be deflected by a magnet or electric field. It is so light as to be virtually inertialess and moves freely under the influence of magnetic or electric fields with no time delay. When used as a radar indicator this beam is swept rapidly across the face of the tube thus causing a line of glow. The signals received by the receiver are caused to make the beam move in a plane at right angles to this line. The two signals therefore cause the spot to trace a path as in figure 2. In practice the trace is set in motion (or fired) at the instant the outgoing pulse leaves the transmitter and the process repeated rapidly, many times a second. The larger pulse is called the ground wave and the smaller the echo.

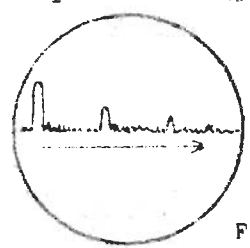


Fig. 2

10 It would not be possible to measure the time interval between a single pulse and echo and the measurement is only possible by a rapid repetition which by persistance of vision gives the impression of a constant picture. It is in fact a succession of pictures repeating, according to the set, from 50 to 500 a second.

11 The transmitter thus transmits a series of radio pulses with each of which the display trace is synchronised.

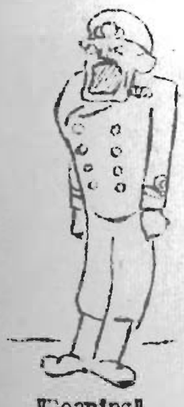
12 The time interval between the pulses must be such that the echoes from wanted targets are received and displayed before the next pulse is fired otherwise confusion will result. A pulse repetition rate of 500 a second gives a time interval between successive pulses of $\frac{1}{500}$ of a second or 2,000 microseconds. Radio waves travel at 162,000 miles (nautical) per second so that they can travel $\frac{162,000}{500}$ = 324 miles between two pulses and allowing for the fact that the signal has to make the return journey, this means that theoretically echoes from targets no more than 162 miles away can be received on a set with at PRR of 500 per second.

13 This point is of such importance that airguard sets have to be built with a comparatively slow PRR to give them the required range.

14 This display is called an "A" display and is the earliest and simplest form.

15 In order to measure the time between the two pulses a calibrator based on an oscillating crystal or resonant circuit is added to the set. A crystal cut to oscillate at 163,800 cycles per second makes a complete oscillation in 6·1 microseconds which is the travel time for the echo from a target distant one thousand yards. If therefore these oscillations are converted to an electric signal and imposed on the tube face on the same time base as the echoes there will be one complete oscillation per thousand yards thus enabling the range between the echoes to be easily measured. In practice the oscillations are not presented in their sine wave form but are distorted to give the familiar narrow pips.

16 Refinements are many but this is basically the radar display.



"Bearing"

BEARING

17 An all round transmitter will give no indication of a target's bearing and it is necessary to concentrate the transmission into a beam in order that it may be rotated to give a position of maximum echo signal. The narrower the beam the more accurate will be the bearing indication, but equally the greater the chance of missing the target.

18 Where bearings, accurate to a fraction of a degree are required as in gunnery radar, the device of beam switching is employed.

Fig. 3

"Beam-Switching"

19 Figure 3 shows a radar station A which transmits a narrowly beamed signal towards a target T. If the beam is swung rapidly from left to right pausing in the extreme positions, it will give an echo in each of these positions. As most of the signal energy is concentrated in the centre of the beam, the echo will vary in size according to its position in the beam. Only when the beam is switched symmetrically about the target will the echoes from the two beam positions be the same. The two echoes are presented on the display, side by side, and the aerial is simply rotated until both echoes are the same size. It is possible to get a bearing accuracy of 3 minutes with this system.

HEIGHT

20 There are two methods of measuring target height namely:-

(a) Elevating the beam until it is pointing at the target. Beam switching may be used to ensure great accuracy as in 262 or 275 or reliance may be placed on the position of maximum signal as in 277. This method will not indicate the height of a land or ship echo but only an aircraft or other detached object.

(b) Estimation from the vertical coverage diagram. This will be referred to later and is the method employed with air-guard sets. It is not accurate.

TYPES OF DISPLAY

21 "A" Display

This, as described above consists of a single trace (generally horizontal); the ground wave and echoes causing a deflection of the trace in the form shown in figure 4. A calibration trace has been also shown. This display is very valuable to the technical staff as it is from this that a trained person can deduce most information about the target. As it is the only form of trace in which the amplitude of the echo is directly visible it is also used in tuning the receiver.

Fig. 4

22 PPI

The Plan Position Indicator has a radial time base which is rotated in step with the aerials. The spot moves radially from the centre and covers the whole tube face as the aerial rotates. The effect of a signal is to cause the display to glow brightly thus indicating the presence of a target by a bright spot on the screen.

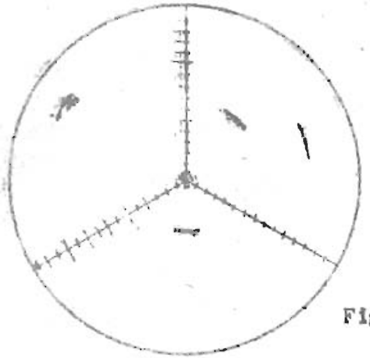


Fig. 5

Range is measured radially from the centre and bearing from a bearing scale round the screen edge. This display presents an all round picture and the screen is such that it continues to glow for several seconds after the trace has passed, thus enabling the whole picture to be visible at once. It is particularly valuable for comparing land echoes with a chart as the land echoes will form a picture that bears some relation to or may even resemble the land's true outline.

SECTOR SELECTOR

"Sector Selector Display"

23 When the aerial is continuously rotating it is sometimes desired to examine the echoes on a particular bearing. This can be achieved by a "sector selector display" which shows on a class "A" display, the echoes appearing on a sector determined by rotating a bearing dial. Each time the aerial sweeps through the target sector, the picture is flashed upon the screen. On other Sectors, the picture is suppressed. The tube has a long after glow so that the picture remains visible for some seconds.

'B' DISPLAY

24 This display has horizontal ordinates of bearing and vertical ordinates of range and gives a picture rather like a section of PPI except that the bearing is read from parallel and not radial scale marks. It is a distorted picture

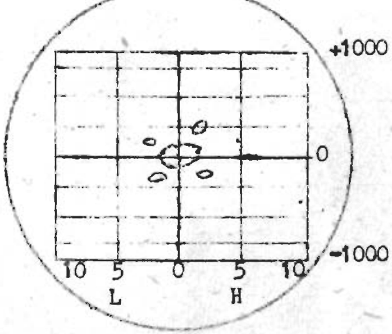


Fig. 6

in which the lower half of the picture is on a greater scale than the upper. It is used in "spotting" sets where the aerial sweeps through a sector only. It presents the target in the centre of the screen and a plan picture of the surrounding sea whereon shell splash echoes are easily seen.

Chapter III

EFFECT OF VARIOUS FACTORS ON RADAR PERFORMANCE

WAVELENGTH

"Wavelength"

1 "Frequency" of oscillation and "wavelength" are related in such a way that their product is always the same. Thus increasing frequency means that wavelength diminishes and vice versa.

2 The choice of wavelength for a radar set designed for a particular function, is of fundamental importance. The main effects are as follows:-