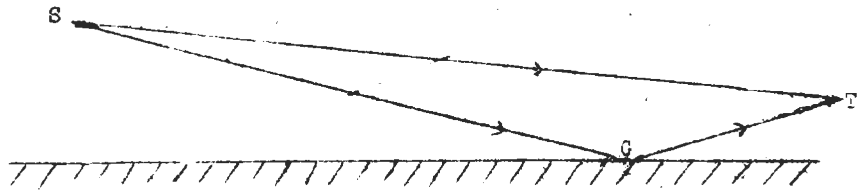
(a) DETECTION OF OBJECTS ON THE SURFACE

Fig. 7

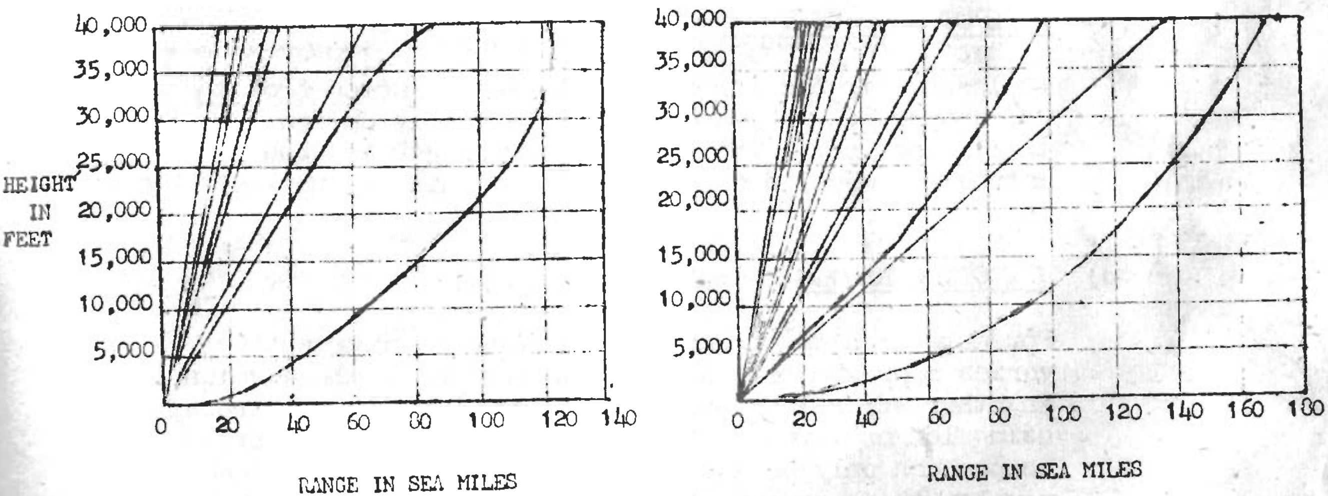


Consider the effect of a station S emitting short waves which are received at T. The waves travel by two paths "S-T" and "S-G-T", - the latter being reflected from the ground. Where S and T are near to ground level, the two signals tend to cancel out as the lower ray on reflection undergoes a phase change of half a wave-length. Thus if the difference in the two paths is small in terms of a wave-length, the two waves tend to destroy each other.

The principal effect of this is that at metre wavelengths it is impossible to obtain a long range echo from a target near the surface. At centimetre wavelengths, this is not the case and no difficulty exists in obtaining echoes from targets close to or on the surface as far as the horizon. Thus centimetre wavelengths are essential for radar designed for surface detection.

THE VERTICAL COVERAGE DIAGRAM

Airguard radar is however compelled for various reasons to use a wavelength of several metres and thus such a set will not detect objects on the surface. The areas where no signals are received are indicated by the set's vertical coverage diagram a typical example of which is shown in Figure 8 in which comparative diagrams for 79 and 281 are shown together.



Type 79 VCD

Fig. 8

Type 281 VCD

The hatched areas indicate where aircraft will produce echoes and the unhatched where they will not. It will be observed too, that the VCD of the set with the longer wavelength (79) is much more elevated than that of 281.

As an aircraft approaches, its echo amplitude will vary from a maximum near the centre of the lobe to a complete fade between the lobes. A study of this fluctuation can give information about the target's height.

(b) REFLECTION FROM THE IONOSPHERE

It is undesirable for signals to be reflected from the ionosphere and the wavelength is normally chosen so that this is not so. The critical wavelength is about 11 metres and wavelengths greater than this are not suitable for radar.

(c) DETECTION RANGES

For detection of aircraft maximum range of detection varies approximately as the square root of the wavelength. In other words less power is required to detect aircraft using longer waves. But small objects such as periscopes can only be detected by centimetre waves whose wavelength is comparable to the size of the target.

(d) ABSORPTION BY THE ATMOSPHERE

"Absorption by the Atmosphere"

The radio energy is more rapidly absorbed and dissipated by the water vapour etc. in the atmosphere if the wavelength is short. Hence longer wavelengths are used with long range air warning sets.

(e) REFRACTION

Certain atmosphere conditions will cause a bending of the transmission path. This is most noticeable with centimetre waves and during conditions of super-refraction enable such sets to detect targets beyond the horizon. In effect this increases the range of the set while such conditions last.

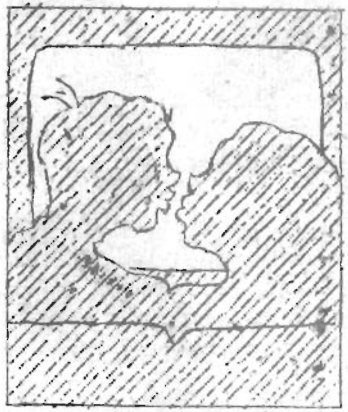
Similarly conditions of infra-refraction (during fog) may cause the opposite effect and reduce ranges.

"Beam Width"

(f) BEAM WIDTH

It is easier to focus the shorter wavelengths into a narrow beam and thus concentrate the energy where it is required and enable the set better to discriminate between targets close together in bearing. See below (para. 6).

(g) PULSE LENGTH



"The duration of the pulse length has an Important effect on the Space that each echo occupies on the Screen"

The duration of the pulse has an important effect on the space that each echo occupies on the screen. As explained in Chapter 2 above the use of pulses enables the transmitted signal to be completed before the echo signal is returned. If the pulse is too long, it means that echoes from near targets will not be distinguishable. Similarly, if targets are close together the target echoes will merge. An Aim of designers therefore is to reduce the pulse length as much as possible. As however maximum detection range roughly depends on the mean power of the pulse long range airguard sets will continue to use long pulses at the expense of discrimination. Shortening of pulse length is easier with a shorter wavelength and consequently range discrimination is usually better at these wavelengths. A typical pulse length is that of the 277 which gives an echo occupying about 300 yards of the display for each target. Echoes closer than this will merge.

AERIAL HEIGHT

3 With centimetric sets the normal limit of detection is the horizon as the beam, like light, will travel in a straight line unless it is reflected or refracted. Hence a higher aerial means a longer horizon and a greater detection range.

4 Similarly, with metre sets, such as those for air warning, a high aerial causes more of the energy to travel close to the surface of the earth. This increases the ability of the set to detect low flying aircraft or surface objects.

5 The importance of a high aerial may be reduced during conditions of anomalous propagation when the radar beam may be bent round the surface of the earth and so detect objects beyond the horizon. If the refracting layer is low, it is possible for the aerial to be too high to take advantage of it.

AERIAL SIZE

6 The unit of an aerial array is a dipole of length half a wave-length. A simple dipole is insufficiently directional for radar purposes and it is usual to use a multiple array of dipoles and reflectors to concentrate the energy into a beam. For centimetric waves, the beam is concentrated and focussed by a metal parabolic reflector with a dipole (or waveguide aperture) at its focus. The ratio of the total

width of the array to the wavelength determines the width of the beam: the greater the ratio the narrower the beam.

7 Thus in practice, it is only possible to produce a very narrow beam at centimetric wavelengths owing to the need to keep aerial height and size to a minimum.

8 Another effect of concentrating the beam is that all the available energy tends to be directed to the target and not wasted. This economizes transmitter power and also increases the range of detection of small objects within horizon range.

PULSE REPETITION RATE

9 It is necessary to send out a rapid succession of pulses so that the echoes may be continuously observed. If they occur in too rapid succession, there will not be time for an echo from a long range target to be received before the next pulse is transmitted.

10 In practice, the normal rate is 500 per second. A lower rate is used for Airguard sets because of the longer ranges involved.

SPEED OF SWEEP

"Speed of Sweep"

11 A slow speed of sweep detracts from constant all round warning but it is possible for the speed of sweep to be so great that sectors are missed between successive pulses. Thus if the beam width of the set is less than the angular distance swept by the beam between two pulses, the aerial is sweeping too fast. A rapid sweep also causes "spoking" on PPI displays and incomplete echo paints, which is a nuisance and leads to bad tracking. This limits the speed of sweep with old airguard sets where PRR is 50.

12 Again, in practice it is found that a target at sea at nearly maximum range will not reflect an echo from every pulse owing to the motion of the vessels in the waves and optimum detection conditions require a slow sweep. Trials have shown however that no appreciable loss of performance results if the speed of sweep is greater than this optimum. The faster sweep means that the target is swept more often and this compensates for the fact that during some sweeps, no echo will be returned.

In practice with a pulse repetition rate of 500 a speed of 10-15 rpm is satisfactory and for 50 a speed of 2 or 4 rpm.

TRANSMITTER POWER

13 An increase in transmitter power effects an increase in either size of echo or detection range. To double to size of an echo it is necessary to increase transmitter power four times. To double the detection range the power multiplying factor is 16 for aircraft and 256 for surface targets: in the latter case within the limits of the "optical horizon".

Chapter IV

LIMITATIONS ON PERFORMANCE

14 Certain limitations to radar performance exist and the aim of development and design is to overcome them as much as possible. A knowledge of the chief of them will help to an understanding of the difficulties of designers and the possibilities of improvement in future sets.

RANGE

15 Some of the factors affecting range have already been discussed, namely aerial height, transmitter power and aerial size. Increasing any of these will, up to a point, increase range of detection.

16 The limit of detection is reached when the radiation from the aerial is unable to reach the target. Thus if the target is below the horizon an increase in aerial power will not enable it to be detected. The only method then of extending range is to raise the aerial.

17 If, however the target is very small but within horizon range an increase of power may enable it to be detected.

18 Conditions of anomalous propagation may increase ranges while they exist.

19 The accuracy of measurement of range is set by the human factor in using the apparatus. In practice an error of 15 yards should not be exceeded when using proper ranging equipment.

BEARING

20 The echo from a target which subtends an angle small in relation to the beam width will occupy an arc on the display equal to the beam width of the set. With warning sets, the bearing of the echo is measured by bracketing and with small beam widths an accuracy of one or two degrees is easily achieved. To improve this it is necessary to reduce the width of the beam and this involves an increase in aerial size or a reduction of wavelength.

21 Where extreme accuracy is required as in gunnery radar beam switching (see Chapter II para. 18 above) is employed. This, with modern sets as 274 and 275 will give an accuracy of about 3-10 mins. This method is not suitable for warning sets as it requires the aerial to be stopped, nor will it operate with land echoes as it requires a detached target.

HEIGHT

22 This is the dimension radar at sea finds difficult to measure.

With airguard sets it can be estimated by plotting the height of the echo as the target approaches the ship and comparing it with a vertical coverage diagram for the set in question. The method may produce a height accurate to within 1000 feet but it requires much skill and experience to achieve acceptable results.

23 The better way is to elevate a narrow beam on to the target and measure the angle of sight. If at the same time vertical beam switching and at least two-plane stabilization are employed an accuracy of a few minutes of arc can be achieved. This method is used in some gunnery sets intended to operate against aircraft.

DISCRIMINATION

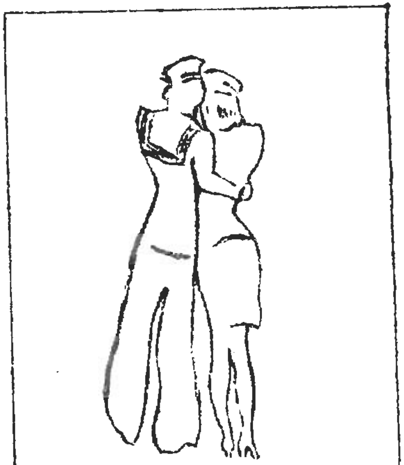

"Discrimination"

24 In this connection, discrimination means:

(a) The ability to distinguish targets which are close together.

(b) The ability to distinguish wanted from unwanted echoes.

A. TARGETS CLOSE TOGETHER



"Targets close together"

25 When the pulse length is so great that the echo from the farther of two targets is received before the whole of the echo from the nearer, the echoes merge and cannot be distinguished. It is then necessary to reduce the pulse length and most warning sets incorporate a switch to enable this to be done. This as a rule reduces the transmitter mean power and thus the range of the set and is only used when necessary. Pulse lengths of gunnery sets are purposely made very small, if necessary at the expense of range.

26 In the same way beam width sets the limit to ability to distinguish between echoes from targets at the same range but close together in bearing. It is not normally possible to differentiate between targets that are so close together that the radar beam strikes them both simultaneously.

27 Thus an aim of designers is to reduce both pulse length and beam width and this is most easily achieved at short wavelengths. The 10 centimetre sets have on average a beam width of 4° and a pulse length of 300 yards. This cannot be substantially improved without drawbacks, which are acceptable in the case of some gunnery sets but not warning sets.

28 Reduction of the wavelength to 3 or $1\frac{1}{2}$ centimeters as in 268 and 931 respectively enables both these factors to be improved, and the display picture on both these sets is much sharper than with others. This is particularly valuable when comparing land echoes with a chart. Every improvement in beam width or pulse length makes the PPI picture approximate more and more to that of the chart.

29 The practical limits are likely to be reached with a pulse length of 75 yards and a beam width of 1°.

B. WANTED AND UNWANTED ECHOES

WAVE ECHOES

30 During rough weather, large waves produce echoes which blot out the first few thousand yards of the display, and obscure echoes from small targets such as periscopes. Warning sets are fitted with a device - Swept Gain unit - which reduces the gain of the receiver while wave echoes are being received and enables small target echoes to be more easily distinguished. Care is required in adjusting this control as it is easy to wipe out target as well as wave echoes.

LAND ECHOES

31 Echoes of aircraft flying over land will be confused on the display with the land echoes and difficult to distinguish. It is technically possible to separate "moving" from "stationary" echoes by employing doppler effects but no such apparatus has yet been fitted to naval radar. This is a line of development which might be expected to influence future sets.

Chapter V

RADAR IN CURRENT USE

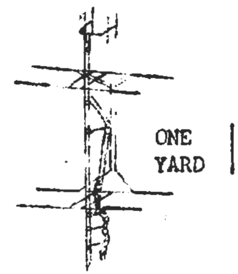
The principal naval sets are as follows

AIRGUARD

279	- Double mast aerials	obsolescent
79B	- Single mast aerials	
281	- Double mast aerials	obsolescent
281B	- Single mast aerials	
281BQ	- Single mast aerials, all round rotation	
960		

1 TYPE 79 as modified is the survivor of the navy's first Radar set. It is reliable and gives excellent high cover but these advantages are outweighed by the following disadvantages:

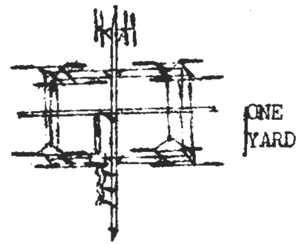
(a) Poor low cover.
(b) Wide beam width making set useless for use with PPI.
(c) Wavelength 7·5 metres is not in a band allocated for future naval use.



WA TYPE 79

No more sets of this type are being fitted and those already in ships will be removed and replaced by 960 as ships come in for refitting.

2 281 and its varieties is at present fitted in the large majority of cruisers, battleships and carriers. Its wavelength is 3·5 metres, this having been chosen as the best compromise between the factors mentioned in chapter 3. Provided the target aircraft is not low it gives long range warning out to about 80-100 miles. Its low cover is not good as a result of its fairly long wavelength. A choice of a shorter wavelength would result in maximum ranges of detection being less and this defect is partly met by the use of the seaguard set 277 in conjunction with it.



WA TYPE 281