It had always been the aim to go to shorter and shorter wavelengths so as to be able to produce sharper and sharper beams, as much like a searchlight as possible, from a practical size of aperture. This would much reduce the problem of the inverse-eighth-power law at metre waves "under the lobe", as seen in Fig 3 opposite Page 147, which was the cause of short ranges on ships compared with aircraft. For the vital war against the submarine in the Battle of the Atlantic centimetre waves were clearly necessary.

It was mentioned above that SS in 1936 was experimenting on 23 cm but with CW from a split-anode magnetron, for use at short ranges for signalling and station keeping. As Dr A B Wood recalls:

> "In mid-37 the theory of the magnetron was rather obscure but Megaw's work" (referred to on p 122) "indicated that the higher the frequency the smaller must be the diameter of the cylindrical split-anode surrounding the hot cathode. Even at a high efficiency this implied that a single magnetron oscillator for cm waves could not handle much power without overheating. (In the case of IR radiation from funnels billions of EM oscillators are involved!) So it seemed an obvious step to make a magnetron into a multiple oscillator also. I sketched out two such systems. In one, concentric corrugated cylinders formed an annular ring of small interconnected split-anode cylinders, each having its own heated cathode. In another I planned a cylindrical annular block having 6 or 8 small cylindrical holes, each with a slit leading into the central cavity containing a common central cathode. The whole of the 'multiple magnetron' was to be enclosed in an evacuated glass envelope. When I showed these sketches to Shearing he seemed very dubious, and said Hughes' valve laboratory was too busy making large silica valves for the fleet." (and also for Bawdsey of course.)

The second suggested design was a remarkable anticipation of the eventual cavity magnetron produced at Birmingham University by Randall and Boot in mid-40. This fact is not generally known: the author joined Dr Wood in July '37 and 'went back to Hertz' trying spark excitation of large transmission-line cavities with some success. Dr Wood left in Oct '37 to be Chief Scientist of HM Mining School in "Vernon".

It was not until the autumn of 1939 that Prof Oliphant at Birmingham and other leading physicists at Oxford and Bristol were asked to solve the fundamental valve problems: "give us many watts on few centimetres". Electrical firms were brought in including GEC (already well launched by DSR in 1938 on radar valve development with the 'micropup', which enabled the 1½ metre Air Interception sets in night fighters to work effectively), STC, BTH and EMI. The work was co-ordinated by the inter-service committee for Co-ordination of Valve Development (CVD) under DSR Admiralty, in fact presided over by Brundrett and operating via 7 sub-committees.

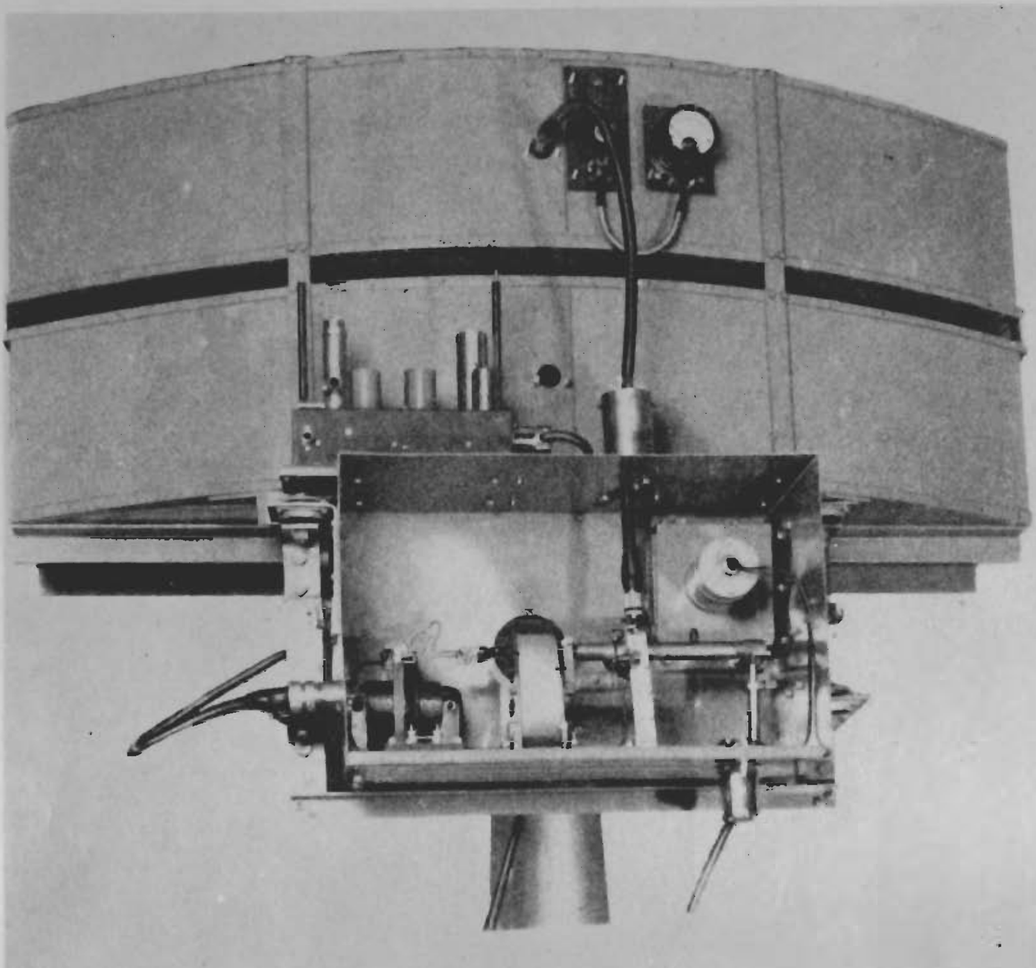

Figure 7. Type 271 transmitter

Figure 10. Type 282 aerial

Brilliant progress ensued. J T Randall and H A H Boot at Birmingham produced their successful magnetron with hole and slot cavities. The valve worked for the first time on 21.2.40 giving some 500 watts of cw power on 9.8 cm, and more than a kilowatt pulsed. The GEC (Megaw, Willshaw) designed a production model, the first being produced in July 1940 as the E1189. It was soon found that the old cat's whisker and crystal gave better results than the valves in receivers. The silicon crystal with its later protective gas-switch (Dr A G Ward a Canadian at TRE Swanage), which gave the necessary protection against transmitter powers of hundreds of kilowatts, even allowing common aerial working eventually, gave a very simple receiver. In the summer of 1940 Skinner and associates at the AM Research Establishment, Swanage, erected radar sets with parabolic mirrors, with which they detected sheets of tinplate, boys on bicycles and men on foot going down "Centimetre Alley", as the path of this sharply defined beam came to be called. In Sept '40 they followed a submarine out to 7 miles, and even detected the periscope and conning tower of a submarine at 4 miles. A new era in radiolocation began.

At the time the problem of defeating the U-boat was very pressing, so a new group of 4 members of Signal School staff was formed under Dr S E A Landale, (A R G Owen antennas, C A Cochrance transmitter, J Croney receiver) which went to Swanage in Sept '40 for 6 weeks to take advantage of this successful research. They returned to Eastney at the end of December with a replica of the Swanage laboratory apparatus, fitted in a trailer, and began to build the set which became known as Type 271. It was decided to produce an equipment able to go to sea in a corvette which was known to roll heavily. An aerial had to be made capable of being trained on any bearing and yet the beam must not roll off the target; and be housed so that weather would not affect it because the transmitter magnetron and receiver mixer were to be put at the back of the aerial (Fig 7 opposite), rotating with it because cable feeders would have had too much attenuation. The whole structure was mounted on the roof of the office and over it was a cylindrical 'lantern' with perspex windows (the 'greenhouse'). The 'cheese' aerials gave a narrow beam in the horizontal plane and a fan shaped beam in the vertical plane.* The set was ready by February 1941. Capt Willett decided on his own initiative to accept the risk that trials might prove unsatisfactory. He ordered components for 150 sets a fortnight before the trials by HMS Orchis in the Clyde could begin. A number of sets (25) had been planned to be made at Eastney, with the help of Allan West of Brighton, as soon as essential modifications had been indicated by preliminary trials, but on phoning D A/S Warfare during a meeting

*Ref 40g Radar Convention p 45; O. Kühn 'Cheese Aerials' of production representatives, the Captain was told that 150 sets would be required. To save development time and make use of an existing supply the indicator unit for ASV Mark 2 was adapted to the 271.

In spite of the low power of the magnetron, about 7 kW, a small submarine running on the surface could be seen to 5000 yds and a destroyer to 12000. Even so small an object as the submarine's periscope, when the boat was submerged, could be picked up at 1300 yds.* Such a degree of sensitivity was quite new in naval radar.

By July, only 5 months after the first experimental model was finished, 25 corvettes had been fitted; at the end of the year 100 sets had been made and 50 ships fitted.

The Commanding Officer of "Orchis", after 2 months experience at sea, wrote "after being in a ship fitted with Type 271, night navigation in one without will seem a perilous business." In the middle of the Atlantic there was then a gap of 1500 miles in the air protection of convoys, and in this region the 271 was of particular value.

An outstanding feature of the CVD organisation, Brundrett quotes, was that the GEC worked out a method of pre-production by which small quantities of new valves could be produced by relatively unskilled workers while the problems of mass-production were being overcome. In these crash programmes there was often more difficulty in arranging to make the sets than the valves. Manufacturers found it very difficult to give up mass production in order to make the 200 or so sets "off", which were often so effective in helping "to finish the job".

The first U-boat kill with the aid of Type 271 was on 14.4.42 and the ship HMS 'Vetch'.

Other types of warships began to be fitted with cm radar; the Prince of Wales which had had an early 284 had a 271 by Aug '41. In the bigger ships, because less rolling was likely, full parabolic ('dish') reflectors 4' 6" in diameter were used instead of the cheeses of the Corvette set. These were also housed in a lantern with perspex windows. The next move was to stabilise these mirrors.

In Sept 1941 Sayers in the Birmingham team produced the 'strapped' magnetron. By cross-connecting the poles of the slots which should have the same instantaneous polarity, the individual cavities were made to pull

*The ASE report to DSD on the Orchis trials, enclosed with a letter dated 7.5.41, was in File FI/271(1) which regretfully has not been preserved! But the existing file FI/271 preserves much of interest from Mar '71.

Figure 8. Type 273Q aerial

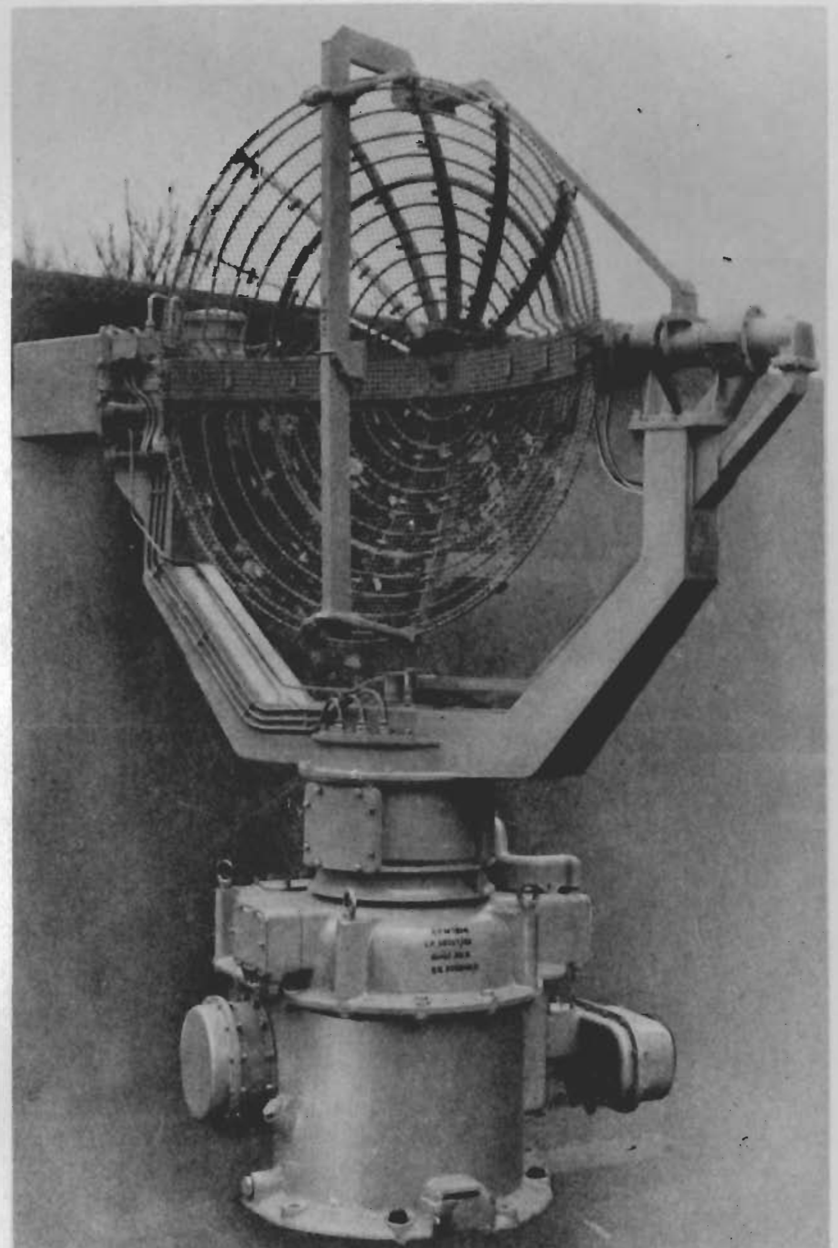

Figure 9. Type 277 aerial

together, so to speak, and not waste their efforts by giving power in a number of 'modes' with slightly different frequencies, even during a single pulse. Thus they gave one (single-note)music, not as before, but vaster; this opened the way to the 100 kW magnetron CV56 Mark 4 set, and then the 500 kW valve CV76, Mark 5 equipment. Since the power of the former was above the limit for flexible cables the next great innovation, rectangular waveguides (3 in. by 1 in. for 10 cms), arrived. The 271/3 Mark 4, so called model Q, was developed by the end of 1941 and in production in 1942. 273Q in a big ship gave 46000 yds against a Battleship, 15500 yds against a U-boat and 12-15 miles against low aircraft. At this time, 1942, the plan-position-indicator, PPI, revolutionised the display of the vast amount of information that was arriving from the volume of space scanned by the beam of the warning radar and the basis of all modern warning and fighter dirn. systems was finally achieved. Future developments to the end of the war were refinements of the techniques thus established on cm waves by 1942, and particularly the extensive use of the 3 cm wavelength band, X band, and some application of K band $1\frac{1}{4}$ cm, to give map-like displays of increasing discrimination

Cm gunnery equipments In 1941 the cm wavelengths were envisaged for greater ranges and more accurate bearings than with the 50 cm sets, in fact adequate blind fire against aircraft as well as ships. It was not until early 1943 that a set of development panels of the surface equipment Type 274 was produced in a trailer and given trials at Eastney and at Llandudno, the Army artillery range. The wavelength was 9.1 cm and since the very high power 400 kW type of transmitter was to be used with $\frac{1}{2}$ microsecond pulse, considerable development time was involved. The modulator employed a triggered spark gap, rather than the mercury-vapour thyratron of the warning and height finding equipment Type 277, because of the short pulse length and rapid rate of rise of pulse required to enable accurate ranging to within ± 25 yds to be achieved. 14" shell splashes were visible at 34000 yds and were displayed on a spotting-tube with 1000 yds either side of the target and spotting was quantitative in range, and it was possible to tell whether the shots were to left or right of the target. The bearing accuracy was ± 3 minutes of arc on small targets, the limitation being wandering of the instantaneous effective reflection point (glint) on the larger targets, a new phenomenon in radar at these very high precisions.

In parallel with Type 274 the AA set, Type 275, was produced. Whereas 285 on 50 cm could only have the split-beam technique in azimuth, the 8.5 cm equipment, with separate transmitting and receiving dishes (nacelles) and conical scanning on the latter, provided it in both elevation and training; except below 3 degrees the elevation accuracy was about 15 minutes. However it was not until early 1945 that a Type 275 was fitted in a destroyer for trials. This set was the first in which the conical scanning technique was used. As time was insufficient to develop a conical scanning system for the very high power of 400 kW on transmission, separate aerials had to be used.

High Power Warning Radars

The development of the 500 kW equipment at Eastney in 1941/2 was among the most brilliant of the technical feats of ASE during the war in speed of achievement of so great an advance on the 'first-born of the family' the Type 271; see ref 40f on p 147. The 277 was primarily developed as a surface warning equipment, and in the first instance was used as a trailer installation for coast defence and warning of low-flying aircraft. A large cheese aerial reflector was mounted on the roof and the whole cabin was rotated to avoid a rotating waveguide joint. The latter had however to be developed for the ship and common T and R employed to enable a large dish to be used within the limitations of space and weight in the ship. The trailer equipment was adopted by TRE and the Army for shore use. A 4 ft 6 in diameter paraboloid was chosen for the ship aerial as this required a much smaller circular space in which to rotate than a 'cheese' of similar gain. The aerial was power driven, stabilised along the line of sight and rotated continuously as necessary for a smoothly painted display on the PPI, which was fitted to a naval set for the first time and overcame the difficulty of detection caused by the narrow beam of 4.5°. A photograph of the aerial is Fig 9 on the preceeding plate. The difficulty of getting the target in elevation remained at close ranges with the narrow beam of course. Hence it was necessary to use the 281 with 79 filling the vertical gaps of the former, and in 1944 the HP cm wave 293 (2.0° horizontal), to give the PPI picture, and there was an additional cursor on the PPI driven in bearing by the aerial of the 277 so that this cursor could be set on the target paint. Then the 277 operators were able to search in elevation in the knowledge that the set was trained on the right bearing. Type 277 provided warning of low-flying aircraft and filled the gap below the bottom lobe of Type 281. The radar information was thus in the form required for the Fighter Direction and this whole new operational technique was rapidly and extensively developed in consequence. In order to get a good PPI picture with the 281 this set was fitted with a slip-ring feeder system allowing continuous rotation of the aerial. Type 277 was fitted for surface warning and low air cover to escort ships and the larger ships early in 1944.

The Moves to Haslemere and Witley

Steps had been taken in late 1940 to provide evacuation plans for the headquarters of the Experimental Dept of Signal School, and by mid-1941 Lythe Hill House, Haslemere had been prepared. The 50 cm and 10 cm developments were already away from the RNB at Onslow Road, Southsea and Eastney Fort East respectively. The Dept became Admiralty Signal Establishment, Haslemere officially on 26.8.41 with the production dept at neighbouring Whitwell Hatch. The Experimental Captain became the Captain Superintendent ASE on that date (Capt B R Willett CBE DSC). It was necessary to gather the Radar groups together for better integration of the warning, gunnery, and IFF and electronic warfare (EW) programmes. This was done by the move of staff groups to King Edward's School at Witley the latter being the next station up the railway to Waterloo from Haslemere. The new radar dept organisation of Sept 1942, was a radical departure from the previous concentration of staff rather on a 'wavelength' basis necessary to secure rapid development of the related basic techniques; it consisted of three 'equipment' divisions RE1, 2, 3 and nine 'techniques' divisions (RC1-9) serving them as necessary with the Aerials, Transmitters, Receivers, Displays, Test equipment and Measurements, Servos, Mechanical Design, AJ and Research, and Theory appropriate to their systems ie Warning, Tactical and Anti-Sub RE1 (S E A Landale); Gunnery RE2 (J F Coales) and IFF, Navigation and Countermeasures RE3 (H E Hogben). See organisation chart in 'Archives 7'. Mr L H Bainbridge-Bell, one time member of Watson-Watt's original team at Slough, was head of Library, Publications and Information Services. King George VI visited Haslemere in June '42 and Witley Mar '43; photos are in 'Archives 7'. The measurements group (S J Moss) of the Radio side of ASE moved to the Cavendish Lab, Cambridge, (100 years old on 16.6.1974). Perhaps only those hallowed buildings were thought fit to house the Establishment's frequency standard.

Identification Friend or Foe. Distinction between friend or foe was initially attempted by controlling the disposition and movements of all friendly forces so that they could be 'named' when detected by our own radars. This was impossible in the air, where speed and urgent missions often made it impossible to keep radar stations fully informed. Full advantage of the early warning given by radar could not be taken if doubt existed as to the friendly or hostile nature of the echoes.

The first step towards a solution was the fitting of a transponder in friendly aircraft which enhanced the echoes. IFFs Mark 1 and 2 provided a temporary answer in aircraft but not in ships owing to its low power and mechanical shock and vibration difficulties.

When many radar frequencies were being used the only answer was to have a specific band of frequencies, A Band, and separate pulsed interrogators synchronised to the main radar pulses and the received signals displayed on the same tube as the radar echoes. The change over to this IFF Mark 3 was a very large undertaking and it was quite impossible to ensure that all stations were fitted by an agreed date, in an area such as west and central Mediterranean where the changeover coincided with a number of important operations. The situation of course gradually improved. For the full story of IFF and homing beacons (racons) see pp 20-25 'Technical Staff monographs '39-'45 - Radar' in 'Archives 13'.

D-Day: Jamming and Deception; Decca

A feature of D day was the very great use of electronic countermeasures (ECM). There had been for some years a Dover ECM chain operated by naval personnel with various types of modulation to deny range to enemy gunnery radars. This was used, with wide-band noise modulation for the first time, on D-day as part of the great combined Navy, Air Force deception exercise to make the enemy believe the landing was coming in the Calais area. Aircraft sowed a corridor of 'window' to simulate the covering of ships which weren't there, as well as concentrated window inside the corridor to simulate phantom ships. This story is well known.

In the many hundred ships of the assault force, as a result of the outstanding collaboration that existed between the UK and US in this technical field, compact jammers were installed, again with wide-band noise modulation employed for the first time, to deny the enemy range for their heavy guns. Also many craft were fitted with deception devices to produce false echoes both behind and 'ahead' in range, the latter requiring extremely stable pulse repetition frequencies to prevent unnaturally rapid 'drift' of the false echo. Jammers were also provided against the German glide bombs (HS293) and their high-altitude guided bombs.(41)

The Decca hyperbolic navigation system was first used operationally on D-day. The necessary charts had been prepared under conditions of great secrecy in one of the Nissen huts on the 'cricket-pitch' at Lythe Hill House. ASE continued to be very closely associated with the Decca Co on the rapid expansion of this unique system both geographically and technically, more particularly for impartial monitoring and assessment of its actual performance and potentialities.

(41) D D Silvester and P T W Baker, 'Radar Countermeasures' JRNSS 4 p 155 Nov 48.