Early Centimetric Ground Radars – a Personal Reminiscence

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A previous paper(1) showed that the Chain Home (CH) radar system, although based largely on Marconi technology of the 1920s, sufficed to be invaluable to the air defence of Britain in 1940. The paper also described, largely from personal recollection, how an East Coast CH station, the earliest and most elaborate of all CH stations, was organized, how it operated on a daily basis, how it was calibrated and how it was maintained. Although those recollections date from 1942–43, and are based on experience of the station at Ottercops Moss in Northumberland, they would not have been very different, except only in the intensity of air activity, from an account of a station in S.E. England in 1940, when the CH system was put to its most severe test. It passed that test, despite its deficiency in low cover and inaccuracy in measuring position and height, mainly because the enemy onslaught was generally in daylight and at a great height. Some other contributory factors are given in the previous paper.

The value of the CH system was greatly diminished, however, when in mid-September, 1940, the enemy turned to bombing by night, having evidently given up all hopes of achieving air supremacy as a prelude to an invasion. Given the rudimentary state of AI (airborne interception) radar at this time, CH was not accurate enough to direct night-fighters to within interception range: much less was it capable of directing anti-aircraft gunfire.

The Night Battle over Britain

As early as 1935, when early experiments at Bawdsey had raised hopes that the battle against the day bomber could be won, attention had been turned to the night bomber problem, because it seemed likely that if the enemy could be frustrated in his daylight attacks, he would turn to night bombing. It was Tizard(2) who, in 1936, suggested an attempt to make a radar set small enough to go in an aircraft. The first crude AI radars were installed, first in a Heyford bomber and later in an Anson: one of these sets, in September, 1937, tracked the Home Fleet as it passed up the Channel. Thus was born ASV (air-to-surface-vessel) radar which in due course (and in later and more refined versions) played such an important role in the battle against the U-boats. AI radar was important, no doubt, but ASV was to be crucial.

The progress of AI radar is vividly described by Rowe(3). By the summer of 1940, AI Mk. III was operational in Blenheim aircraft. Its maximum range was about 3 km, and its minimum range about 250 m, any closer range being obscured by the recovery time of the receiver after the transmitter pulse. The set was also liable to 'squint', that is, to give a false indication of the position of the target relative to the centre-line of the fighter. Moreover, the Blenheim was too slow to overtake its target easily: one pilot flying a Blenheim chased a Dornier bomber for 80 km, followed it over the sea to make his attack and landed at his base with empty fuel tanks(4). By the end of October, 1940, only one bomber had been shot down using AI.

However, Mk. IV AI sets, with a maximum range of 6 km, and a minimum range of less than 200 m, installed in much faster Beaufighter aircraft, began to be available towards the end of 1940. In parallel, a crash programme to produce a dozen GCI (ground control interception) radars was initiated. The GCI set, on 200 MHz, was a derivative of the CHL (Chain Home Low) sets used around the coast to improve the low-cover capability of the chain: however, GCI sets were positioned inland, preferably in a shallow saucer of ground two or three kilometres in diameter. Hence there were no permanent echoes (PEs) from beyond the rim of the saucer. The set was equipped with a PPI (plan position indicator) display on which any aircraft within range appeared as a bright 'sausage', and an A-scope on which signals from upper and lower aerials were displayed side-by-side, thus giving a height on the target. Since the PPI radial timebase was generated magnetically by a coil rotating around the CRT neck, it was always difficult to generate a linear timebase, and thus to get an accurate display. Fortunately, any errors applied equally to the fighter and its target, and it was therefore possible for a controller to direct a fighter to within AI range.

Rowe describes the results of this programme. A dozen GCI sets had been installed by January, 1941, and with these and perhaps 100 AI sets, the casualty rate of enemy night bombers was raised from less than 0.5% to over 7%. In May, 1941, 102 bombers were shot down by night-fighters, and 172 assessed as probably destroyed or damaged†. These were prohibitive figures, and systematic enemy attacks by day or night virtually ceased.

It may be of interest here to note that the AI sets discussed above were Mks. III and IV. In a GEC Review paper[5] in 1993, Welsh describes the 'Foxhunter' radar, otherwise known as AI Mk. 24 (see fig. 1). In other words, British AI radar went through twenty variants in just over forty years. Even in 1993, one of the major problems is ground clutter: in the 1940s, this was so severe that the early AI sets could see no target at a range greater than the night fighter's own height above the ground.

Obvious though it may have been to an objective observer that CH stations in general, and Ottercops Moss in particular, were largely redundant by 1943, it was not obvious to the station personnel and morale remained high. However, there was a steady drain of people, especially mechanics, away from the station so that by late in 1943 there was one fairly inexperienced mechanic and one fairly inexperienced technical officer left. As I explained to a senior Wing Technical Officer, this made a nonsense of the prescribed routine maintenance procedure: we were down to basic checks, as and when time permitted, to try to ensure the technical health of the equipment. By and large, the station was as fault-free under this austere regime as it had been under the daily attention laid down in the manuals, which required six or eight mechanics.

I was not sure how well this account had been received at Wing HQ, and it was therefore with some trepidation that I went to Wing to meet the same senior officer. He had news for me: I was to go on a centimetric radar course for three weeks at the end of the year. This would mean a second Christmas at Yatesbury, near Calne, in Wiltshire, a fact for which he apologized: No. 2 Radio School was not a welcoming place in winter. Thus began an involvement with centimetric techniques, and with centimetric radar in particular, that was to last for more than forty years.

† These figures of enemy aircraft shot down, destroyed or damaged should be taken cautiously. For various reasons, some of them genuine (and not merely morale-raising propaganda), RAF claims of Luftwaffe losses in 1940 were nearly three times their post-war claims, and well over three times the losses listed in the German High Command diary.

1 ***Foxhunter radar installed in a Tornado aircraft***

The Advent of Centimetre Radar

In a previous paper[6], the present author called the magnetron 'perhaps the most important scientific innovation of the second world war, even taking the atomic bomb into account'. This view is borne out by Rowe††, who wrote that

> 'few in a position to judge would hesitate to name the cavity magnetron as having had a more decisive effect on the outcome of the war than any other single scientific device evolved during the war. It was of far more importance than the atomic bomb'.

Rowe is careful to write of the cavity magnetron, invented in 1939, as distinct from simpler forms: the simplest of all, invented by Hull in the USA in 1921, was a diode with a cylindrical anode having a cathode along its axis, the current between the two being controlled by an axial magnetic field. Between 1921 and 1939, many variants and a voluminous literature had evolved: it is perhaps fair to say that no very consistent overall theory had emerged. However, there was a general tendency to use multi-segmented anodes. Hull's original magnetron had used only one anode: Habann (1924) had used two segments, and Postumus (1934) used four. In all these cases, however, the

†† A.P. Rowe, as secretary to the Tizard committee, was one of only four men present at the Daventry experiment in February, 1935. In May, 1938, he succeeded Watson-Watt as Superintendent of the Bawdsey Research Station.

resonant circuit was external to the vacuum envelope. For further details of this early work on magnetrons, the reader is referred to Willshaw(7) and Harvey(8).

The crucial breakthrough was made by Boot and Randall early in 1940, and consisted in the use, in Willshaw's words,

> 'of six resonant circuits machined out of a solid copper block forming the anode, through the centre of which a wire cathode was mounted. Power was extracted through a concentric line coupled to a loop in one of the cavities'.

This prototype magnetron was water-cooled, continuously pumped and run in a large electromagnet at a high field: it was hardly a practical proposition for use in the field, much less in an aircraft. However, for the first time, a useful amount of power became available at a wavelength of 10 cm.

The Boot-Randall prototype, developed at the University of Birmingham, was shown to Megaw and his team at the Hirst Research Centre of GEC at Wembley. Megaw had been working on magnetrons for some years and was in touch with Gutton's developments in France. He quickly designed a sealed-off version of the Boot-Randall valve, and then proceeded to various improvements, as detailed by Willshaw. This gave, by July 1940, what was (except for one important step yet to come) virtually the final design, and many valves of this type were made in the laboratories at Wembley and in the BTH labs at Rugby, both for military services use and for further study and evaluation.

Many of these early cavity magnetrons suffered from the defect that they were apt to jump discontinuously in frequency with slight changes in operating conditions. This problem was solved (the one important step mentioned above) by Sayers, also of Birmingham University, in 1941. Sayers showed that by 'strapping' alternate cavities together, the frequency was stabilized and efficiency improved by a factor of five or six. The strapped cavity magnetron was a relatively docile device which was produced in its tens of thousands through the war years and for many years thereafter, mainly on wavelengths of 10 cm and 3 cm. Until its advent, no country had produced useful power at a wavelength below 50 cm; British radars had been restricted to wavelengths of 1.5 m, and that only at low efficiency.

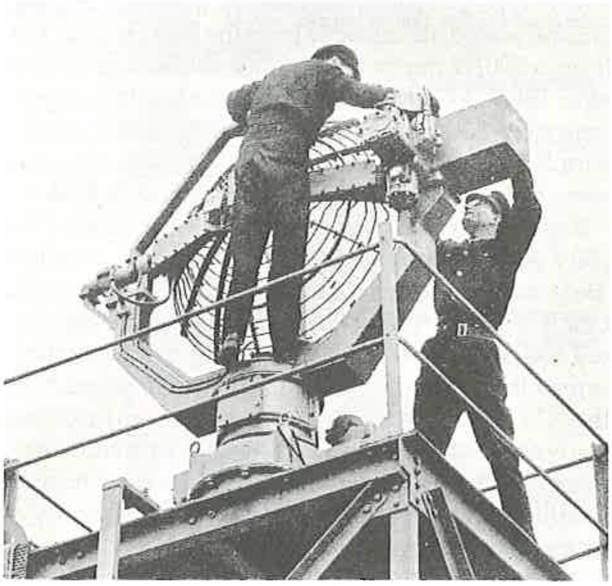
The availability of useful power at wavelengths of 10 cm and below spawned a whole new technology – 'microwaves'. Thus waveguides, which had been discussed by Lord Rayleigh in 1897, and by several other authors in the mid-1930s, at last became a practical proposition, combining low loss and high power-handling capability. Also, for the first time, it became possible to form a radio beam from a single launch point and a suitably shaped reflector, rather like a searchlight, instead of from an elaborate array of dipoles: moreover, for the same overall size of antenna, the beam would be much narrower. It was now possible to think of a narrow-beam radar in an aircraft as small as a night-fighter: in a large aircraft, such as a heavy bomber or a long-range maritime reconnaissance aircraft, a centimetric radar system would fit relatively easily.

The Centimetre Radar Course at Yatesbury

The Yatesbury radar course was, as usual, intensive: eight hours a day in class-room or practical sessions, and six days a week. It was an achievement to have assembled such a course in the two years or so since Sayer's discovery of strapping, before which, I suspect, the magnetron, major breakthrough though it undoubtedly was, must have been a doubtful proposition for services use. There was little attempt to go deeply into theory, rather to give a working 'picture' of what went on. For instance, Yatesbury gave a pictorial view of the operation of a waveguide, whereas the textbooks, Lamont(9), for example, usually develop the theory from Maxwell's equations. As far as the magnetron itself went, there was not then, or for many years thereafter, a fully satisfactory theory: instead, we were invited to visualize a cloud of electrons rotating in the anode-cathode space and giving up their energy to the cavities machined in the anode.

Only one radar set was taught on the course, the Type 277. This had originally been developed by the British Admiralty, and 'could be used both for fighter direction in carriers and for target indication for the anti-aircraft weapons in other large ships'(10). In 1943, it was installed in trailer cabins for coastal defence. The RAF installed it at the top of 60 m towers, and used it to watch over coastal shipping, reporting to naval plotting rooms: in RAF terms, this was a radar Type 52 (fig. 2).

There could hardly be a greater contrast than between CH (Type 1) and Naval Type 277 (RAF Type 52) radars. Some of the differences are outlined in table 1; however, a mere table does scant justice to the contrast. The 277 used one transmitter valve (a magnetron CV76, which could be carried on the palm of one hand (see fig. 3) to produce as much peak power as, and more mean power than, the CH transmitter, which used three very large



2 ***The dish antenna of the naval version of a Type 277 radar***

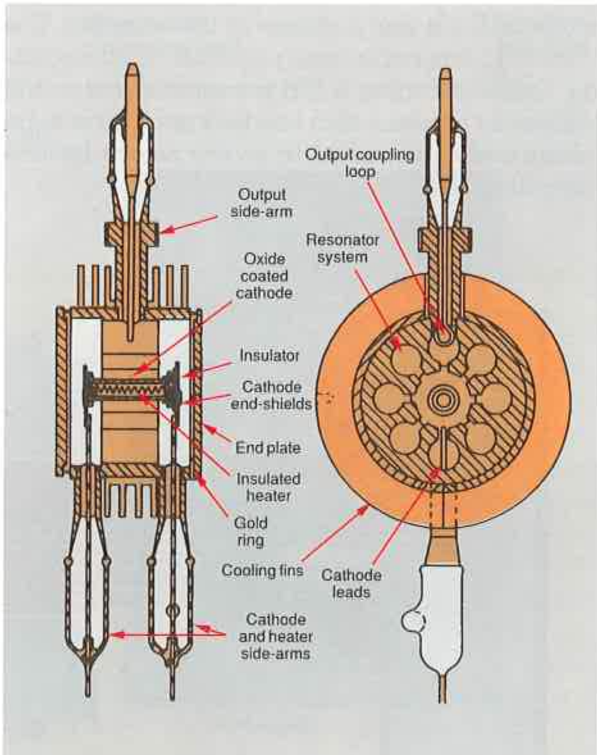
TABLE 1

A Comparison between CH and Type 277 Radars

Parameter	CH	Type 277
Wavelength (m)	10	0.1
PRF (p.p.s.)	25 or 12.5	500
Peak power (kW)	400	500
Mean power (W)	200 or 100	500
Pulse width (μs)	6–30	2
Beam width (°)	110	3.5
Display	A-scope	A-scope, PPI
Range of display (km)	0–320	0–100
Vertical coverage (°)	1.5–15	0–4
Transmit & receive	separate	common

valves, heavy enough to need pulleys and chains to lift them. A CH Station had nine towers (three for the main transmitters, over 100 m high, four for the main receivers, and two for the buried reserve station): the main transmitters and receivers were in relatively large permanent buildings, each surrounded by an anti-blast wall and bank of earth.

a)



b)

3 a) ***The CV76 S-band strapped magnetron, as used in the Type 277 radar. The device operated at 25 kV, 40 A and produced radiation at a wavelength of 10 cm; and*** b) ***diagrams showing construction of the magnetron***

By contrast, the Type 52 had one tower, 60 m high, carrying a 2 m dish antenna and the receiver/operations room was in a single Nissen hut near the foot of the tower. The total volume and weight of the CH transmitters and receivers must have been 100 times greater than their Type 52 equivalent.

There were in fact two variants of the Type 52. In the more common type, the transmitter and the early stages of the receiver were housed in a 3 m cube cabin immediately below the antenna; the received signal at an intermediate frequency (IF) of 60 MHz was fed down the tower in coaxial cable to the main IF amplifier, which was part of the A-scope. In the less common type, the transmitter and receiver were in an extended Nissen hut at the foot of the tower. The transmitter power and the received signal went up and down the tower in waveguide. This was, of course, a much more convenient system, but, as we were able to show later, it paid a considerable price in performance.

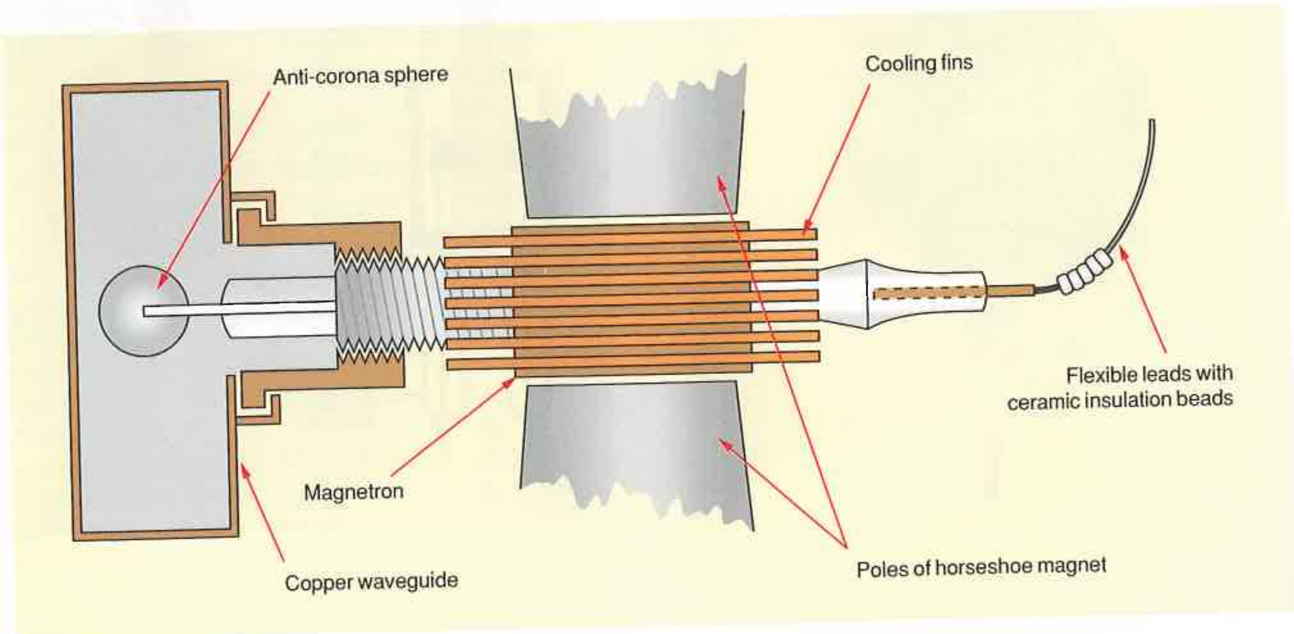
Even in the long-waveguide stations, there was turning gear and the rotating joint at the top of the tower, for which maintenance was required. The tower was therefore provided with a small lift that ran from ground level to an open platform some 6 m below the antenna: from this, one climbed a vertical 3 m ladder into the upper cabin, which in most stations, as already noted, housed the transmitter and the early stages of the receiver. The journey to this cabin was physically undemanding, unlike climbing a CH transmitter tower, but sufficiently tiresome that one took good care to be adequately prepared in every sense before ascending.

The Type 277 Radar

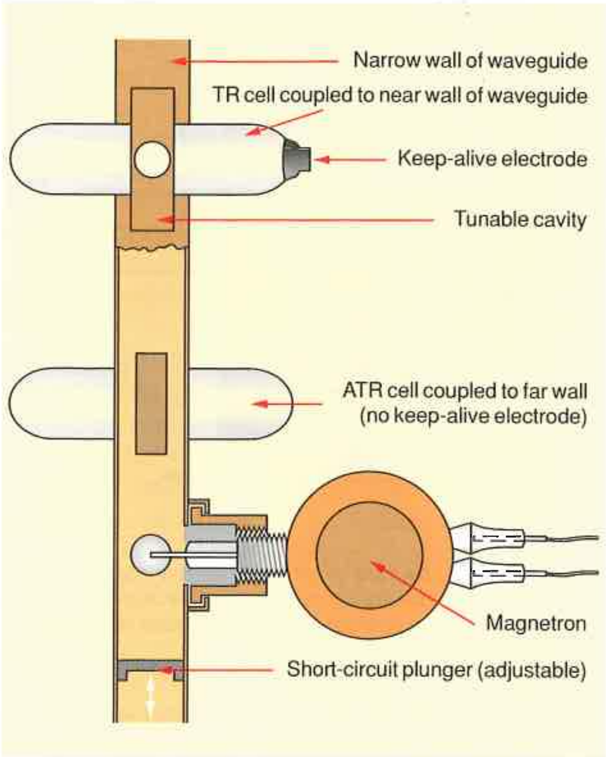
The Type 277 radar, as befitted its naval origins, was powered, not directly from the 50 Hz mains, but from a 500 Hz motor generating set, whose output was 180 V AC. The pulse recurrence frequency was also 500 p.p.s., linked directly to the 500 Hz supply: at 500 Hz, of course, the DC power supplies were much more easily smoothed than at 50 Hz.

The transmitter was simple and compact. The 180 V AC was transformed to about 6 kV, rectified and used to charge a 2 μs pulse-forming network. Using a trigger pulse derived from the 500 Hz supply, the network was discharged by a mercury thyratron through a 4:1 step-up pulse transformer to the CV76 magnetron, which was supported between the poles of a powerful permanent magnet. The magnetron output, derived from a coupling loop in one of its cavities, was fed by a probe through the broad face of the waveguide, and launched via an anti-corona sphere on the tip of the probe. Thus, there were three adjustments: the probe could be moved into or out of the waveguide (the only degree of freedom available to the magnetron itself), the position of a short-circuiting waveguide plunger could be adjusted, and the permanent magnet could be moved slightly to give optimum alignment between its field and the magnetron axis. Any tools used in this area were of brass, and wrist watches were at considerable risk. The arrangement of magnetron, magnet and waveguide is sketched in figs. 4 and 5.

The magnetron power was delivered via a rotating joint to the antenna feed horn, which



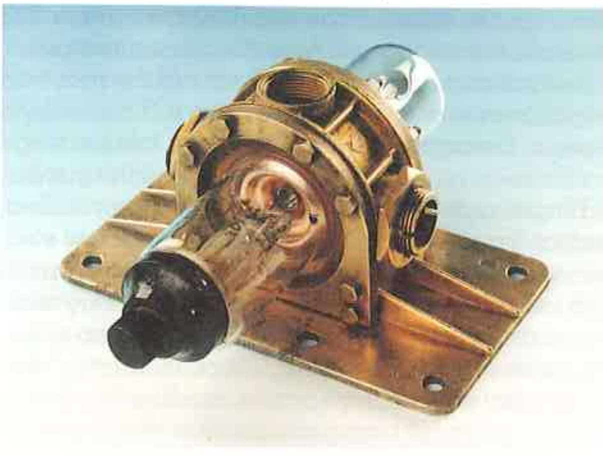
4 Detail of the magnetron/waveguide arrangement in the Type 277 radar



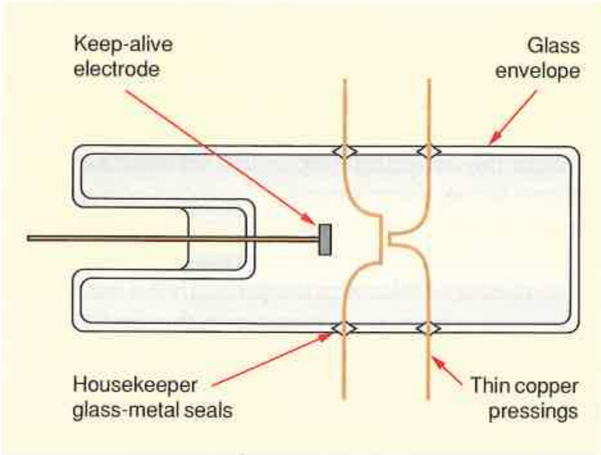
5 *Diagram showing the magnetron, transmit/receive (TR) cell, ATR cell and waveguide arrangement in the Type 277 radar*

illuminated the 2m circular dish antenna. There was no method of power measurement available, and the custom was to place one's hand over the feed horn to ensure that the magnetron was delivering at least some power. This crude attempt at power measurement was also a very early example of microwave cooking! As has been noted elsewhere(5), the mean power of a radar magnetron, even such an early example as the CV76, was closely comparable to that of the magnetron in a modern microwave oven. The CV76 was equipped with a heater for the cathode, but the heater was switched off as soon as the magnetron reached full power: thereafter, the cathode was heated only by electron bombardment.

The received signals ('echoes') were collected by the antenna and passed, via the feed horn and rotating joint, to the vertical waveguide run leading to the magnetron. However, they were intercepted about 30cm above the magnetron by a TR (transmit/receive) cell clamped to the narrow wall of the waveguide, to which it was coupled by a slot in the wall. The TR cell (fig. 6) ingeniously combined a toroidal resonant cavity and a gas discharge device. During the transmitter pulse, the gas discharge across the centre of the cavity effectively threw an open-circuit across the waveguide wall slot, and confined the power to the



a)



b)

c)

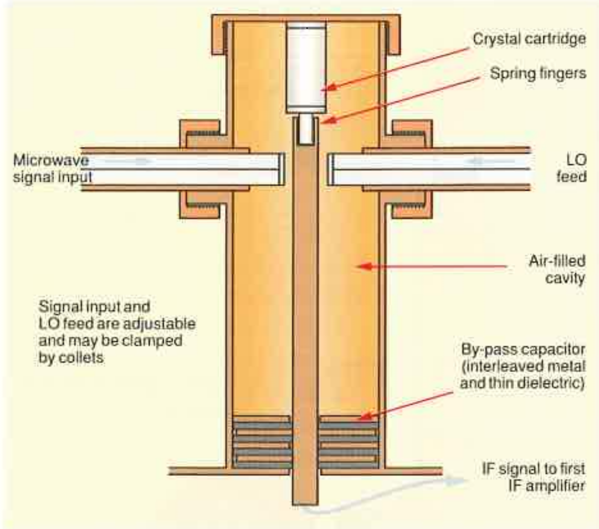
6 *TR tube:* a) *general view; and* b) *in section;* c) *is a view through the waveguide coupling port showing the structure of the cavity. The flange dimensions are 115mm × 64mm and the tube is 30mm in diameter and 130mm long overall.*
(Photographs courtesy of Mr. R. B. Molyneux-Berry)

waveguide, save for the small fraction needed to sustain the discharge. After the transmitter pulse, the discharge was extinguished and the received signals were coupled to the cavity and hence, by a loop in the cavity, to the mixer, that is, the first stage of the receiver. To aid rapid initiation of the gas discharge, a 'keep-alive' electrode was provided, which ensured that there were always a few electrons available in the discharge gap. Between the TR cell and the magnetron, there was a very similar transmit/receive cell, without a keep-alive, known as an ATR cell. The ATR cell's function was to present such an impedance, combined with that of the quiescent magnetron, that the received signals were directed through the TR cell, rather than back into the magnetron, which would seem a more obvious and natural destination. Both TR and ATR cells could be tuned by means of plungers screwed into the cavity: the TR cell tuned very sharply, the ATR cell so flatly that it was difficult to believe that its presence had much effect.

From the coupling loop in the TR cell, the signal passed via a short length of coaxial cable to the mixer cavity, into which the local oscillator (LO) was also fed (fig. 7). The intermediate frequency (IF) signal at 60 MHz was fed through the base of the cavity via a by-pass capacitor to the first valve of the IF pre-amplifier, whence it passed to the main IF amplifier in the A-scope display. The cable between the two IF amplifiers could be quite short in a 'long waveguide' station (transmitter and receiver both at the foot of the tower) or 70 m or more in the more common short waveguide station: this distance was tens of wavelengths at the IF of 60 MHz.

There was at this time (early 1944) no microwave test-gear available: one could not measure either the power or the frequency of the magnetron, nor the tuning or sensitivity of the receiver: so, as will be seen later, stations could operate for long periods at well below optimum performance. Every station had its favourite selection of permanent echoes (PEs), and relied on the signal-to-noise ratio (SNR) measured on these as the sole criterion of station well-being: ideally, there would be a range of signal strengths, so that tuning could be done initially on a signal of saturation strength (which at least gave a response when things were well off-tune): later, when tuning was well under-way, the final fine tuning was done with a SNR of say 10:1. Clear and identifiable PEs were a boon, not only for tuning, but also as a check on the range and bearing accuracy of the station.

Where a new magnetron was needed, the complete tuning procedure must be followed for optimum results. After running up the valve, and checking that some power was available by the



7 *Schematic diagram of mixer assembly (not to scale). Local oscillator feed is adjusted to give required crystal current signal and the feed for optimum response on permanent echoes.*

'hand-over-horn' test, the crucial step was to tune the LO (a klystron) so as to see some echoes. Thereafter, concentrating on a known PE of moderate size, all the other adjustments were gone through (magnetron insertion into waveguide; waveguide short-circuit position; TR cell signal coupling and tuning; signal coupling to the mixer cavity; LO drive to the mixer cavity; magnet alignment; ATR tuning) and probably reiterated, since some adjustments were interactive. Every hour, the more critical adjustments (LO tuning, TR cell tuning) were checked. The only (and very fallible) criterion of success in this complex tuning procedure was that the station's standard PE was showing its customary signal-to-noise ratio.

The Type 52 stations were designed to watch over the coastal shipping lanes, and initially took no interest in aircraft: as will be related shortly, however, their low cover capability proved useful in another, and quite unforeseen, role. The 60 m tower was often sited very near the sea, generally on low (10–30 m) cliffs, so that the dish was 70–90 m, above sea level, that is, about as high as the mean height of CH radar arrays. If the reflecting surface were flat enough for a sea-reflection lobe structure to be formed, the first lobe would have been at 0.022°, with nearly 30 lobes in the first degree of elevation, as compared with the first CH lobe at 2.2° [(1)]. However, it is unlikely that any reflecting surface, sea or land, would ever have been smooth enough (that is, smooth to within $\lambda/2$, or 5 cm, over a considerable area) to give the classical lobe structure. For practical purposes, the cover could be regarded as following the surface of the sea as far as the horizon, nearly 40 km away, for an antenna height of 80 m. This solid cover extended upwards to 3° or 4°, so that the system of 10 cm stations was sometimes known as CHEL (Chain Home Extra Low).

These coastal ship-watching stations had two main functions: first, to ensure that shipping moving up and down the coast navigated safely along the 'swept channel' between the inner and outer minefields, and second, to warn of the presence of 'E-boats', which were the enemy equivalent of the British MTBs (motor torpedo boats). These boats were fast (40–50 knots), of shallow draft and heavily armed for their size. A few such boats could wreak havoc on an undefended convoy of coasters in a few minutes, and then escape at high speed.

To fulfil these functions, the operations room was fitted with two displays, an A-scope, showing the amplitude of the echo against its range, and a PPI (plan position indicator) on which the echo showed as a bright 'sausage' against a grid map from which its position could be read off directly. Such a display was based on a linear radial timebase, rotating in synchronism with the antenna: on it, of course, the coastline and any inland features showed up clearly, to give an easily recognizable map of the surroundings.

The rotation of the antenna was controlled by the A-scope operator, and could be either continuous at 4 revs/min., or as controlled by a small hand-wheel, by which the operator could turn the antenna backwards and forwards over any angle. In this way, any desired ship could be 'D/Fed' for a maximum A-scope signal, and its range and bearing read off. In accordance with naval gun-ranging practice, the A-scope range was measured in thousands of yards (1 yard is c. 0.9 m). The range and bearing of each ship in a convoy, or perhaps only of the leading and trailing ships, would be converted into grid positions and passed to the local naval plotting room, routinely every fifteen minutes, but more often if required; for instance, as the convoy approached a turning point in the swept channel.

All ships within range also appeared, of course, on the PPI, from which their position could in principle have been read-off at once, thus making the laborious plotting from the A-scope unnecessary. Unfortunately, the PPIs of this vintage were too inaccurate to give reliable plots, so that the role of the PPI was to monitor the position continuously while the aerial rotated steadily at 4 revs/min. The PPI operator would check, on each sweep, that there was still the right number of ships in the convoy, and that no strange responses, especially those appearing at extreme range to seaward of the swept channel, appeared. Such echoes, especially by night, were likely to be E-boats. Any strange echo was reported at once, even if its position was not accurately known, and sufficed to alert, and often to alarm, the naval plotting room. From the PPI plot, a more accurate range and bearing plot from the A-scope was passed as soon as possible.

The reason for the inaccuracy of the early PPIs has been discussed earlier in this paper; because there was no error in bearing, and because the relative error in range between a night-fighter and its target was much less than the absolute error, the GCI controller could guide the fighter to within AI range. For ships, of course, absolute positional accuracy was essential to avoid the mine-fields.

The RAF response to naval demands for the more accurate (but time-consuming) plots of range and bearing was sympathetic until we made a liaison visit to the naval plotting room. Here we found a large plotting table, perhaps 3 m × 2 m, on which ship positions could indeed be marked up accurately. However, routine plotting was done on a much smaller map, perhaps 0.5 m × 0.3 m, on which the standard 'Chinagraph' pencil made a blob covering several square kilometres! Nevertheless, in the interest of good inter-Service relations, the RAF stations continued to plot from the A-scope.

Quarterly Overhauls on Centimetre Stations

On returning to HQ, 73 Wing, then at Malton in Yorkshire, from the three-week Centimetre Course at Yatesbury, I found that my new job was to carry out quarterly overhauls (QOs) on the Wing's centimetre stations. To this end, and to learn what the job involved, I was despatched to Bempton, a Type 52 station situated on the cliffs just north of Flamborough Head. Here a QO was already in progress, under a W/O Walker, about whom I had already been given some sage advice at Wing - 'go easy with Mr. Walker'. The advice was superfluous, since I treated any W/O, and especially a W/O radar mechanic, with the utmost respect and deference, acknowledging their years of experience. Mr. Walker was a small hard-bitten man, with prodigious experience, knowledge and work-rate: he was not averse to colourful language about anything, or anybody, if things did not go well. However, he treated me very correctly, although he must have despised my smattering of centimetre knowledge. He called me 'Sir' once a day and even got me to sign the QO report, which he had already carefully filled in.

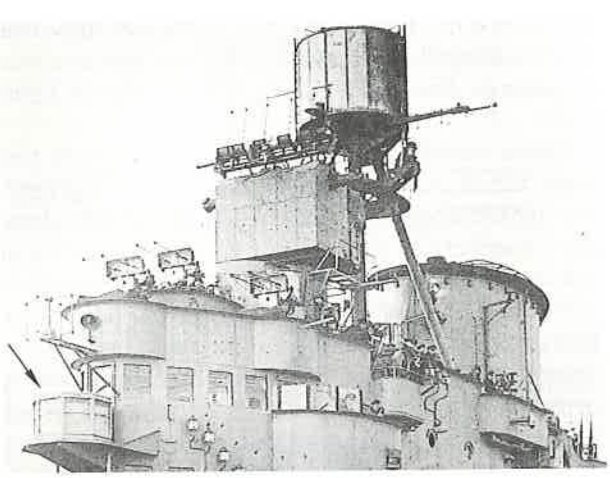
A QO party generally consisted of two or three men, and its purpose was sufficiently explained by its title. Since there was no stand-by set, the daily maintenance period of an hour was far too short for any deep investigations: the mechanic would go through the tuning procedure and do a few routine checks, taking care not to disturb anything, if possible. Allowing for one or two trips up the tower, an hour seemed an impossibly short time for even routine maintenance: any over-run of the allotted time called forth protests from the plotting room, and possibly a complaint to Wing HQ. The QO party was allowed three or four days, working from 0900–1800 hours. Even then, a QO party which had indulged in any major dismantling in an endeavour to solve a long outstanding problem would take care to begin re-assembly by, say, 1400 or 1500 hours. Every station needed to be at its best during the hours of darkness, when, even if there were no E-boats, the routine navigation of convoys was more difficult and dangerous.

When the Bempton QO was finished, Wing HQ rang up to say that they wanted Mr. Walker back for another job – would I take the party on for QOs at Ravenscar and Saltburn, which were Type 271 stations, 30 and 50km to the north, respectively. I protested that I had never yet seen a Type 271 station, let alone been instructed about it: my companions were only a little more experienced. My protests were over-ruled: 'it's a simple little set', they said, 'you'll soon find your way around it'. This time, at least, Wing HQ were quite wrong.

Type 271 was one of the first, if not **the** first operational centimetric radar in the UK. It was a naval design, and the prototype had been fitted in HMS Orchis in March 1941[10]: twelve more sets were hand-built in Admiralty Signal School Workshops by the end of June, and 52 more in industry by the end of 1941. 350 sets were then ordered (fig. 8).

As adapted for use on land, the Type 271 was fitted into a cabin, perhaps 4 m by 2 m, and mounted on a turntable. Two 2 m dishes were mounted externally on a cabin wall, one to transmit, the other to receive. The display was an A-scope, mounted on a bench in the cabin, with most of the radar mounted on the floor below the bench. The operator sat at the bench to observe the A-scope and traversed the whole cabin manually, using a hand-wheel geared to the turntable: thus he could read off the range and bearing of any target. There was no tower, and the set was of low power but, because it was mounted on high cliffs, the range was adequate for routine convoy watching: presumably E-boats were not expected so far north.

The Type 271 radar may have looked simple as a block diagram on paper, but it was of poor design mechanically and fiendishly difficult to work on. All the RF circuits were in coaxial line (that is, there was no waveguide). In one place, as I remember,



8 *HMS 'Indomitable' shown fitted with Type 271 radar in 1943. The radar is housed inside the 'lantern' fitted on the bridge front. A particular virtue of this radar was its compact size, allowing it to be fitted into vessels as small as a corvette, for example.*

(photograph courtesy Conway Picture Library)

two coaxial lines came together in a T-junction, the inner conductors, about 3mm in diameter, being of copper or very soft brass. The end of one conductor was threaded, and screwed into the other: when the threads became slack, as they inevitably did in time, the only solution we could devise was to solder both threads, hoping that the joint would hold tight at least temporarily. No doubt the sensible thing would have been to have telephoned Wing HQ to ask advice, or to seek a spare part. Already, it seems, I was imbued with the QO ethos – don't bother Wing with such a small problem, go ahead and do it yourself. Many more flagrant examples of this philosophy occurred later: I can only assume that QO parties (or at least my QO party) became imbued with hubris, in the dictionary sense of 'arrogance which invites disaster'. The disaster that followed our Type 271 endeavours took the formidable form of W/Cdr Scott-Taggart, who followed us up the coast receiving the complaints of the station personnel and writing his own which were fairly scathing even in the attenuated form in which they filtered back to me. Fortunately, we had taken care to leave all the paper-work in impeccable order, a strong point in our favour in the W/Cdr's view.

The other problem with the cabin-mounted Type 271 was that all the tuning adjustments were under the bench, while the display was on it. The tuning procedure was therefore to turn the set onto a PE, then sit on the floor to make adjustments blindly whilst craning the neck to watch the display. This was not conducive of optimum tuning, and was positively destructive of good temper and bodily comfort.

We were therefore heartily glad to have finished, at least for the moment, with Type 271. I never saw these two stations again (they were the last in 73 Wing, and were replaced by a high-power Type 277 at Goldsborough).

So, back to radar Type 277. There was only one job the QO party could perform which was outside the scope of the station personnel. The QO party had a signal generator covering the IF frequency of 60 MHz, and an important part of the QO was to check, and if necessary, to re-align the IF amplifiers, which, as already noted, were generally split, with a head amplifier of three stages at the top of the tower, and a main amplifier of five or six stages as part of the A-scope. The separation was generally 90–100 m, that is, nearly thirty wavelengths. Even over a bandwidth of 1 MHz, which was the standard, this meant that any reactance at one end of the IF cable showed as a rapid variation of reactance at the other. To complicate the issue, the signal generator, made by Marconi-Ekco (a fore-runner of Marconi Instruments) covered frequencies up to 60 MHz in one band, and over 60 MHz in another. 60 MHz could be achieved in either band, but not necessarily with the same power in both. IF alignment was therefore a tedious and frustrating process, one which would of course have been almost trivial with a swept signal generator.

After some months, we acquired, hot from the Telecommunications Research Establishment (TRE) laboratory, a microwave power meter. This device consisted of a section of waveguide, perhaps a metre long, which was inserted in the main waveguide run: another length was always required to make up the length (~3 m) of a standard waveguide section. A small fraction of the power in the main guide was coupled into an auxiliary guide, and this coupled power was used to light up a filament. This filament could be viewed, and compared with another, powered by a variable DC source. The DC power required for equal brightness was used as a measure of the microwave power in the main waveguide. This was hardly a precision instrument, but it was incomparably better than the 'hand-over-horn' guesswork that preceded it.

Use of this power meter enabled us to do some undoubtedly valuable work. First, we measured the transmitter power at the top and bottom of the waveguide run on a 'long waveguide' station. This showed that the waveguide loss in one transit was 3 dB – a long waveguide station must therefore be 6 dB less effective (allowing for transits either way) than a short waveguide arrangement. Such a loss implies a short-fall in range of some 40%.

In a second series of measurements, we were able to eliminate a long-standing problem at Trimingham. For a considerable time, perhaps even from initial installation, there had been complaints of intermittent arcing in the rotating joint. Measurements above and below the joint showed a loss of 3 dB, far above the expected level. The joint was dismantled, and a misplaced gasket, which reduced the waveguide aperture by a factor of three, was found. This obstacle caused a severe mismatch, of course, and was solely responsible for the arcing and the loss of power. The station staff were delighted at the obviously improved performance and, on this occasion at least, were not dismissive of the efforts of the QO party.

In April or May of 1944, 73 Wing, which had previously covered the east coast from the Scottish border to Suffolk, took over the corresponding extent of the west coast. There were three centimetre stations in the new responsibility, and two of us were despatched to carry out QOs on them. We were of equal rank and seniority, and, rather than squabble, we agreed that we would toss for the doubtful privilege of being in charge. I won and was therefore in charge for the first station (Cregneish, on the Isle of Man, Type 271) and the third (South Stack, on Anglesey, a Type 277, but mounted on a low gantry, rather than a tower). Nothing remarkable happened at either station, except that while we were at South Stack, the allies landed in Europe. However, the second visitation to Great Orme, near Llandudno, also a Type 271, was more eventful. We found that the station was about 20 dB off tune, and apparently had always been so. There had been, of course, no objective way of assessing performance, but once a station had achieved a certain standard, it should never fall far below that standard. At Gt. Orme, the standard had been set at an appallingly low level: in a very short time, and without any special equipment, we improved its performance by a staggering margin. PEs appeared as if by magic: in particular, the Liver building at Liverpool now gave a strong echo, which had never been seen by the station staff. My colleague, whose turn it was, wrote a scathing report, with which I fully agreed. In retrospect, one can sympathize with the station staff: evidently, no one had ever shown them how the station should perform.

Unfortunately, we had left ourselves open to counter-attack. On the floor of every Type 271, there was a small metal box containing a copper oxide rectifier, used to top up the emergency 50 V battery: there was a space on the QO pro forma for comment on this device, to which no one ever paid any attention. We had written 'Inspected and cleaned', (the universal euphemism for doing nothing, which satisfied the RAF mania for cleanliness). The station staff, in reply to the damaging report, picked up this point and complained to Wing HQ; it was all too apparent that neither we, nor they, had touched the rectifier box for weeks, or even months. This was another example of hubris: again it concerned a Type 271 station, and again nemesis took the burly form of Wing Commander Scott-Taggart. My colleague, as author of the QO report, was summoned to see the great man and explain the discrepancy, albeit on an almost trivial point, between the QO report and the undeniable fact. It must have been an uncomfortable interview, but the W/Cdr was lenient, and took no further action: probably he was as anxious as anyone not to aggravate the incident.

This affair, and that of the misplaced waveguide gasket at Trimingham, highlighted the difficulty of knowing whether or not a centimetre station was performing as it ought. There was no way for the station staff or, for that matter, the QO party, to check any of the three vital characteristics (transmitter power, receiver sensitivity, aerial gain) which determined the radar range. All they could do was to check the tuning very carefully and establish some performance criterion against a suitable PE. On Type 271, as already mentioned, tuning was an awkward and frustrating process: moreover, on the west coast, there was not the slightest risk of E-boats, and it is even doubtful if there were minefields. Morale at Great Orme was diminished by sheer boredom, and would have been higher, had a few WAAFs been present; they would probably have swept the cabin every day, and so avoided a thick and revealing layer of dust on the rectifier box! WAAFs were never used on Type 271s, presumably because they were thought not equal to the task of turning the cabin by hand.

A QO party was no better equipped than the station staff to assess the efficiency of a particular station (except for the power meter when it became available). Indeed, the station staff were better acquainted with the local pattern of PEs, the return from which was the only possible criterion of efficiency. Therefore a QO party would spend the first hour or two in carefully measuring a few prominent (but not too large) PEs. This was followed by a careful run-through, and reiteration, of the tuning procedure, noting any improvement. Then, towards the end of the overhaul, we would always change the TR cell and the mixer crystal, the most critical components in the receiver. The TR cell was important in itself, in that signal strength would be lost unless it was on tune and correctly coupled to the outgoing coaxial cable; it was even more important in its role of protecting the crystal from the 40-odd million transmitter pulses per day. The inside of the TR cell cavity was carefully polished, which was said to improve its performance, presumably by improving its Q-factor and so hastening the onset of the gas discharge. (Many years later, it was shown that a TR cell broke down ten or twenty nanoseconds into the transmitter pulse.)

The mixer crystal was an even more problematic device, not really very far removed from the 'cat's whisker' of 1920s domestic radios. In a post-war paper[11], Moxon gave an analysis of 1000 crystals: of these, 20% were not worse than 1.5dB down (compared with the best), 60% not worse than 3dB down, and only 20% worse than 4dB down. He also measured the noise factor of twenty-four crystals: with an IF noise factor of 6dB, the best overall noise factor was 13dB, the worst 16.5dB. It is not known what criterion was used to pass or reject crystals after manufacture, but it might well be thought that the results on the 1000 crystals show either a very good manufacturing process or a reasonably good screening system. Nevertheless, since a loss of 1.5dB in the crystal means a 10% reduction in radar range, only one crystal in five would enable the measurement of range to within 10% of the optimum: at the other end of the spectrum, one crystal in five would yield a range measurement that was 25% or more down on the optimum. There was no way of measuring crystal performance in the field, by means, for example, of a noise factor measurement, nor were the Moxon statistics available. The QO party did its best in these circumstances to have a reasonable stock of new crystals available (they were never in easy supply) and by keeping them screened (for example, in a tobacco tin) whenever the transmitter was running. (We suspected that the incessant transmitter pulses – well over a billion a month – produced a slow degradation of the crystals, even if an occasional rogue pulse did not completely destroy them.)

The QO routine thus comprised two contrasting phases: the three or four days of the overhaul itself – frantically busy and not without anxieties for the whole party, especially perhaps its leader; and the day (or days) between overhauls, when the party would move to the next station, settle in, and perhaps even take a day off.

This routine was only occasionally interrupted, as for instance when I went to a mini-conference on the microwave stations at Fairlight, near Hastings. The chairman was Squadron Leader Eastwood, then Head of Calibration at 60 Group, later of course Director of Research, both at Marconi Research Centre and for the whole of GEC[12]. He invited me to give an account of our measurements with the power meter.

On this visit, I saw the new Type 11 radar, specifically designed to be on the same wavelength (c. 50 cm) as the German Würzburg radars, the theory being that the enemy could not jam the Type 11 without also jamming the Würzburgs. The Type 11 was highly classified at this time, and never radiated over the sea. Whether inspired by this experience or not, Dr. Eastwood initiated after the war a highly successful series of 50 cm radars for air traffic control. He was also sufficiently interested in the waveguide power measurements to offer me a job. He had already been appointed as Chief of Research to the Nelson Research Labs at Stafford: fortunately for us both, by the time I was ready to seek a job, he had moved to the Marconi Research Centre at Gt. Baddow.

In September 1944, working on one of the most southerly of 73 Wing stations, we were able to 'see' (in the radar sense) the air activity connected with the parachute landings at Arnhem. Of course, Arnhem, being about 300 km from the Suffolk coast, was far beyond normal radar range. Even if the radar could see that far, the radar horizon at 300 km is about 5 km above the ground, and most of the air activity was much lower than this, and would not have been seen. Evidently, anomalous propagation ('anaprop') was occurring, caused by an inverted layer in which the air temperature rises as the height above the ground increases. The radar power is trapped in a duct, perhaps 100 m thick, and follows this duct over the earth's surface instead of spreading into space. In this way quite remarkable ranges were sometimes observed, especially in warmer and less windy climates.

The radar picture was most confused, of course, since echoes from a range of 300 km, resulting from one transmitter pulse, would arrive back at the same time as the next pulse: echoes at slightly longer range showed up as if they were short range echoes from the second pulse. Since the radar picture was so confused, especially on the PPI, all one could say was that there was considerable air activity at a range of about 300 km on a south easterly bearing.

At this time in 73 Wing, there were 11 Type 52 stations, two 271s and two GCIs which were now equipped with centimetric radars based on the Type 277 transmitter and receiver, as well as the older 200 MHz radars. There was therefore more than enough work for a QO party, allowing for days off, leave and training, to make the rounds every three months. This busy, if rather boring, prospect, was brought abruptly to an end by operation 'Diver': for the first time, an aerial dimension was added to our coast-watching role.

Operation 'Diver'

The first V1s (the 'V' was for 'Vergeltungswaffe', or revenge weapon) were launched from northern France against London within a week of the Allied invasion of Europe on June 6th 1944. These flying bombs, each carrying about a ton of explosive, were nick-named 'doodlebugs' by their intended victims, based on the recurrent 'phut-phut' of their ram-jet engines, which were cut off when the bomb had flown a prescribed distance. The device then glided for a small distance, crashed to the ground and exploded. Altogether nearly 10000 bombs were launched from France, causing major activity by fighter and anti-aircraft defences: the anti-aircraft guns were greatly aided by an American 10 cm radar, the first radar capable of automatically tracking its target[(13)]. These defences, allied to the unreliability and inaccuracy of the V1 itself, meant that only about a quarter of the bombs launched hit London, whose citizens, having been free of any serious assault for more than three years, were not unnaturally indignant. They took comfort in the fact that the Allied armies would shortly overrun the launch sites.

All of this is fairly well-known, and is within the experience of many. What is not so well-known is that the enemy, also anticipating the loss of the launching sites in France, began to equip Heinkel III bombers to launch V1s from the air: the main target was still London, the direction of the attack was now from the north east instead of from the south and the weight of the bombardment was of course much reduced. The first air-launched bombs were aimed at London on July 8th, 1944, and by the end of August, about 400 had been launched in this way, of which only 50 or so reached London. This compares with more than 200 launched within twenty-four hours from France in mid-June, of which 73 reached London.

It might well be thought that the threat of air-launched V1s was trivial as long as the rate of arrival in London was less than one a day, on average. However, the threat was taken very seriously, and a considerable redeployment of anti-aircraft guns and fighters took place in an effort to minimize the danger. The enemy tactics were to operate only at night, often in the evening, as if daylight, or at least twilight, was important for take-off: the Heinkels would cross the North Sea at a height of 100 m or so, and climb to about 500 m at the launch point, generally 60–80 km off shore. The position and direction of launch were important, since the trajectory of the bomb, once launched, could not be controlled either in direction or in distance to be flown. One can have a certain sympathy for the German pilots: to fly hundreds of kilometres very slowly in an almost defenceless aircraft and encumbered with a ton of high explosive must have been a nerve-wracking experience. It is little wonder that the arrival points were somewhat scattered: between 27th and 29th September, eight bombs landed in Essex, two in Cambridgeshire, three in Suffolk and one each in Kent, Sussex and Hertfordshire.

These enemy tactics proved difficult to combat. The best solution would obviously be for a night-fighter to shoot down the Heinkel before it launched its bomb, but this proved to be nearly impossible, given the wide choice of launch points and the slow speed and low height of the bomber. By this time, the best British night-fighter was the Mosquito, equipped with AI Mks. IX and X: however, even if the bombers could be located without aid from the ground, the Mosquito proved to be far too fast to employ the usual tactic of creeping up slowly behind the target until visual contact was achieved. Beaufighters with their obsolete AI radars were brought back from retirement, but achieved little success. Similarly, although radar-directed guns had been successful when the general direction of attack was known, they were difficult to site effectively when the attack might come from a variety of directions.

Thus, although the air-launched V1s were never likely to be a serious threat, given that specially-equipped Heinkels must be used, and given that this method of delivery was intrinsically inaccurate, they were undoubtedly a nuisance and caused quite disproportionate alarm and dismay. Few of the attacking bombers or their bombs could be shot down, and the nuisance seemed likely to persist until every enemy airfield within range had been overrun.

In these circumstances, and for the first time, the centimetre stations came into some prominence. Until the advent of 'Divers' (the code word for V1s), they had suffered somewhat in prestige as compared with the CH and CHL stations, which had larger staffs and purpose-built operation rooms that tracked fast-moving aircraft. The centimetre stations were generally smaller in terms of staff, were housed in Nissen huts and tracked (for the most part) coastal convoys travelling at 10 knots or less. The main enemy was tedium: only the girl on the PPI need be constantly alert, while the A-scope girl and the plotter were involved for only a few minutes every quarter hour, only to find that the convoy had moved along its predictable path by three or four kilometres. However, the CH stations did not see Divers at all, and the CHLs only very late, that is, well after launching: they could never see the launching aircraft. The 73 Wing centimetre stations in Suffolk and Norfolk were the only stations likely ever to 'see' the launching aircraft, and to be able to follow the Diver throughout its path. There were four stations chiefly concerned: Benacre in Suffolk, Hopton, Winterton and Trimingham in Norfolk, and as luck would have it, my QO party dealt with all four. These four stations had the further advantage of being the furthest from Wing HQ in Yorkshire: telephone contact could always be made from our end if required, but the small QO party could be very elusive when phoned from HQ ('Sorry, Sir, he's up the tower').

When Divers first appeared in the North Sea, there was presumably a high-level appraisal of what could be done to improve the effectiveness of Type 52 stations against them. Not much could in fact be done, the Type 52 being very inflexible in its main properties. The pulse repetition frequency was governed by the 500 Hz motor generator set, the pulse width by the pulse-forming network and the peak and mean transmitter powers by the magnetron: the receiver sensitivity was poor in absolute terms, but the best available at the time.

In the event, it was decided that instead of the normal 1 MHz bandwidth, the optional 4 MHz bandwidth would be used, the only modification needed being to improve the bandwidth of the second detector by using four thermionic diodes instead of the standard single diode. This involved some tricky wiring in the already cramped IF amplifier box: more difficult was the greatly increased problem of IF amplifier alignment to give a flat 4MHz bandwidth, especially when, as in all short waveguide stations, the head and main amplifiers were separated by 100 m or so of coaxial cable.

This modification, of course, decreased the signal-to-noise ratio (SNR) by four times, but it was supposed that the improved shape of the received pulse would nevertheless give a better PPI response. (The PPI now became the display of choice, because with the antenna rotating continuously at maximum speed, there was very little chance of seeing anything useful on the A-scope). The QO parties carried out the modification and the change of bandwidth as ordered, but I have wondered to this day whether the sacrifice of SNR was really justified.

The QO routine carried on throughout the Diver campaign, and was used as a time for the modifications to the IF bandwidth and the second detector diodes: it was of course even more important than usual that the stations were fully efficient, and that they were back on the air at 1800 hours. We were frantically busy for several months, and it was difficult to avoid the temptation to stay in the operations room until midnight or so to see any divers that might appear on the PPI. At a distance of nearly fifty years, only two incidents stand out in memory: as it happens, both were at Benacre, which, for several reasons, was my favourite station.

In the first case, we were doing a QO, including the IF modifications. We had managed to procure a spare IF chassis, modify it and pre-align it to the required bandwidth. It remained only to substitute this amplifier for the unmodified one from the station and complete the alignment with the head amplifier. Since the output stage of the head amplifier and the input stage of the main amplifier were interdependent, this could only be done with the two amplifiers connected together. At about 1600 hours, with only two hours to go to our deadline, in walked Wing Commander Scott-Taggart, the senior Technical Officer from Wing HQ. Needless to say, I broke off from what I was doing, greeted him politely (even deferentially) and explained that, against a tight time-scale, we were engaged on the final alignment of the two amplifiers, having changed the station's amplifier for a modified and pre-aligned one. His only response was to demand to see the relevant Form 1497, on which any change or modification should have immediately been entered. Alas, we had neglected to make any entry, a cardinal sin in his eyes. I was duly reprimanded at some length, but finally allowed to get back to work: even a Wing Commander could see that there was still quite a lot to do, and only an hour or so left to do it in. By great good fortune, the Divers duly appeared soon after darkness, and Benacre reported them that night before any other station. This must have been a geographical accident, since Benacre, a long waveguide station, was intrinsically less powerful than its neighbours, as explained earlier. The Wing Commander was well pleased, and almost forgave us our trespasses over the Form 1497.

Certainly, to watch a Diver attack on a PPI was an unusual, not to say eerie, experience. One first saw a number of tracks, slow moving and at near-maximum range, perhaps 80 or 90km. After 10km or so, each track split into two, of which the slower returned on a reciprocal course while the other continued on the same path, but now much more quickly. (The laden Heinkel bomber could only do about 250 km/h, whereas the V1 travelled at 500–600km/h, that is, faster than most contemporary fighters). There was some discussion at the time as to whether the launch point was determined by the maximum range of the missile or by the fact that the enemy knew the extent of the radar cover and was determined not to encroach too far into it. (The range to central London from a launch point 80km due East of Benacre is almost the same as that from the ground launchers in the Pas de Calais).

On another occasion, a battery of anti-aircraft guns, complete with its auto-tracking radar, was deployed in the field adjacent to the Benacre radar. Divers duly appeared, and were tracked as usual, except that now the plots were also passed directly to the adjacent battery. At first, it seemed that the missiles would pass directly overhead, and everyone who could be spared rushed outside to view the engagement. Alas, the PPI, on which the scale was 20cm to 100km, had misled us, and the V1s passed a couple of kilometres to the south. The guns did not fire, presumably because their radar, which had a 4° beamwidth and conical scanning[12], could not track at so low an angle. Only when the excitement had subsided did it occur to us to wonder what might have happened if the guns had achieved a hit at short range. The guns, and their crew, were protected by a sandbag wall and by steel helmets; by comparison, a Nissen hut seemed a rather fragile refuge.

There was one final twist to the Diver story. At Christmas, 1944, I was at Wing HQ, now located at Boston Spa: it was my first Christmas spent in the RAF, since over the two previous Christmases I had been at Yatesbury, and had therefore been at home for the festival. On Christmas Day, according to protocol, the officers served dinner to the other ranks: my task, as it turned out, was to serve the waitresses from the Officer's Mess. They could not refrain, in the spirit of the day, from a good deal of comment and advice on my deficiencies as a waiter.

Fortunately for the light-hearted tone of that meal, we did not know that on Christmas Eve, the enemy had air-launched fifty V1s, aimed, by their account, at Manchester. Only one of these landed within the city limits, six more within 15km and eleven more within 25km. 28 people were killed and 38 badly injured in Oldham[14]. The distance from Manchester to the east coast is about 160km, and these V1s must presumably have travelled about 200km from launch, putting most of British industry within range. Again, there was a suspicion that the enemy knew that only centimetre stations could track their attacks and that there were few such stations in the north of England. In fact, between the Wash and the border, there were only five stations: at Skendleby (Lincolnshire), at Dimlington (Spurn Head), at Bempton (Flamborough Head) at Goldsborough (N. of Whitby) and Cleadon (S. Shields). I had worked on all these stations at one time or another, although less frequently than on the Suffolk and Norfolk stations.

Although real enough to those who suffered from it, the attack on Manchester was really a pinprick, with no military significance. Nevertheless, it was taken sufficiently serious that I was on the road northwards on Boxing Day, charged with reporting on the suitability of a certain site for a mobile station to be deployed, to help guard against another such attack. I have no recollection either of where this site was, except that it seemed an interminable distance from Boston Spa, or of what I reported about it. As far as I know, the station was never deployed, and there were no further similar attacks, although Divers continued to be launched against London.

Early in 1945, I was posted from 73 Wing to TRE (Telecommunications Research Establishment) at Great Malvern as a PDS (Post Development Services) officer. After a learning period at TRE, I was to go to India, to help in the introduction of centimetre radars to SEAC (South-East Asia Command). Full of enthusiasm, I willingly put up with life at TRE: by day, I studied secret documents, alone in some gloomy basement of Malvern College, and by night I slept in a bunk bed in a vast dormitory at the Abbey Hotel. Most people were there for the short term, and there was no guarantee that one's upper berth companion would still be there in the morning, much less the next night. However, I slowly learnt something of Type 11 (50 cm, already referred to), Type 14 (10 cm surveillance), Type 13 (10 cm nodding height finder) and the DU5, the latest PPI display, in which the problems of linearity had finally been solved by using more elaborate circuits and many more valves.

Finally, on VE Day, we set off for India by air – obviously, we said, they need us in a hurry for the vast programme of updating the older radars to centimetric sets. A tour of two, three perhaps even four years before Japan was defeated, plenty of interesting work and a whole new continent to explore. Alas, the reality was far different: very few new radars arrived before the defeat of Japan, and I found myself the odd-job man: a one-man court of inquiry, for instance, into the circumstances surrounding the collision between a British despatch rider, who broke his knee, and a bullock cart, which, according to its owners, was worth lakhs of rupees†. All the evidence was given verbally, written out by me by hand and signed on every sheet by the witness: as can be imagined, this procedure was difficult, as they spoke little English and I even less Hindi.

† 1 lakh = 10^5. At the time of this event, a lakh of rupees was equivalent to about £7 500 sterling.

Eventually, by dint of a certain amount of lobbying, arguing that if my originally intended role of helping to set up a chain of centimetre stations had failed (there being no such chain), my most useful role would be with one of the few such stations as in fact existed, I was appointed as CO of AMES (Air Ministry Experimental Station) 21022. This was a mobile radar, consisting of a Type 14 (surveillance) and a Type 13 (nodding height finder), complete with a display cabin (DU5 displays) and two 20 kVA diesels to supply the power, all mounted on heavy trucks. At least, this was a radar job in which my specialist knowledge could be employed, even if it fell far short of the job I had been led to expect at TRE.

Alas, the radar was never deployed or operated as a system. In December, 1945, AMES 21022, complete with about 40 men and eight to ten vehicles, sailed from Madras to Singapore, in good time for Christmas. The convoy was eventually parked at Paya Lebar, together with hundreds of other vehicles on what had been an airfield. It was impossible to run the radar in such tightly-packed conditions, since we found that the mixer crystals were immediately burnt-out by reflections from adjacent vehicles. The men (and their CO) rapidly became bored of this regime; the only reasonable aim was to be demobilized and sent back to England as soon as possible. I managed this in May, 1946: my radar career in the RAF was over.

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