s

The History of Radar Technology in Germany

Reference to its Application to radio Location

(Dr. H. Diehl)

Until it absorbed the Flak artillery, the Luftwaffe was not obliged to seek the co-operation of scientific research and development in this particular field as the possibility of applying high-frequency measurements to aircraft operating over land areas had not yet been perceived. However, once the flak became an integral part of the Luftwaffe, the latter assumed responsibility for presenting the appropriate tactical and technical demands. Naturally, it was some time before the Director of GAF Signals became an effective force as regards organisation and in a practical role. In October 1937 responsibility for the coastal aircraft reporting service was also transferred from the Navy to the Director of GAF Signals.

With the emerging Allied air threat from mid-1941 onwards and for a period of 12 - 18 months after the end of 1941, smooth co-operation between all parties concerned with the advancement of radar technology was ensured. In July 1941 the Director of GAF Signal was instructed by C-in-C Luftwaffe to set up the so-called "Professor Conferences", involving the participation of a number of scientists engaged on work in the high-frequency field and, with the status of Special Commissioner for Luftwaffe Radar Technology accorded him in 1941, he had the opportunity of co-ordinating the efforts of all parties engaged in this field.

In 1942 the office of the Commissioner for high-frequency Research was also established to co-ordinate all high-frequency research activity.

After these responsibilities had been duly allocated, tactical and technical demands were worked out in co-operation with the Army, the Navy, the Luftwaffe Operations staff and the heads of the various arms of the services, the information provided by Technical Office on what was within the bounds of technical possibility being borne in mind.

My object now is to point out some dates of historical importance in the overall field of development, with special reference to the application of radar technology to radio location.

As early as 1904 the German engineer Hülsmeyer took out a patent on a process, which was supported by practical experiments, for "reporting the presence of distant metallic objects (ships, trains and the like) to an observer by means of electric waves". Thus, both the possibility and essential principles of locating objects by means of radio waves were established. However, owing, to the state of technology and of valve development in particular at that time, this principle lacked the application of impulse technology. Thirty years were to pass before the way to radar technology was open in Germany.

At the beginning of 1933 Dr. Rudolf Kühnhold of the Naval Signals Experimental Establishment urged that tests be made with short electro-magnetic waves to determine whether and at what range an echo could be obtained from metallic objects. In the early summer of the same year the firm of Pintsch, which, in co-operation with Professor Kohl, had developed transmitters and receivers based on the Barkhausen brake-field principle, supplied a 13.5 cm transmitter and receiver for the initial tests. The transmitter had an output of about 100 milliwatts and was, like the receiver, installed in a parabolic reflector. Tests with this equipment were commenced in Kiel harbour in the autumn of 1933 over a range of about one sea mile. Reception was good, but no reflections could be observed.

In January 1934 the firm of GEMA and the Naval Signals Experimental Establishment co-operated in the construction of the first laboratory installation, using Philips magnetrons of about 50 cm. On 20 March tests were again carried out in Kiel harbour, reflections being observed on the "Hessen" at a range of about 100 metres. Between 7-12 May 1934 the firm of Pintsch carried out further tests with improved equipment at Schilksee at the entrance to Kiel Bay. The transmitter consisted of a brake tube with an output of about 300 milliwatts and operated at a wavelength of 13.5 cm. Reflections were obtained on the 500-ton experimental vessel "Grille" at a range of 2,100 metres, the transmitter being set up 8 metres above the level of the water.

Meanwhile, GEMA had improved the screening of the magnetron transmitter and the brake receiver. These devices were again tested at Schilksee between 18-28 June 1934. Once again, reflections were obtained from a small vessel fitted with a dummy metal superstructure up to a range of 300 metres. In similar tests on the same vessel with Pintsch equipment, the range obtained was 6OO metres. Further tests, which had then been transferred to Pelzerhaken, were continued with GEMA magnetrons with a continuous output of 50 watts on a wavelength of 50 cm. The transmitter was set up on a turntable mounted on a wooden tower 12 metres high, the receiver being located 200 metres away. On 28 October 1934 reflections were obtained from the experimental vessel "Grille" at a range of 11.5 km and from an aircraft flying over the sea at a range of 700 metres. Every test described so far was carried out with tone-modulation.

The next step consisted in the introduction of impulse technology, the first tests with an impulse transmitter being commenced in February 1935. In co-operation with the Heinrich Hertz Institute and GEMA, a ranging unit for a total range coverage of 10 km was produced. By using improved receivers and transmitters and fish-bone beacons, ground reflections were obtained at a range of about 20 km in June 1935.

The state of development in September 1935 was as follows: with equipment mounted 12 metres above the surface of the water, ships of 500 tons could be picked up at a range of up to 11.5 km with an accuracy of about 100-150 metres, directional accuracy being about 0.1°. It was there upon decided to continue work along the following lines:

1) Tests based on the Pintsch installations to be continued and a magnetron transmitter and a brake receiver in the 10-15 cm band range to be constructed.
2) The magnetron to be replaced by a triode as the frequency stability of the former was not satisfactory, the introduction of a wavelength longer than the 50 cm used until then being accepted at the same time.
3) The development of an installation with pulse excitation and a high transmitter output in the 2-metre band, range.

The first experimental installation - later known as the "Freya" - was undergoing tests on the 2-metre wavelength at the beginning of 1936. Strong permanent echoes from the Hook of Travemünde could be observed and a W-34 type aircraft was located at a range of 28 km out to sea. With increased transmitting power, improved high-pressure pulse excitation and more efficient valves, an aircraft of the same type was soon located at a range of 60 km.

In the spring of 1936 the medium installation (80 cm), set up aboard a ship, located vessels at range of 10-12 km with a directional accuracy of 0.15°.

In September 1937 the Naval Signals Experimental Establishment's vessel "Strahl" was equipped with an 80 cm and a 2.10 metre installation. The first installation located ships (400-500 tons) at a range of 14 km, while the second picked up aircraft at ranges varying between 40 and 60 km. These favourable results, the appearance of symmetrical reflections and the instability of the transmitter and receiver in the 14 cm installation influenced the decision to abandon the shorter wavelength and to perfect equipment for various specialised purposes on the longer wavelengths.

After the experimental "Freya" had located Ju 52's at ranges of 70 and 80 km, the later "Freya" model was demonstrated to political and military leaders at Eckernforde in July 1938. On this occasion a Ju 52 was located at a range of 90 km.

In 1937 the firm of C.Lorenz had been given a contract for the development of a radar installation for the flak, the result being the "39 L" (62 cm, 2 kw) and the "40 L" (53 cm, 50 kw). Two reflectors 2.4 metres in diameter arranged one above the other constituted the transmitter and receiver antennae.

When responsibility for the aircraft reporting service was transferred from the flak to the Director of GAF Signals in 1937 the following objectives for the development of a medium radar installation were specified - constant target-tracking with a mean bearing error of less than plus or minus one sixteenth of a degree, range measurements exact to -10 metres, a search range of 50 km, exact range measurements up to 25 km and the ability to report aircraft at close range. In addition, efforts were made to effect automatic control of the target-seeking end plotting process. Moreover, it was implied that the centimetre wavelength was more appropriate in view of the accuracy required for firing. The results of Professor Esau's fundamental research in the centimetre and millimetre fields may have had a decisive influence in this respect.

An installation developed along these lines - later known as the "Würzburg A" - was demonstrated to government and service chiefs at Rechlin at the end of July 1939. The directional accuracy achieved was about ±½°and the range accuracy about ±100 metres, but in 1941 this was increased to ±30 metres by the "Emil" attachment developed by Telefunken.

In October 1939 the Director of GAP Signals established the Wangerooge experimental group for the purpose of testing various types of installation and investigating their operational potentialities.

On 18 December 1939 the experimental "Freya" at Wangerooge picked up British aircraft approaching Heligoland Bay at a range of 113 km and direct control of fighters on the basis of cathode ray tube readings was carried out for the first time. The great success achieved on this day drew attention to the supreme importance of radar installations not only to the aircraft reporting service but also to fighter control and resulted in the additional employment of these installations in the latter role.

The next demand to be met was for greater accuracy in establishing direction and altitude within the range of the "Freya" installation. Directional accuracy was improved considerably by the "A.N." system, which was introduced into night fighter operations in 1940. The "A.N." control system enabled night fighters to be directed to their objectives without the aid of searchlights or aircraft radar. The first successes with this system were scored in September 1940.

The state of development in mid-1940 was as follows:

1) The rotating transportable "Freya" operating on 2.4 metres with a range of about 150 km and the installation which could be dismantled for air transportation ("Z-Stand") were available. Altitude readings were not obtainable from either of these installations.
2) The Lorenz "40 L" already mentioned was available.
3) The Telefunken "Würzburg C" was in mass production and formed the basis of the "Würzburg Riese", an installation with a 7-metre reflector and a range of 70 km which was in the process of development.

The first "Würzburg Riese" employed at the Zoo flak tower in Berlin gave such good results that a total of 1,500 were produced, the majority being employed in the "Seeburg" fighter control system. Development was subsequently concentrated on aircraft reporting and control installations, flak warning and firing devices and aircraft radar equipment.

The demand for location of aircraft over wide areas resulted in high-capacity installations with ranges in the region of 300 km, such the "Elefant" operation on 7.5 metres and the "Mammut" on 2.4 metres, but these installations were not produced on any appreciable scale. Continuing development on the basis of the "Freya", Siemens produced about 150 rotating "Wassermann" attachments operating on wobble range frequencies on the 1.2 to 4 metre wave-band for establishing altitude and direction on the "A.N." system. However, the "Freya" continued to be the basic installation for medium ranges of up to 150 km.

In the field of specialised flak equipment, the "Mainz" and its successor the "Mannheim" were developed by Telefunken. Compared with the "Würzburg", the latter came considerably nearer to meeting the flak's requirements. The 53-cm wavelength with a 3 metre reflector were retained and, with automatic direction and range-finding, the "Mannheim's" degree of accuracy was more than twice that of the "Würzburg". One of the last installations on the 50 cm band was the "Ansbach", the largest flak radar device capable of being transported by road.

In the field of night fighter operations it was realised at an early stage that aircraft radar was a necessity, as there was no certainty of continuous contact when night fighters were being guided towards bombers by the "A.N." or "Seeburg" ground-to-air systems. The "Lichtenstein SN 2" operating on the 2 metre band and with maximum and minimum ranges of 7 km and 200 metres respectively proved fully capable of filling this role.

In the spring of 1942 the frequency-governing components of a "Würzburg" installation fell into British hands, thus bringing about the danger of jamming. At first it was possible to avert this threat only by changing frequencies. Although this operation, known as "Wismar", was made more difficult by installations' components, which were specified for high constancy of frequency and a limited variation range, conversion to permanent frequencies was soon effected.

At the same time, however, the possibility of jamming by means of "Window" became apparent. The air defence situation at that time and the consideration that the employment of "Window" in enemy air attacks would be particularly effective led Goering to issue a personal order to the effect that the potential threat of this means of jamming was not to be revealed as a result of experiments with apparently suitable counter-measures. However, in view of the penalties involved, this order in effect resulted in the suppression of all experimental work in this field. This ban was subsequently lifted and the "Doppler effect", which had been developed by Fack in 1940, was applied to radar installations in a simplified form. This device, called the "Würzlaus", increased the efficiency of the "Würzburg" in a ratio of 1:3. A further step against jamming was taken by mans of the "Nürnberg" listening attachment, but a really effective solution was not found until the "K-laus" was developed. Further relief against jamming was also provided by the "Windlaus" and the "Taunus" system.

In addition to "Window" jamming on the 50 cm band, the enemy employed jamming transmitters and appropriately adapted "Window" against the "Lichtenstein SN 2" aircraft radar. These jamming measures, which necessitated the continual modification of radar installation, led to the realisation that a more effective answer to the problem could be found only by means of centimetre and panorama technology. The development of panorama installations began as early as 1940. In the initial stages a large rotating antenna column, which was set up on a tower, plotted echoes on a panorama screen by mans of a Plan-position indicator. The final version of the panorama installation - called "Jagdschloss" - had a range of 300 km. By April 1945 Siemens had supplied 18 of these installations in the 1.2 - 1.9 meter band and 62 in the 1.9 – 2.4 metre band. Of these, about 15 were put into operation and were found to be extremely effective as regards both panoramic scanning and against jamming.

The State of German Centimetre Wave Technology at the End of the Second War

(Professor L. Brandt)

In his memoirs, Sir Winston Churchill stated that at the beginning of the war the standard of German radar was at least equal to that of British radar. The choice of the 50-cm wavelength, which was proposed as a standard wavelength by Professor Runge, proved to be so fortunate in the case of both communications and radar that there seemed to be no need for further technical advances. However, in his specifications for the Flak firing installation, which was later developed from the "Würzburg", the Director of GAF signals demanded the centimetre wavelength as a possible further step towards achieving the high degree of directional accuracy required for the firing of Flak artillery.

In spite of the favourable British estimation of German technology, there existed one vital difference between the two nations, namely the integration and promotion of radar technology resulting from Winston Churchill's personal interest in this field. This situation did not exist in the German state leadership, which impeded development, ignored the necessity for long-term projects and hindered the completion of current undertaking by removing specialists.

In spite of this unfavourable influence much was achieved in the field of radar technology by both scientific research and industrial development, but these achievements were dealt a serious blow when British Commandos attacked a "Würzburg" post at Dieppe and captured the frequency-governing components of the installation. From this moment onwards it was assumed that the enemy would take measures against German radar technology. We were absolutely correct in foreseeing jamming transmitters and decided upon the exceptionally difficult task of changing the wavelength of every radar installation from northern Norway to Africa. The employment of "Window" was also foreseen, but after considering the dangerous effect of the enemy's reaction to major experiments in this field and that of not developing counter-measures at all, the latter course was decided upon.

A few weeks previously, at the end of December 1941, all work in the field of radar was co-ordinated - at least within the Luftwaffe - under the control of the Director of GAF Signals a situation which, unfortunately, lasted for only about 18 months. Recognising the necessity for intensifying development, the Director of GAF Signals promised to release 15,000 Luftwaffe signals specialists for research, development and production. At the same time specialists employed in industry were made available as leaders of development groups by the Technical

Office of the Air Ministry and were later taken over by the Commissioner General for Technical Signals Equipment, General Fellgiebel. Development of remote-control technology was to be directed by Professor Runge, navigation by Dr. Kramar and radar installations by myself.

With the assistance provided by the Director of GAF Signals it was possible to continue work on a broader basis. Unfortunately, this work did not include centimetre wavelength technology as various scientific circles considered the employment of this wavelength to be impractical.

However, when the British "H2S" experimental navigation device operating on the centimetre wavelength was discovered in an aircraft shot down in the vicinity of Rotterdam, General Martini immediately convened a "Rotterdam" working committee under my direction to deal with this problem.

The first step was the reconstruction of the "H2S". Unfortunately, the rebuilt installation was severely damaged by fire in an enemy bombing attack in March 1943 which heavily damaged the Telefunken laboratories. The installation was assembled once again, this time in a bunker in Berlin and, upon being put into operation on the roof of the bunker, provided clear images of the Berlin area end its lakes. It was then obvious that there was a large number of new tasks of the highest priority in the fields of radar search equipment, jamming and camouflage. However, these results provided an explanation of the heavy U-boat losses sustained during that month during which U-boat radar search installations did not obtain any response on a length of 1.5 metres, which, until then, was known to be the wavelength used by British aircraft search devices ("AVS").

Within a very short time the "Naxos 1" was issued to U-boats. The range of this device was 8 km but, with a larger antenna, this was increased to 50 km. Thus, the threat of "H2S"-guided bombing attacks on U-boats was virtually eliminated.

In the case of the Luftwaffe the employment of "H2S" produced a situation completely different to that which had confronted the Navy in respect of its U-boats. Owing to the fact that it revealed the presence of those employing it, there was some doubt from the outset as to whether such a device would do more harm than good. The employment of this same "Naxos" device fitted with a rotating antenna aboard aircraft as an automatic search installation was immediately proposed. In spite of initial doubts as to its efficiency, this simple device installed in a "Wilde Sau" fighter proved to have a range of 50 km and by the end of the war 1,500 German night fighters had been thus equipped. The fact that only 50 of these aircraft were able to operate on any given night was due to the decline in synthetic fuel production from 500,000 tons in January 1944 to 10,000 tons in October 1944. This in turn was due to a considerable extent to the fact that there were insufficient day fighters available and that the vastly superior Me 262 made its appearance two years too late, and this only in very small quantities, owing to the senseless attempt to produce a bomber version of this type.

The problem of identifying "H2S" from the ground was solved by Dr. Güllner of Blaupunkt, who developed the "Korfu" receiver. This device was finally employed through the entire wave band from 2.7 to 18 cm in eleven different versions which were assembled in "Kornax" D/F installations. Results were so good that "H2S" installations could even be observed when they were switched on to warm up 20 minutes before aircraft took off from airfields in Britain. From the moment they took off until the moment they landed again, pathfinder aircraft were under the surveillance of the "Korfu" network, which covered the entire defence zone of Western Germany and was centralised in Berlin. Mention must also be made of the fact that these radar search devices were also operated on the 3-cm wavelength and were thus equally able to pick up "H2X" installations.

The employment of jamming transmitters as a defensive measure had been under consideration from the outset, but the usefullness of these installations was regarded as highly problematical in many respects. Nevertheless, Siemens and Halske, assisted by Dr. Schultes, developed the "Roderich" jamming transmitter with an output of about 5 watts for the 3 and 9-cm bands. Jamming was very effective at close range, but even at a range of 10 km only a poor general coverage was achieved. The Reich Post Office Research Laboratory developed the "Feuerball", a jamming transmitter with a continuous output of 100 watts and a parabolic beam antenna 50 cm in diameter. This device appeared to be effective against "H2S", but as it was employed an only a limited scale it was not able to jam an attacking force completely. Jamming installations with a peak-voltage of 5 kilowatts developed by Lorenz were effective against "Oboe", and the "Korfu" and "Kornax" radar search antennae and the jamming transmitters were successfully combined in the "Korona" installation.

Two projects which from the very first appeared to offer greater prospects of success than the jamming measures taken against "H2S" and "Oboe" were the fields of camouflage and deception, and of these two deception was probably the more important. Deception devices, which Dr. Kühnhold tolled "Bolde" from the word Lügenbold meaning habitual liar, were particularly effective when used at sea as they simulated exactly the reflections of a U-boat or a small ship. Thus, if several Bolden were employed to protect a U-boat there was little probability of the real target being discovered. At the suggestion of Dr. Roosenstein, U-boats also discharged deception antennae from their torpedo tubes, a measure which was given the code-name "Thetis". Dr. Kühnhold also showed particular interest in a project to camouflage the U-boat's "Schnorchel". The result of his work, a device called the "Schornsteinfeger", reduced the range of the enemy's radar equipment by about half and, although this may appear to be insignificant at first sight, it increased the enemy’s research effort fourfold.

From the fields of radar search and jamming measures we pass on to the of direct radar warfare, a strange campaign in which the radar installations themselves were the weapons. The development of offensive radar devices was as difficult as that of research installations such as "Naxos" and "Korfu", was easy. The German "H2S"- the "Berlin", was initially intended merely as a ground observation instrument, but the Luftwaffe was forced progressively from offensive to defensive operations, this device had little military value. The radar devices employed by the aircraft reporting service, the flak and for night fighter operation, namely the "Freya", "Würzburg", "Riese" and "Lichtenstein SN 2", were of decisive importance to a defensive policy, but the belief that centimetre wavelengths were not suitable for these installations still existed. Nevertheless, a centimetre device was installed in a "Würzburg" and on 22 December 1943 the first test with aircraft was carried out at the Erika laboratory at Wittenau. It was estimated that the range of this installation would be 8 km, but in fact the normal "Würzburg" range of 30 km was achieved. A scheme for the modification of radar installations to the 1, 3 and 9-cm wavelengths was thereupon worked out during the Christmas of 1943 and, at the beginning of January 1944, was submitted to the Director of GAF Signals, the Air Officers commanding the various branches of the Luftwaffe, Admiral Stummel and his staff and leading industrialists at a meeting presided over by Field Marshal Milch.

Comprehensive plans had been drawn up for 9-cm installations, extending to the operational employment of almost every type. On the 3-cm wavelength preparations had been made for the mass production of practically every type of Installation on the 1.5-cm wavelength automatic rocket-firing device to be installed in the wings of jet fighters was ready.

Tactical and technical requirements had also necessitated a transition to the field of millimetre wavelengths and Professor Esau had produced wireless listening receivers operating on wavelengths down to 4 mm. At the same time Siemens and Halske and Telefunken had developed large-scale panoramic installations to succeed "Jagdschloss", for which normal transmitters with a high-level impulse output of 20 kw and high-powered transmitters with an output of 100 kw were available.

The "Egerland", which was devised for the flak and comprised the "Kulmbach" panoramic device and the "Marbach" firing installation, was a particularly successful development. As regards target altitude and direction, its accuracy was considerably greater than that of any other flak device and was, in most cases, greater than one sixteenth of a degree. Moreover, this installation had a panoramic range of 50 km, was able to locate targets in rapid succession and could not be blanketed by "Window".

In the air the "Berlin" night fighter device, which found operational employment with Night Fighter Geschwader 1 at Gütersloh in March 1945, was responsible for the destruction of ten enemy aircraft.

In view of its many coastal defence commitments, the Navy was quick to appreciate the importance of coastal stations provided with centimetre wavelength equipment. GEMA therefore equipped each of a number of coastal observation posts with "Würzburg" reflectors and a 9-cm "Berlin" installation. These installations were called "Renner" and were able, for example, to track a group of five British small craft up to a range of 32 km. "Riese" installation fitted with "Berlin" 9-cm devices achieved particularly good results and to pick up the mastheads of ships at ranges of up to 70 km.

Artillery fire control tests with cm-wavelength radar installations equipped with to automatically rotating antenna and a plan-position –indicator also produced very good results. Shell-splashes could be identified quite clearly and only one correction was necessary to enable the artillery to fire for effect.

It must not be forgotten that the British and Americans had meanwhile achieved exceptionally high standards in the field of centimetre wavelength equipment. The entry of America into the war provided enormous scope in this sphere, while in Germany space, material and manpower became increasingly restricted. However, it is interesting to note that peak radar equipment output was achieved in December 1944, when 400 installations of the "Würzburg" type alone were produced and that a total of 500 centimetre-radar installation was produced in April 1945.

In conclusion, a brief reference must be made to valve technology. Britain had taken the lead from Germany with the high-level impulse magnetron, although very large magnetrons operating on 20 cm and efficient 10-cm magnetrons had been developed before the war by Dr. Steimel and Professors Esau and Rukop respectively. German magnetrons wars not considered suitable for employment in radar installations as, amongst other reasons, they were believed to be unstable and untenable.
Later, work in the field of magnetron technology was resumed at high pressure. To achieve tunability and continuous frequency change, the employment of cavity triodes was proposed by Dr. Steimel at a very early stage and these were subsequently utilised in the "Pauke S" aircraft firing device on 10 cm and in a "Feuermolch" jamming transmitter. But for the conclusion of the war, cavity triodes would also have been employed in the V2 guide-beam control device on 20 cm and in relay installations ("Kogge") in rockets to be used by remote-controlled flak rocket-firing batteries, as well as in fighter rocket armament and remote-controlled bombs of the HS 293" and "Fritz X" typ.