JANUARY 1988 £1·20

ISSN 0141-0857

Practical Wireless

The Radio Magazine

EXPEDITION to the pole

BATTLE of the beams

BUILD the pw 'otter' 50MHz receiver

REVIEW of the 'revex' wave monitor

Practical Wireless
The Radio Magazine

JANUARY 1988 (ON SALE 10 DECEMBER 1987) VOL. 64 NO. 1 ISSUE 970

THIS MONTH

NEXT MONTH

Beginning *PW* "Orwell" High-performance m.w. receiver

Directivity Gain in Transmitting antennas

The ICOM IC-761 Reviewed

plus

All the usual features

Don't miss it—place your order with your newsagent now!

On sale January 14

Contents subject to last-minute revision

Regular Features

Editorial and Advertisement Offices:
Practical Wireless
Enefco House
The Quay
Poole, Dorset BH15 1PP
☎ Poole (0202) 678558 (Out-of-hours service by answering machine)
Prestel 202671191

Advertisement Manager
Roger Hall G4TNT ☎ 01-731 6222

Editor Geoff Arnold T.Eng FSERT G3GSR
Assistant Editor Dick Ganderton C.Eng. MIERE G8VFH
Art Editor Steve Hunt
Technical Features Editor Elaine Richards G4LFM
Technical Projects Sub-Editor Richard Ayley G6AKG
Editorial Assistant Sharon George
Technical Artist Rob Mackie
Administration Manager Kathy Etheridge
Clerical Assistant Claire Horton
Accounts Annette Martin

The Battle of the Beams—Part 1

1940 . . . Now, nearly 50 years on from those near-disastrous days, how many of us remember (or even know of) the debt of gratitude owed to one man who confounded the radio experts, overcame officialdom—to earn Churchill's praise as the man who "broke the bloody beams"—and went on to unravel the secrets of German radar and Hitler's "V-weapons": the V1 pilotless flying bomb (the "doodlebug") and the V2 rocket?

But for Professor Reginald Victor Jones our official language today might well be German. D. V. Pritchard Dip Ed G4GVO tells the story.

Born in London in 1911, R. V. Jones was educated at St. Jude's, Herne Hill, and later at the Elementary School in Sussex Road, Brixton, where he won a scholarship to Alleyn's School, Dulwich. Awarded an Open Exhibition in 1929 to Wadham College, Oxford, he worked in the Clarendon Laboratory under the formidable Professor Lindmann (later Lord Cherwell and Winston Churchill's wartime Scientific Adviser), where he turned his talents to infra-red detection—an interest he was to pursue for the next 30 years.

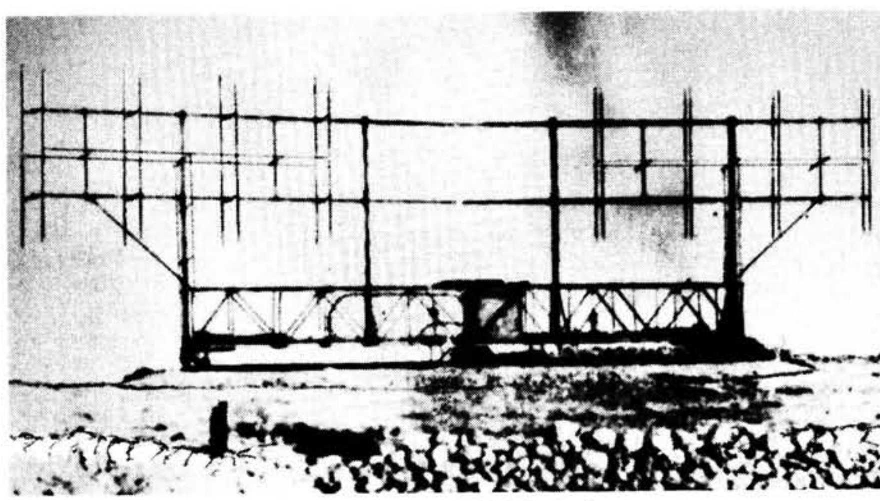
Fortunately for us, in 1939 he was appointed Scientific Officer to the Military Intelligence Service (MI6) to find out what the Germans were doing in the way of applying science to warfare, and in early 1940 he came to believe that they had a radio-navigation system by which they hoped to bomb accurately at night.

Knickebein—The Crooked Leg

From captured documents found in crashed German aircraft he came across the word *Knickebein*, or "crooked leg", The Germans were ridiculously informative with their codenames—it even sounded like a beam. But what kind was it?

Then two prisoners of war in conversation were heard to speak of something called *X-Gërat*, or "secret apparatus"; evidently it was something used in an aircraft and involved radio pulses. A thriller could hardly have a more intriguing title, but what was X-Gërat—and was it the same as Knickebein? Deeply interested, Jones pressed his Intelligence sources for more information and in March he was rewarded with the navigator's notes from a shot-down Heinkel: *Navigational Aid: Radio Beacons working on Beacon Plan "A". Additionally from 0600hr Beacon Dühnen. Light Beacon after dark. Knickebein from 0600hr on 315°.*

Shortly afterwards a co-operative prisoner said that Knickebein was a beam so narrow and exact that two of them could pinpoint a target with an accuracy of less than a kilometre. He also added that Knickebein was in some ways similar to X-Gërat, assuming that we were familiar with both systems!



Front view of a small Knickebein array

From the wreck of another Heinkel a diary was rushed to Jones. It read: *March 5. Two-thirds of flight on leave. Afternoon training on Knickebein, collapsible boats, etc.*

By this time the cryptographers at Bletchley Park performed a near-miracle by breaking the German *Enigma* code. One of the intercepted messages from a German aircraft was sent to him: *Knickebein, Kleve, is confirmed at position 53°24′ north and 1° west.* This meant that the aircraft had reported receiving the beam a few miles south of Retford in Lincolnshire, and Kleve (where Anne of Cleves came from) was on the nearest German soil to England.

But, clearly, there had to be two beams: one along which the bomber flew, and another one—a marker beam—to tell the pilot when he was approaching his target. Evidence of this second beam arrived a few days later in yet more salvaged papers from a crashed Heinkel: *Long-range Radio Beacon: Knickebein (Bredstedt) 54°39′, 8°57′, Knickebein (Kleve) 51°47′5″, 6°6′.*

So Bredstedt in Schleswig-Holstein was the source of the second beam!

Amateurs and Experts . . .

Obviously beams less than a kilometre wide at well over 300km called for very high frequencies—possibly something in the centimetric region—and although this part of the spectrum was in some use at the time, the power generated by valves then available was very low. Certainly the German system suggested they had overcome the problem. (It was only later that we discovered that German radar had been operating on 50cm since about 1930!)

However, Rowley Scott-Farnie G5FI, then a signals officer in RAF Intelligence, showed Jones a report by T. L. Eckersley, the country's leading propagation expert, in which Eckersley had computed the possible range of a 20cm transmitter sited in the Hartz Mountains. If the calculations were correct the signals would bend round the earth and might well be heard by a bomber at 20 000 feet over England. This information, together with the evidence he had already collected, prompted Jones to alert Professor Lindemann to the possibility that the Germans had a narrow-beam system for bombing the country. Lindemann naturally countered with the objection that the frequencies they would have to use could not possibly bend round the earth, but Jones produced Eckersley's calculations and told him that indeed they could.

But how were the Germans doing it? Inspection of captured aircraft revealed nothing unusual and the radio equipment seemed perfectly normal —certainly nothing in the way of centimetric receivers. He pressed for yet more information, especially from the prisoner-of-war interrogation centres. Did their aircraft carry special receivers for beam reception? Had we missed something?

Quite correctly the prisoners admitted nothing. But at one centre a prisoner was overheard to tell his friend that no matter how hard we looked for the equipment we would never find it. This startled Jones, for it implied that it was under our very noses and therefore we would never see it. Methodically he sifted through the captured equipment but the only item that fitted the bill was the receiver marked E Bl 1 (Empfänger Blind 1)—Blind Landing Receiver Type 1—which was used by both the RAF and the Luftwaffe for blind landing on the Lorenz Beam System.

The Lorenz System, however, only had a range of about 8km at best, unless the Germans has somehow dramatically increased its range. Knowing that Farnborough had evaluated the equipment, he enquired if there was anything unusual about the receiver.

"No," came the reply. "But since you mention it, the receiver is many times more sensitive than they would ever need for blind landing."

Could that be it! Dr Jones spoke to Lindemann, who drafted a note to Churchill: *"There seems some reason to suppose that the Germans have some type of radio device with which they hope to find their targets."*

Churchill initialled the note and sent it to the Air Minister, adding: *"This seems most intriguing and I hope you will have it thoroughly examined."*

A committee of enquiry was formed and Squadron-Leader R. S. Blucke was put in charge of flying operations. Three Ansons were fitted with suitable receivers and flown by Lorenz-trained pilots. Rowley G5FI, told Jones that the German pre-set frequencies were likely to be 30, 31.5 and 33.3MHz, and sure enough a few days later a scrap of paper recovered from yet another crashed aircraft read: *Knickebein (Kleve) 31.5.*

On June 20 a Heinkel was shot down and the radio operator, who had baled out, had torn his notes into shreds and was actually burying them when he was captured. An Intelligence NCO unearthed them, gummed them together and sent them to London: *VHF. Knicke 54°38'7"N, 8°56'8"E, 51°0'30"N, Eqms., Stollberg 30mc/s. Kleve 51°47'N, 6°2'E, 55°N, 2°Eqms., 31.5mc/s.*

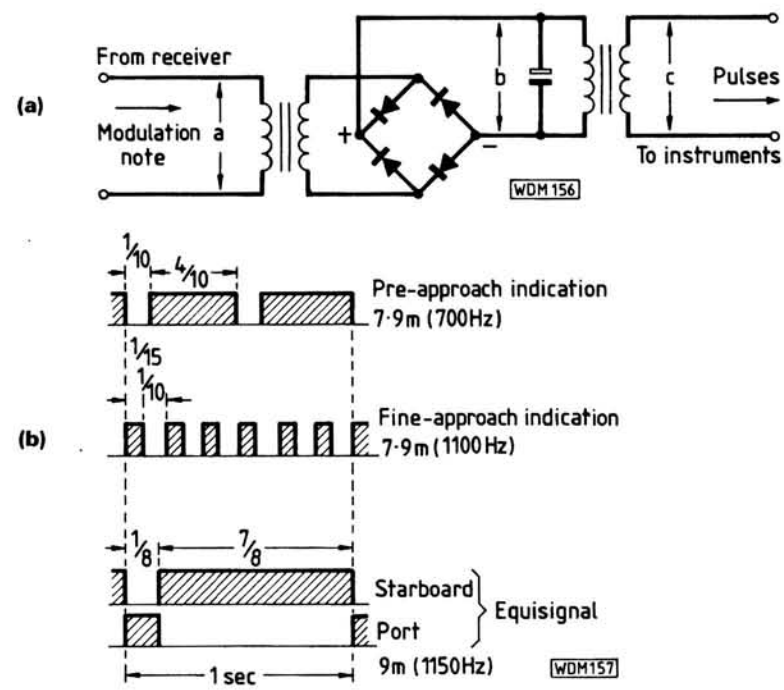
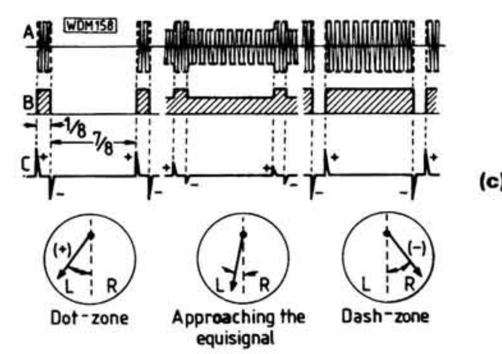


Fig. 1.1: The target-approach indication with the Knickebein system. (a) Pulse rectifying circuit. (b) Pulse-rate timing—distances in metres, tones in hertz (for approach on flightpath)



(c) Pulse-rectification and wave-forms (A) tone-modulated signal. (B) At rectifying circuit and (C) as final pulse

This seemed to confirm the existence of another Knickebein installation at Stollberg, also in Schleswig-Holstein, and also Scott-Farnie's guesses about the frequencies. Yet after two flights the Ansons failed to find the beams.

Was Jones wrong after all? Many thought so. Sir Henry Tizard was sceptical (and fell from Churchill's favour as a result); Air Chief Marshal Dowding was doubtful and Air Chief Marshal "Bomber" Harris was scathing. Other military and scientific brains looked askance at the young man who questioned established wisdom. Then suddenly on the same morning Jones was summoned to a meeting at Downing Street.

Thinking the message was one of Scott-Farnie's practical jokes, he arrived half an hour late to find the meeting already in progress. A galaxy of talent confronted him. Churchill sat on one side of the table flanked by Lindemann on his left and Beaverbrook on his right. Facing them was Sir Archibald Sinclair (the Air Minister), Sir Cyril Newall (Chief of the Air Staff), Sir Henry Tizard, Watson-Watt, and Portal and Dowding (Commanders-in-Chief of Bomber and Fighter Commands). Breathing his apologies to the Prime Minister, Jones took his place at the end of the table. An argument was taking place: did the beams exist or didn't they? Soon Jones realised that nobody in the room knew as much about the matter as he did. Suddenly Churchill snapped a question at him, and feeling he couldn't answer it out of context Jones said, "Would it help, sir, if I told you the story right from the start?" Churchill seemed somewhat taken aback but then replied, "Well yes, it would."

For the next 20 minutes Jones outlined his evidence. As he later recalled *". . . although I was not conscious of my calmness at the time, the very gravity of the situation somehow seemed to generate the steady nerve for which it called. Although I was only 28, and everyone else around the table much my senior in every conventional way, the threat of the beams was too serious for our response to be spoilt by nervousness on my part."*

When he had finished an air of incredulity filled the room. Sir Henry

Tizard demanded to know why the Germans should use a beam anyway, assuming such a thing was possible —our own pilots found their targets very well by astro-navigation. (They didn't!—*Author.*) Others round the table seemed doubtful. But Churchill was convinced and asked Jones what should be done.

"I told him that the first thing was to confirm their existence by discovering and flying along the beams for ourselves, and that we could develop a variety of countermeasures ranging from putting a false cross-beam for making the Germans drop their bombs early, to using forms of jamming ranging from crude to subtle."

With a typical "Let this be done at once!" Churchill then turned round and tore a strip off the Air Ministry for their tardiness.

And Expert Amateurs . . .

Elated at having convinced the Prime Minister, Jones dashed away to attend a conference in the office of the Director of Signals, Air Commodore Nutting, to discuss the possibility that the Germans might exploit pulse techniques as navigational aids, and on which T. L. Eckersley was to give evidence. However, because Eckersley disagreed with Jones' findings, the subject reverted to Knickebein.

But what about those propagation calculations? Oh, those! Eckersley pooh-poohed them: he didn't believe them himself. He was only trying to demonstrate how far the signals *might* go under certain conditions. He thought he had been stretching theory too far, and doubted if signals in the 30MHz band would curve round the earth.

The Ansons had failed to detect the beams during their previous flights and another one was due that evening. In order to cancel it the Principal Deputy-Director of Signals, Group Captain O. G. Lywood, picked up the phone saying, "Well we have here *the greatest expert on radio propagation in the country* (author's italics) and he says the beam theory is all wrong. We've wasted a lot of time and let's not waste any more. This evening's flight should be cancelled!" But Dr Jones stood his ground. Pointing out that Eckersley's evidence had neutralised itself because he had said one thing a few months before and now said something quite different, and that enough evidence already existed to convince him, he demanded that Eckersley's statement should be ignored. He also told Lywood that if the flight was cancelled he would "jolly-well let the Prime Minister know who had countermanded his orders." Lywood backed down.

From the Chair, Air Commodore Nutting demanded: "And what do we do if we find the beams?" Quietly Jones whispered to Rowley Scott-Farnie, "Go out and get tight!"

Black Night and Bright Dawn

Dr Jones went home to spend one of the most miserable nights of his life. *"Had I, after all, made a fool of myself and misbehaved so spectacularly in front of the Prime Minister? Had I jumped to false conclusions? Had I fallen for a great hoax by the Germans? Above all, had I arrogantly wasted an hour of the Prime Minister's time when Britain was about to be invaded or obliterated from the air?"*

It was a beautiful summer's night—the shortest night of a terrible year for Britain—when Flight-Lieutenant Bufton and Corporal Mackie climbed aboard their Anson and flew over the area between Huntingdon and Lincoln. Neither had been told the Knickebein story, but merely to search for beams with Lorenz characteristics. Suddenly on the Hallicrafters receiver they heard signals on 31.5MHz. Dots!

The aircraft swung to the north. Still dots. Then—a continuous note, and later, as expected, a zone of dashes. When the dashes ceased Bufton and Mackie began intently to plot the beam. The following afternoon Bufton's report was on Jones' desk:

(1) That there is a narrow beam (approximately 400–500yd wide) passing through a position 1 mile south of Spalding, having dots to the south and dashes to the north, on a bearing of 104° (284°T).

(2) That the carrier frequency of the transmissions on the night of 21/22 June was 31.5mc/s, modulated at 1150 cycles and similar to Lorenz characteristics.

(3) That there is a second beam having similar characteristics but with dots to the north and dashes to the south synchronised with the southern beam, apparently passing through a point near Beeston on a bearing lying between 60°+ and less than 104°.

In other words the director beam was aimed at Derby where the Rolls-Royce factory produced engines for the RAF—as Jones had suspected. The impact of Bufton's report on the meeting that afternoon may well be imagined. Jubilation was in the air. Even "Daddy" Nutting was skipping round the room in delight. All doubts were now dispelled and countermeasures could go ahead urgently.

In the midst of the revelry Scott-Farnie button-holed Jones: "Remember what you said yesterday?"

So they bowled across to a pub to celebrate.

The Lorenz System

In 1932 a Dr E. Kramar of the German Lorenz Company began to develop a high-frequency blind-landing system on pre-set frequencies between 30 and 33.5MHz, continuous-wave modulated at 1150Hz. The beacon transmitter and its associated antenna system stood at the end of a runway and had a range of 3–5km (sometimes more depending on conditions) even though the transmitter developed 500 watts. The output was fed to a single dipole, to the left and right of which and at a ¼-wave spacing, was a single reflector cut at its centre point. A relay was employed to alternately close and open the reflector, as shown in Fig. 1.3, whereupon a beam was generated at an angle left and right of the driven element composed of dots to one side and dashes to the other (Fig. 1.4). These alternating beams partially overlapped each other centrally to give a narrow zone of about 3° angle in which

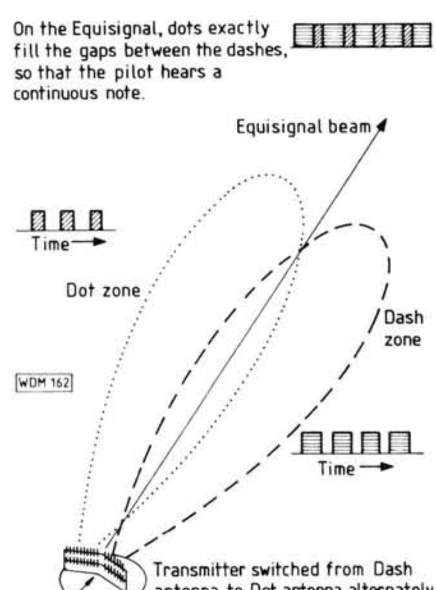
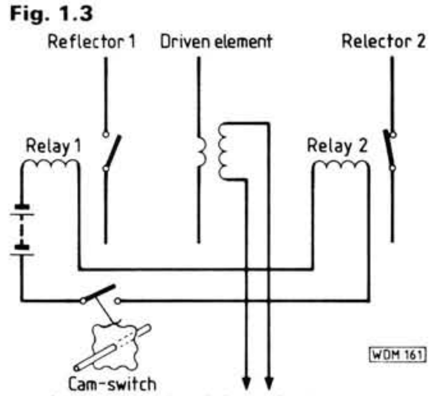


Fig. 1.2

Fig. 1.3


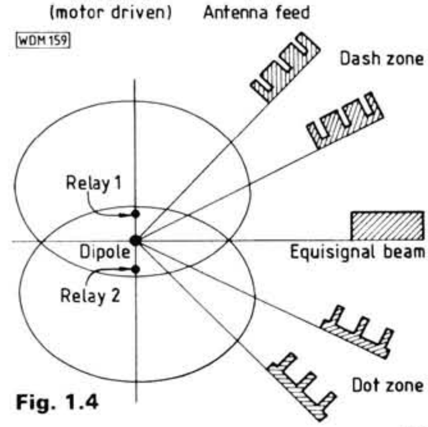


Fig. 1.4

Fig. 1.2: The principle of the Lorenz (Knickebein) beam

Fig. 1.3: The principle of the operating reflectors

Fig. 1.4: The principle of the Lorenz beam system

the dots and dashes were heard as a single note, thus telling the pilot he was on the correct approach. A simple presentation unit was also provided in the cockpit which showed the course-deviation on a meter, and a form of range measurement was furnished by an S-meter arrangement.

Two additional transmitters were employed to aid landing (Fig.1.5). At a point 3km before the runway was an early-approach system on 38MHz with a power of 5W, but having a slower keying rate and a lower modulation note. The second system comprised a transmitter at 300m before the runway, with a higher key-rate and modulation tone. Both these systems operated a lamp on the presentation unit to give further visual indication.

The accompanying aircraft receiver was known as the EB 1 (Blind Landing Receiver 1), which was developed from the earlier EBE receiver. The system was made available to Lufthansa in 1934 and the aircraft were fitted with vertical rod antennas, usually ¼-wave whips. Later, the Luftwaffe produced a specification for what was to be called the Blind Landing System FuB 1, and which required two separate receivers: the EB 1 for signals in the range 30–33.3MHz, and the EBL 2 for 38MHz. All multi-engined aircraft of the Luftwaffe were fitted with these up to 1941.

As war seemed inevitable, in 1938 Dr Lohmann of Telefunken developed a much larger system which was called the FuS An 721. This was an antenna array of metal girders 30m high and 90m long which revolved on a circular iron track; in the middle was a 50-watt transmitter for 30–33.3MHz. The framework supported 16 vertical wire dipoles and reflectors and was arranged at an angle of 165° (looking down on the array), so that 8 2-element antennas were in each leg of the framework. From this "broken neck" appearance, *geknickten* in German, came the code-name Knickebein.

Details of the transmitters and receivers used are, unfortunately, no longer in existence, but the antenna lobes were similar to those shown in Fig. 1.6, except that the narrow equisignal zone was ±0.3° wide and the keying of the dash-dot system had a ratio of 1:7. The improved receiver, another mark of the EB 1 known as the Fu Bl 1, could receive the beam at a range of 500km and a height of 6500m. The principle was that the main beam was directed at a target and the pilot knew he was on course when a continuous note appeared in the receiver; if he strayed to the left a preponderance of dots was heard, and a swerve to the right produced dashes.

By 1940, 10 smaller versions of Knickebein had been built which only required a circular track of 45m diameter, and each leg of the angled frame contained only 4 sets of vertical 2-element arrays which were broadbanded to tune between 30 and 33.3MHz by constructing them from wide-diameter tubing. The range was almost the same in practice as the large Knickebein, although the main beam width was wider at ±0.6°.

As already mentioned, in use the main beam was directed at the target and at a pre-determined point some distance before it was reached it was overlapped by a second beam on a different frequency, thus telling the pilot he was so-many kilometres from his objective. Fig. 1.6 shows the method in more detail.

Although no details remain of the receivers employed, it is known that they were t.r.f. types and, as will be seen later, very susceptible to jamming. For this reason a Dr W. Kloepfer of Lorenz developed a superhet, the EBL 3 H, which needed only slight preparation as it used the same p.s.u. as its predecessor and fitted the same cabinet. This was tunable over a number of channels from 1 to 34 in the spectrum 30–33.3MHz, and could receive the Knickebein transmissions at the same height and range of the earlier model.

Pulling the Crooked Leg

A special unit was set up to counter the beams (which were code-named *Headaches*) under the command of Wing Commander E. B. Addison of No. 80 Wing at Radlett. The technical design of the countermeasures was the responsibility of Dr Robert Cockburn of the Telecommunications Research Establishment at Worth Matravers. Both organisations were accorded the highest priority.

Receivers were placed on top of the masts of certain stations of the Chain Home RDF (radar) system, and the unlucky operators in these dizzy crows' nests were connected by telephone with Fighter Command Headquarters at Bentley Priory.

Professor Jones records how he, too, spent a night on top of one of these towers, listening to the signals which Eckersley had said could not be heard even by a bomber at 20 000 feet over England: *"When about dusk the German beams were switched on, the men in the towers would be able to pick them up and let us know, for instance, if a beam was going between tower 'A' and tower 'B'. That would give us a clue to the beam's position, and one of our chaps would go up in an Anson and fly back and forth until he picked up the beam, which could then be plotted."*

The first jammers were diathermy sets used by hospitals to cauterise wounds. These were requisitioned and tuned to the Knickebein frequencies, and although they only emitted a mush of signals it was thought that they had some effect on the beams. Installed mainly in police stations, they were switched on when ordered by No. 80 Wing.

Fortunately we had acquired the Lorenz licence before the war, so Lorenz transmitters were modified and strategically placed, as were "Meacons", or mock beacons. The Luftwaffe, with more than 80 radio beacons at their disposal in Germany and occupied Europe, began to find radio-navigation an ever-increasing problem. But it was Cockburn's jammers (code-named *Aspirins*) that were most effective. Immensely powerful, they flooded the beams with dashes and the German pilots, flying into their own dash-zones, would steer to find the equisignal only to find Cockburn's dashes. They would continue turning until they found a dot-zone (and Cockburn's dashes) which often synchronised into a false equisignal note. After they had found themselves flying round in circles during bombing raids for a few weeks, they came to realise that we had found and jammed their system. We had, in fact, "pulled the crooked leg". An additional bonus lay

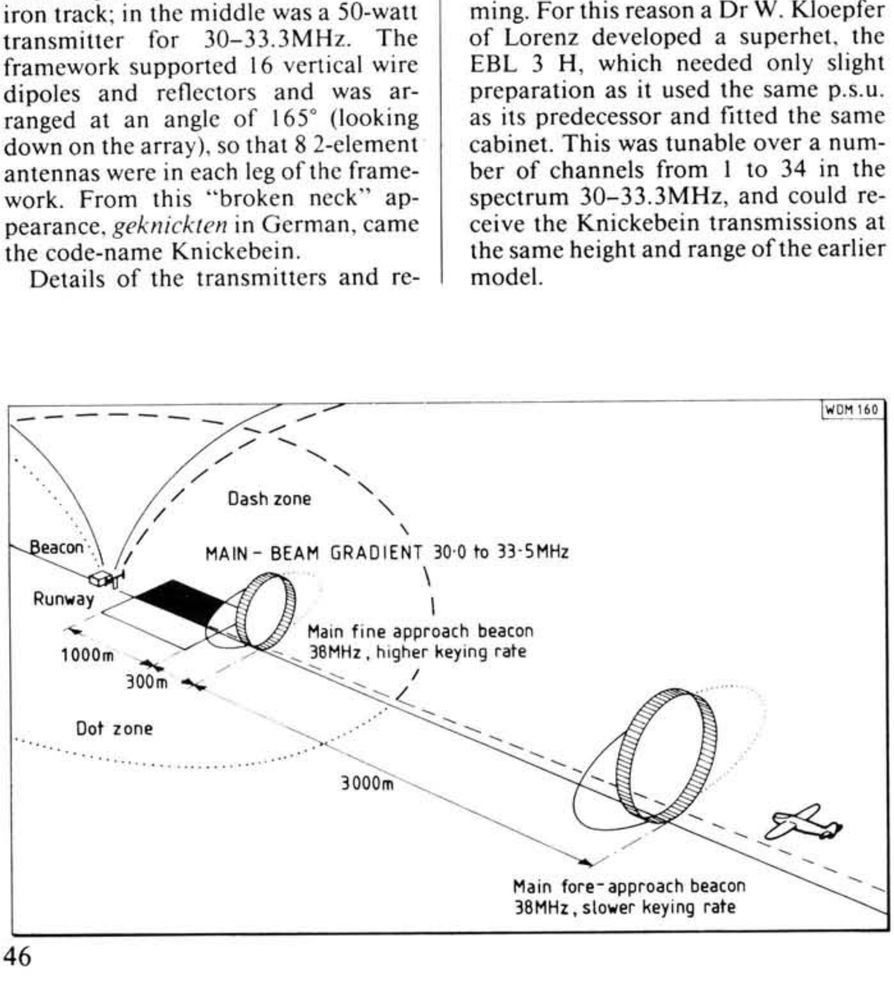


Fig. 1.5: The principle of the Lorenz blind-landing system

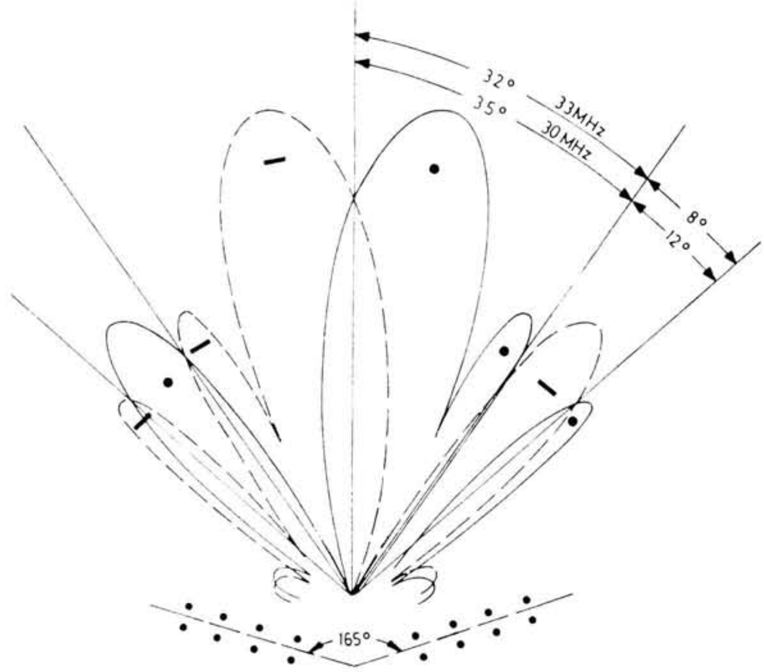


Fig. 1.6: The antenna pattern of the Knickebein array

in the fact that it was several months before the German pilots had the courage to tell Goëring that Knickebein was useless.

Had the system worked successfully a number of bombers could have put a bomb *every 17 metres* into a selected target. As it was our cities suffered a severe mauling from the Luftwaffe: how much worse the loss of life and property would have been but for the efforts of a young physicist who refused to believe the experts, and courageously challenged his superiors.

Today one wonders how many Londoners and citizens of our other major cities have heard of Professor R. V. Jones.

In Part 2 of his series, G4GVO describes how the X-Gerät mystery was unravelled.

FEBRUARY 1988 £1·20

ISSN 0141-0857

Practical Wireless

The Radio Magazine

Build the PW "Orwell" High Performance MW Receiver

Part 1

Directivity Gain in Transmitting Antennas

The ICOM IC-761 HF Transceiver Reviewed

Practical Wireless

The Radio Magazine

FEBRUARY 1988 (ON SALE 14 JANUARY 1988) VOL. 64 NO. 2 ISSUE 971

THIS MONTH

Regular Features

NEXT MONTH

Beginning A New Series For Beginners: Understanding Circuit Diagrams

A "Digital Dial"

The Howes SWB30 SWR/Power Meter Reviewed

plus

All the usual features

Don't miss it—place your order with your newsagent now!

On sale February 11

Contents subject to last-minute revision

Editorial and Advertisement Offices:
Practical Wireless
Enefco House
The Quay
Poole, Dorset BH15 1PP
☎ Poole (0202) 678558 (Out-of-hours service by answering machine)
Prestel 202671191

Advertisement Manager
Roger Hall G4TNT ☎ 01-731 6222

Editor Geoff Arnold T.Eng FSERT G3GSR
Assistant Editor Dick Ganderton C.Eng. MIERE G8VFH
Art Editor Steve Hunt
Technical Features Editor Elaine Richards G4LFM
Technical Projects Sub-Editor Richard Ayley G6AKG
Editorial Assistant Sharon George
Technical Artist Rob Mackie
Administration Manager Kathy Etheridge
Clerical Assistant Claire Horton
Accounts Annette Martin

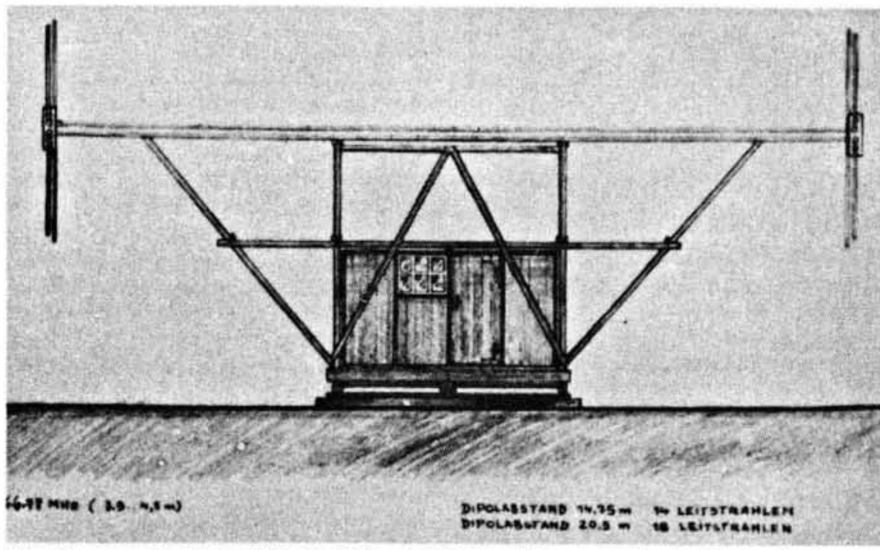
Feature

The Battle of the Beams–Part 2

D. V. Pritchard Dip Ed G4GVO continues the story of the "Crooked Beams" as he tells us about X-Gerät—The Secret Apparatus.

As early as 1934, when *Knickebein* was in its infancy, a German scientist began to have doubts about its efficiency if exposed to jamming. He was Staatsrat (Privy Councillor) Dr H. Plendl of the Deutsche Versuchanstalt für Luftfahrt (German Aeronautical Research Establishment) and he began to produce designs for a new system for accurate blind bombing.

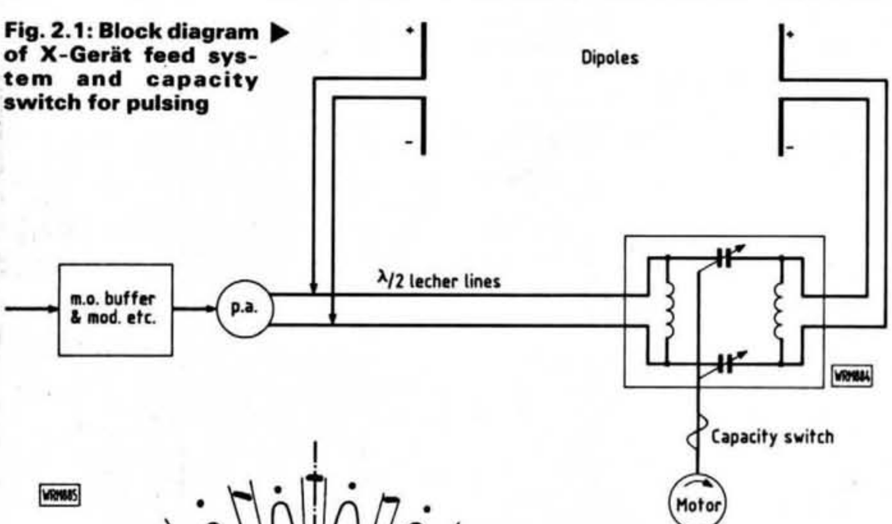
Under his leadership, a new department was formed at Rechlin (the German equivalent of Farnborough) which began research in June of that year. This was in co-operation with another department led by a Dr W. Kühnold which was also engaged on beam techniques for blind landing. The beams of Kühnold's system, however, had an aperture angle of about 5°, corresponding to an 8km beamwidth at a range of 100km, and were clearly unsuitable for accurate pin-pointing of targets. Obviously a beamwidth of not more than 0.1° was required and this, at that time, could only be attained with reasonable antenna dimensions and suitable power if a frequency between 66 and 77MHz was employed. Accordingly, experiments were begun with an 80-watt transmitter designed by a Dr Ochmann which was code-named *Bertha 1*, but as this was not powerful enough a second was designed, *Bertha 2*, which delivered 500W and was tunable over the required range.



The layout of a typical X-Gerät installation with operating cabin and antenna array of a rotating platform **Photographs by courtesy of Fritz Trenkle**

Preliminary tests carried out over Lake Müritz near Mecklenburg in 1935 resulted in ranges of only 1500m. Stationary beam antennas which could be phased to swing through about 10° were used, and the airborne equipment consisted of two t.r.f. receivers developed at Rechlin and an analyser for unlocking the 2000Hz modulated dot-dash system of the adopted and improved Knickebein apparatus. Unfortunately full details of both transmitter and receivers are no longer available.

Fig. 2.1: Block diagram of X-Gerät feed system and capacity switch for pulsing



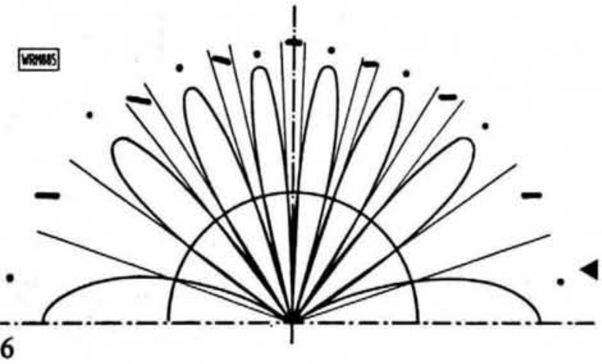


Fig. 2.2: Antenna pattern of X-Gerät system

Wotan 1

By 1938, the system had been greatly improved. Dr Kühnold had developed ground installations capable of easy dismantling and removal, with an operating cabin and antenna array mounted on a platform which could rotate through 360°. The antennas were mounted on a gantry and spaced at 14.75m (3.5 wavelengths). Originally, simple half-wave dipoles were employed, but before long directors and reflectors were added for extra power and range; these were energised with pulses at 120 per minute via a vacuum switch (soon replaced by a capacitor, nicknamed a "mill switch", designed by Dr K.H. Fischer). The schematic block diagram of this system is shown in Fig. 2.1 A half-wave Lecher line is used in conjunction with the "capacity" switch and its associated inductances to pulse both dipoles with the required dot-dash sequence.

The array generated a fan of 14 beams each with a bandwidth of 0.05° (Fig. 2.2), and 8 of these installations were erected in Germany, followed by many more on the coasts of occupied Europe. By now the airborne equipment had also been drastically improved by Dr H. Hanel and Dr Rücklin of Telefunken, who had designed and developed a superhet for 66 to 77MHz (code-named *Anna*), while an analysing system designed by Dr Plendl known as the AVP (Anzeige-Verfahran von Plendl) was being mass-produced by Siemens.

At the same time a Dr K. Müller set up a Mobile Research Unit which produced some versatile mobile stations under the code-name *Möbelwagen* or "Furniture Vans". He was also responsible for the clever camouflaging of their antenna—a feature which was later to prove troublesome for British counter attacks.

The complete system was known as *Wotan 1.*

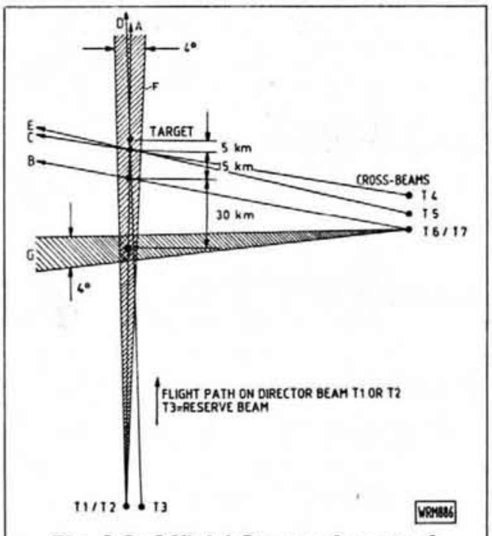


Fig. 2.3: Official German layout of the X-Gerät system

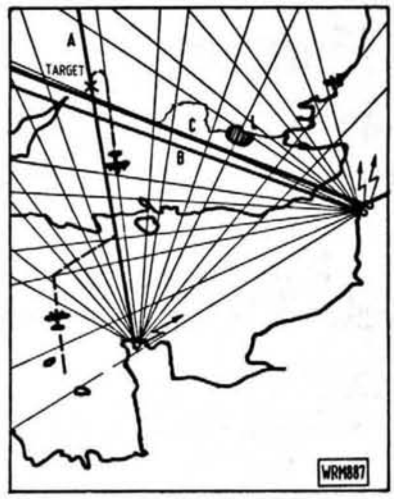


Fig. 2.4: German layout of beams showing main beams and associated fans

Principle of Operation

One of the 14 beams was selected to act as a director beam which, on being aimed towards the target, provided a flight-path for the aircraft; this system was similar to Knickebein in that the pilot could plot his course according to a direction indicating meter which told him if he was right or left of the beam. The official German layout of the beam approach system and its associated cross beams at points before the target is shown in Fig. 2.3, while Fig. 2.4 represents not only the director beam and reserve beam, but also the cross beams and the associated fans of beams which enabled stray aircraft to plot their courses to the correct one. The main beams of the system used for the devastating raid on Coventry in 1940 is shown in Fig. 2.5, and Fig. 2.6 is another official German layout showing the disposition of all beam systems in use at that time. (In this series the author has concentrated only on the more widely known systems.)

In practice the bombers did not fly along the director beam immediately after take-off, but used either normal navigational methods or one of the fan beams in order to present a smaller target for British radar and to try and cause confusion. The director beam was usually joined sometime after crossing the English coast.

At approximately 30km before the target, the aircraft would encounter the coarse advanced cross beam which, like the other beams, was similarly pulsed with dots and dashes but on a different frequency. Before reaching this point the bomber's radio operator would have consulted a table giving the characteristics of his particular type of machine and fed them into a combined calculator and stopwatch called the *X-Uhr*, or "X-Clock". This was an incredibly accurate mechanism designed at Rechlin by a Dr Hepper. A small upper dial on the left-hand side showed how long the instrument had been running, while the lower dial was used for calculating the "flight-path ratios"—that is to say, information about the aircraft's type, height and speed was inserted to give a flight-path ratio of, say, 2.78:1 for 18km, or 3:1 for 6km according to circumstances.

On arriving in the dash-zone of the advanced cross beam the operator would listen for the (very brief) continuous note produced by the merging of dots and dashes, and press the clock's top button. This started the green "minute" hand and the black sweep-hand simultaneously and, according to the inserted data, the time taken for the bombs to drop was now fed in.

◀ **Fig. 2.5: The X-Gerät system for K. Gr. 100**

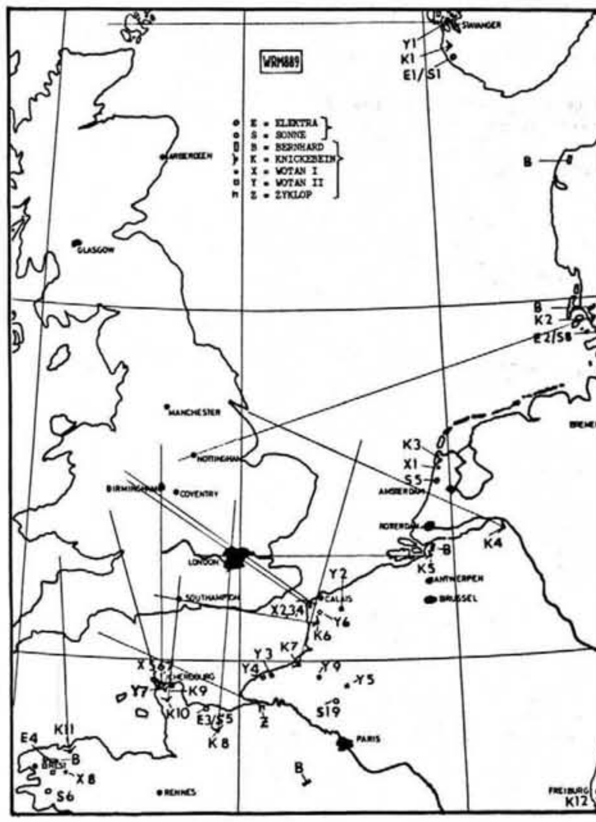


Fig. 2.6: Official German layout showing the disposition of all beam systems in use at that time ▶

At the "fore-cross-signal" a button on the left was pressed whereupon the green and black hands stopped and the red "hour" hand started. By pressing the third button at the main cross beam the red hand would stop at the same point as the previous ones and, if the correct data had been given, the bombs would be automatically released.

After tests by a research squadron, the system was finally installed in Ju 52's and He 111's of *Kampf-Gruppe 100*, a Group led by an outstanding Luftwaffe officer, Major Viktor von Lossberg. Quarter-wave whips were mounted on top of the fuselage behind the cockpit and these, in conjunction with the whip antenna for RT operation which was situated further back, gave rise to the nicknamed "Three-master".

The airborne equipment was installed in the radio operator's position and repeaters for the course meters were fitted in the cockpit for the pilot's benefit. A motor generator fed from the aircraft's batteries (rotary converter) was placed at the bottom of the installation and immediately above it were two audio units, to the left of which was the power distribution panel and, above, the twin receivers for the director and cross beams, the Anna receiver being on the right.

Intelligence Breakthrough

The phone shattered Dr R.V. Jones' sleep in the early hours of a morning during the first week of September, 1940.

"We've got something new here! God knows what it is, but I'm sure it's something for you!"

The excited voice of Professor Frederick "Bimbo" Norman, a cryptographer at Bletchley Park, shook Jones into consciousness. They had broken some new Enigma traffic in which radio beams were mentioned, including the information that the beam-width was 8 to 10 seconds of arc, or an angle of 1:20 000, suggesting that *the beam was no wider than about 20m at 320km!*

Then came the electrifying word X-Gerät! Whatever X-Gerät was, it was being installed in aircraft of Kampf-Gruppe 100, one of the Luftwaffe's crack squadrons.

Jones hustled the intelligence services into greater activity. Across the Channel the Resistance organisations pulled out all the stops, and British Signals Intelligence (including Voluntary Interceptors—a body of dedicated radio amateurs) doubled their efforts. Their activities prompted Jones to record his appreciation: *"Our community of radio amateurs in Britain was to prove an invaluable reserve, both in Signals Intelligence and Signals proper, as well as furnishing many of the staff for our rapidly increasing number of radar stations".*

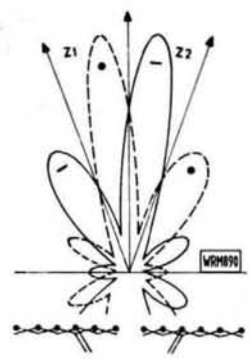


Fig. 2.7: Beam patterns of mobile X-Gerät

It was that well-known amateur of his day, Rowley Scott-Farnie G5GI, then an officer in RAF Signals Intelligence and a close friend of Jones, who reported beam signals from the Calais and Cherbourg areas around 70MHz. By September 24, 6 beam stations were identified: 2 north-west of Cherbourg, 3 near Calais and the last near Brest. The Germans had code-named them *Weser, Spree, Rhein, Elbe, Isar* and *Oder*. Evidently K.Gr.100 was working through a book of numbered targets and by the time the stations were identified Jones had the actual directions for the beams—and even that the Germans had specified them to the nearest 5 seconds of arc, *an accuracy of about 10m at 320km!*

But how could such an accuracy be possible on 70MHz?

The "Anna" Numbers

Further decoded German transmissions revealed the existence of coarse and fine beams, including a mention of centimetres. This latter, however, referred to the precision with which a monitoring vehicle had to be positioned to orientate the director beam. Frequent mention of something called "Anna" was made, usually associated with a number between 10 and 85, and often a multiple of 5. By October 17, Jones had collected 10, 15, 25, 30, 35, 44, 47, 55, 60, 75 and 85. Another set of numbers gave crystal frequencies (typically 8750kHz, since 8750kHz × 8 = 70MHz) and he suspected that Anna referred to the dial on the aircraft receiver, if not the aircraft itself. Since one set of numbers ended in 0 or 5, and the other in 0 or 0.5, simple deduction showed that the Anna reading had to be divided by 10 and either added to, or subtracted from, a constant number.

Learning from the Enigma traffic that a certain Feldwebel Schumann at a beam station at den Helder had signed a return for 3 crystals for 69.5, 70 and 71.1MHz and that his station was ordered to transmit on Anna numbers 30 and 35, it was clear that the constant had to be 66.5 if one-tenth of the Anna number had to be added, or 73 if it had to be subtracted. As he knew that crystals for 75MHz existed, the second possibility could be dismissed; and when he obtained further confirmation from the two crystals whose frequencies were not exact or half integers, the problem was solved. Other information that emerged from the Anna numbers was that both the coarse and fine beams lay between 66.5 and 75MHz.

Measurement Inaccuracy

The immense value of Anna numbers was that if the transmitted orders to the beam stations could be decoded in time, he could then tell 80 Wing the frequencies to be jammed. Incredibly, his interpretation of the numbers was rejected because our monitoring services thought there were frequencies outside the range he had found. Dr Jones' hackles rose—a posture they were seldom slow in assuming—and plain words were spoken. *"These, it transpired, were due to bad measurement of the frequencies of the German beams on the part of the countermeasures organisation, a feature that was to plague us through the whole battle. The fault in this case probably lay not with the observers, but with the calibration of our receivers which were not up to the German standards of precision".* His findings were accepted.

Dr Robert Cockburn of the Telecommunications Research Establishment, having successfully prescribed "Aspirins" for the Knickebein "Headaches", now developed "Bromides" for this new system which was code-named "Ruffian". We now knew that the director beam was radiated from near Cherbourg and the cross beams from the Calais area; as insurance against the failure of the main director beam (Weser) a reserve beam was provided by the adjacent station (Spree). The accuracy of the beams was so great that in calculating their paths it was necessary to take into account that the earth is not a sphere, but flattened towards the poles; this made a difference of 275m in where a beam from Cherbourg would cross London!

Countermeasures and Counter Arguments

Cockburn's jammers came into operation in October, but at this time K.Gr.100 began to drop flares over its targets and this was hailed by some of Jones' antagonists as proof that the beams didn't work, or that the Germans were so unsure of them that they were using flares to find out where they were. However, Jones silenced these critics by pointing out that there was no evidence that K.Gr.100 was upset by our countermeasures (which was true) and were not only using the system, but acting as pathfinders for other Luftwaffe groups.

Yet other problems had to be overcome.

If the Enigma transmissions to the beam stations could be broken in time (they were usually sent out in the afternoon preceding a raid) we would know where and when K.Gr.100 was going to attack, and our fighters could be ready for them; our jammers, too, could be set on the correct frequencies. For this to be possible the cryptographers at Bletchley Park strained all their resources—and it was a *magnificent* effort, for they achieved this incredible feat late in October. Dr Jones was then able to tell Fighter Command the exact place of the attack, the time of the first bomb to within 10 minutes, the exact speed of the bombers, their line of approach to within 90m, and their height to within 2 or 3 hundred metres!

Yet our night fighters repeatedly failed to find the enemy. Jones wrote: *"I almost began to wonder whether the only use the Duty Air Commodore made of my telephone calls was to take a bet with the rest of the Command as to where the target would be for that night"*. On top of this was the growing suspicion that our jamming was not working. Why not?

The answer soon came—but not before tragedy struck.

Moonlight Sonata

On November 10 Jones received an Enigma decrypt of a transmission to the beam stations which told them to prepare operations against target numbers 51, 52 and 53, giving the beam settings at the same time. It took only a few minutes to work out that 51 was Wolverhampton, 52 was Birmingham, and Coventry was 53. Then another signal was passed to him which contained orders for a major operation under the code-name *Moonlight Sonata*. Four target areas were mentioned but there was no indication of the *order* of the attacks. Frantic guesses were made by the Air Staff and the best they could come up with was that Moonlight Sonata might mean a target in southern England. Strangely, no attack had been made on Wolverhampton, and on November 14 everyone braced themselves for the coming night and whatever Moonlight Sonata might mean.

Tragically, it was one of those afternoons when Bletchley Park failed to break the Enigma signals in time, and 80 Wing asked Jones which frequencies should they set their jammers on, giving a list of frequencies as determined by our monitoring aircraft. *"I could see at once that the measurements must be wrong, in that they did not match up with the figures I knew from the Anna code. I therefore made a mental correction of the measurements as far as I could—for example, 68.6 should have been 68.5, if our receivers had been properly calibrated, or 70.9 should have been 71.0. But deciding what, for example, 66.8 meant was more of a lottery. The only other clue that I spotted was that there seemed to be a convention that the director beams would generally be on frequencies between 66.5 and 71.5 and the cross beams between 71.5 and 75.0MHz, the division being presumably due to operational convenience. Remembering that we needed to knock out the main and reserve director beams and at least one of the cross beams, I then made my mental gamble and suggested a set of frequencies to Addison which he said he would adopt. All this took no more than five minutes on the telephone: but I was well aware that in these snap decisions I was probably gambling with hundreds of lives. Sobering though this thought was, the fact remained that someone had to do it, and I was easily in the best position."*

Then on the night of November 14/15 Coventry was attacked, with heavy civilian casualties. What had gone wrong? The next day the decoded Enigma signals to the beams stations arrived and Jones' wretchedness turned to bewilderment. He had guessed the frequencies correctly—so where was the failure?

Incompetence and Carelessness

The failure arose originally from a silly inter-service squabble which led on to a ghastly mistake. On November 6 one of K.Gr.100's Heinkels became lost over southern England and ditched on Chesil Beach. The Army took over, secured a rope around the fuselage and set about salvaging it, when a naval inshore vessel arrived and demanded to know what the Army thought it was doing. As the aircraft was in the water salvage was a Navy matter and, taking the rope aboard, dragged the aircraft deeper into the sea, breaking the rope in the process. The X-Gerät equipment aboard, now heavy with silt and corrosion, was fortunately discovered and rushed to 80 Wing and then on to Farnborough for investigation.

On November 21 Jones, accompanied by Scott-Farnie and their assistants, went to see it for themselves. They learned that Farnborough had examined the audio filter and found it set to 2000Hz. But our jammers had been modulated at *1500Hz*, which meant that while our carrier frequencies were correct the modulation tone had no effect on the beams.

"It was one of those instances, of which I have since found many, where enormous trouble is taken to get the difficult parts right and then a slip-up occurs because of lack of attention to a seemingly trivial detail. Of all the measurements in connection with the German beams, easily the simplest was to determine the modulation note, because this could be done at any time in comfort; and yet whoever had done it had either been tone deaf or completely careless, and no one had ever thought of checking his measurements. I was so indignant that I said whoever had made such a mistake ought to have been shot." It is hard to believe that the citizens of Coventry would have disagreed with this opinion.

Jones' anger was further increased by the fobbing-off he encountered. He was told that the modulation note was originally 1500Hz but the Germans had changed their filters to avoid jamming. This ridiculous excuse was countered by Jones who pointed out that if that had been the case we would obviously have heard the change in note for ourselves. In any event he was able to prove that K.Gr.100 had been using the same filters since the start of their operations.

On his insistence the jamming modulation frequency was changed and when, later, the Germans attacked Birmingham their bombs fell wide of the target, most of them outside the city. Gradually they came to realise we had broken X-Gerät and their confidence in the system diminished, and Britain which knew nothing about Dr Jones and his scientific war went on "business as usual".

In Part 3, G4GVO tells how Wotan's "other eye"—the Y-System—was successfully countered.

ERRORS & UPDATES

Letter—"Morse" January 1988

The Morse code equivalent of "ES" is, of course, "dit di-di-dit", and not as was shown on page 14 of that issue in the letter about American Morse.

Making Waves, Part 2 January 1988

The decibel equivalent of 50 picowatts is −103dBW, not as shown in the third column of page 52, where the minus sign became separated from the figures.

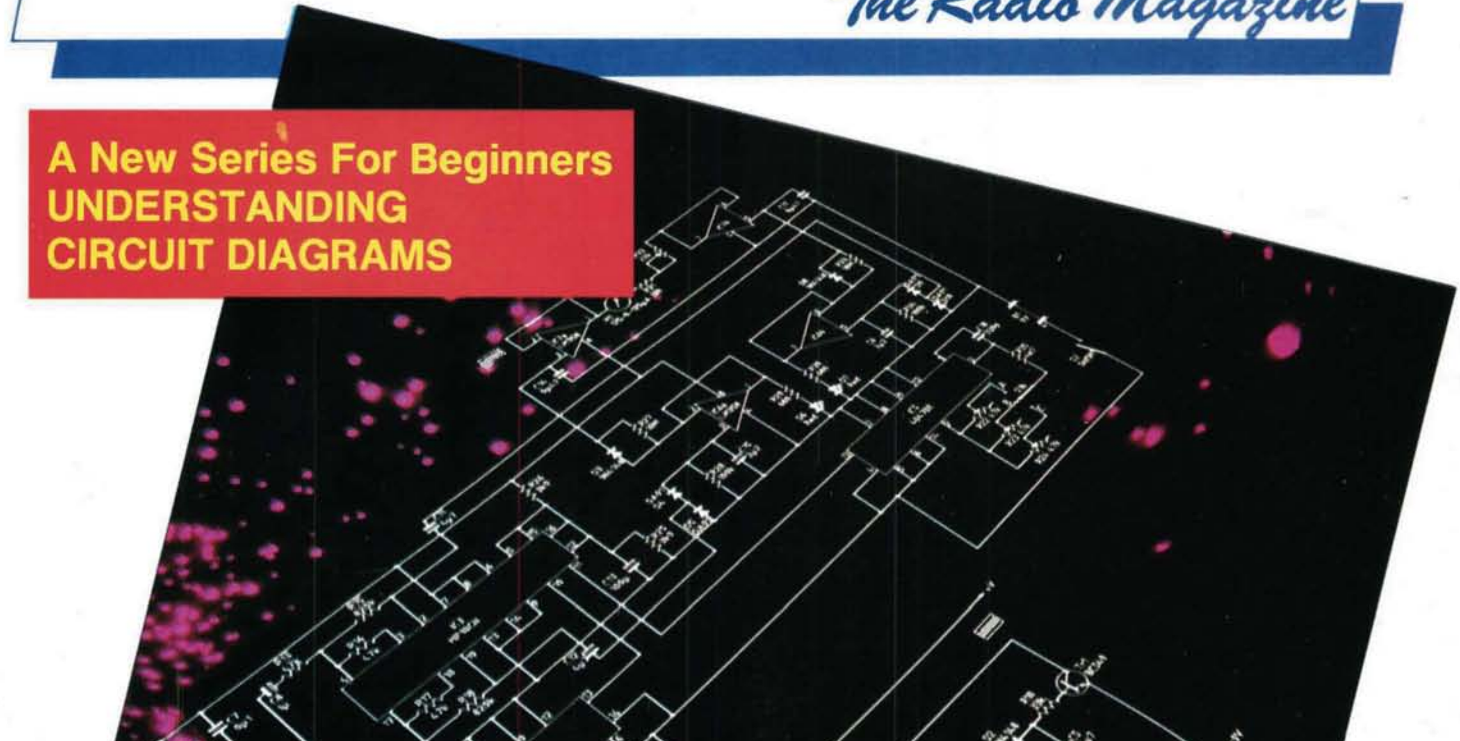
Practical Wireless

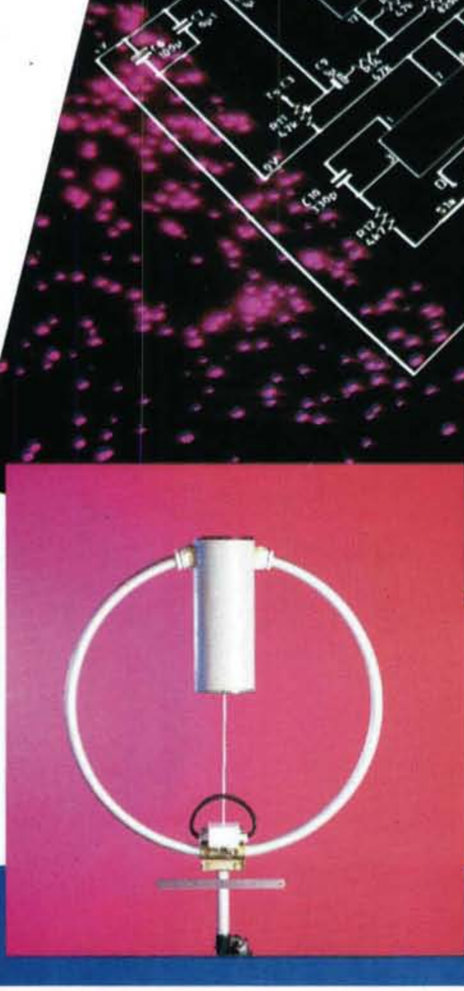
MARCH 1988 £1·20

ISSN 0141-0857

The Radio Magazine

A New Series For Beginners
UNDERSTANDING CIRCUIT DIAGRAMS





Reviewed
The Howes SWB30 SWR/Power Meter

WIN A £390 Cap. Co Magnetic Loop!

Practical Wireless
The Radio Magazine

MARCH 1988 (ON SALE 11 FEBRUARY 1988) VOL. 64 NO. 3 ISSUE 972

THIS MONTH

We are sorry that, due to technical difficulties, the promised article about a Digital Dial has had to be held over until next month

Regular Features

NEXT MONTH

A Modular VHF Monitor Receiver

A "Digital Dial"

The Alinco ALX-2E 2m Handheld Reviewed

plus

HF Beacon Chart Pull-out

Don't miss it—place your order with your newsagent now!

On sale March 10

Contents subject to last-minute revision

Editorial and Advertisement Offices:
Practical Wireless
Enefco House
The Quay
Poole, Dorset BH15 1PP
☎ Poole (0202) 678558 (Out-of-hours service by answering machine)
Prestel 202671191

Advertisement Manager
Roger Hall G4TNT ☎ 01-731 6222

The Battle of the Beams–Part 3

Ever since 1939, Dr Plendl of the German Aeronautical Research Establishment entertained doubts about the effectiveness of X-Gerät in the face of strong jamming; accordingly, schemes for a new system were put in hand at that time. D. V. Pritchard Dip Ed G4GVO concludes this most interesting story.

Ideally, such a system would have only one director beam for the guidance of the bomber and another for a range-measurement system which would enable ground control to drop the bombs accurately. Clearly improved accuracy would be needed, and it was possible that owing to the nature of the system the number of aircraft on the beam at any one time would be necessarily low.

Early Experiments

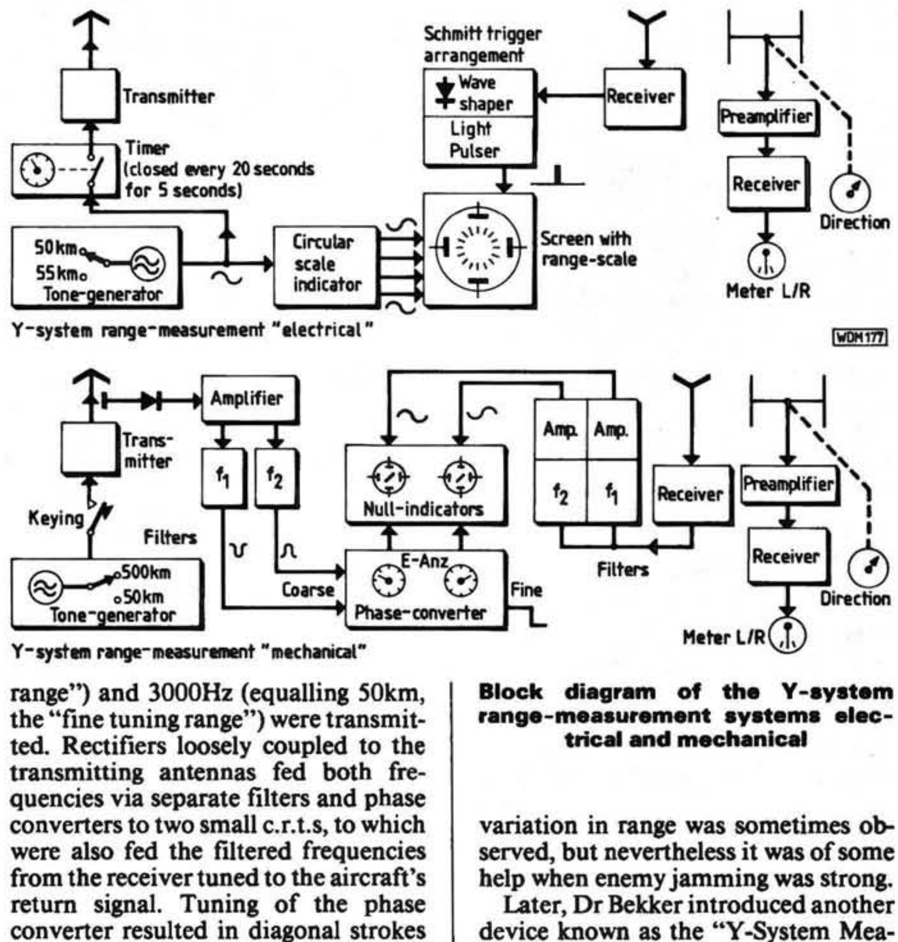
Since the only aircraft receiver available was the FuG 17 (42 to 48MHz), a multi-beam beacon was designed for it by a Dr Herzog of the Götz Company and given the code-name *Wotan 2.* A system similar to X-Gerät was also built which used the *Bertha 1/–2* television transmitter, with similar pulsing and modulation having a dot-dash ratio of 1:7 modulated at 2000Hz. Plendl's analyser was also employed: this system was envisaged as the director beam for the aircraft's flightpath.

For range-measurement another special "dash-system" was developed at Rechlin. A transmitter tunable between 42 and 48MHz was modulated for 10 seconds at 300Hz, its signal being received in the aircraft on a later mark of Herzog's receiver—now the FuG 17 E and on the German production line. Its output was fed through a tone filter and the resulting note modulated an airborne transmitter which returned the signal to the ground on another frequency in the 42 to 48MHz range. There the returned modulation note was compared with the original one sent from the ground and the phase difference, after deduction of the time lag in the aircraft's equipment, gave a direct measure of the range between the ground transmitter and the aircraft.

Different Ideas

In fact several systems were tried for the early Y-System, but the one chiefly employed was the "Y-Range Measuring System Mechanical" developed by Dr H. J. Schmidtmann at Rechlin and a Dr Jenns of Siemens. Two tone frequencies of 300Hz (corresponding to 500km, the "coarse measuring range") and 3000Hz (equalling 50km, the "fine tuning range") were transmitted. Rectifiers loosely coupled to the transmitting antennas fed both frequencies via separate filters and phase converters to two small c.r.t.s, to which were also fed the filtered frequencies from the receiver tuned to the aircraft's return signal. Tuning of the phase converter resulted in diagonal strokes appearing on the screens which served as null-point indicators, and range was read from a scale marked in kilometres.

Siemens also produced a range-measurement known as the *Electrical Notebook* which recorded the ultimate range of five simultaneously measured aircraft. This incorporated a fine-measuring system devised by a Dr Bekker which used a larger c.r.t. with a circular range-scale showing a range from 0 to 20km. A transmitted tone of 7500Hz generated a "dark pulse" circular time zone calibrated against a further circular "bright zone", the phase-converted voltage from the receiver being then transformed into a pulse which the electron beam converted into light-points so that a change in range could be observed directly. This system was somewhat unreliable in that a 5km variation in range was sometimes observed, but nevertheless it was of some help when enemy jamming was strong.



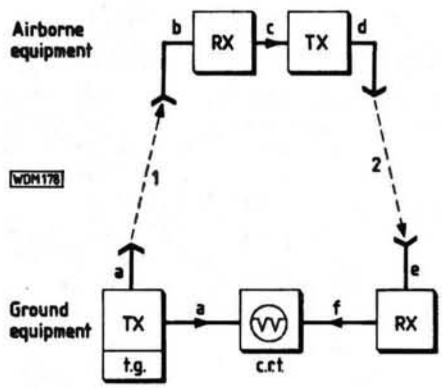
Block diagram of the Y-system range-measurement systems electrical and mechanical

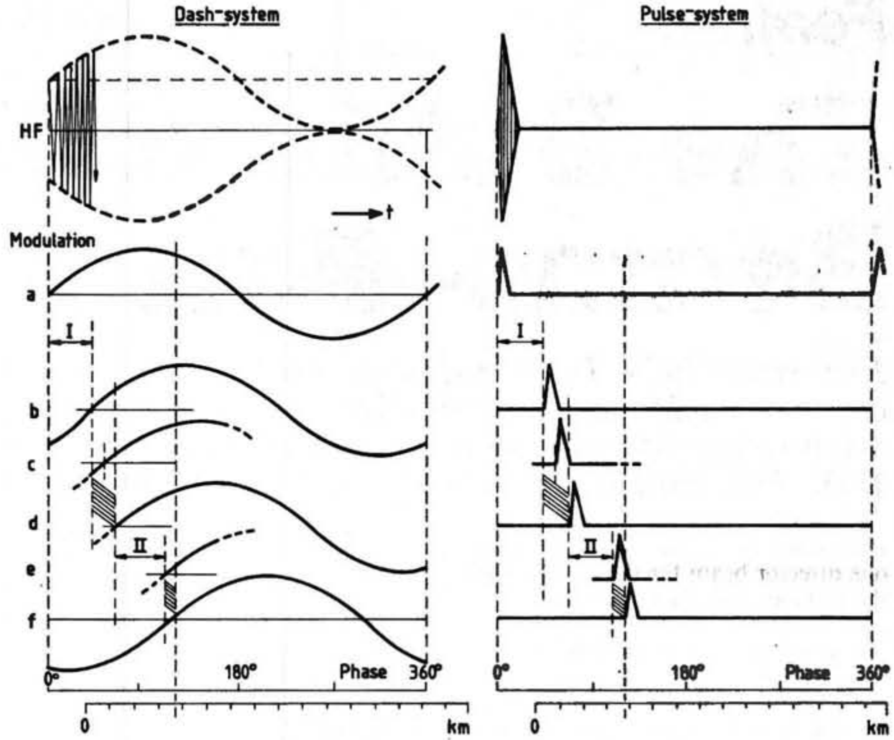
Later, Dr Bekker introduced another device known as the "Y-System Measuring Electrical" which was produced by the Graetz Company. A modulation note of 300Hz corresponded to 50km, but it could also be used for an indication at, say, 20km and by switching to a frequency 10 per cent higher the range was extended to 32km, and so on. Little more, unfortunately, is known about this method.

First Trials

These systems were, however, only useful at first for random location: only an all-round representation of an aircraft was given. For example, the aircraft flew to a given point by standard navigational methods and its range was then measured by these various electronic systems. Its approach to the point was ascertained by coupling the system to an ultra-short-wave Adcock

1—Outward Beam. 2—Return Beam. t.g.—tone generator. TX—transmitter. RX—Receiver. c.r.t.-c.r.t. with range scale. The running-time inside the equipment is shown on the shaded parts of the graphs, the range-scale is therefore displaced by this value on the right-hand graph





General layout of the Y-system with graphs of range, modulation and timing

direction finder, code-named *Heinrich*. Variants of the earlier X-Gerät system were often incorporated wherein a director beam was used, but where the old cross beams would have been empoyed instead of the X-Uhr combined clock/calculator would indicate the precise timing according to range-measurement from the ground. On approaching the bomb-release point the X-Uhr received a nine-second Morse signal and on the last dot the bombs were released.

Final Form

Under the direction of Dr Plendl a development was devised from this method by Dr Herzog in 1940. This new system retained the code-name Wotan 2, the full title of which was the "Y-Double-Beam Beacon System" and included parts of the multi-beam system already described.

Although the same rotating installation with transmitter and operating cabin was used, new antennas were introduced with seven parallel dipoles and reflectors which generated a long club-shaped lobe with smaller side lobes. At a half-wavelength in front of these were two further dipoles spaced at a wavelength apart which, on an opposite phase, produced a "washed out" cardioid pattern; thus two sets of beams were sent out, one for the flightpath to the target and the other for the aircraft's return.

Keying the system was originally effected by mercury switches or vacuum relays, but as they gave rise to key-clicks they were replaced by the so-called "capacitive mill" designed by a Dr Escherish. This was a motor-driven differential capacitor which used a light bulb to take the transmitter load between the pauses in transmission. The long-lobed directional antennas were keyed at 176 pulses per minute, followed by the cardioid-shaped dipoles; this resulted in a slower dot-dash pulse with much shorter gaps at a ratio of 8.8:1, and was acoustically more acceptable.

In addition, a new receiver based upon Herzog's FuG 17 E was developed by Dr H. Donn and Dr W. Hepper and designated the FuG 28a; manufactured by the Heliowatt Company, this was combined into one unit with Plendl's improved AW 28 analyser. This latter contained a motor driving a cam making 180 contacts per minute which conducted the receiver output to two series-connected capacitors: their differential voltages then biased the grids of two valves so that one was bridge-switched and a balance existed if the field strength of the two pulses from either transmitter was the same—that is, if the aircraft was found on one of the two beams. Variation to left or right gave opposing bridge currents with corresponding responses on the indicating meters.

The gap between transmissions in each case caused a magnetic coupling between the motor and the switch to drop and only to be re-instated when the next cycle of transmissions commenced. In this way a positive synchronisation between the ground station and the aircraft was established. To position himself on the correct beam the pilot switched on his equipment which also incorporated a sensitive (and heavy duty) relay with an extra winding. The relay operated according to course variations by switching over the polarity for left and right directions: thus the motor would be in the correct rotation sense when switched on until a potentiometer connected between the motor and the additional winding on the relay delivered sufficient voltage to release the relay.

The Y-System could probably have been the most effective (if not dangerous) system of all the German beams had it not been for one small item the Germans, in spite of their customary thoroughness, had somehow overlooked . . .

Norse Mythology —The Give-Away

As early as June 1940 when Dr R. V. Jones had final proof of the existence of Knickebein he received an Enigma decode from Bletchley Park: *It is proposed to set up Knickebein and Wotan installations near Cherbourg and Brest.*

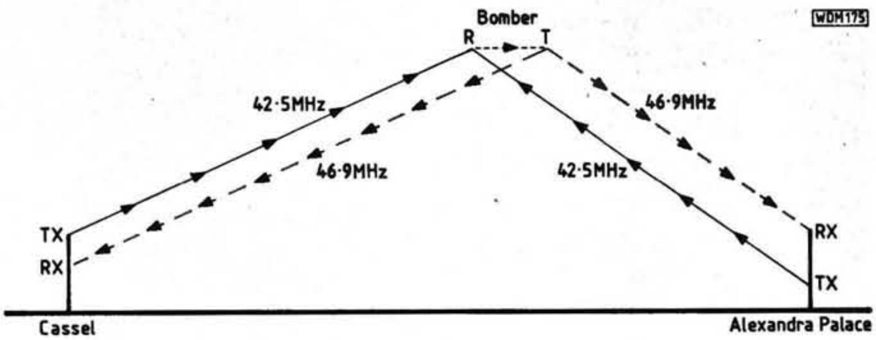
Wotan was certainly something new, but what did it mean? He knew that Wotan was the greatest of the German gods, but was there anything unusual about him—what attributes did he possess that moved the Germans to use his name as a code-word?

Jones phoned his friend Frederick "Bimbo" Norman, Professor of German at King's College, London, then one of the cryptographers at Bletchley Park. "Bimbo" was renowned for his lightning-fast mind and at once gave proof of it.

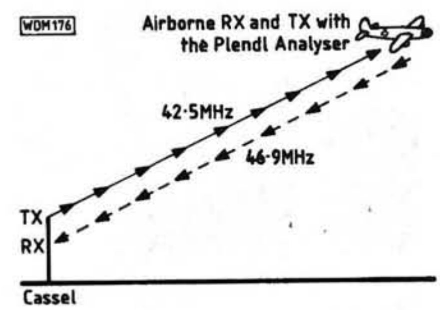
"Yes, Wotan was the chief German god—wait a moment, he had only one eye . . . One eye—one beam! Can you think of a system that would only use one beam?"

Dr Jones could, in principle; but it was not until the end of 1940, when X-Gerät was finally mastered, that he and his assistant Dr F. C. Frank suspected that another German beam system might be making its appearance. Could this be the Wotan they were looking for? The new system seemed to involve a director beam plus a means for ranging and Jones' suspicions were aroused when on October 6 an Enigma transmission to what appeared to be a station called "Wotan 2" north-west of Cherbourg read: *Target No. 1 for "Y" co-ordinates 50°41'49.2" north, 2°14'21.2" west.*

Study of a map revealed these to be the co-ordinates of an army depot at Bovington in Dorset, and they showed a great difference from the X-Gerät system in which a number of beam directions were always sent out, each station having to set its beam in the required direction. With this new method, however, the position of the target was given to a single station which suggested that the station had the entire means of directing the bomber to its target. This seemed to be confirmed when Bovington was attacked a few days later by two aircraft with results which, though somewhat inaccurate in direction, were good as regards range.



The method of interfering with the Y-beam system



Ranging principle of the Y-system

Frequencies and Cyphers

Signals Intelligence and our monitoring services soon began to report the existence of beams on frequencies between 40 and 50MHz which had very different characteristics from Knickebein and X-Gerät. Instead of the left and right transmissions being modulated with dots and dashes, the emissions were of equal duration except for a short pause in transmission when one signal, for example the left, came directly after the pause and the other signal followed in a sequence thus: pause—left, right, pause—left, and so on.

Dr Robert Cockburn and his assistants at the Telecommunications Research Establishment put the signal on an oscilloscope and immediately observed its principle. The beam emitted three directional transmissions per second and seemed to have been designed to operate a beam-flying indicator in the aircraft. As things turned out, more surprising developments were to be revealed.

Jones discovered that the aircraft using the new system were not from K.Gr.100 but from the Third Group of KG 26. He also learned that the scientist who had developed the system was none other than Dr Plendl who had devised X-Gerät. Plendl was the German equivalent of T. L. Eckersley, our leading radio propagation expert, and when Jones asked Eckersley what he thought of Plendl he replied, "He's not much good, he bases his theory on experiment!"
(Amateurs please note!)

On 19 January 1941 an aircraft of KG 26 was shot down and though it was badly damaged it could be seen that it carried equipment similar, though not identical, to X-Gerät. But of greater significance was the charred radio operator's notebook:

Loge	*244*	*142*	*10*
Schmalstigel	*454*	*149*	*11*
Bruder	*372*	*120*	*11*
Suden	*272*	*117*	*11*
Bild	*405*	*137*	*11*

Rückflug

Knowing that KG 26's base was at Poix, south-west of Amiens, and that "Loge" was the German code-name for London, Jones and Charles Frank were able to make the following interpretation:

Objective	*Distance to Poix*	*Rhumb Bearing to Poix*	*Magnetic Variation*
London	*244km*	*142°*	*10°*
Sheffield	*454km*	*149°*	*11°*
Bristol	*372km*	*120°*	*11°*
Southampton	*272km*	*117°*	*11°*
Birmingham	*405km*	*137°*	*11°*

Homeward flight

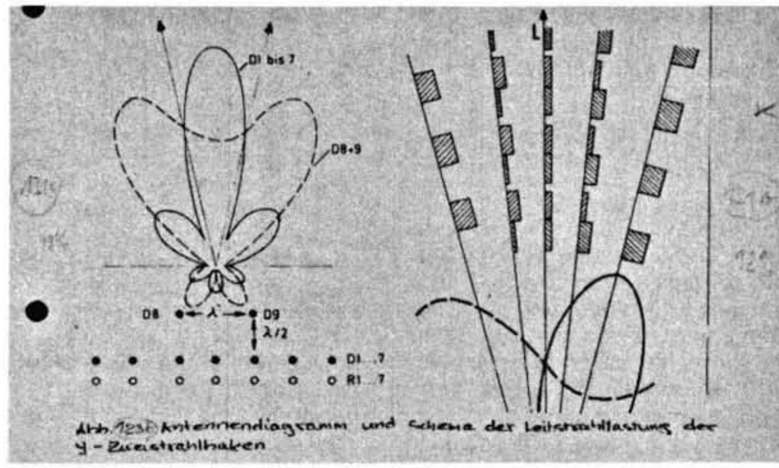
The second table in the notebook gave:

Hinflug	
294	*10*
318	*11*
283	*11*
274	*11*
302	*11*

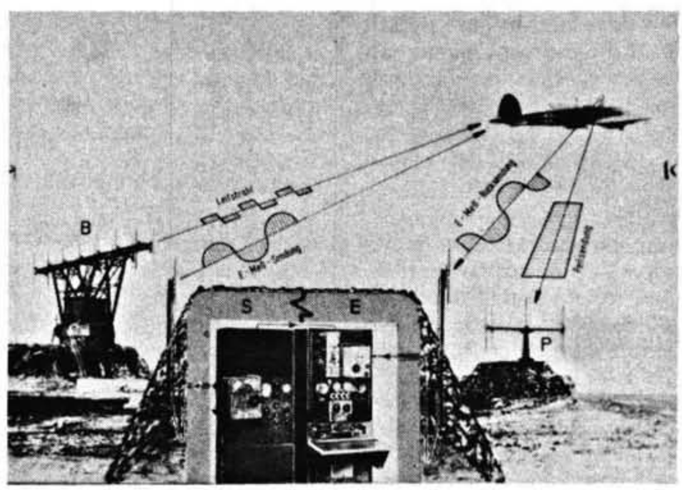
By assumimg that these entries referred to the same cities as those in the first table and that they were bearings,

Professor R. V. Jones at Clarendon Laboratory, Oxford 1936

Apologies to the inhabitants of Retford, Nottinghamshire, for "relocating" their town in Part 1 of this series.



Official German diagrams of antenna patterns for (left) return path and (right) directional pulsed beam



Official German lay-out of a Wotan 2 Y-system station B—Leitstrahl (Double-beam Beacon). S—Meft-Sendung (Range measurement transmitter, 1kW "Bertha"). E—Meft-Rucksendung (Control centre with range measurement equipment). P—Peilsendung (Direction finder "Heinrich")

Photographs courtesy of Fritz Trenkle

the intersection point appeared to be at Cassel in north France, which gave them:

Outward flight

Objective	*Approach Bearing from Cassel*	*Magnetic Variation*
London	*294°*	*10°*
Sheffield	*318°*	*11°*
Bristol	*283°*	*11°*
Southampton	*274°*	*11°*
Birmingham	*302°*	*11°*

Jones could therefore deduce that: *(a) the aircraft approached its target from the direction of Cassel; (b) it was not concerned with distance calculations, which would be consistent with the distance being determined by a distant ground station; (c) after it had reached its target it intended to return direct to an airfield near Poix, and since it was navigating on its own it needed to know the distance from the target back to Poix, as well as the direction.*

A third table in the notebook contained the frequencies for both the beam itself and the ranging system. Typically, the station radiated a sinusoidally modulated signal to the aircraft on 42.5MHz and its modulated note was then detected, amplified, and used to modulate a transmitter in the aircraft which sent a signal on 46.9MHz back to the ground station —which then determined the distance of the aircraft by the delay in the return signal. As we know, an analyser was used.

The Delicious Leg-Pull!

From a security viewpoint it is remarkable that the Germans failed to ensure that notebooks and tables giving important information were not taken aboard aircraft: it would have been a simple matter to memorise these things for a single operation. On the other hand it could be said that the Germans were completely unaware that we had broken their Enigma signal system, which gave away so much more vital information. At all events, these matters added up to British intelligence being able to glean much information which the enemy confidently believed to be secure.

Dr Jones immediately spotted a "delicious method" of upsetting the Y-System. (Doubtless his prowess in practical joking came to his assistance here—after all, if disguised as a telephone engineer he had been able to persuade an Oxford physicist to plunge a telephone into a bucket of water, finding a way to bamboozle the enemy was likely to come quite readily to mind.) We in England could receive the 46.9MHz signal from enemy aircraft even better than their ground station could, and so we could *re-radiate the already re-radiated signal back to the aircraft on 42.5MHz, the frequency used by the ground station.* As Dr Jones pointed out, *"This would therefore be fed into the aircraft receiver, along with the signal coming in from the ground station, and in turn be fed back to the ground station again. The effect would be rather like that which occurs in public address systems where the noise from the loudspeakers impinges on the original microphone, and is therefore picked up and relayed back to the speakers again. The effect on the ground station would be to make it think that the aircraft was at a false distance, because the returning waves would have travelled round an extra loop between the aircraft and our own station before getting back to their original base; and if we used a powerful transmitter ourselves the whole system would 'ring' just as a public address system squeals if the gain of the amplifier is made too high".*

The BBC television transmitter at Alexandra Palace was just right for the task because it operated in the right frequency band. Dr Cockburn immediately requisitioned it for the purpose and it transpired that this countermeasure, code-named *Domino,* was first put to use the very night that KG 26 took over from K.Gr100—because we had now successfully jammed X-Gerät.

Jones advised that for the first few nights only a minimum of power should be used, just enough to inject a small signal into the Y-System to give the Germans a false range without arousing their suspicions (a process of "acclimatisation" by slow change). The first results were not only successful but afforded a source of innocent merriment: one aircraft became involved in an acrimonious exchange with the ground station who suggested he must have a loose wire in his receiver and that he should abandon the attack for that night. Over the following nights Alexandra Palace gradually increased its power and the Germans woke up to the fact that we were now successfully jamming the system, whereupon they abandoned it.

Dr Jones' original aims were that, since he was not entirely sure for how long the Germans had successfully used the system, he should break their confidence by making them think that we had been interfering with it in a way that had remained undetected for a considerable time. This policy reaped a further (and at times hilarious) bonus because once the Germans suspected we were interfering with the system other alarms entered their heads: *"Since the aircraft had to be instructed* *by the ground station when to release its bombs, it had to be monitored all the time during its bombing run, and the ground station could handle only one aircraft at a time. The aircraft would therefore fly to a convenient area from which it could be ordered onto the beam by the ground station, and so commence its bombing run. In principle, all we needed to do was transmit false orders to the aircraft. In fact we did not do this, but it seemed such an easy countermeasure that the German crews thought we might, and they therefore began to be suspicious about the instructions they received."*

Substance was added to this later when an aircraft was ordered by the ground station to steer due west (possibly because it was east of the beam) to bring it onto the start of its bombing run. Failing to hear further ground station orders, the aircraft flew a considerable distance west then returned to base to complain that the British had given false orders. On other occasions when the power of Alexandra Palace had been increased, aircraft became confused and were ordered back to their bases after being told, again, that a wire was probably loose somewhere in the equipment. *"What with our real countermeasures and those imagined by aircrews, Y-operations became a fiasco and the system was withdrawn; we had restored our moral ascendency for the rest of the winter."*

Only later did Dr Jones learn that the Y-System was really *Wotan 2*, and X-Gerät was *Wotan 1*. *"And so, while Wotan may have had one eye for 'Y' he could not have crossed eyes for 'X'..."* In fact the Y-System was nicknamed "Benito" because Mussolini was considered to be the one-eyed end of the Axis!

So ends the battle of the beams. The author hopes that some interest may have been aroused to prompt readers to study further this aspect of scientific warfare and to live again those momentous days of the 1940s in the company of such distinguished (if then secret) servants who unravelled the enemy beam systems.

But to one man, above all, must go the highest recognition: R. V. Jones, the young scientist who defied the experts, confounded officialdom, and quietly saved the country from a terrible disaster—yet inexplicably, is still denied the knighthood he so richly deserves. The man who, to repeat Churchill's words, *"Broke the bloody beams."*

Acknowledgements

I am grateful to Professor R. V. Jones, Emeritus Professor in the Department of Natural Philosophy, University of Aberdeen, for his kind help and advice, and also for his permission to use extracts from his book *Most Secret War*, published by Hamish Hamilton. My thanks must also go to AEG (formerly Telefunken) for their permission to use extracts from *Die deutschen Funklenkverfahren bis 1945*, and especially to Dr Colin Hamilton, manager of the Airborne Early Warning Department, for his kind assistance and advice. I am also grateful for the help received from some old and respected opponents, notably Herr Fritz Trenkle, author of *Die deutschen Funk-Navigations und Funk-Führungsverfahren bis 1945*; Dr Rudolph Kühnhold, designer of the *Freya* and *Seetakt* radars; the late Professor Dr Wilhelm T. Runge, designer of the *Mannheim, Darmstadt, Würzburg* and *Lichtenstein* series of radars, who was able to give valuable help regarding Telefunken's work in the field of beam systems; and Dr Herbert Kümmritz, Dr B. Röde and Dr Gotthardt Müller.

Further Reading

Most Secret War by R. V. Jones. Published by Hamish Hamilton.
The Bruneval Raid by George Millar. Published by The Bodley Head.
The Ultra Secret by F. W. Winterbotham. Published by Nicolson.
The Rise of the Boffins by Clark.
Instruments of Darkness by Alfred Price.

For our German speaking readers:
Die deutschen Funk-Navigations und Funk-Führungsverfahren bis 1945 by Fritz Trenkle. Published by Motorbuch Verlag.

NEWS DESK EXTRA

Enclosures

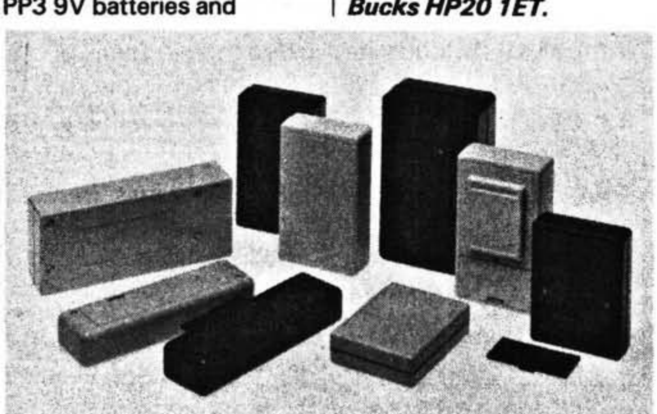
Two electronic case ranges, designed for hand-held portables, have been launched by West Hyde.

The TINOS and ELOS ranges are available in a total of nine different sizes and in light grey and black ABS, costing from £1.44.

The TINOS range have, on one side, a textured finish to provide a firmer grip, also a battery compartment for PP3 9V batteries and rounded corners throughout. One model in the range even has a moulded pocket clip.

The ELOS, whilst being the more general purpose range and without a battery compartment carries, as standard, moulded pads to provide a base for a p.c.b. and sub-chassis mounting.

West Hyde Developments, 9–10 Part St. Ind. Est., Aylesbury, Bucks HP20 1ET.



Diplome du Calvados

The REF regional club of the Department du Calvados in Normandy, have an award available to all radio amateurs and s.w.l.s.

Applicants must have worked (or heard) 10 stations located in the Calvados district (No. 14) on any band and/or mode. There are special endorsements available for h.f., v.h.f., s.h.f., c.w., RTTY, etc., on request.

Contact with the club station, FF6KCZ on h.f. or FF1KCZ on v.h.f. counts as two contacts.

No QSLs are necessary, send your log details, certified by two licensed amateurs and 10 IRCs to:

The Award Manager, Pierre Roger FC1CNJ, 8 Rue des Petites Haies, F. 14440 Douvres La Delivrande, France.