Feature

Battling the Radio Beams

Part 1: Headache and Aspirin

In this modern age of GPS and precision long-range radar, it's difficult to imagine the difficulty of navigating an aircraft at four miles a minute in darkness across blacked-out enemy territory using only dead reckoning, star fixes and maps.

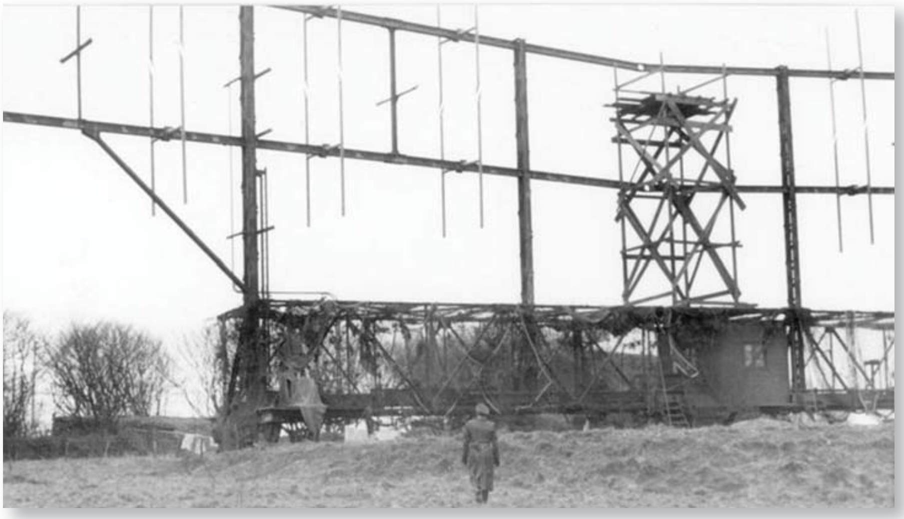
Thus it was hardly surprising that during WW2 the Luftwaffe adopted radio methods to guide night bombers to their targets in Britain. The story of the secret and silent 'battle of the beams' between the attackers who developed these specialised systems and the defenders who strove to disrupt them is one of the most fascinating in the history of short wave radio. It is a drama in which British radio amateurs played a pivotal role.

The Knickebein beams from Kleve and Stollberg could be directed to intersect over targets such as the Rolls-Royce aero-engine factory at Derby. *(Image: Dahnielson/cc by-sa 3.0).*

Lorenz

On 28 October 1939, in the first air raid on Britain in WW2, a Heinkel He 111 medium bomber was shot down by a Spitfire of 602 Squadron over the Firth of Forth. When the plane's radio equipment was taken to RAE Farnborough for examination, the technicians were surprised to find that the Lorenz blind approach receiver from the aircraft was a 7-valve superhet of much higher sensitivity than the 2-valve straight set that was adequate for normal service. Later, captured aircrew from another He 111 were overheard saying that no matter how diligently the British searched their plane they would never find their bombing navigation equipment, implying that it would be overlooked because it was right under their noses.

The blind approach system had been developed by the Lorenz Company in Berlin long before the outbreak of war and it had been installed at many airfields throughout the world. The system initially used motor-driven switches to modulate the antenna lobes of a 120W 33.33MHz MCW transmitter located at the end of the runway, such that if an aircraft were to the right of the approach path it received a series of 1150Hz tone 7/8-second dashes, whereas if it were to the left it received 1/8-second dots. The dots and dashes were synchronised, so that directly on the correct flight path they merged in an equisignal zone



August 1941 photo of part of a 20m-high Knickebein transmitter antenna, possibly in Halinghen, Hauts-de-France. *(Image: Bundesarchiv, Bild 101I-228-0322-04 / Friedrich Springorum / CC-BY-SA 3.0).*

to form a continuous tone. Was it possible that this popular commercial system had been modified to serve long range military purposes?

Initially the responsible civilian Air Ministry official, talented young Assistant Intelligence Director Reginald Jones, was advised by the Marconi Company's propagation expert that a system operating at frequencies above 30MHz couldn't be used to guide bombers over Britain, since such short wave radiation wouldn't bend sufficiently around the curvature of the earth. (Phenomena such as tropospheric ducting were not well known at this time). Indeed, the maximum range of the standard Lorenz system was only about 30 miles but an enthusiastic radio amateur, Rowley Scott-Farnie, G5FI, convinced Jones that it should be possible to extend the range by the same techniques that were used by radio amateurs to achieve DX communications. Using a much larger ground antenna with a narrower beamwidth, higher transmitter power and more sensitive receivers he believed that at least high-flying planes could be able to use a modification of the system in the reverse direction for long range navigation. He also suggested that the frequencies of 30, 31.5 and 33.3MHz might be used, since these were the frequencies to which the Lorenz receivers from crashed Heinkel's were found to be tuned.

The crooked leg

The first clear indications that the Germans might have deployed such a blind bombing aid came from coded messages intercepted by the Y Service, which was largely manned by pre-war radio amateurs and by radio amateur Voluntary Interceptors (VIs). Arthur Watts, G6UN, President of the RSGB from 1938 to 1940, assisted in recruiting over 1000 VIs. They used their skills to copy weak Morse code enemy radio messages from their own homes, often with homebrew receivers. When these messages were decrypted by the code breakers at Bletchley Park, one was found to read "Knickebein at Kleve is confirmed at point 53°21'N, 1°W." Significantly, the town of Kleve is near the western frontier of Germany in the part closest to Britain; Jones guessed that the message reported that a radio beam from there had been checked as crossing England at the geographical location specified, which is near Retford in Nottinghamshire. The name Knickebein ('crooked leg') suggested a system that employed two directional radio beams intersecting at an angle over a target, although it was later discovered that it actually referred to the 165° angle of the dual-beam antennas used at the transmitters. The first Knickebein antennas at Stollberg, Kleve and Maulburg were nearly 31m high and mounted on 90m diameter circular railway tracks to permit aiming.

The Y Service also successfully eavesdropped on Luftwaffe airborne communications, some of which were in plain language. Surprisingly, some messages used the international Q-Code familiar to radio amateurs, even including abbreviations in English (such as 'RPT' for 'I repeat')! Additional evidence was gathered from fragments of paper and wireless operators' logs recovered from Luftwaffe aircraft that had been shot down over Britain. One airman who had bailed out from his crippled aircraft was captured as he was trying to bury the pages of his notebook, which he had torn into hundreds of pieces. When the jigsaw was laboriously reconstituted, it was found to include a table giving the positions of transmitters at Kleve and Bredstedt, with their operating frequencies of 31.5 and 30MHz.

Restoring an aircraft Knickebein system (foreground). Left: EBL2 signal processing unit; Middle: EBL3 superhet beam receiver; Right: U8 210V HT rotary converter. *(CDV&T and Hans Goulooze).*

Many experts remained sceptical about the idea that Luftwaffe bombers were navigating by radio beams. Arthur Harris, later the head of RAF Bomber Command, was positively scathing since he thought that any skilled aircrew could find their targets without such paraphernalia. He changed this view when in August 1941 the Butt Report revealed that actually fewer than one RAF bomb in ten fell within five miles of its intended target. But Churchill himself had scientifically literate advisors and he was convinced by Jones to authorise a few exploratory flights to search for beams. At the time the RAF didn't have any general coverage receivers for these frequencies, so Jones sent one of his civilian team to Webb's Radio in Soho. Masquerading in a hired uniform, he successfully requisitioned their stock of Hallicrafters S-27 amateur radio sets, promising that the Air Ministry would pay for them later. The S-27 was a 15-valve AM/FM/CW superhet that covered 27 to 143MHz in 3 bands. An advanced receiver for the time, it had variable selectivity and used miniature acorn valves for the RF amplifier, oscillator and mixer, utilising an IF of 5.25MHz. The receivers were installed in aircraft at the Blind Approach Development Unit at Boscombe Down, which had aircrew with much experience of beam flying. They were modified to run on the aircraft's 28V DC supply and skilled pre-war radio amateur members of the Y Service were posted there to operate them – they were designated as 'Special Wireless Operators'.

On 19 June 1940 an old twin-engined Mk 1 Avro Anson took off from RAF Wyton to search for beams. As bad luck would have it, the vibrator HT supply of the S-27 receiver developed a fault on the first flight, while on the second night the Luftwaffe made no sorties. Although there were calls for the search attempts to be abandoned, one more flight was authorised on the night of 21 June and this time a 31.5MHz beam from Kleve was located about one mile south of Spalding in Lincolnshire. The Anson then flew along it until the operator picked up a crossbeam from Stollberg. He discovered that the beams intersected over the Rolls-Royce factory at Derby, which made the Merlin engines for Spitfires and Hurricanes. The seriousness of the threat was now apparent and the RAF appropriately code-named the enemy beam system 'Headache'. When Fighter Command Chief Hugh Dowding was asked what should be done, he replied in one word: "Jam!".

80 Wing

In August 1940 a radio countermeasures unit called No 80 (Signals) Wing was formed by signals specialist Edward Addison to provide

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Hallicrafters S-27 amateur radio receivers were used to search for the Luftwaffe beams.

After the occupation of the Netherlands and France, more compact second-generation 45m-wide FuSan721 Knickebein antennas could be used, as they could be sited nearer to Britain. (Model by Michael Kayser)

electronic intelligence and counter the German beams. Its motto was "Confusion to Our Enemies". The Wing Headquarters was established in the Aldenham Lodge Hotel in Radlett, a village about 14 miles north west of London in convenient proximity to the London/Birmingham GPO trunk cable. It was linked directly to the Fighter Command Operations Room at Bentley Priory in Stanmore. The old Lodge was infested with rats and cockroaches but it had a swimming pool, rather a rare asset for a WW2 RAF base!

Because of their technical experience, resourcefulness and ability to improvise solutions rapidly, many British radio amateurs served in this unusual unit, with the General Secretary of the RSGB, John Clarricoats, G6CL, acting as a 'Recruiting Sergeant'. Fifty BBC radio engineers also joined and within a year Addison had built up monitoring and jamming systems at over 120 outstations throughout the country. By September 1941, 80 Wing had a strength of 2000 men and women of all ranks. A staff of 27 WAAFs was engaged to use 242 telephone lines to connect the Radlett HQ with the outstations.

Before specialised systems to counter Knickebein could be built, Addison's team improvised makeshift jammers by commandeering 150W 27.12MHz diathermy sets from local hospitals. These were converted to RF power amplifiers and driven by small transmitters made at the Peto Scott factory to emit radio noise on the Knickebein frequencies. Two sets were installed in vehicles that could rapidly be despatched to any target area. Others were installed in dispersed police stations, which were alerted by telephone from Wing HQ when they were required. One village bobby put a set in his bedroom, where his wife could switch it on if he was out on his beat at the time of a call.

The Rediffusion factory in south-west London produced a number of powerful jammers very rapidly by converting the 2kW audio amplifiers on their production line into radio transmitters.

80 Wing also modified eight RAF Lorenz airfield approach transmitters to radiate fake beams across the Knickebein ones to induce the attacking planes to stray off course, or to drop their bomb load in open country before reaching the target.

The Air Arm of 80 Wing, which later became 109 Squadron, carried out regular flights to locate the radio beams. To narrow the search area for the Ansons, manned receiving stations were set up by lashing garden sheds to the tops of the towers of a few selected Chain Home radar stations. Braving the freezing cold in these high level shacks, the listening operators could indicate to Wing HQ the Knickebein frequencies that were being used on any night, and to which side of each station the beams lay. Knowing the antenna patterns of the Knickebein transmitters and their locations, the information from several such receiving stations could be combined to estimate the bearings of the main lobes. Since the beams were often turned on well before each night attack, this gave time to identify the probable target and set up the jammers.

Meanwhile a more sophisticated antidote for Headache was being developed by Robert Cockburn and his team at the Telecommunications Research Establishment (TRE) in Worth Matravers, which included Martin Ryle, G3CY. This countermeasure was aptly named 'Aspirin'. When a Knickebein raid started, the 500W Aspirins netted on to the frequency and transmitted dashes with the same modulation tone at exactly the same rate as the real transmitter. When the jamming signal was strong enough, pilots on the correct track continued to hear dashes, causing them to diverge from it. This even resulted in several bombers flying in circles; navigation became so unreliable that by mistake some German bombers landed in England instead of at their home bases. At least one inexperienced young bomber crew, who hadn't been taught to navigate at night without the Knickebein beams, bailed out from their plane when they found they were jammed.

When the start of systematic Aspirin jamming revealed that Knickebein had become well understood by the RAF, many German bomber pilots preferred to keep out of the beam since they feared (mistakenly) that night fighters or aerial mines might be waiting for them all along the route to the target. This psychological effect may actually have caused more disruption than the jamming itself. By the autumn of 1940 raiders no longer considered Knickebein usable enough for target identification, although it was several months before the young German pilots plucked up the courage to tell Göring that the system was useless. However, as we shall see in Part 2, the German Aviation Research Institute (DVL) had been developing another highly secret and much more accurate VHF radio beam system that would soon be used by the Luftwaffe with devastating effect.

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Part 2: Bromide, Domino and Benjamin

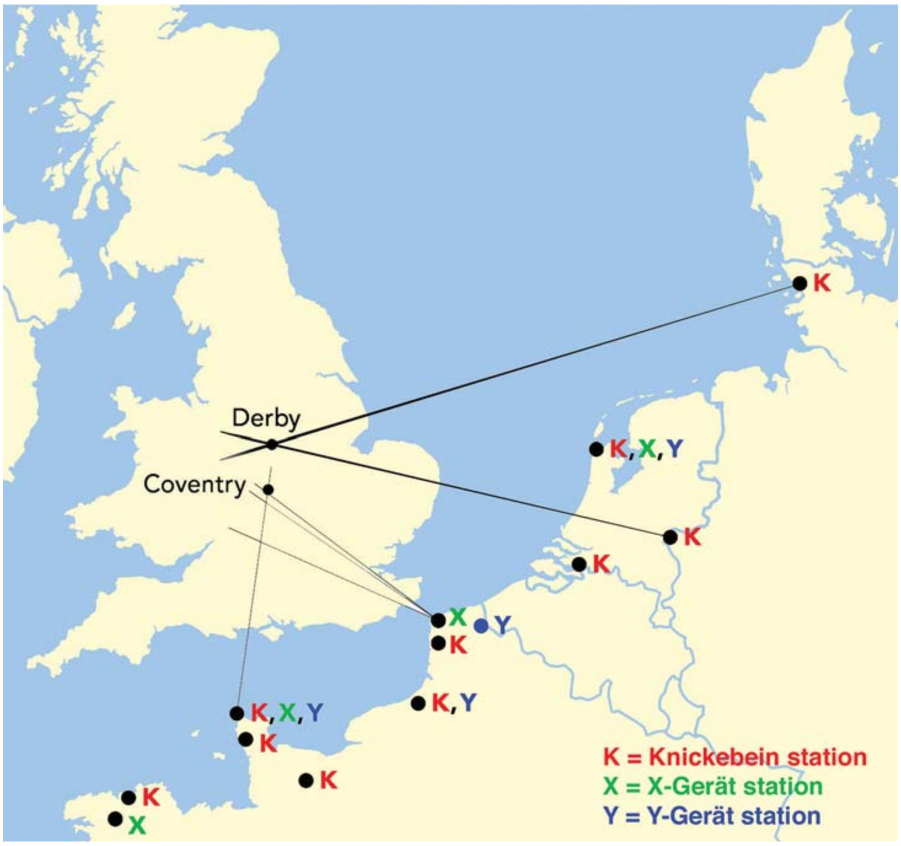
Radio amateurs played a pivotal role in electronic countermeasures during WW2.

In Part 1 we saw how the RAF used amateur radio receivers to discover the Knickebein system of radio beams that the Luftwaffe employed to guide its night bombers to targets in Britain. 'Aspirin' jammers for this 'Headache' had been developed by TRE and deployed successfully by 80 Wing, and the system was considered no longer usable for accurate navigation. But the enemy had other tricks waiting in the wings.

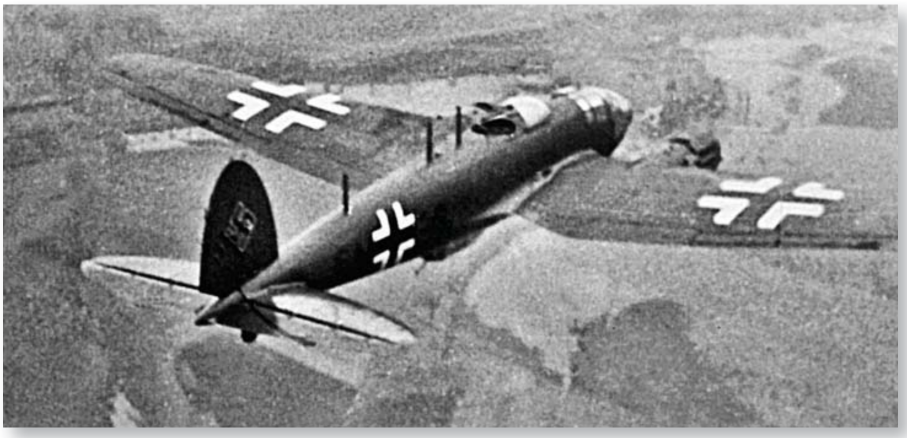
X-Gerät

On 6 November 1940 a raiding Heinkel III bomber that had suffered compass failure over England tried to return to its base in occupied France by using a radio beacon at Saint-Malo. But the beacon was being jammed by 80 Wing, so the crew became disorientated and instead of landing in Brittany the plane ran out of fuel and crash landed just offshore from the beach at West Bay in Dorset. British Army soldiers waded into the shallows and secured a rope around the fuselage, but then the Royal Navy arrived and claimed that because the plane was in the sea it was theirs to salvage. When the sailors towed it into deeper water to secure it to a ship, the rope parted and the plane sank to the bottom!

In spite of this incident the waterlogged radio equipment on board the aircraft was recovered and sent to RAE Farnborough, where it was found to include a new type of bombing radio navigation aid called X-Gerät. This system was considerably more sophisticated than Knickebein, having both coarse and fine director beams and 20 operating frequencies in the higher frequency range of 65-77MHz. The X-Gerät system also laid three very narrow crossbeams across the director beam prior to the target, which allowed the aircraft's ground speed to be determined and the bomb release point to be computed by a special 'bombing-clock'



Locations of the radio beam transmitters in 1941. (Courtesy of Bill Rankin, www.afterthemap.info).



The three dorsal antenna masts reveal that this Heinkel 111 was an X-Gerät pathfinder.

mechanism on board the plane.

The 0.05° fine director beam was so narrow that in calculating its bearing 5-figure log tables had to be used to take account of the fact that the earth isn't a perfect sphere (it's slightly flattened near the poles). A result of the antenna configuration required to achieve this high directivity was that the radiation pattern had 14 lobes, several of which the bombers had to fly across to find the true guide beam. The crossbeams also had multiple sidelobes, and as the flight progressed the aircrew had to resolve the ambiguity by counting them until they reached the genuine first marker beam. These sidelobes also complicated 80 Wing's task of determining the target.

Since the X-Gerät system required special equipment and trained aircrew operators, it was fitted only to the bombers of an elite group of pathfinders called Kampf Gruppe 100 (KGr100), whose task was to mark the target with hundreds of 1kg thermite incendiaries, on which the main force would bomb visually. But the poor ballistics of these incendiaries resulted in considerable spread and they didn't have a special flare colour to distinguish them from fires caused by misdirected bombs. Learning from experience with Knickebein, the 500W X-Gerät transmitters emitted spoof beams before each raid, while the real ones weren't turned on until as late as possible, a tactic that sometimes confused the bombers as much as the defenders. Fortunately for the Allies, KGr100 was based at Vannes, far to the west of France and beyond the reach of secure German military landlines, so the unit had to use wireless for ground communications. This allowed the control messages to be intercepted by the Y Service and radio amateur VIs and decrypted at Bletchley Park.

With these decrypts, Jones was able to deduce how the operating frequencies were related to the receiver settings that were transmitted to the pathfinders before each raid. Using this information, Cockburn's team at TRE rapidly introduced 100W X-Gerät jammers called 'Bromides' that were equivalent to the Aspirins for Headaches. Nevertheless, Bromide proved ineffective during the devastating 10-hour raid on Coventry, even though the jammers at Birdlip Hill, near Gloucester, Kenilworth and Hagley were well within range. This was because their modulation tone was set to 1500Hz, whereas the X-Gerät receivers had a sharp audio filter centred on 2000Hz.

The mistake was corrected before the raids on Birmingham five days later, when the Luftwaffe bombers were partially disrupted and dispersed. By April 1941, 80 Wing had enough Bromides to disrupt all the X-Gerät director and crossbeam frequencies and no other inland British city was to suffer such highly concentrated damage. In spite of at least eight attacks on the Rolls-Royce works at Derby during WW2, only a single bomb actually hit a factory building.

The X-Gerät 'bombing-clock' measured the time to fly between two crossbeams to determine the bomb release time. (Horst Beck Collection, photo Frank Dörenberg, N4SPP/F4WCN).

Except on moonless or cloudy nights, no radio aids were required to find the sprawling metropolis of London. But specific industrial assets in the city couldn't be targeted accurately without the help of reliable beams and the enemy bomb loads were scattered over almost 100 boroughs. Although no longer used by raiding bombers, the 65-77MHz X-Gerät transmitters were kept functioning as decoys until they were finally dismantled in November 1942.

Y-Gerät

As early as mid-1940, when the existence of the Knickebein beams was confirmed, Enigma decrypts from Bletchley Park included mention of what appeared to be another system, code-named 'Wotan'. Since this is the name of a Germanic God with only one eye, Jones guessed that it might refer to a new navigation aid that used only a single beam. It turned out that this reasoning was wrong but the conclusion was perfectly correct! Monitoring stations began to report beam signals between 42.1 and 47.9MHz that had different characteristics, with alternate right and left signals of equal duration transmitted at a high rate, for they were decoded in the aircraft electronically rather than aurally. The bearing analyser was coupled to the modified He 111 autopilot by an automatic flight control system that was much ahead of its time.

This more advanced 'Y-Gerät' system reduced the number of confusing sidelobes by switching between a cardioid and a more directive antenna pattern. It achieved very accurate slant ranging by transmitting a 300Hz, 3kHz or 7.5kHz tone-modulated carrier to a transponder in the aircraft on one frequency, and comparing the phase with the return signal carrying the same modulation sent back from the aircraft on a different one. The range measurement was made by the ground controller, who used a version of the X-Gerät stop-clock to determine when to order the aircraft to release its bombs. Since the system was more complex and could only operate with five aircraft at a time, Y-Gerät equipped planes were formed into a specialised pathfinder group (Group III of KG26) that led the main bomber stream.

III/KG26 made the error of practising using Y-Gerät for many weeks before trying it on a major bombing raid. So Cockburn's team had time to analyse the signals and devise a subtle countermeasure called 'Domino', which was ready for action on the very first night that the system was used for a large-scale attack on Britain. They borrowed the powerful BBC TV transmitter at Alexandra Palace, which by chance operated in the same frequency band and had been shut down at the outbreak of war lest it be used by the Luftwaffe to home on London. An EMI TV receiver was set up at the former outside broadcast relay station at Swains Lane in Highgate, with its bandwidth enlarged to accept both the ground control transmission on 42.5MHz and the response from the pathfinder bomber on 46.9MHz. From there, the modulation signal was sent by Post Office landline to Alexandra Palace, together with a subdivision of the carrier frequency that allowed the TV transmitter to zero beat with the ground transmission. At Swains Lane Ewart Farvis sat listening to the German radio communications with his finger on a key that controlled Alexandra Palace remotely. At the critical moment, he sent the modulation back to the aircraft on 42.5MHz, using a power that was sufficient to give a false range indication but not enough to arouse suspicion of jamming.

Thirty years after the event, when Farvis finally felt free to tell me about this secret war work, he described the result as hilarious. Being fluent in German, he could follow the acrimonious radio dialogue between the bewildered young bomber aircrew and their ground controller as they argued about the cause of the perplexing behaviour of their instruments. The aircrew accused the ground station of sending bad signals, while the ground controller attributed the problems to airborne equipment failure, probably due to a loose wire. He even told the distraught operator to "thump the box", which caused Farvis to remark that he was evidently a *real* radio man! The jamming was repeated successfully with more pathfinders before the Luftwaffe abandoned the attack.

At TRE, Farvis went on to analyse the signals of the German VHF Identification, Friend or Foe

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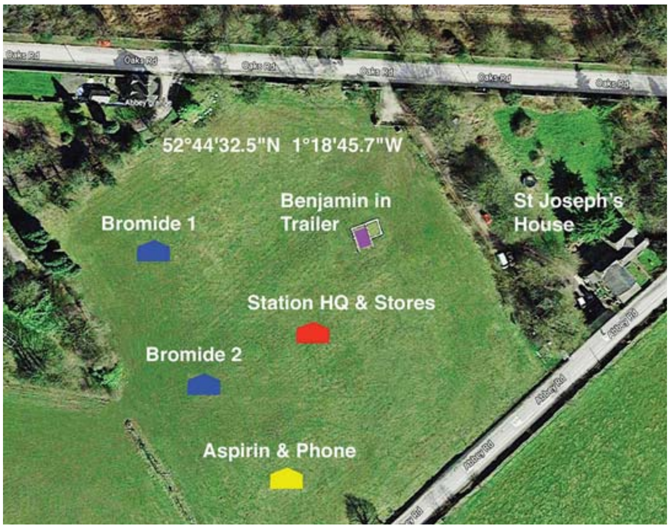

The Coalville Outstation of 80 Wing on the flight path to Derby had Aspirin to jam Knickebein, two Bromides for X-Gerät and Benjamin for Y-Gerät. In 2013 Loughborough ARC operated GB8CHG from the site. (Charley Heritage Group, Bluesky/Google Earth).

The Alexandra Palace TV transmitter was used to disrupt Y-Gerät on 42.5MHz. (Photo based on Duncan Harris/CC-BY-2.0).

(IFF) system, allowing the team to develop the 'Perfectos' radio device that RAF night fighters used to trigger the transponders in enemy aircraft, to determine their positions without using radar. Following the deployment of Perfectos, many Luftwaffe crews flew with their IFF switched off and were shot down by their own side's flak. After the capitulation of Germany, Farvis was given the temporary rank of Squadron Leader (and a revolver) when he was flown to Munich to interrogate German engineers and scientists. He had a fruitful discussion with the designer of X-Gerät and Y-Gerät, Johannes Plendl.

Benjamin

Having established an effective countermeasure for the ranging system of Y-Gerät, Cockburn lost no time in manufacturing production versions of Domino, which could also deal with rapid frequency changes that were sometimes made in the middle of an operation. Although a Domino station on Beacon Hill near Salisbury was attacked by a small force of bombers it was soon back on the air and, during the first two weeks of March 1941, only 18 aircraft of 89 Y-Gerät sorties received the bomb-release signal.

Domino was an effective but complex countermeasure, requiring two-way communication between jammer and aircraft. But Cockburn soon found that Y-Gerät navigation could be disrupted by an even simpler form of jamming. When three Heinkel bombers were shot down during a raid over Liverpool in May 1941, the vulnerability of their Y-Gerät signal analyser was studied in detail at Farnborough. It was found that a short gap between the pair of direction signals was essential for the electronic bearing-analyser to lock to the beam. By filling in this gap by transmitting a continuous note on the beam frequency, the analyser unlocked and gave no useful indication. Within three weeks 80 Wing had a new jammer on the air that used this technique, and five more were operational before the end of the month. Cockburn called it 'Benjamin' (for 'Ben jamming', since Benito was the British codename for Y-Gerät).

The Luftwaffe eventually realised that Y-Gerät had been compromised from the first day that it was used. Bomber pilots no longer put any faith in wireless navigation aids, making the accurate night bombing of inland targets very difficult. In one raid the crews that thought they had bombed Nottingham dropped their weapons in open country 15 miles east of the city, killing two chickens with 230 high explosive bombs, one oil bomb and five sticks of 36 incendiaries. In some raids bombing was so scattered over the southern counties of England that it was impossible to deduce the intended target until it was revealed by the crews of downed bombers. Meanwhile, the tide of war began to turn. The experience of 80 Wing proved invaluable when the Allies began to take the fight to the enemy and in the summer of 1942 the RAF used radio beams to guide the bombing of the Krupp arms factory in a precision night attack through ten-tenths cloud.

Conclusion

In his memoirs on the Battle of Britain, Churchill wrote one sentence about the vitally important role of radar, but eight pages on the German radio beams. Were it not for Jones, Scott-Farnie, Cockburn, Farvis, TRE, 80 Wing and the efforts of numerous dedicated radio amateurs, there would undoubtedly have been many more instances like the destruction of Coventry. Without effective electronic countermeasures, concentrated pin-point bombing might well have destroyed the British aero-engine and Spitfire factories, changing the course of the war. In a light-hearted tribute at the end of the conflict, he wrote, "You certainly did pull the crooked leg".

A downed Heinkel 111 pathfinder.