MILE STONES

# Early air defence radar

Dr Carlo Kopp

WORLD WAR II WAS PIVOTAL IN TERMS OF NEW TECHNOLOGY AND AS A RESULT NEW warfighting techniques were developed. Radar was one of these critical new technologies to emerge operationally, and much of the contemporary paradigm of air warfare and electronic warfare remains anchored in ideas of the period.

In the broadest sense the modern concept of a radar-equipped fighter being vectored to an intercept by a ground based or airborne surveillance radar is a model that emerged during the 1940s. Since then the technology has evolved enormously but the conceptual ideas remain much the same, as the basic physics and geometry problems involved remain unchanged realities.

## Britain – the Chain Home Network

The backbone of the British air defence system was the extensive Chain Home network of radar stations developed during the 1930s and deployed just in time to protect the British Isles from the onslaught of the Luftwaffe after the falls of France and the low countries.

The initial Chain Home system was arguably as basic as a radar system can be built. Each radar site used a fixed mast mounted arrangement which 'flooded' the volume of space in front of the three or four 360 ft masts with a 350 kiloWatt fixed wide-angle transmitter beam at 20 to 30 MHz frequency (similar to contemporary HF radars), with a pulse repetition frequency of 12.5 or 25 pulses per second. Direction finding was performed by comparing outputs from paired receivers, with the target azimuth proportional to the ratio of signal outputs from the receivers. Rangefinding was done by looking at the time for the pulses to return. Heightfinding was performed by comparing the signals from two sets of vertically displaced receiver antennas, but was not particularly accurate.

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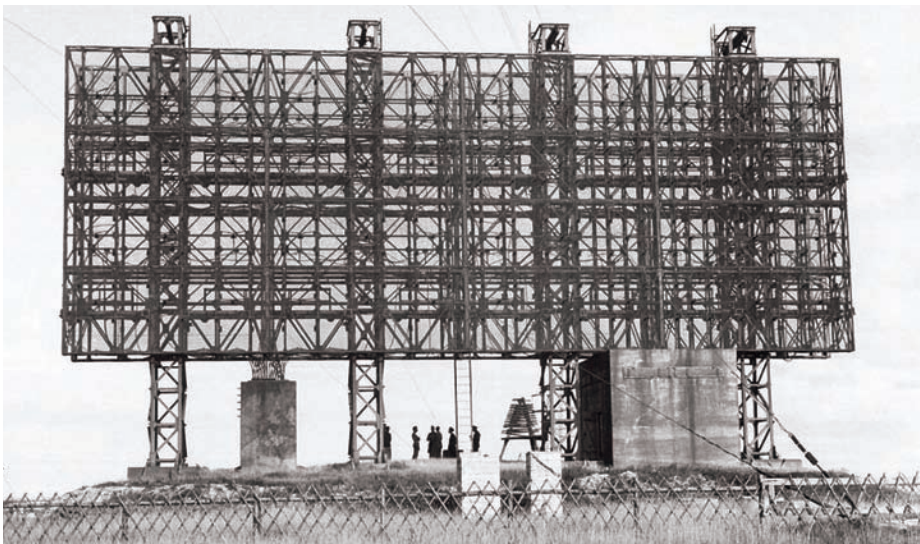
Around fifty stations were eventually built, with 21 along the vital east coast of the British Isles, at Ventnor on the Isle of Wight, Poling, Pevensey and Rye in Sussex, Swingate and Dunkirk in Kent, Canewdon and Great Bromley in Essex, Bawdsey and Darsham in Suffolk, Stoke Holy Cross and West Beckham in Norfolk, Stenigot in Lincolnshire, Staxton Wold and Danby Beacon in Yorkshire, Ottercops Moss in Northumberland, Drone Hill, Douglas Wood, School Hill and Hillhead in Scotland, and finally Netherbutton in the Orkneys.



*The immense GEMA Mammut early warning radar was the first phased array radar to enter operational service. Usually fixed on top of a large concrete bunker, this metric band system used no less than 192 electronically phase shifted dipoles to effect beam steering in azimuth and elevation.*

A major gap problem with the Chain Low system was poor low altitude coverage, partly due to the wavelength of the radar and partly due to the antenna design. This led to the deployment of the 200 MHz band 150 kiloWatt Chain Home Low system, initially using the Type 2 Chain Home Low (CHL) masted system, later supplemented by the 500 – 600 MHz band mobile (relocatable) 50 kiloWatt Type 11 CHL/GCI radar.

Persistent problems with Luftwaffe pilots penetrating under the coverage of the existing CH/CHL radars led to the Chain Home Extra Low network, built up using a mix of equipments including the Type 13 CMH (Centimetric – Height), a nodding heightfinder later emulated extensively by Soviet radar designers. Early in 1944 the British deployed the semi-mobile 500 kiloWatt 3 GHz band Type 14 CHEL/GCI capable of tracking a target at 50 ft AGL from 20 miles away. These were supplemented by the S-band Type 52 - 56 CHEL/CD, which used a steerable dish antenna to track individual targets at low level.

The early warning components of the Chain Home network were used to detect and track incoming threats but the problems of Ground Controlled Intercepts using this system were formidable, as the radars' tracking outputs had to be manually correlated and relayed to pilots or later radar intercept officers.

This led to the development and deployment in 1940 of the first specialised GCI radar with a 'modern' Plan Position Indicator (PPI) display, the Type 7 GCI radar. PPI provides a 'God's Eye' situational picture and is the standard radar presentation technique in most contemporary systems. The 100 kiloWatt class Type 7 operated at ~200 MHz and used a rotating turntable mounting a framework with 32 stacked dipoles, providing heightfinding capability in addition to the PPI tracking data.

Despite the limitations of the British Chain Home system, it resulted in devastating losses to the Luftwaffe throughout the war, to the extent that it compelled Germany to develop and deploy the FZG-76/V-1 cruise missile and A-4/V-2 ballistic missile.

## Germany – the Kammhuber Line

Germany, like Britain, was deeply involved in the development of early radar equipment and its operational use. While the first generation of German equipment was demonstrably more sophisticated than its earlier British counterparts, the Germans were late in deploying this equipment in strength, and it did not play a major role until well after the Battle of Britain campaign. German tardiness in this area was arguably a result of the offensive mindset in the Luftwaffe leadership, who were overly confident in their ability to sweep opposing aircraft from the skies. As the later Combined Bomber Offensive proved, this confidence was not matched by real capabilities.

Much of Germany's effort in this area was split between two manufacturers, the GEMA (Gesellschaft für Elektroakustische und Mechanische Apparate) startup company, which designed and built the Seetakt/Freya/Jagdschloz and later Wassermann / Mammut family of surveillance, GCI and early warning radars, and Telefunken who developed and built the Würzburg family of precision tracking radars.

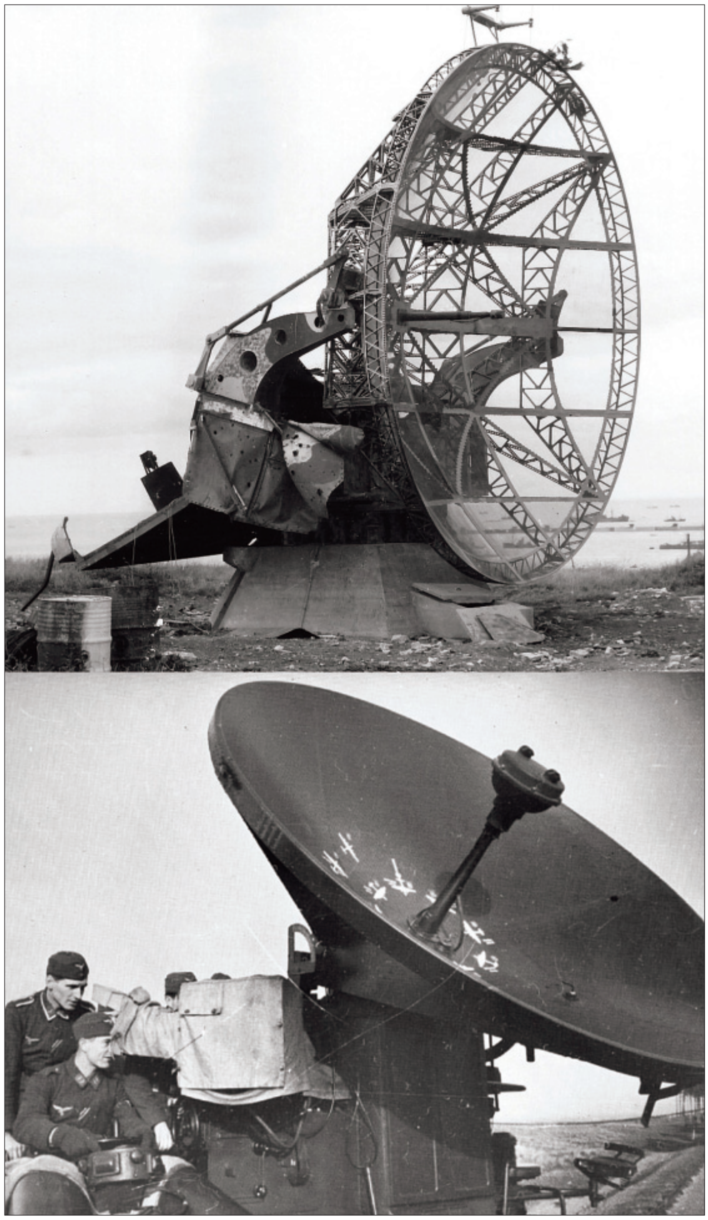
Named after the Norse goddess of love and fertility, the Freya FüMG 39G surveillance radar was a derivative of the earlier Seetakt naval surface search radar but designed to operate at 1.8 to 2.0 metres (later 2.3 to 2.5 m) wavelength, unlike the Kriegsmarine variant at 0.8 metres. It compares in configuration to the British Type 7 GCI radar. While at the beginning of the war only eight Freyas had been built, by May 1945 around two thousand had been deployed according to German sources. Two basic variants were the static FüMG 39G and air transportable Freya LZ (FüMG40G-fb Lufttransportabel und zerlegbar).

The Freya was a 2D radar by modern definitions, but had an integrated Erstling IFF capability to deconflict friendly and hostile tracks.

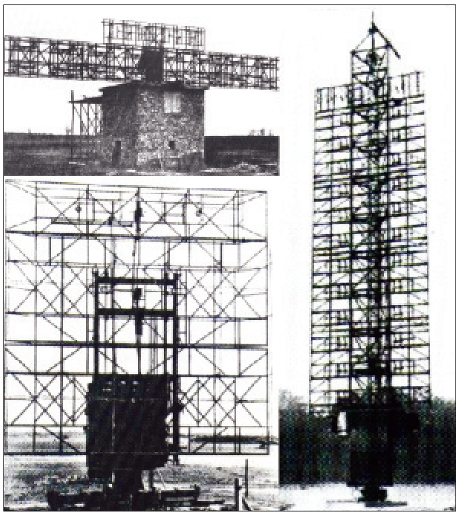
The Freya was soon subjected to British chaff bombing, and later jamming. The Mandrel noise jammer was specifically built to disrupt the Freya. Mandrels were then supplemented by the Moonshine false target generator, initially carried on obsolete Defiant fighters. This resulted in the design changes to a longer wavelength, and other counter-countermeasures adaptations.

The Freya was a specialised surveillance radar and provided rudimentary tracking capabilities, the latter being the role of the Telefunken Würzburg. The Würzburgs were specialised tracking radars, using parabolic dish antennas and a scanning device in the focal antenna feed point. Two principal variants of the Würzburg were built. The smaller semi-mobile FuSE 62A Würzburg and later Würzburg D and Mannheim was initially developed for Flak (AAA) gunlaying, and operated at 50 cm wavelength, with around 5000 units claimed to have been deployed by the end of the war. The larger FuSE 65 Würzburg-Riese or "Giant Würzburg" was built to facilitate fighter intercepts, with a 7.5 metre antenna size, 80 km range, and much higher angular accuracy at 0.1 to 0.2 degrees of arc.

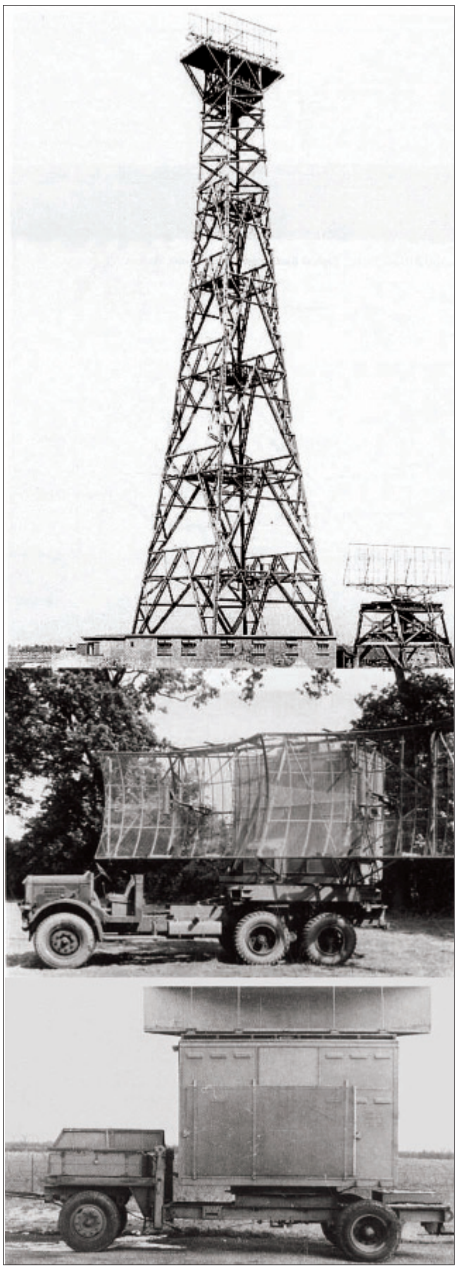
An interesting feature introduced on some Würzburgs was a Non-Cooperative Target Recognition (NCTR) capability based on identifying specific harmonics modulating the radar return, a feature which re-emerged during the 1970s (the author is indebted to Prof Z. Budrikis at UWA for pointing this out).



*Precision tracking for intercepts was provided by the ubiquitous Telefunken FuSE 65 Würzburg-Riese, with Flak gunlaying provided by the smaller FuSE 62 Würzburg.*



*German surveillance radar equipment. The primary surveillance radars used to support GCI operations were the GEMA FuMG 39/40 Freya (left lower) and less common GEMA FuMG 404 Jagdschloz (left upper). Early warning was provided by the GEMA Wassermann (right) and Mammut.*



*The poor low altitude coverage of the Chain Low radar network led the British to deploy the supplementary Chain Home Low system, comprising a range of systems. The Type 2 CHL radar was a static installation (upper), not unlike the Type 1 CH radars. The Type 11 (middle) and 14 (lower) radars were semimobile systems, the latter sharing antenna and other hardware with the nodding Type 13 CHL heightfinding radar.*

While the Würzburgs were highly accurate, managing an intercept especially by a night fighter was cumbersome, as a pair of radars would be committed, one to track the target and the other the fighter stalking it. Many Würzburgs had integrated Zwilling IFF interrogators. The RAF deployed the Shiver jamming equipment against the Würzburgs, later supplemented by the more advanced Carpet I/II noise jammers.

The limitations of the Freya led GEMA to develop the more capable derivative 3D Wassermann and Mammut long range early warning radars based on Freya technology but with much larger phased arrays of dipoles to increase angular accuracy and range. The enormous Wassermann S (Schwer or 'heavy') used 188 dipoles mounted on a towering sixty metre tall frame structure – a model purloined by the Soviets in their later Tall King series. The Wassermann used the now common technique of lobe switching to provide exceptional height-finding performance for that era. The Wassermann was supplemented by the even bigger Mammut, which used a 16 by 30 metre array of 192 electronically switched dipoles. The Wassermann could track bombers at 210 to 300 km range where not limited by the curvature of the earth. Early Wassermanns operated at 120-158 MHz delivering 100 kiloWatts, later subtypes were at 250 MHz delivering as much as 800 kiloWatts of power. German sources claim GEMA discovered PPI radar presentation, termed 'Panorama', before the British did.

The GEMA early warning and surveillance radars were supplemented by several dozen Siemens & Halske built 158-240 MHz band Jagdschloz FuMG 404 PPI/GCI radars, which fed tracking data to control centres using landlines or radio datalinks.

Another interesting Luftwaffe innovation was the Klein-Heidelberg bistatic radar system, which relied on the British Chain Home radars as its transmitter component. Coastal Klein-Heidelberg stations were used to track the Allied bomber streams over the English Channel and North Sea as they departed their staging areas.

As the Allied CBO ramped up, the Luftwaffe invested ever increasing resources into radar equipment to facilitate both fighter intercepts and Flak gunlaying against the RAF and 8th AF. Much of the Luftwaffe's success in night fighter operations must be credited to Colonel (later General) Josef Kammhuber, who established a chain of radar sites across Western Europe known as the Kammhuber line, starting as early as 1940 in anticipation of the Allied CBO. The Kammhuber Line was divided into a series of killboxes, in modern terms, each of which was patrolled by a section of night fighters supported by a Freya, searchlights and later Würzburg radars to support intercepts. GCI operations were termed Zahme Sau (Tame Boar), later supplemented by single seat fighters using Wilde Zau (Wild Boar) tactics without close GCI control.

The Kammhuber Line was successfully penetrated by the RAF and 8th AF, but at an often staggering cost in bomber and aircrew losses.

## Analysis

Many of the ideas pioneered in 1940s radars remain in use today. While the radar transmitter, receiver, control and processing technology has evolved immeasurably against the technology of the 1940s, antenna technology for instance continues to exploit many of the techniques and configurations first discovered during that period.

What is no less interesting is that ideas like PPI presentation have remained as mainstay, just as has the idea of GCI control. While a 1940s system would see voice directives sent to fighter crews, with heading and climb/descent commands, a contemporary system largely automates this process using a digital radio datalink or network, which feeds target tracking information directly into the memory of the fire control computer in the fighter. At the most fundamental level the last 60 years have seen the progressive replacement of human warmware/wetware on the ground and in the air with digital hardware/software.

There are other interesting comparisons. One is that the British had an enormous advantage due to the compact geography of the British Isles, which allowed for dense and overlapping radar coverage with a mere fifty or so Chain Home early warning stations. The RAF could achieve much greater concentration of fire, on average, due to geography. The Germans had a geographical nightmare to deal with, attempting to cover much of Western Europe. By the same token, the additional geographical depth available to the Luftwaffe provided many more engagement opportunities against Allied bombers, which in turn was reflected in often crippling aircrew losses suffered by the Allies.

The Allied effort in developing electronic countermeasures against the Luftwaffe's radar systems is a case study in its own right. The deployment of chaff by the RAF during the bombing of Hamburg is now the classic example of an overwhelming defeat produced by technological surprise. The RAF's 100 Group, equipped with Halifaxes, B-17s and B-24s, was arguably the first unit specifically dedicated to electronic combat operations. Not only did the RAF jam German radars, they expanded this effort to jamming voice communications of the GCI network using the AirBorne Cigar equipment. This was supplemented by the transmission of deceptive German language voice messages on the Wilde Sau radio channels using Corona equipment.

In this day and age of networked systems and glossy brochure driven marketing of military technology the study of 1940s radar and electronic warfare is often dismissed as irrelevant. This is a misleading perspective since most of the basic ideas discovered then remain central to air defence operations today, once the facade of digital technology is stripped away. For serious students of air defence and electronic warfare the 1940s remains as some of the best introductory training material in existence.

Further Reading:
There is a wealth of excellent and often remarkably detailed technical material on WW2 British and German radars now available on the W3. Recommended sites are:
http://www.baermann.biz/pauke/
http://www.radarworld.org/
http://www.radarpages.co.uk/