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Foundation: Centre for German Communication and related Technology 1920-1945

Pater Pirestraat 29
1111 KR Diemen
Tel. 0031 20 6996262, 6002205
Fax 0031 20 6991848
The Netherlands
E-mail: stgcdv&t@xs4all.nl
Website: http://cdv-and-t.org

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Synopsis

Some Aspects of German Airborne Radar Technology, 1942 to 1945

It is rather curious, that after more than sixty years, there are still ongoing discussions on aspects of German radar technology. This may be also due to the circumstance that, for several decades, most communities were "indulging in the glorious past". What not directly originated from this country was often being considered to have a very minor (obscure) status, and was not worth spending much time on it.
I have selected, for this DEHS Symposium, the following aspects: Lichtenstein and Berlin radars as well as, briefly, the passive systems Flensburg and Naxos. Of which Lichtenstein type (version) SN2 had, for some time, a frightening impact on the air battle over Germany. The Berlin radar design was primarily based on what became known the "Rotterdam apparatus". Which actually was the British H2S radar equipment discovered in a crashed Stirling bomber aircraft in the vicinity of Rotterdam, early February 1943. From then on, the sophisticated "electronic warfare" beat the Germans merciless.
After the discovery of this revolutionary British radar apparatus, the Germans responded almost instantly by constituting the so-called "**A**rbeits**g**emeinschaft **R**otterdam" (AGR), being a coordinating research and engineering committee. Given the bleak early 1943 circumstances they showed new élan, and merely unlimited resources were made available to counter the menace of backlogs in German radar science. It is not that they were backwards in radar theory, though, they considered decimetre wavelengths *de facto* as most sufficient, whereas in Britain and America centimetre technology was already gaining maturity. Significant was that in the centimetre regions common valve techniques failed to match with new radar requirements.
Nowadays, radar-technology is unthinkable without the application of "FFT" computations (fast Fourier transformations). It is hard to imagine, that early radars could have been operated successfully without micro-processors and comparable facilities.
We also may expect that in a few years time, no one will be able to explain wartime technology from own experience. I opt therefore, to explain some underlying facts of German airborne radars in detail.

Arthur O. Bauer
chairman

Reflection

In a retrospect on German wartime technology, we have to contemplate (bear in mind) the moral implications of aggression and War in particular. The last decades prove, however, that historians are becoming more interested in backgrounds of history. Also the meaning (understanding) of historical facts is, to some extent, changing. This is not because the moral standard is deteriorating though, that what was taken as an absolute axiom of truth, proved, sometimes, to be (a bit) different than is (bore) in the minds of most of us.
Engineering placed in its context, besides its moral implications, compel historians to go deeper into technical aspects, as to understand why things went as they actually did. An approach is, to compare action and reaction, being lethal stakes of cat and mouse.

Introduction

After the subjects of this paper had been selected, it was not yet clear to me where to start my retrospect and how to approach it. Contemplating, that my website has become rather wide-ranging and, that one can find various contributions on radar related topics on it (of which several contributed by Hans Jucker of Switzerland, who is also a member of our Society). I have, therefore, decided to deal with particular details, which are more or less complemental to what already have been made available on it. [1]

The Germans introduced their first experimental airborne intercept radar sets in 1941. Albeit, against the meaning of many Luftwaffe (German Air Force) pilots and officials. Göring, as well as many German pilots, were considering radar aids disdainfully, as it diminishes the open man-to-man air-combat. Others were, nevertheless, very impressed (encouraged) by the new possibilities of radar aids.

Unlike to what occurred in Britain, German industry was very much involved in the early stages of design of most new projects (they sometimes even initiated them). In the pre-war years, competitions between the two major German electronic firms C. Lorenz and Telefunken decided who of them should become the chief project contractor. However, after the war proceeded and German industry was being bothered with too many projects, the military services (Luftwaffe, Navy and Army) decided who should work on particular projects. To some extent, the C. Lorenz company was kept out of advanced radar projects, as it was owned by (affiliated with) the American IT & T company (sometimes known as: Standard Electric company). Only later in the war (1942/43), Lorenz became significantly engaged in radar work. Although, not directly in the confidential fields of SHF radar technology.

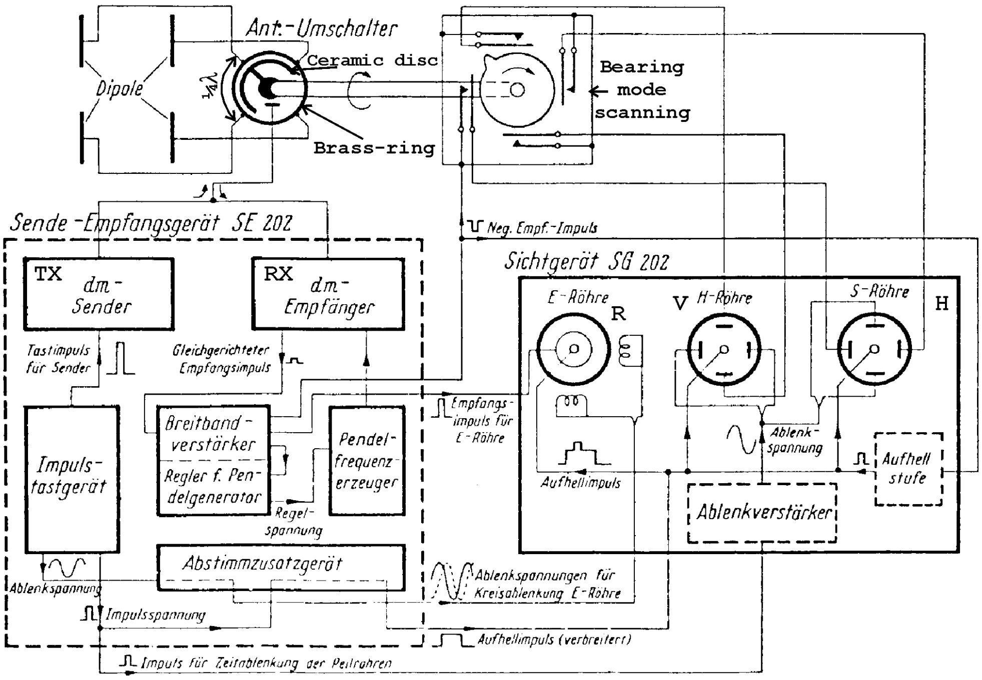
Lichtenstein airborne radar

Most references on German airborne radar mention type Lichtenstein, though, without distinguishing between the versions. Which used the same code-name, but that had only in common that they had been of Telefunken design. In my opinion, this significant shortcoming is one of the reasons why it makes sense to discuss aspects of "Lichtenstein radars" today. Glorious stories have been told, as to how cleverly one had been operating by misleading their "war opponent". That the counter side was, sometime, able to trick-out Allied intelligence services for more than eight months, has often been ignored. Regard, however, Hinsley's well balanced comment on SN2, at the end of this Lichtenstein chapter.

FuG202 b/c

Without dealing with derivate types (such as, for example, the to the rear looking FuG214), we may consider Lichtenstein type b/c being the backbone of German early night-fighter radar in 1942 and most of 1943.

It operated at ≈ 490 MHz (λ = 61 cm)



Zeichn. 1. Aufbau des Bordfunkgerätes FuG 202

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RX = receiver
TX = transmitter
H = horizontal bearing display (azimuth)
V = vertical bearing display (up/down)(elevation)
R = range display (circular presentation)
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Fig 1 Principle diagram of FuG 202

The dipoles of the antenna array (up on the left-hand side) consist of two groups, which are being scanned in a capacitive manner* (see the explanation # in this paragraph). Providing split-beam bearings of: up-down (elevation), left-right (azimuth) and distance of existing electro-magnetically reflecting targets, for up to 4.3 km distance (greatly determined by the physical size of targets, however, the theoretical range of type b/c was 8 km). The 4.3 km figure, according to Hans Jucker's calculations, could only be reached against B 24 bomber air planes [2, p. 7]. The two dipole groups provided two planes of observation (both split-beam), by which means it was quite simple to home onto the displayed (radar) signals. One had to keep all correlating target-amplitudes as equal as possible (Flugrichtung, in figure 3).

* German manual D.(Luft) T.g.Kdos. 4103 provides the principle description of the capacitive antenna selector (AU202): *Infolge der Ankopplung der Dipolanordnung an den Sender über den rotierenden kapazitiven Umschalter werden ständig alle vier Dipolanordnungen erregt, jedoch mit unterschiedlicher, stets wechselnder Phase. Dadurch ergibt sich das in Zeichn. 4* (our figure 3, AOB) *dargestellte Richtdiagramm der Antenne, das sich im Takt der Umschalterdrehzahl um die Achsrichtung (Flugrichtung) dreht. Die Hauptstrahlrichtung dieses Diagramms weicht von der Achsrichtung um etwa 6° ab; seine Halbwertbreite beträgt ungefähr 17,5°. Die mechanische Abmessungen des Umschalters sind so gewählt, daß an zwei gegenüberliegenden Anschlußpunkten die Spannungen stets gegenphasig sind. … Den Antennenschalter stellt im Prinzip einen kapazitiven Phasenschieber dar, dessen fester Beleg ein Messingring und dessen drehbarer Beleg eine diesen umschließende sichelförmige Scheibe ist. An dem Messingring sind, um 90° gegeneinander versetzt (1/4 λ), die Anschlüsse für die zu den vier Dipolanordnungen … .*
# The four antennae were internally (galvanic) interconnected by means of a concentric brass-ring. A tap was provided every ¼ λ (please bear in mind figure 1). Which equals each time 90° signal phase-shift (consequently, the ring perimeter is 4 x ¼ λ = 61 cm). The antennae were interconnected in such a manner, that the signal phase between antenna groups was always 180°, as to obtain split-beam operation. A special shaped ceramic disc (*sichelförmige Scheibe*) (one side deposited with Ag or Cu), provided a revolving capacitance, coupling capacitive the fixed brass-ring with the central in/output of the radar signal, creating a revolving phase-shifter in all quadrants (*elektrisches Drehfeld auf dem Messingring*). They accomplished, that the transmitted signal was always available at all times at all four antennae. Though, the beam forming was owing to the revolving ceramic capacitance (creating a revolving phase-shifting delay-line). The four mechanical switches for azimuth and elevation on the right of the beam forming antenna selector, guaranteed that only the appropriate signals were shown on the bearing displays. It is evident, that the inner dimension of the antenna-group selector (*de facto* the brass-ring perimeter), made frequency change hardly possible. [3, pp. 24-25][3a, p. 4]

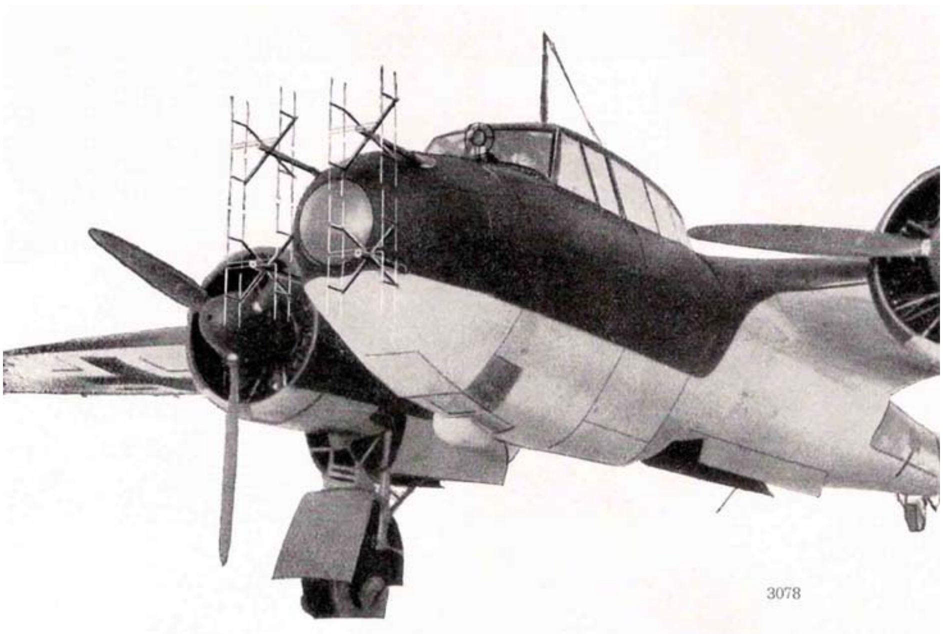
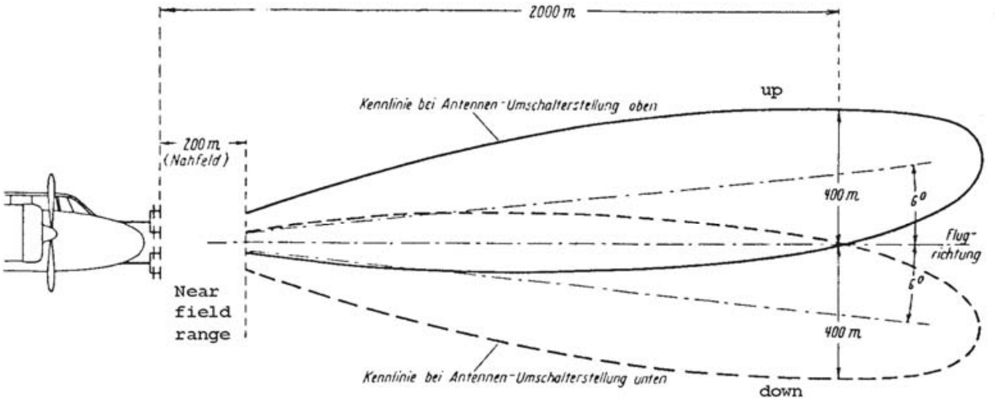


Abb. 3. Anordnung der Antennen an der Flugzeugkanzel

Fig. 2 Lichtenstein b/c antenna array at the nose section (Flugzeugkanzel) of a Junkers 88 (Ju88) (night-)fighter aircraft



Zeichn. 4. Kennlinie der Richtantennen

Fig. 3 FuG 202 b/c antenna aperture
The beam-width (aperture) is at 2000 metre distance maximally ≈ 800 metres wide, which is equal to an average aperture (measured between the lobe centres) of 12 degrees. These figures are equal for both vertical and horizontal planes (elevation and azimuth). [3]

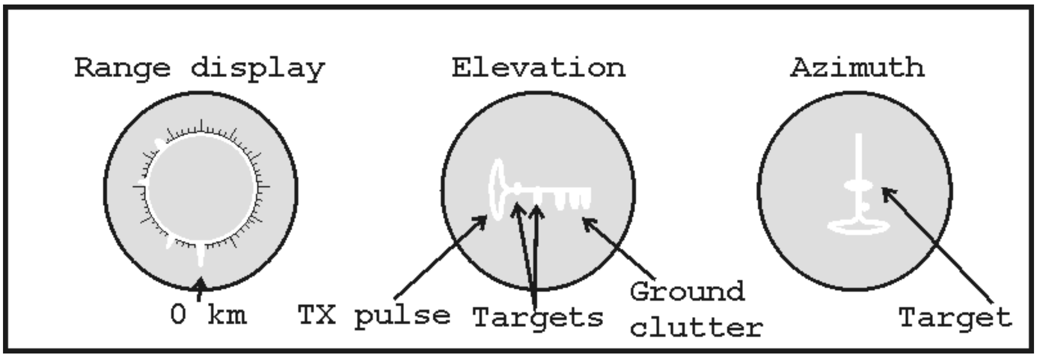


Fig. 4 Three screen examples of the Lichtenstein b/c radar display. The main elevation target originates from an aircraft flying at a lower altitude. According this azimuth display, the (main) target is in the line of sight, thus being straight ahead (Flugrichtung). (Elevation = Höhe) (Azimuth = Seite)*

*This drawing is a compilation (reconstruction) based on a FuG202 manual of January 1943 [4]. The bearing signals do not, for this occasion, entirely correlate to the range presentation. We also must take in to consideration that some minor details of Lichtenstein b/c might differ from what have been mentioned in Hans Jucker's paper. It could well be, that the bearing range originally exceeded the 2 km limit, as is mentioned in Hans Jucker's paper [2].
Hans Jucker sent me the following comment, after I transferred this paper for a review to him:

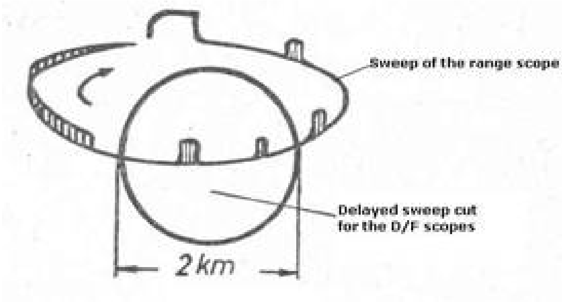
I have reviewed your manuscript last night, there isn't much to add!

A general remark in view of the FuG202 as well as the FuG220 antenna could be that the early German radar antenna designers were well aware of the basic concepts of Electronically Steered Array Antennas

- The antenna was mounted in a fixed opposition on the aircraft structure
- Its beam was steered by individually controlling the phase of the radio waves transmitted and received by the radiating elements

Perhaps you could mention that the D/F (Azimuth & Elevation) scopes utilized already an early form of the Sweep Delay Principle (see figure and text below) but feel free it isn't absolute urgent ….

The D/F scopes display a sweep cut of 2 km only. The sweep delay contains for this purpose an adjustable phase shifter for the 2700 Hz sine wave. Its can be adjusted in flight by the operator within the 8 km of the range scope.



So far Hans Jucker's additional comment to this paper.

However, the elevation and azimuth CRT indicators displayed only a (limited) bearing range of 2 km. The overall range display (most left) used a circular-deflection cathode ray tube. Circular magnetic CRT deflection provides an ultra linear time-base line (when a pure sinusoidal deflection current is being concerned). The two deflection coils were operated (tuned) in resonance (a technology originally invented by Manfred von Ardenne, early 1930s). One spot revolution represents the maximum range of a system. A disadvantage is, that any kind of PRF deviation will cause a distortion of the painted circular trace on the range display. The advantage of circular presentation is, in contrast to regular CRT display (A-scope), that the time-base line is extended (multiplied) by the factor π.
The German and British ways of elevation and/or azimuth screen presentation had both, for some time, much in common (presumably, the most obvious way of solving the job).

Let us consider figure 1:
The receiver concept was quite simple and used a superregenerative circuit design (to my knowledge, no other German radar set used a "superreg" receiver). Some British IFF sets employed also superreg receiver technology. Its striking advantage is, that it provides a quite sensitive (radar) receiver, and requires only few components. The superregenerative receiver concept was invented by Armstrong in the early 1920s.
Let us follow, to some extent, Hans Jucker's paper [2]: ..... *The output of the* (receiver, AOB) *detector is fed to the broad band amplifier having 5 stages. Its bandwidth is 3.5 MHz at 6 MHz down, the overall voltage gain is 4000 times at 100 kHz falling to 2000 at 500 kHz. The broad band amplifier also contains the automatic gain stabilisation circuit. This circuit provides a negative voltage which is applied to the quench generator to control the quench amplitude applied to the superregenrative detector* (circuit, AOB) *and thus control the gain of the detector. The quench oscillator consists of an oscillator operating at 454 kHz, whose output is fed to the a.g.s. control stage. The broad band amplifier output is fed to the other input of the a.g.s. control stage. The output of the a.g.s. control stage supplies a variable quench voltage of 1 - 40 volts as plate voltage to the triode oscillator of the R.F. unit* (in casu, the receiver front-end, AOB). *The time constant of the whole a.g.s. system is about 120 ms, the range of the gain control 60 dB. The*

a.g.s system greatly reduces the vulnerability of the receiver to jamming. The video output of the broad band amplifier for any kind of signals consists of 0.2 µs pulses at a quench rate of 450 kHz. Thus the pip on the screen appears filling in, and there is no break in the baseline.

The transmitter, following again Hans Jucker's description:

The transmitter operates on a frequency of 490 MHz and has a peak output power of 450 watts, approximately at a pulse repetition rate of 2700 Hz. Two RS394 triodes are used in an anode modulated push-pull oscillator. Tuned anode and grid lines (consider also his original paper [2], AOB) *are used in and cathode tuning is also is also provided. The antenna coupling loop feeds the RF power over a T/R unit into the antenna. The high voltage supply consists of 1 µs pulses from the separate modulator unit. The peak modulator voltage is approximately 1500 volts and the modulator power is 2 kW. The repetition frequency of 2700 Hz is obtained by dividing down from a 19 kHz master timing oscillator which drives all the timing circuits in the FuG 202 equipment.*

The design of the pulse-modulator (in figure 1 called: Impulstastgerät) may have caused Telefunken engineers considerable difficulties, as its circuitry had to be integrated into a rather small and light-weight (aluminium) module. Secondly, the then available German Air Force valves series did not facilitate small sized pulse-power triodes. They managed, nevertheless, to employ, successfully, two pairs of standard (Luftwaffe) LD2 triodes in push-pull (totally using 4 valves). (LD2 provided Q_a = 12 W, I_k pulse = 3 A)

For more details please consider [2].

Lichtenstein SN2, also known as FuG 220 SN2

Its basic apparatus concept goes back to Telefunken's type FuG213 of 1942/43, which latter type will not be a subject of this paper.

It is not clear to me, who, and why, one have coined (tossed) the suffix b/c and SN2, this will, probably, remain a mystery for ever. It proved, however, that this strategy (tactic) worked out better than one could have imagined.

Let us regard, briefly, the circumstances of 1943.
Germany was facing increasing disruption of its industrial structure and, on the other hand, had to find ways to provide enough weapon systems of all kinds.

Air defence had gained utmost importance. The Luftwaffe was responsible, exclusively, for the wide fields of German air-defence (inclusive Flak). To counter the bomber peril, night-fighter defence became increasingly significant. The German air defence had grown to a huge organisation providing adequate information to Flak and individual night-fighters. It had been proved that these (night-)fighters could strike rather effectively. Though, it is rather difficult (stressful) for a pilot to seek an enemy aircraft in darkness - being engaged in navigating, manoeuvring and managing it into a favourable striking position at speeds (replacement) of, sometimes, more than 500 km/h (> 140 m/s)! New effective radar aids were urgently necessitated.

It was quite clear, especially after the Germans discovered the British H2S radar set on 3 February 1943 (Rotterdam-Gerät), that German air supremacy was at stake. It has to be noticed, that H2S was regarded by German air force, primarily, being a bombing aid, and that PPI presentation was useless in air combat (the Germans called PPI sometimes “Panoramaröhre” which may be translated “panoramic display”). The direct aim was to point their heavy machine guns at enemy aircraft effectively. Time of action (and taking decisions) had to be commenced within, stressful, seconds only! Consider for tactical aspects on “Schräge Musik” Hans Jucker’s paper [2, p.9].

It was also considered, that the live time of new systems is, often, being limited to not yet one year.

And, that Lichtenstein type b/c was partially within the frequency range of Würzburg, which covered 480 up to 560 MHz (later extended to 580 MHz). The Germans knew that Allied radar jammers existed, and it was clear to them that it was only a matter of time before these facilities were used against Lichtenstein b/c too (The Allies have indeed tried to explore this fact, though, with negligible effect).

They initiated a crash-program, to get a new radar weapon operational soon. I have no knowledge what the sequence of the process was, we know, however, that Lichtenstein SN2 (FuG220 SN2) had been introduced in the second half of 1943.

The Germans faced increasing shortage of strategic materials and Speer’s ministry of armament watched, eagerly, that resources were not being spoiled. They decided to use for SN2, 2 mm Fe sheet and 1 mm Fe tubes, as basic (construction) material. Most surfaces had been “schooped” (sprayed with a zinc layer). The antennae tubes or rods (*in casu*, the dipole radiators) had, nevertheless, electrolytic (galvanic) been copper plated.

What made Lichtenstein SN2 so peculiar, that the British intelligence communities were so surprised (excited), after a fully equipped German Ju 88 aircraft had landed at Woodbridge on 13 July on Britain’s territory? (was it a classical navigation blunder, or.. ?) The “Lichtenstein” code-name was, certainly, very well known to them.

Let us follow the most obvious way of intelligence, which was, for most belligerents, photo-recognisance.

We may assume, that actual photos of recent German fighters equipped with radar existed. We also expect, that Lichtenstein radar was acknowledged in the frequency region of about 490 MHz. Most of you will be familiar that antennae (radiators) are (mostly) build of central fed half wave dipole (sections), regardless its ultimate configuration. After Hertz we know, that in this case, the main radiation lobe is perpendicular to the mechanical plane of the antenna (array).

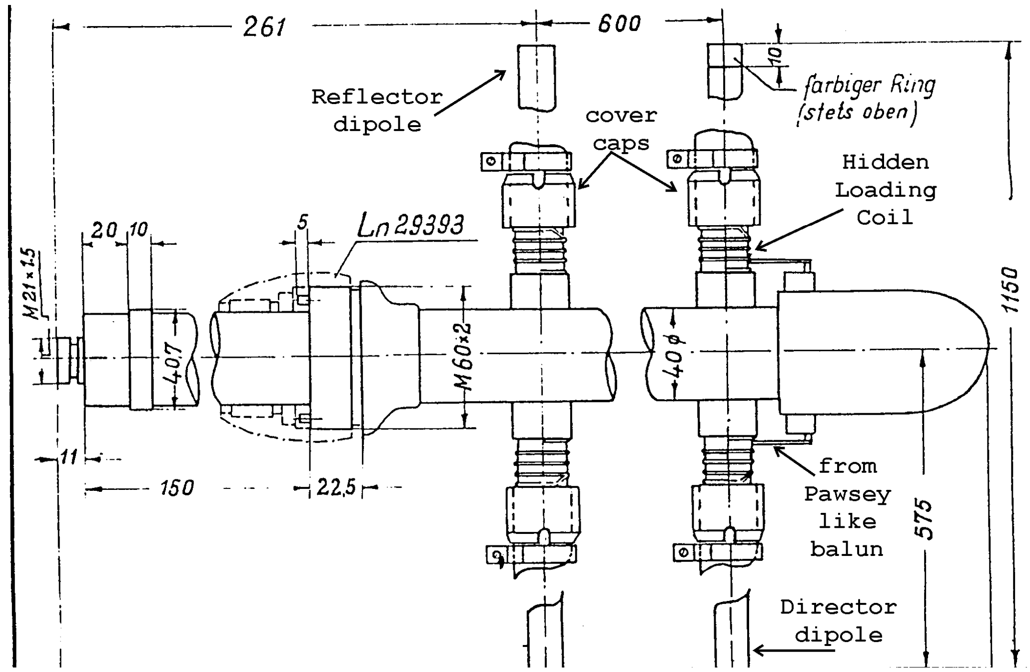


Fig. 5 SN2 antenna construction drawing according Ln29377

We can see in this drawing that the dipole measured 1150 mm (1.15 m), and that such a dipole, consequently, should resonate at ≈ 130 MHz (neglecting the reduction factor of approx. 5%). This is well within the Freya frequency spectrum.
Nothing suspicious was noticed, particularly not that something striking had just been photographed!

What Telefunken actually did was, they inserted in series with the dipole feeding points (centre) a pair of (hidden) loading coils (LC), which lowered electrically its resonance frequency (thus extending its wave lengths). SN2 initially operated in the 91 - 85 MHz regions. See also figure 7.*
*However, straight from the 1943 system concept, they were aware that the operating frequency range should be spread, as to prevent jamming of friendly systems. And, consequently, that these (various) types were not being introduced after the Allies had discovered what SN2 is about (thus, two weeks after 13 July 1944), but earlier. A wide variety of frequency bands was already dealt with, in a mid 1944 SN2 manual. It may be, of course, that they did not consider its operation at 70 MHz or even below, when they introduced Lichtenstein SN2 (Zustand "0")! Quite confusing is, that the SN2 manual speaks (for security reasons) of ranges (Streuwelle) "... III - VI - V - ...". They mention, however, that "Antenne IV" (Grundwelle) was the original system frequency (let us consider being somewhere between 88 - 90 MHz).

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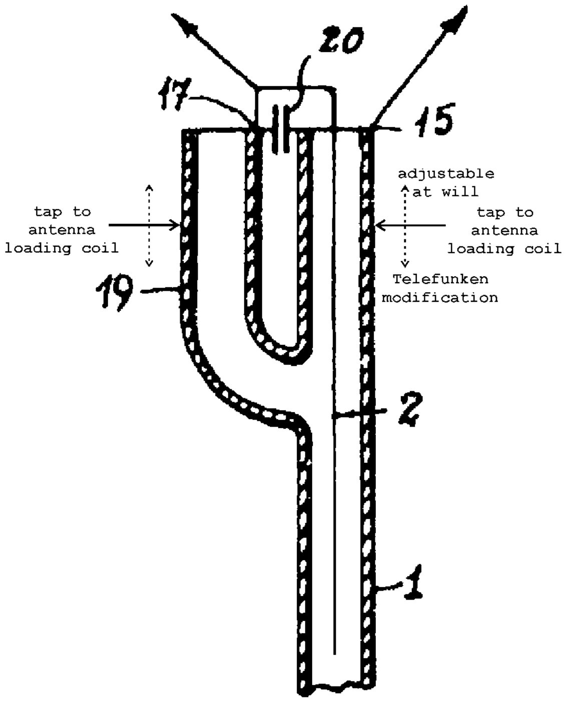


Fig. 6 SN2, Pawsey like arrangement (derived from the German patent drawing)

Let us, for this occasion, regard that SN2 should be operated at 100 MHz, which is equal to a λ of 3 metres. And, that baluns or symmetry-to-un-symmetry networks often changes (transforms) the matching impedance on both sides. In the 1930s, British EMI engineers were very famous for their work in this field. Because Pawsey was well known for his contributions, I, simply, call all related circuitry "Pawsey (like) arrangements".

In 1934, Castling White Eric Lawrence and Spencer Percival William (that is what is mentioned on the patent file) applied for British patent GB438506 owned by EMI. In Germany they got DE755778 (16 February 1935), which was, additionally, extended with DE890821.

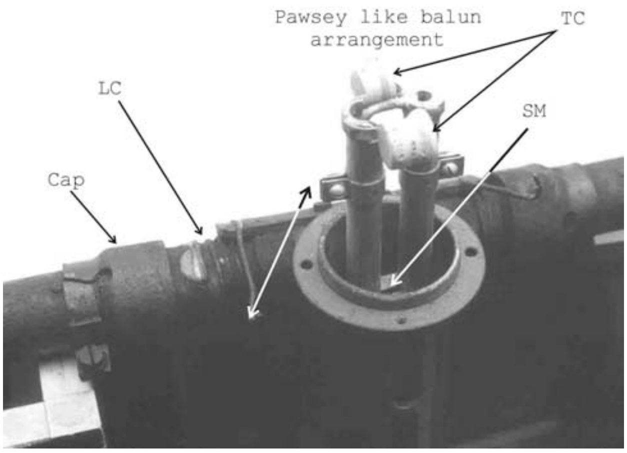


Fig. 7 Photo of SN2 loading coil arrangement

What is, in my opinion, very clever is that they (EMI) implemented, in one of their patent claims, a capacitor represented by part number 20 (patent figure 6). Its intention is, to reduce the physical size of the balun like arrangement, which normally should be in the order of a 1/4 wave length. Thus in case of SN2 about 75 cm long! [4] Implementing an additional capacitor (in this case it is about 100 pF), the length between position numbers 2 and 15 in figure 6 is reduced to roughly 15 cm (instead of ≈ 75 cm)! In figure 7, this capacitor is being marked TC. That they have employed two capacitors alternatively, may been for practical reasons, as these two smaller sized components could better fit within the limited space inside the bakelite cover cap.
I have made a replica of the entire antenna arrangement and tuned (adjusted) one antenna at its operating frequency. The caps, visible in figures 5 and 7, allow fine tuning of the director and the reflector loading coils. Such an antenna arrangement clearly performs as a "tuned band filter".

The taps shown in figures 6 and 7 are arranged as to create an optimal match (energy transfer) of the dipole arrangement onto the symmetry network.

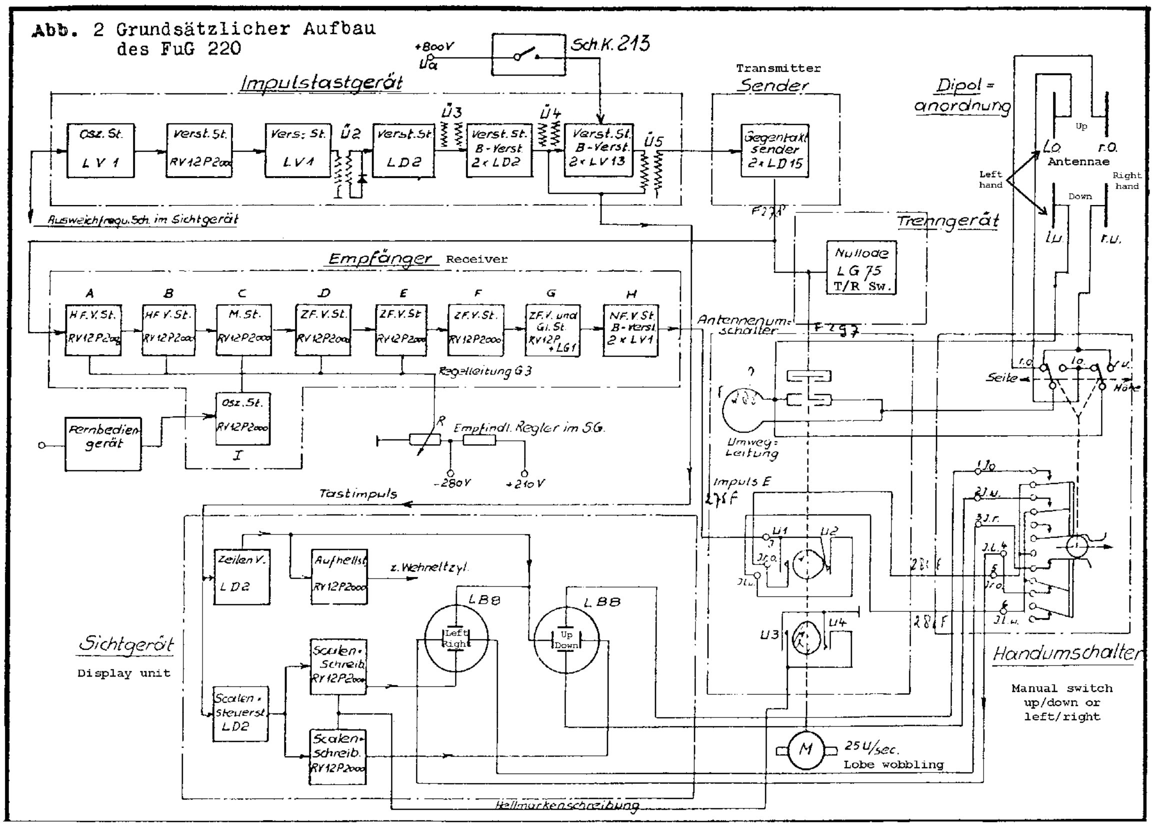


Fig. 8 Lichtenstein SN2 schematic diagram (Blockschaltbild)

When we compare figures 1 and 8, we can see that Lichtenstein type SN2 is a more elaborate radar apparatus. It is, however, of quite conventional design and bears nothing really new. The main thing that may be of interest is: the antenna circuit between antennae and "front-end" of the radar receiver. The relatively low operating frequency of the system (91 - 70 MHz), allowed the application of the conventional "Wehrmacht pentode valve" type RV12P2000, which was produced in huge quantities (> 16,000,000 samples). It actually was the "backbone valve" of nearly all their electronic (military) equipment. [5]

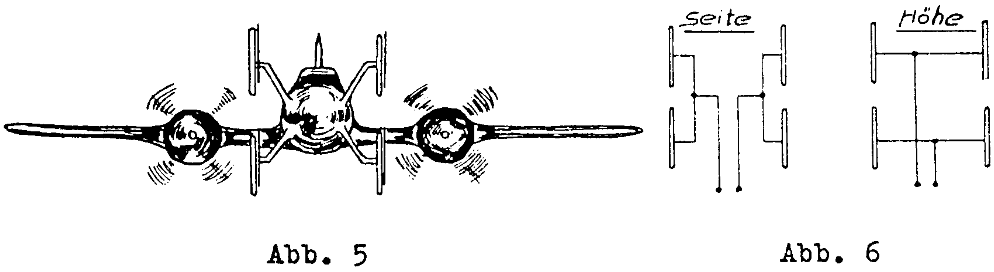


Fig. 9 The way in which the SN2 antennae were mounted and how these could be interconnected

It is clear that the antennae can be configured either for azimuth (= Seite) or elevation (= Höhe) operation. The operator could select, by means of a manual selector, what plane should be considered. There existed also a motor-driven version, which allowed observation of both planes at once, though, that hardly can be found (presumably, it was too complicated and/or too delicate in operation). One would get, with the latter motor-driven plane-selector switch, the display presentations shown in figure 10.

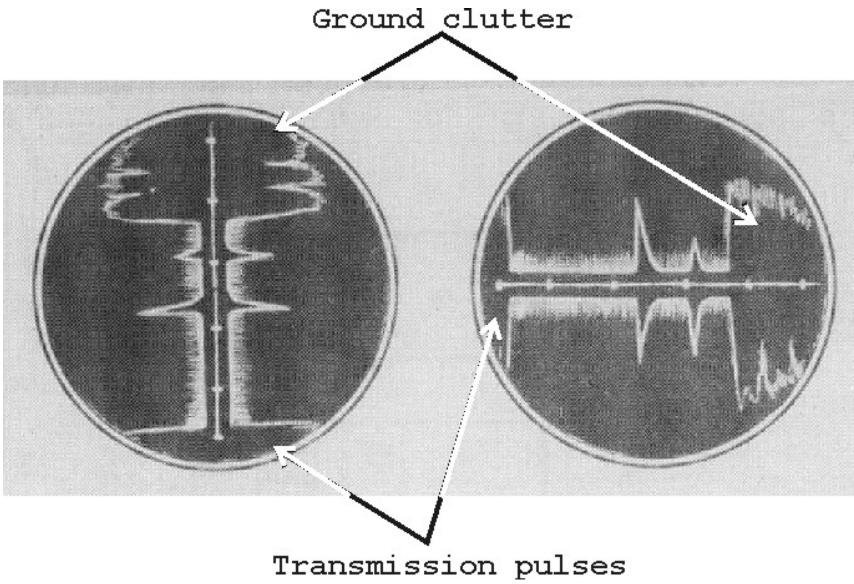


Fig. 10. On the left is shown the azimuth bearing, on the right we see the elevation bearing display.* We notice that the second target is a bit towards starboard. The right-hand display shows that this target is flying at a slightly lower altitude. The white dots are indicating the 2 km range markers (Eichmarken). *Notice that the azimuth and elevation displays have been interchanged, compared to Lichtenstein b/c.

It is evident, that the actual operating range is limited by the distance (range) of ground clutter (Bodenechos). This may not have caused them too much problems. The next figure 11 indicates, that the maximum antenna aperture is towards earth ≈ 30 degrees. When we regard that a night-fighter aircraft is flying at an altitude of say 5000 m (16400 ft), the slant range (*in casu*, the down looking antenna lobes) will be then ≈ 10 km, which is equal to the maximum system range. The range of ground clutter in figure 10 starts at a distance of ≈ 7.7 km.

However, the outputs of the two antenna groups (either elevation or azimuth) were fed, after passing through the plane-selector switch, onto a rotating butterfly capacitor. An antenna group was (always) inter-connected by means of a so-called “Umwegleitung” (delay line) consisting of a relatively short coaxial line. The wobbling, motor driven, butterfly-capacitor output created (provided) the following polar diagram:

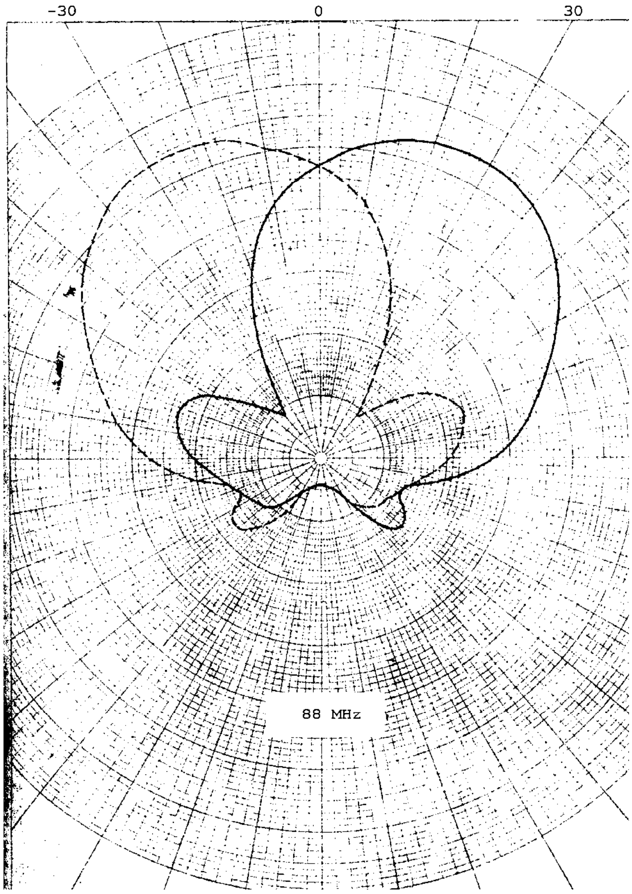


Fig. 11 SN2 polar diagram at 88 MHz

The overall radiation plot looks quite good, and it can be noticed that for 88 MHz the system aperture was about 60 degrees (-30 - 0 - 30). As the dipoles were mounted symmetrically (see figure 9), this plot is equal for both elevation and azimuth.

As one might have noticed, the antennae (output) are simply being connected in parallel. The (centre)impedance of a half wave dipole is about 70 ohms, which is equal to the (coaxial) line impedance used by the Germans in those days. Two 70 ohms cable outputs would make a match of 35 ohms. To match each point in the antenna circuit, they used coaxial cables(lines) of a particular length which was of n x ½ λ (n = 1,2,3,...). Each cable length (cable number) had carefully to be adjusted for its purpose. They had very special test gear to measure (match) and control each individual cable (system) parameter.

Of some interest may also be the employed “Nullode”, a T/R (transmit-receive) switching arrangement.

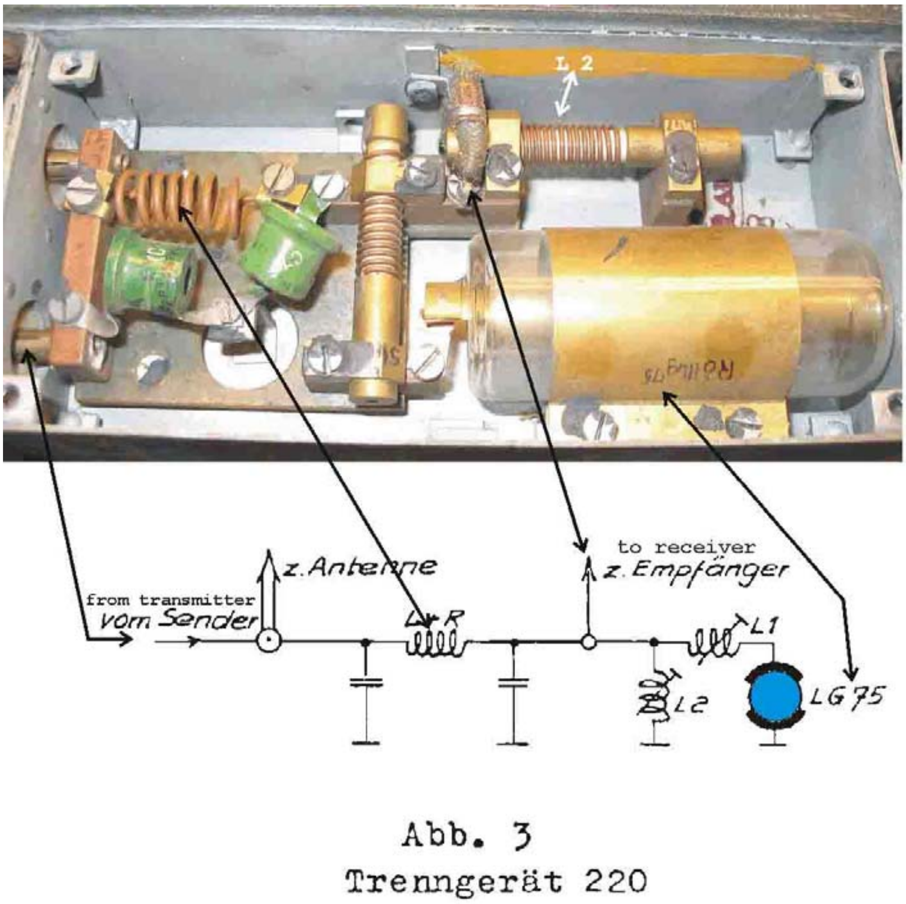


Fig 12 T/R switch with Nullode circuitry (Trenngerät 220)

It was already common practice, in pre-war years, to detune the front-end circuit of a radar receiver; by using the impedance change at the open end of a coaxial line, when the radar transmitter is in its switched-off sequence.

Telefunken applied for patent DE761708 on 30 September 1941, which was invented by W. Stepp.*

*There is a mystery about this sort of patent document, as they disappeared for almost 60 years!
After due engagements with German patent documents for more than a decade, I have reached the conclusion: that (first) the Third Reich took the patent claim of Telefunken (visible because Telefunken’s name had been crossed out) (this was, however, not always the case). And after the war, the Allies may have considered them being trophies of war, as it was then legally owned by the Third Reich. Searching for German wartime patents in the British Patent Office, it proved for many file numbers to be impossible to find them on micro-films, as is displayed: “this patent is not available” (this will, most likely, never change)! However, because the computer system at St. Pancras was on a day last February (2006) out of order, the staff advised me to use the German “Depatisnet” instead. A virtual miracle occurred, the ‘lost’ numbers proved to be accessible since recently! I have marked them on my website with the extension ‘ap’ (please, don’t enter this extension when using Depatisnet). Very noteworthy is, that the newly discovered patent files differ totally from the regular patent documents. It is a photo copy of the original application form(this is why I use the extension ‘ap’), with all its hand-written changes during the application (acceptance)

procedure. The final date of granting cannot be found (determined) although, it is visible that the German patent clerks have worked on them between late 1945 and 1948. It is, nevertheless, almost certain, that the patent numbers had been given (granted) during war time years.
We have to consider, nevertheless, that the prior interest of a State always prevails, and that ownership may be taken away by legal means. Be it that an applicant has to be reasonably compensated for its commercial (legal) loss of property (today we say "intellectual property"). Consider for more details, what the state of German patent legislation was since 1936 (may have been valid for the war period too)[6] [7].

Stepp's transmit-receive switch covered a range of applications of H_2O vapour filled glass envelopes (at an internal pressure of ≈ 1 mm Hg; they added traces of radioactive gas, as to enhance its response-time characteristic). The technical word "Nullode" means a device without (internal) electrode.

Let us consider figure 12
The electrical circuit is quite easy to understand. When an appropriate HF field is applied between the outside electrodes of "LG75" shown in the schematic diagram, the water vapour will get ionized and inductor L1 will be connected, capacitive, to earth potential. L1 and L2 are now connected in parallel and will, effectively, detune (block) the front-end of the SN2 receiver. Its application differs a bit from what is shown in the schematic diagram. The envelope of LG75 (as many other derivates as well) is made in a tubular way. Its centre is kept hollow and has to hold a metal stub over its full length. The outer electrode does not even have to cover the entire outside of the envelope (see figure 12), as the ionized (water) vapour is conducting all available HF current through it. Several German decimetre radars employed these kinds of Nullodes. Like: Würzburg equipped with Urechse SÜ62d , Mannheim, Hohentwiel, ...   Consider also [2, p.9]

One thing is, in my vision, of historical significance. That is the design of the coaxial connectors.

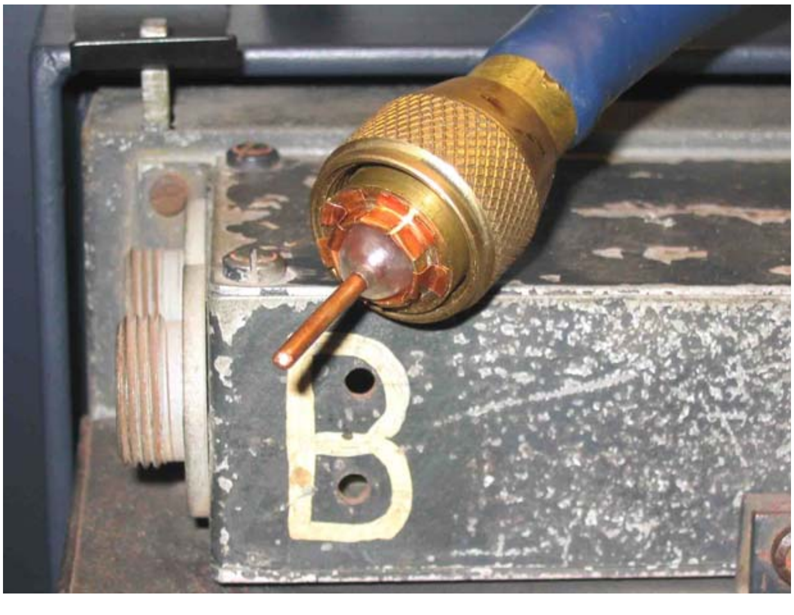


Fig. 13 SN2 coaxial cable connector
The heavy inner core (conductor) of the coaxial cable is directly used as connector (centre) pin. This technology is adopted in our "satellite age" and being applied in the F-connector type too.

Although, I have traced a reference on its design by Telefunken, I could not yet translate (match) the old German (D.R.P.) application number with a modern European patent reference.

The electrical properties of this kind of so-called "Vacha cable" are very good (they often have 70 ohms impedance). It is of the "air space" type, with very interesting spacers. Its velocity factor is about 0.86 and it could be employed up to 1000 MHz. Its outer shielding consists of three heavy copper layers (from in- to outside): longitudinal copper stripes, copper sheet (layer) and a heavy copper wire braid acting as outer screening. The rather solid (blue) plastic cable-cover is made of PVC.*

* A downside of this cable type is, that bending has to be carefully controlled (carried out) and its mechanical pressure resistance is quite limited.

After introduction in 1943, it showed that SN2 had very poor short range sensitivity. This was mainly owing to saturation phenomena in its receiver system. To counter this downside, in first instance, they kept a simplified version of Lichtenstein b/c operational (without bearing facility), its obligation was to fill up the gap between 300/400 to 800/1000 metres.

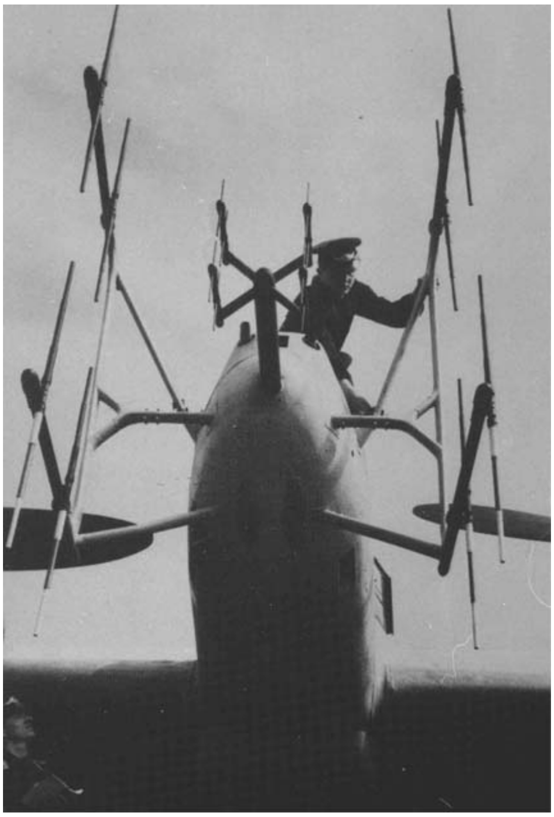


Fig. 14 Photo of aircraft with both SN2 and b/c antennae

After some time modified SN2 sets (Zustand "A & B") became available, and Lichtenstein b/c set was removed from night-fighter aircraft.
A switch on the front panel of the display-unit provided operation at either 4 or 10 km range.

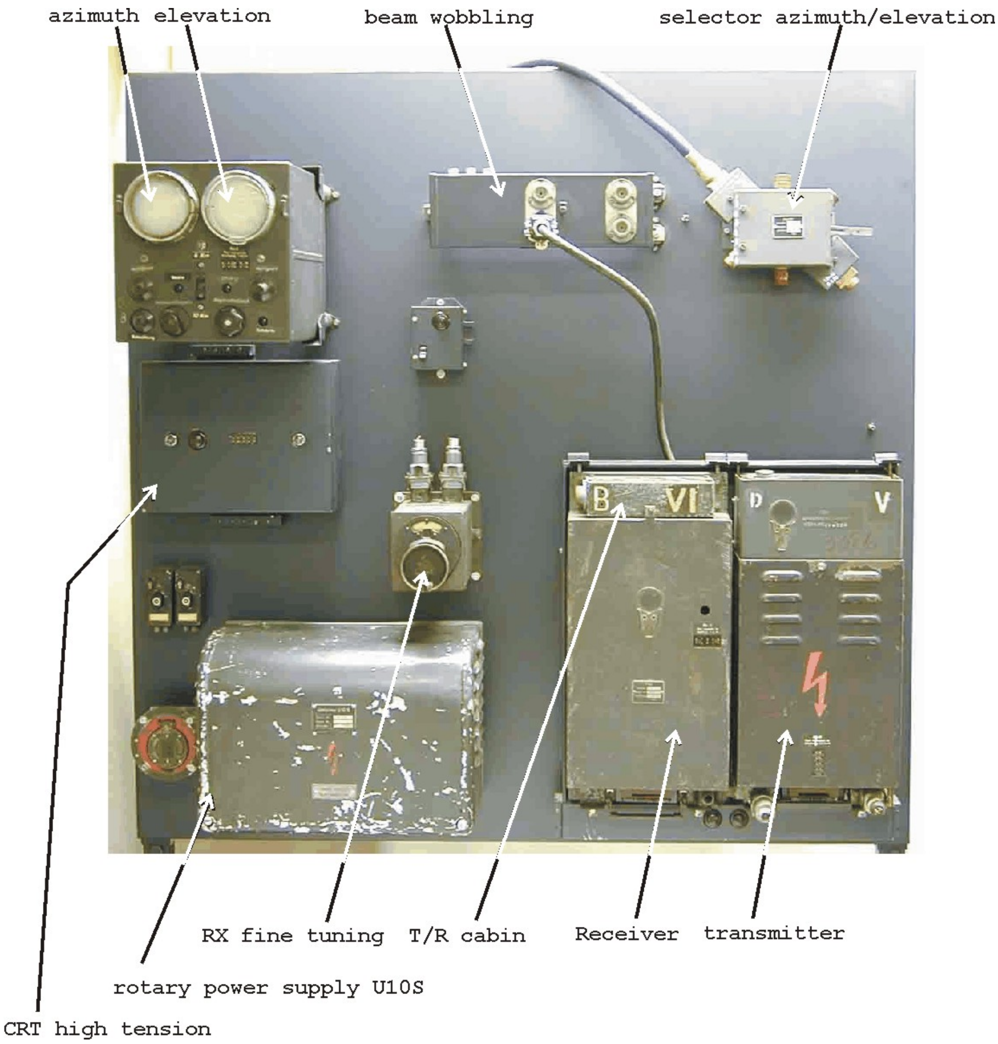


Fig. 15 Reconstruction of PT220 SN2 (PT = Prüftafel), being a "Test frame", which circuitry is equivalent to an aircraft installation

To close the technical aspects of this paragraph, some essential SN2 specs, based on Hans Jucker's paper [2, p.18]

Transmit peak power	2 kW
Receiver sensibility	-90 dBm
Antenna gain	5 dB
Antenna slit frequency	25 Hz (I have called it wobbling frequency, AOB)
Pulse length	1 µs
PRF	292, 295 ors 298
Instrumented range	8 km (against B24 or Lancaster bombers)

I would also like to cite from Hinsley [7a, p. 557 - 558]
Lichtenstein SN2 (FuG 220) was an Air Interception (AI) set employing a frequency range from 80 to 85 M/cs which was immune from 'Window'. It began to replace earlier Lichtensteins (the previously discussed FuG 202 b/c, AOB) *in the equipment of the German twin-engined night-*

fighters, the only fighters big enough to mount its unusual aerials, sometime between August and October 1943. In a crash program, the Germans had produced 200 sets by February 1944 and 1000 sets by May 1944. SN2 enabled its fighter to make early contact with the bomber stream once it had been given a general idea of the enemy's whereabouts by other warning and location devices and then enabled it to keep contact. ..... and it made a great contribution to Germany's biggest victories against Bomber Command. ... The possibility that a new Lichtenstein was being introduced was raised in February 1944, after No. 80 Wing RAF had noticed a decline in Lichtenstein transmissions. By the beginning of March No. 80 Wing had failed to find any unfamiliar signals, but the increase of bomber losses had made it 'painfully obvious' that the enemy was using a new AI set, and occasionally references by agents and POW *and in Enigma decrypts to new equipment code name Neptun and SN2...... No further progress was made until June, when the Air Ministry's Technical Intelligence Section noticed in the film of a combat between US fighter and a Ju88 night-fighter that the Ju88 was fitted with an aerial array similar to the rough sketch supplied by an agent in April; this had suggested a frequency of about 150 M/cs. The photographs were good and they estimated doubt that this was the SN2 and that its frequency was less than 100 M/cs....**

*Considering, what my explanation has brought to fruition, here must Mr. Hinsley have been confused by various details. We have noticed, that the optical size of SN2 antennae was well in the range of 130 MHz (be it, 150) and that the electrical extension (length) of SN2 antennae had been owing to "hidden built-in loading coils". What might have confused him is, that Neptun operated in the 150 MHz range and that it employed, visibly, more or less similar antenna arrays(configuration) as did SN2 (Neptun did not make use of hidden loading coils, AOB).

Never mind, Hinsley concluded:... *Bomber command brought this counter-measure into force within ten days* (after the Ju88 had landed at Woodbridge on 13 July 1944, AOB), *but by then SN2 had operated to great effect without interference for nearly nine months.*

Berlin radar type coming into being

On 3 February 1943, a British Stirling bomber aircraft crashed near Hardinxveld-Giesendam (south-east of Rotterdam) in the Netherlands. According to Leo Brandt, it carried at one of its units the inscription "experimental 6". What not should have happened is, that only a few days after the Royal Air Force was permitted H2S operations over occupied continental territories, a crashed aircraft was discovered by the Germans, carrying a more or less intact top secret British radar apparatus (it should have destroyed itself). [8, p. 81]

To keep this story within limits, the Germans responded quasi instantly. After a very short lasting shock, a committee was established on 22nd February provided with wide reaching powers. The minutes of this so-called "Arbeitsgemeinschaft Rotterdam" (AGR) committee survived, luckily, the war. It provides a comprehensive inside vision, as to how their institutions approached this tremendous difficult task. We have to be aware that German industry was by no means able to cope with entirely new, highly complicated, secret projects. Considering its urgency, in peace time this may have been a difficult objective. Responding, nevertheless, adequately in view of the facts - that a few days before their 6th Army had surrendered in Stalingrad to the Russians, and that they were facing increasing struggles on nearly all war theatres, acquired outstanding personalities with persistency.
What often is neglected is, that wartime production necessitates a period of preparation, as (raw) materials have carefully to be distributed over all fields(sectors) of industry. Even the availability of skilled labour was a great matter of concern (such as qualified engineers).

They aimed to bring scientists and engineers to cooperate effectively, something that was not directly a German endowment! The committee started with élan, and approached wide fields of SHF radar technology. [9]*

*Original German text:
1. Ziele
Der Arbeitsgemeinschaft wurde die Aufgabe gestellt, durch Zusammenfassung aller Erfahrungen von Forschung u.d. Industrie auf dem Zentimeterwellengebiet schnellstens die notwendigen Gegenmaßnahmen gegen das Verfahren „Rotterdam" zu schaffen. [9, p. 11]

They, briefly, aimed:

To build an equal (matching) apparatus as the recently discovered H2S radar set which got the German code-name Rotterdam-Gerät, in first instance, they decided to copy 6 Rotterdam sets [9, p.11]).*

*The US 3 cm radar set H2X got German code-name Meddo-Gerät , after a tiny village in east of the Netherlands, near to the German border, where it had been discovered in 1943. On 19 April 1943 even an un-destroyed set was captured by the Germans [9, p.27]

To construct a range of early warning SHF receivers (mobile, land and ship based)

To initiate fundamental research on, for example, the behaviour of decoys and Düppel.*

*This was the German code-name for Window, which technology was well known to them, but was kept most secret as to prevent the enemy from using it against them! Even Wilhelm Runge of Telefunken was once nearly prosecuted, after he had mentioned, at an occasion, the application of reflections of electromagnetic waves at conducting objects, due to Rudolf Kühnhold's denunciation. [regard for Kühnhold also, 10]
Shortly before Fritz Trenkle died in 1996, he told me that "historical battle names" had to be used for this kind of device (Düppel is a place in northern Germany).

To copy the British cavity magnetron CV64 (when necessary, making a "Chinese copy", the Germans called it "Nachbau") Which got German nomenclature LMS10 (10 stands for 10 kW).

To research and manufacture reflex klystrons, not necessarily a copy of the British Sutton tube.

A lot of work was done on aspects of "synthetic diodes" (SHF mixer and detector applications).

To indicate some of the difficulties they encountered: to make (produce) even one experimental valve sample, an entire production line had to be hold up for a considerable time.

To restrict this summary, for us significant is: that, at least, two programs were brought to maturity. Namely, Berlin radar which operated on 9 cm and Naxos, which latter was an automatic, passive, radar DF (homing) system.

Berlin FuG224

To reduce time of development and bringing cm radar into being quickly, they decided to copy basic SHF parts of H2S. Be it, that they converted it into metric measures (slightly different size, and threads) .
Simply copying everything was out of the question, as German aircraft did not provide equal space as did British aircraft. They were, for several reasons, forced to reduce the size of the

system (about 30 %) as well as to employ standard German components (especially the application of standard radio valves).

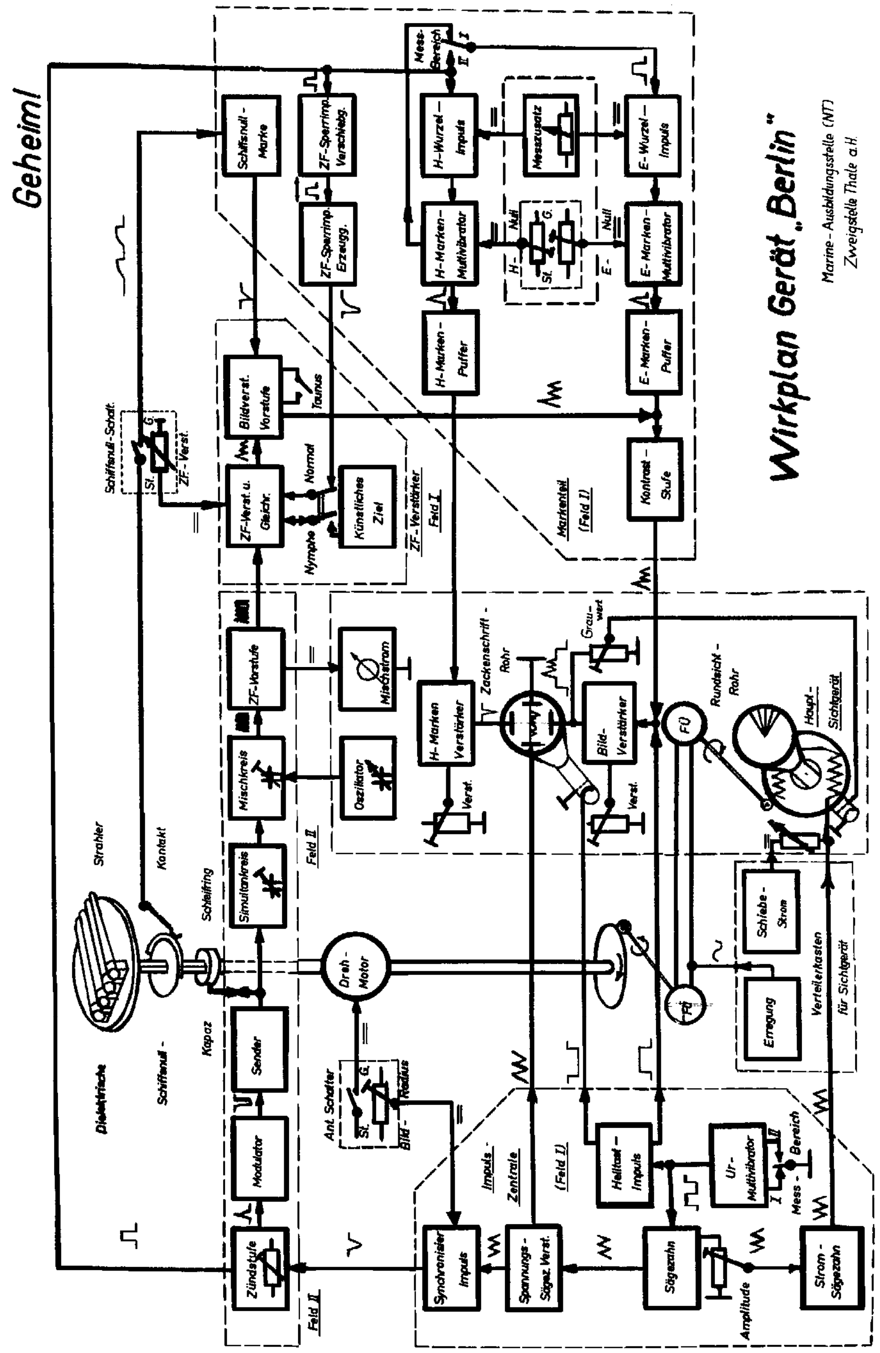


Fig. 16 Berlin FuG 224 block diagram (Wirkplan)

The basic concept of this block diagram is, more or less, similar to H2S. However, who of us is actually familiar with H2S circuitry?

Fore those who would like to study it, I have added a brief translation of some German expressions (abbreviations):

Bildverst. = video amplifier
E- = distance
Feld = block or field or frame
Gleichr. = detector or rectifier
Impuls = pulse
H- = height
Kreis = stage (may also be a tuned circuit)
Künstliches Ziel = artificial target (range checking of the PPI)
Marken = marker
Misch... = mixer
Puffer = buffer (separation) stage
Simultan = T/R switch
Strom = current
Ur- = master
Verstärker = amplifier
Vorstufe = pre-amplifier
ZF... = IF
Zünd... = ignition

I would like to focus your attention on to two points of interest.
First: Its actual antenna design (concept), which is known in this country since 1944. The Germans called it “Dielektrische Strahler” which may be translated “dielectric antenna” (in Britain also known as Polyrod antenna).
Second: the first oscillator (LO) which was, like in (early) H2S, integral part of the PPI display unit. This was done, as to ease operation of the system. Of its nature, cavity magnetron is, in its frequency domain, not very stable. Therefore, the first local oscillator had to be tuned (controlled) manually by the radar operator (tuning at optimal signal amplitude). The Germans employed a quite odd magnetron type RD2Md, because they did not (yet) possess a better tuneable signal sources in the frequency spectrum of 3 GHz. This split-anode magnetron necessitates a current source, to feed it appropriately. Its circuit concept may be, for some of you, of interest.

Dielectric radiator

Its basic principles had been described in my first CHiDE paper of late 1995, which contribution is available, be it slightly adapted, on my website. [11]

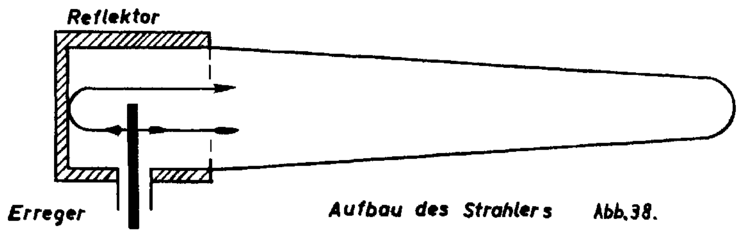
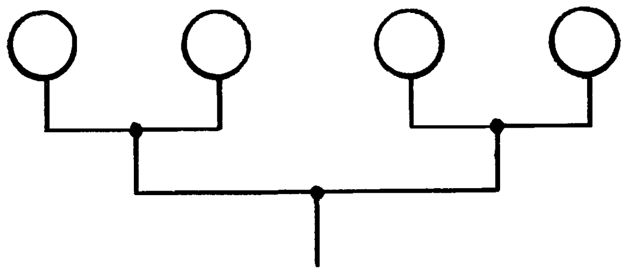


Fig. 17 Polyrod (Stiehlstrahler) principle

The EM field is travelling trough a conical dielectric rod made of polystyrene ($\varepsilon \approx 2.5$). Its shape and physical length has to obey to the expected (calculated) array radiation pattern and to match with the impedance of free space, which is equal to $120\ \pi$ ($377\ \Omega$).

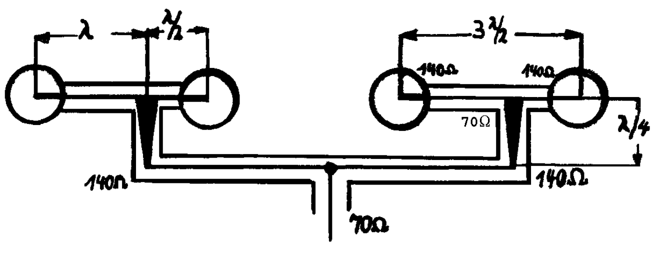
A single polyrod radiator as shown in figure 17 provides an aperture of 40 degrees. An array of four dielectric rods provides 10 degrees aperture. The down side of these kinds of dielectric arrays is, that with increasing numbers of dielectric elements, the (spurious)side lobes get out of control. Electronic computers did not yet exist and everything had to be calculated by (exhausting) manual means. What we nowadays can accomplish in a few seconds, took engineers often days or even more.

The polyrods were being spaced 1.5 λ, equal to the Naxos array (see figure 24). Be it, that their physical length was elongated to ≈ 3 λ (Naxos used 1.8 λ rod length). Exact details about the Berlin antenna array are not available to me.



Amplituden- und Spannungsgleiche Speisung der Strahler

Abb. 37



Speisung der Strahler

Fig. 18 Principle of impedance grouping of the Berlin antenna arrangement

Connecting (linking) antennae together, necessitate careful matching. We can see that, basically, the arrays consist of two identical groups. Which are being spaced 1.5 λ. The outputs of the two radiators (in two groups) are not placed in a symmetric manner. When we consider the two radiators of the groups, it is clear that these are pointing in opposite directions. This would constitute a split beam radiation pattern and is not appropriate for regular (PPI)radar. By means of a 180 degrees phase shifting arrangement (1/4 λ spaced from one radiator), both polyrod (signal)outputs are now getting in phase, and the signal outputs can now accumulate. The two 70 ohms coaxial outputs are, by means of two conical 1/4 wave lines, stepped up to an impedance of 140 ohms. These lines are also connected in parallel and finally matching to 70 ohms.*

*Without bringing the proof: when air is regarded being the dielectric constant (μ = 1) inside an asymmetric coaxial system - 70 ohm impedance is provided when D_{max} /d_{min} = 3, AOB.

We have to bear in mind, that most Berlin information is derived from a very comprehensive German navy description of 1944. I found evidence, that some details had been, however, manipulated for security reasons, as to confuse their navy personnel. This was evidently the case on their LMS 10 cavity magnetron description (a copy of CV64), which should have employed 12 cavities. This is clearly nonsense! [12] [13]

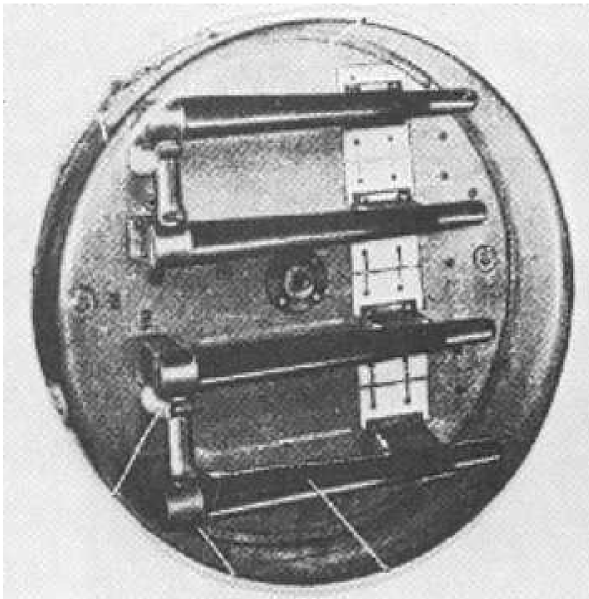


Fig. 19. Photo of Berlin actual antenna array

Please proceed on the next page.

Split-anode magnetron RD2Md

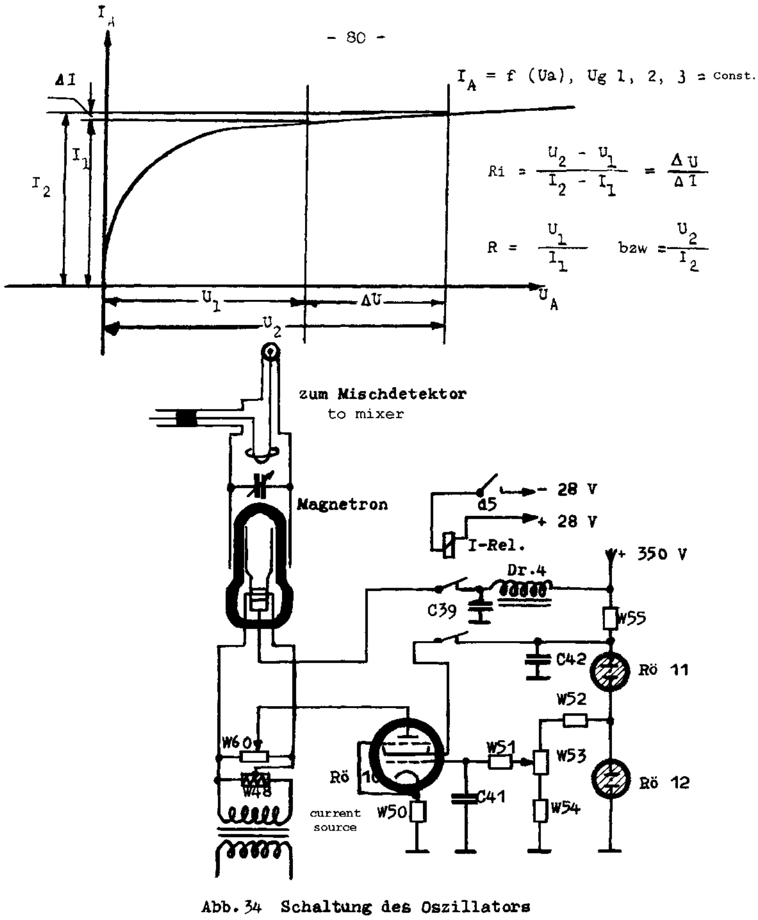


Fig. 20. Principle of the, tuneable, first local oscillator magnetron RD2Md

This magnetron consist of four anodes grouped together connected onto an internal Lecher line. Outside is a second Lecher line arrangement, which is capacitive coupled to it. The tuning capacitor (left of the word magnetron) is part of a cavity resonator. Recent findings indicate, that this originate from Telefunken patents DE753483 and DE760436 (both are so-called ‘ap’ files. Please notice my comments on page 14-15). We can see, that the anodes are being fed with 350 volts, and that the cathode, *in casu* the filament circuit, is connected onto valve number 10 (EL11), which constitute a current source. In our transistor age this is common practice, but current sources were rarely used in the “valve era”.

To close the Berlin subject, a few things that may be have interest too.

Berlin radar originally was designed for a fixed magnetic deflection system, consisting of two, perpendicularly placed, deflection yokes. Virtual rotation and deflection of the PPI beam was generated by a very complicated revolving variometer, which was mechanically united with the (revolving) antenna system. It proved, however, that it was very difficult to control all long term (mechanical)variometer parameters. Resulting in an unstable (jittering) centre of the PPI presentation (the centre area of the PPI display, whereof the time base starts moving outwards).

They later changed the system to a much simpler one, in which the deflection yoke rotated around the neck of the PPI CRT (display). This had an advantage for naval applications. The servo-system (Selsyn - known in Germany “Drehfeldgeber”) allowed application of up to three PPI stations simultaneously. The navy aimed, on board their heavy (capital) ships, the application of up to 3 PPI displays (one master and up to two slave units). Of which, at that stage of the war, hardly a capital ship was operational (had survived so far).

The employment of a dielectric antenna arrangement, had the advantage that it could revolve with 400 rounds per minutes. Which are 6.6 revolutions per second. The Berlin PPI display unit (Sichtgerät) could, however, cope with much lower revolutions, too [12, pdf file p.96]
It used a PPI CRT type LB9N (‘N’ may stand for “Nachleuchten”, which may indicate that a special fluorescent screen was concerned). A German source claimed, that due to this relatively vast beam rotation, the development of special fluorescence screen(storage ability) for LB9N, did not caused them too much problems. AGR dealt, however, with the development (science) of double layer fluorescence screens, as were common practice in British and American radar displays.

The physical process inside a magnetron is, significantly, influenced by the homogeneous magnetic flux perpendicular to the movement of electrons. For each magnetron type, a particular field-strength has to be provided. British and American cavity magnetrons were equipped with permanent magnets. Though, it is not easy to control their long-term parameters. The Germans may have faced difficulties in this respect. They used electromagnets instead.* A special current-regulator or **E**isen**w**asserstoffwiderstand (EW), also known as barretter, kept the applied magnetic flux within range. This caused, though, careful circuit protection measures. When magnetic flux fails, the magnetron acts as an ordinary diode and will be “kaput” in a short while!
*Boot and Randall employed during their (early) cavity magnetron experiments electromagnets too. The AGR commission discussed, occasionally, increasing the cavity numbers (up to 24), as to reduce the appropriate magnetic flux. Apparently, this would increase the precision (tolerance)of magnetron manufacturing, which they were not able to accomplish, in this stage of the war (beside, if this really would make sense, AOB). [9]

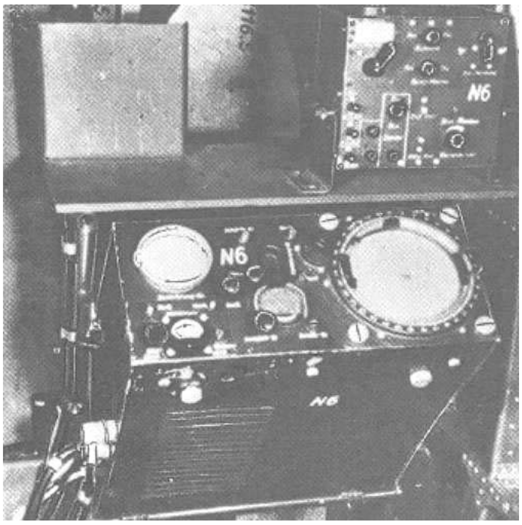


Fig. 21. Photo of a Berlin A apparatus onboard of a Focke-Wulf 200*, long distance, aircraft (probably serial number 6).*FW200 aircraft was called “Condor”.

To close this chapter:
The Germans used, like the Lichtenstein story, "Berlin" as a general code-name for several 9 cm radar systems. Although, some sets had only in common that they operated in the 9 cm wave regions. There existed in the last weeks of the war so-called Berlin FuG240 N1 (which suffix "N" may stand for Nachtjagd). It operated successfully in the 9 cm band and consists of SN2 like display unit combined with a steerable parabolic dish antenna in the nose-section of a fighter aircraft. It should have brought down 10 Allied aircraft (March/April 1945) [14, p.118 - 122] [8, p.95]. Also some Gema radar apparatus, like Seetakt (Freya?), had been converted into 9 cm radar systems, which were named: "Renner". These were deployed, particularly, in coastal defence (sector search, no PPI application). To my knowledge, they kept their regular radar displays (presentation) for azimuth and elevation, though, they replaced all (HF) parts as to operate in the 9 cm spectrum.
British interception services received, in the last phase of the war, various German 9 cm signals, which were easily recognisable due to their different PRFs.
Also, prototypes of "3 cm radar sets", known as "Bremen" apparatus, existed at the end of the hostilities. [8][14][15]

Passive radar systems

I would like to bring to your attention, briefly, two passive systems, which were onboard the ominous Junkers 88 night-fighter aircraft, that had landed on 13 July 1944 at Woodbridge airfield.

Flensburg FuG227

Very little had, technically, been published on Flensburg since. It could home on to Monica (a British rear viewing radar system). R.V. Jones was quite astonished, how well Flensburg performed against it. And, Monica was soon thereafter made redundant. After Monica was no longer operational, the Luftwaffe had to dismantle Flensburg. In such case, most information had, obligatory, to be destroyed. My contribution is, nonetheless, based on (derived from) a genuine Flensburg manual.[16]

What Flensburg actually did was, it could home (approaching from the rear) on aircraft equipped with Monica, without transmitting a signal itself.

It was, like most German countermeasures introduced in the second half of the war, of a rather uncomplicated concept.

It was designed by Siemens & Halske (now Siemens) and used components and technology which were already available for other applications. Consequently, its receiver was, in contrast to regular German aircraft gear, constructed not very soundly (neatly). It was, for aircraft application, too bulky. Nevertheless, it performed very adequately!

Let us look how it worked, briefly.

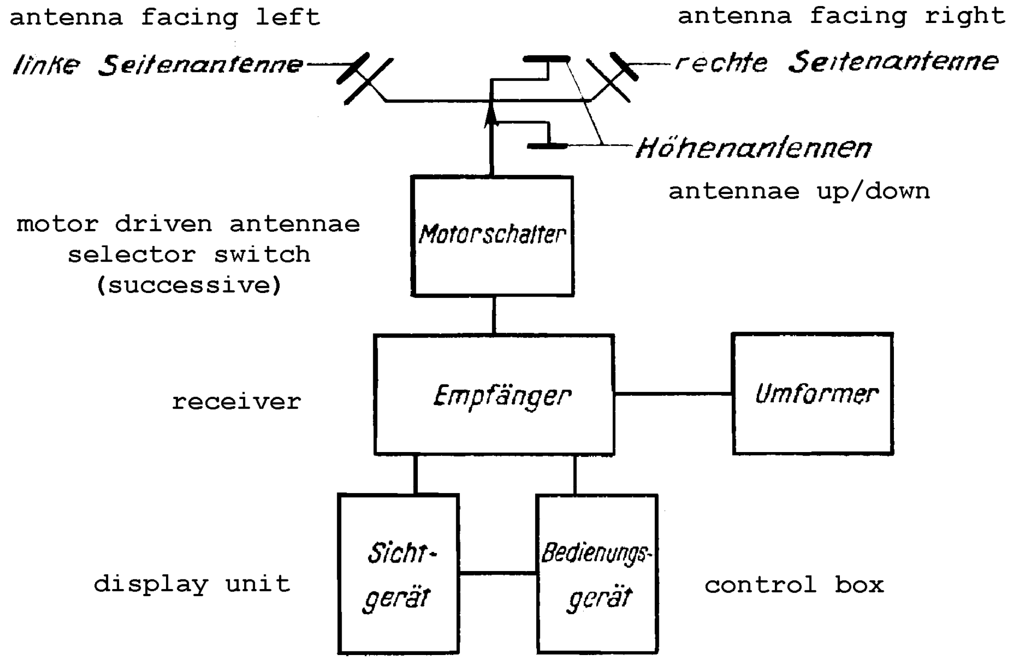


Abb. 1: Aufbau des Bordfunkgerätes FuG 227

Fig. 22 FuG227 principle (Blockschaltbild)

It employed four antennae, of which two were directional and two consisted of simple horizontal dipoles. These latter dipoles were mounted, one above and one below the right aircraft wing, which acted as an electrical screen between them. The two directional (horizontally looking) antennae were pointing a bit sideward (may be at angles of 45 degrees).

The motor driven (selector) switch, scanned sequentially the: left - right - upper and lower antenna outputs.

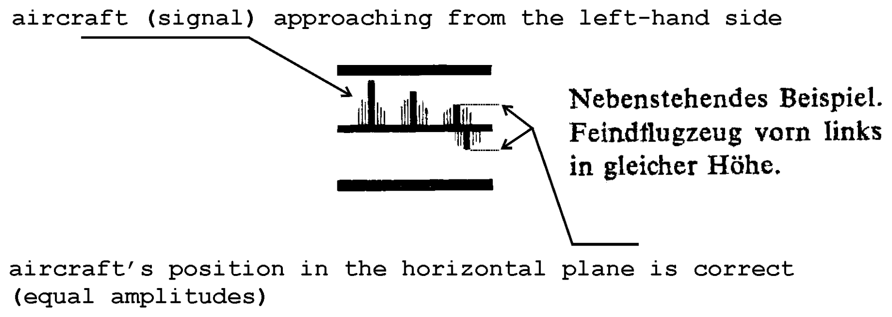


Fig. 23. Screen presentation. The black horizontal lines are, presumably, meant for checking the correct receiver sensitivity (preventing overloading of the receiver)

We have noticed from previous figure 22, that only one receiver channel is being concerned. Consequently, each signal amplitude shown on the display screen, represents the actual output level of an antenna. It is evident that, in this case, the horizontal signal (component) is

approaching from the left-hand (port) side of the aircraft, and that the displayed target is flying at an equal altitude.
We will not discuss screen presentation of signals approaching from the rear and that like, as it does not enhance our understanding of Flensburg.

Finally, a few details of Flensburg system:

The bearing (homing) accuracy was about 2 degrees
Bearing aperture for elevation 180 degrees; and azimuth +/- 180 degrees

It was designed for a maximum altitude of 9000 metres (≈ 30,000 feet)

Power consumption 170 watts

Total system weight 42 kg (inclusive rotary converter(Umformer))

Naxos

I have published a quite comprehensive paper on Naxos for the first CHiDE meeting in 1995, held at Bournemouth University.
As already been mentioned, it is made accessible on my website on internet [11]. I therefore will focus your attention on the general outline of the system only.

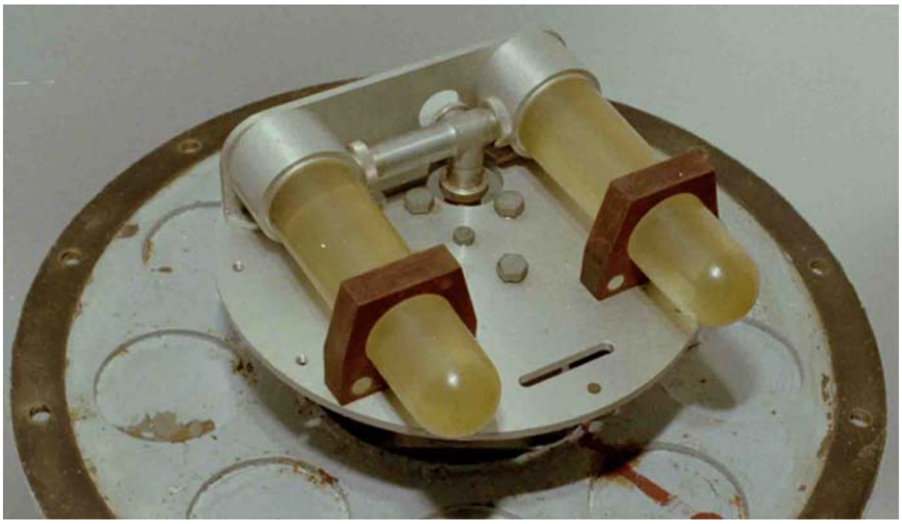


Fig. 24. Photo of Naxos antenna arrangement

This antenna is part of our collection, and the shown type is Navy version ZA 290M 1/44 of 1944. The navy used a Plexiglas (Perspex) radome, which had been removed for this occasion.
The main difference between the navy and air force type was, that the navy (Kriegsmarine) operated their systems mainly on 220 volt AC, whereas Luftwaffe supplied, onboard their aircraft, 28 (29) volt DC (24 volt battery, being fully charged).

Albeit, it used similar polyrod antenna technology as we have already discussed in the Berlin antenna paragraph. Its basic principle is shown in figure 17.

To explain the principles of Naxos, I would like to cite from my 1995 CHiDE contribution.[11]

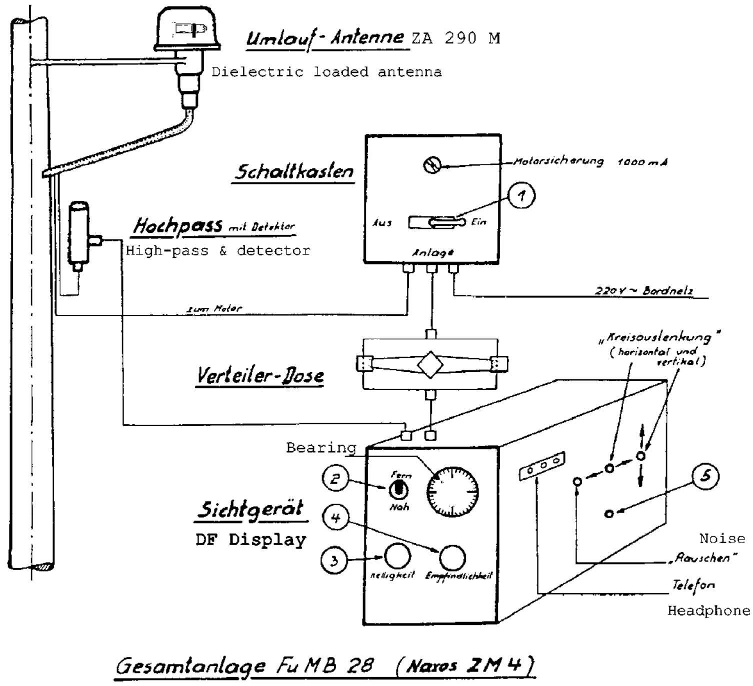


Fig. 25. FuMB 28 (**F**unk**m**ess**b**eobachtung type 28) Navy “Naxos ZM 4”

Figure 25 shows the basic design of the Naxos system. … *The main problem in developing centimetre wave equipment is that the extremely high frequencies prevent the use of standard receiving techniques. Adjustment to the radar transmitter can easily result in large frequency shifts causing loss of signal in a selective receiver or not receiving the signal in the first place. Sheer necessity or rationalisation may have been the reason that for Naxos a: wide-band, passive and un-tuned receiver was chosen. The detector is directly connected to the antenna output. The first SHF detector diodes probably were not of very high quality, but this caused no problems, as the high power of the radar transmitters produced a respectable signal at the detector anyway. The output of this detector contained a strong component at the pulse repetition (recurrence) frequency (PRF) of the radar, received by the Naxos receiver. This component in turn was modulated by (influenced in turn with 22 Hz, caused by the rotation frequency of the antenna, due to the ≈ 1300 revolutions per minute. The antenna had to rotate so quickly as to ensure that several radar impulses, from the also rotating H2S antenna, were always picked up. The signal was passed to the receiver first via coaxial motor shaft and a capacitive coupler to the detector.* (This was equally as for the Berlin antenna)

The detector was followed by a, low frequency, amplifier with a gain of about 120 dB (10^6), and a frequency response that was optimized for the PRFs of the radars to be observed. The output of the amplifier directly controlled the cathode ray tube.

The left-hand picture of figure 26 represents the early display of Naxos type FuG350 Z, whereas on the right the advanced FuG350 Zc screen presentation is shown.

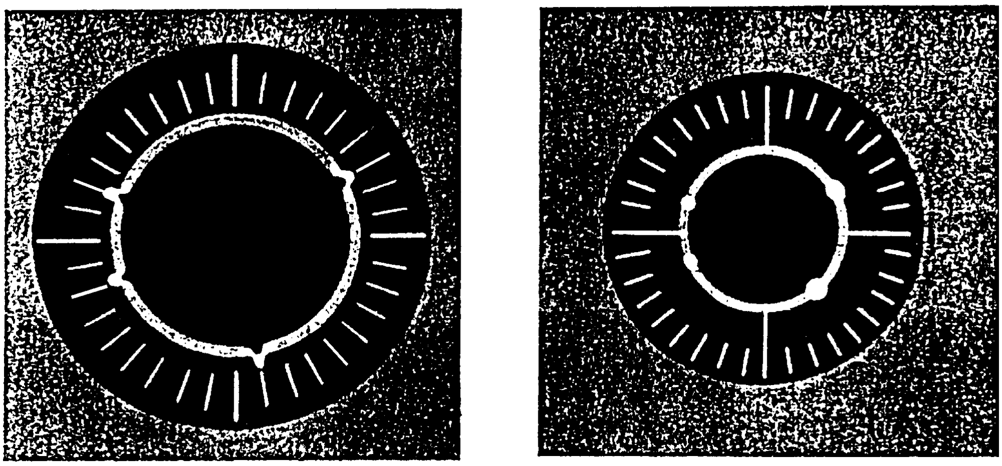


Fig.2: *Naxos c.r.t. display, showing four radar signals being received from different bearings. The display at the left is of the first generation, at the right a later version*

Fig. 26. Screen presentations.

First experimental Naxos-Z flight took place on 11 th September '43. According to Sir Bernhard Lovell: the British intelligence "obtained overwhelming evidence that Germans were plotting it H2S transmissions (they had started as early as 28th November 1943), and were in fact equipping their fighters with a receiver code-named 'Naxos' to home on to the transmissions not only from H2S but also on the kindred equipment fitted to our bombers.... ".

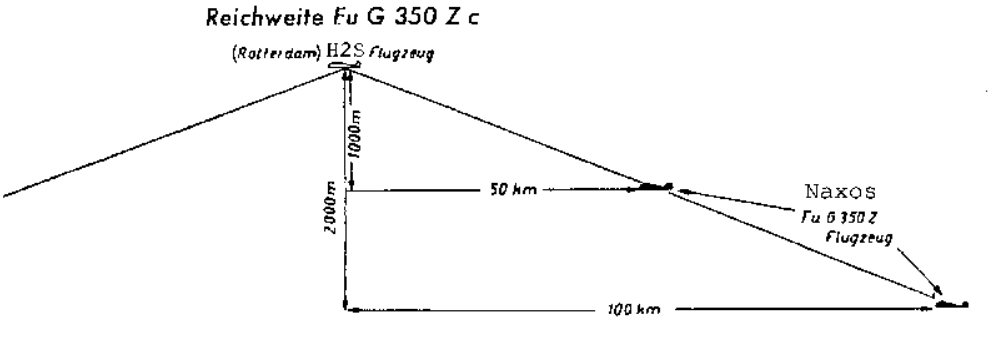


Fig.11: *Interception range of Naxos versus H2S*

Fig. 27. Naxos interception range versus foe aircraft.

What Naxos tactically could accomplish is shown in the drawing above.
We have, however, to notice that the aircraft antenna was, for aero-dynamical reasons, adapted to the surface of an aircraft fuselage, and that the plexiglas (perspex) cover plate did not obstruct the air flow too much. It was placed (build-in) for looking (operating) upwards, as is visible in figure 27.

Pondering

The Germans were finally not able to implement centimetre radar in full extent. According to Brandt (who was the chairman of AGR 1943/44), a total number of 500 centimetre units had been produced, whereof approximately 100 systems were actually operational in the final stage of the war. [8, p.99]

Cockburn, in his post war TRE résumé of 1945, has put his finger on a significant point: The superiority (advantage) of H2S and H2X should be regarded as only temporarily, as an enemy sooner or later will operate similar systems.

For us luckily (not underestimating the great endeavours of Allied forces generally), the Germans were brought down strategically because their essential chemical plants had been destructed systematically time and again, since early 1944 onwards (increasingly hampering, for instance, the production of synthetic rubber named “Buna”). The so-called “Hydrierwerke” were supplying chemical products of all sorts though, their main objective was to provide wide varieties of synthetic fuels (these plants were, ultimately, their only source of aviation fuel).
German war-production reached its zenith in July/August 1944. Huge quantities of modern aircraft were made available. Significant was, however, the increasing deficiency of fuel supply, so that their air-defence could not operate effectively anymore.
Radar played, certainly, an important role in the defence of these (essential) chemical sites. The deficit in availability of sufficient numbers of German centimetre radars, and the increasing shortage of (synthetic aircraft fuels) reduced, doubtless, Allied air losses over Germany!

All these accumulating factors have, indeed, accelerated the termination of Nazi Germany.

To get an impression as to what the mood of some leading Germans was, between 12 December 1944 and 4 April 1945, I can recommend an abstract of the war diary of the chief technical air armament of Speer’s ministry, available on my website (Kriegstagebuch Chef technische Luftrüstung, KTB-Chef TLR). It provides an impressive inside vision on the state of affairs of Germany’s strategical short and medium term objectives.
It is really unbelievable, to notice the many subjects on which they still were working on (dealing with), up to the last days of the war! It also provides interesting figures on the state of disruption and their strategic fuel deposition (production)[15]. (mainly German language)

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2. www.xs4all.nl/~aobauer/lichtenstein.htm (German FuG 202 / FuG 220 Lichtenstein airborne radars, by Hans Jucker)

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3a. Werkstattbuch, Antennenanlage für FuG 202, B164, XIII/44

4. They claimed in DE755778: (German text) 6. Anordnung nach Anspruch I, dadurch gekennzeichnet, dass (sz) die natürliche Länge des Hilfsleiter kürzer als eine Viertelwellenlänge ist und dass(sz) zwischen den Enden des Hilfsleiters und des Aussenleiters(sz) der unsymmetrischen Leitung eine Kapazität eingeschaltet ist.

5 http://www.ieee.org/organizations/history_center/Che2004/Bauer.pdf My IEEE 2004 contribution on: German Electronic Engineering in the 1930s
Which also can be found on: www.xs4all.nl/~aobauer/nieuwe_pagina_1.htm

6. www.xs4all.nl/~aobauer/german_patents.htm

7. www.xs4all.nl/~aobauer/patent-history.htm Also the next link is worth to be considered, as it reflects the new approach on patent matters versus the interest of the Third Reich. www.xs4all.nl/~aobauer/patentgesetz_1936.htm

7a. F.H. Hinsley, published as appendix 20 on volume 3 part 1 of F.H. Hinsley's: British Intelligence in the Second World War, pp. 557 - 558

8. Der Stand der deutschen Zentimeterwellen-Technik am Ende des 2. Weltkriegs, pp. 76-104, Brand's talk during the Frankfurt 1953 radar conference. Funkortung in der Luftfahrt, 2 Bücherei der Funk-Ortung, Verkehrs- und Wirtschafts-Verlag G.M.B.H. Dortmund

9. AGR Report (our archive reference ZR409), Best.-Nr. 1011/II. Published by the: Ausschuß für Funkortung (DGON, formally DEGON), printed in 1952. There existed various versions of these reports. (I am intending to get this full report on my website, though details should be discussed (cleared)with DGON in Bonn, first)

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