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

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Synopsis

"The significance of German electronic engineering in the 1930s"

Until the end of the nineteen twenties the general developments were quite comparable to those in other important countries. The major divergence started about the beginning of the next decade, just when radio communication was gaining maturity. Because of the industrial philosophy of the Lorenz Company, originally engendered by economical reasons, magnesium-aluminium die-cast techniques were introduced for chassis construction and these considerable improved the specifications of their new products.

At the same time, in the early thirties, the Hescho Company developed ceramic substrates with stable dielectric properties and which had a very low loss factor in the HF region.

The third important factor in the new German technology was the invention of low loss iron dust-core material by Hans Vogt.

In Europe both Switzerland and Germany had a penchant for the extensive use of complicated and fine mechanical constructions and the above developments were a contribution to that style of technology.

All these developments opened the way to completely new kind of electronic apparatus design. Today, it is quite common that advances and improvements in technology can only be realized by the use of newly developed techniques (often originating from outside the discipline) as, sooner or later, current techniques become outdated.

Arthur O. Bauer

Diemen,
The Netherlands

Introduction

The first years of the early 1920s was the period of time when wireless technology became more and more the product of scientific approach. The technology, theory and the mathematical implications of thermionic valves, as these were called, became common knowledge. In Germany, among others, Barkhausen and Schottky became very famous for their theoretical work in this field. Aspects of the developments in Britain are, for instance, described by Keith Thrower in his book: History of the British Radio Valve to 1940. (1)

It was also the time when wireless apparatus was, generally, constructed on open boards or (for luxury occasions) in a wooden box. Electrical shielding between the stages and/or housing was, for many years, a great exception. Valve holders, like most other components, were directly screwed to the wooden frame, rarely was a copper or aluminium ground plate used.

The coils were often of the so-called open type and their stray inductance usually caused some difficulties. RF dust-cores were still unknown and some quite heavy copper wire had to be used to acquire a fair Q factor. To overcome this disadvantage "litze wires" and special coil winding technologies were introduced to enhance the performance of the wireless apparatus.

Though, this picture changed quite rapidly in the second half of the 1920s, the entire industry had to stand tough competition and more competitive components with enhanced reliability became commercially available.

Until the end of the twenties the general developments in Germany were quite comparable to those in other important countries. The major divergence started about the beginning of the next decade, just when radio communication was gaining maturity. However, the roots for this evolution go back the mid nineteen twenties.

Ceramics were already widely used for all sorts of low and high tension insulators, however, their electrical properties for frequencies above 1 MHz showed considerable losses. In the second half of the 1920s Handrek and the chemist Rahn of the Hermsdorf-Schomburg-Isolatoren-Gesellschaft, also known as Hescho (it was in fact a subsidiary of the Kahla company), developed new types of ceramic materials (Calit, Calan, Mg -silicate group), which didn't contain any iron and which showed, for that time, very low RF losses. However, Handrek faced considerable problems evaluating the electrical parameters of this new material. He tried several technical Institutes in and outside Germany, but could not get, even for the same type of material, comparable figures. Purely by coincidence he met Lothar Rohde who was working as an assistant of Prof. Esau at the technical University of Jena. Although he had gained his Ph.D in 1931, he couldn't find an appropriate job in the university (due to the world wide economic recession) and, for the time being, stayed working for Esau in his Institute. Rohde and his friend Schwarz decided to solve Handrek's problems, and they could, on this occasion, use the facilities of Esau's lab. Soon after, in November 1932 (2), they had solved Handrek's measurement problems and they started thinking of establishing their own laboratory. Soon after, Handrek promised them that the Hescho company would certainly have more for them to do so they commenced working in Munich under the name: "Physikalisch-technisches-Entwicklungslabor (PTE) Dr. Rohde & Dr. Schwarz". After World War Two this company became well know as: Rohde & Schwarz (R & S). Rohde had more feeling for technology and Schwarz was more commercially orientated. This proved to be a successful and complimentary life long partnership. Their first export order which was gained from Britain in 1934 concerned a "tan * measuring device" for ceramic materials. (3)

After 1933/34 low loss titanium dioxide capacitors (Condensa .. , Tempa... , and Kerafar... the latter produced by Stemag) for temperature control became widely available and those components soon proved to be of the utmost importance, because these were especially suitable for frequency stabilisation.

The products of the Hescho company changed the electronic industry tremendously although, the full integration of this new progressive technology only occurred in Germany. An internal Philips study of 1964 by the Philips components division (4) stated that, despite all the industrial capabilities of the company, the raw ceramic material which was used for temperature control (based on titanium dioxide, rutile group) still had to be bought straight from the Hescho company as, until 1939, they couldn't manage to replace it with material of their own manufacture. Gevers's paper, which was published in Philips Research Reports 1945-46 (5), is the best which came to my attention in this field.

Iron dust-cores were widely used by the telephone industry from the early 1920s (for low frequency purposes especially for pupin cores) though, their maximum frequency was limited and rarely reached 10 kHz. Notwithstanding, it sometimes achieved a permeability of $\mu \geq 1200$! (6), (7), (8)

These early cores consist of iron dust which was sintered together with an insulating material. The shape of the iron dust particles was rather irregular and they had very sharp edges due to the way they were produced. However, more important was the fact that the particles were too massive. To avoid eddy currents the iron dust particles had to have too much space left between them.

Vogt had the smart idea of using "carbonyl iron", which was originally produced for industrial chemical processing (IG Farben). The advantage of this material was that the iron dust particles were spherical and were only between 2 and 6 :m (2 - 6 microns) in diameter and had, on their surface, a very thin oxide film. (9) (British Patent 394,870, convention date (application filed) 12 November 1931 and 15 March 1932).

Vogt's first step was to impregnate a paper tape in a solution of iron dust (carbonyl iron) and a low loss insulating material. After a foregoing drying process these tapes (carrier) were stacked together (depending on its future purpose this could be of a height of up to several cm) and were then pressed to a more or less solid block; after this process any kind of profile could be cut out from them like, for example, a H or an E core. Those kinds of cores were, in the 1930s, well known, in both Britain and Germany by their trade name "Ferrocart".

Siemens produced, after the second half of the 1930s so-called "Sirufer" dust-cores, which usually had a μ between 6 - 15. Special dust-cores were developed for the so-called "iron dust-core antennas, used for the long and medium wave aircraft DF apparatus (please refer to the list of abbreviations in the appendix). According to reference (10) a captured antenna was measured and they had found an effective $\mu \approx 60$, which was a remarkably high value in those days!

In the early days of the nineteen thirties, the C. Lorenz company (since May 1930 owned by ITT, after WW II known as Standard Elektrik Lorenz (SEL) until the end of the 1980s; now owned by French Alcatel) was searching for more rational construction techniques. As today, prefabrication could be the means to minimize labour costs and at the same time of improving the quality of the product. Until then communication apparatus was built on a frame construction in which the entire electrical and electronic circuit was integrated. Subsequently this chassis moved all the way from the metal workshop up to the calibration site at the end of the production line. Thus, only a few people could work on it at the same time. It was soon realized that this was a production bottleneck which needed to be removed (it would also be useful if, at the same time, a more rigid chassis system could be incorporated which would add to stability and circuit screening). Wasn't it possible to change the apparatus construction (design) so that it consisted of several modules only, which could, in the final stage of the production process, be screwed or clicked together? Such modules could subsequently be manufactured at the most suitable production site, even being tested and calibrated at that location. The idea soon came up that for this purpose die-casting ("Spritzguß") would be the solution. Although Lorenz was acquainted with die-casting techniques in general, the production of relatively small and extremely complicated constructions, with very narrow tolerances, forced them to obtain outside support. It was a logical step to use the experience of a piston manufacturer, where the production of aluminium die-castings, combined with narrow tolerances, was the daily practice. Thus, Lorenz contacted the Mahle company which was, in those days, a well known piston manufacturer. Ultimately, the alloy used became well know as: Elektron. Nonetheless this material became widely used for many other purposes as well. (11) According to an advertisement in a German technical magazine of 1938, "Cc Mahle" could produce die-cast samples of 0.5 up to 2000 gr, within tolerances of a few hundredths of a millimetre! (12)

I have started a brief German patent search and have unearthed some early evidence of Magnesium alloys, for which patents were granted to the: Chemische Fabrik Griesheim - Elektron in Griesheim a.M (near Frankfurt) D.R.P. 361,086 (Klasse 40 b Gr. 20, after called Gr.1) with the convention date of 5 August 1919. This company, and some US companies as well, were experimenting for some years with all kinds of Magnesium alloys and accompanying additives. However, from the above company a Magnesium alloy called "Elektronmetall" was mentioned for the first time in a German patent 387,278, with convention date 15 February 1921 (granted on 19 January 1924), although this latter material was not yet like the one that would be suitable for Lorenz's future purpose.

The first patent 613,511 which was more likely to be suitable for this purpose was owned by Briske & Prohl and Alexander Luschenowsky in Berlin and with convention date 28 June 1931. For the first time, considerable amounts of aluminium (14 to 18 %) and, of course, magnesium was used for this type of alloy.

However, I haven't found any patent reference after the 1930s of the Mahle company which was concerned with an "elektron" alloy, which ultimately became well known by its trade mark "Elektron" (± 8.5-9.5% Al, 0.5% Zn, 0.2% Si, 0.2% Mn, and the rest Mg). I suppose that the Mahle company kept their elektron recipe, more or less, a secret or, perhaps, they had obtained a licence from another patent owner (which circumstance has also to be taken in to consideration). According to reference (13) "elektron" has a specific gravity of 1.8. However, recently I have discovered that the huge chemical conglomerate IG Farben might have possessed most key patents, as this was world’s leading supplier of Magnesium related materials.

Nonetheless, it proved to be quite a difficult task to bring this technology, and its ultimate product, to maturity. For instance, they encountered difficulties in making the fluid alloy nearly as liquid as water in order to ensure that the (intricate) mould was entirely filled up with the elektron alloy, without leaving any air pockets.

Ultimately, the Mahle (and also the Nural) company became the major suppliers of die-cast artifacts for the German electronic industry, up until the end of WW II.

At the same time, as in other major countries, the newly developed plastics were becoming very popular and many products became available on the market. Bakelite was, in my opinion, the most widely used material. Phenol formaldehyde (and its derivates) was the technical and chemical name (the Germans used the general group expression "Kunstharz" as well). (14), (15), (16)

Another very important, low loss RF insulator (no dipoles), which, originally, came from Germany was "Trolitul" which was also its brand name (ε = 2.3 - 2.4, group name "Polystyrene") and which was, even in Britain, quite well known before the war. Wireless World in 1939 quoted examples such as *...."Trolitul" made in Germany, "Victron" in America, and "Distrene," recently produced in this country.* (17), (18)

Commercial attitudes

Already, around the turn of this century, the German authorities were very keen to avoid being dependent upon one industrial supplier only. Ultimately, Telefunken and C. Lorenz (two huge powerful companies) had to share the market for wireless communication apparatus.

In the twenties and thirties the radio industries of the world became very large enterprises, whose commercial power often tended to monopolize the market in their country. In Germany the major players were: - AEG, Telefunken, Siemens and Lorenz.

It is evident that much effort was put into the development of consumer products and that in this market big money could be earned. In many respects broadcast receivers became, in the 1930s, quite sophisticated items. It is obvious that often the same engineers were designing broadcast receivers and were also at the same time engaged with the development of communication apparatus. What was more likely than that components and applied technology (which was already "in-house") would been made freely available for their commercial communication products as well?

I have come to the conclusion, after studying this subject for more than forty years, that generally speaking most communication receivers produced in the world were (with the exception of some German apparatus), more or less, enhanced broadcast receivers in a metal housing! Their circuit concepts were also very similar, even the same valves, coils and tuning capacitors were often employed.

In the second half of the 1930s the German Air Forces engendered wireless equipment whose technology could well be described as "state of the art" at that time. This was a product of their quasi inexhaustible resources combined with a comprehensive vision. Lorenz introduced three dimensional construction technology, whereby optimal screening between stages was made possible and the optimal possible space to volume ratio was being achieved.

Implementation of new technologies

We have got an idea of three major pillars of the basic improvements in Germany's electronic apparatus design. We have tried to deny any political dimension in this technical explanation, but now it cannot be avoided. The "Third Reich" was hastily searching for new solutions to acquire the greatest possible "autarchy". Goering's industrial "Four Years Strategy" (Vierjahresplan) was the major State controlled programme, to force the German industry to become as self-sufficient as possible. An important material (up until today) is quartz for filtering as well as frequency control. This could be replaced perfectly, as we will discuss later, by the above mentioned developments by German industry. Problems in HF and IF filtering could, more-or-less, be solved by better circuit design in combination with the lavish use of iron dust-core techniques.

Nowadays, at a time where large scale integrated circuits are widely used, which often incorporate more than hundred thousand integrated semiconductors, it is quite hard to imagine that in the early days of the radio industry they tried to save, as much as possible, on the use of components. The previously discussed modern technologies were in the first place used to improve the performance of the radio apparatus, though, on the other hand, this allowed a reduction in components numbers as, for example, valves, which were rather expensive.

The major players in the German wireless communication industry were both C. Lorenz, which was established in 1880, and Telefunken which was established in 1903 and, until 1941, owned fifty-fifty by AEG and Siemens & Halske. According to an internal Siemens paper there existed, since 1920, a bi-lateral agreement (19), which determined (among other things) that Telefunken could only handle wireless matters including equipment associated with their radio valves; whereas Siemens, on the other hand, could only deal with wire linked matters and, subsequently, could only supply valves to the telephone industry (though, it is not unlikely that this agreement replaced a similar one). However, this agreement was made redundant in 1941 and Siemens & Halske divorced from Telefunken. Siemens sold their Telefunken shares to AEG (partly exchanged), because Siemens wished to get, from then on, a fair *quota* of the very lucrative wireless communication market!

Before some aspects of the typical German construction technology can be explained, we have to consider the development of new valves too. The opportunity to create a new standard in valve design persuaded the military organisations to reduce the number of valve types. This also benefited the supply of spare parts. For instance, the entire FuG 10 installation (*described later)* was only equipped with two different type of valves. The receivers, depending on their purpose, employed eight or eleven RV 12 P 2000 valves and the transmitters only three RL12P35s, a valve of thirty five watts anode dissipation.

On the next page, from left to right: valve socket and its accompanying RV 12 P 2000 (pentode). The tall valve in the centre is the universal transmitter valve RL 12 P 35 (the latter valve can not be considered as a newly designed special valve, because it was a regular commercial product, though it was widely employed) and to its right we see the LS 50 with its socket. The LS 50 (50 watt dissipation) was particularly designed for power transmitters and for high slope impulse circuits such as used in radar systems (as, for instance, Würzburg radar). It is quite evident that, the RV 12 P 2000 and the LS 50 were designed for modular technology and only needed to have access from the top to be removed. The RV 12 P 2000 was plugged upside down into its socket and could be easily mounted in between two adjacent compartments. Both valves could be used up to approximately 200 MHz.

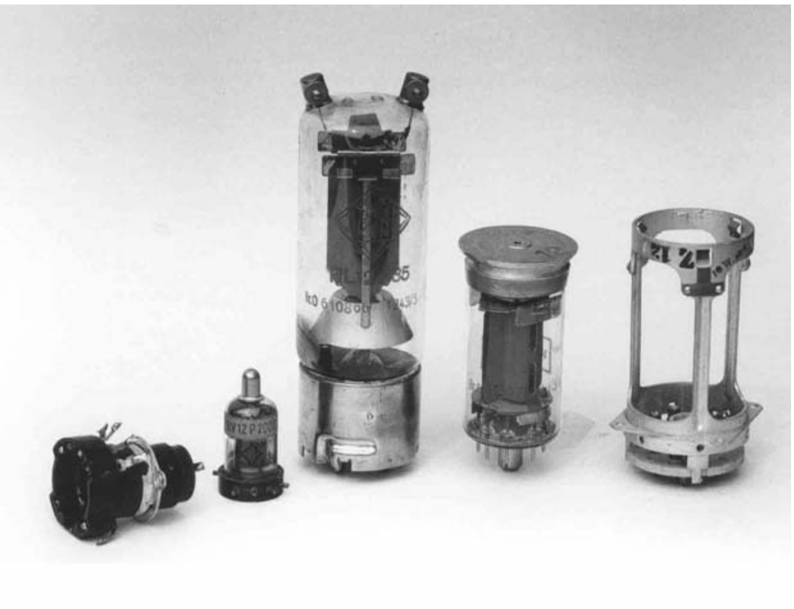

Fig. 1: Some typical examples of German valves

The RV 12 P 2000 became the backbone of nearly all German commercial and military equipment and more than 16 million were produced during WW II. It was really a major step forward to supply a maintenance organisation with only two different valve types for an entire wireless installation. This was illustrated in Farrar's paper of 1947 (20), which among other things, explained: - *For use as triodes and diodes the anode and grids were strapped together and in one medium frequency superhet a pentode was employed quite successfully as* ***a double-diode triode and suppressor grid acting as the diode anodes, and the screen-grid as the triode anode****. This system greatly simplified both valve manufacture and provision of spares, and appeared to have no adverse effect on the performance of the receiver.*

Lorenz's modular construction technology

Soon after Mahle, and its subsidiary company Elektron-Co-mbH in Stuttgart-Bad Cannstatt and Berlin Spandau, began production of stable Elektron die-castings, Lorenz produced their first portable wireless sets, which already showed the so characteristic Lorenz die-castings. (21)

According to Kloepfer's paper (22), (he was involved in the modular die-casting developments from the very beginning) Lorenz started in the autumn of 1934 with the design of a new aircraft wireless communication apparatus FuG VIII. However, the real breakthrough came after the German Air Ministry (RLM), in August 1936, told the German communication industry of their requirements for the development of entirely new wireless equipment, covering long wave, short wave and in the future the VHF band as well. It was intended that this should be standard equipment to be in service for more than a decade. From the very beginning Lorenz put all their industrial efforts into this project, which became known as FuG 10 (**Fu**nk **G**erät 10, wireless set 10), and all other (later) derivatives were based upon the same product philosophy.

The sequence of this dynamic and fascinating process is listed below:

- 1936 August, RLM requirements were set
- 1937 February, two prototypes, in conventional plate construction, handed over
- 1937 February, first airborne trials in a Junkers 52 aircraft
- 1937 July, two die-cast prototypes were available for trials
- 1937 July, two Lorenz sets had to compete with products of the Telefunken company
- 1937 August, the official RLM decision to purchase the Lorenz system
- 1937 December, Lorenz delivered to the Air Forces eight complete installations
- 1938 January, the mass production started
- 1939 September, all long distance Air Force aircraft were equipped with FuG 10

We can learn much from this sequence! If the parties concerned are really desperate to process a project rapidly then, in close cooperation, even the most complicated projects can be completed in a very short period of time! Under regular (usual) military circumstances the common testing procedures would have taken several years!

The FuG 10 installation was and still is to me the best example of modular and three-dimensional construction technology of the thirties and forties. An advantage was the improvement in serviceability! From the technical point of view - operation and maintenance was kept very simple, even for a regular service man, complete units and /or parts of it could now conveniently be changed, in very little time (even by minimally trained personnel). All modules could simply be fixed to their bulkhead rack (Aufhängerahmen), by revolving only two 90° lock screws. All units on the bulkhead racks were automatically connected, via flat-cables (Flachbandkabel), to their particular junction box mounted on the fuselage. These flat-cables are comparable to those used today in computers. However, its origin goes back to the early years of the last century, but it had been rarely used.

The FuG 10 and its derivates, had to rely on a so-called MOPA (master oscillator *MO* as the VFO, and power amplifier *PA*) concept. If it had to replace quartz control, this system was the most unpractical starting point one could imagine. First the HF generator (MO) as VFO had to be designed for relatively high output power, because it had to drive the PA circuit directly. This could only be realized if the oscillator valve had similar power ratings to the PA valves. This could be managed by one RL12P35 in the VFO and two RL12P35s in parallel in the PA stage. Logically a nice solution, but a technological nightmare.

Nearly all German transmitters were keyed by blocking the driving grids (g_1) in all the stages. It had the practical advantage of nearly full break-in. Therefore, the VFO stage would only warm up during the transmission intervals. With CW keying, a constant temperature could never be reached, because all working conditions were, to some extent, changing erratically. Secondly, the internal mechanical dimensions of the oscillator valve (RL12P35), as well as the output valves, were constantly changing. In particular the influence of the anode and the grid system caused a change of anode capacitance and its interaction with grid capacitance, amplified the Miller, as well as other effects. The major problem was to counter the changing temperature during CW transmission. A very difficult problem, concerning temperature compensation: - the reaction tending to be delayed.

Telefunken countered this, for the EZ 6 direction finder (also a component of the FuG 10 system), by increasing the surface of the compensation (measuring) capacitors. If, for instance, 100 pF was required, they divided it and replaced it by ten x 10 pF capacitors in parallel. This increased the direct relation between the change in temperature and the related capacitance, proving adequate for the DF receiver, but not for a transmitter under fast changing working conditions.

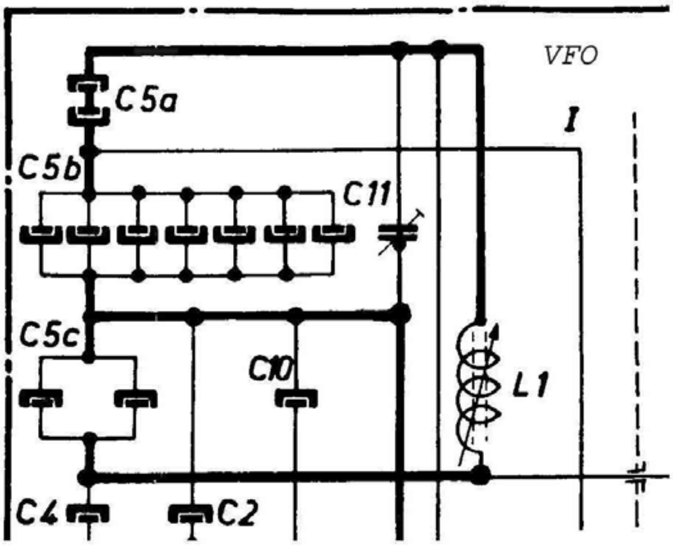

Fig. 2: Static and dynamic temp. compensation

Their brilliant solution was to place temperature sensitive capacitors as well as capacitors having a more-or- less high loss, for the working frequency, into the circuit. It's clear that high losses in a power circuit always influence the working temperature of such a device (arrangement of capacitors). So the direct dissipation of the capacitors and not just the surrounding temperature, affected the compensating and controlling factor of this system. These special dynamic capacitor arrangements were mounted inside porcelain tubes, which were sealed off from (direct) air flow. To increase the dynamic temperature response of these capacitor arrangements, they were made of very thin tubular ceramics. They had introduced a static compensation which could reduce the external temperature influence by 90 % and, on the other hand, a dynamic compensation to counter the transmission and power related aberrations.

The capacitors C 5a to C 5c in figure 2 are all mounted on a ceramic support as one integrated block and are the centre of the static as well as the dynamic frequency compensation, although other capacitors were also incorporated in the entire controlling system. The arrangement of the parallel capacitors C 5b was used to increase the surface area, so as to enhance the response of the ratio of) C in respect to K. (similar idea to that of the EZ 6)

We are not always aware of the extreme environmental conditions, especially for high altitudes (as in an aircraft) which often led to sparking in the tuning capacitors. There are several ways to counter this, for instance to increase the space between the tuning plates. But, to deal with it for a long-wave transmitter between 300 kHz to 600 kHz, or a short wave transmitter between 3000 kHz to 6000 kHz, which could generate 70 to 80 watt antenna power, and which is packed in a very small housing of only 21x22x22 cm, was nearly impossible. We also have to consider that the VFO, as master oscillator, had to work at a relatively high power level.

The invention of iron dust-cores by Hans Vogt, one of the new innovations we have discussed, brought the solution. Variometers, as the Germans called them too, became the new tuning device for both stages and were tuned (for the entire transmitter) by only one knob. But, to start with, new techniques had to be explored to counter the saturation problems of the iron dust-cores. Ultimately, they used rather bulky blocks of sintered iron dust-cores inside the variometers.

The receiver E 10 ...

The white arrows in the next figure are directed to the sockets of the RV 12 P 2000 valves. For this illustration the aluminium cover plates were removed, and the lower module section is pulled a bit backwards out of the receiver block. We clearly can see that the density of the wiring and the components is rather high. In the 1930s, it certainly would have been hard to imagine that, in a cube of only 20 x 20 x 19 cm, a high grade super-heterodyne receiver (employing eleven valves) could have been housed.

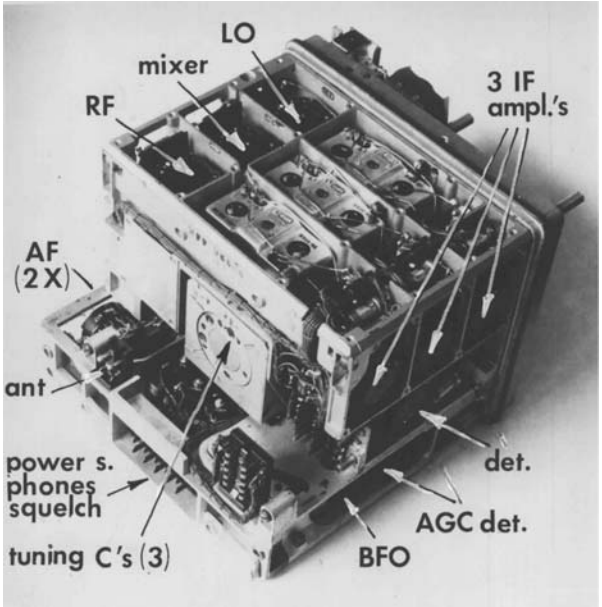

Fig. 3: Inside view of the modular receiver E 10aK

The numbers in the figure below, represent the four major modular sections of which the short wave receiver E 10 aK was built from.

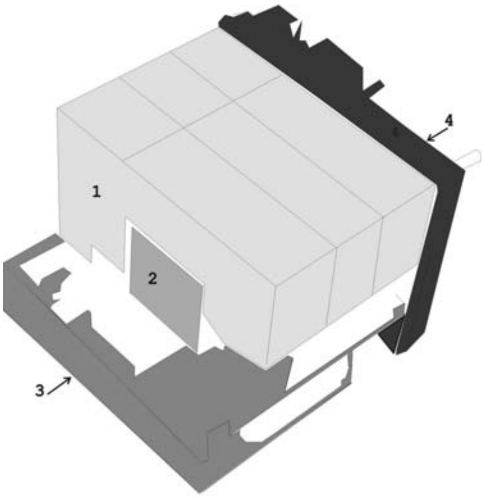

Fig. 4: The four modular sections of the E 10ak

•**1** is the RF and IF block
•**2** is the tuning capacitor, which was considered as a module
•**3** this section contains: BFO, AGC and the LF amplifier (2 x RV 12 P 2000 in parallel) stages, inclusive of all line suppressor filters
•**4** is the front section, which carries the tuning gears and scale dial, inclusive the four click selectors (frequency memories).

(As we already know, all these independent modular sections could have been produced, and aligned, outside the own factory).

After the entire FuG 10 system had been introduced, the concept resulted in a transmitter as well as a receiver, with a nearly quartz stable signal. It could meet the required specifications under all conditions for a temperature range between: - 50° C up to +50° C, and a power supply voltage swing between: 22 and 29 volts (aircraft conditions) for a max. frequency deviation of: 3×10^{-4}. According to an American publication, they have measured even a better specification: 0.001% which is equal to 10 ppm $\cdot$ K^{-1}, ...*these tests were made over a temperature range o*f *+ 50° to - 30° C* (though, power supply swing was not mentioned, probably average conditions prevailed AOB). ... *This is considered very good stability.... Both transmitter and receiver units operate entirely satisfactorily under conditions of vibration*. (23)

Telefunken

The Telefunken company designed, in my opinion, the most advanced apparatus (though often electrical and mechanically rather complicated). Whereas, from the mechanical point of view, Lorenz often made very pretty mechanics, nonetheless their circuit design was usually quite conventional. Telefunken circuit concepts often showed more elaborate engineering than that of most other competitive companies. For this paper we shall review three products which, for me, express the optimum of apparatus design during the "*interbellum*". These are: - the medium and short wave receiver KwE a, the short wave transmitter T 200 FK 39, and the short wave receiver E 52 a, although the latter apparatus was not brought to maturity until after 1941. However, this very interesting latter project was initiated by the RLM in 1939.

KwE a

The so-called "Kurzwellenempfänger Anton" (hereinafter to be called 'anton') was a five band, high grade, super-heterodyne receiver for 980 kHz up to 10.200 kHz. This receiver was originally designed for mobile use and is equipped with eleven RV 2 P 800 valves. This tube can be seen as a (larger) kind of forerunner type of the RV 12 P 2000, but it was a 2 volt direct heated (battery) valve. Telefunken employed on a regular basis a slightly different construction technology (philosophy) whereby, for most occasions, no (direct) three dimensional constructions were utilised. The auxiliary components, surrounding the valves, were often placed (mounted) in a vertical manner around the valve base. Nonetheless, in most cases, die-cast framework was used as well. Due to this technology, very compact constructions were possible. However, it often became rather difficult to get access to, for instance, grid connections and comparable components (deep) inside the chassis. In the horizontal plane it became rather easy to separate the position of adjacent stages by only a few cms. The valves, which were positioned upside-down in their sockets, were always accessible from outside the chassis frame.

The RF concept of the 'anton' receiver consists of three stages of preselection (two RF amplifiers, mixer + LO) which are tuned by **a six fold** tuning capacitor. Before the signal can reach the mixer stage it has passed five tuned filter sections (four are inductively coupled). Quite interesting is that, generally, in most German commercial communication receivers additive mixers were used, and that multiplicative mixers were seldom utilized. This, probably, could also have been initiated by specific military requirements whereas, in German broadcast receivers hexode or heptode valves were regularly employed.

The coil turret (l x d = 35 x 13 cm) and its mechanics, shown below, are of superb quality and is in many respect the best ever made. Each coil section was entirely enclosed in tiny die-cast chambers which were separately insulated from ground. Most RF coils were totally enclosed in iron dust material like modern "pot cores" (as all IF self inductances were too). All 21 turret contacts were plated with a gold like material and are lifted before the turret starts revolving, which was, among gears, controlled by a "maltese cross". Whatever the direction of movement of a switch or selector, it always ends up in a pressure contact. Nonetheless, a very slim contact movement, to clean (rub) the surface, is always maintained.

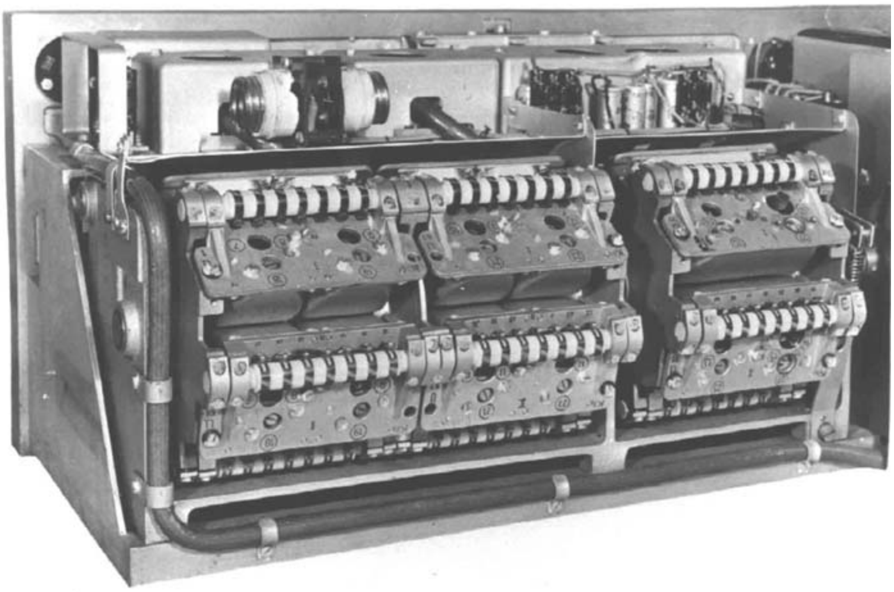

Fig. 5: The coil turret of the receiver KwE a

However, this quite comprehensive preselection meant little, if we consider the precautions which were taken to control the IF bandwidth for all its three stages in succession. The IF centre frequency is 250,9 kHz, which seems to be rather low, however, according to the KwE manual, is its image rejection at 10 MHz ≥ 78 dB. (most unfavourable frequency)

Shown next is one of the three identical IF band filters. The selector switch is set on number one, which bandwidth response gives, according to measurements done by Hans Evers (24): -

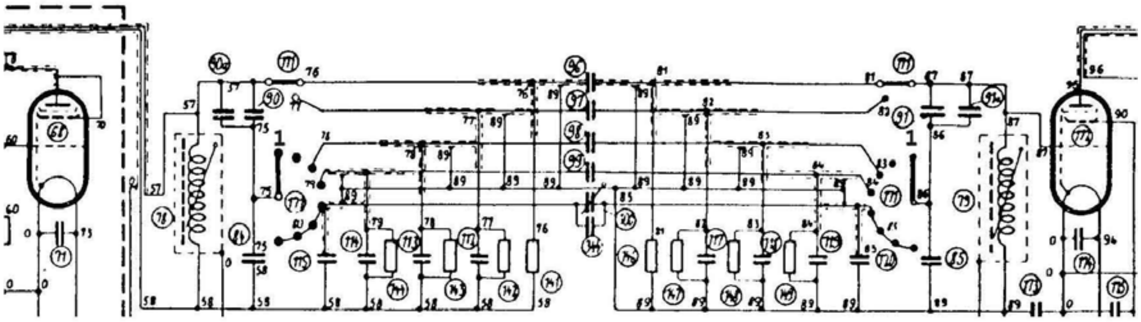

Fig. 6: One of the IF band filters of the KwE a

selection	bandwidth (kHz)	IF-filter-setting	audio-filtering	side-band
1	8	only	no	lower
2	5.1	only	no	lower
3	3.4	only	no	lower
4	1.7	only	no	lower
5	0.9	only	no	lower
6	0.4	= 5	yes	lower
7	0.2	= 5	yes	lower
8	0.2	= 5	yes	upper

(The bandwidth in positions 7 and 8 is equal, though the sideband has interchanged)

In position eight the over-all bandwidth is equal to that of position seven, but the BFO frequency has been changed from lower to upper sideband reception, whose frequency is determined by a so-called double quartz of 250 and 251.8 kHz. This quartz oscillator is also used as a calibrator. It is remarkable that the calibration points marked on the frequency dial (scale) are compensated for the BFO frequency off-set of 900 Hz!

It is known that if we change the coupling of a band filter that this changes its angular frequency ω_0 as well. For broadcast receivers this deviation can often be tolerated but for high grade communication apparatus this has to be intolerable (although often neglected). Fig. 6 shows that for each IF band-pass setting the appropriate damping resistor - coupling **and** tuning capacitors are (separately) selected.

Finally an interesting detail is the way the AGC (AVC) voltage is generated. After the third IF amplifier this signal is split in two directions, one is fed, on a regular manner, to the "audion" (audio) detector, the other signal is then amplified in an extra stage and fed to a pair of "sirutor" (early semiconductor) diodes. The AGC circuit was of the threshold type and worked only above a certain signal level. The AGC amplifier valve was (also) controlled via a feed back of the AGC signal level. The time delay response could be selected for 100 ms or 1 s.

T 200 FK 39

The German Navy nomenclature often gives quite a lot of information: T = Telefunken; 200 = 200 watt antenna power; F = Fern (long distance) which stands for frequencies between 7 and 25 MHz; K = Kurz = short wave between frequencies of 3 - 7 MHz; 39 = the year of acceptance by the German Navy and is also regarded as the year of its service introduction.

This Telefunken transmitter is a magnificent example of thorough ceramic construction technology, which is worthy of explanation. In the introduction we have noticed that ceramics were introduced for insulating and dielectric purposes, however, Telefunken used them in other ways as well.

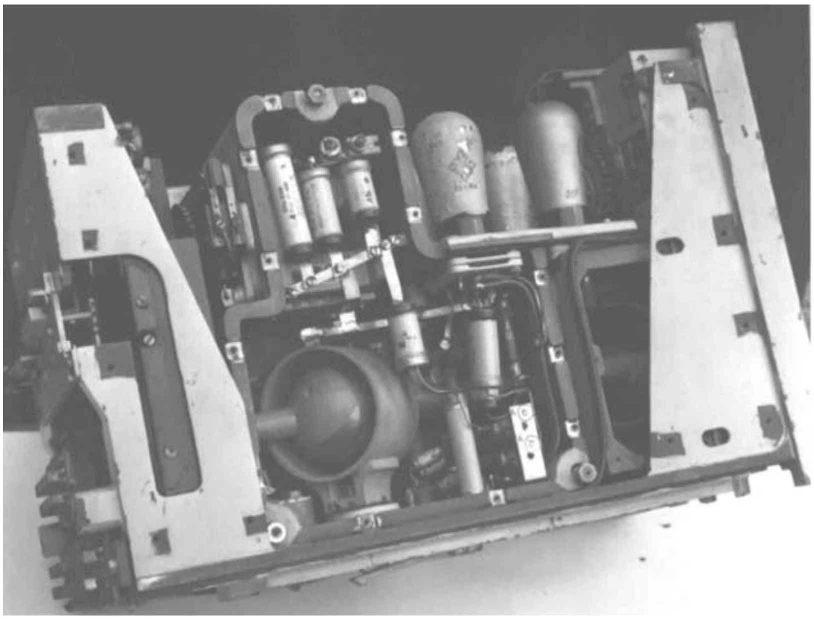

Fig. 7: Inside view of the VFO of the transmitter T 200 FK 39

Shown here is an inside view of the (push-pull) VFO and the (push-push) buffer stage of the transmitter T 200 FK 39. The white (vertical) tubes contain special temperature controlled capacitors, which are hermetically sealed off (soldered) from outside environment. This type of capacitor housing was very commonly used in Germany. Often, when special temperature compensation was required, two capacitors of different temperature coefficients were integrated inside these porcelain tubes. (please notice also in fig. 7 the use of flat wire strips!)

The housing which has some similarity to a "dome" is a casting frame which is entirely made of ceramic! The electrical shielding (inside) is obtained by using a rather heavy copper layer which is fired onto the ceramic surface. Probably, for this purpose, a galvanic process was employed in addition. The removed cover plate is made of the same ceramic/copper construction. Heavy soldered taps (on ceramics!) ensures optimal shielding (grounding).

Inside we see, mounted on the bottom of the ceramic housing, the ceramic ball variometer of the oscillator (VFO). Both inductances, the self inductance inside the tubular ceramic variometer housing and the conductor on the tuning ball are fired on the ceramic surface. This ensures that optimal frequency stability is obtained. From looking at the figure it cannot be clearly seen that the tuning ball of the variometer is not just shaped as a single closed ring conductor. In fact, three closed rings (at particular angles) have been utilized in the construction. Its purpose is to enhance the linearity of the scale reading as a function of the tuning angle. It was based upon a (German) Telefunken patent 626 597, with convention date 25 June 1933. Such variometers are tuned only between zero and ninety degrees. When the closed ring conductor picks up maximum magnetic flux the self inductance is on its lowest value and when no flux is being picked-up by it, the self inductance is at its maximum value.

It is quite evident that conductors which are fired on the surface of a ceramic layer are rather more stable than ordinary wire conductors. The Hescho company introduced, amongst other things, a technique with which it became possible to fire a solid copper or silver layer (conductor) onto a ceramic cylinder (obviously on flat layers as well). For instance, in coil construction, the electrical windings were, by means of a milling cutter, cut out of the cylinder surface, as a helix, leaving a (flat) inductive element and thus improving greatly the Q factor, of this type of solenoid. The Q factor is enhanced too due to the considerable reduction of (parasitic) capacitance between the (solenoid) windings. From a Funkschau publication of 1943 (25) we now know that this technique decreased the temperature coefficient by a factor of 200, compared to a normal solid wire wound solenoid! This technique became widely used for frequency determining solenoids.

The tuning dial was, for those days, very remarkable and highly advanced; its scale (dial) was stored on a microfilm which was carried on a circular glass disk, and which is directly mounted on the (tuning) shaft of the variometer(s), so as to negate any back lash. By optical means the frequency reading was projected onto a frosted glass window (Mattscheibe) on the front panel. This allowed a very accurate setting of a frequency (it still does), accurate tuning within a few hundred hertz was easily possible. According to Kloepfer (26) by use of a variometer meant that only a frequency tuning ratio of approximately 1 : 2 was achievable. It is likely that, due to this limitation twelve separate frequency bands were employed with the T 200 transmitter.

More details about this transmitter and related technology are outlined in my contribution to the HYR conference of 1995 in London. (27)

Köln E 52 a

In the 1930s the German Air Force was built up very rapidly and, consequently, was equipped with all sorts of apparatus, some of it not always the most efficient but, there were limitations imposed by the availability of equipment. At the end of this decade the RLM intended to reorganize their Ordnance service and, as was done for the FuG 10 system, they conceived new requirements for the German radio industry. Their aim was to standardize the equipment of the ground to air (and vice versa) communication services. The most advanced features had to be made available for all receivers and/or transmitters. Ultimately, the Telefunken company design won this competition.

Some details of the requirements for the so-called "Einheitsgerät" (standard receiver concept) for active and passive reception are outlined below (although it was planned to standardize the employment of transmitters as well, these were, probably with a few exceptions, never purchased by the Air Forces. (28) Receivers were sometimes "code-named" after German cities and transmitters after rivers!): -

- Covering a frequency range between 7500 m and 2 m
- Manually and remote tuning control for all functions on the front panel
- "Leipzig" E 51, 40 - 1500 kHz (long wave)
- "Köln" E 52, 1.5 - 25 MHz (short wave)
- "Ulm" E 53, 24 - 68 MHz (VHF I)
- "Kulm" E 54, 60 - 150 MHz (VHF II)
- Motor controlled tuning of four memories, for every possible frequency **and** band

- Adaptation for DF service (Loop and/or Adcock)
- Occasionally remote control service, via two wire or long distance telephone line
- Diversity operation
- Standardisation of all receiver housings

(E = Empfänger = receiver)

Options

- Additionally, automatic RF filter tracking
- For the VHF versions: TV reception

Ultimately, only the type E 52 ... and E 53 b were purchased. This design was intended to do service for more than a decade. According to Hans Widdel's very comprehensive statistical survey of 1997 (29), it is estimated that about 2400 to 2600 Köln receivers had been built between the start of series production in 1942/43 and the end of the hostilities.

Some aspects of the design

The outside dimensions of all receivers were equal as was the positioning of all controls. We have noticed that remote control had to be possible, and it would seem to be sensible for the master and slave units to be similar for the entire receiver series. A very comprehensive servo system was designed by Siemens (certainly due to the already mentioned bi-lateral agreement) for the required tuning accuracy. For the tuning of the frequency control, a double-phase-servo controlled signal was fed back to the master (remote) control unit. The master and slave units could be (linked) by multi-core cable though, when long distance telephone facilities were required, the units could be linked by means of very advanced binary multi-tone multiplex signals.

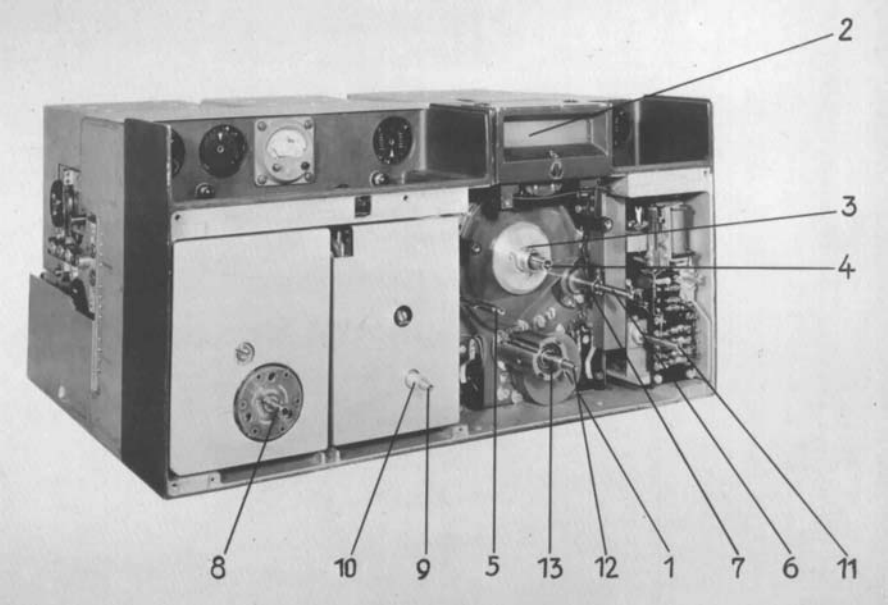

Fig 8: Prototype number 1, of the Köln E 52 receiver

Shown here is the prototype "number one" (Versuchsmuster 1) of the Köln receiver, with front cover plate and housing removed. Notice the valve sockets in the upper compartment.

Brief explanation of the layout
2 The frosted glass projection window for the accurate reading of frequency
3 The clamp mounting of the circular microfilm glass disk (a bit grey and transparent)
8 Bandwidth control of the IF module
9 BFO quartz and/or variable BFO tuning control
10 Volume control

From left to right we see the three modular blocks for: IF; detector - AGC - BFO; and on the very right hand the LF plug-in (audio output module), these modules were fixed by one central (locking) screw only and could, by this means, be very easily removed.
The optical microfilm projection for the frequency scale was probably one of the most advanced for those days. It could enlarge the length of the frequency scale for up to about 2 metres! The microfilms, of the (early) receivers, were individually calibrated at the receiver. One micro film disk was regularly employed in the projection section of the receiver, whilst a second film copy was stored in a small pocket in the rear of the Köln. A third copy was stored in an archive at the factory. The second microfilm disk could be used for the same purpose in the master remote control unit (by this means it was always guaranteed that the frequency reading for both the receiver and, the master apparatus, were matched).

The RF tuning capacitors (inclusive of the LO consist of six sections) were lined up parallel to the broadside of the receiver and these were coupled, via an additional gear, with a separate shaft which was accessible on the left hand side of the receiver (similarly for the band-selector control). Its purpose was to link an auxiliary RF adapter (for example, used for DF) such that it could be tuned by the regular control(s) on the front panel of the receiver.
From the very beginning, this project aimed to create receivers which were entirely based upon modular technology, even for the wiring. As we have already noticed, the conventional way of receiver construction involved the assembly of components one by one. This bottleneck could be overcome by the implementation of modular technology. It doesn't matter where modules are manufactured, because they are only brought together at the final assembly stage. Even the RF coil modules could be assembled in the same way.

The plate on the left in figure 9, with the pin connectors, is the wiring module or "mother board" of the receiver and its function is the linking (electrically) together of all modules. On the right hand side of this board we see the IF module (cover removed), it consists of a three stage IF amplifier including a double tuneable quartz filter (see later). All three RV 12 P 2000 valves are accessible from the top. This is the same for all other valves in the receiver. It is a useful facility as valves can be quickly and easily changed. The modules on top of the mother board belong to the second RF stage and the local oscillator/mixer stage. The multi-pin connector facing to the left has to connect in the power supply. The forward facing multi-pin connector could connect (electrically) auxiliary units on the left hand side of the receiver. (notice also, on the right hand, the pretty "vertical construction manner", and the three integrated valve sockets of the IF module)

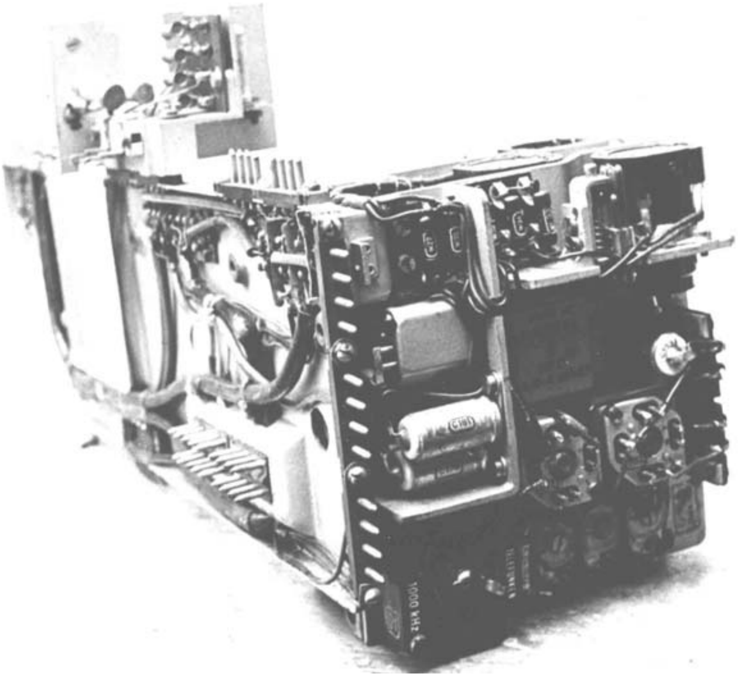

Fig. 9: The “mother board” of the Köln E 52

Telefunken quartz filters

Tuneable quartz filters were already used in the 1930s, though those were often of the so-called phasing type which, for the ordinary service man, were often hard to operate and which, on occasion, could be counter productive.
Without getting involved in an in-depth proof, we will follow briefly some aspects of these quartz filters.

It is known that the frequency difference between series and parallel resonance of a quartz crystal is caused by the static capacitance (C_0) of its holder and wiring. Increasing the parasitic capacitance also increases the frequency of parallel resonance of a quartz, though it does not change its frequency of series resonance, hence the gap between both resonance conditions is increased. It was Hansell (US) who invented a neutralisation bridge circuit for quartz filters, which allowed one to compensate for this parasitic phenomenon (BP 293,446 owned for the UK by Marconi, original US convention date 7 July 1927). Although, also Marrison of the Bell laboratory claimed a similar patent one month earlier (US 1,994,658 convention date 7 June 1927).

Campbell has already described, in the early 1900s, filter arrangements which used series resonance circuits as a coupling device, though the dielectric and self inductance losses hampered its application for RF narrow band filters. The application of quartz, as a coupling device for band-pass filters, seemed to be *the* solution. Although many types of quartz filters were invented, one of the great disadvantages was that the output levels (thus modulus) was rather dependent upon the ratio of centre frequency and the applied relative bandwidth.

I would like to draw your attention, briefly, to the essentials of Kautter's modified quartz filter design, which was not influenced by the previously described disadvantages and which was granted a German (Telefunken) patent 675,313 (convention date 21 November 1936), I will just outline the main points.

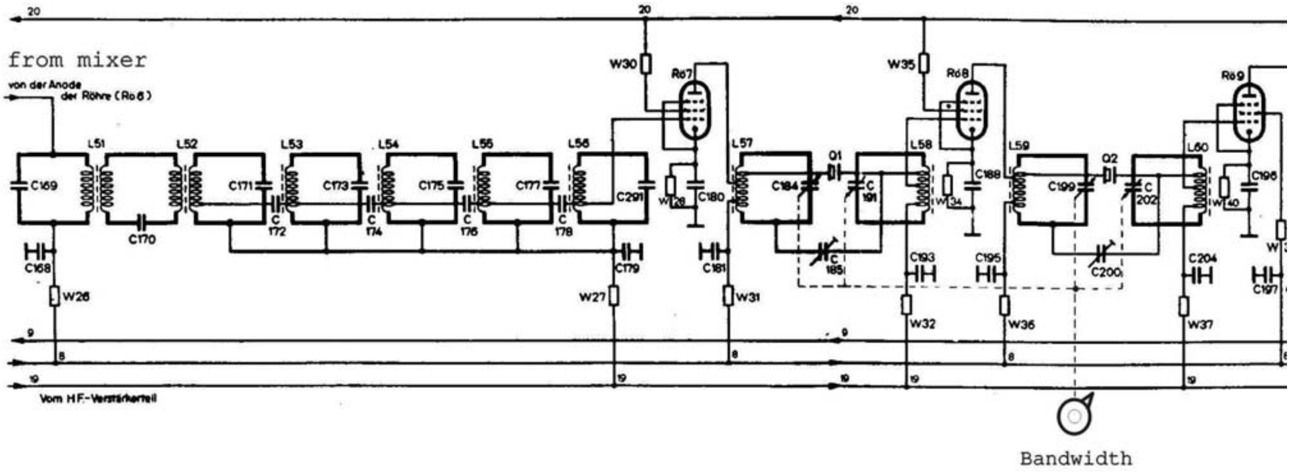

Fig. 10: Basic diagram of the IF stage of the Köln E 52

When a neutralized quartz crystal is employed in a filter circuit (in its series resonance) as a coupling device between two parallel resonance circuits - then the modulus of the (narrow) filter bandwidth is determined only by the quartz Q factor (hence its bandwidth). It is known that, in series resonance, ωL - 1/ωC = 0 and that the remaining virtual loss is represented by R_1. According to details in Kautter's patent application a regular Telefunken quartz (filter) vibrator, at 1.5 MHz has a bandwidth of ≈ 5 Hz (hence, Q ≈ 300,000) and its R_1 is equivalent to ≈ 20 ohm and with L_1 having a value of ≈ 0,3 Hy.

Let us consider the left hand quartz filter in figure 10. Kautter's real invention was to (de-) tune L57/C184 and L58/C191 in opposite directions, so that one is decreasing whereas the other circuit is increasing in frequency. This could be done by capacitive or inductive means. Telefunken always used, for this purpose, differential tuning capacitors whereas, Lorenz de-tuned by inductive means.

The bottleneck is the Q factor of the de-tuned input and output circuits thus, its impedance. We have to consider that, for frequencies outside the quartz series resonance, the coupling impedance gets a bit complex, though, according to Kautter's explanation, this doesn't matter. (30) However, when this filter has to show a relatively wide band-pass response (modulus) with a (more or less) constant gain, then it is the Q factor (and hence the input and output circuit impedances) which determines the frequency response of this filter. Widening its band-pass means increasing the impedance of the de-tuned circuits. The maximum bandwidth of this quartz filter type is limited by the ratio (percentage) of *ω_1 - ω_2* and ω_0 (of the quartz) ± 1 %. To obtain the optimal match of the quartz parameters, in respect to the input and output impedances of the filter circuit, several coil taps were provided on both sides (not shown in figure 10). This filter can thus be seen as being, a regular, constant k-filter.

The Köln receiver employed a 1 MHz IF frequency which was, for a short wave receiver in those days, rather high and quite unusual. Due to the IF frequency employed, and the comprehensive pre-selection the image rejection of the Köln receiver was ≥ 96 dB at 20 MHz!

When a maximum bandwidth of 10 kHz was required the loaded Q of the tuned circuits can be estimated as ≈ 100 (1000 : 10). It is evident that iron dust-cores had to be used to achieve this.

The **symmetrical** quartz filter response was tuneable between 200 Hz and 10 kHz. Donald Prins has once wobbled (plotted) the filter response of the IF module of a Köln receiver in 1990, in the Philips quartz factory. He measured 130 dB down and he didn't find any irregularities! I presume that this favourable behaviour was also due to the six fold filter (L 51 - L 56) sections between the mixer stage and the first grid of Rö 7 (valve 7), according to a particular source the overall bandwidth of a signal arriving at this grid, is reduced to 15 kHz. Prins also measured the electrical parameters of the filter quartz, which didn't show, over a relative wide range, any spurious resonances! These filter crystals were designed and developed by Rudolf Bechmann, who was the leader in this field for many decades. After the war he worked for a while (until about mid 1950s) in the UK, and then he immigrated to the United States.

Conclusions

We have learned about the developments and the implementation of ceramics, iron dust-cores and magnesium die-castings in Germany. The question arises as to how were those new technologies accepted in other countries? This query can only be judged by studying references dating back to the 1930s and 1940s. Many references to these technologies can be traced in articles in both British and American technical magazines. But, were these techniques and ideas understood by the design engineers?

As an example I have chosen Robinson's IEE paper of 1940 (31), because, to me, it well reflects the "state of the art" in Britain, in those days. The discussion following this paper is very illuminating. ***Mr. G. Britton*** *(communicated): - Although German and British low-loss ceramics have been manufactured on a considerable scale for several years past, many electrical designers still have little knowledge of their properties, and less of the technique of manufacture. .... I cannot too strongly endorse the author's remarks on the value of collaboration between electrical designer and ceramic maker at the earliest possible stage, in order to simplify insulator shapes and minimize close tolerances.*

Robinson's paper quite obviously indicates that the common acceptance was more or less limited and that there was a wide gap between industrial knowledge and its technical application. Just to know about chemical and/or technical aspects of ceramics is not sufficient to ensure its rapid implementation in new products. Temperature control of frequency determining circuits proved to be, in many respect, "empiric engineering" which required "hands on" experience to really acquire the necessary skills and practical knowledge.

We have learned that the implementation of ceramics in apparatus design made it possible for the use of quartz crystal control, as a frequency determining device, to be made more or less redundant. We can question whether this was the aim from the beginning of research (in Germany) but I think that there is little doubt that this was, indeed, a prime consideration (32), (33). In Germany quartz crystals were mainly used for calibration purposes and in IF quartz filter circuits (though, also for radar time base control). The US alone produced 30 million of them between 1941-1945: whereas Germany produced less than a million! (34)

Die-casting was, as we have seen, lavishly used in Germany and we have learned about some of its applications. According to Farrar (35): - *It is interesting to note that light alloy castings was being introduced into British Military equipment at about the same time as the germans began to abandon it, probably, for reasons of material shortage* (1943/44, AOB). The tenor of his conclusion is to me that, for more than a decade, die-castings were solely a German concern.

In 1950 the British intelligence objectives sub-committee, among others, came to the following conclusions (36): - *The German ceramic industry, already in advanced state of development before 1938, was a valuable asset during the war, and in the early days was undoubtedly ahead of the United Kingdom in applying ceramic techniques to communication equipment. ....The report stated that, electrically and mechanically, the best firms (in Germany) were ahead of the United Kingdom in this field.........The report gives the general impression that in the early stages of the war Germany was well advanced in material research and could as a result produce outstanding designs in some details of radio equipment. In the general development and engineering of HF. communication systems, however, the Germans displayed less initiative and originality than the Allies so that, as the war advanced and their efficiency decreased due to inadequate co-ordination of associated branches of industry, they fell behind in communications technique.*

Reflections

We have briefly covered some aspects of the approach to mechanical, electrical and electronic engineering which took place in the German radio industry during the "Interbellum". In a way, I found it quite difficult to select just a few items for discussion from the many subjects which could have been considered. One might have approached the subjects from the point of view of applied physics (or engineering) but I found it quite fascinating to realise that the "trigger" for new discoveries was, quite often, simple applied technology rather than fundamental science. A good example is the invention of the quartz controlled generator (and equally the introduction of valves) where the theoretical understanding of the physics of the phenomenon was only really understood well after the basic invention was developed, as in the case of Cady's application for his famous US patent on 28th January, 1920.

Acknowledgement

I have to thank those who made it, in some way, possible for me to acquire the references for this paper over the many years of my research in this field: - Hans Evers, Tom Going, Karel Hagemans, Günther Hütter, Donald Prins, late Fritz Trenkle and late Hans-Ulrich Widdel.

Without the indispensable support of my good friend Richard Walker this paper would not being published.

Abbreviations

AGC = automatic gain control
AVC = automatic volume control
BFO = beat frequency oscillator

CW = continuous wave, though used for morse mode
DF = direction finder
FuG = Funkgerät (radio apparatus)
HF = high frequency
IF = intermediate frequency
K = kelvin
LF = low frequency
Ln = Luftnachrichten ... , (also Air Force wireless stock number)
LO = local oscillator
MO = master oscillator
PA = final amplifier
RF = radio frequencies
RLM = Reichsluftfahrtministerium (Air Ministry)
VFO = variable frequency oscillator
VHF = very high frequencies
: = permeability

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