RECEIVER AND TRANSMITTER DEVELOPMENT IN GERMANY 1920-1945

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The Netherlands

From 1920

After the devastating period of the first World War, Germany had to recover under the most difficult circumstances. Not only because the Germans were as pariahs in post war Europe, but also because the crumbling European industries were recovering very slowly from their deep wounds.

If we compare the international scientific literature of the twenties (via their references), for instance the British, American, or Japanese Proceedings, with their German equivalents, there was not much difference in general knowledge. In Germany the scientific publications usually appeared in respectable magazines like: ENT, ETZ, as well as several "Physical" magazine's, etc. Perhaps this was caused by the same kind of individualism which could later be recognized during the technical developments in WW II, where this individualism was an important factor.

It soon became common practice in Germany to use die-casting in commercial electronic artifacts, mainly for the housing and sometimes integrated with the chassis too. Electronically the artifacts were quite comparable to those of foreign design.

Quartz as a frequency controlling device was slowly becoming more and more important. Already in the mid twenties the Germans relied on quartz, mainly as a secondary standard. Mögel (1). The "Leuchtquarze" were a very special example, sealed in a glass envelope filled with low pressure neon gas. When HF energy was fed straight to the quartz, the crystal started to glow at the appropriate resonant frequency. This was a very simple technique where no further components were needed, but at the same time adequate for most purposes.

The major steps in German equipment design, after 1930

Although Hans Vogt invented low-loss HF iron dust-core material about 1928, causing a tremendous improvement in German electronic circuit design, no other country in the world used this basic material so extensively up until 1945. This is to me still an unsolved riddle. From the mid thirties onwards, an extensive programme of iron dust-core products became available to the electronic industry, from small HF and IF transformers up to the medium power transmitter-variometer, as well as many other applications.
The second approach to a totally new equipment-design also originated at the end of the twenties and the beginning of the thirties.

Originally engendered by economical factors the Lorenz company (later Standard Elektrik Lorenz owned by ITT) were searching for more rational construction techniques. As today, prefabrication could be the means to minimize labour costs and at the same time improving the quality of the product.

At the end of the research period, it had been proved that, for this kind of mechanical construction, die-casting was the best solution. Although Lorenz was acquainted with die-casting techniques in general, the production of a relatively small and extremely complicated construction, with very narrow tolerances, was forcing them to obtain outside support. It was a logical step to use the experience of a piston manufacturer, where the production of aluminium die-casting, combined with narrow tolerances, was their daily practice. So the "Mahle" company came on the stage of this progressive innovation. Ultimately this company became the major supplier of die-cast artifacts for the German electronic industry, up until the end of WW II.

The empirical optimum seems to be a special magnesium-aluminium alloy called: "Elektron" (± 8.5- 9.5% Al, 0.5% Zn, 0.2% Si, 0.2% Mn, and the rest Mg.). Until the end of the hostilities, this basic material was the bases of nearly all small and medium sized receivers as well as transmitters and many other artifacts ("Spritzguß"). When Germany started to suffer from a severe shortage of aluminium, they were subsequently forced, more and more, to replace the lightweight Elektron by an alloy based more on zinc. As a local raw material, it caused no trouble to obtain, although the weight of the artifacts increased significantly. The German Luftwaffe, as the best equipped force of the entire Wehrmacht, kept the high quality aluminium die-cast artifacts, up until the bitter end. But after the middle of 1943 the Army was supplied, more and more, with the zinc substitute alloys.

It was a hard and long way to go, before this new construction technology became reliable enough for mass-

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production, in the beginning of the thirties. To increase productivity was one step, but on it's own it would not bring a practical improvement.

In the fall of 1932 two graduates Dr. Rohde and Dr. Schwarz, former students of Prof. Esau, of the technical university of Jena, met Mr. Handrek of the Hescho company (Hermsdorf-Schomburg-Isolatoren-Gesellschaft). As we now know this was a key meeting for the future of the German electronic industry.

After the mid twenties, the chemist Rahn developed a completely new kind of temperature controlled ceramic dielectric with very low losses up to 100 MHz, a relatively high frequency for those days. The major problem in getting this new product onto the market was that its physical characteristics were not clearly understood. Several institutions had been consulted on this technical problem and were forwarding, for the same type of sample, non-comparable results. This was unacceptable for the Hescho company, as no progress in solving this problem was being made. Dr. Rohde and Dr. Schwarz got their opportunity to solve this problem once and for all. In August 1933, this resulted in a new company: Physikalische-technisches-Entwicklungslabor Dr. Rohde & Dr. Schwarz, after 1945 the well known R & S company of Munich. R & S (2)
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 (3) stated that, despite all the industrial capabilities of the company, the raw ceramic material (based on titanium dioxide) still had to be bought straight from the Hescho company, up until 1939 as they couldn't manage to replace it with material of its own manufacture.

Thus after 1933 full temperature control became available, especially suitable for frequency stabilisation.

We have got an idea of three of the 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 becomes inevitable. The "Third Reich" was hastily searching for new solutions to acquire the greatest possible autarky. Goering's industrial "Four Years Strategy" (Vierjahresplan) was the major State controlled institution, 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 by the above mentioned developments by the German industry. Problems in HF and IF filtering could, more-or-less, be solved by better circuit design in combination with the extensive use of iron dust-core techniques.

But, to improve frequency stability is a far more delicate problem, where different factors are nearly always working under "Murphy's law" into the worst conditions.

Goering was not only responsible for the autarky planning, but was also in command of the new Luftwaffe. This combination of both responsibilities also influenced the strategy concerning the re-armament of the Luftwaffe. Because of this, the Luftwaffe was generally equipped with the best communication- as well as radar- systems, compared to the Navy in second and the Army in the third place.

The Luftwaffe and the two other military communication organisations, were trying to standardize their components as much as possible. A big problem in this was the large variety of radio valves for communication purposes. They decided, because a new generation of valves would soon come onto the market, to force the industry to integrate and co-ordinate their military and commercial activities. This resulted in a completely new generation of radio and transmitter valves. Not only the specifications were a problem, but also the integration of the new valves into the mechanical design of the artifacts. Not, as was usual before, to build equipment around a valve, but now to integrate the new valves into the mechanical design of the apparatus itself.

The opportunity to create a new standard in valve design brought 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 types of valve. The receivers, depending of their purpose, employed on eight, eleven x RV12 P2000 and the transmitter only three x RL12P35, a valve of thirty five watts anode dissipation.

The universal RV12P2000 (*nomenclature: R = valve, V = low-power amplifier, 12 volt filament, P = pentode, 2000 static amplification factor*) for those days a very small radio valve (miniature). It was applied in nearly all major circuit designs as: triode, pentode, a single or double-diode, or a combination of these. It became the backbone of nearly all commercial and military equipment. More than 16 million RV12P2000s were produced during WW II. It was a really major step forward to supply a maintenance organisation with only two different valve types for an entire system.

The major problem was to be really independent of the supply of quartz crystal. To counter all the electro-mechanical problems, causing frequency instability, rigid chassis and housing design was only one of so many factors. Temperature control was also now available.

But this was still not good enough to meet the technical specifications desired by the professional users.

The next logical step, introduced by the Hescho company, was to vaporize and burn a heavy copper and / or silver film onto a ceramic cylinder. The electrical windings were mechanically cut from the cylinder surface, as a helix, leaving the inductive element and thus improving greatly the Q factor, of this type of solenoid. From a Funkschau publication of 1943 (4) we now know that this technique decreased the temperature coefficient by a factor of 200, compared to a normal solidly wire wound solenoid!

The design and manufacture of tuning systems, particularly where complex and precision mechanisms were involved, was matched to the skills of both the German and Swiss nations. (An example will be given later in Fig. 3.) To avoid backlash and other kinds of mechanical instability, the extensive use of spring loaded gears was common in nearly all of their equipment design.

The Lorenz company started, by constructing complete stages of an apparatus in modules, to simplify the production of commercial and especially military equipment, where special interconnections were integrated into the mechanical design. The direct spin-off was that the production could easily be spread over different manufacturing sites. At the end of production, all the modules had to be brought together, simultaneously for final assembly.
Space is always a problem in aircraft. The commercial and military specifications were forcing industry to miniaturize their radio installations, as far as possible. Modular techniques, and the introduction of special valves, made construction in a "three dimensional way" only a matter of cost. And this was, in a Germany with their 1000 Years lasting policy in mind, a minor problem.

The Lorenz company won an industrial competition of the Luftwaffe in 1937, with their revolutionary FuG 10 wireless system (sometimes written as: FuG X). This system became *the* preference of the Luftwaffe for the next decade. Until the end of production, after Germany's defeat, 50,000 of these systems had been delivered, comprising a total of 300,000 units (modules).

The FuG 10 installation was and still is to me the best example of modular and three-dimensional construction technology of WW II, attained by the previous mentioned technological advances. An advantage was the improvement in serviceability! Complete units and /or parts of it could now conveniently be changed, in very little time, by minimally trained technicians. All modules could simply be fixed to their mounting frame (Aufhängerahmen), by revolving only two 90° lock screws. All the units (receivers, transmitters and all other parts) were automatically connected via flat-cables (Flachband-kabel) to the junction box, mounted on the fuselage. These flatcables are comparable to those used today in computers.

Let's have a closer look at the difficult problems the Lorenz engineers had to solve before they could incorporate most of the techniques we have just reviewed.

The Lorenz system; the FuG 10 and its derivates, had to rely on a so-called MOPA (master oscillator *MO* as the VFO, and power amplifier *PA*) design. If it had to replace quartz, 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 as the PA valves. This could be managed by one RL12P35 in the VFO and two RL12P35 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 continuously changing. 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 were causing a change of anode capacitance and its interaction with grid capacitance, amplifying the Miller, as well as other effects.

In the FuG 16 (17), a VHF aviation wireless set (R/T) on 38.5 and 42.3 MHz, they countered this warming-up effect by reducing the filament (heater) power during the transmission periods for the VFO stage. It could be easily done in this system, because this apparatus only had to work on amplitude modulation (AM), and therefore under more-or-less stable dissipation conditions, though the design of this VHF system was as difficult as for the FuG 10 working on 3-6 or 6-12 MHz.

The major problem was to counter the changing temperature during CW transmission. A very difficult problem, concerning temperature compensation; the reaction coming later, always after the momental circumstances.

Telefunken countered this, for the EZ 6 direction finder (later also implemented into 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 capacitor in parallel. This increased the direct relation between the change in temperature and the related capacitance, proving adequate for the D/F receiver, but not for a transmitter under fast changing working conditions.

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 only the surrounding temperature, caused the compensating and controlling factor of this system. 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 abberations. Sarkowski (5)

C 5a to C 5c in Fig. 1 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.

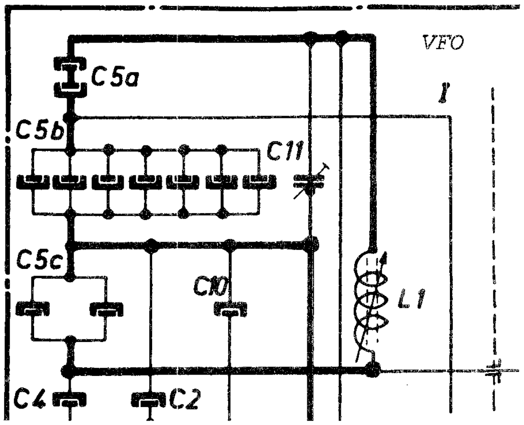

Fig 1:S10K VFO temp/comp.via C5a-C5c

We are not always aware of extreme environmental conditions, especially for high altitudes, as in an aeroplane, which often caused 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, and 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.

The invention of iron dust-cores by Hans Vogt, one of the new innovations as we already know, 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.
In Pat Hawker's (6) well known Technical Topics it was mentioned that such a variometer, without iron dust-core, could be tuned between 4 to 17 µH, and with an iron dust-core, between: 6 to 38 µH, creating an inductance ratio of 1 : 6.3. But first new techniques had to be explored to counter the saturation problems of the iron dust-cores.

After the entire FuG 10 system had been introduced, the concept engendered a transmitter as well as 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 (aeroplane conditions) for a max. frequency deviation of: 3×10^{-4}.

In my opinion, the Americans based their beautifully designed SCR 274 N ≈ AN/ARC 5, perhaps better known as the Command Set (BC453-455 and 656-658), on the philosophy of to the FuG 10 system.

Telefunken was, in my opinion, not only the best and most advanced manufacturer of German electronic equipment, although their products were far more complicated and perhaps more expensive.

We will take a closer look first at the transmitter: T 200 FK 39a. (Telefunken, 200 watt, F = long distance, K = short wave, 39 = year of introduction). This transmitter generation was especially designed for very limited space (width 26.5 cm!), for example on board of submarines. As we know now, all German transmitters had to be completely independent of quartz control, except for calibration. But, when a submarine had to transmit, sometimes for only 10 to 15 seconds, or for an even shorter period of only 454 ms, without any external reference, according to the Kurier or Squash transmissions, it's clear that the specifications of this equipment had to be of a very high order.

We also have to consider that under offshore condition unbelievably strong, low frequency, mechanical vibrations could occur. According to the test specifications for the long-wave version T 200 L 39 these transmitters were tested for: vibration freq. = 20 Hz, vibration deviation = 2 mm and this for two hours (1 hour was divided in: 20 minutes CW keying, 20 minutes stand by and 20 minutes CW keying). At 600 kHz the deviation should be ≤ ± 100 Hz, a really remarkable specification for those days!

The "a" versions were equipped with an extremely complicated motor-controlled tuning system, to decrease the tuning time of the transmitter. All four transmitter stages were tuned by this controlling system, reducing the tuning to only "1½" knob, except for the antenna tuner, which had to be adjusted manually. All important dials were linked with a mechanical digital read-out. For the operator this was a simple job as he only had to read the tuning card. The frequency reading was stored on a microfilm and projected on a frosted glass plate (Mattscheibe). The frequency range covered: 3000 kHz - 23077 kHz and was divided into 12 relatively small ranges (bands).

To counter the mechanical forces and keep the calibration tolerances, the entire housing of the VFO and buffer- annex doubler-stage were made entirely of heavy ceramic, coated on the inside with solid copper. It's clear, that under such conditions iron dust-core, as a tuning device, had to be avoided. The variometer of the VFO was coated on to the surface of a ceramic sphere which had a special profile to increase frequency linearity. These were of the short circuit type, avoiding any unreliable contacts. When the closed circuit ring of the variometer sphere was parallel to the inducting solenoid (stator), the inductance was at a minimum. (max. coupling). The inductance of the solenoid reach-ed a maximum when the conducting ring of the variometer was revolved through 90°; it then having no coupling at all.

The VFO, as shown in Fig. 2, was designed for push-pull and the next stage for push-push. The purpose of this design can be explained as follows: if the transmitter had to work for the lower frequencies (straight trough), valve ③ had to be blocked by a negative voltage. At the same time the valve capacities were acting as a neutralizer circuit, having exactly the same capacitance as the working valve in the same stage, they were fed in counter phase (180° difference). For higher frequencies, this valve ③ worked normally, and only even harmonics could be produced, all the odd harmonics being suppressed.

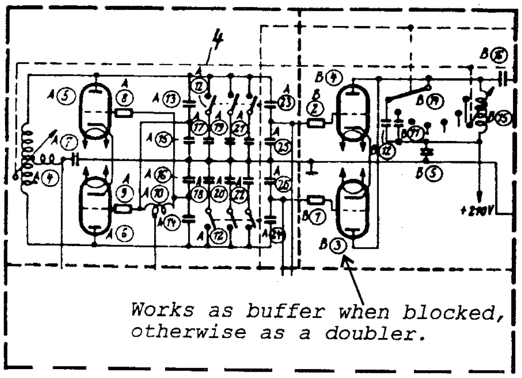
Works as buffer when blocked, otherwise as a doubler.

Fig 2: VFO + buffer/doubler stage

To control the relation between temperature and frequency, most of the capacitors in this VFO circuit were specially manufactured for this purpose. But to avoid any influence of humidity all were of the so-called "Sikotrop" type; as the name already suggests, produced by the Siemens company especially for tropical conditions. The capacitors were covered on the outside

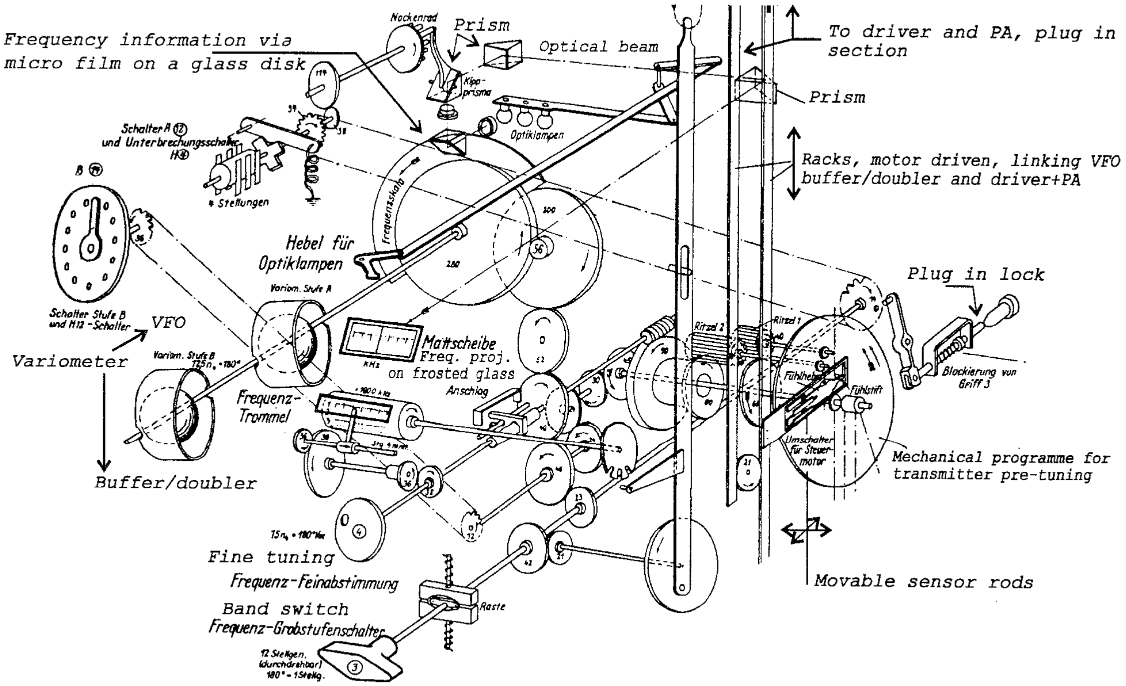

Fig 3: T 200 FK 39a tuning mechanism for: VFO and Buffer/doubler, plug in unit

by a porcelain tube, sealed at both ends by soldered caps. Depending on the purpose, different types of temperature coefficient or a combination thereof, could be used.
The overall temperature coefficient of this marvellously constructed transmitter was quoted as: 6 x 10^{-6} K^{-1}.
Its hard to imagine Fig. 3 covers only 25 % of the transmitter's mechanics!
The program disk was prefabricated at the factory and the movable (comparing) sensor rods were linked to the driving system. If the mechanical tuning exceeded a certain limit, it forced the tuning system to a safe position always within proper tuning limits, to protect the transmitter from unnecessary overloading. Only the fine tuning had to be done by the operator. He could read this on the calibration chart. Tuning could be done completely without any transmission at all.

The E 52 Köln constructed by the Telefunken company, was the most revolutionary receiver of this period. The optical frequency projection had a lot of similarity to that of the T 200 ..xx. apparatus. But it had several more outstanding features. Because of the limited space, we can only have a brief look at this wonderful receiver.

For the first time all interconnections were integrated into one mother (circuit) board (Bu 3). All stages, were designed as modules. From the front-end up to the power supply, all were interconnected via self contained contacts. The tuning capacitor had six sections: five for the pre-selection and the last one mounted on the shaft of the micro film disk for the Local Oscillator (LO). Both HF pre-selector stages were band-pass filters tuned, except for the mixer. The IF stage at 1 MHz was equipped with two quartz filters, of a very high order, and symmetrically tunable between 100 Hz up to 10 kHz; no external phasing was required. This could only be managed by the extensive use of iron dust-cores.

The photograph Fig. 4 allows a close look at this mother board Bu 3.
On the left the three valve IF amplifier (cover removed, with visible a RV12P2000 up-side down) with at the front the tuning shaft of the quartz filter. On top of Bu 3, on the left, the module of the first HF stage and on the right, the local oscillator and the mixer block. Not plugged-in, for this photo, were the demodulator / bfo, LF and the second HF module and the power supply.

This receiver had originally also been designed for special purposes, like remote controlling by telephone. Also a direction finding (DF) adapter could be connected mechanically, at the left of this receiver, although we have never seen any of these artifacts. But, after mid 1944 receivers were produced with information: this receiver is not for "Peilbetrieb" (DF), which in my opinion means that the previous receivers were intended to do so.

To mention only a few of the specifications: image suppression below 20 MHz ≥ 96 dB, above 20 MHz ≥ 85 dB. Each of the five frequency bandscales were magnified by the optical system up to nearly 150 cm!

Conclusions

In the twenties there was not much divergence between the electronic developments in the western world. Near the end of the twenties, when communication technology was gaining maturity, new and revolutionary techniques were becoming available. But, to my surprise the just mentioned technologies occurred mainly in Germany.

Being independent of quartz, especially for bulk production, had a major impact on the flexibility of the German signals organisation. Between 1940 up until 1945 less than a million, quartz crystals were produced

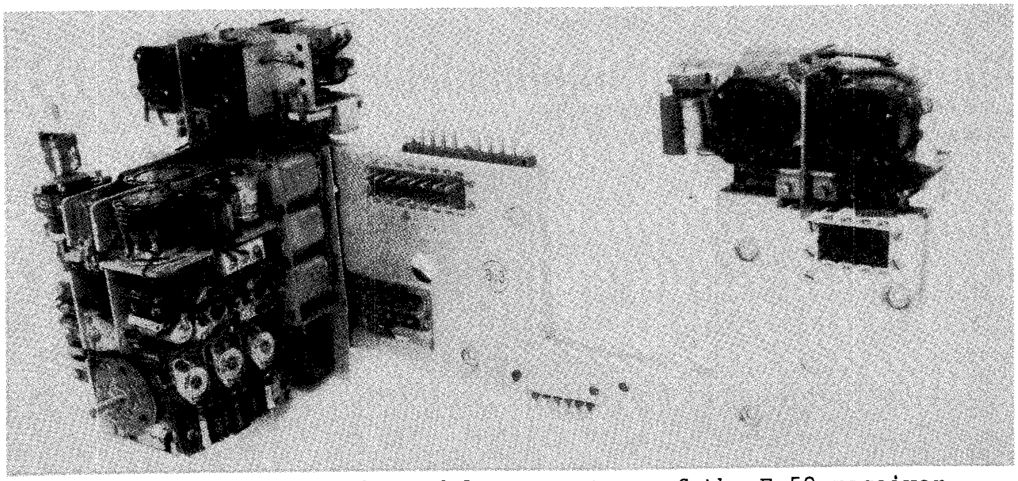

Fig 4: A view of the modular structure of the E 52 receiver.

in Germany, whereas the US alone produced more than 30 million from 1941 up until 1945. (7) (8)

Two conclusions stated in a British report (9): *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.*
Finally, as was expressed in (9): ....*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.*

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