22. German WWII Identification Friend or Foe and Command Transmission

By Hans H. Jucker, E-Mail hhjucker@ggaweb.ch, Guenter M. Koenig E-Mail dj8cy@t-online.de, October 2012

Abstract

The need to be able identify aircraft more easily and reliably led to another German wartime radar development, the Identification Friend or Foe (IFF) system, which had been created as a means of positively identifying friendly aircraft from enemy. The German IFF system was based on powerful pulse modulated interrogation of the FuG 25a Erstling transponder in the aircraft and was from that point of view rather insensitive against electronic jamming. So when Allied jamming in 1944 disrupted the fighter – control voice radio channels, the German Airforce made trials with rather uncommon concepts to accomplish Command - Transmission by means of the FuG 25a IFF system. One of these unique concepts, the so called Nachtfee FuG 136 allowed transmission of sixteen commands from the ground radar to the aircraft. The German Nachtfee FuG 136 system was a method for transmitting fighter direction commands over the beam of the controlling radar by space (phase) modulation of the Freya pulses within a repetition cycle. In order that a number of fighters may be controlled from a single Freya ground station, the airborne equipment was built in 10 different models with crystal controlled repetition rate oscillators operating at frequencies grouped around 15 kHz. Fighter direction commands are indicated by the angular position of pips appearing on a circular sweep CRO trace.
However such kind of communication requires synchronicity of the repetition rate oscillators in the ground and air equipment as well as a compensation of the phase change caused by the continual changing propagation path by the moving aircraft. This had to be manually done by the ground operator – a rather unique method never accomplished since and before. One ground equipment of a Nachtfee system survived in the United States all the decades since WWII and the executive of a technique historic museum in the Netherland took great care to restore and recover the systems functionality.
The topic of this article deals with the principle of the Nachtfee FuG 136 Command – Transmission procedure as well as a technical description of the FuG 25a IFF transponder. The Command – Transmission procedure represents the concept of transmission orders from a ground direction center to aircraft and pilot on night fighting missions.

Introduction

Since the begin of WWII the German Airforce used several embryonic IFF systems. By 1941 the deficiencies in performance provided by earlier systems lead to the development of the target identification transponder FuG 25a Erstling. A FuG 25a Erstling prototype was developed on late 1941 by the GEMA company located at Berlin - Köpenick for interrogation by Freya, Wassermann and Mammut medium and long range radars operating in the 125 MHz frequency band and a pulse repetition frequency (prf) of 500 Hz.
Consequently it was laid out for ranges beyond 100 miles. The Freya, Wassermann and Mammut radars were the backbone of the German early warning radar organization and in service along the Atlantic coast and in other countries occupied by the German forces. In a later phase of WWII the FuG 25a were used occasionally for ground to air Command – Transmission communication as well as bombing – release in aircrafts.
The British radio listening service monitored the emissions of the German radars at the Atlantic coast since the begin of WWII. Surprisingly for the British Telecommunication Research Establishment (TRE) involved for signal analysis was the high precision of the transmissions radiated by the German early warning radars. Especially the stability of the pulse repetition frequency (prf) of the radars working on the 125 MHz frequency band seems unnecessarily high.
In the second half of 1944 and early on 1945 the listening service had evidence of German radars operating on 125 MHz with hopping pulse repetition rates. The second pulse was phased at a constant interval from the normal pulse and the two blips were of equal size. The latter point excludes the possibility of the second blip being a permanent echo. At an other case the phase difference of the two pulses varied rapidly. So for the British Electronic Warfare Analysts it appeared most probable that the varied pulse phase

difference equal to a hopping prf was used for some kind of command - transmission done by pulse modulation.

According to the official US Army postwar summery report F- SU-1109-ND

THE HIGH FREQUENCY WAR, A Survey of German Electronics Development occasionally WWII

The chapter Command – Transmission on page 114 of that volume describes a collection of concepts used by the German Air Force for transmission of commands from ground direction centers to aircrafts and pilots, engaged in night fighting. Most control of the German night fighter airplanes was carried out by commands passing from ground to air. Early in WWII this was done by wireless telegraphy later by radio telephony traffic with FuG 10 shortwave or FuG 16, 17 vhf radio equipment.

However, if in a later phase of the war this **radio traffic was severe jammed by the allied Airforces,** so control had to be carried out rather with substitute transmission concepts.

Some of the Command – Transmission concepts were carried out by means of the FuG 25a Erstling Transponder, so it is worthwhile to go more closely into these applications. The two systems mentioned below were used operational at the end of the war for rather few special raids, but not introduced as standard procedures.
A British military historian has recently discovered in the PRO/NA archieves, Kew U.K. some wartime Air Scientific Intelligence documents originated by Wing Commander S.D. Felkin. Wing Commander S.D. Felkin has worked in World War II for Sir Reginald Victor Jones a physicist and head of the British Scientific Military Intelligence.
Especially one of the captured German documents the report Radar News No. 19 dated on 25th February 1945 originally addressed to the German Generalnachrichtenführer vom Oberkommando der Luftwaffe contains interesting information according two German Command – Transmission concepts.

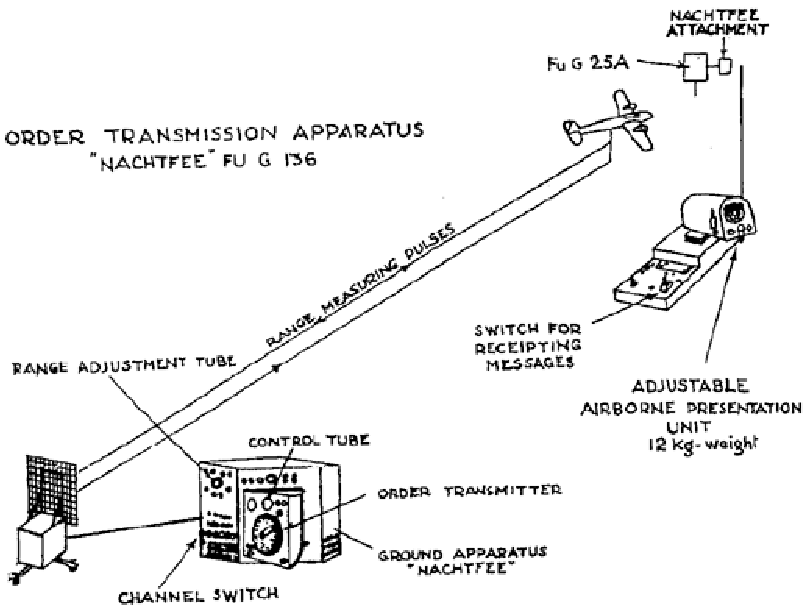
“Nachtfee” FuG 136 System (see drawing on next page)

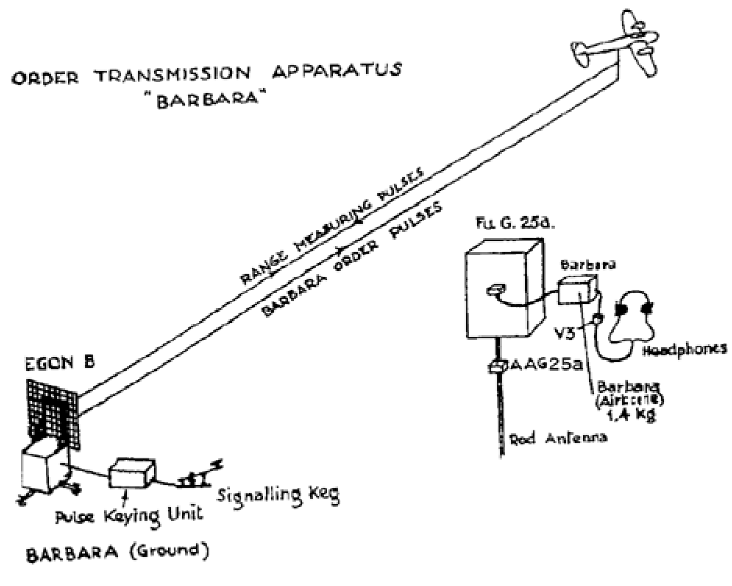
It consists of an airborne attachment to the FuG 25a Erstling receiver in the aircraft, and a ground attachment to the Freya radar transmitter, needing two operators. Transmission of 16 different visual signals which are read off on a cathode ray tube (crt) in the aircraft. The apparatus was only suitable for two seater aircraft, as a continuous intensive watch has to be kept on the visual crt indicator. Transmission of commands was only possible when the aircraft was flying in the antenna lobe of the ground radar.

“Barbara” FuG 138 System (see drawing on next page)

It consists of an airborne attachment to the FuG 25a Erstling receiver in the aircraft, and a keying attachment to the Freya radar transmitter on the ground. Audible signals (Morse characteristics) made it possible to use the apparatus for single seater aircraft, if the pilot was able to read simple Morse code groups. As in the Nachtfee, transmission of commands was only possible when the aircraft was flying in the antenna lobe of the ground radar.

German Nachtfee & Barbara Command Transmission Systems





The chapter Command – Transmission of the American summery report F-SU-1109-ND gives some evidence that the German Command Transmission systems were targets for recognition by the Combined Intelligence Objective Subcommittee (CIOS) teams after the occupation of Germany. So it is probable that a Nachtfee FuG136 system was captured by the CIOS team and sent for analysis to an electronics laboratory of the Government to the United States. As for most of the captured enemy booty the interest went lost over the years and much of these artifacts were later disposed.

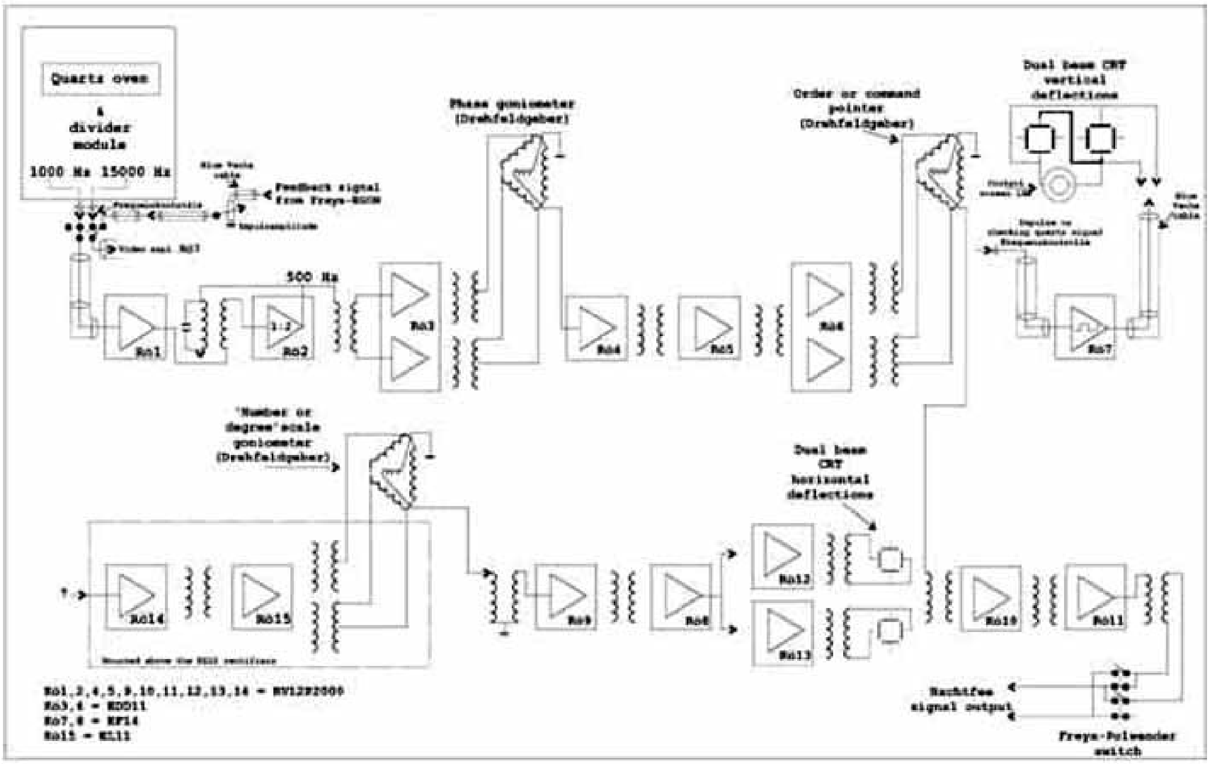
Some 65 years later someone found the equipment advertised it on E-bay and a collector bought and let shipped it to his home at Amsterdam NL.

Nachtfee FuG 136 Ground Equipment

Nachtfee FuG 136 Command Compass
for up to 16 different Orders

When the collector started to investigate and restore this Nachtfee FuG136 ground equipment neither the airborne portion of the system nor any functional diagram or description was available. Although, in the US summary document the report No. 10262 Command – Transmission Sets originated by the Joint Electronics Information Agency (JEIA) was referenced, it could not be found yet. So the collector did over many weeks a hard and diligent job to get some basic knowledge about the numerous subunits and their mutual cooperation.

The figure below shows the Block Diagram of the Nachtfee FuG 136 Ground Equipment as presented by the Dutch collector occasionally his investigation.



The Nachfee ground equipment generates basically the timing signal for the Freya radar system, if it operates for command transmission. For the transmission of the 16 possible commands the timing signal must be phase shifted in 16 steps of 22.5°. This phase shift of the 500 Hz timing signal could be done with a rotating treephase Synchro Control Transmitter (Selsyn).

One important characteristic of the Nachfee procedure is the fact, that beside a phase shift on the prf no extra pulses have to be emitted, so the Freya radar does not cause second time around echoes and stays fully operational for radar application.

The Nachtfee ground equipment contains two CRT displays one with a circular sweep and one other with a common X - Y deflection. The frequency of the timing signal is round 500 Hz, it is derived from a Quartz Oscillator time base and used for keying the Freya radar as well as for the sweep time base of the CRT's. The frequency around 15 kHz of the Quartz Time Base can manually fine tuned. For a higher frequency stability is the Quartz Crystal mounted in a temperature controlled environment. In addition to the command phase shifter there are two further phase shifters one for the phase adjustment of the time base and one other for compensation of the time delay caused by the propagation delay between ground station and aircraft.
The phase modulated 500 Hz timing signal is converted into a pulse signal for keying the Freya radar transmitter. The Freya radar radiates 125 MHz VHF pulses with a prf of 500 Hz and a typical pulse width of 1.5 µs.

The Dutch collector succeded step by step with a pragmatic trial and error method to bring the Nachtfee ground equipment in an operational condition. The photography on the next page give evidence for the successful operation of the command generation as well as its indication on the CRT display. Unfortunately, little is known about the airborne portion of the system. Nevertheless, has the collector built up a reproduction of Nachtfee functional chain. He integrated for this purpose the FuG 25a IFF airborne Transponder and the Gemse IFF ground receiver in a functional close loop system. With some nowadays commercial equipment like a Signal - Synthesizer and an Oscilloscope he simulated the missing airborne portion of the Nachtfee system. With this close loop arrangement he could successful demonstrate the transmission of commands from the ground equipment to the airborne portion.
However, the designers original system timing philosophy and the stability requirements and limitations of the time bases available in those days, could not be fully cleared with that trial.

The Nachtfee FuG 136 Control CRT LB 2 indicates with the Notch which of the 16 commands is currently transmitted

The figure shows the position N of the Order compass at 0°

The figure shows the position Pauke of the Order Compass at 180°

German Nachtfee FuG 136 Ground Equipment in Operation

Command Compass

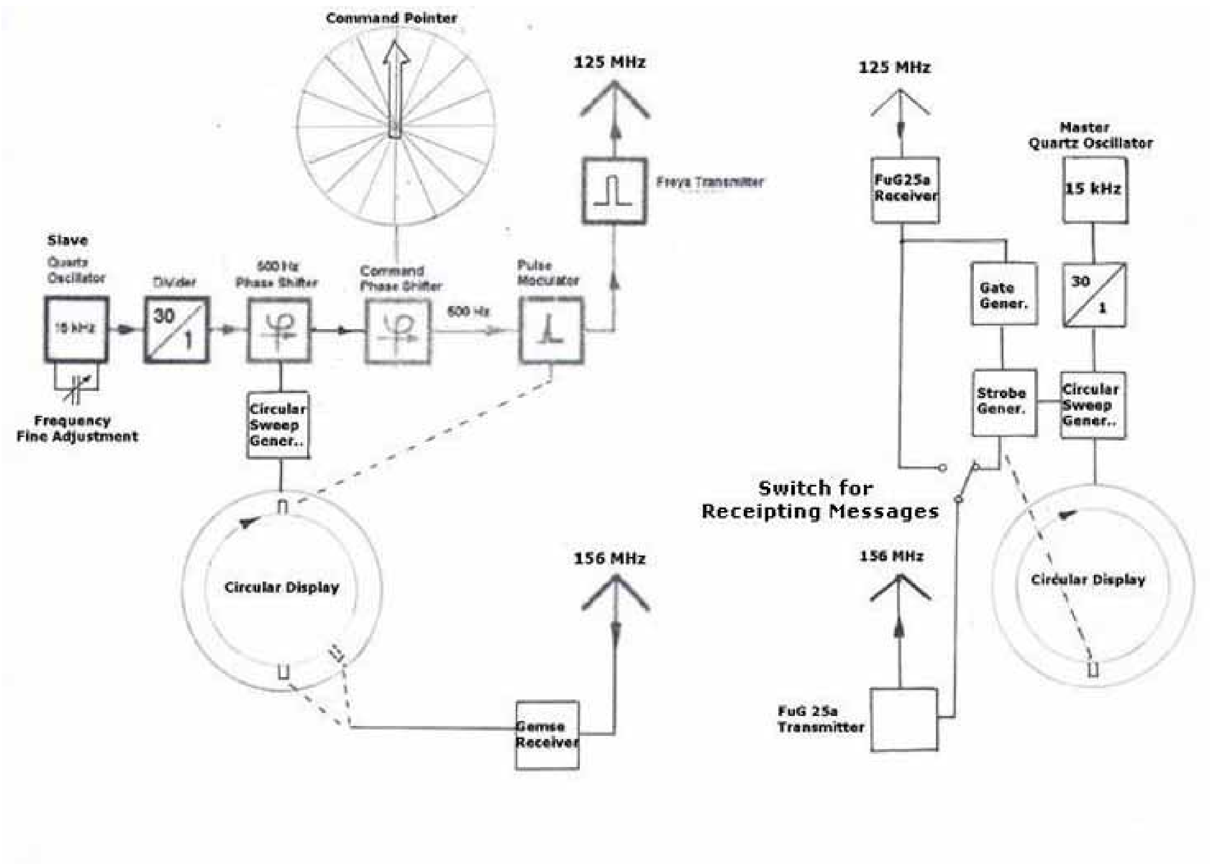
Some additional considerations according the Nachtfee timing philosophy.

Some time later a German engineer began to study and discuss the first investigation results. Experienced on other advanced control systems, he realized that the Nachtfee procedure was based on two remote synchronized timing systems. He made some calculations according the stability requirements for a real functional system.

He came to the conclusion that a command transmission from ground to the air could only be operational, if one time base fills master and the other slave function. Because it doesn't make sense to bother the aircraft crew with the required periodic time and phase adjust procedures, it's necessary that the time base in the aircraft overtakes master function.

Nachtfee FuG 136 Airborne Equipment

Although few is known about the original airborne portion of the system, the intelligence report proofs that the Nachtfee airborne equipment contains a CRT display with a circular sweep and a control switch designated **Switch for Receipting Message**. It is necessary that the display used a sweep circuitry to paint the circular sweep on the CRT, so it is possible that the time base of the airborne equipment used a similar temperature controlled quartz oscillator as the Nachtfee ground equipment. The figure below shows the assumed time base adjustment procedure.



Nachtfee Time Base Adjustment Procedure

Assumed Adjustment Procedure for the Ground and Airborne Time Bases

Starting Point: The time bases of the ground and the airborne aren't synchronized, it means that neither frequency nor phase of the two time bases are in coincidence.

The ground equipment is keying the Freya radar, if the circular sweep of the CRT crosses North position. The 125 MHz rf pulse of the Freya radar is received by the FuG 25a airborne transponder, it opens the response path of the FuG 25a transmitter. But the transmitter is waiting to be keyed until the circular sweep of the airborne equipment crosses the South position.

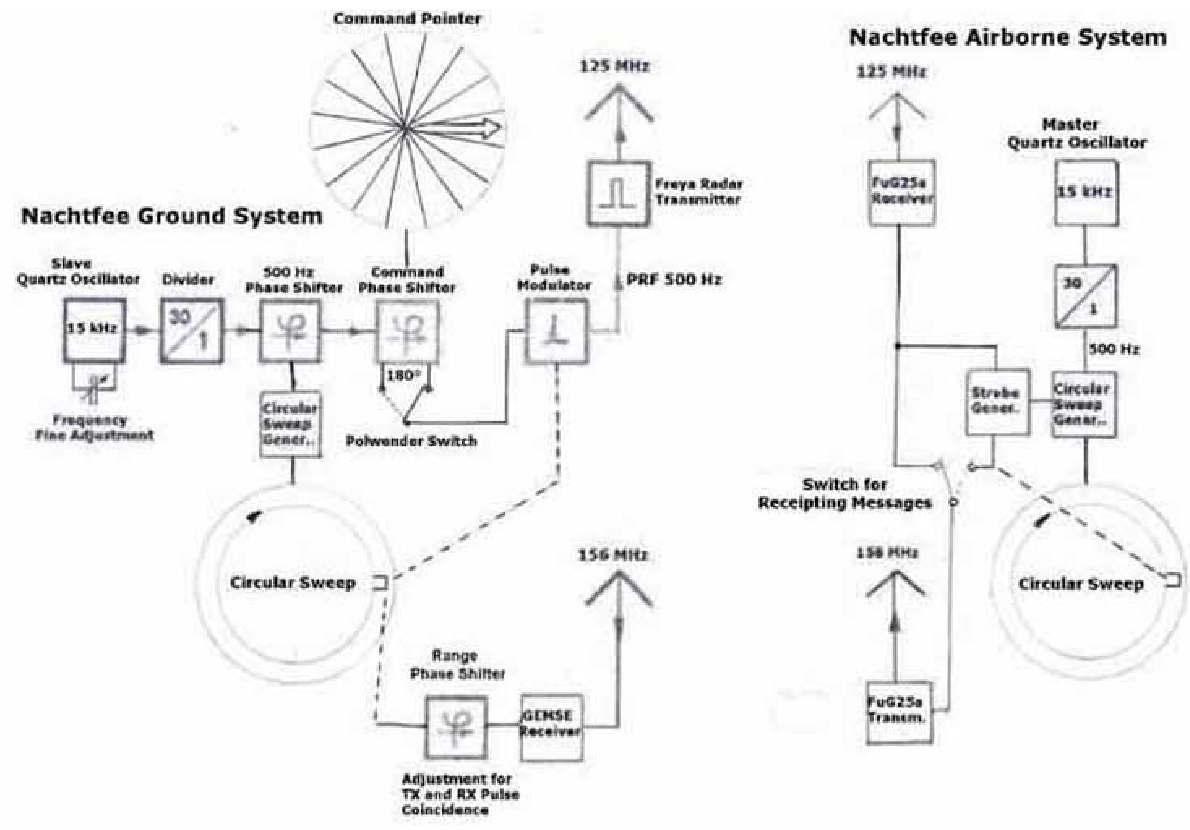
The radiated 156 MHz rf pulse of the FuG 25a transmitter is received by the Gemse receiver at the ground station and displayed on the circular sweep of the CRT. Caused by the frequency difference of the two time bases the pulse isn't stationary, it moves on the circular sweep of the CRT.

The frequency of the Quartz Oscillator has to be tuned by the **Fine Adjustment** for a stationary pulse on the circular sweep display.

Finally with the **500 Hz Phase Shifter** the pulse has to be manually adjusted to the South position on the display CRT.

After this initial adjustment procedure the two time bases are in a phase coherent condition and the system is ready for Command Transmission

The figure shows the system configuration for the Nachtfee Command Transmit procedure



Nachtfee Command Transmit Procedure

Proposed Command Transmit Procedure

Starting Point: The memory **Command Pointer** (large pointer without electrical function) is adjusted on the wanted Command.

The ground operator is signalling to the aircraft operator that a Command Transmission will be sent by actuating the **Polwender Switch**. This causes a 180° phase change, the pulse on the airborne display CRT moves from the South to the North position.

The aircraft operator a**cknowledges** the message by changing the **Switch for Receipting Messages from the idle position to the command position. This causes that the received phase from the ground equipment is sent back to the ground again by the FuG 25a transmitter.**

The pulse on the circular sweep of the ground display moves away from the South position.

The operator of the ground equipment has to reset the Polwender Switch. This measure
causes an 180° change of the pulse position on the airborne display CRT to North.

For to compensate the propagation path delay between ground station and aircraft the retransmitted pulse from the FuG 25a transmitter has to be manually adjusted by the **Range Phase Shifter** to the North position on the circular sweep display.

The Command Pointer (small pointer with the electrical function) has to be manually adjusted in coincidence with the small memory pointer, this causes the transmission of the wanted Command to the aircraft.

On the CRT of the ground equipment and on the CRT of the airborne equipment appears now the wanted command.

After recognition the displayed command has the aircraft operator to reset the **Switch for Receipting Messages** into the idle position.

This causes that the pulses on the circular sweep of the ground CRT as well as on the circular sweep of the airborne CRT are moving to the South position. The displayed pulses on both displays appears with the phase of the airborne master time base and their coherency may be checked and readjusted again.

For to return to the Starting Point: The ground operator has to reset **now** the large and the small **Command pointer** to North.

Summary Conclusion

Although, the last evidence does not exists that the procedures above are in accordance with the designers original idea, however the editors hope that they could help to provide a better understanding of that enigmatic WWII system.

GERMAN WWII FuG 25a Erstling IFF transponder

Occasionally WWII many war planes fitted with unknown radio and navigation gear emerged to airbases in Switzerland. So the FuG25a Erstling IFF transponder as well as many other equipment and instruments were found occasionally the investigation by the Swiss authorities. Only few of these artifacts have been survived over the decades since.

After the discovery of the Nachtfee FuG 136 equipment last year I was asked by the British and Dutch investigators for technical information on the FuG 25a IFF transponder. This caused me to bring the some 60 years old FuG 25a equipment in operation to figure out the requested parameters. This paper shows the result of my investigation.

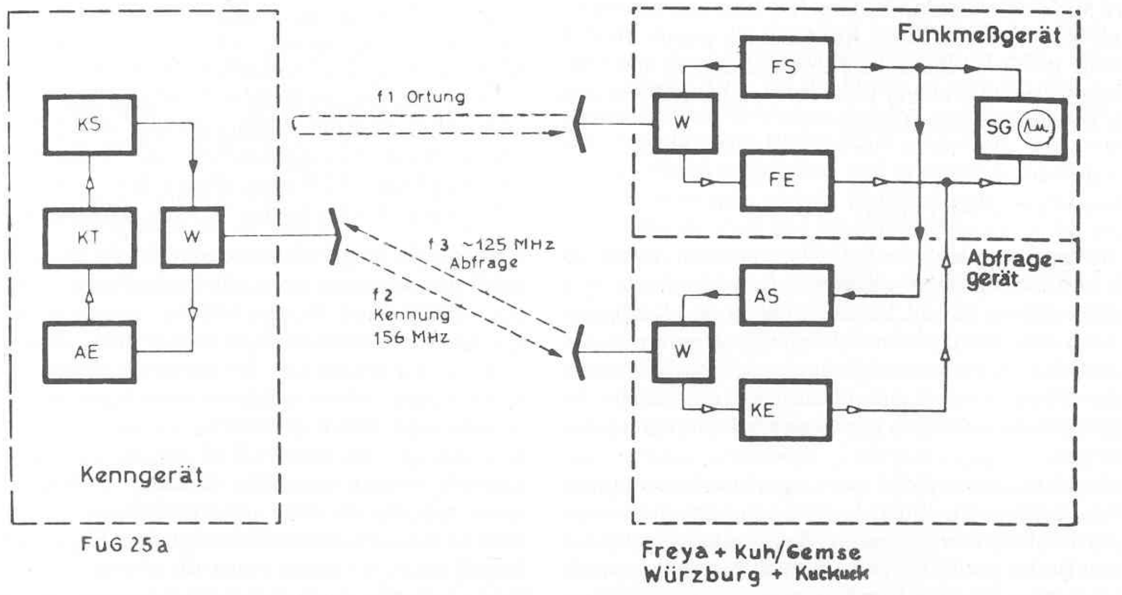
The figure below shows the system configuration of an airborne FuG 25a Erstling identification transponder interrogated by a German Freya or Würzburg type ground radar.

Airborne Transponder

AE Receiver
KS Transmitter
KT Code Keyer
W T/R Filter

Ground Interrogator

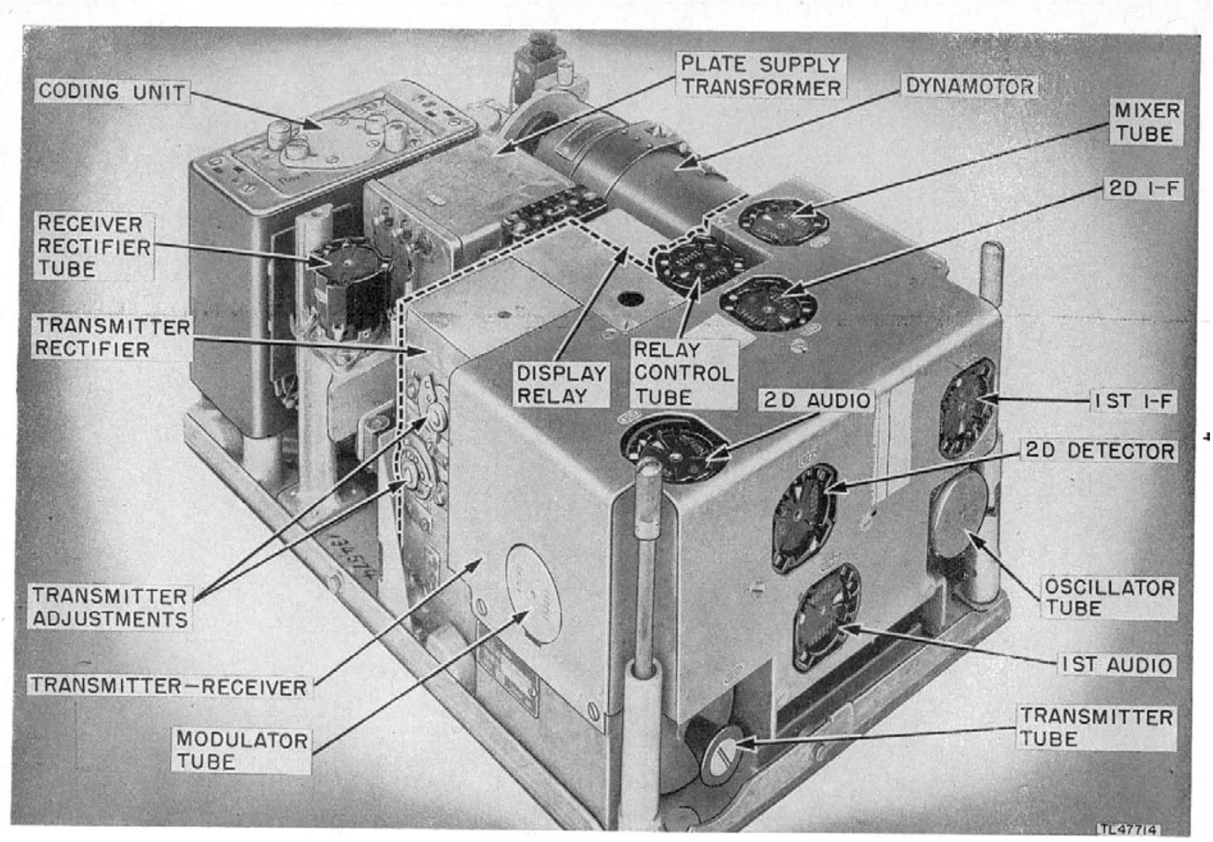
AS Transmitter „KUH"
KE Receiver „GEMSE"
W T/R Unit



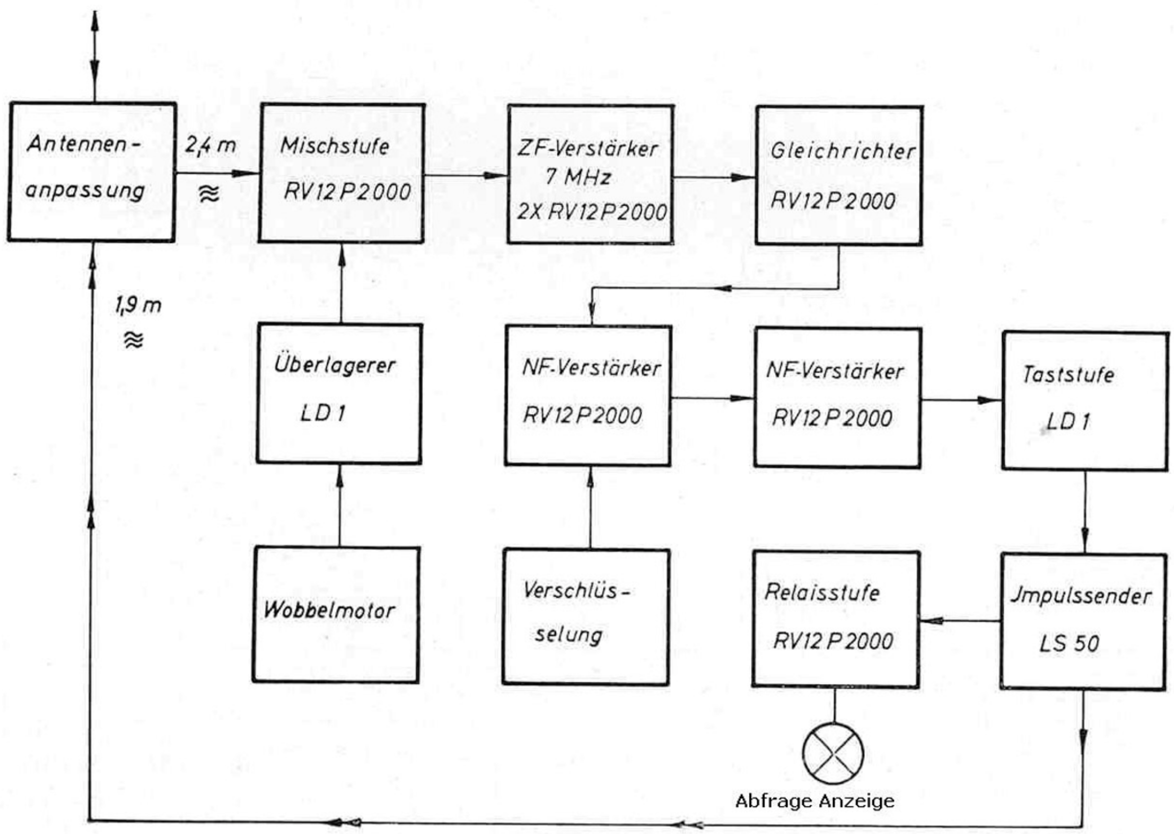
While its primary use was for identification purposes with the Freya radar it could also be used together with radars operating on other frequency bands, however for that purpose the 125 MHz interrogation transmitter « KUH » was necesssary. Later in WWII the FuG 25a was sometimes employed as bombing – release controller as well as for ground to air communication.

The FuG 25a airborne transponder consists of three subsections: transmitter/receiver, code keyer, and power supply. In flight two preset codes can be selected by the crew to modulate the transponder transmitter. The codes are derived from one of two keys inserted in the two banks of the electromechanical code keyer, theoretical 1023 codes are possible.
The power supply consists of a rotary type inverter supplied from the 24 volts aircraft battery. It generates an AC of 18 volts with a frequency of 134 Hz. The rotary inverter also drives over a gear box the rotating cam of the mechanical code keyer. The 18 volts 134 Hz AC is converted by a transformer rectifier and filter group into the supply voltages for the transmitter – receiver section. The filament voltage of the electron tubes is supplied directly from the 24 volt aircraft battery.

The figure shows the very compact design of the FuG 25a airborne transponder assembly.

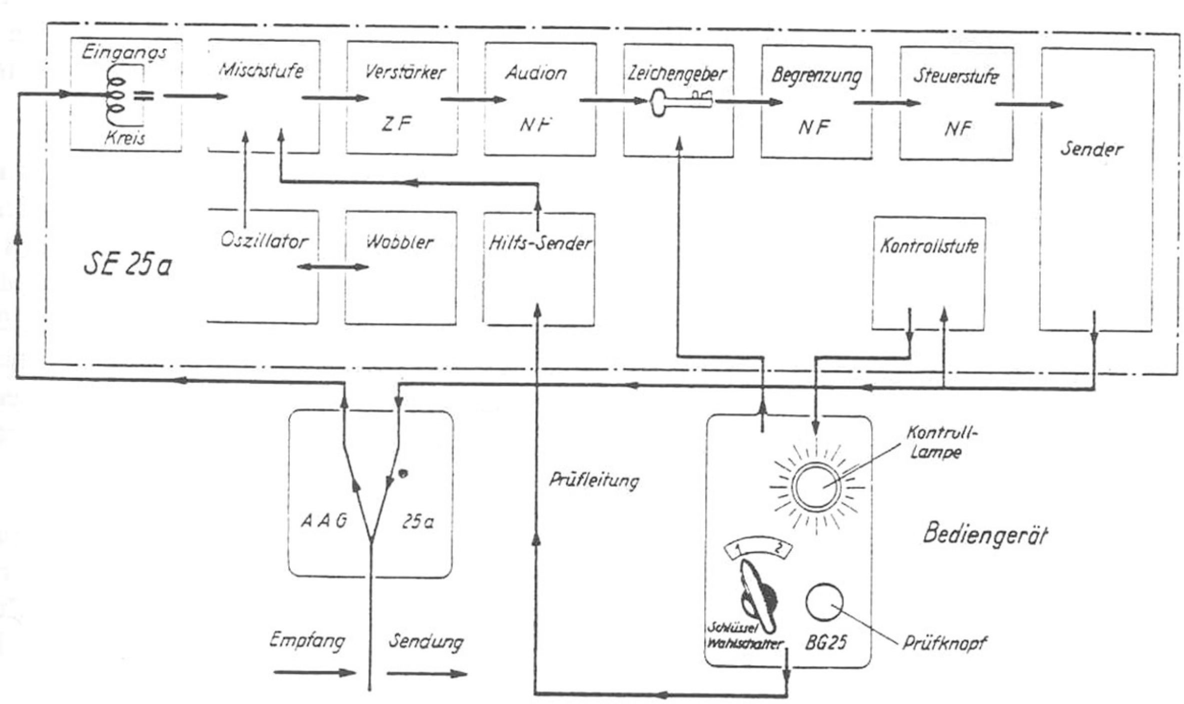


The figure shows a Block Diagram of the FuG 25a airborne transponder.

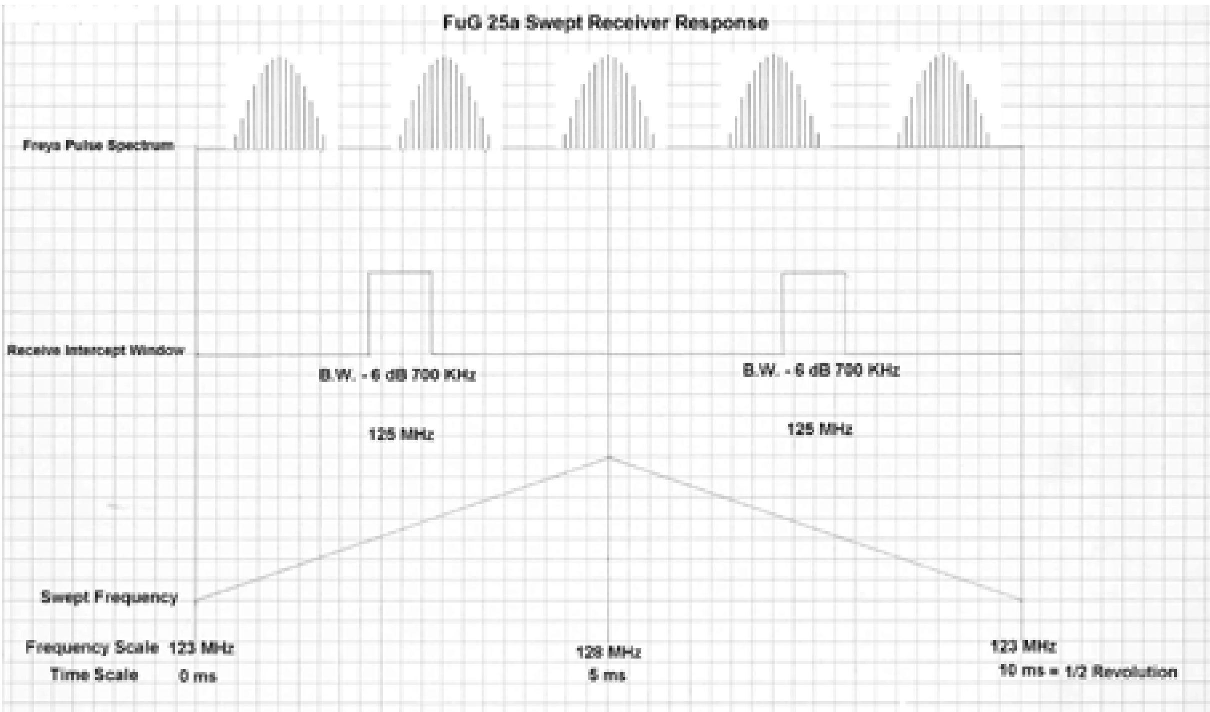


The receiver is an eight tube superheterodyne type that sweeps (Wobbeln in German) over the frequency band 123 – 128 MHz with 200 Hz by a motor turning at 3000 rpm a variable differential capacitor in the local oscillator circuit.
The front end consists of a mixer stage, a local oscillator operating above the radio frequency, two stages of double tuned IF amplifier at a center frequency of 7 MHz (bandwidth 600 KHz for - 3 dB, 700 KHz for - 6 dB), a detector stage, a limiter stage, a differentiating stage, and a trigger stage. The trigger stage produces pulses in a pulse transformer which are applied to the grid of the one tube transmitter.

The figure shows a more detailed functional diagram of the FuG 25a airborne transponder

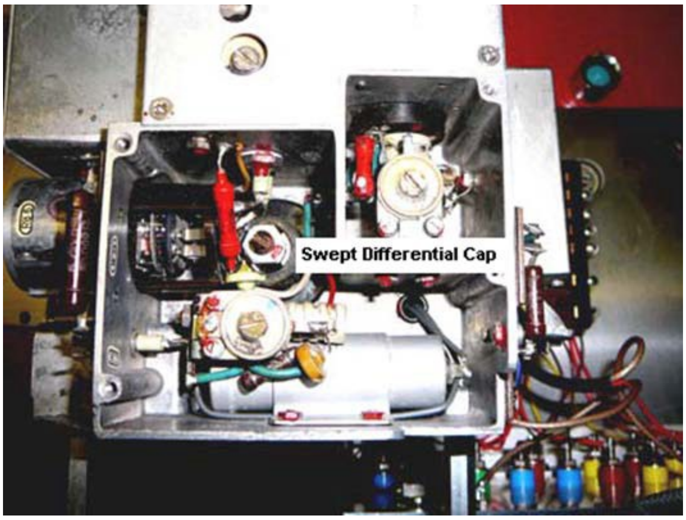


The figure shows the Swept Receiver Response over a ½ revolution of the variable capacitor



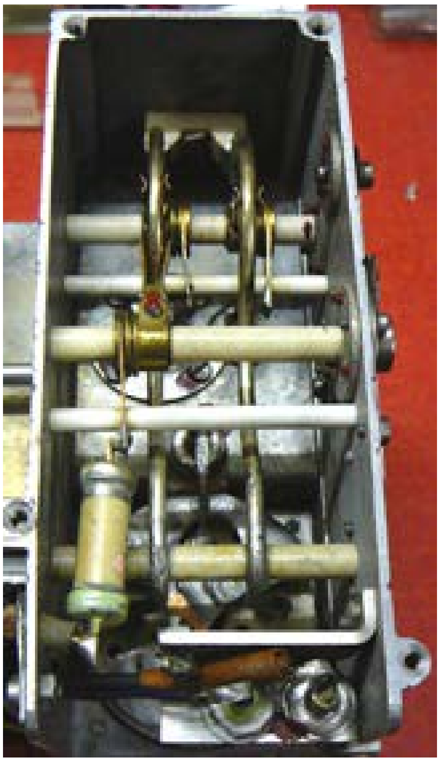
The figure shows that during one revolution of the variable differential capacitor the receive frequency sweeps 4 times over the frequency band within a time interval of 20 milliseconds. As for instance the Freya pulses radiated with a prf of 500 Hz equal a time interval of 2 ms are intercepted by the FuG 25a receiver, if parts of their frequency spectrum are in step with the receivers interception windows.

The photography shows the local oscillator with the differential capacitor



The output of the receiver is used to modulate the FuG 25a transmitter. The transmitter can be set at a spot frequency in the range 150 – 160 MHz usually 156 MHz. As it is modulated by the receiver output, it produces pulses as determined by the combination of the radar prf (Freya 500 Hz) and the receiver FM rate. When the two are in step, so that a radar pulse arrives whenever the receiver is sensitive to the radar frequency, the transmitter gives 200 pulses per second. The pulse length is 0.3 microseconds.

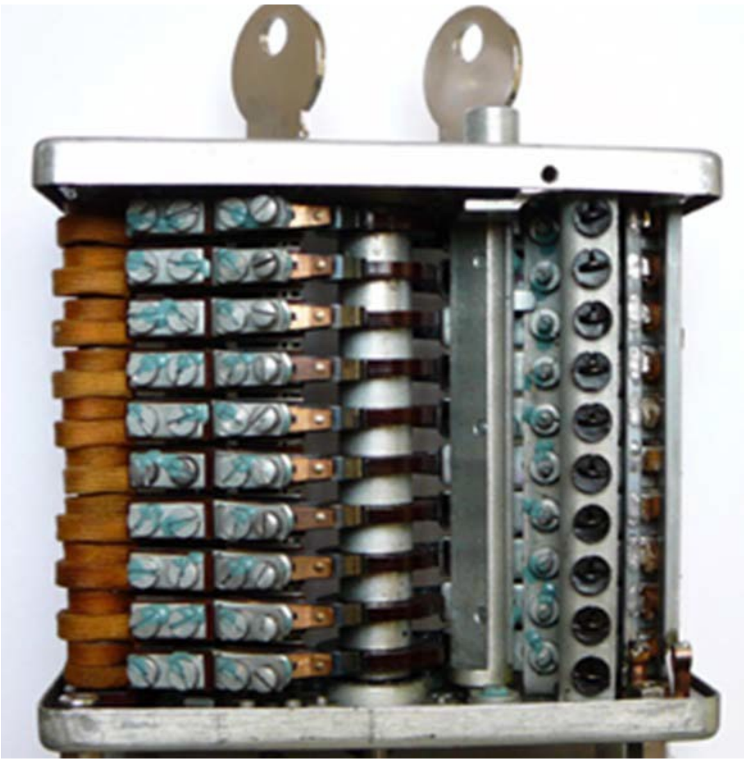
The photography shows the transmitter resonance circuits



Part of the transmitter output is tapped of to a detector which operates a relay that turns on a neon tube on the control unit located in the airplane cockpit, indicating the pilot that he is challenged and is responding. One and the same antenna, a vertical rod, is used as well for receiving and transmitting.

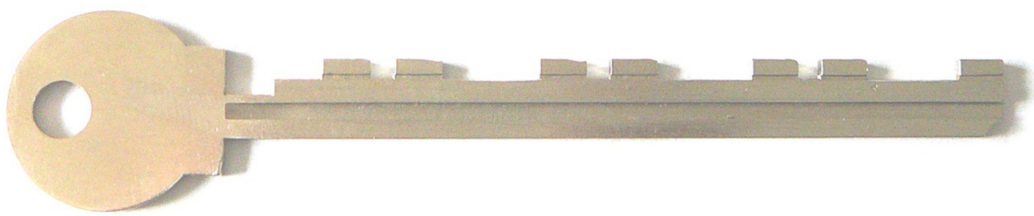
For coding, the plate supply from the limiter stage of the receiver is keyed. This is done in the electro-mechanical code keyer by means of contacts on cams mounted on a shaft driven from the rotary inverter over a gearbox.

The photography shows the open electromechanical code keyer with two code inserted keys.



There are ten cams connected in parallel, each covering an adjacent 30°. Normally the contacts operated by these cams close in rotation, with slight overlap, so that the set would be on for ⅚ of a revolution and off for ⅙. The period of rotation is about one and one - half seconds. The coding is obtained by lifting the contacts off any o the 10 cams, using a key for this purpose.

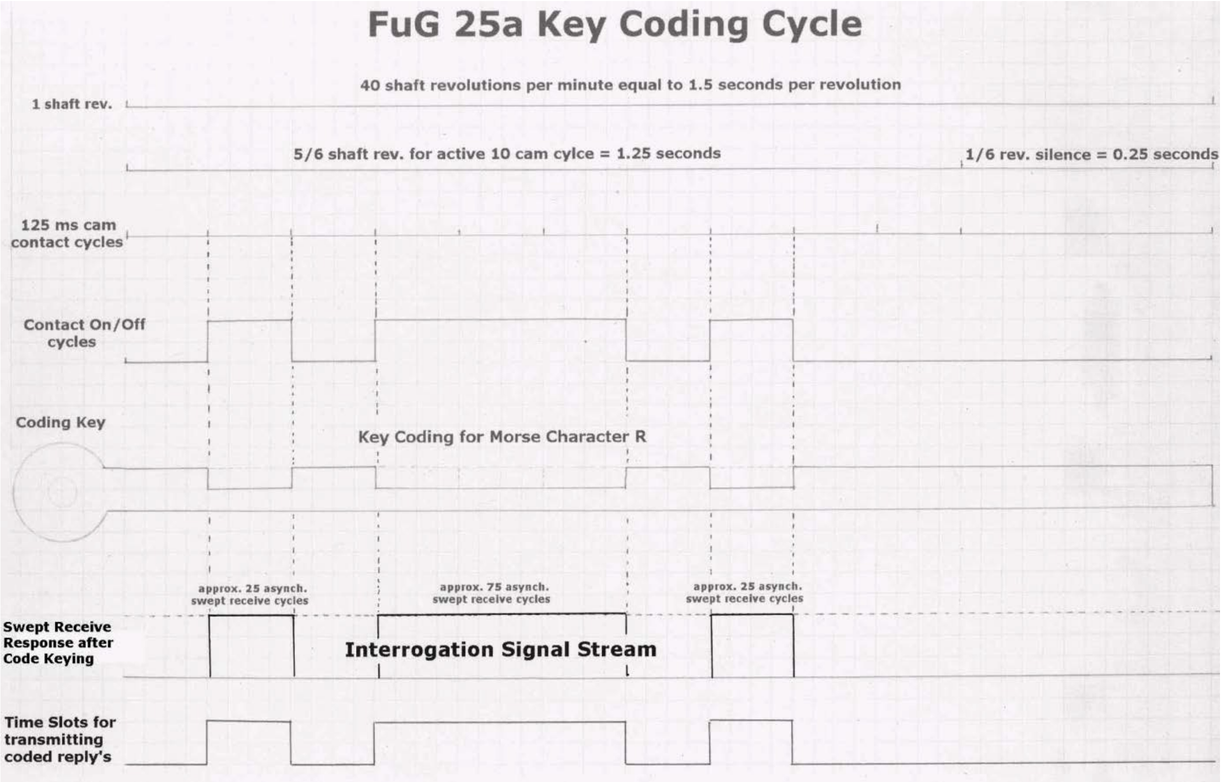
The photography shows a FuG 25a key coded with a Morse recognition signal « S »



The key blank has 10 lands, and some of them are filed off. When the key is inserted and turned, the cams corresponding to the missing lands are disconnected.

The code keys must be inserted into the keyer on the ground before the take – off, it is no access in air for the pilot to the code keys.

The figure below shows the swept receive cycles versus coding cycle of the keyer. The figure shows how the keyer is involved in the transmitter trigger circuitry.



The FuG 25a transmitter is triggered by a combination of swept receive cycles and the key code. Caused by the 500 Hz prf of the Freya radars the FuG 25a transmitter might be triggered up to 25 times during one cam contact cycle of 125 milliseconds. The break – through to the receiver of the transmitted pulse drastically reduces the receiver's sensitivity, which then recovers gradually. It takes about 200 microseconds for the normal sensitivity to be restored. Thus pulses at 8 KHz would have to be 10 dB above the normal minimum input signal in order to trigger off the set 100 %.

For a detailed analysis it is worthwhile to have a look into the part of the circuit diagram shown on the next page how processing of the received interrogation signal was done on the FuG 25a.
The demodulated interrogation pulses are coupled over capacitor C32 to the grid of tube Rö 5. The plate and screen grid voltage of tube Rö 5 is keyed by the code keyer, if a contact is closed the interrogation pulses are coupled over C35 in tube Rö 8. A differentiating of the pulses are caused by the plate to grid feedback, arranged by capacitor C50 and resistor W42, it prevents double triggering of the transmitter. The interrogation pulses are then coupled to the trigger stage of the transmitter, the trigger is generated by tube Rö 9 and pulse transformer U1. The secondary winding is coupled to the grid of the transmitter tube Rö 10. The transmitter tube is normally held inactive by a negative grid bias. If a peak signal of approximately 2.6 volts appears at the grid of the trigger tube Rö 9 the transmitter turns on and generates a rf pulse with a pulse width of approximately 0.3 µs.

Some remarks according the investigation of the FuG 25a equipment.

The investigation was done in fall 2011, the equipment used for this purpose came to Switzerland some 60 years ago with the German Nightfighter JU 88 G-6, C9+AR occasionally its emergency landing on 30th April 1945 at Dubendorf airbase.

The figure shows the nameplate located on the T/R unit of the FuG 25a equipment Occasionally WWII the German war industry used for security reason a coded desig-nation for the companies. The code „bya" was used for the GEMA GmbH located at Berlin – Köpenick.

The modular built subunits were removed from the original housing and baseplate for the investigation, and they were built on test adapters as shown in the photography below.

That measure allows to open the circuits temporary for measurements, stop specific functions as well as get better access to certain components. On the test adapter the code keyer could be operated with variable speed for some specific experiments.

Measurements

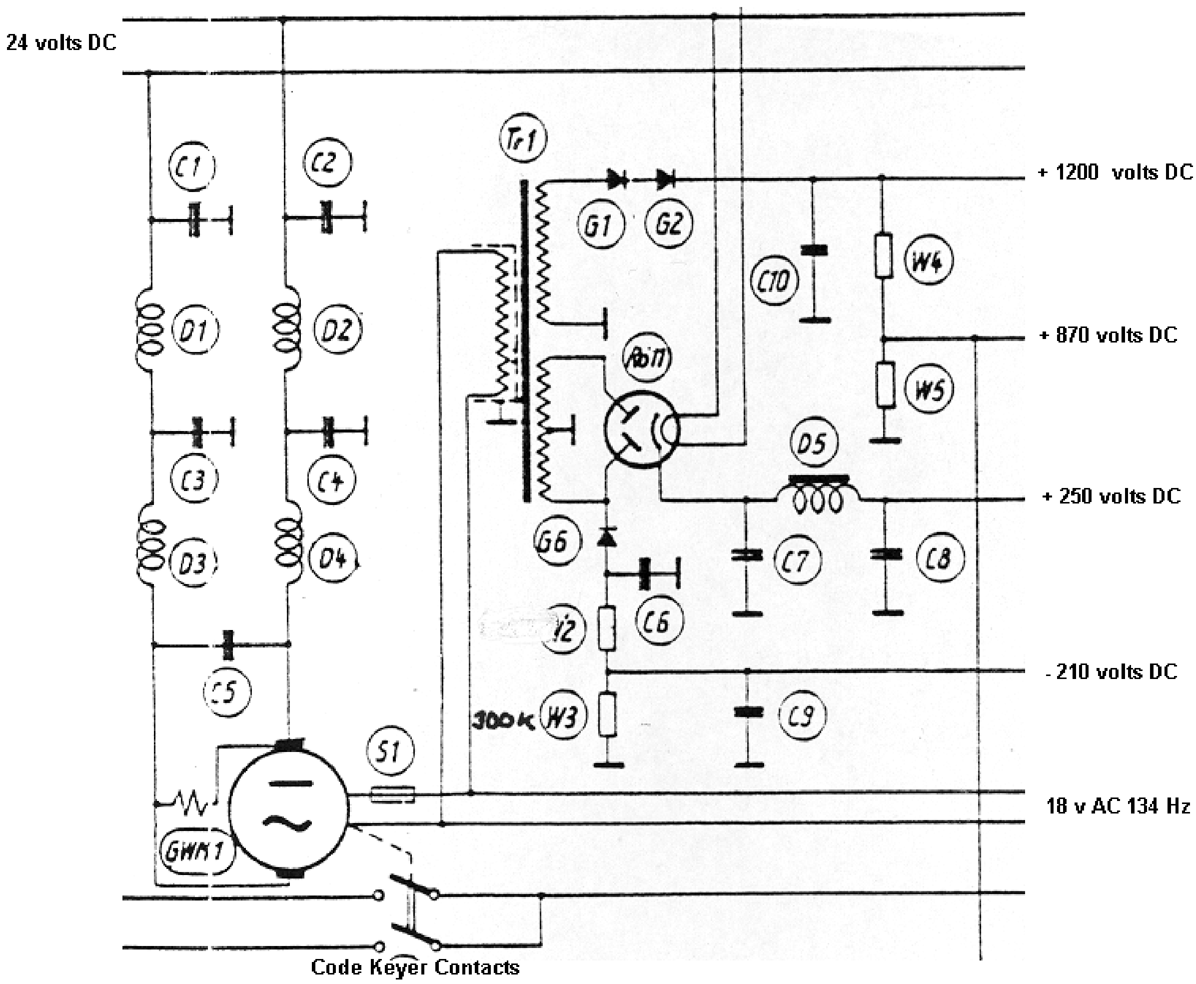
FuG 25a Power Supply

Power Input 24 volts DC, 4 - 5 amps.

Rotary Inverter Output 18 volts AC 134 Hz used as primary voltage for to supply the rectifier, is used also for the motor of the swept capacitor

Rectifier Output 250 volts DC, used as Receiver plate voltage with a current of approx. 30 mA
- 210 volts DC, used as Transmitter grid bias voltage
1200 volts DC, used as Transmitter plate voltage, stored energy 0.072 Joule
(see also the remarks Transmitter Energy Consideration)
860 volts DC, used as Transmitter screen grid voltage

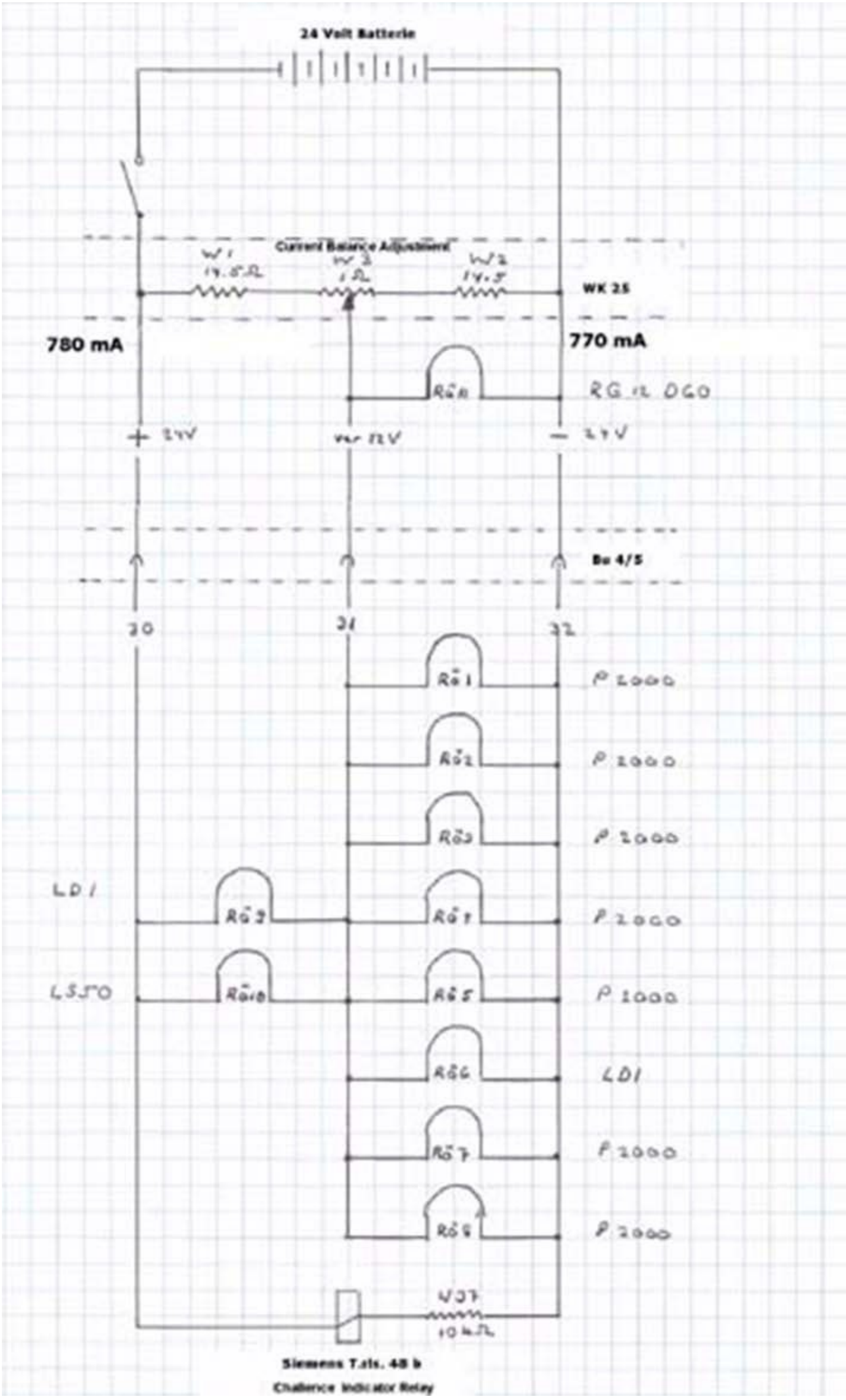
The figure shows the schematic of the FuG 25a power supply



FuG 25a Electron Tube Filament Supply

The FuG 25a transponder contains in total 11 electron tubes (typical German Wehrmachtsröhren) with 12.6 Volts filament, but different current requirements. As mentioned already the filament of the electron tubes are supplied directly from the 24 volt aircraft battery. Although the tube filament supply is not a major task of the investigation it’s interesting to see how the German designer have solved this problem.

The figure shows the FuG 25a electron tube filament supply



FuG 25a Receiver

The noise figure of the receiver is approx. 8 dB mainly determined by the mixer tube and the receiver bandwidth. However, the minimum interrogating pulse signal at the receiver frontend necessary for triggering the transmitter is approx. 250 - 300 µV at the 60 ohms input impedance equal to approximately - 88 dBw, as measured on T/R unit with Werk - Nr. 927'167

FuG 25a Transmitter

The rf pulse peak power of the transmitter was approx. 200 – 300 watts (depends from the condition of the LS 50 transmitter tube) the pulse length was approx. 0.3 µs.

The delay between the leading edge of the interrogating pulse und triggering of the transmitter was 3 – 6 µs depending from the level of the interrogating pulse signal.

Transmitter Energy Consideration

Dependent on the parameter of the intercept receiver the prf of the FuG 25a transmitter is limited to 200 Hz for any interrogation with rf pulses on a constant spot frequency as transmitted by the Freya radar.

The transmitter duty cycle is therefore very low just in the order of 0.3µs/5ms = 0.00006

For an rf output peak power of 300 watts with a typical transmitter plate voltage of 1200 volts a peak current of 0.54 amps was measured. The required DC pulse power was 650 watts, and the DC energy per pulse is equal 0.0022 Joules. The measurements of the transmitter average plate current have shown values of approx. 35 µa. The 1200 volts storage capacitor in the power supply stores for the transmitter an energy of 0. 072 Joules and it is reloaded at a 134 Hz cycle.
Trials have shown that the 1200 volts source could be loaded up to 1 ma. It results a DC/RF transmitter efficiency in the order 46%. At a prf of 200 Hz the average rf power is approximately 18 milliwatts for a rf peak power of 300 watts.

Conclusion

Certainly at the time of design was the FuG 25a a very skillful combination of an electronic and electromechanical device. Beside the identification capability the almost perfect time coherency between interrogation and response makes the equipment unique for range measurement applications. The conversion in the power supply from DC to 134 Hz AC enables a very compact design as well as a hidden reserve for the 1200 volts transmitter HV supply for later upgrades.
After all the inactive years was the FuG 25a occasionally the investigation still in an excellent mechanical and electrical condition. The only necessary maintenance before operation was cleaning out the ball bearings of the rotary inverter and the worm - gear and provide them with new grease. It seems that nevertheless the war, the equipment was built with the highest quality parts available at the time.

References

Summary Report No. F-SU-1109-ND, The High-Frequency War, A Survey of German Electronic Development 10 May 1946

Report 411-95 Survey of German Radar from the Countermeasures Point of View Office of Scientific R&D National Defense Research Committee 4 September 1944

Radar News No. 19 British Air Ministry Translation: Funkmess - Nachrichten No. 19 des Oberkommados der Luftwaffe Generalnachrichtenführer Nr. 40 164/45 g. Kdos. Ln.Isp. 6 Abt. IA 25 Februar 1945

Directory of German Radar Equipment, US War Department, Technical Manual TM E11-219, 15 March 1944

Bordfunkgerät FuG 25a, Geräte Handbuch, Der Reichsminister der Luftfahrt und Oberbefehlshaber der Luftwaffe Technisches Amt GL/C-E4 Berlin 18. Januar 1943

Fritz Trenkle, Die deutschen Funkführungsverfahren bis 1945, ISBN 3-7785-1647-7