GERMAN WWII FuG 25a Erstling target identification transponder

The need for an electronic means of the target identification for use with the Freya and Würzburg radars had been recognized in Germany as early as 1938. Several early transponders were developed with limited success for use with the Freya and Würzburg radars. By 1941 the deficiencies in performance provided by the early systems lead to the development oft the target identification tranponder FuG 25a Erstling.
A FuG 25a Erstling prototype was designed on late 1941 by the GEMA company for interrogation by the Freya medium- and long - range ground radar operating on frequencies round 125 MHz. Consequently it was laid out for ranges up to 100 miles and beyond.

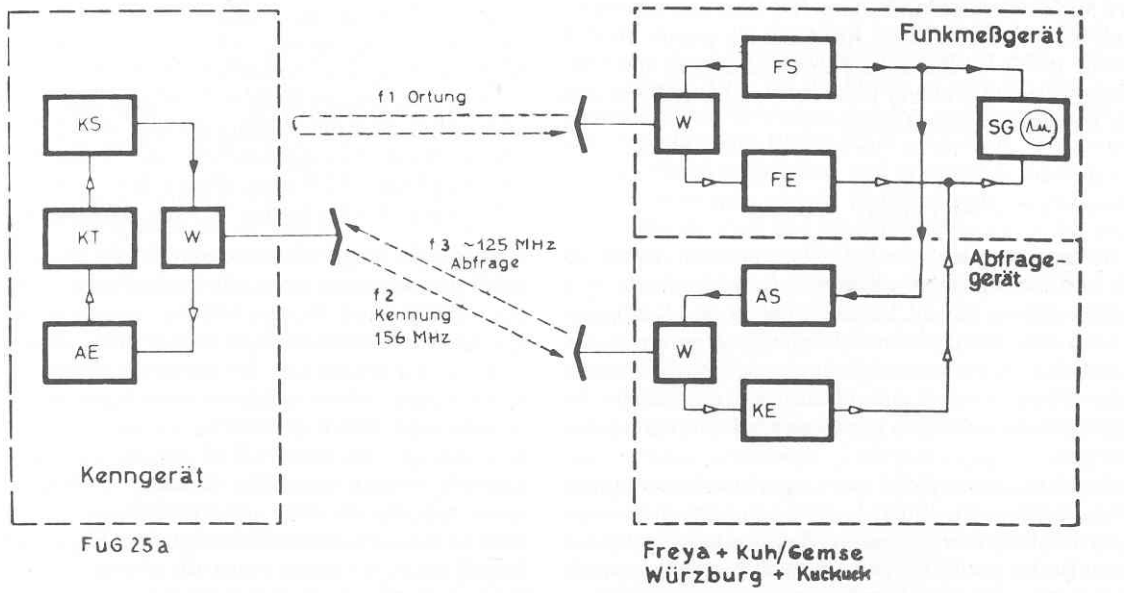
The figure below shows the system configuration of an airborne FuG 25a Erstling identification transponder interrogated by a Freya or Würzburg ground radar.

Airborne Transponder

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

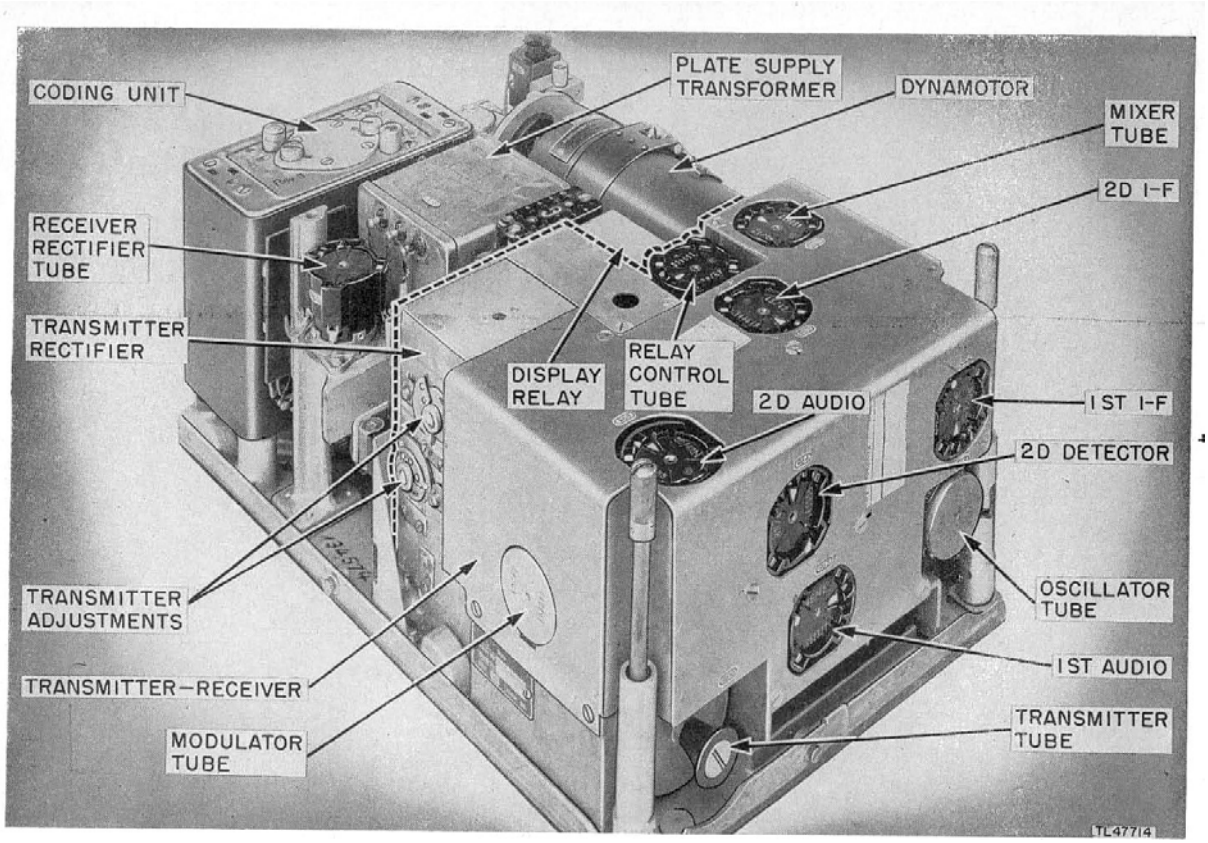
Ground Interrogator

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

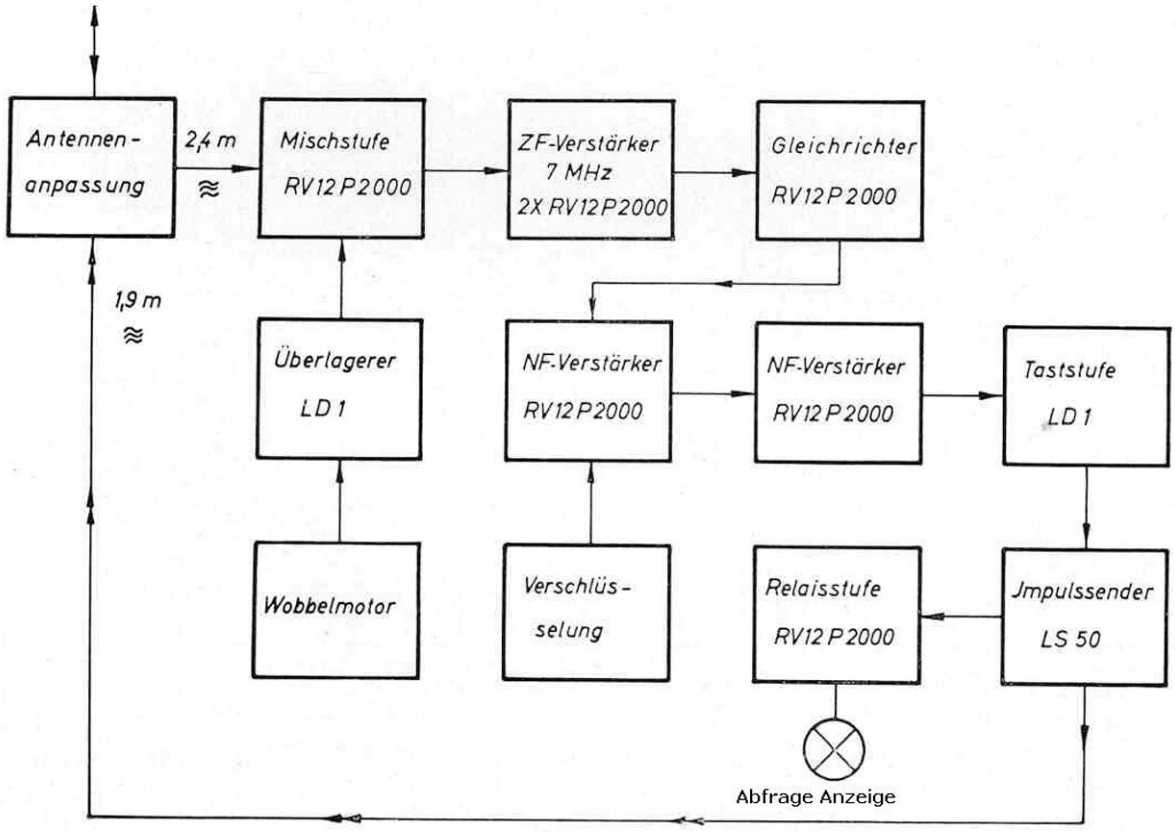


While its primary use was for identification purposes with the Freya radar it could also be used together with radars operating on other frequency bands, however for that purpose the 125 MHz interrogation transmitter « KUH » was necesssary. Later in WWII the FuG 25a was also employed as bombing – release controller as well as for ground to air communication (Order Transmitter Apparatus).
The FuG 25a airborne transponder consist of three sections: 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 electro-mechanical code keyer, over 1000 codes are possible .
The power supply consists of an 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 filter group into the supply voltages for the transmitter – receiver section. The filament of the electron tubes are supplied directly from the 24 volt aircraft battery.

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

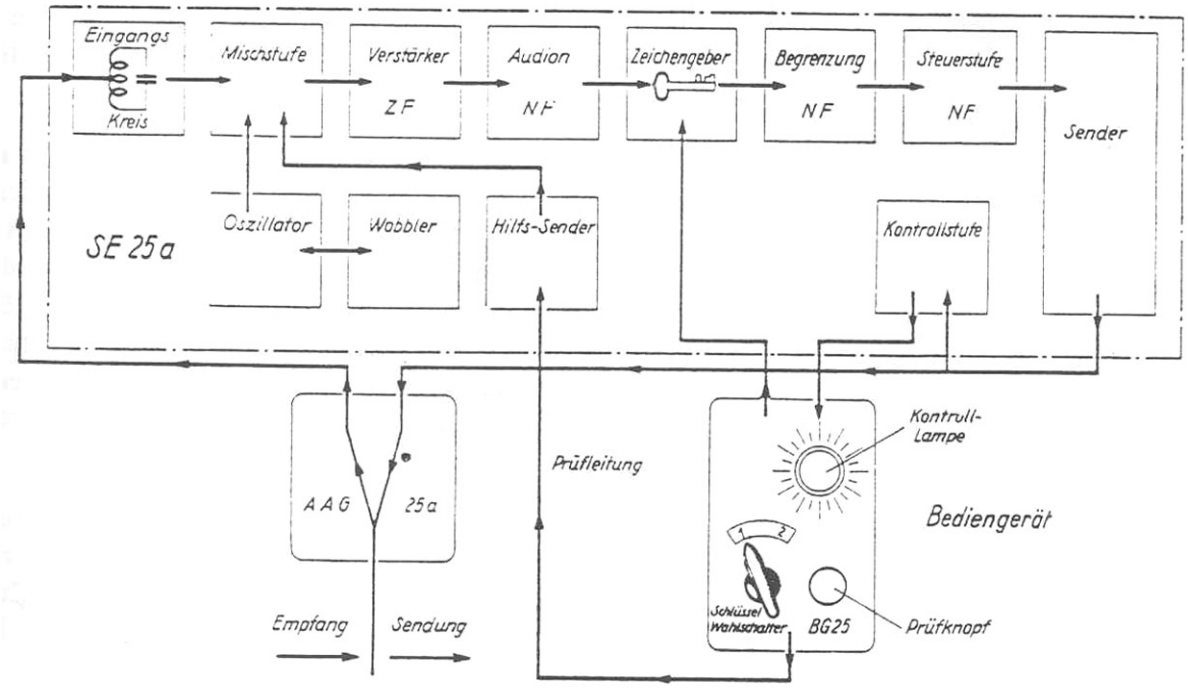


The figure shows a Bloc Diagram of the FuG 25a airborne transponder.

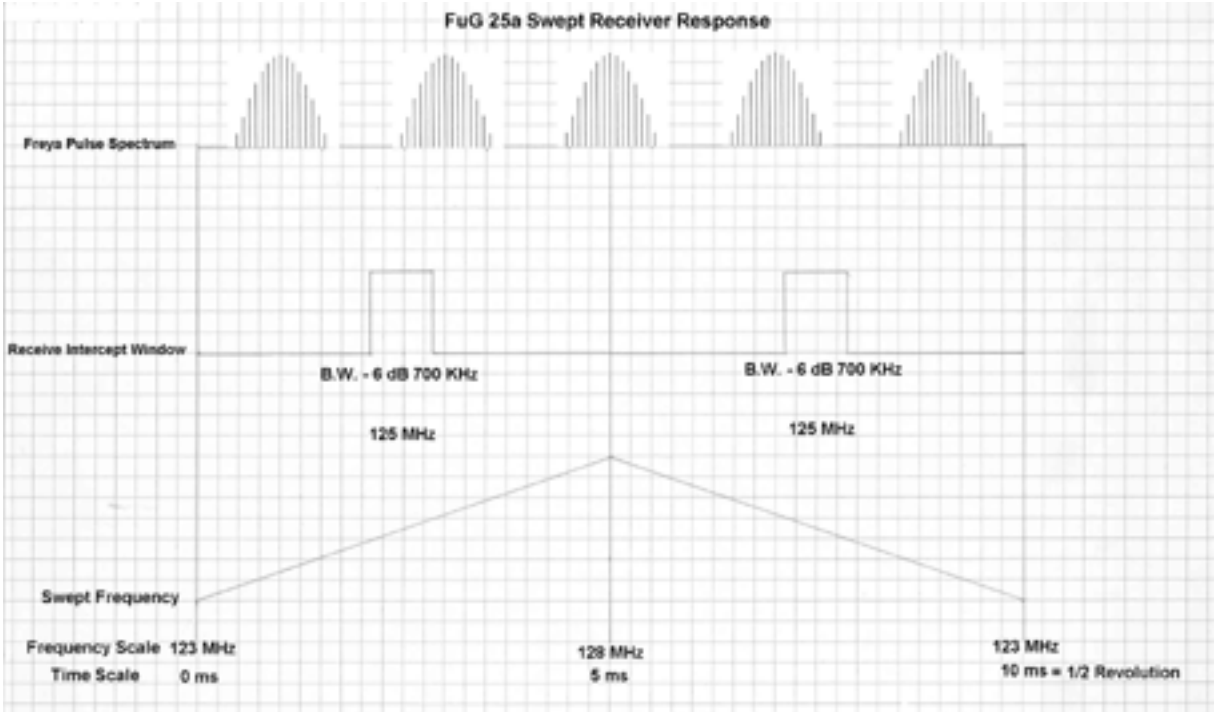


The receiver is an eight tube superheterodyne type that swept (Wobbeln in German) over the band 123 – 128 MHz at 200 Hz by a motor turning at 3000 rpm a variable differential capacitor in the local oscillator (Ueberlagerer) circuit.
The front end consists of a mixer stage, a local oscillator operating 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 triggerstage 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



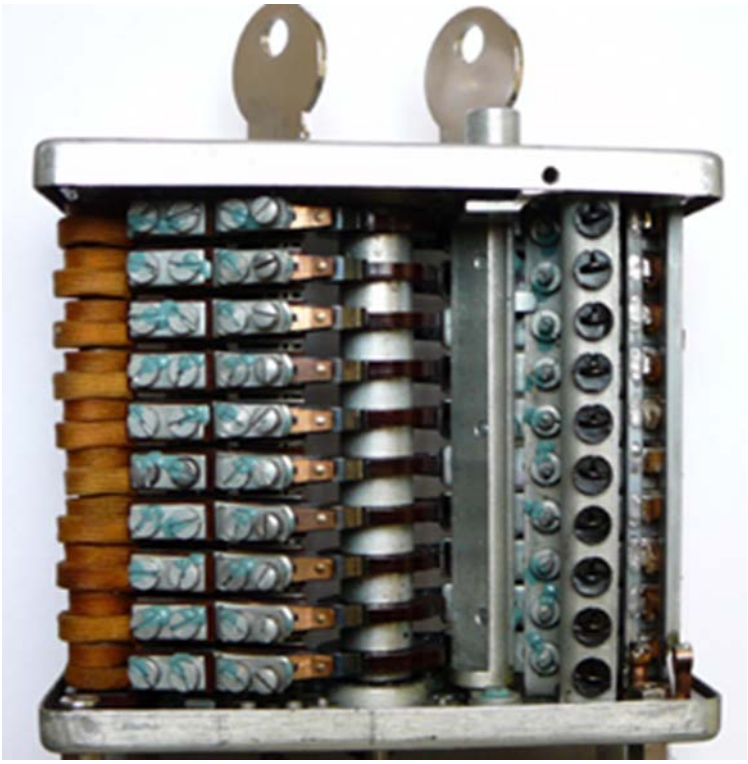
The figure shows that during one revolution of the variable differential capacitor the receive frequency sweps 4 times over the frequency band within a time interval of 20 milliseconds. As for instance the Freya pulses radiated with a prf of 500 Hz equal a time interval of 2 ms are intercepted by the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

The 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 radars's prf (Freya 500 Hz) and the receiver's FM rate. When the two are in step, so that a radar pulse arrives whenever the receiver is sensitive to the radar's frequency, the transmitter gives 200 pulses per second. The pulse length is 0.3 microseconds. 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 %.

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 for receing and transmitting.

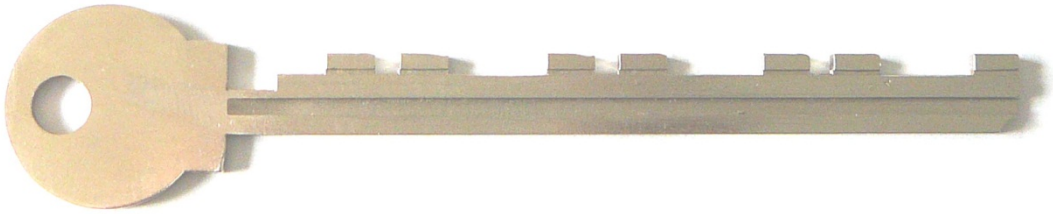
For coding, the plate supply from the limiter stage of the receiver is keyed. This is done in the electromechanical code keyer by means of contacts on cams mounted on a shaft driven from the rotary inverter over a gearbox.

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



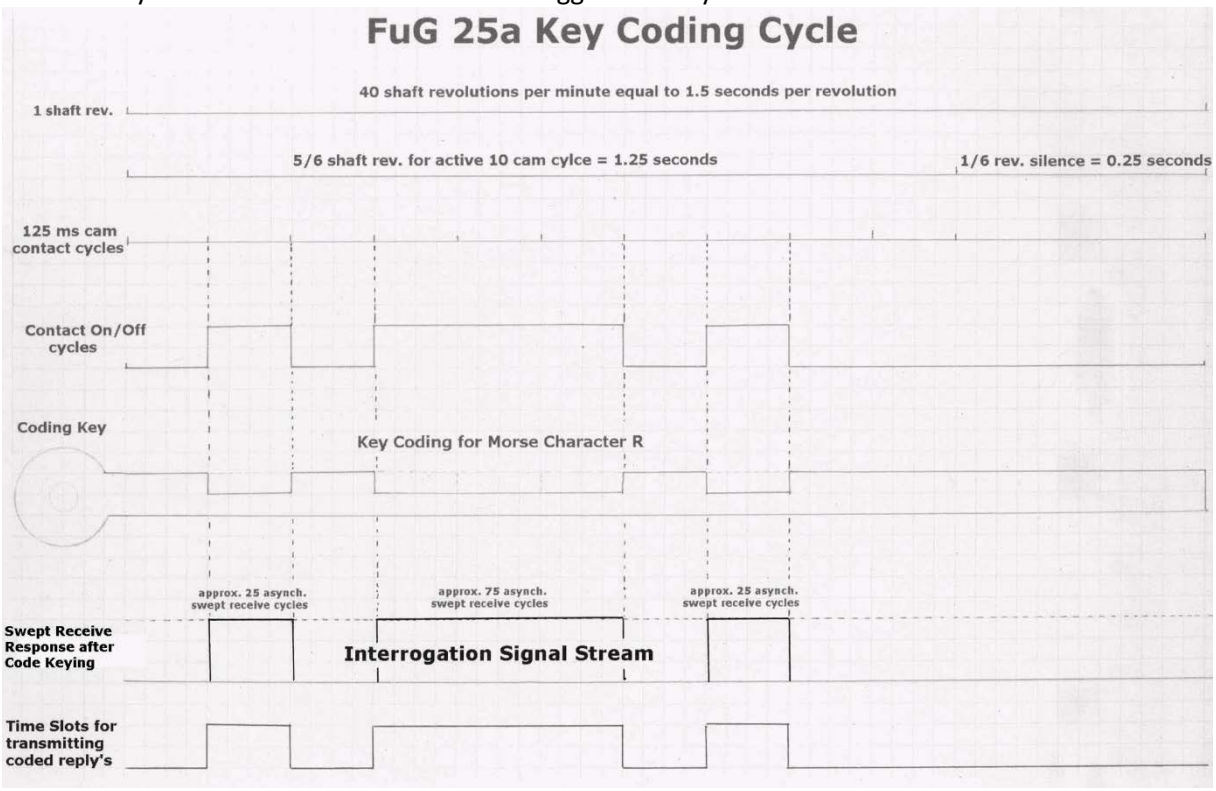
There are ten cams connected in parallel, each covering an adjacent 30°. Normally the contacts operated by these cams close in rotation, with slight overlap, so that the set would be on for ⅝ of a revolution and off for ⅛. The period of rotation is about one and one - half seconds. The coding is obtained 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 reckognition signal « S »



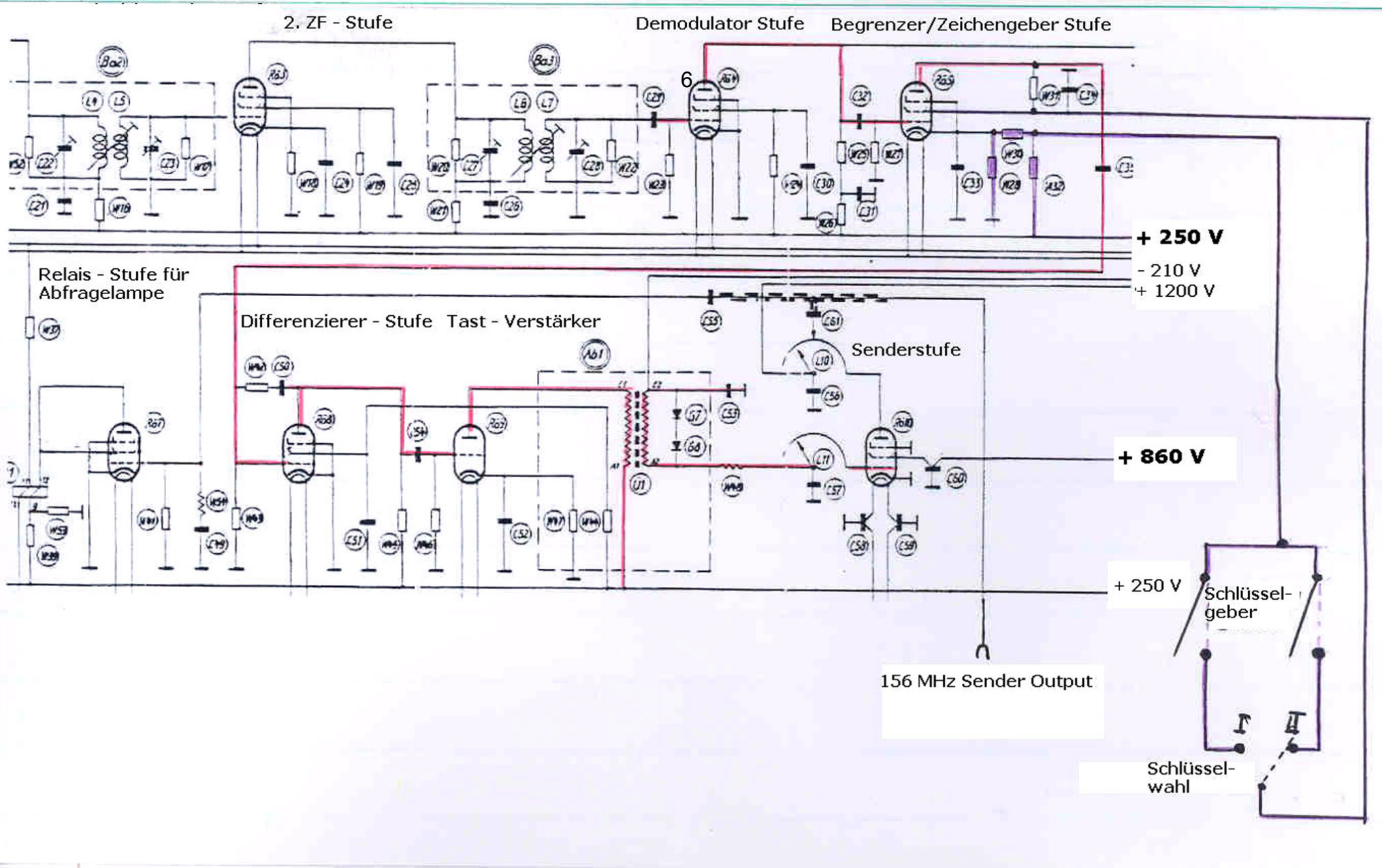
The key blank has 10 lands, and some of them are filed off. When the key is inserted and turned, the cams corresponding to the missing lands are disconnected.
The code keys must be inserted into the keyer on the ground before the take – off, it is no access in air for the pilot to the code keys.

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 triggred 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 migth be triggered up to 25 times during one cam contact cycle of 125 milliseconds.

For a detailled analysis its 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.


2. ZF - Stufe
Demodulator Stufe
Begrenzer/Zeichengeber Stufe
6
+ 250 V
- 210 V
+ 1200 V
Relais - Stufe für Abfragelampe
Differenzierer - Stufe
Tast - Verstärker
Senderstufe
+ 860 V
+ 250 V
Schlüssel-geber
156 MHz Sender Output
Schlüssel-wahl

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

The investigation was done in fall 2009, 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

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

This measure allowed to open the circuits temporarly 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 specific experiments.

Measurements

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 0.72 Joule (see also the remarks Transmitter Energy Consideration)
860 volts DC, used as Transmitter screen grid voltage

Receiver

The minimum interrogating pulse signal at the receiver frontend for triggering the transmitter was approx. 250 - 300 µV as measured on T/R unit with Werk - Nr. 927'167

Transmitter

The rf pulse peak power of the transmitter was approx. 200 – 300 watts (depending from the condition of LS 50 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 – 7 µs depending from the level of 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 like 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 the 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 equal 0.0022 Joules. The measurements of the transmitter average plate current have shown values of approx. 35 µa. (Although 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 an electromechanical device. Beside the identification capability the almost perfect time coherency between interrogation and response makes the equipment also 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 for operation was cleaning out the ball bearings of the rotary inverter and worm - gear and provide them with new grease. It seems nevertheless the war, the equipment was built with the highest quality parts available at the time.

Schwerzenbach (Switzerland) 26th November 2011, by Hans H. Jucker