German FuG 202 / FuG 220 Lichtenstein airborne radars

by Hans H. Jucker, Schwerzenbach, Switzerland

Nachtjäger Messerschmitt Bf 110, 2Z + OP 6

Interception Radar: Lichtenstein FuG 202
Weapon: 4 x MG Cal. 7.8mm, 2 x MK151, Cal. 20 mm

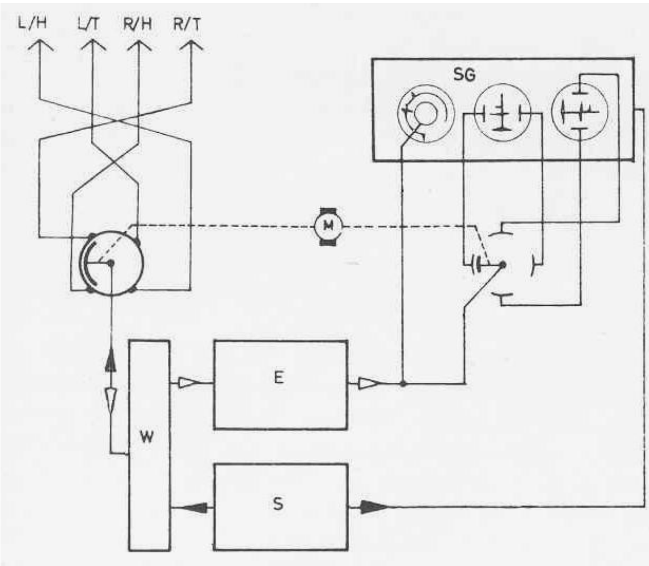
Landing on 15th March 1944 at Dubendorf Airbase (Switzerland)

Crew: Pilot Oberfeldwebel Helmut Treynogga
Radiooperator Unteroffizier Heinz Schwarz

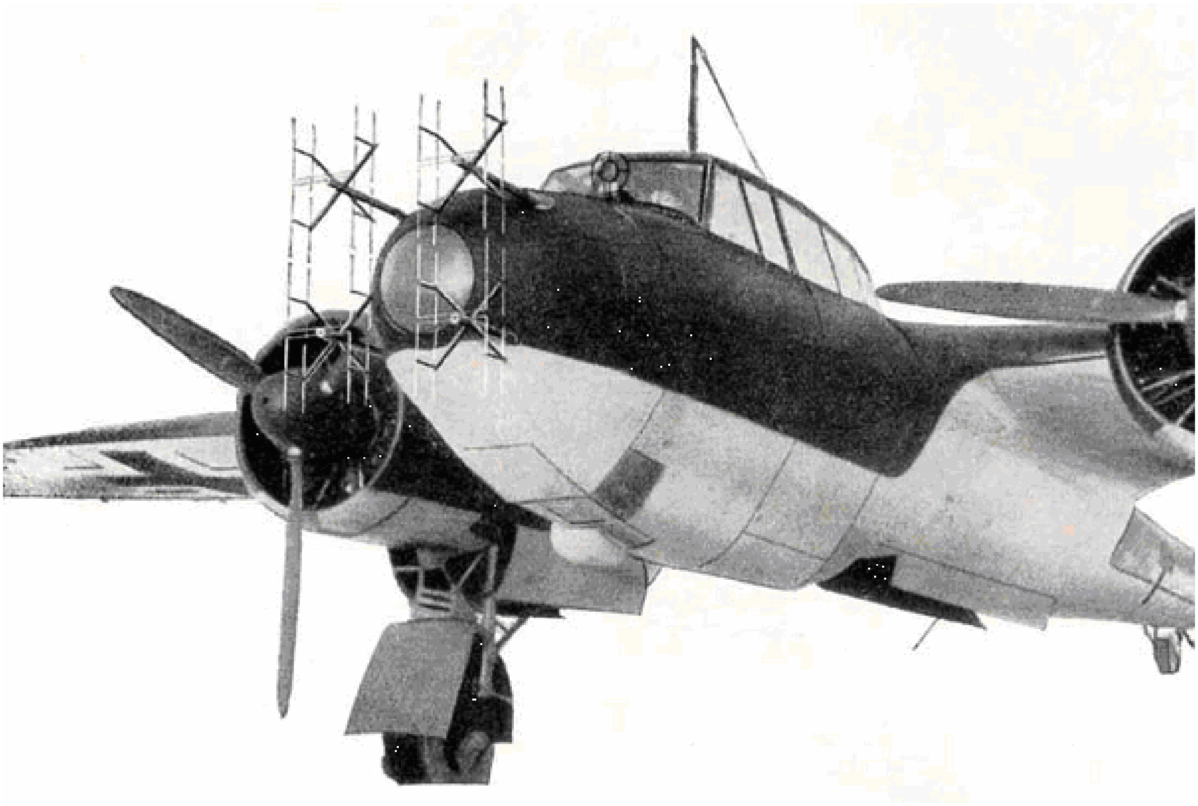
On the night of 15th March 1944 a German Night Fighter crew defected to Switzerland with an Messerschmitt 110G. They approached intact with an operating Lichtenstein FuG202 interception radar at Dubendorf airbase. (see photography of the airplane after the landing). According to the authentic landing report, the ME 110 had taken off from Echterdingen in order to attack a British bomber formation approaching Munich. The crew told they have lost its bearing due to radio failure.

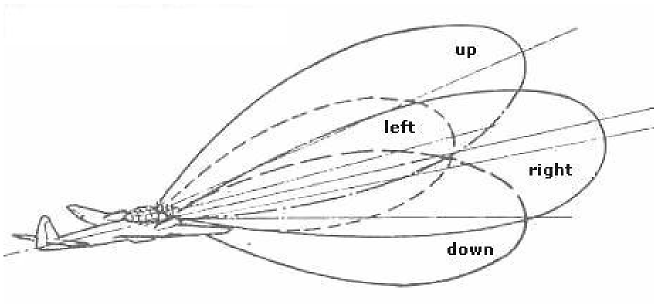
The purpose of this paper is to show the result of investigations and conclusions on the German Lichtenstein FuG202 and FuG220 night fighter radars.

The Lichtenstein FuG202 radar equipment combines a relatively narrow cone of search, around ±20°, with high sensitivity to change in direction of the target (e.g. 1.4:1 in pip size at 5° off axis), so it is well suited to assist a fighter to keep on the tail of a bomber taking evasive action, once the fighter has get approximately on an overtaking course. The greatest practical range of the set is approximately 2.5 km; the minimum range is very short around 150 meters. The range is limited by the height only up to 1000 m. Above this height targets are visible beyond the ground clutter.

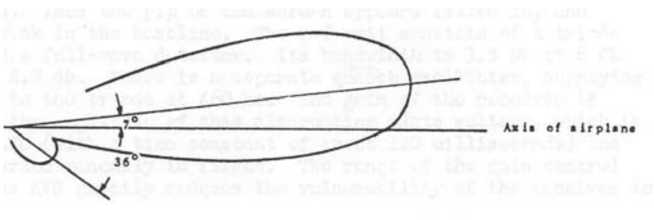


The Lichtenstein FuG202 equipment consist of transmitter S, receiver E, T/R unit W, multi-element direction finding antenna array, motor driven antenna switch and indicator unit SG. The pulse modulated radar operates on 50cm wavelength, the instrumented range is 8 km but the maximum range on a large bomber is approx. 4 km. The antenna array consists of sixteen end-fed half-wave dipoles with sixteen reflectors connected in four sets each of four dipoles with reflectors. A switching device feeds the antenna sections in varying phase to swing the antenna polar diagram left, right up and down. The indicator has three CRT's, one has a circular time base and the other two have normal straight traces, horizontal and vertical respectively





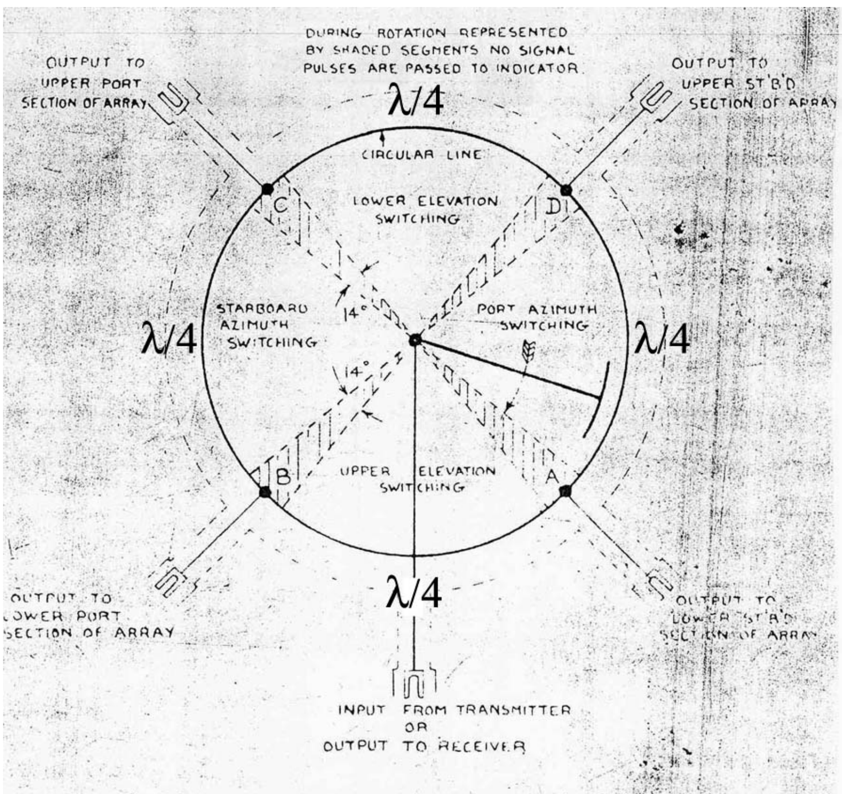
In the switching unit the relative phases in which the four antenna sections are fed are varied. In this way, the beam is rotated in a split angle of ± 7° about the axis of the airplane. The split rate is 25 Hz. The cross - over point is only 1.1 dB (77% down from the maximum. At the same time, the angular sensitivity is very good out to 25° from the axis of the airplane. The antenna gain is 14 dB.



All four sections are used at once, giving a beam 25° wide (one half power) with the direction of maximum gain 7° off the axis of the airplane. There is one appreciable side lobe, pointing 35° to the other side of the axis. Its maximum is 8-10 dB down relative to the maximum of the main lobe.

Lichtenstein FuG202, Aerial Switch Functional Description

The figure shows the schematic diagram of the aerial phasing switch. This is essentially a circular line, with feeders to the four array sections tapped off at equal intervals. The capacity feed point from the transmitter moves continuously round this circular line. With the feed point moving between A and B the upper elevation diagram is obtained, the beam being inclined upwards at the greatest angle when the feed point is midway between A an B. The two lower array sections are then in phase, and the two upper sections in phase with each other, but with a phase delay relative to the lower ones. The other diagram for elevation Direction Finding and these for azimuth, are obtained in a similar way, the beam being inclined towards that section with the greatest phase delay.
The output switching is arranged so that no signals are passed to the plates of CR display tubes during an angular rotation of ± 7° about each of the points A, B, C, D.



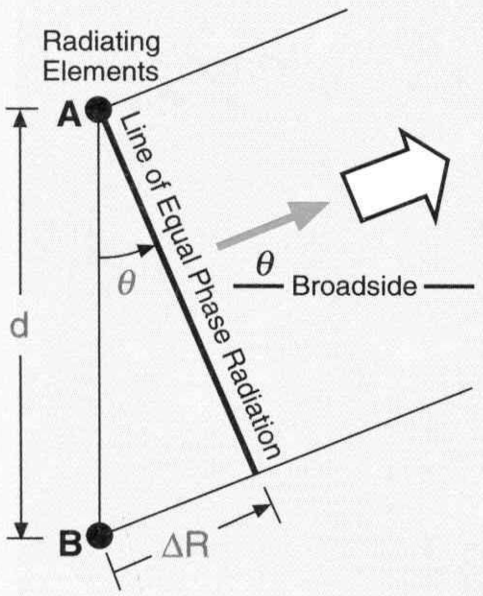
SCHEMATIC DIAGRAM OF AERIAL SWITCHING UNIT

The four antennas were internally (galvanic) interconnected by means of a concentric brass-ring. A tap was provided every λ/¼ (please bear in mind figure 1). Which equals each time 90° signal phase-shift (consequently, the ring perimeter is 4 x λ/¼ = 61 cm). The antennas were interconnected in such a manner, that the signal phase between antenna groups was always 180°, as to obtain split-beam operation.
A special shaped ceramic disc (*sichelförmige Scheibe*) (one side deposited with Ag or Cu), provided a revolving capacitance, coupling capacitive the fixed brass-ring with the central in/output of the radar signal, creating a revolving phase-shifter in all quadrants (*elektrisches Drehfeld auf dem Messingring*). They accomplished, that the transmitted signal was always available at all time at all four antennas. Though, the beam forming was owing to the revolving ceramic capacitance (creating a revolving phase-shifting delay-line). The four mechanical switches for azimuth and elevation on the right of the beam forming antenna selector, guaranteed that only the appropriate signals were shown on the bearing displays. It is evident, that the inner dimension of the antenna-group selector (*de facto* the brass-ring perimeter), made frequency change hardly possible.

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

PHASE SHIFT NEEDED TO STEER THE BEAM

To steer the beam θ degrees off broadside, the phase of the excitation for element **B** must lead that for element **A** by the phase lag, $\Delta\phi$, that is incurred in traveling the distance, ΔR, from radiator **B**.



In traveling one wavelength (λ) a wave incurs a phase lag of 2π radians. So, in traveling the distance ΔR, it incurs a phase lag of

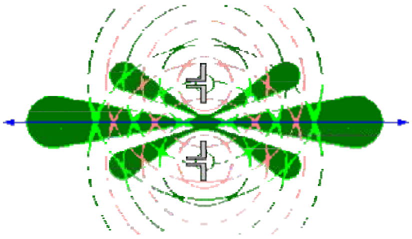
$$2\pi \frac{\Delta R}{\lambda} \text{ radians}$$

As can be seen from the diagram,

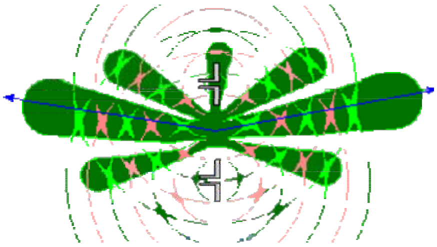
$$\Delta R = d \sin\theta$$

Hence, the element-to-element phase difference needed to steer the beam θ radians off broadside is

$$\Delta\phi = 2\pi \frac{d \sin\theta}{\lambda}$$



Radiation Pattern if Element A and B are in phase



Radiation Pattern if phase of Element B leads approx. 10° against phase of Element A

Note: The two radiator elements A and B (either dipole or dipole arrays fed in phase) are shown without the reflectors.

Some additional remarks according the Lichtenstein FuG202

The first technique used for angle tracking of targets by radar was to sense the target location with respect to the antenna axis by rapidly switching the antenna beam from one side of the antenna axis to the other.

The German Lichtenstein BC airborne intercept radar for instance used an array of 16 radiating elements arranged on the nose of aircraft normal to the line of flight. They could be switched in phase by sections of four elements to provide four beam positions (left – right for azimuth and up – down for elevation) for the lobbing operation.

The radar operator observed two oscilloscopes (one for azimuth and one for elevation) that displayed side by side the video returns from the four beam positions. When the target was on axis, the two pulses on both oscilloscopes were of equal amplitude, if the target moved off axis, the two pulses became unequal.
The radar operator, observing the existence of an error and its direction, could tell the pilot to steer the airplane to regain a balance between the beam positions. This provided a manual tracking loop.

The continuous beam scanning was accomplished by a mechanical operated phase shifter with a rate of approx. 25 Hz. See the explanation for beam steering by phase shifting on the previous page.

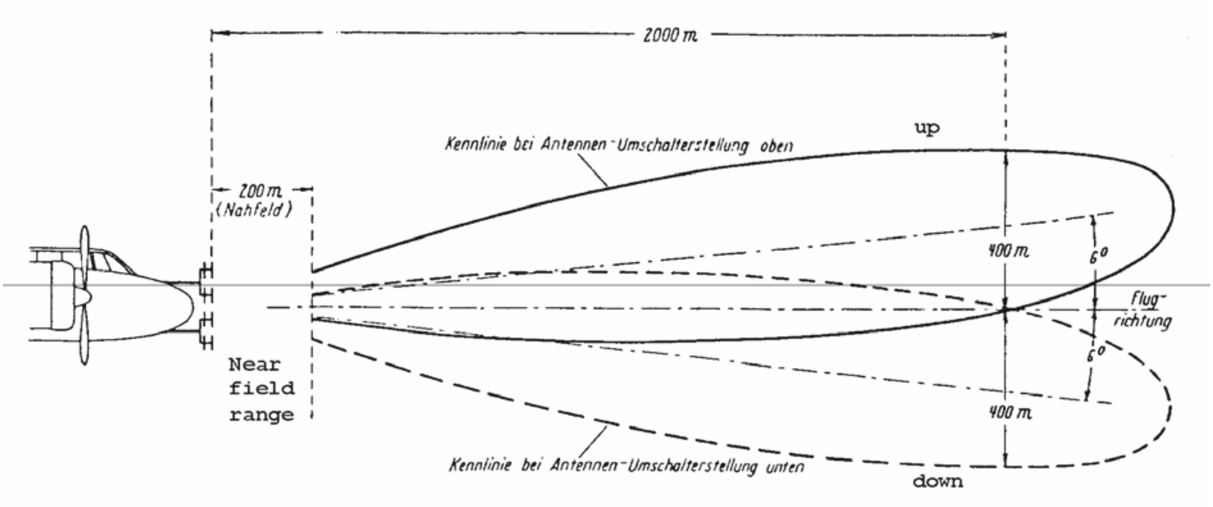
The shortcoming of the early beamscanning tracking radars was the time fluctuation of the echo signal amplitude. Other sources of echo-signal-amplitude fluctuations such as target scintillation had caused false indications of tracking error too.

The undesired fluctuations that cause difficulty occur at about the same rate as the scan rate. Since target scintillation energy of air-craft in concentrated in the lower frequency range below approx. 100 Hz (particularly the troublesome propeller modulation), it would be desirable to increase the scan rate as high as possible. The maxi-mum practical rate is one fourth of the pulse repetition frequency so that four pulses provide a complete scan with one each up, down, right and left.
High scan rates are difficult to achieve with mechanical scanning de-vices, so a variety of techniques to scan electronically were used in later years.

However, the susceptibility of scanning and lobbing techniques to echo amplitude fluctuations was the major reason for developing a tracking technique that provides simultaneously all the necessary lobes for angle- error sensing. The output from the lobes may be com-pared simultaneously on a single pulse, eliminating any effect of time change of the echo amplitude.This technique was initially called simul-taneous lobbing – later so in the sixties the term **monopulse** came in use for it.

* The Original German manual D.(Luft) T.g.Kdos. 4103 provides the fol-lowing principle description of the capacitive antenna selector:

Infolge der Ankopplung der Dipolanordnung an den Sender über den rotierenden kapazitiven Umschalter werden ständig alle vier Dipolanordnung-en erregt, jedoch mit unterschiedlicher, stets wechselnder Phase. Dadurch ergibt sich das in der Zeichnung dargestellte Richtdiagramm der Antenne, das sich im Takt der Umschalterdrehzahl um die Achsrichtung (Flugrichtung) dreht.



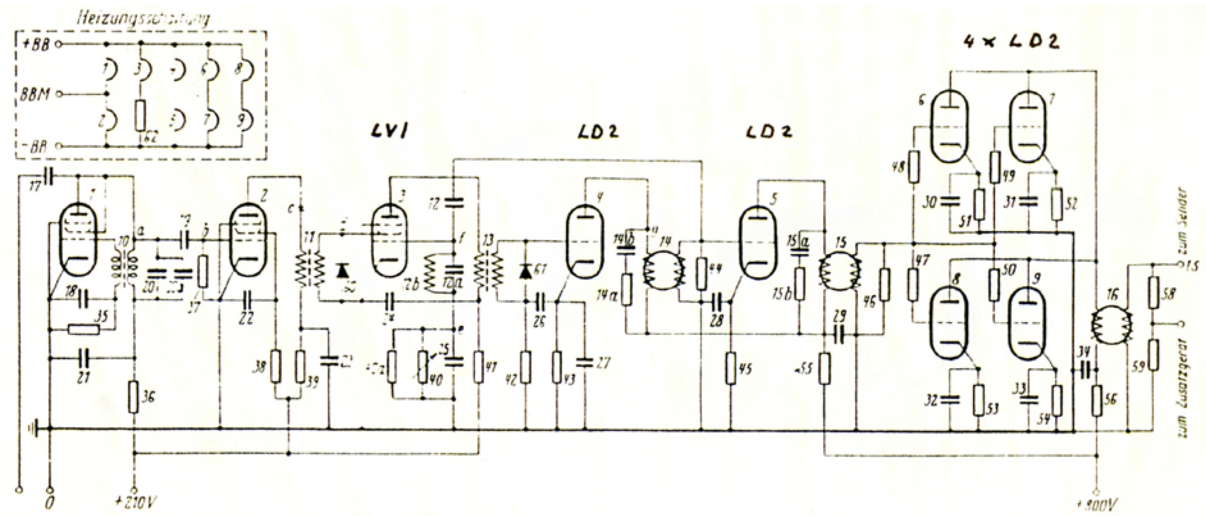
Kennlinie der Richtantennen

Die Hauptstrahlrichtung dieses Diagramms weicht von der Achsrichtung um etwa 6° ab; seine Halbwertbreite beträgt ungefähr 17,5°. Die mecha- nische Abmessungen des Umschalters sind so gewählt, daß an zwei gegenüberliegenden Anschlußpunkten die Spannungen stets gegenphasig sind. Der Antennenschalter stellt im Prinzip einen kapazitiven Phasenschieber dar, dessen fester Beleg ein Messingring und dessen drehbarer Beleg eine diesen umschließende sichelförmige Scheibe ist. An dem Messingring sind, um 90° gegeneinander versetzt, die Anschlüsse für die zu den vier Dipolanordnungen angebracht.

FuG 202 Transmitter Unit

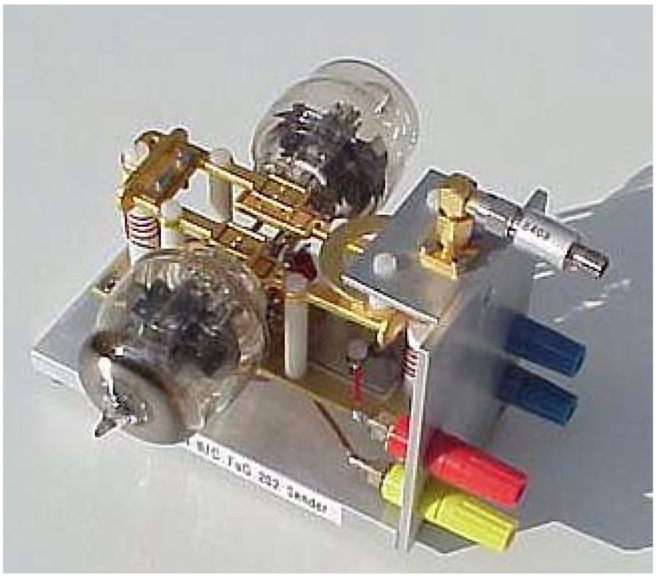
The transmitter operates on a frequency of 490 MHz. Two RS 394 triodes are used in an anode modulated push pull oscillator. The anode voltage supply consists of one microsecond pulses from the separate modulator unit. The normal pulse repetition frequency is approximately 2700 Hz and the peak modulator power is 2 kW.

Circuit Diagram of the separate FuG 202 Modulator



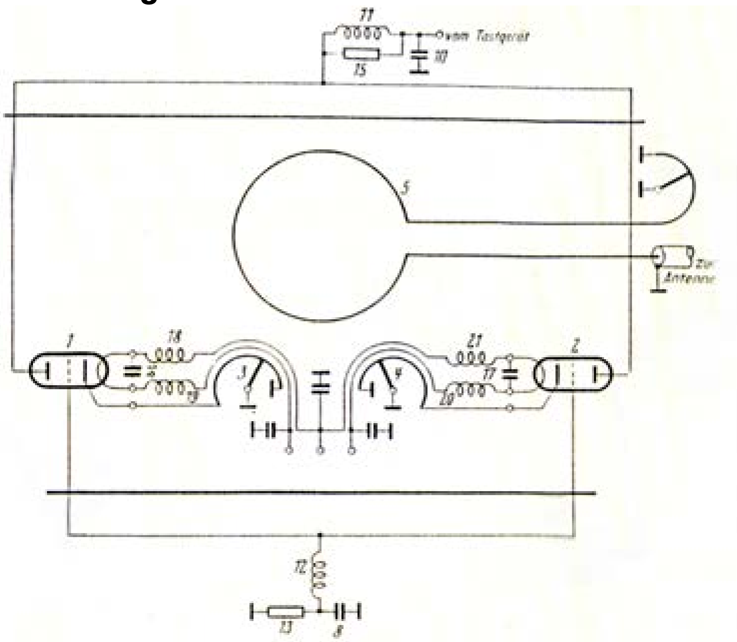
The tube 1 of the modulator is the master oscillator, its actual frequency of 19 kHz can be varied by either 0.5 or 1% by the switch mounted on the baseplate. The output is fed to tube 2 which is cut off except 8 µs at the peak of each oscillator cycle. The secondary of transformer 11 has a metal rectifier connected across this damps out the negative half cycles. Tube 3 and 4 together form a frequency dividing by 7 : 1 and pulse sharpening. A positive output pulse of approximately 2700 Hz is applied every seventh master oscillator cycle to Tube 5 that serves to amplify this pulse. Its output is then applied to the four parallel output tubes. The output of the tubes 6, 7, 8 and 9 is fed to the pulse transformer 16. The output of this transformer is a 1µs pulse of 2000 volts peak amplitude and a peak current of 0.9 amps.

The pulse transformers 14, 15 and 16 of the modulator are toroidally wound on a core consisting oft thin metal strip wound to give a hollow cylinder as shown on the photo on the left.



Transmitter operates on a frequency of approx. 490 MHz it generates a rf output peak power of approx. 1 kW at a prf of 2700 Hz. Two RS394 triodes are used in the anode modulated push- pull oscillator. Tuned anode and grid lines (see photo of the laboratory replica) with the original RF circuitry) are used and cathode tuning is also provided. The antenna coupling loop feeds the RF power over the T/R unit into the antenna. The high voltage supply consists of 1 µs pulses from the separate modulator unit. The modulator pulse is approx. 2000 volts and the modulator power is 4 kW. The repetition frequency of 2700 Hz is obtained by dividing down from a 19 kHz master timing oscillator which drives all the timing circuits in the FuG202 equipment.

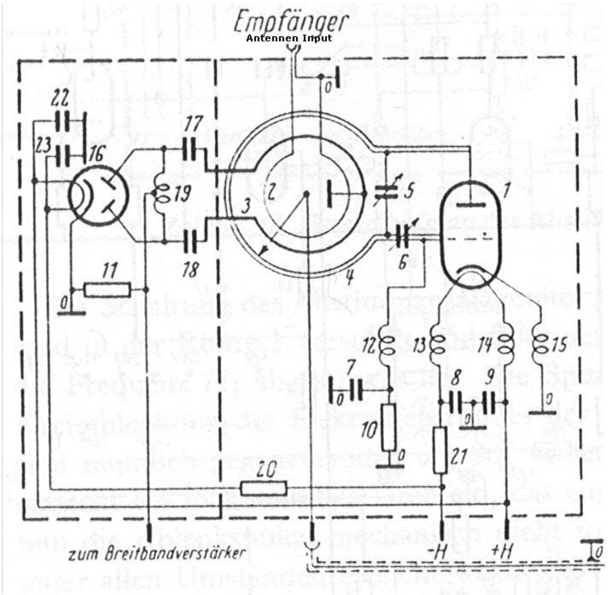
Circuit Diagram of the FuG 202 Transmitter



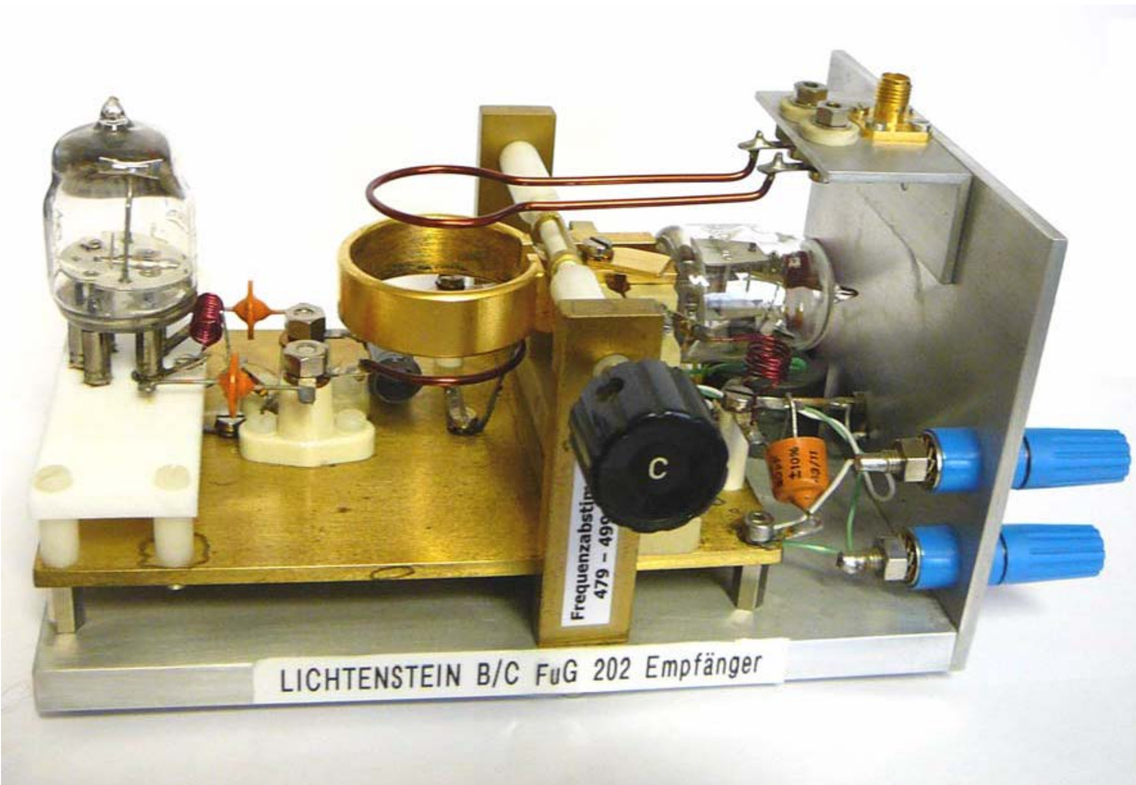
FuG 202 Receiver Unit

The Lichtenstein FuG202 is unique among German radars in its use of a **s**uperregenerative receiver. The receiver consists of three units, an R.F. unit, a quench generator and a video amplifier, the latter including an automatic gain stabilisation (a.g.s.) circuit. The sensitivity of the receiver is approximately -80 dBm (30µV at 70 ohm's for signal plus noise equal to twice noise) and the bandwidth is 3.5 MHz at 6 dB down. The receiver is tunable from 479 to 499 MHz. The R.F. unit consists of a triode oscillator and a double diode detector. The plate supply to the triode consists of cycles of the quench voltage at a frequency of 454 KHz, without a steady D.C. component. The magnitude of the applied quench voltage is varied by the setting of the gain control and by the automatic gain control system. Full wave detection is used, the detector output being fed to the video amplifier. The voltage gain from the antenna input to the detector output is approximately 160 (44dB) under average operating conditions, but depends on the setting of the gain control. The receiver can be tuned in flight by the operator, with the variable capacitor 5. The dial of the tuning capacitor is divided in 20 steps.

Circuit of the FuG 202 superregenerative receiver unit

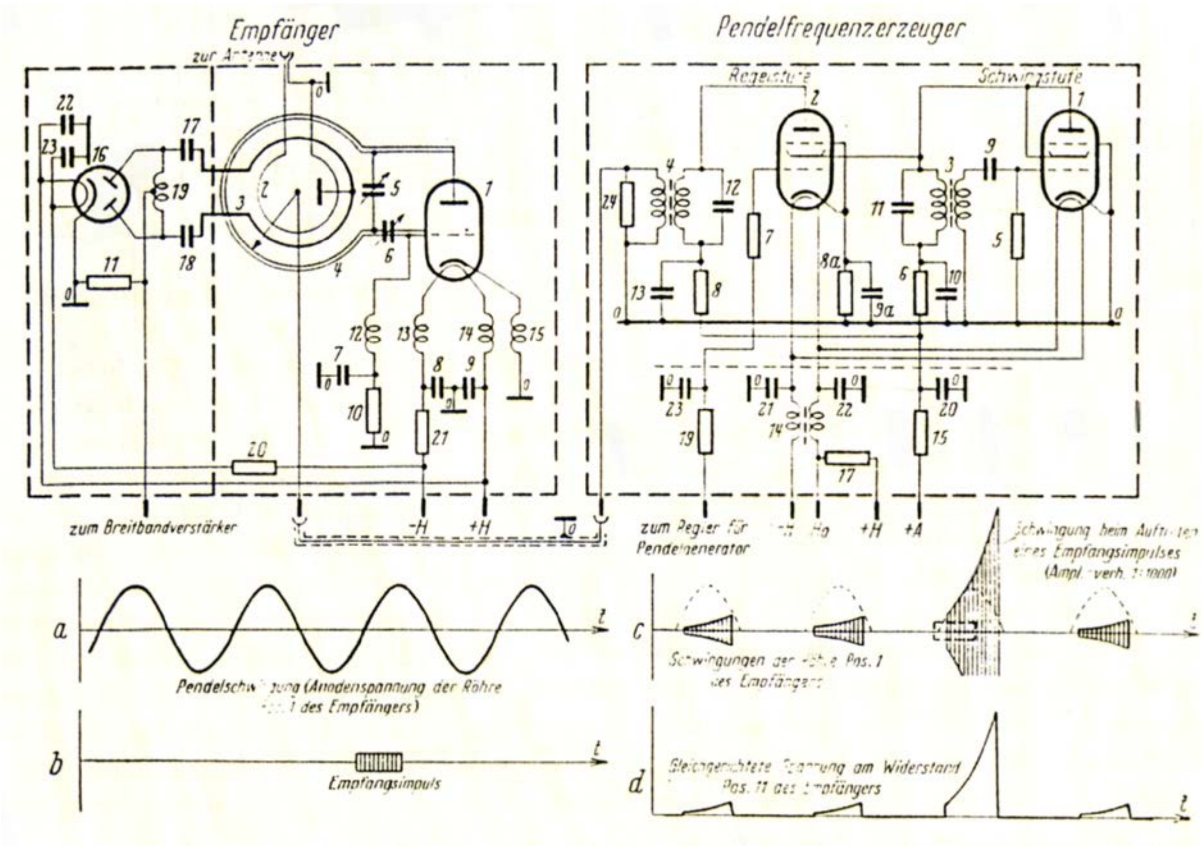


The output of the detector is fed to the broad band amplifier having 5 stages. Its bandwidth is 3.5 MHz at 6 MHz down, the overall voltage gain is 4000 times (72 dB) at 100 kHz falling to 2000 (66 dB) at 500 kHz. The broad band amplifier also contains the automatic gain stabilisation circuit. This circuit provides a negative voltage which is applied to the quench generator to control the quench amplitude applied to the superregenerative detector and thus control the gain of the detector.

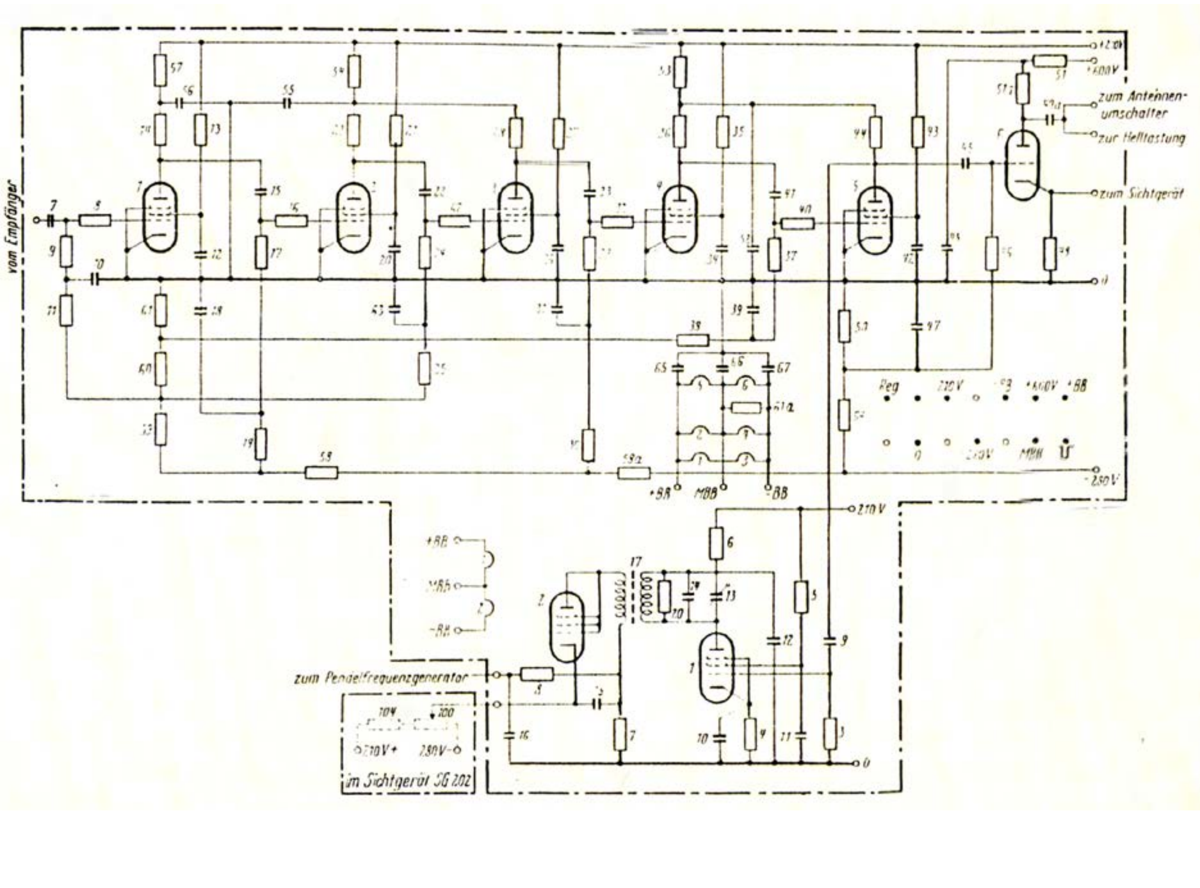


The quench oscillator consists of an oscillator operating at 454 kHz, whose output is fed to the a.g.s. control stage. The broad band amplifier output is fed to the other input of the a.g.s. control stage. The output of the a.g.s. control stage supplies a variable quench voltage of 1 - 40 volts as plate voltage to the triode oscillator of the R.F. unit. The time constant of the whole a.g.s. system is about 120 ms, the range of the gain control 60 dB. The a.g.s. system greatly reduces the vulner- ability of the receiver to jamming. The video output of the broad band amplifier for any kind of input signals consists of 0.2 µs pulses at the quench rate of 454 kHz. Thus the pip on the screen appears filling in, and there is no break in the baseline.

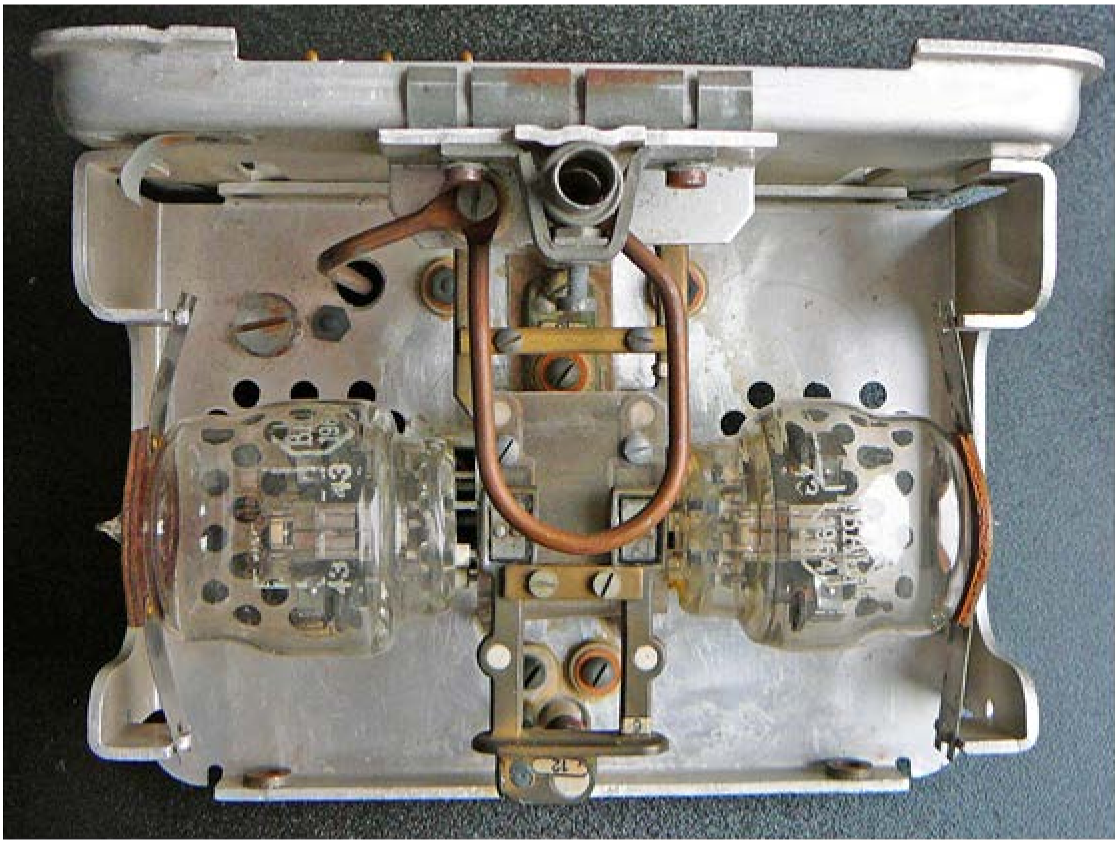
Circuit Diagram of the FuG 202 Receiver and Quench Generator



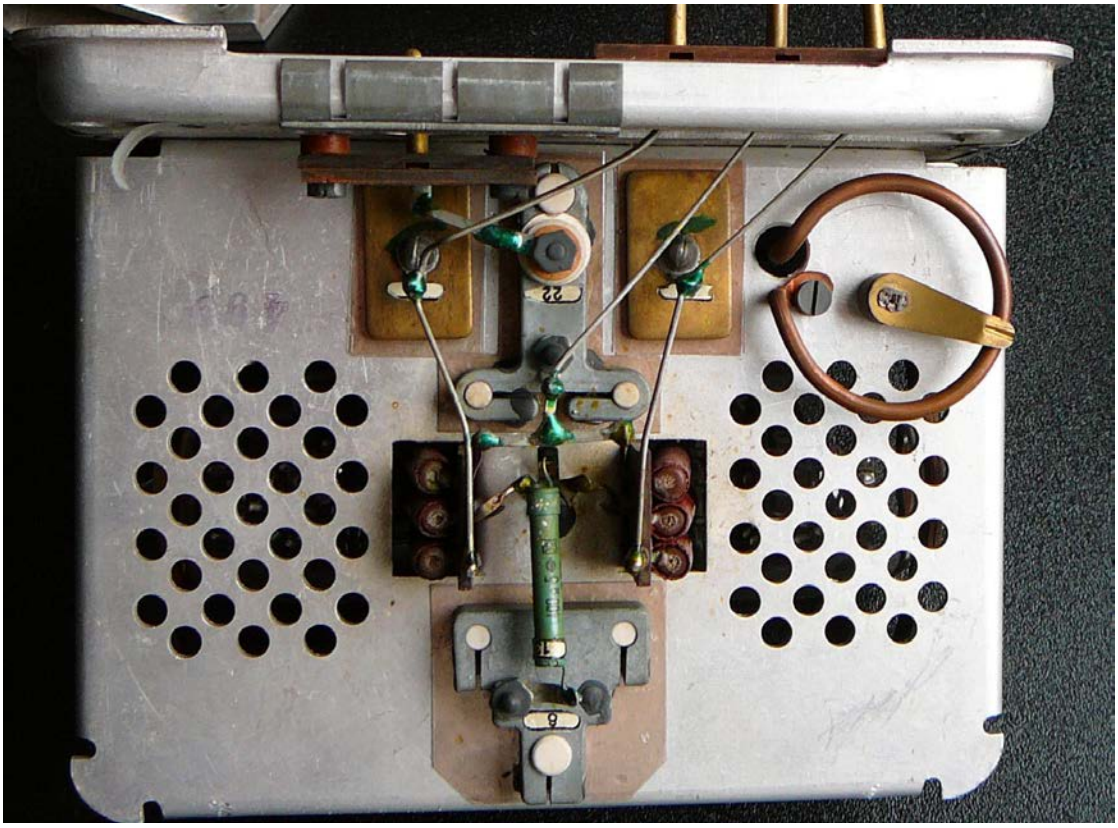
Circuit Diagram of the FuG 202 Video Amplifier



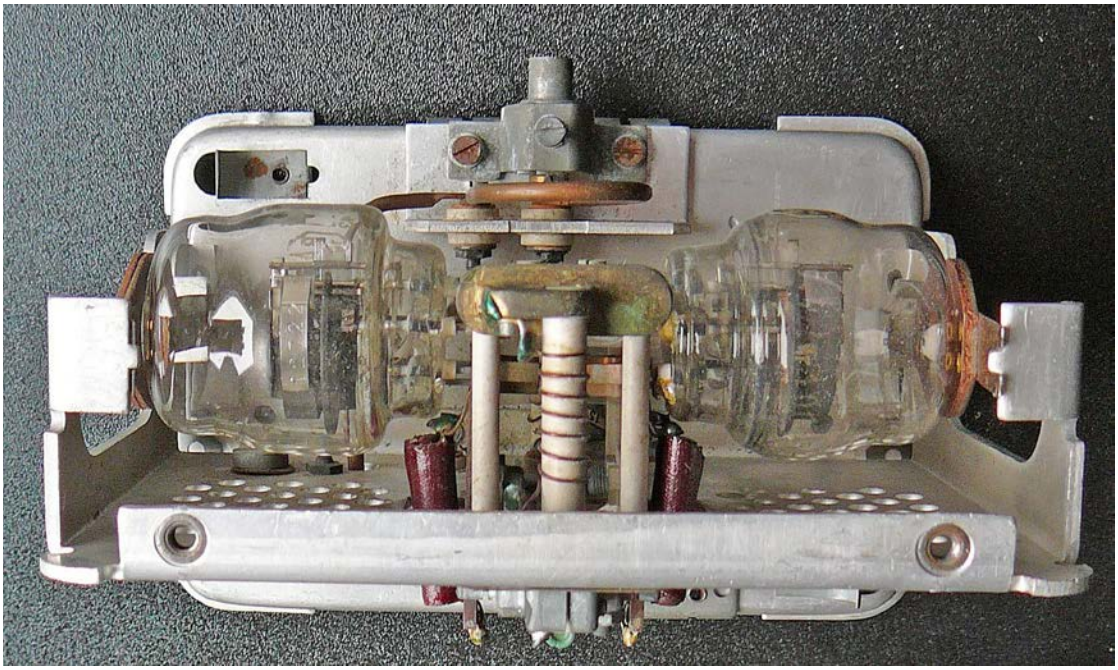
Original FuG 202 Transmitter (View from the side)



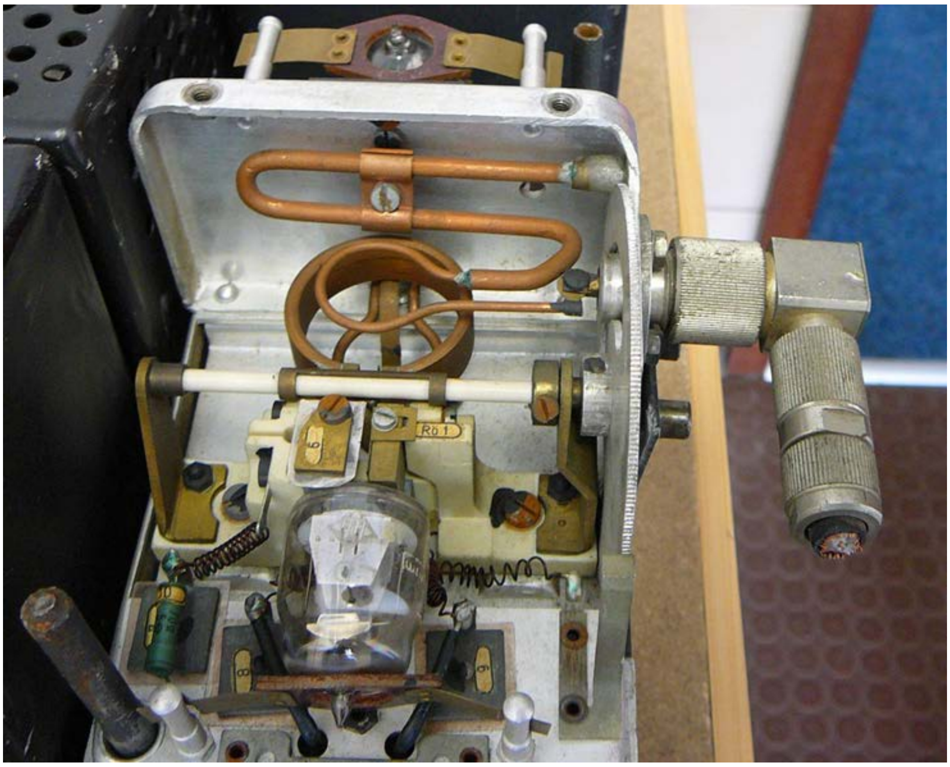
Original FuG 202 Transmitter (View from the backside)



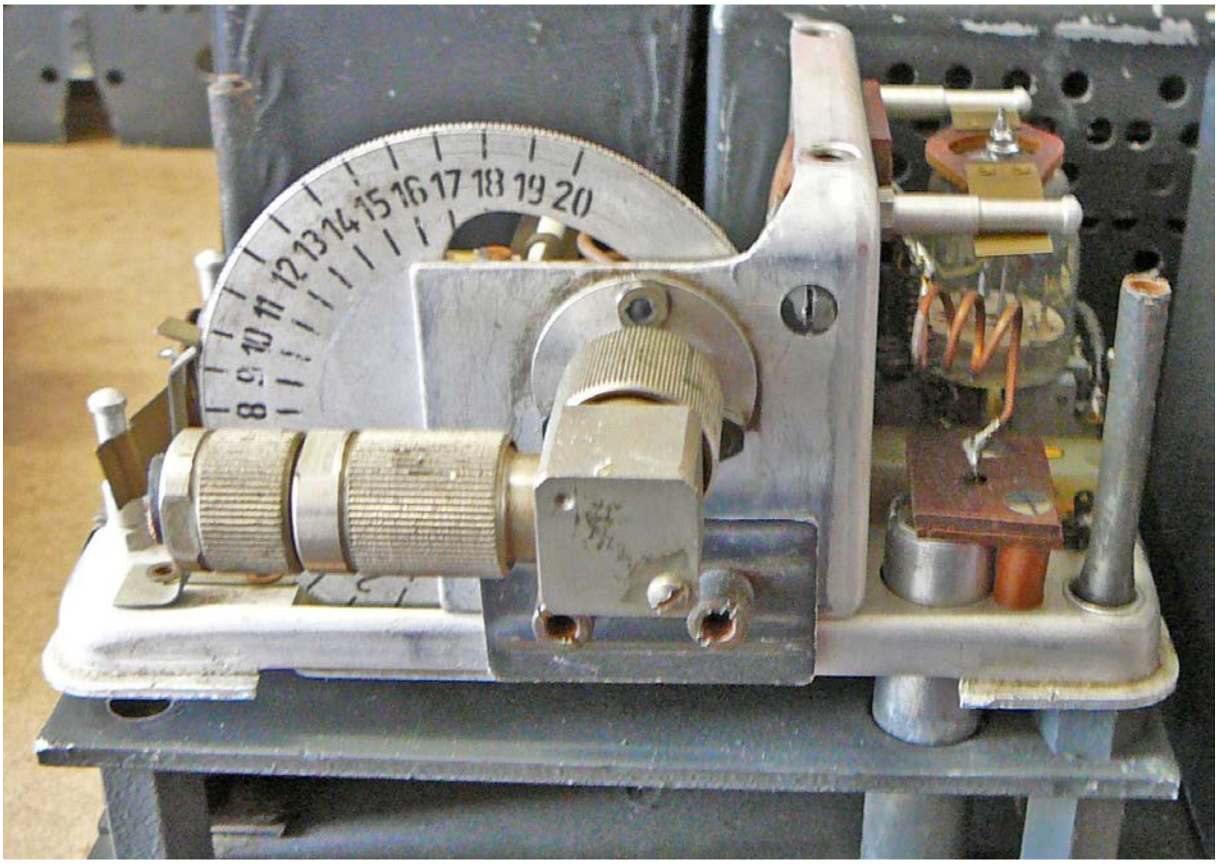
Original German Lichtenstein FuG 202 Transmitter (Top View)



Original German FuG 202 Lichtenstein Receiver (Top View)

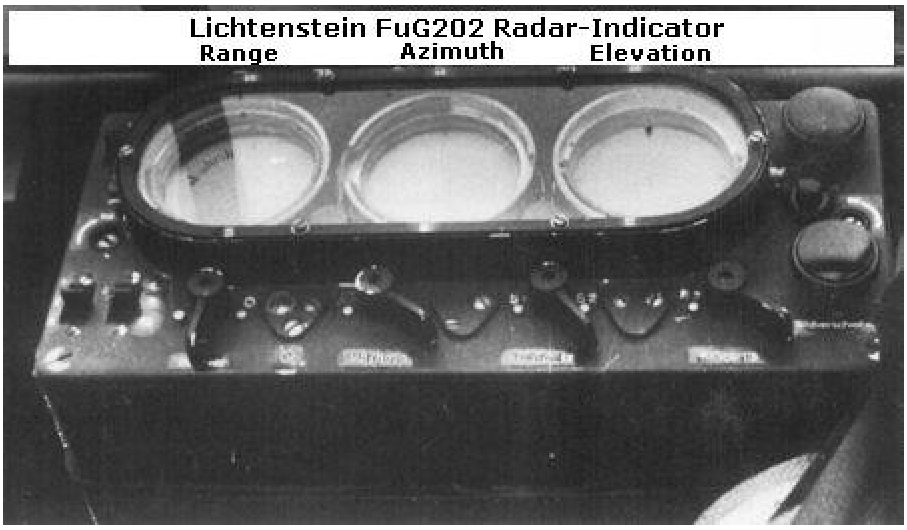


Original German FuG 202 Lichtenstein Receiver (Side View)

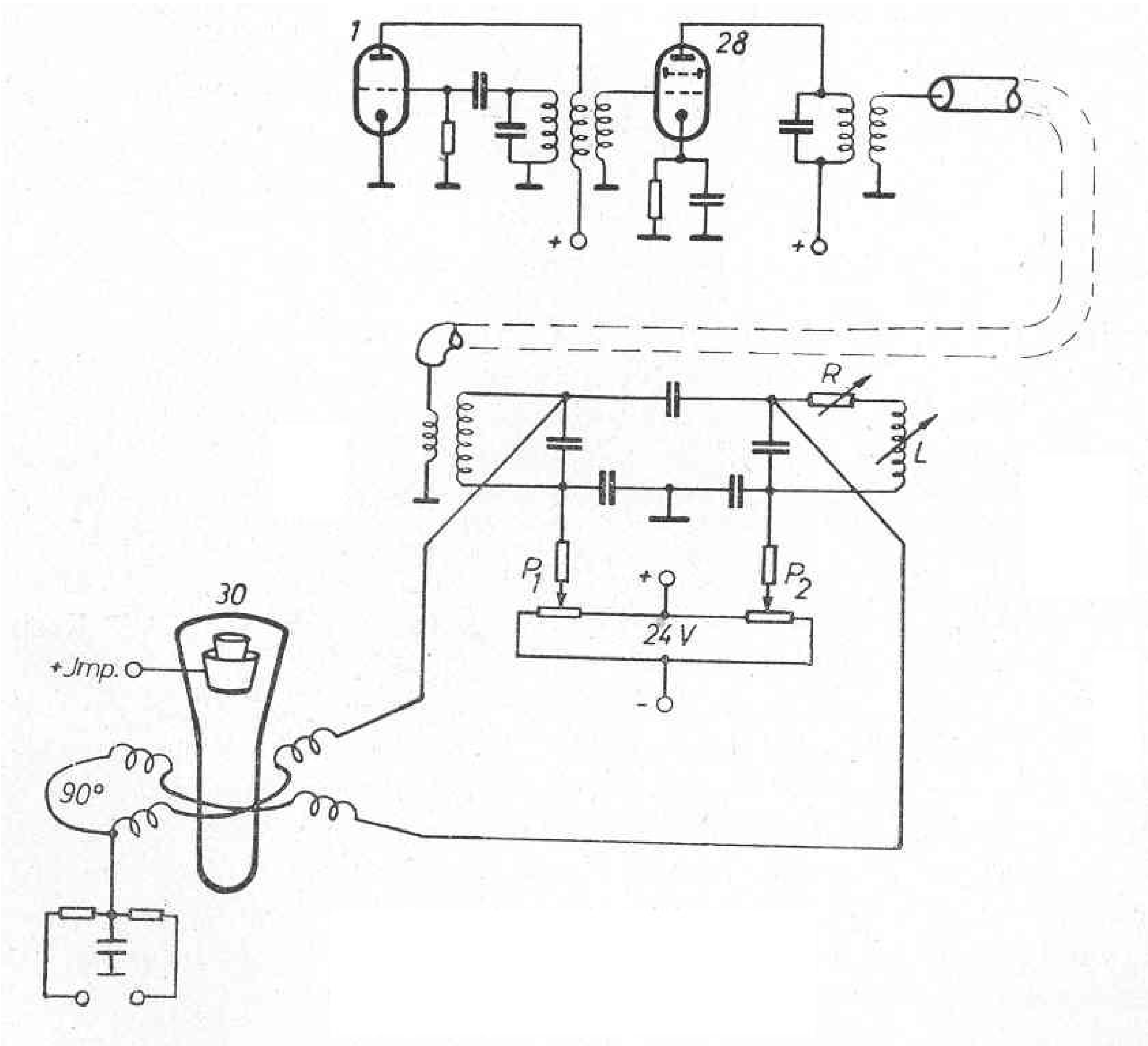


Indicator Unit

The indicator consists three scopes (about 2½" diameter) alongside each other, a circular range scope reading up to 8 km, an azimuth scope with the pips on opposite sides of the vertical base- line, and an elevation scope with the pips on opposite sides of the horizontal baseline.



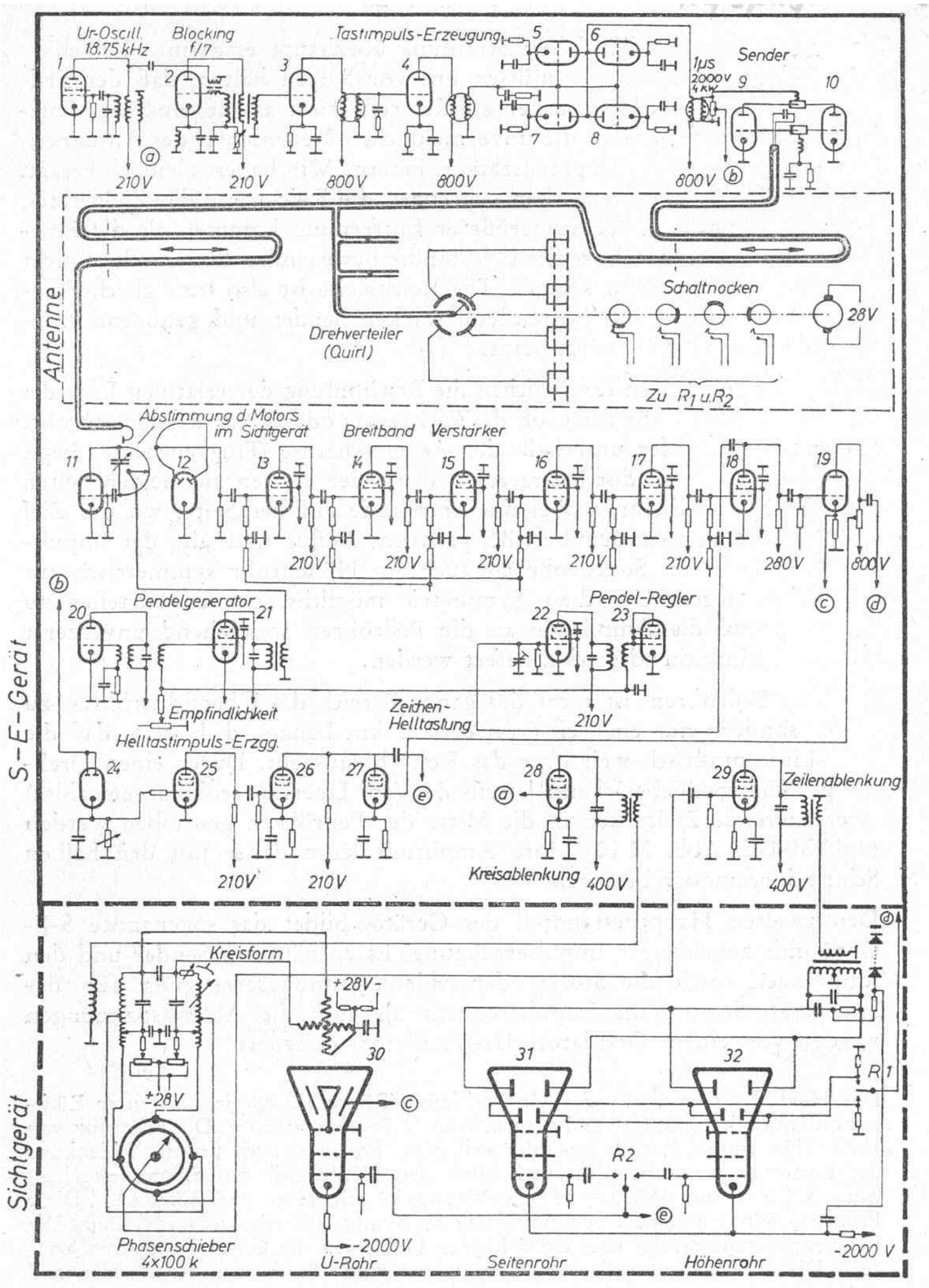
Magnetic Deflection System for the Circular Range Scope



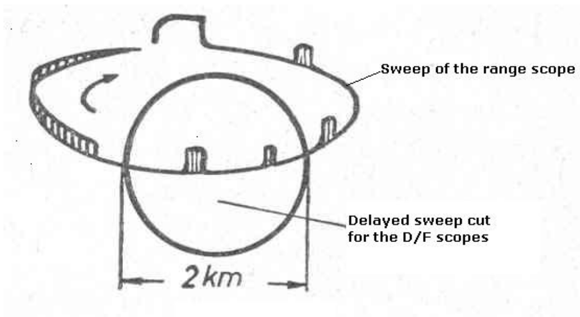
The presentation in range tube is more than simple deflection type. There is also intensity modulation the brightness of the trace being an increasing function of the output of the video amplifier.

Lichtenstein FuG 202 airborne radar, schematic diagram

Tastenstufe **Sender**
4 x LD2 parallel **2 x RS394**



The sweep frequency is that of the 19 kHz master oscillator frequency, the electron beam in the circular range tube makes 7 revolutions per transmitted pulse. In addition to the circuit for intensity modulation, there is a brightness circuit which applies a square brightness pulse for the duration of the first revolution, making it alone visible. Thus targets more tan 8 km away cannot ever be seen. In the range tube, an 8 km scale, with 100 m divisions, is engraved on the face. The deflections are outwards.



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

Lichtenstein FuG 202 Airborne Intercept Radar

Developed 1941 at the Telefunken-Laboratory Zehlendorf-Berlin

Hypothetical calculation of the effective detection range against flying targets:

System Parameters:

R Maximum Detection Range in meters

P_t Transmit Peak Power (750 w = 58.5 dBm)

G Antenna-Gain (G^2 = 28 dB)

λ Wavelength (0.61^2 = -4.3 dB)

σ_t Radar Target Cross Section in Square Meters

$(4\pi)^3$ Sphere Surface (twice) (= 33 dB)

MDS Signal plus noise equal to twice noise (-80 dBm)

$$R^4 = \frac{P_t \; G^2 \; \lambda^2 \; \sigma_t}{(4\pi)^3 \quad MDS} = \frac{58.5\text{ dBm} \;\; 28\text{ db} \;\; (-4.3\text{dB}) \;\; 0\text{or}10\text{or}16\text{ dB}}{33\text{ dB} \qquad (-80\text{ dBm})}$$

R for σ_t 1 m^2 (ME109 small fighter) = < 1’700 meters

R for σ_t 10 m^2 (HE111/HE177) = < 3’000 meters

R for σ_t 40 m^2 (B24 or Lancaster bombers) = < 4’300 meters

Nachtjäger Messerschmitt Bf 110 G-4, C9 + EN

Interception radars: Lichtenstein FuG 202 & FuG 220 Weap-

ons: 2 MG 151 Canons Cal 20 mm in the nose
2 MG FF Canons, Cal 20mm firing upward

Landed on 28th April 1944 at Dubendorf airbase (Switzerland)

Crew:

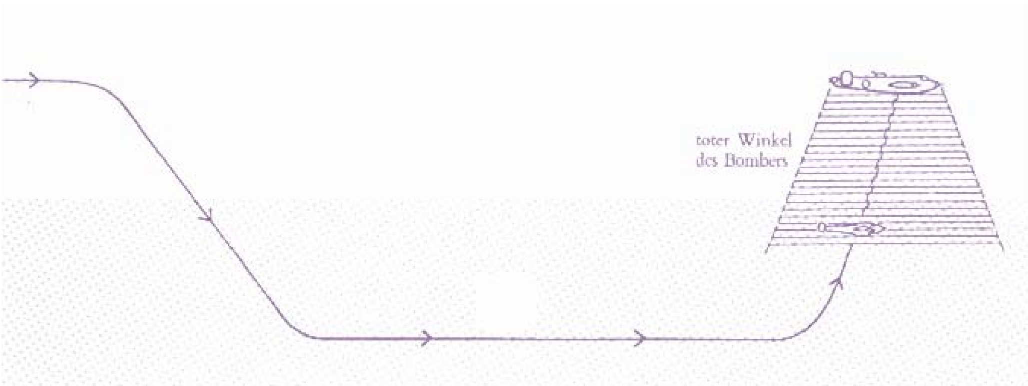
Pilot: Oberleutnant Wilhelm Johnen

Radiooperator: Leutnant Joachim Kamprath

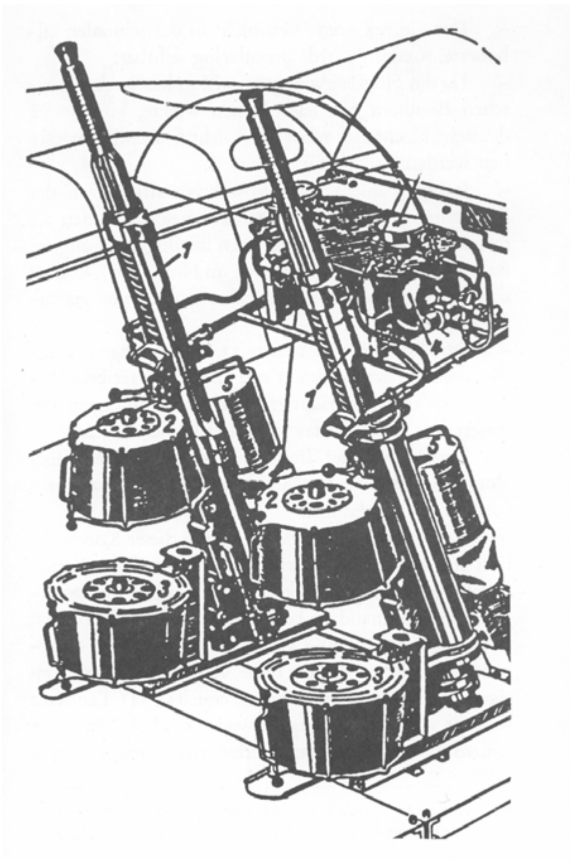
Gunner: Oberfeldwebel Paul Mahle

The German ME110 C9EN airplane had taken of from Hagenau to attack night bombers in Southern Germany. Having established contact, the experienced crew managed to destroy an Avro Lancaster. After some problems with the left DB605 engine, the pilot made an emergency landing at the Swiss Dubendorf airbase. The top secret night-fighter was equipped with the brand new Lichtenstein FuG220 interception radar as well as its predecessor the Lichtenstein FuG202. The aircraft also carried the secret “Schräge-Musik” - two upward firing 20mm Oerlikon canons.

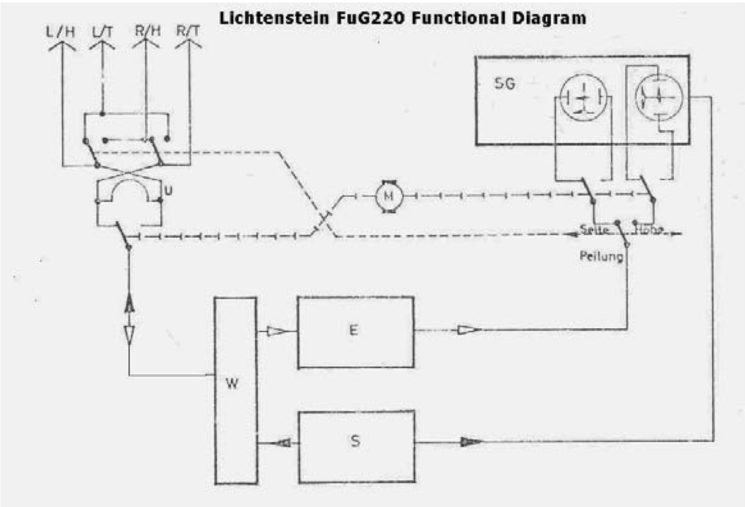
Attack procedure of the ME-110 Nachtjäger with the „Schräge Musik“ - weapon



Installment of the „Schräge Musik“ twin canon M.G. FF Oerlikon in the already cramped cockpit of the ME110G-4 night fighter.



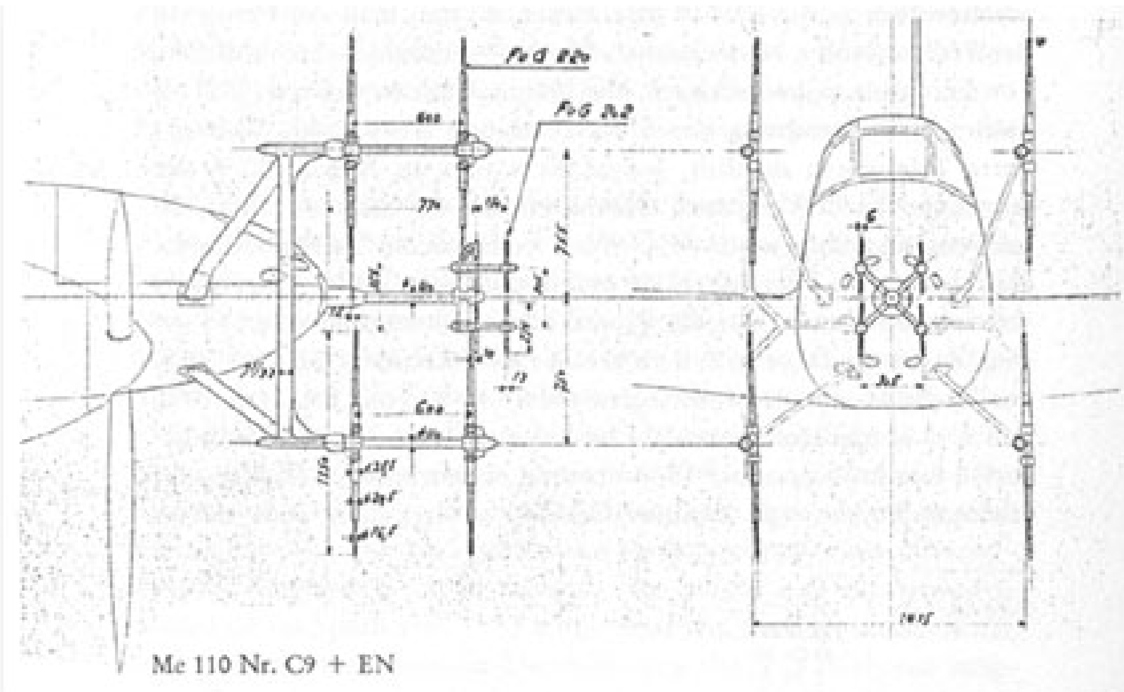
The German Lichtenstein FuG220 intercept radar was installed in twin engine night fighters. In addition to the numerical coding, it had the code Lichtenstein SN2. The Lichtenstein FuG220 intercept radar has a relatively wide cone of search, around ±45°, direction finding for flying targets was good, being 1.65:1 for 10° off centre at an operational frequency of 90 MHz. The forward cover against flying targets was excellent and the ambiguities not yet serious. The Lichtenstein FuG220 had an instrumented range of 8 km, however the greatest practical range of the set was limited to the flight altitude, beyond ground clutter appeared on the scopes. The minimum detectable range of the set was limited by the T/R switch around 900 meters. For to improve the limited near range resolution of the Lichtenstein FuG220 an additional Lichtenstein FuG202 was installed in the Messerschmitt Bf 110 G-4, C9 + E**N** night fighter.



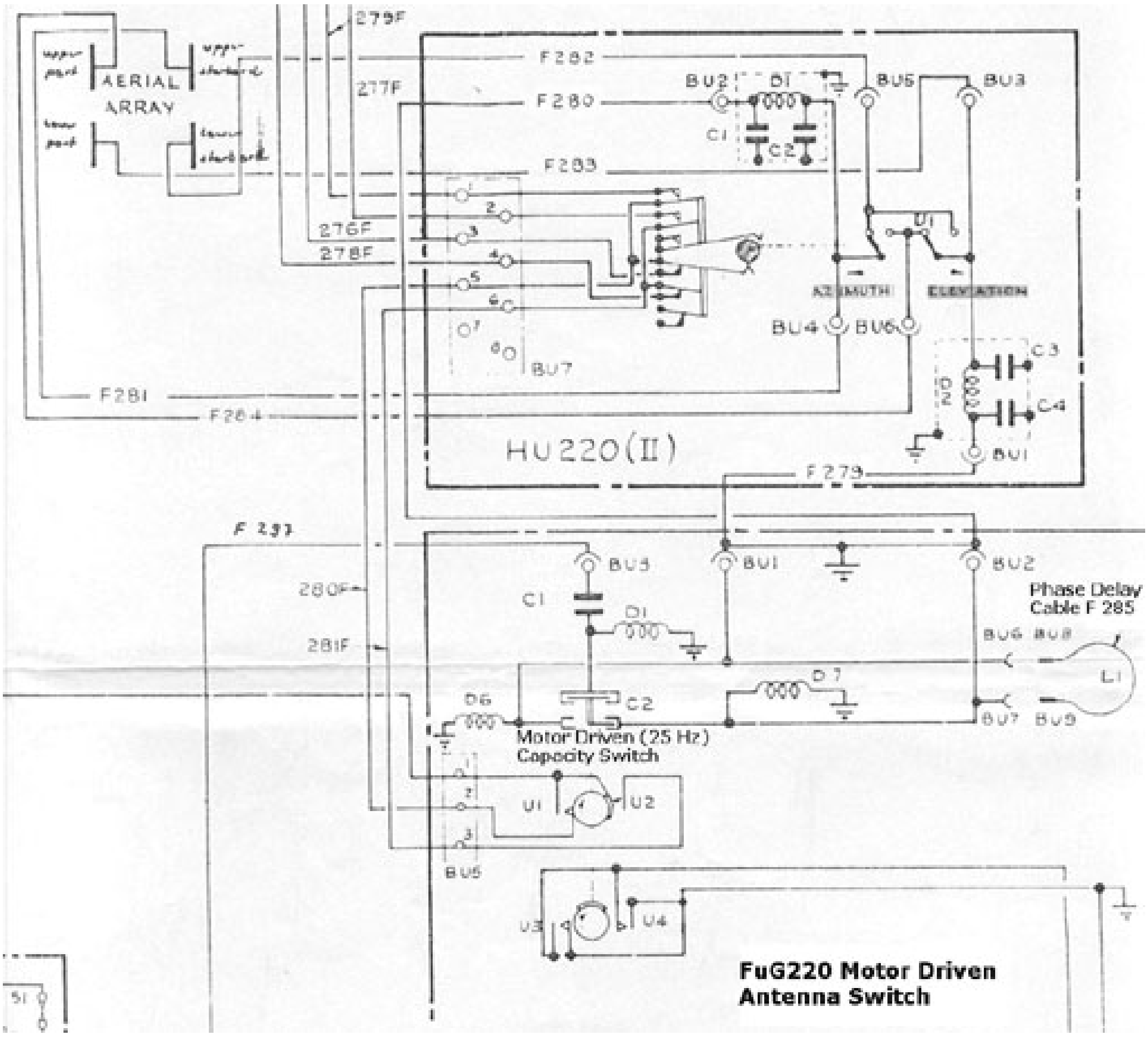
The Lichtenstein FuG220 equipment consist of transmitter S, receiver E, T/R unit W, multi-element direction finding antenna array, motor driven antenna switch and indicator unit SG. The pulse modulated radar operates on 90 MHz, the instrumented range is 8 km. The antenna array consists of four half-wave dipoles, each with a parasitic reflector, arranged in the form of a square. In order to obtain direction finding a split system is used, the main lobe of the polar diagram being switched either up and down for elevation or left and right for azimuth beams. The indicator has two CRT's, both with normal straight traces, one for azimuth, the other for elevation.

Lichtenstein FuG220 Antenna

Antenna Array of the German ME 110 C9EN airplane landed on 28th April 1944 at Dubendorf airbase (The drawing was taken occasional the investigation at Dubendorf airbase).



The antenna array consists of four half-wave dipoles, each with a parasitic reflector, arranged in the form of a square. In order to obtain Direction/Finding a split system is used, the main lobe of the polar diagram being switched either up and down for elevation or left and right for azimuth beams.
To accomplish the beam switching, the antenna array is fed with one pair of antenna array lagging in phase by 90° with respect to the other pair so that the beam is deflected in that direction. The delay is then switched into the circuit of the other pair so that deflection in the opposite direction occurs. This switching is carried out by a motor driven capacity switch at a rate of approximately 25 Hz. An additional manual operated switch (see the schematic below) is used to accomplish direction finding either in azimuth or elevation.



FuG220 Motor Driven Antenna Switch

It will be noted that depending on position of switch U1 the beam will be switched either up and down (elevation) or left and right (azimuth) that speed. It will be seen that the cable F297 from the transmit/receive unit, enters through condenser C1 on the first stator of C2 of the motor driven capacity switch. The rotor here has 360° vanes so that a constant coupling is maintained whilst revolving. The second part of the rotor has very small vanes which couple with alternate sides of the second stator as it resolves.

As there is a length of **phase shift cable F285** between the two halves of the second stator, output from these halves are alternately delayed by an amount dependent on the length of the cable.
This delay is used to obtain switching of the polar diagram main lobe. The two output cables F279 and F280 are connected to switch U1. Connections to the actual switch mechanism are made through low pass filters for harmonic suppression of the transmitter signal.

Calculation of lobe deflection by the antenna switch

$$\Delta\phi = \frac{2\pi\ d\ \text{sine}\ \theta}{\lambda} = \frac{2\pi\ \ d\ 1.415\ \ \text{sine}\ \theta\ 0.4416}{\lambda\ \ 2.5} = \text{rad}\ \ 1.5704 = \Delta\phi\ \ 90°$$

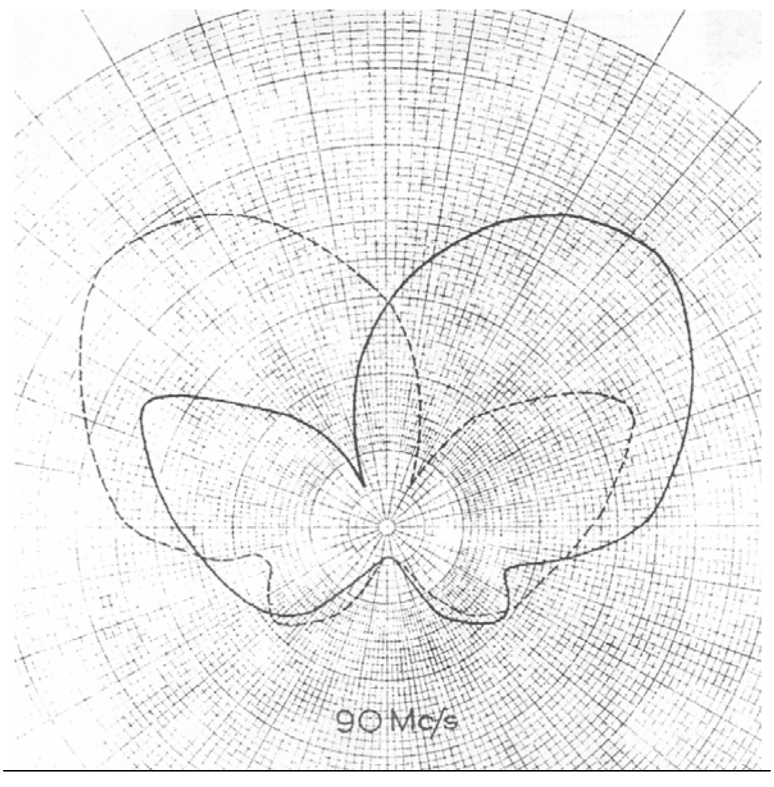
$$\text{sine}\theta = \frac{\Delta\phi\ \ \ \lambda}{2\pi\ \ \ d} = \frac{\text{rad}\ 90° = 1.570\ \ \ \lambda\ 2.5}{2\ \pi\ \ \ d\ 1.415} = \text{sine}\ \theta\ 0.4416 = \theta\ \ 26.20°$$

$\Delta\phi$ = Phase Angle to steer the Beam to $\Delta\phi$ (90° lagging)

sineθ = Deviation of Beam from Broadside

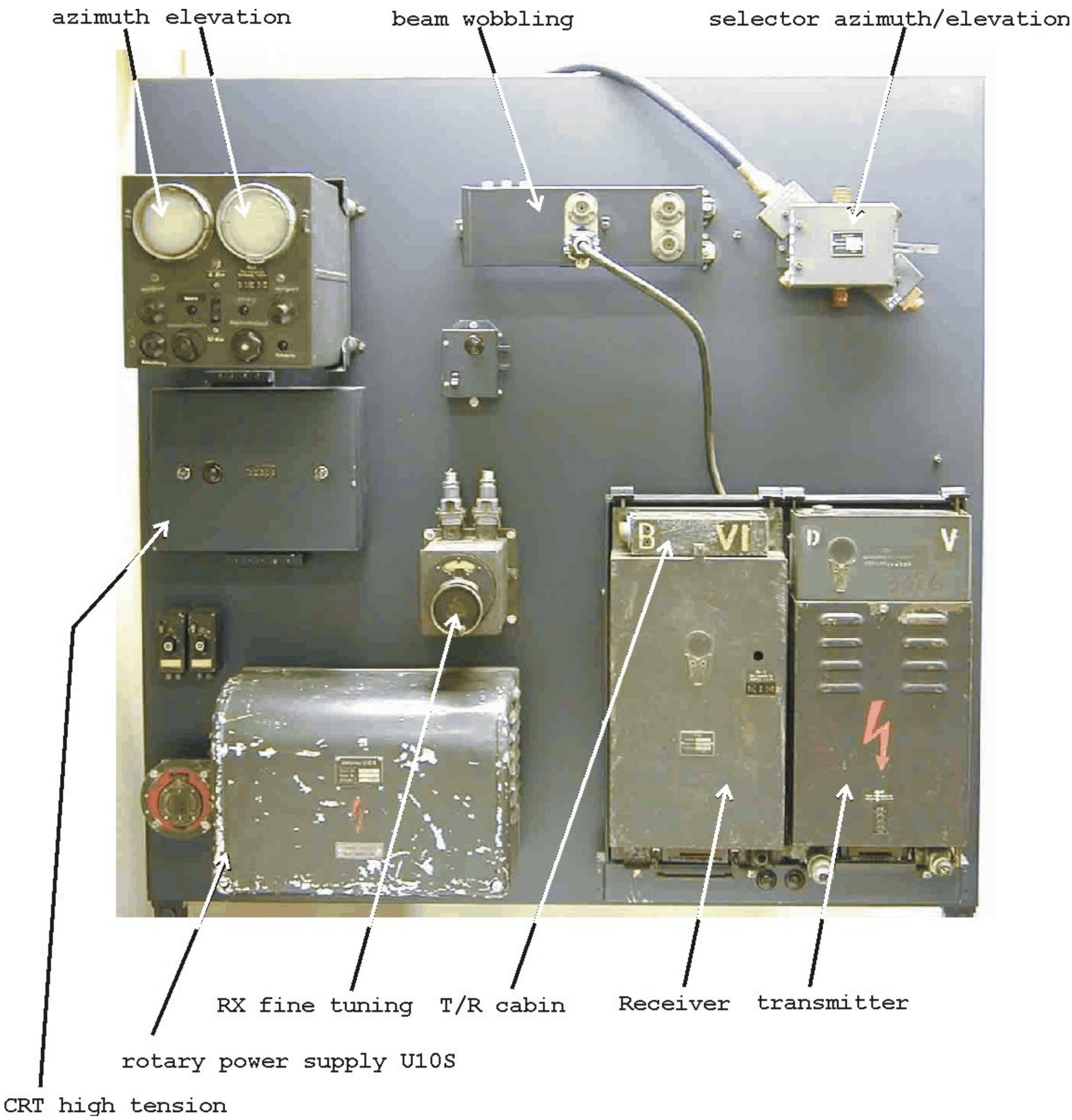
d = Dipol Radiator Spacing 1.415 meters (measured on the ME110 C9EN)

λ = Wavelength 2.5 meters

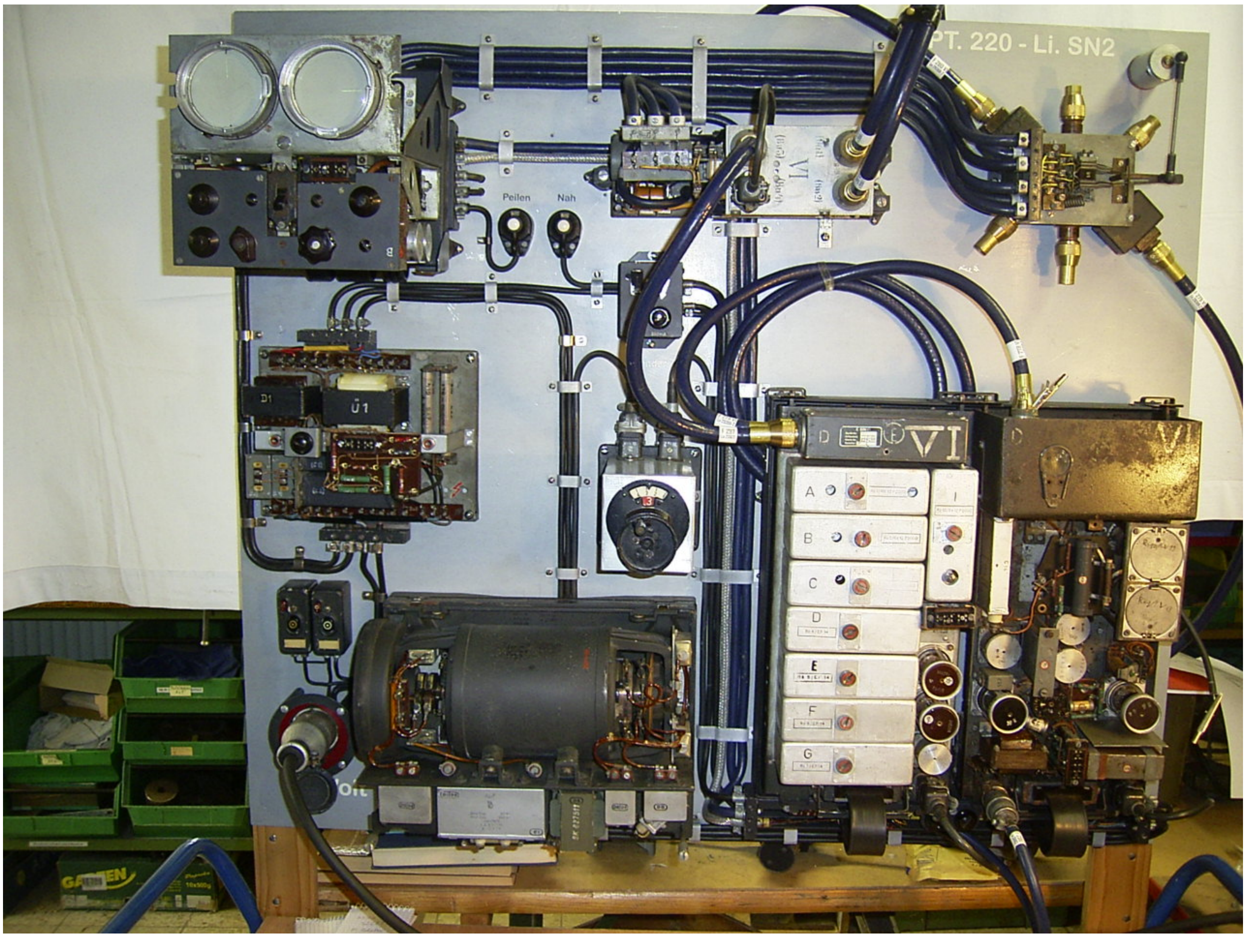


FuG220 Antenna Pattern Diagram for the operational frequency of 90 MHz.
The Lichtenstein FuG220 radar was originally designed for operation in the 87 to 92 MHz frequency band. Therefore the D/F ratio is optimal between 90 and 91 MHz only. At lower and higher operational frequencies the D/F ratio does deteriorate increasingly.

Test configuration of the Lichtenstein FuG220 Airborne Radar in the repair shop, which circuitry is equivalent to an aircraft installation

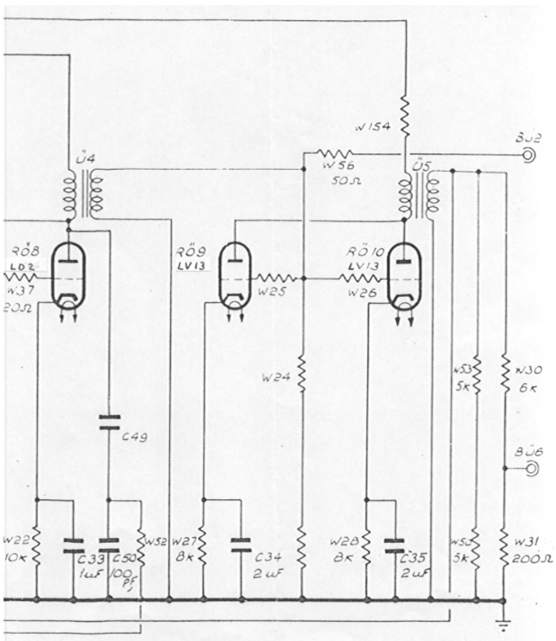


German Lichtenstein SN2 (FuG220) installed on the “Prüftafel”

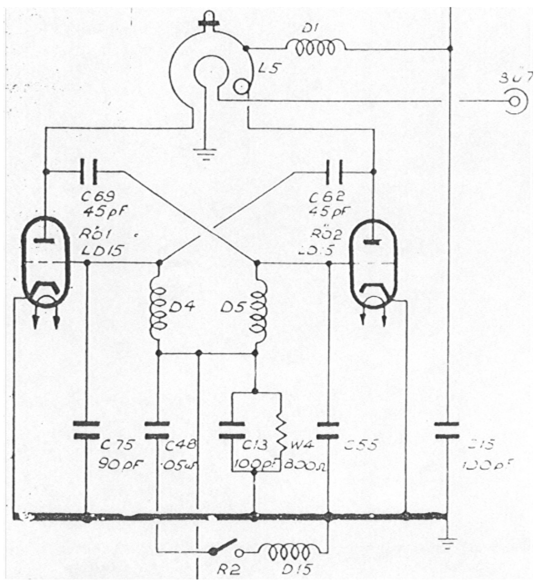


Lichtenstein FuG220 Transmitter

The pulse transmitter found in the Messerschmitt Bf 110 G-4, C9 + E**N** night fighter operates in the frequency band between 87 - 92 MHz with a pulse repetition frequency (prf) of 292 Hz. The prf is derived from an audio frequency generator. To avoid trouble on the receive picture through synchronism with other FuG220 transmissions, a control in the indicator unit provides two other alternative prf's of 295 and 298 Hz. A square wave is derived from the 292 Hz audio frequency and fed into the hard tube modulator driver and final stage.



The figure on the left shows the final stage of the pulse modulator. The driver pulse of Rö 8 is supplied over pulse transformer U4 to the grid of Rö9 and Rö10 (LV13 all-glass triodes). The 15 amps anode pulse current of Rö9 and Rö10 flows through the primary winding of the pulse transformer U5 and induces positive-going 1µs output pulses of 2000 volts in the secondary winding of the pulse transformer U5. Toroid type magnetic cores are used for the pulse transformers. The 2000 volts pulses are applied as high voltage to Rö1 and Rö2 of the plate modulated oscillator stage. The load impedance of the transmitter is approximately 1000 ohms. The peak plate current is typically 2 amps.

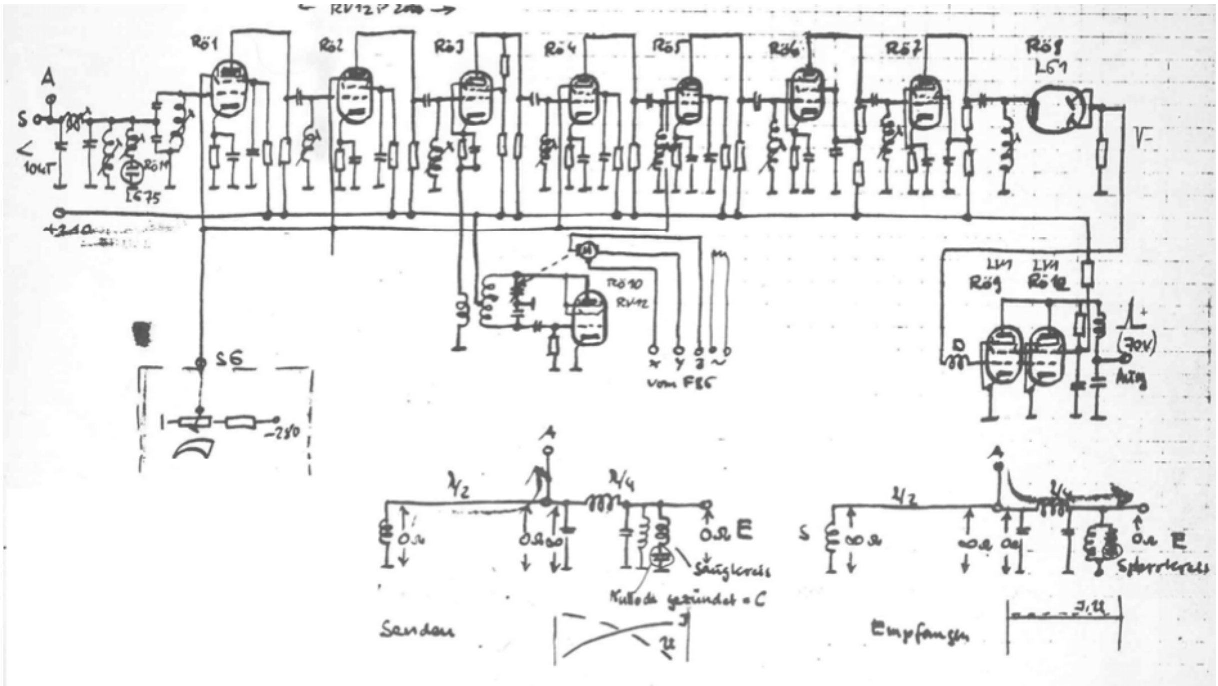


Rö1 and Rö2 are connected in a push-pull RF oscillator circuit, feed back taking place from anodes to opposite grids through condensers C62 and C69. The oscillator frequency is determined by inter-electrode capacities in conjunction with the anode circuit inductance. This consists of a single turn of heavy gauge wire, part of which is bent to form a transmission line. This transmission line has an adjustable shorting bar. The line provides variation of operating frequency by moving the bar. The RF peak power is typically 2 kW. If the "Nahauflösungs-Relais" R2 is closed (activated by a switch on the indicator) the transmitter pulse will be reduced from 1 µs to 0.6 µs.

The operational frequency of the pulse transmitter found in the Messerschmitt Bf 110 G-4, C9 + EN night fighter has to be pre-adjusted in the depot, it could not be changed in flight by the operator.

Lichtenstein FuG220 Receiver

The schematic (freehand-drawing) was made occasionally the investigation after the landing in Switzerland, it shows the circuits of the Lichtenstein FuG220 interception radar.

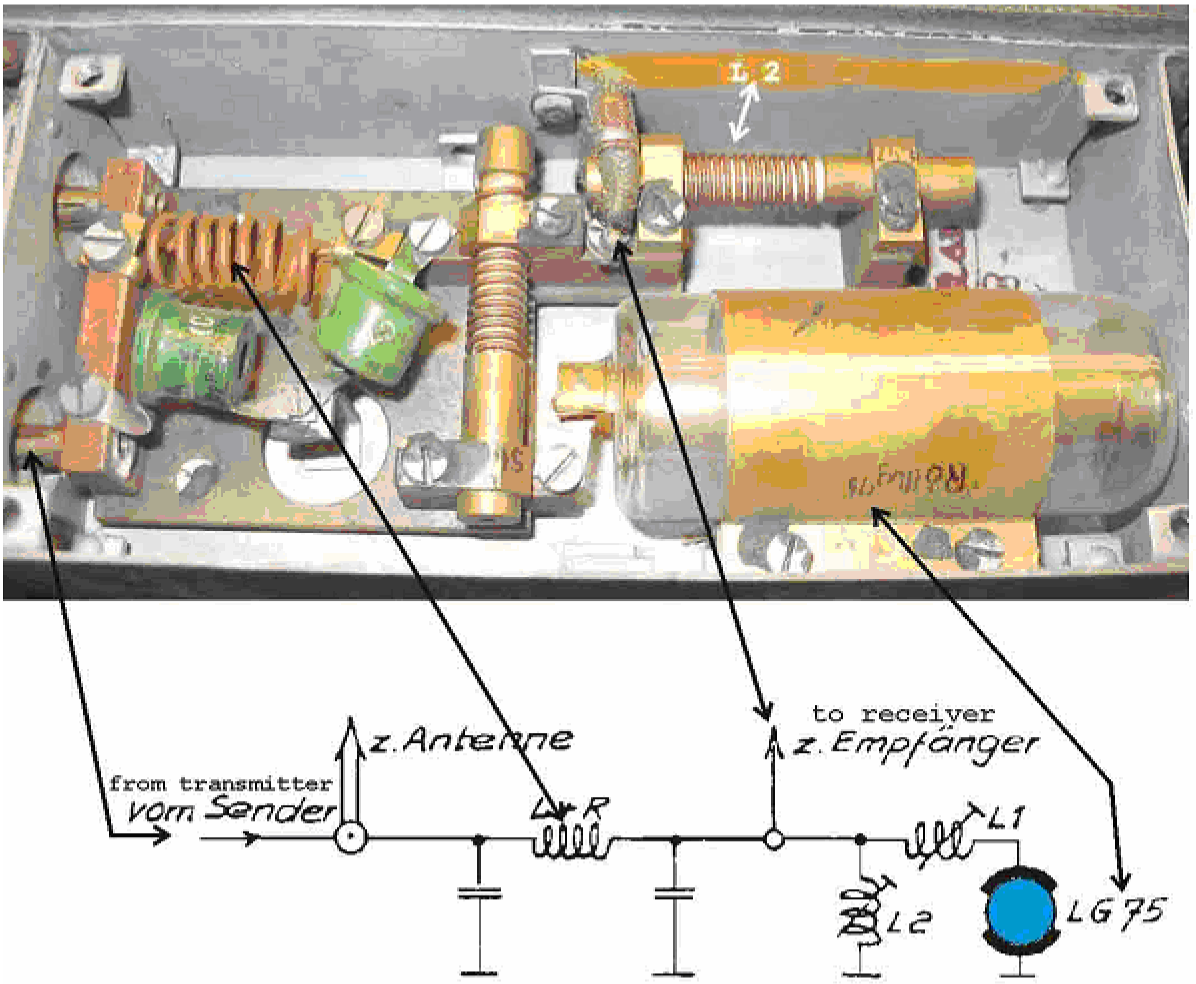


It is a classical 12-tube super-heterodyne receiver with two RF-preamplifiers, a local oscillator with mixer, four IF amplifier stages, a detector and a video amplifier. The IF-frequency is 4 MHz (-3 dB down) at a bandwidth of 2.2 MHz. The receiver sensitivity is better than 5µV (- 90 dBm) for signal plus noise equal to twice noise.
The frequency of the local oscillator may be changed by a variable capacitor. The capacitor is controlled by a selsyn motor linked to the remote tuning unit, and provides a small variation (± 2MHz) of local oscillator frequency whilst in flight. The receiver gain can be controlled also in flight by a potentiometer on the indicator.

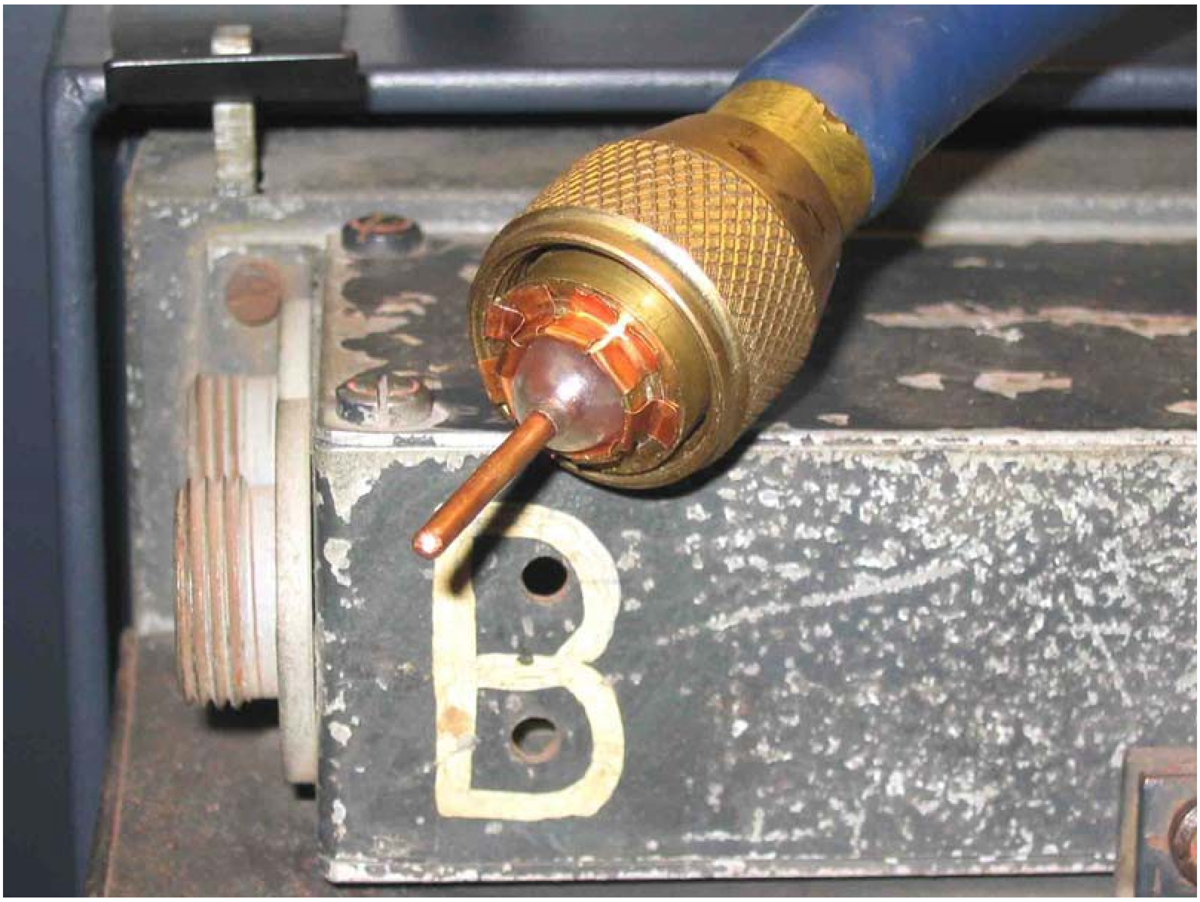
The Common T/R Unit

This unit is mounted at one end of the receiver. The essentials of the circuit are a quarter-wave line using lumped elements, terminated by a spark gap at the receiver input.

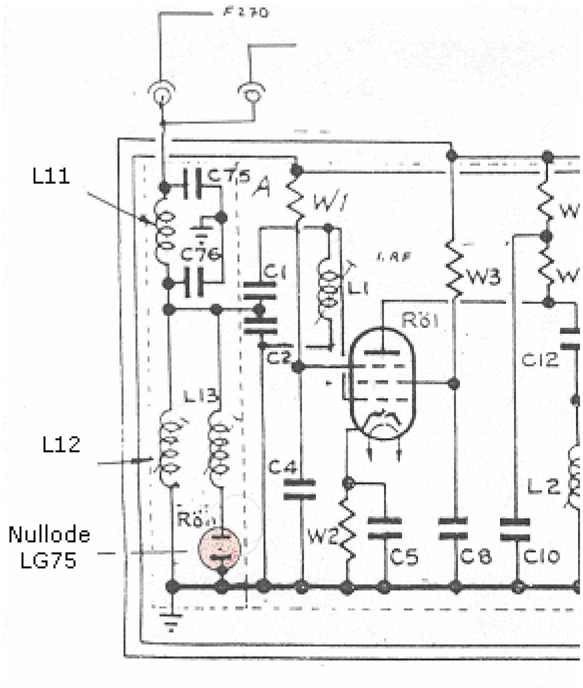
This spark gap a soft tube (Telefunken LG 75 Nullode) passes current during transmitter pulses and consequently the feed to the receiver offers a high impedance during the pulse. Subsequent receiver paralysis is thus much reduced. The Photo on the next page shows the T/R unit of the FuG 220.



Lichtenstein FuG 220 original Antenna Connector on Vacha 70 Ω Cable



Near range resolution of the FuG 220 receiver



The front end of the FuG 220 receiver is protected by an LG75 gas-discharge tube. The gas filling in the tube shall quickly ionize on the leading edge of the transmit pulse and bypass the RV12P2000 receiver preamplifier tube by a low impedance. In the ideal case the gas filling shall quickly de-ionize after the transmit pulse is gone. Unfortunately the gas filled TR tubes are not ideal switches, they have some delay time to ionize and a much longer delay time to de-ionize. This time delay limits the near range resolution of the radar system.

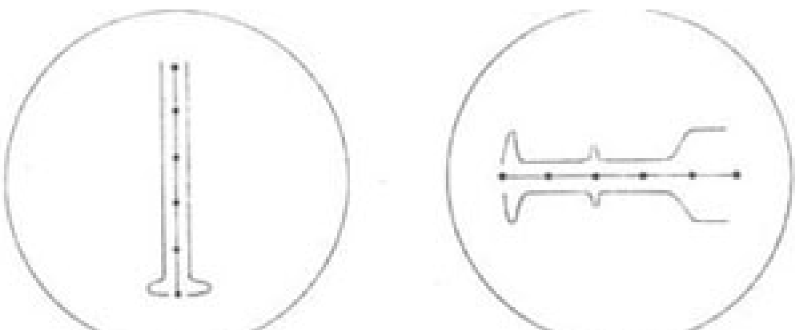
Remark

A later modified version of the Lichtenstein FuG 220 interception radar incorporates the so-called “Nahauflösungs”- fix. The meaning of “Nahauflösungs” is near-resolution, and its function is to improve the minimum range by suppressing the receiver while the transmitter is operating.

For better overall resolution the transmitter pulse-length can be reduced and it was possible also to change receiver bandwidth by bringing in damping resistors across the IF tuned circuits. Also the gain controlling line of the receiver was modified in that the time constants are considerably reduced to allow the suppressor grids to follow the suppressing waveform. Allegedly an improvement in minimum range to 200 m was claimed for the modification.

Lichtenstein FuG220 Indicator

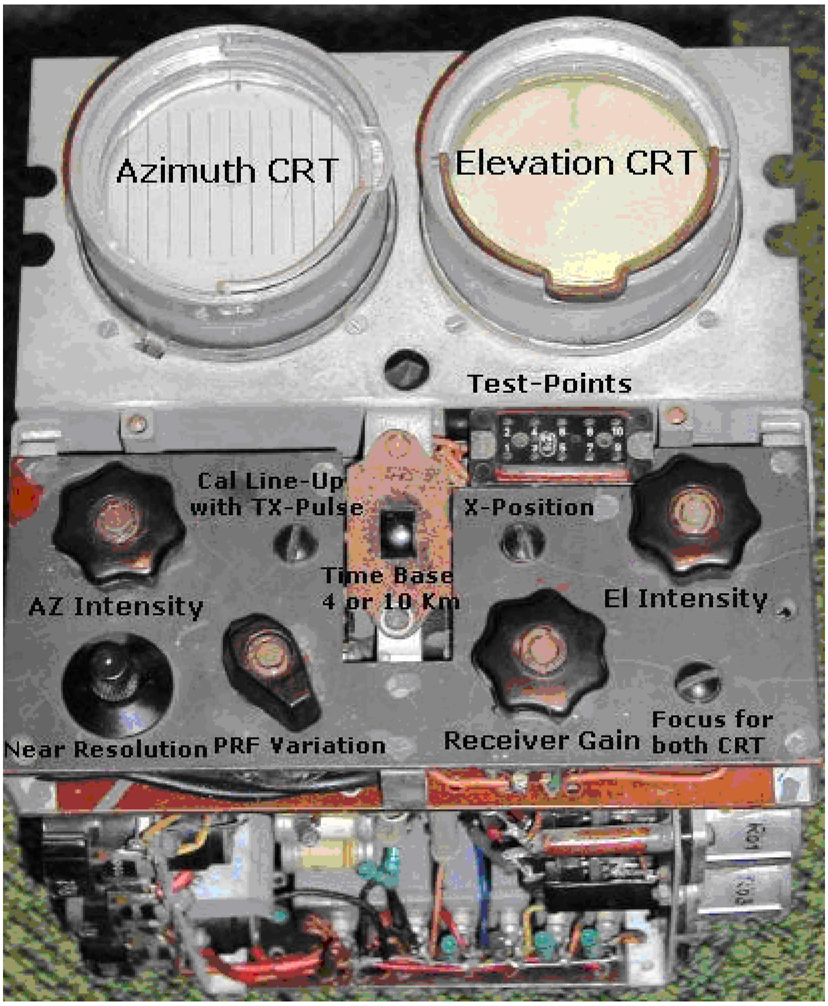
The indicator unit contains an Azimut CRT-Display as well as an Elevation CRT-Display tube, both displays provide simultaneously range indication by a marker generator (see figure below).



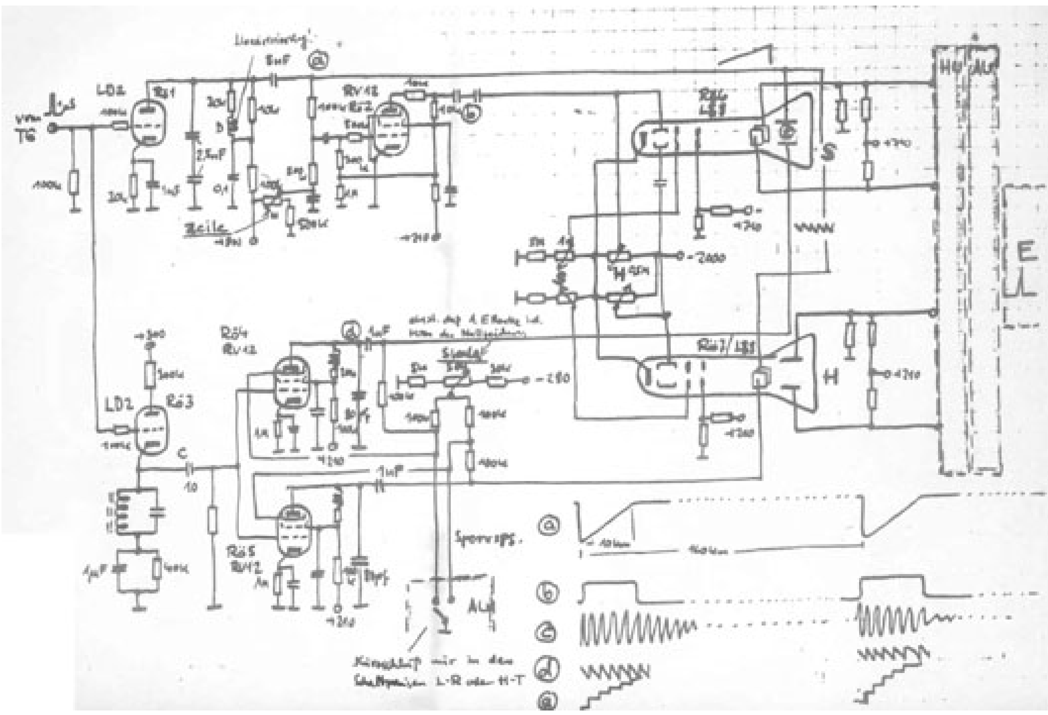
AZIMUTH TUBE

ELEVATION TUBE
(SHOWING ECHO AT 4 KMS
AND GROUND RETURN AT 7 KMS)

Original Lichtenstein FuG220 Indicator



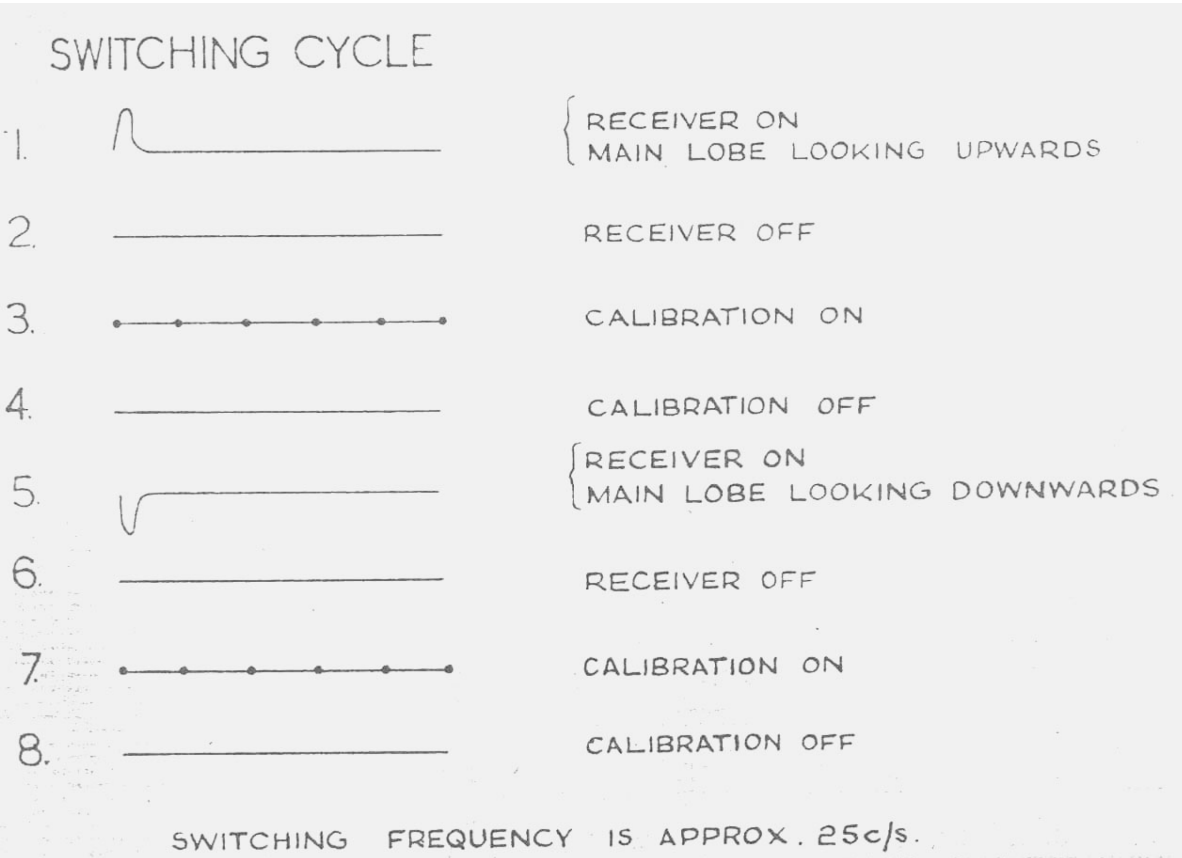
Schematic of the Lichtenstein FuG220 Indicator



Lichtenstein FuG220, Indicator Function

Positive triggering pulses from the modulator are applied to the grid of Rö 1 and the resulting heavy anode current, rapidly discharge C1-2. After each pulse, the capacitor recharges slowly producing the required time-base voltage.
Tube Rö 2 is used to provide a brightening waveform. Tube Rö 3 together with the tuned circuit in its cathode forms the start the calibrator circuit. The cathode rings each time the modulator output trigger is received, the output is fed to the grid of tube Rö 4 and Rö 5. When calibration is required those suppressor grids are brought to ground by the antenna switch motor. The waveform is fed on the X-plates of the CRT's to provide pips of varying brilliance as the time base writing speed changes.
The video output of the receiver is connected to the appropriate Y-plates of the display unit CRT's by means of the antenna switch unit.
The standing anode voltage of the receiver output tube is sufficient to deflect the time base trace in a direction perpendicular to its length so that the resulting screen picture consists of three traces the centre one having calibration dots, the outer ones having signals shown as deflection from the centre trace.

Indicator Waveforms



Lichtenstein FuG 220 Airborne Intercept Radar

Developed 1943 at the Telefunken-Labaratory Zehlendorf-Berlin

System Parameters

Frequency:	91 MHz
Transmit peak power:	2 kW
Receiver Sensitivity:	- 90 dBm
Antenna Gain:	5 dB
Antenna split frequency:	25 Hz
Pulse Length	1 µs
Near Resolution	1000 Meter
PRF:	292, 295, 298 Hz
Instrumented Range:	8 km

Hypothetical calculation of the effective detection range against flying targets:

Parameters:

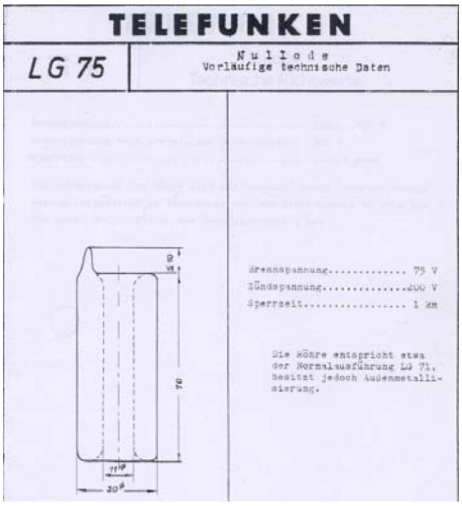
R	Maximum Detection Range in meters
Pt	Transmit Peak Power (2000 Watts = 63 dBm)
G	Antenna-Gain (G^2 = 10 dB)
λ	Wavelength (3.19^2 = 10.35 dB)
σt	Radar Target Cross Section in Square Meters
$(4\pi)^3$	Sphere Surface (twice) (= 33 dB)
MDS	Signal plus noise equal to twice noise (- 90 dB)

$$R^4 = \frac{Pt \quad G^2 \ \lambda^2 \ \sigma t}{(4\pi)^3 \quad MDS} = \frac{63\text{ dBm} \quad 10\text{ db} \quad 10.35\text{ dB} \quad 0\text{ or }10\text{ or }16\text{ dB}}{33\text{ dB} \qquad (-90\text{ dBm})}$$

R for σt 1 m^2 (small fighter) = < 3'200 meters

R for σt 10 m^2 (HE111/HE177) = < 5'800 meters

R for σt 40 m^2 (B24 or Lancaster bombers) = < 8'000 meters



The figure on the left shows the original data sheet of the Telefunken LG 75 gas filled TR-tube installed at the receiver front-end of the Lichtenstein FuG 220 airborne radar - as found in the emerged ME110 C9EN aircraft.
According to the data sheet the recovery time of the LG 75 is specified with 1km (equal to 6.6 µs).

The figures on the left and below show the Telefunken LG 75 TR-tube (in Germany was the tube designated as a so called Nullode)

LG 75 Nullode with removed spray shield

The transmitting triode LD15 used in the transmitter of the Lichtenstein SN2 radar (left on figure) was derived from the Telefunken LD5 triode.
The plate dissipation of the LD15 was 25 watts and the plate peak current 1.5 amps for pulses ≤ 1µs during keying.

To avoid arcing on higher flight altitudes the triode LD15 (left on figure) has a larger glass-body than the LD5 (right on figure) this allowed a wider spacing of the double ended anode terminals (the two top pins) from the other tube terminals.

The power triode LV13 (left on figure) was designed during WWII by Telefunken as high–vacuum switch tube for pulse modulator application in the Lichtenstein SN2 airborne radar system. During the pulse interval the switch must conduct a high current. Therefore for maximum efficiency, the effective resistance of the switch must be as small as possible, so that the potential difference across the switch tube, called the “tube drop” is small during the conduction period.

For pulse operation ≤ 3µs the LV13 triode was able to switch an anode current of 15 amps at 2000 volts by an effective switch power resistance of ≤ 20 ohms. Telefunken could reach this design goal with a large area barium oxide cathode. Two LV13 triodes in parallel were used in the modulator of the Lichtenstein SN2.

The triode RS394, left on the figure, was only used for the first series of the Lichtenstein FuG202 transmitters, in early 1941.

The RS394 looks rather like a laboratory design model than a typical rugged German Airforce tube. The anode dissipation was 30 watts, the tube could be pulse operated up to approx. 500 MHz.

However, the manufacturing process of the RS394 was to complicated for mass production, so Telefunken re-designed later the RS394 into the LS30 tube.

The Telefunken P07S1 CRT, left on the photo, was used as range tube on the indicator unit of the Lichtenstein FuG202 intercept radar.

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