

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



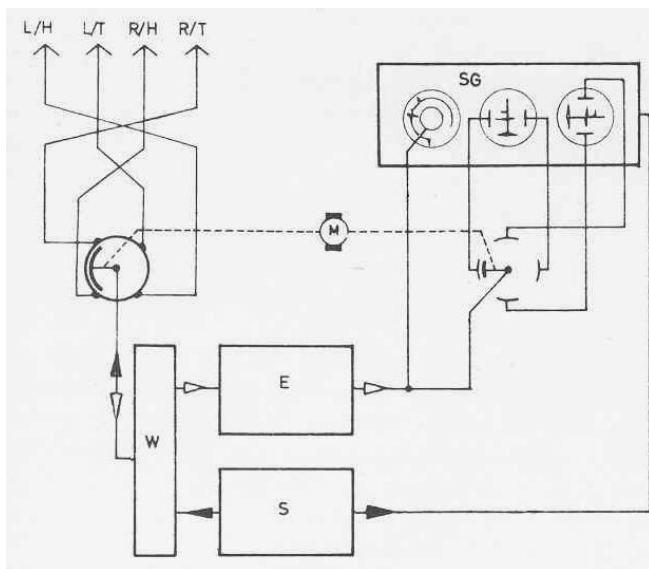
Landing on 15th March 1944 at Dubendorf Airbase (Switzerland)

Crew: Pilot Oberfeldwebel Helmut Treynogga
Radiooperator Unteroffizier Heinz Schwarz

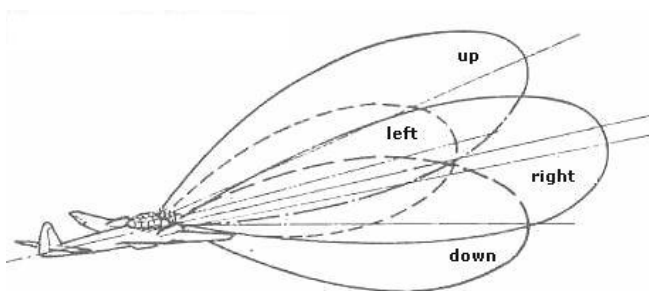
On the night of 15th March 1944 a German Night Fighter crew defected to Switzerland with an Messerschmitt 110G. They approached intact with an operating Lichtenstein FuG202 interception radar at Dubendorf airbase. (see photography of the airplane after the landing). According to the authentic landing 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.

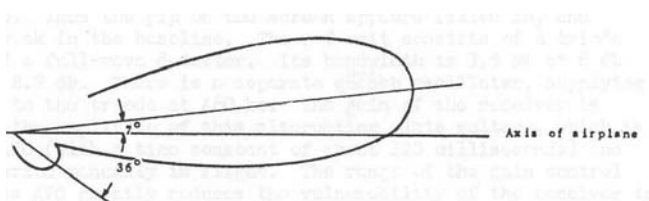
The Lichtenstein FuG202 radar equipment combines a relatively narrow cone of search, around $\pm 20^\circ$, with high sensitivity to change in direction of the target (e.g. 1.4:1 in pip size at 5° off axis), so it is well suited to assist a fighter to keep on the tail of a bomber taking evasive action, 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.



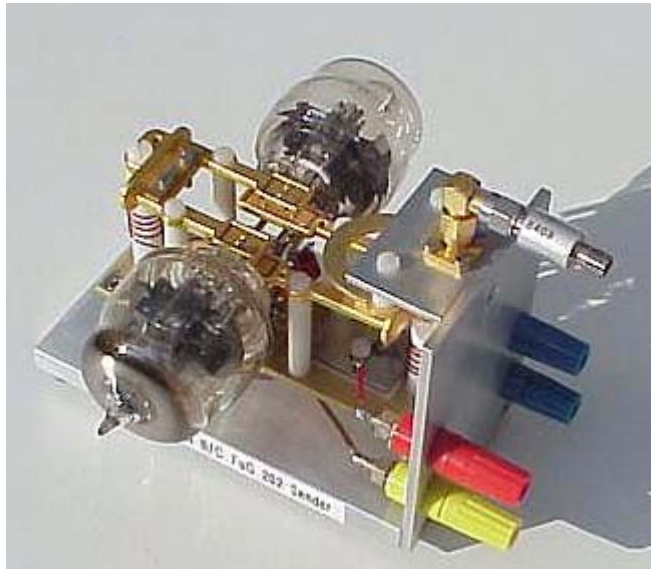
The Lichtenstein FuG202 equipment consist of transmitter S, receiver E, T/R unit W, multi-element direction finding antenna array, motor driven antenna switch and indicator unit SG. The pulse modulated radar operates on 50cm wavelength, the instrumented range is 8 km but the maximum range on a large 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 $\pm 7^\circ$ 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.



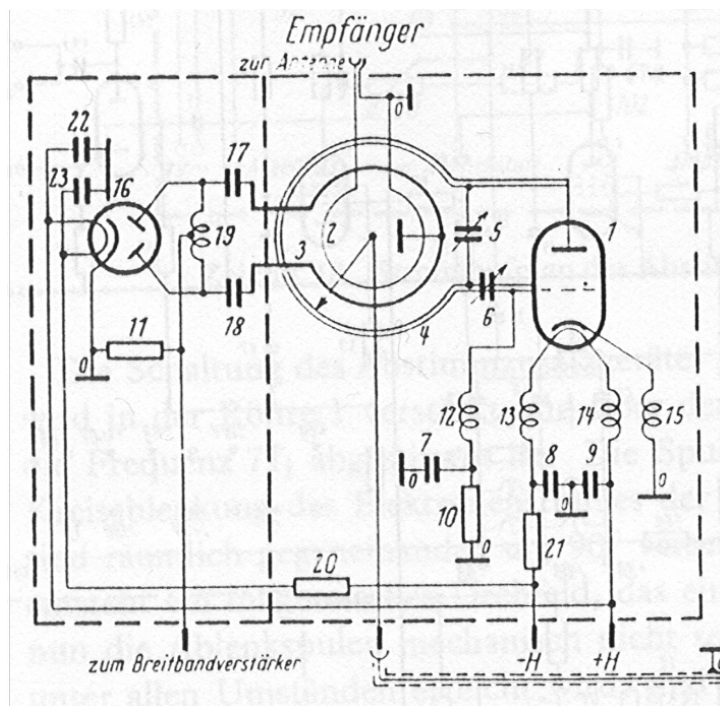
The transmitter operates on a frequency of 490 MHz and has a peak output power of 450 watts, approximately at a pulse repetition rate of 2700 Hz. Two RS394 triodes are used in an anode modulated push-pull oscillator. Tuned anode and grid lines (see photo with the original RF circuitry) are used and cathode 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 μ s pulses from the separate modulator unit. The peak modulator voltage is approximately 1500 volts and the modulator power is 2 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.

The Lichtenstein FuG202 is unique among German radars in its use of a **superregenerative** receiver. The receiver consists of three units, an R.F. unit, a quench generator and a wide band amplifier, the latter including an automatic gain stabilisation (a.g.s.) circuit. The sensitivity of the receiver is 30 μ V 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 tuneable from 479 to 499 MHz.

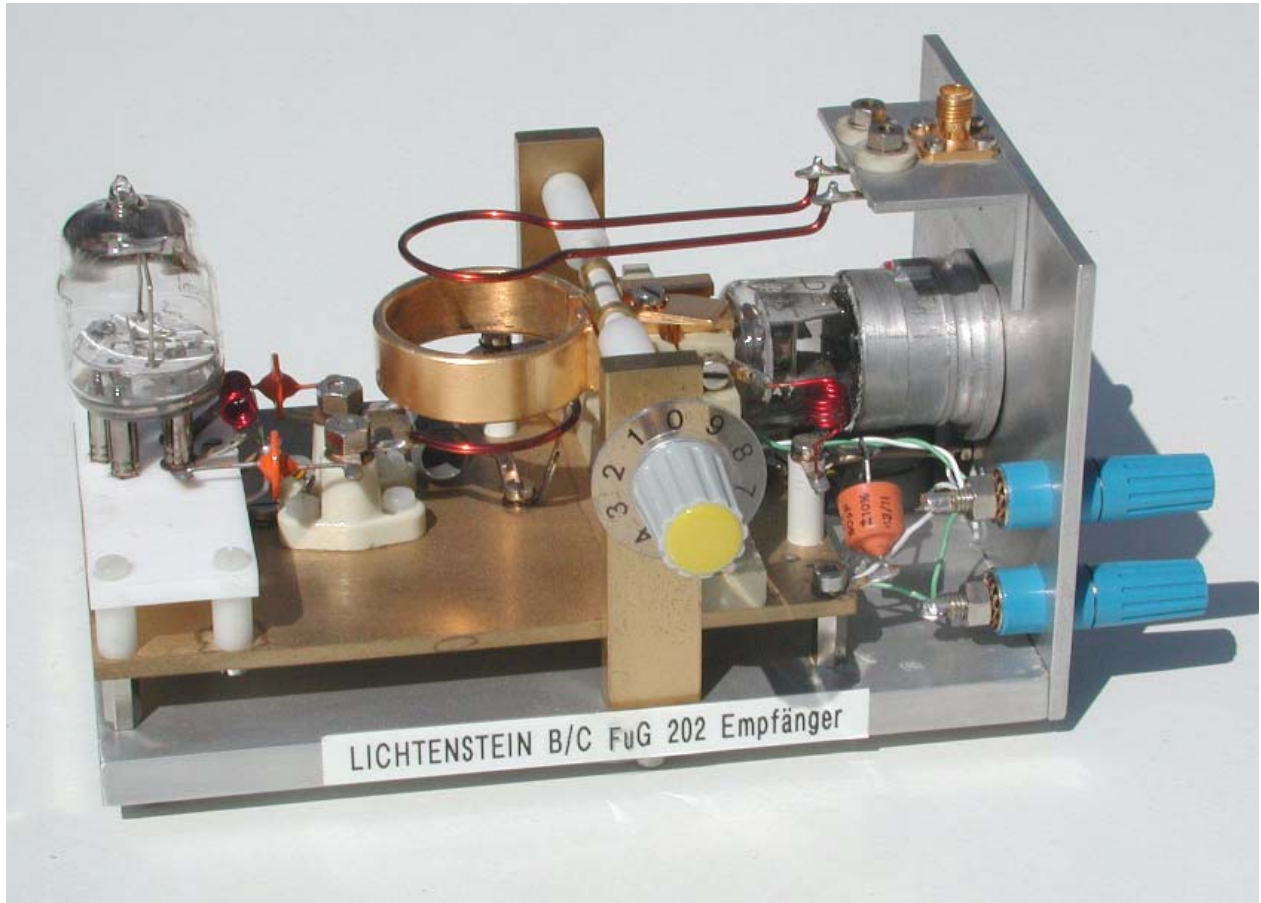
The R.F. unit consists of a triode oscillator and a double diode detector. The plate supply to the triode consists of cycles of the quench voltage at a frequency of 454 KHz, having no steady D.C. component. The magnitude of the applied quench voltage is varied by the setting of the gain control and by the automatic gain control system. Full wave detection is used, the detector output being fed to the broad band amplifier.

The voltage gain from the antenna input to the detector output is approximately 160 under average operating conditions, but depends on the setting of the gain control. The receiver can be tuned in flight by the operator, with variable capacitor 5.

Circuit of the FuG 202 superregenerative receiver unit



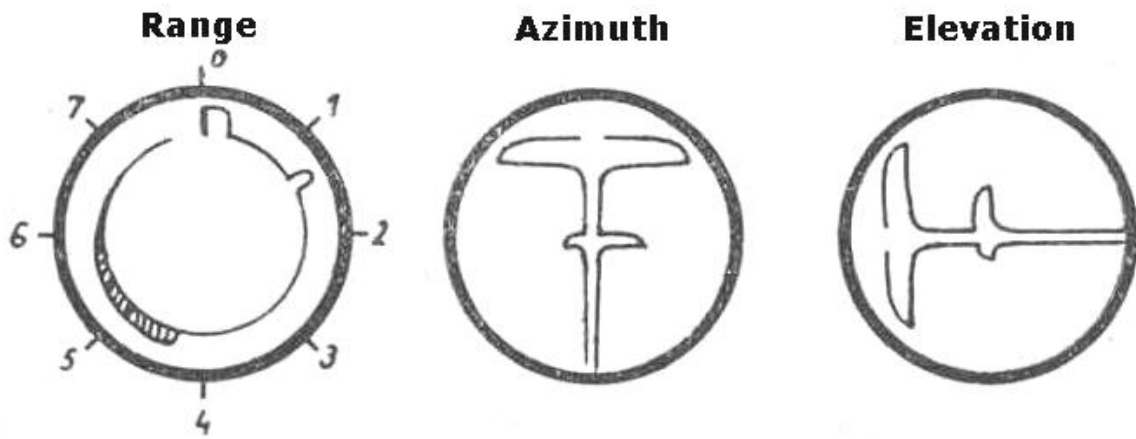
The output of the detector is fed to the broad band amplifier having 5 stages. Its bandwidth is 3.5 MHz at 6 MHz down, the overall voltage gain 4000 times at 100 kHz falling to 2000 at 500 kHz. The broad band amplifier also contains the automatic gain stabilisation circuit. This circuit provides a negative 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.

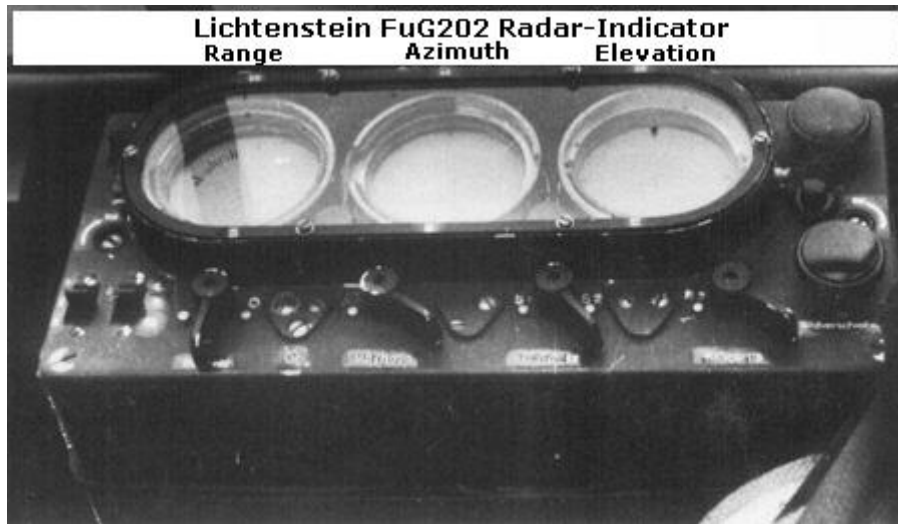


The quench oscillator consists of an oscillator operating at 454 kHz, whose output is fed to the a.g.s. control stage. The broad band amplifier output is fed to the other input of the a.g.s. control stage. The output of the a.g.s. control stage supplies a variable quench voltage of 1 - 40 volts as plate 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 vulnerability of the receiver to jamming.

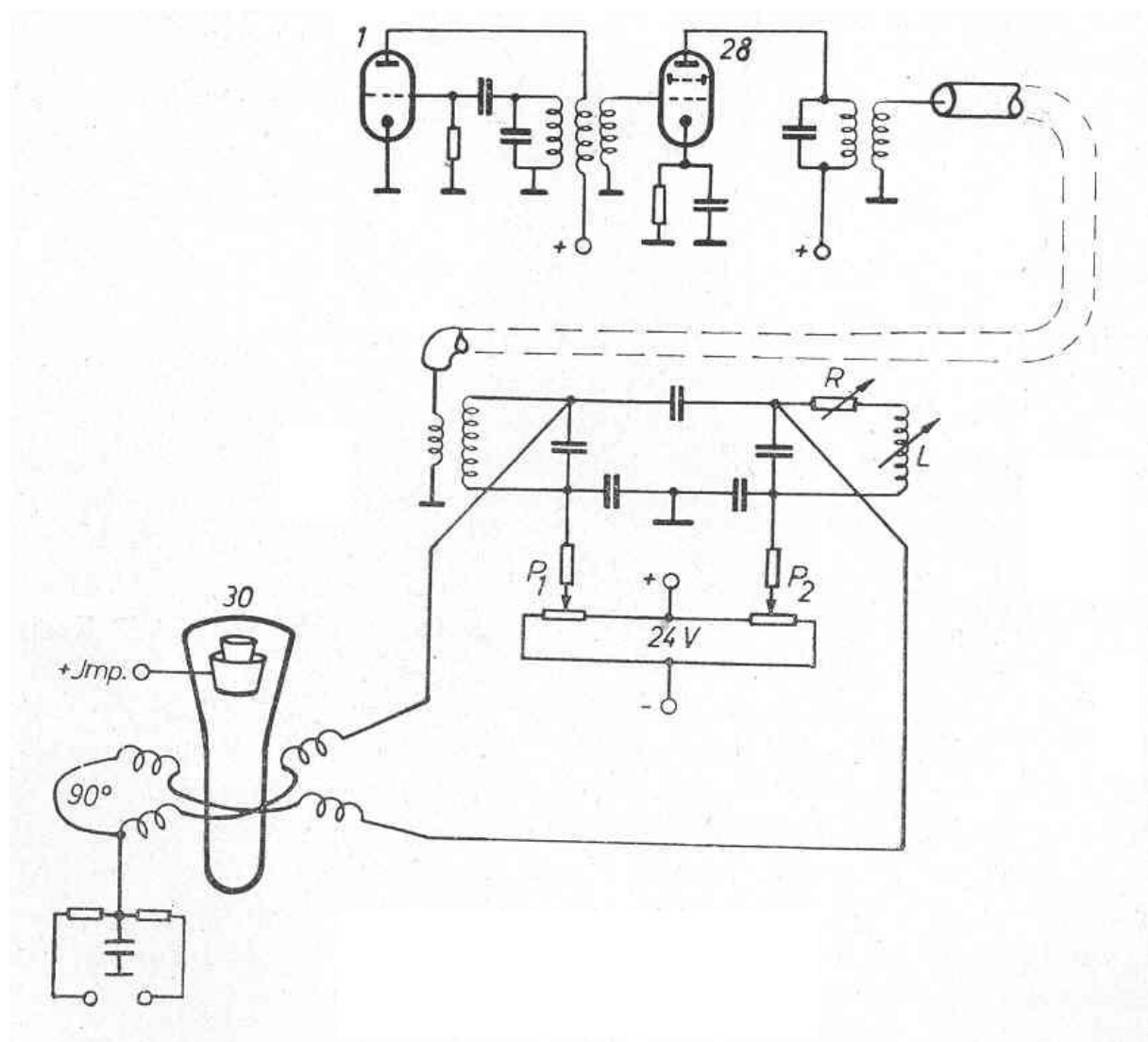
The video output of the broad band amplifier for any kind of input signals consists of 0.2 μ s pulses at the quench rate of 454 kHz. Thus the pip on the screen appears filling in, and there is no break in the baseline.

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 baseline, and an elevation scope with the pips on opposite sides of the horizontal baseline.





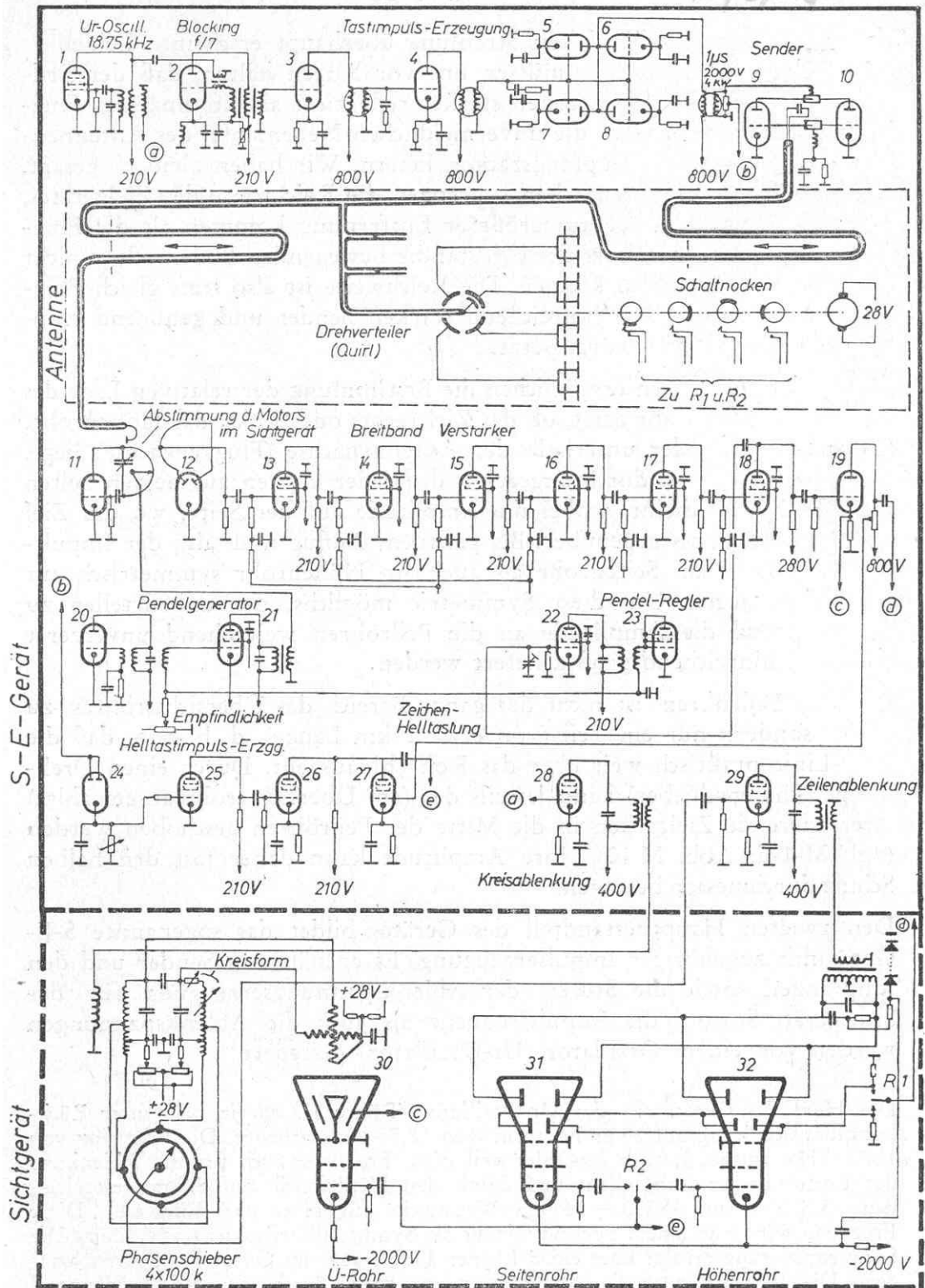
Magnetic Deflection System for the Circular Range Scope



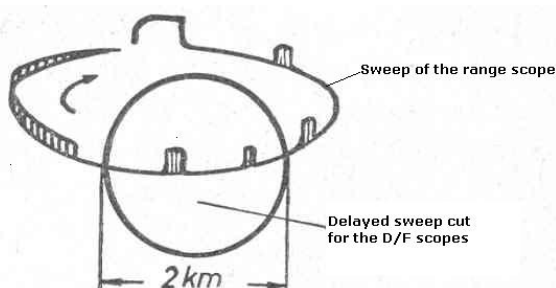
The presentation in range tube is more than simple deflection type. There is also intensity modulation the brightness of the trace being an increasing function of the output of the video amplifier.

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 than 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
- Pt 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 dB)

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

R for $\sigma_t 1 \text{ m}^2$ (ME109 small fighter) = < 1'700 meters

R for $\sigma_t 10 \text{ m}^2$ (HE111/HE177) = < 3'000 meters

R for $\sigma_t 40 \text{ m}^2$ (B24 or Lancaster bombers) = < 4'300 meters

Nachtjäger Messerschmitt Bf 110 G-4, C9 + EN

Interception radars: Lichtenstein FuG 202 & FuG 220

Weapons: 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:

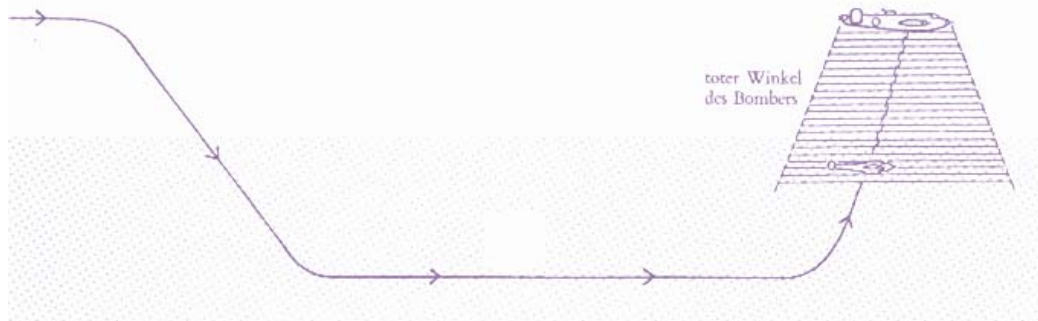
Pilot: Oberleutnant Wilhelm Johnen

Radiooperator: Leutnant Joachim Kamprath

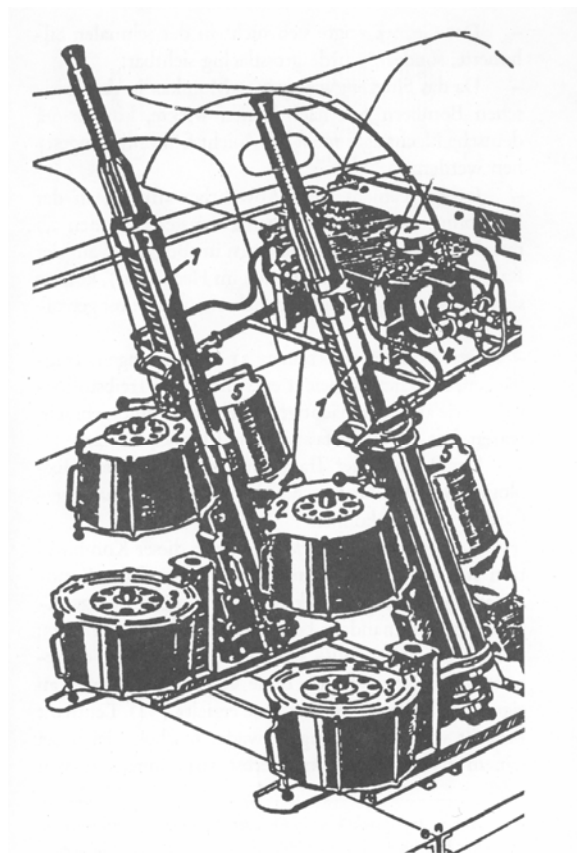
Gunner: Oberfeldwebel Paul Mahle

The German ME110 C9EN airplane had taken off 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.

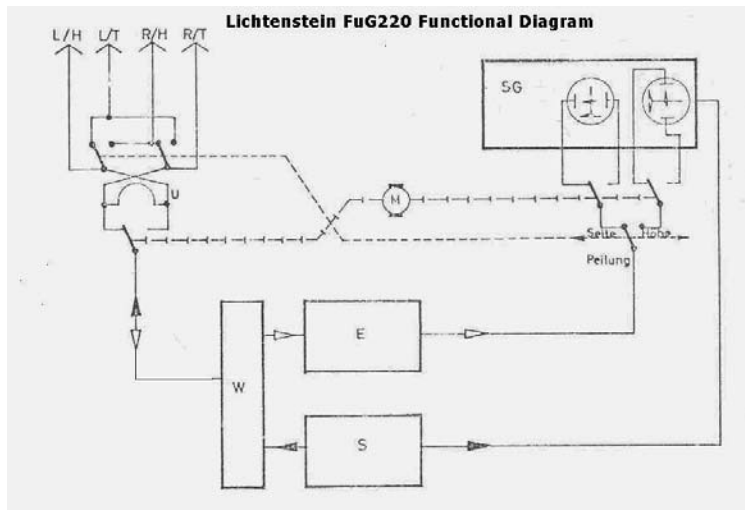
Attack procedure of the ME-110 Nachtjäger with the „Schräge Musik“ - weapon



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



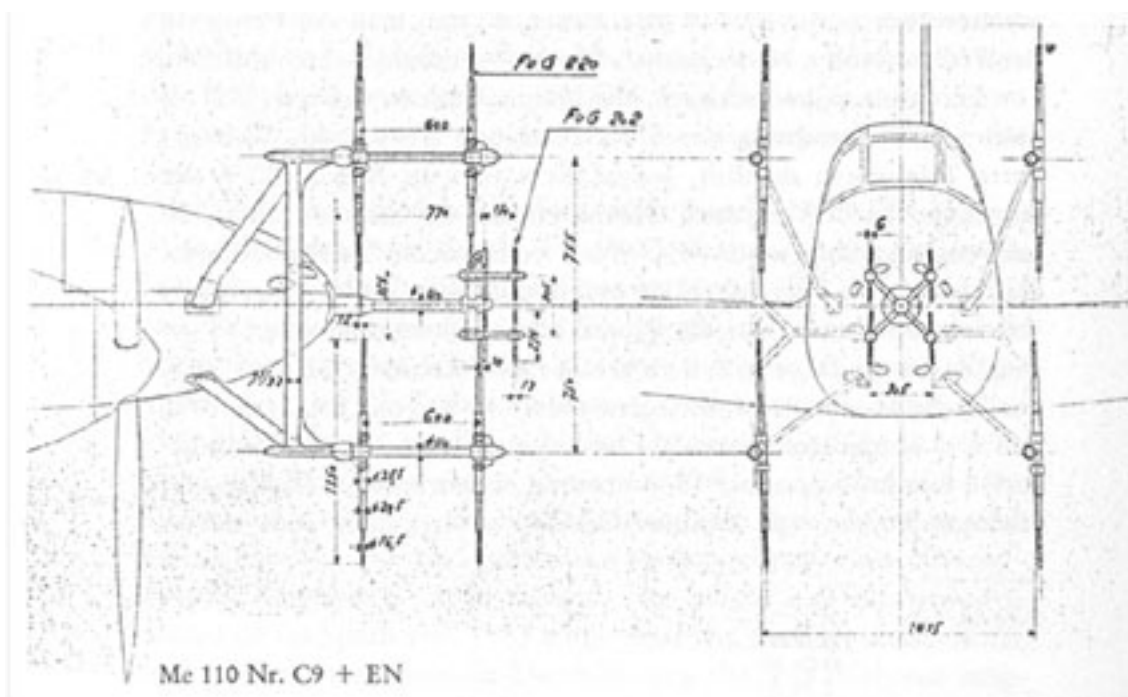
The German Lichtenstein FuG220 intercept radar was installed in twin engine night fighters. In addition to the numerical coding, it had the code Lichtenstein SN2. The Lichtenstein FuG220 intercept radar has a relatively wide cone of search, around $\pm 45^\circ$, direction finding for flying targets 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 + EN 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.

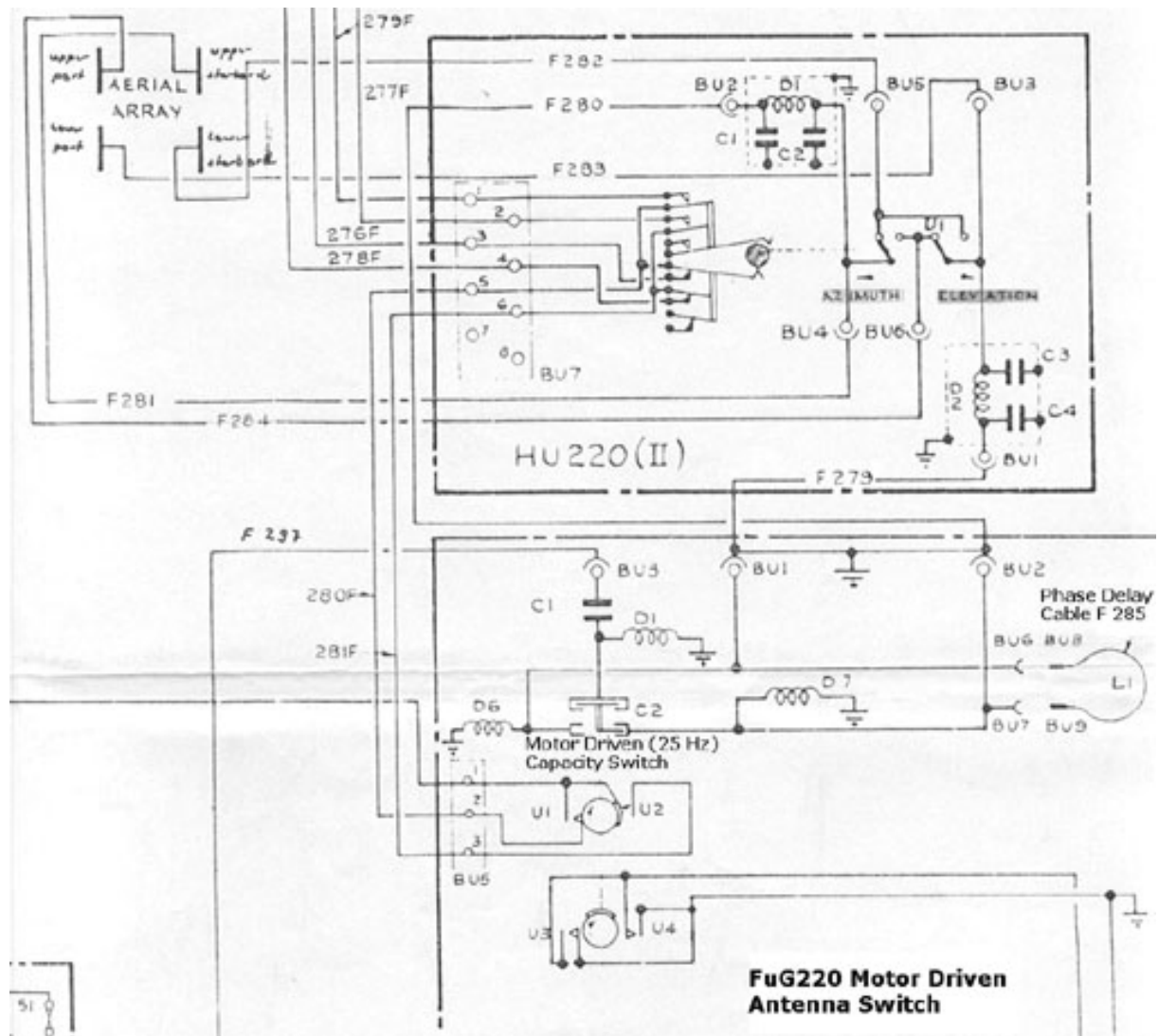
Lichtenstein FuG220 Antenna

Antenna Array of the German ME 110 C9EN airplane landed on 28th April 1944 at Dübendorf 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.



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

$$\Delta\phi_{90^\circ} = \frac{2\pi d \sin\theta}{\lambda} = \frac{2\pi d \cdot 1.415 \sin\theta \cdot 0.4416}{\lambda \cdot 2.5} = \text{rad } 1.5704 = \Delta\phi$$

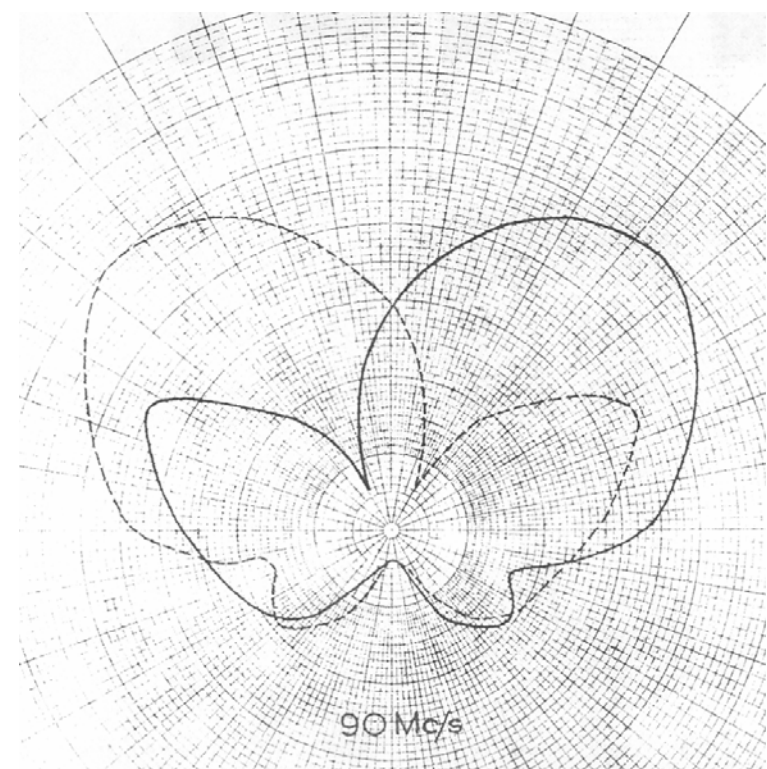
$$\sin\theta_{26.20^\circ} = \frac{\Delta\phi \cdot \lambda}{2\pi d} = \frac{\text{rad } 90^\circ = 1.570 \cdot \lambda \cdot 2.5}{2\pi d \cdot 1.415} = \sin\theta \cdot 0.4416 = \theta$$

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

$\sin\theta$ = Deviation of Beam from Broadside

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

λ = Wavelength 2.5 meters

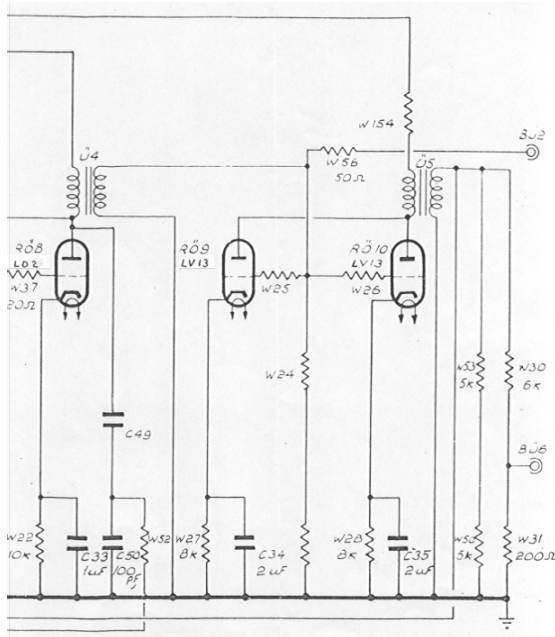


FuG220 Antenna Pattern Diagram for the operational frequency of 90 MHz.

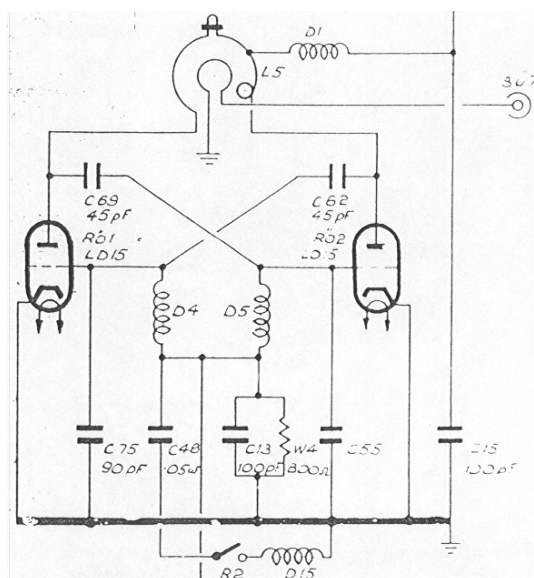
The Lichtenstein FuG220 radar was originally designed for operation in the 87 to 92 MHz frequency band. Therefore the D/F ratio is optimal between 90 and 91 MHz only. At lower and higher operational frequencies the D/F ratio does deteriorate increasingly.

Lichtenstein FuG220 Transmitter

The pulse transmitter found in the Messerschmitt Bf 110 G-4, C9 + EN 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 R0 8 is supplied over pulse transformer U4 to the grid of R09 and R10 (LV13 all-glass triodes). The 15 amps anode pulse current of R09 and R10 flows through the primary winding of the pulse transformer U5 and induces positive-going $1\mu\text{s}$ 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 R01 and R02 of the plate modulated oscillator stage. The load impedance of the transmitter is approximately 1000 ohms. The peak plate current is typically 2 amps.

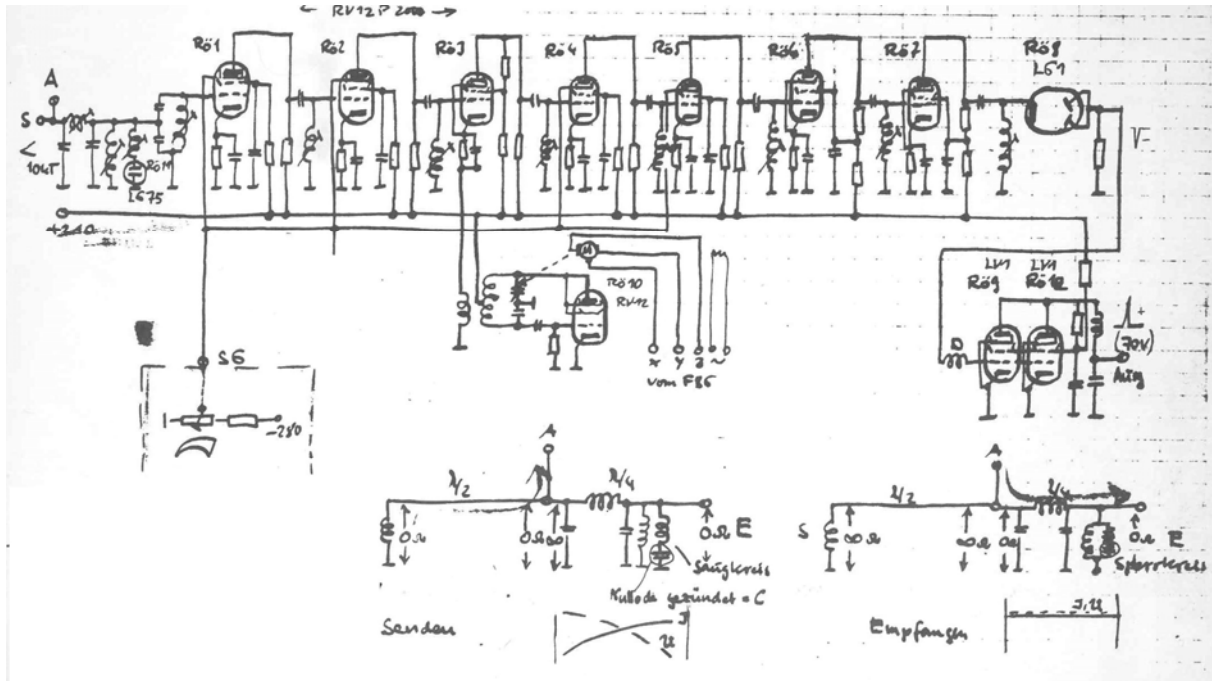


R01 and R02 are connected in a push-pull RF oscillator circuit, feed back taking place from anodes to opposite grids through condensers C62 and C69. The oscillator frequency is determined by inter-electrode capacities in conjunction with the anode circuit inductance. This consists of a single turn of 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 "Nahauflosungs-Relais" R2 is closed (activated by a switch on the indicator) the transmitter pulse will be reduced from $1\mu\text{s}$ to $0.6\mu\text{s}$.

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 $5\mu\text{V}$ (-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 ($\pm 2\text{MHz}$) of local oscillator frequency whilst in flight. The receiver gain can be controlled also in flight by a potentiometer on the indicator.

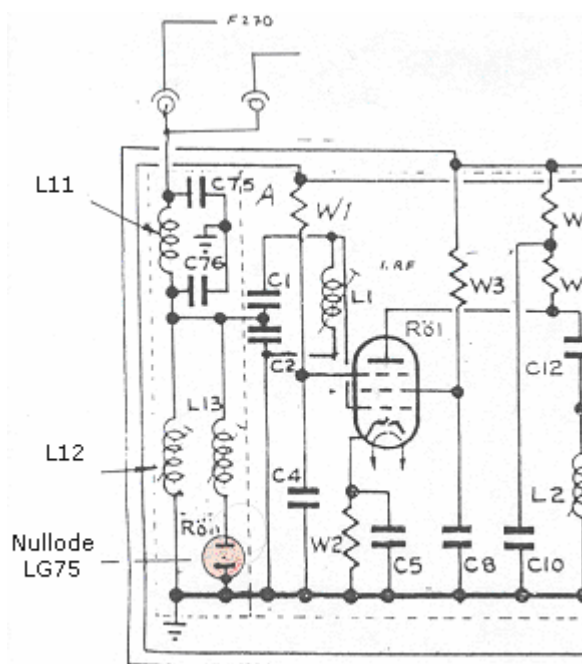
The Common T/R Unit

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.

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.

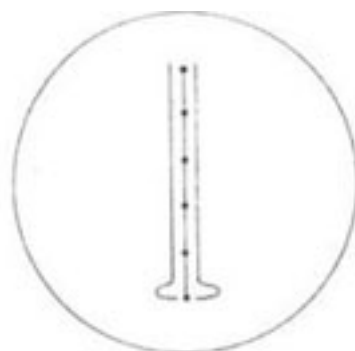
Remark

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.

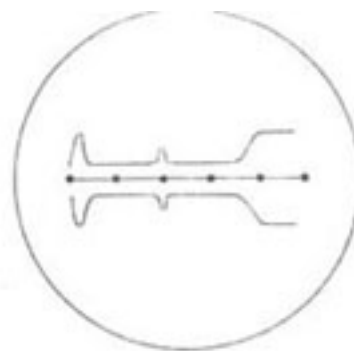
For better overall resolution the transmitter pulse-length can be reduced and it was possible also to change receiver bandwidth by bringing in damping resistors across the IF tuned circuits. Also the gain controlling line of the receiver was modified in that the time constants are considerably reduced 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).

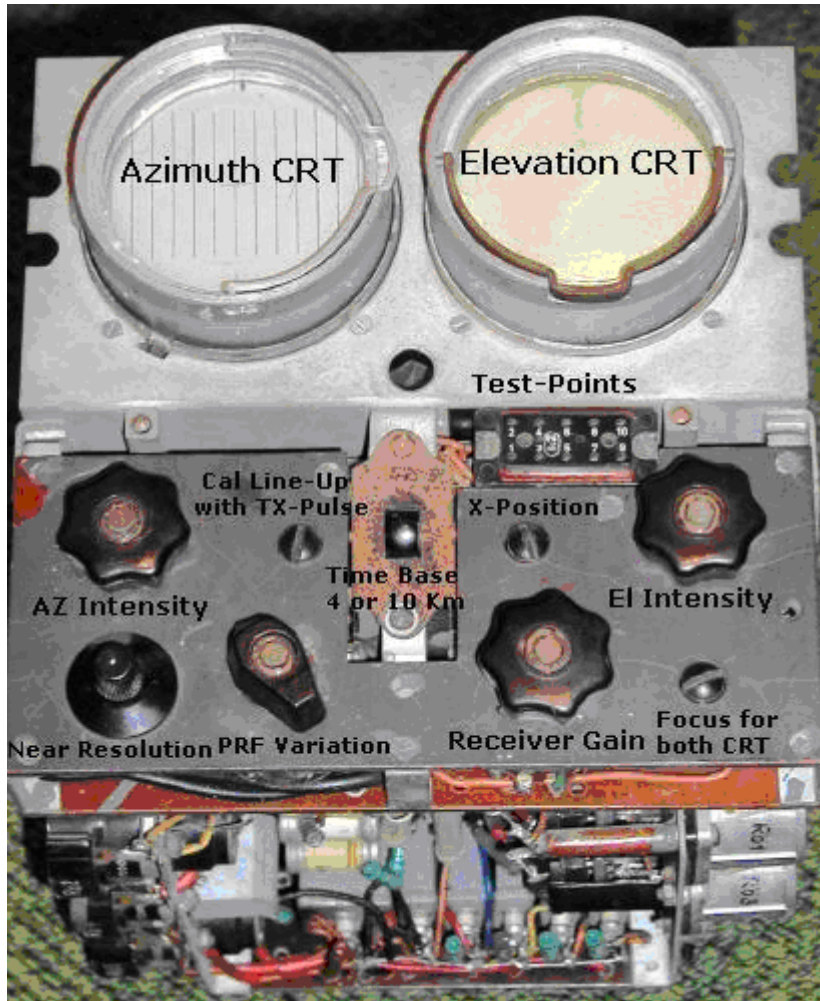


AZIMUTH TUBE

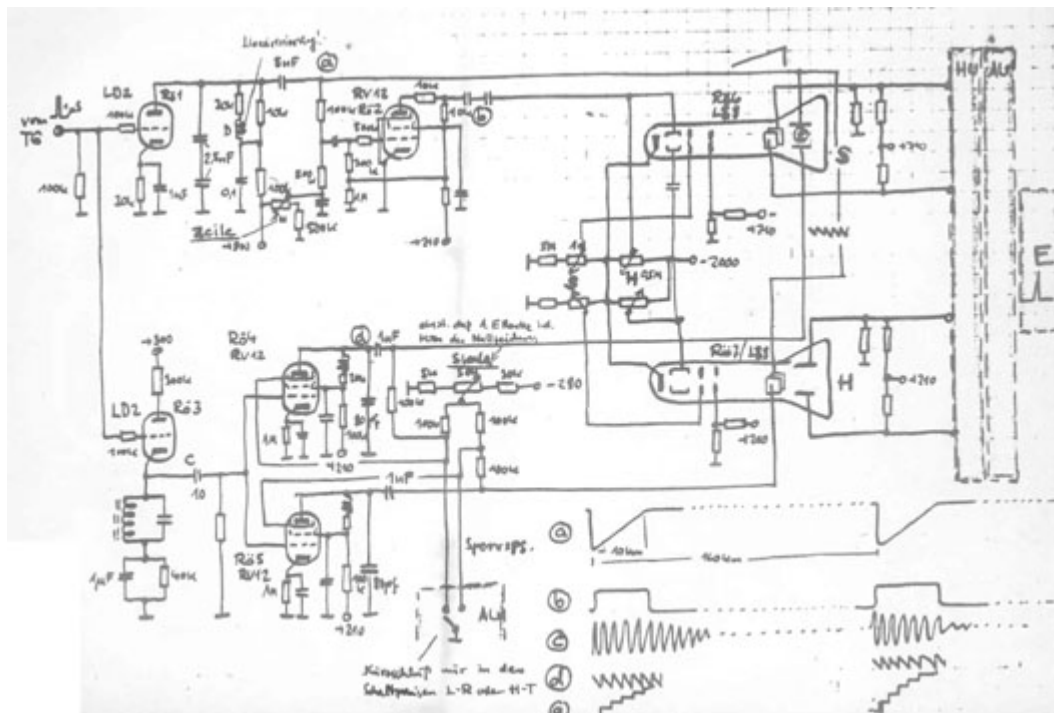


ELEVATION TUBE
(SHOWING ECHO AT 4 KMS
AND GROUND RETURN AT 7 KMS)

Original Lichtenstein FuG220 Indicator



Schematic of the Lichtenstein FuG220 Indicator



Lichtenstein FuG220, Indicator Function

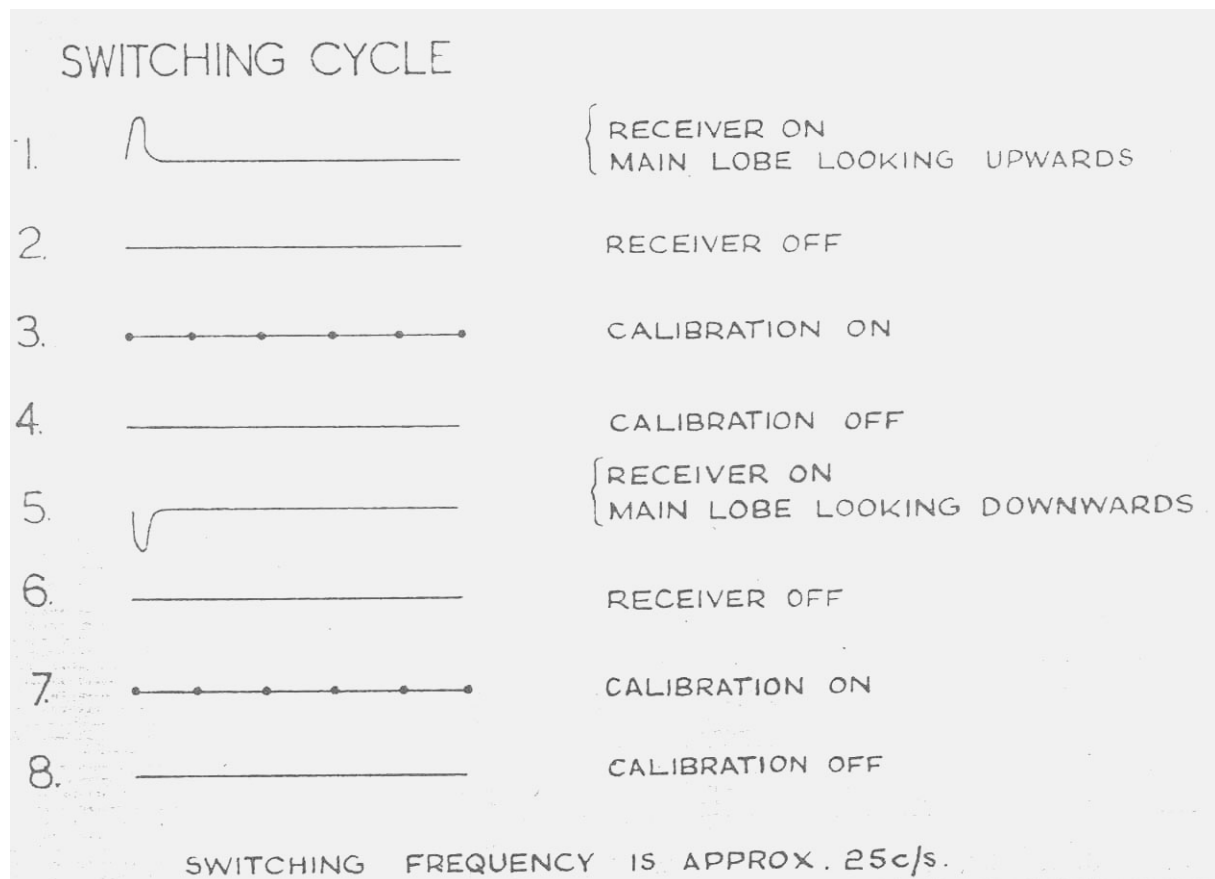
Positive triggering pulses from the modulator are applied to the grid of R \ddot{o} 1 and the resulting heavy anode current, rapidly discharge C1-2. After each pulse, the capacitor recharges slowly producing the required time-base voltage.

Tube R \ddot{o} 2 is used to provide a brightening waveform. Tube R \ddot{o} 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 R \ddot{o} 4 and R \ddot{o} 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-Laboratory 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 μ s
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)
σ	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)

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

R for σ 1 m² (small fighter) = < 3'200 meters

R for σ 10 m² (HE111/HE177) = < 5'800 meters

R for σ 40 m² (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 μ s).



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 $\leq 1\mu$ s 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 $\leq 3\mu\text{s}$ 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 too complicated for mass production, so Telefunken re-designed later the RS394 into the LS30 tube.



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

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