LONG LIFE 100 W TRIODE FOR ATC AND TELEMETRY TRANSPONDERS

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Summary Further development of the Siemens planar triode type RH7C-c used in the Mariner IV S-Band transponder resulted in the conduction-cooled type YD 1380 and air-cooled version YD 1381. These metal ceramic tubes produce a CW output power of 100 W in L/S-Band with a high efficiency around 40%. Small signal gain is 17 dB, and a large signal gain of 14 dB with a 20 MHz bandwidth is achieved. Life of selected sample tubes exceeds 25,000 hours, three times higher than the figure specified for the Mariner IV tube. These tubes incorporate an osmiated metal. dispenser cathode to achieve long life with stable performance. This type of cathode is exceptionally resistant to bombardment by electrons turned back to the cathode as a result of transit-time effects in the cathode-grid space. In transponder applications this allows long intervals between maintenance to be specified for the output stages. Because of the rugged tube design and low weight of the complete amplifier, the YD 1380/81 is also suited for spacecraft applications. An air-cooled, 100 W CW amplifier for 1.6 GHz has a diameter of only 74 mm and length of 175 mm. The laboratory prototype including triode YD 1381 weighs 900 gms, but this weight can be halved if necessary. Fig. 1 shows the tubes YD 1380 and YD 1381.

The main applications for these new tubes are in ATC systems, telemetry, L-band communication UHF and L-band TV (ETV) and SSB microwave link equipment.

Tube Design

Electron Transit-Time Effects In L and S band electron transit-time effects influence the life and efficiency of planar triodes appreciably.

In the grid-cathode space, electron transit-time effects start to become harmful around 2 GHz. Because of the finite transit-time, a portion of the electrons only approach the control grid when the instantaneous value of the alternating control grid voltage is negative again. These electrons are therefore slowed down, return to strike the cathode and dissipate energy there. The “back-heating” produced depends on the transit-time angle and drive level. With oxide cathodes this process results in localized overheating of the emitting layer. Reducing the heater power only partly compensates the effect. As the negative half cycle of the drive voltage accelerates the electrons back to the cathode, in class C operation - necessary for high efficiency - the back-heating becomes particularly pronounced, and leads to localized sputtering of the oxide emitting layer. At CW power levels around 100 W, the life expectancy of a planar triode with an oxide cathode is not especially high.

The Metal Dispenser Cathode A type of cathode that proved over many years of investigation to be substantially less sensitive to bombardment by returning electrons is the so-called metal dispenser cathode. In this type of cathode a porous tungsten disc is the emitting surface. A barium film necessary for emission forms on the surface by capilliary action from a compound containing barium located below the disc in a reservoir. The metal dispenser cathode is also capable of operation at higher current densities than the oxide type. This increases the electron velocity appreciably, which in turn reduces the effect of electron transit time and, improves efficiency. With the present state of the art, only tubes with metal dispenser cathodes have high efficiency (approx. 40%), high reliability and exceptionally long life
simultaneously in L-band.

A cathode current density of 0.4 A/cm^2 was chosen for the YD 1380, which keeps the electron transit time in the grid-anode space sufficiently low. The tube can therefore be operated with large amplitude alternating plate voltages and low residual plate voltages This is a major prerequisite for high efficiency operation.

Grid Design The grid structure has decisive influence on the amplification and intermodulation properties. By using an unsymmetrical cross-wire grid (fig. 2) a performance far excelling that achievable with a regular cross-wire grid has been obtained. The cathode side is a layer of thin tungsten wires. This fine parallel-wire grid is supported on the anode side by a layer of thicker wires with a larger pitch. Both layers are pretensioned almost to the breaking limit and brazed together at each crossover point. This new grid design combines the advantages of the parallel-wire and cross-wire grids and makes possible very close grid-cathode spacing even in operation with high thermal and mechanical stress.

Tube Construction An entirely new contour was selected for the envelope (fig..3). The following features were decisive:

a) Tunability in the quarter-wave mode up to 2.3 Ghz.
b) Reproducibly accurate electrode spacings.
c) Thermally stable anode.
d) Good shielding of the ceramic isolator between grid and anode to prevent deposits.

e) Short paths and hence low temperature gradients for dissipating heat from the anode.

Operating Data and Characteristics

Development History The first generation of planar triodes with metal dispenser cathodes were developed between 1955 and 1960. Typical examples are the Siemens types RH6C and RH7C. Compared with tubes having an oxide cathode, it was possible to increase the maximum frequency for oscillator and amplifier operation from 4 to 7 GHz. Typical life was around 2,000 hours. The main limitation was the grid clogging with barium. Technological improvements enabled the barium evaporation rate to be reduced. By 1964, when the Siemens RH7C-c was selected for the Mariner IV Mars mission, lifetimes of 7,000 to 10,000 hours were being achieved. A subsequent developmental version type V251 produced double the power of the Mariner IV tube - from 10 W to 20 W CW at 2.3 GHz with increased gain. Further development produced the second generation tubes YD 1380 and YD 1381. Type YD 1380 is a conduction-cooled version with a threaded stud anode, type YD 1381 is provided with a radiator for forced-air cooling. The decisive steps were an increase in CW power to 100 W and substantially higher expected lifetime.

Gain By using a close grid-cathode spacing and a fine wire grid, the transconductance could be raised to more than 50,000 micromhos. At a frequency around 2 GHz, this gives a small-signal gain in the ground grid configuration of 17 dB. The input/output characteristic and variation of grid current with input power are shown in fig. 4. With the high gain, a drive power of only 4 W is necessary for 100 W output power, and this can easily be obtained from a solid state source. Because of the high gain, that portion of the grid dissipation power originating from the drive power is also very low. Typical operating values are shown in table 1.

Table 1

Frequency	1.6	2.3	Ghz
CW output power	125	100	W
Gain	14.5	13.5	dB
Plate voltage	1400	1300	V
Quiescent plate current	160	160	mA
Plate current with rf	220	210	mA
Grid current	18	16	mA

Intermodulation A measure of the intermodulation performance is the two-tone intermodulation ratio IM_2 as defined in fig. .5. Its value depends on the output power. The output level can be considered in two respects: The output power of the individual carrier P_{f1} or P_{f2} add to give the sum power $P_o = P_{f1} + P_{f2}$. Because of beating at the difference frequency Δf a peak envelope power of double the sum power is produced. Hence if the YD 1380 is operated with two carriers each of 50 W, the sum power is 100 W and the peak envelope power 200 W.

If traveling-wave tubes or klystrons are operated close to saturation, the two tone intermodulation ratio is only about 10 dB. With transistor amplifiers about the same value applies. By comparison, when the YD 1380 is operated at 200 W PEP, the two tone intermodulation products are 24 dB below the carrier level. Fig. 6 shows intermodulation product level as a function of peak envelope power.

Life Test Results The disadvantage of earlier metal dispenser cathodes was their relatively high rate of barium evaporation during operation. This caused grid “clogging” and resultant characteristic shift despite constant emission. The cathode of the YD 1380 is coated with osmium to minimize this effect. The osmium coating improves the emission and permits the cathode to be run about 100°C cooler.

The osmium coated cathode can be manufactured by a new process in reproducible quality with high emission. This makes it possible to fully exploit for the first time the advantages of the metal dispenser cathode in the YD 1380 and YD 1381 to obtain a gridded tube with extremely long life.

Tube performance at 20 W and 100 W CW output power has been observed with selected tubes over a long time. Up to 20,000 hours no notable changes in performance have been observed. In 100 W operation, the output power with constant input power has so far dropped from 100 W to 90 W. Three tubes operated at 20 W show no measurable changes after 20,000 hours. In both cases the heater voltage was reduced as far as possible to minimize barium evaporation. For 100 W the heater voltage was 5.6 V, for 20 W 5.2 V. The operating conditions are shown in table 2.

Table 2

Frequency	2.3		GHz
Power output	20	100	W
Heater voltage	5.2	5.6	V
Plate voltage	600	1300	V
Plate current	100	≈200	mA
Bandwidth	≈25	≈25	MHz
Temperature	130 to 140		°C

The life tests were conducted at a tube temperature of 130 to 140°C for 20 W operation as well as for 100 W operation. For very long life the temperature should not exceed 150°C.

Shock and Vibration Resistance To test their resistance to acceleration, the tubes were subjected to the same shock and vibration tests as used for the Mariner IV program.

Spurious Noise Voltage Caused by Vibration In six runs each of 5 minutes duration the tubes were subjected to 10 g in both the X and Y direction. During the run the frequency was varied from 50 Hz to 500 11z and back to 50 Hz. When measuring the maximum vibration noise voltage the frequency was held constant for 30 seconds. Tests were made on three tubes (s/n 35, 36, 37) operated as follows:

$E_f = 6.0\ \text{V};\quad E_b = 300\ \text{V};\quad I_b = 10\ \text{mA};\quad R_a = 10\ \text{k}\Omega.$

The results were similar to those obtained with the RH7C-c (table 3).

Shock Test The tubes were subjected to 5 shocks each in the Y_1 , Y_2 and X directions. Here Y_1 denotes the direction along the tube axis from anode to cathode and Y_2 the opposite direction. The acceleration was 500 g, the duration 1 Millisecond.

Before and after the shock test the characteristic data and tube capacitances C_{gk} C_{ag} and C_{ak} were measured. Within the measuring accuracy, no changes to any of the three tubes could be detected after the shock and vibration tests.

Table 3\

Noise Voltage

Tube s/n 35	Direction X	50-500 Hz	32-35 mVrms
	Direction Y	500 Hz	45-48 mVrms
Tube s/n 36	Direction X	500 Hz	20 mVrms
	Direction Y	476 Hz	54 mVrms
Tube s/n 37	Direction X	500 Hz	18 mVrms
	Direction Y	500 Hz	47 mVrms

100 W CW Cavity Amplifier A 100 W CW cavity amplifier was developed for L-band. At this high power level particular consideration must be given to high frequency losses, heat dissipation and tube cooling. High frequency losses in the plate circuit impair the circuit efficiency, which reduces the effective power output and increases the tube loading. The gain also falls as the circuit losses increase, and the intermodulation performance worsens. The basic cavity design shown in fig. 7 is suitable for frequencies from 1.5 to 2.3 GHz. With an unloaded Q_o of about 800 and loaded Q_L of 100, the circuit efficiency ζ is given by:

$$\eta = (1 - \frac{Q_L}{Q_o})\ 100\% = 87.5\%$$

At this efficiency the tube can be operated up to 125 W at 1.6 GHz or 100 W CW at 2.3 GHz.

Particularly important for stable amplifier operation is the neutralization. It prevents the amplifier from oscillating with mismatches at the input and output or during alignment. In YD 1380/81 amplifiers a reverse loss in excess of 24 dB has proved adequate. The reverse loss is obtained by applying a signal to the amplifier output with the tube operated normally and measuring the attenuated level at the input. It can be optimized by a series inductance at the grid terminal or with a neutralization loop. The variation of gain, bandwidth and return loss with neutralization is shown in fig. 8. Maximum return loss represents optimum neutralization. The bandwidth becomes smaller with underneutralization and wider with overneutralization. Slight underneutralization assures adequately stable operation with high gain.

The amplifier shovrn is forced air cooled. The tube radiator is designed for use with a low-pressure blower. With an air inlet temperature of 50°C the tube bulb temperature is far below 15° C, the maximum value for long tube life.

Future Possibilities The tubes and amplifier described are commercially available products. Higher powers can be obtained by connecting amplifiers in parallel to double or quadruple the power. In the future, however, it appears feasible to develop tubes for higher output powers. The design concept of the YD 1380/81 with the highly reliable metal dispenser cathode offers an ideal starting point.

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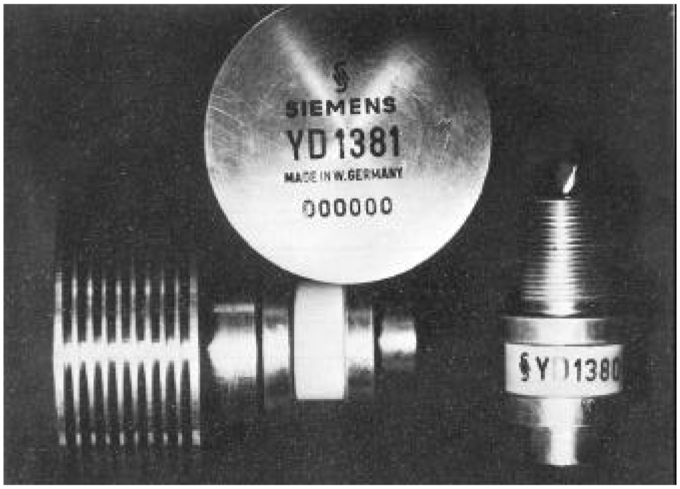

Fig. 1 - Tubes YD 1380 and YD 1381

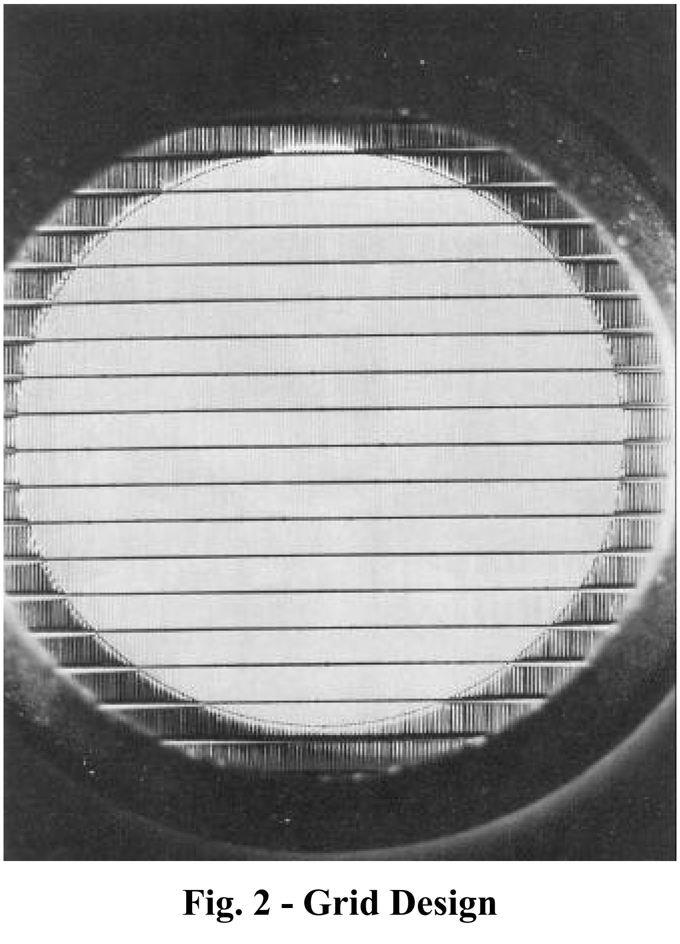

Fig. 2 - Grid Design

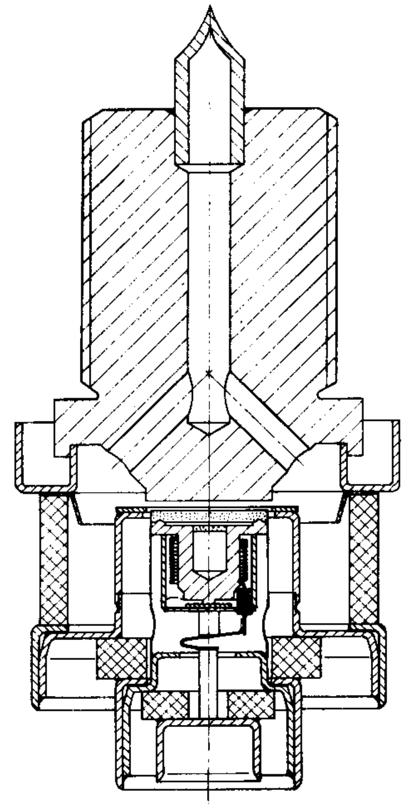

Fig. 3 - Section through the Tube YD 1380

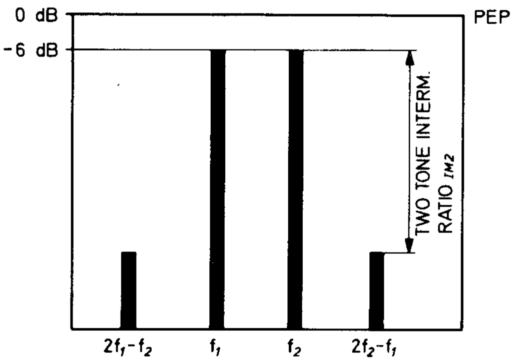

Fig. 5 - Level Diagram to define the Two Tone Intermodulation Ratio.

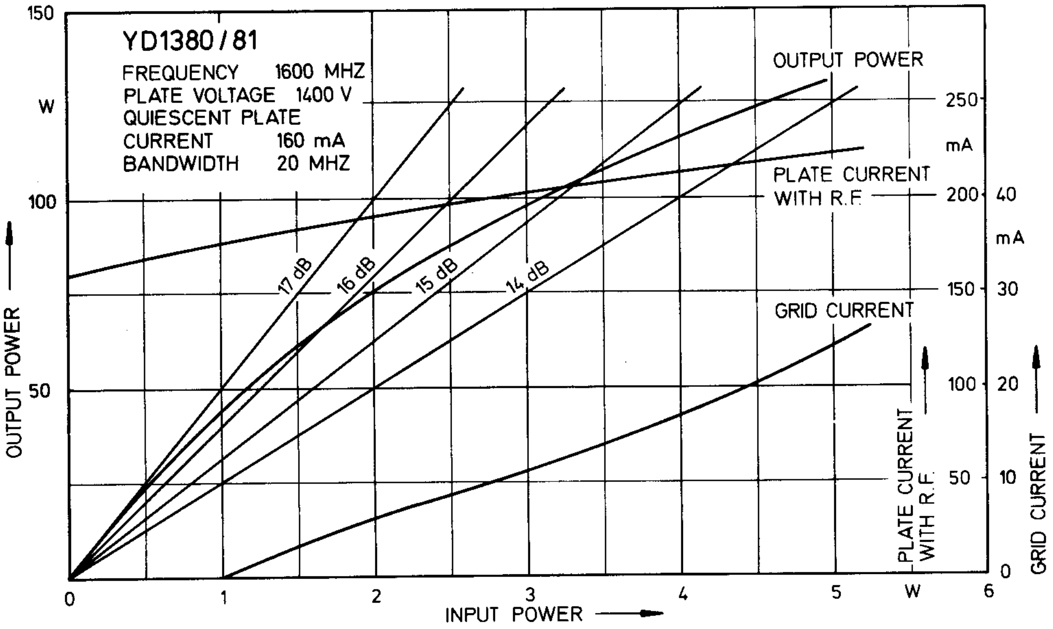

Fig. 4 - Grid Current and Output Power as a Function of the Input Power.

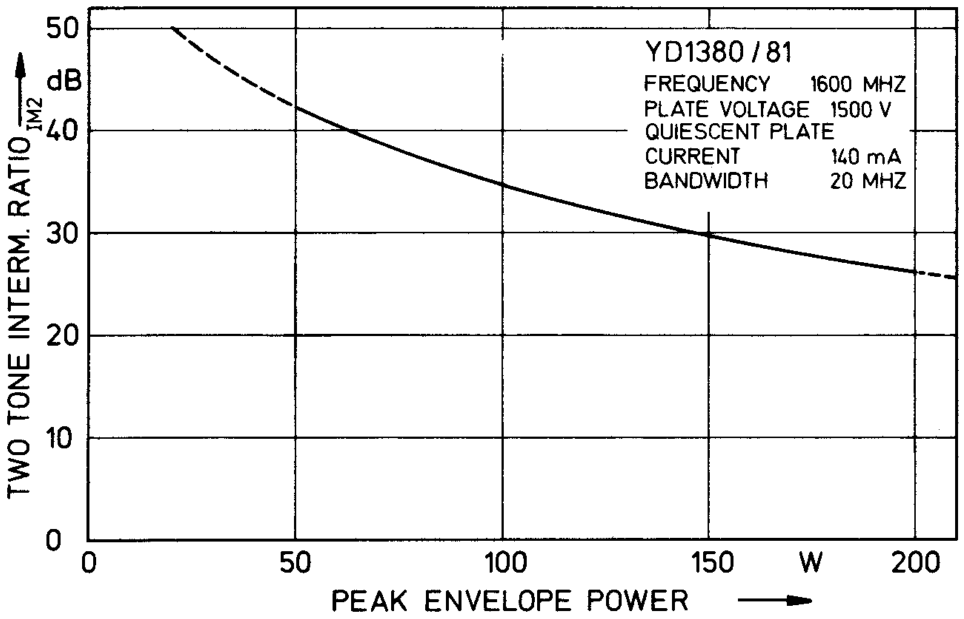

Fig. 6 - Two Tone Intermodulation Ratio as a Function of Output Power.

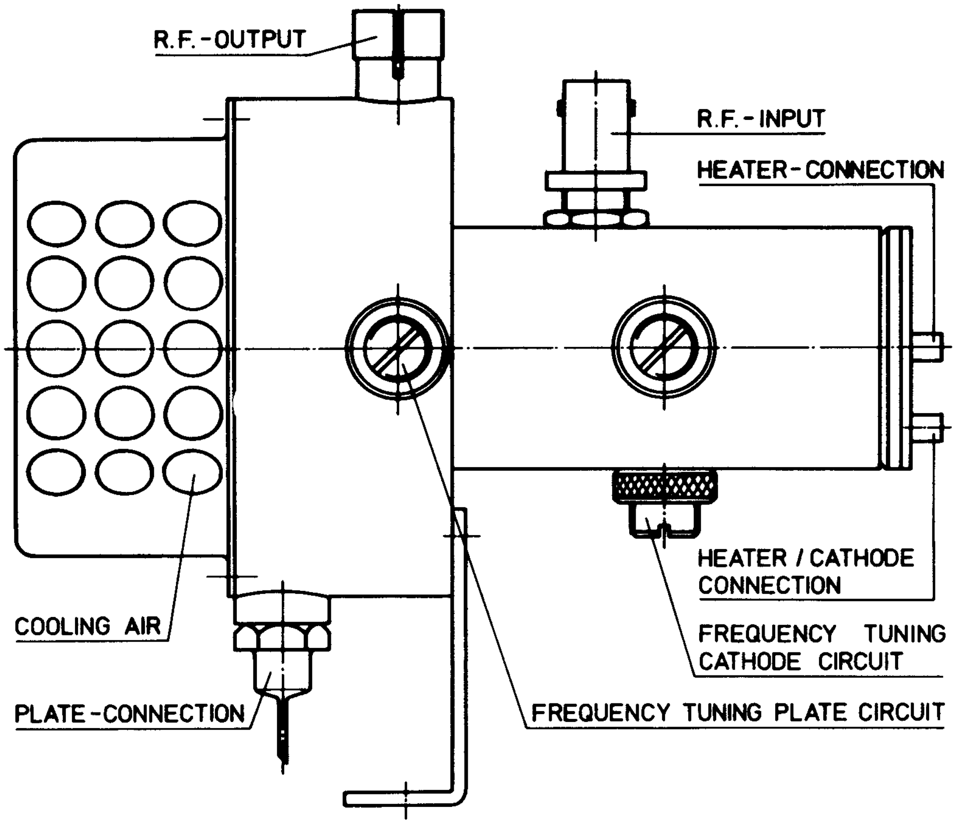

Fig. 7 - L-Band Cavity Amplifier for 100 CW.

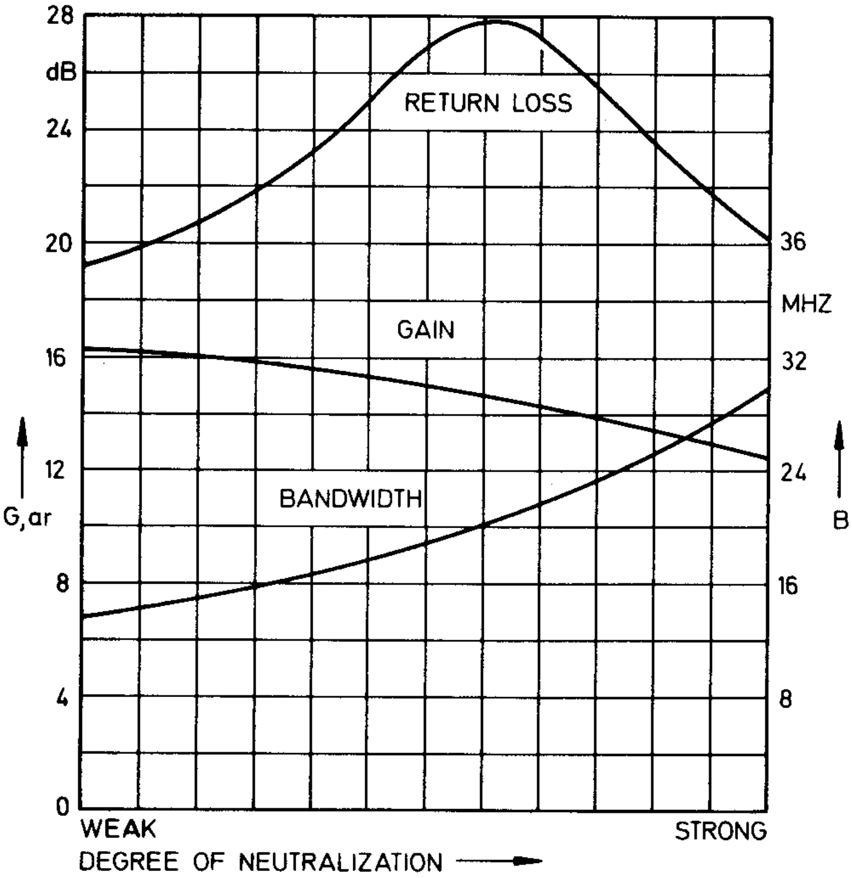

Fig. 8 - Variation of Gain, Bandwidth and Return loss with Neutralization.