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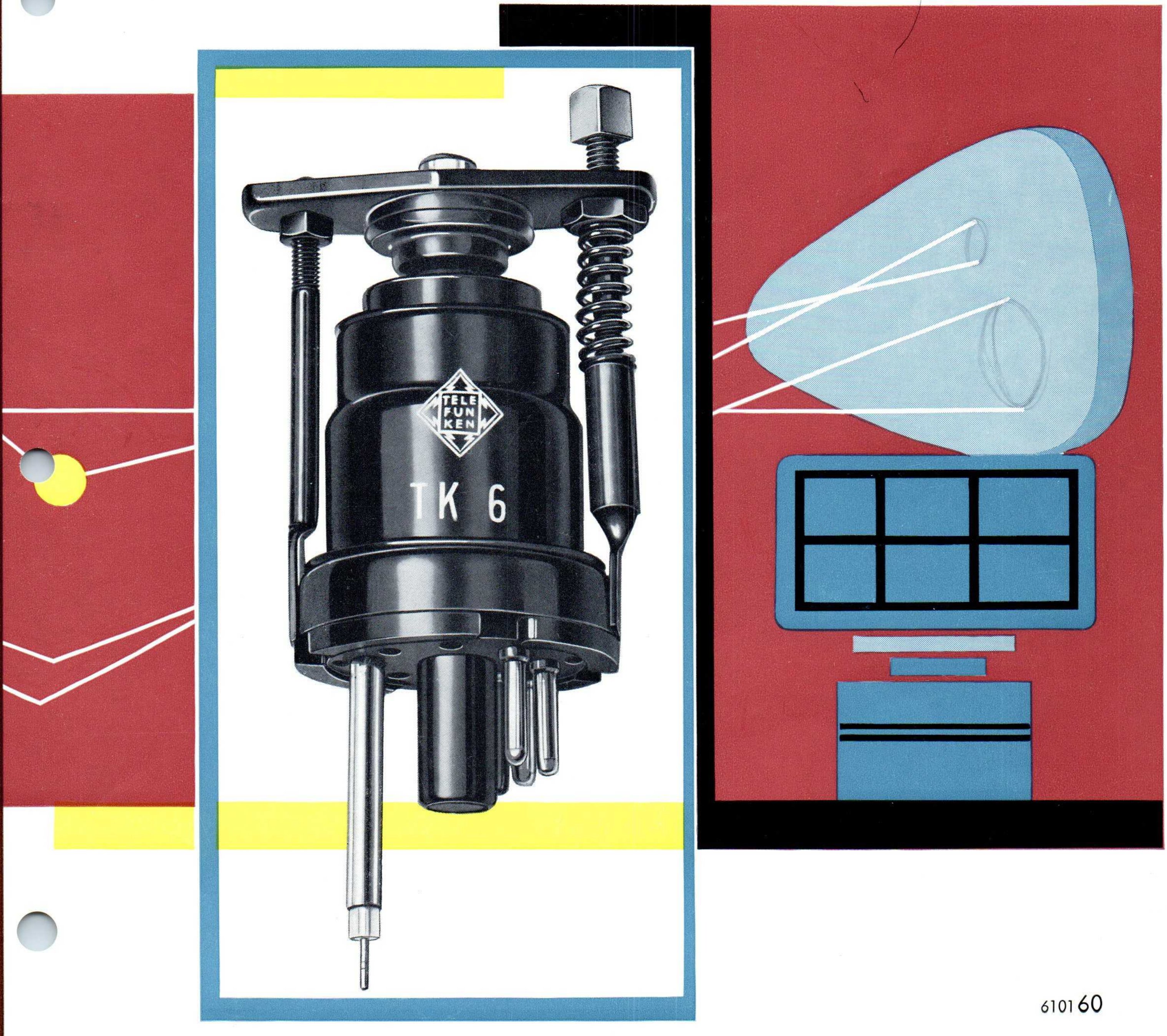
The TELEFUNKEN Reflex Klystron TK 6



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THE TELEFUNKEN REFLEX KLYSTRON TK 6

SUMMARY

This prospectus describes the design and electrical properties of the TELEFUNKEN Reflex Klystron **TK 6** that can be employed as frequency modulator or local oscillator in narrow-band radio link systems and radar links operating in the frequency range from 6.3 to 7.7 Kmc/s.

CONTENTS

1. APPLICATION

Mainly reflex klystrons are used to generate oscillations in the centrimetric band. In many of these tubes the frequency-determining resonant circuit is incorporated in the tube body in the form of a cavity resonator, and thus no external elements are required to generate the oscillations. Such inner cavity reflex klystrons are tuned in a simple manner by using a flexible diaphragm to vary the spacing of the resonator gap. In addition to the heater voltage only two stabilized DC voltages, the resonator and reflector voltages, are required for operation.

The TELEFUNKEN Reflex Klystron **TK 6** described here operates in the frequency range from 6300 to 7700 Mc/s with a maximum power output exceeding 200 mW. In order to satisfy the requirements of equipment manufacturers the frequency range was extended above that of the U.S. Reflex Klystron RK 5976. The **TK 6** can be used as frequency modulator and local oscillator for transmitter and receiver in measuring equipments, portable TV radio-camera channels, radar links, narrow-band radio link systems etcetera.

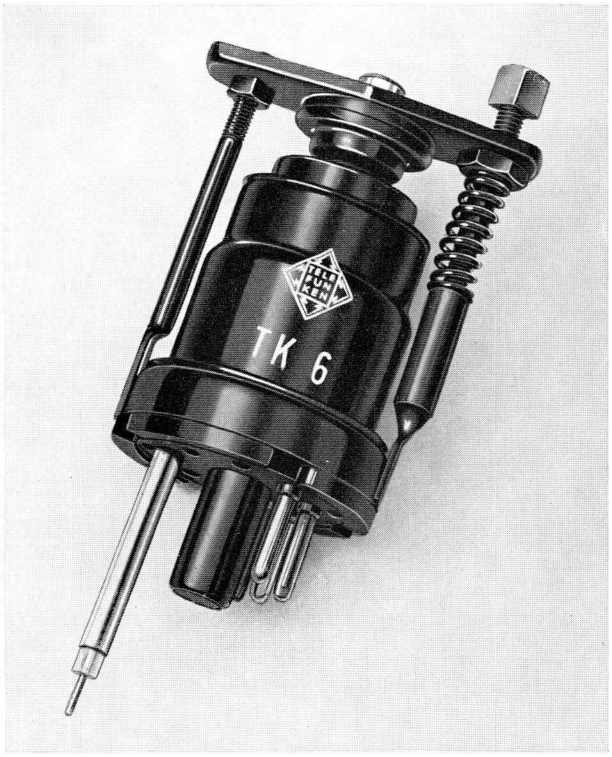

Fig. 1 TELEFUNKEN Reflex Klystron **TK 6**

2. DESIGN

The **TK 6** is an inner cavity reflex klystron constructed entirely of metal with coaxial terminals. Externally (Fig. 1) the tuning device, a screw drive, and the coaxial line at the tube base are conspicuous. The cross-section drawing Fig. 2 shows the construction of the electron gun, the resonator and the reflector.

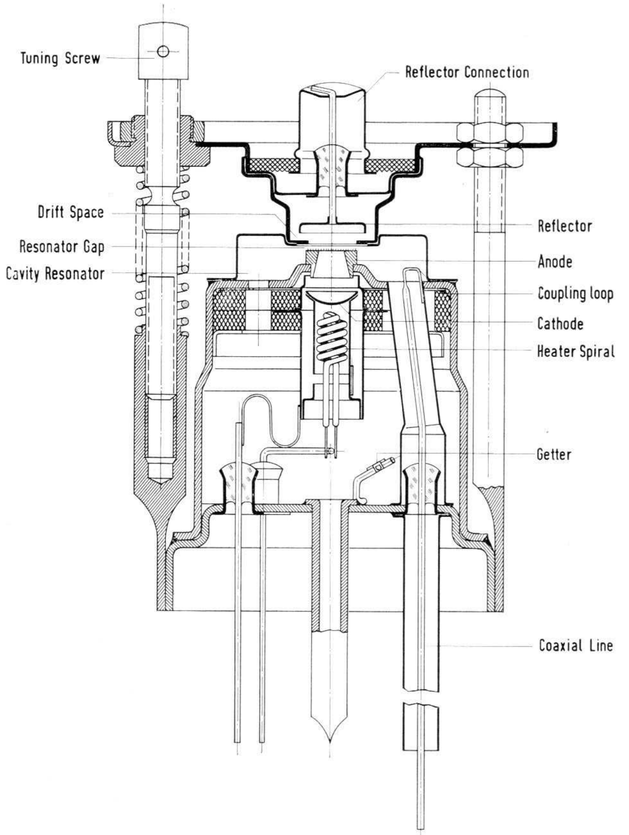

Fig. 2 Design of the Reflex Klystron **TK 6**

2.1 Electron Gun

A high-perveance electron gun was developed as cathode assembly for the **TK 6** since the RF power generated in the klystron, the efficiency and the electronic bandwidth increase with rising perveance. This perveance of the **TK 6** electron gun is approx. $5 \cdot 10^{-6}$ A/V$^{3/2}$, a very high value for electron guns without accelerating grids.
An electron gun not having an accelerating grid has the advantage that the formation of undesirable plasma oscillations of ions and electrons is prevented to a great extent. At an anode voltage of +300 V the system supplies 24 mA current.
The cathode surface is shaped like a button. The cathode current density of the **TK 6** is approx. 100 mA/sq.cm. This low cathode load is an important factor to ensure long life. Special value was attached to a laminar flow of electrons in the electron gun because noise can be reduced to a minimum in this way.
The cross-section of the beam tapers with increasing separation from the cathode and reaches its narrowest width in the resonator gap. In this manner it is possible to keep the capacitive load of the resonator small, and thus the circuit losses also.

2.2 Resonator

The resonant circuit is designed as a circular cylindrical cavity resonator capacitively loaded (Fig. 2). The post used for capacitive loading is the anode at the same time and holds the first grid closing the circuit. The second grid is soldered in the upper front surface designed as diaphragm. Since the resonator coupled to the anode potential is part of the metal tube body, the positive pole of the anode voltage is normally grounded. By varying the resonator capacity the operating frequency of the klystron is adjusted. To this end the upper front surface of the resonator constructed as diaphragm can be shifted in axial direction by means of a tuning device. This movement is brought about by turning a screw which is provided with two threads of slightly different pitch and produces a movement proportional to the difference in pitch. High setting accuracy is achieved in this manner. The advantage of this type tuning device is that the temperature coefficient of the tube can be kept low. At 120 $\pm$ 50 kc/s/°C it is relatively low in comparison with klystrons of a similar type. A further advantage of the tuning device, particularly with mechanical tuning, is the almost linear dependence of frequency on the number of turns of the tuning screw as can be seen from Fig. 3.

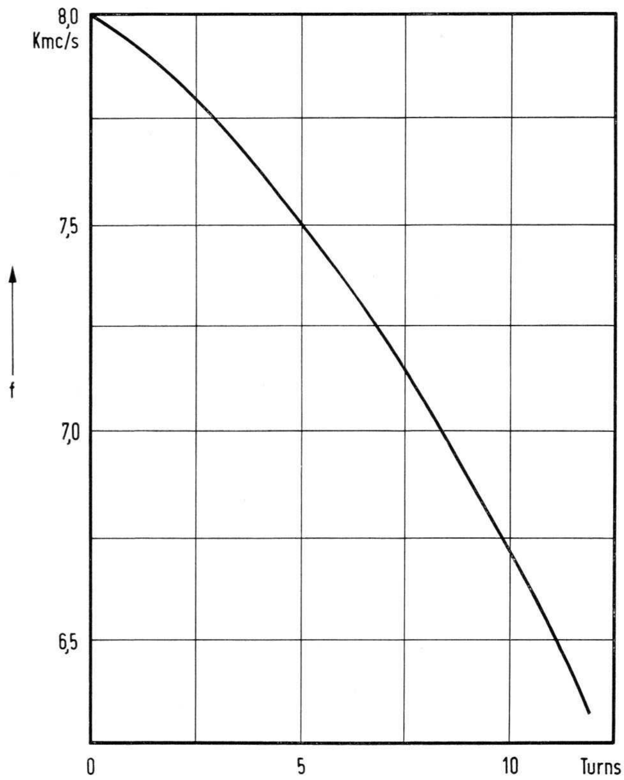

Fig. 3 Klystron frequency as a function of the number of turns of the tuning screw

2.3 Reflector

The reflector space joins the upper front surface of the resonator (Fig. 2). In the reflector space the electrons arriving from the cathode are retarded by the reflector biassed negatively, and finally even reflected back to the anode. Several modes can arise, depending on the reflector voltage selected. In the **TK 6** the length of the reflector space, which is terminated by the reflector, is designed for operation in the 3rd mode corresponding to a phase angle of $\Phi = 7.5\ \pi$. This represents a compromise between maximum output and widest possible bandwidth. Furthermore, in this mode noise is particularly low (cf. Section 3).

2.4 Output Coupling

The RF power is inductively coupled on the cavity resonator and is derived via a coaxial line.

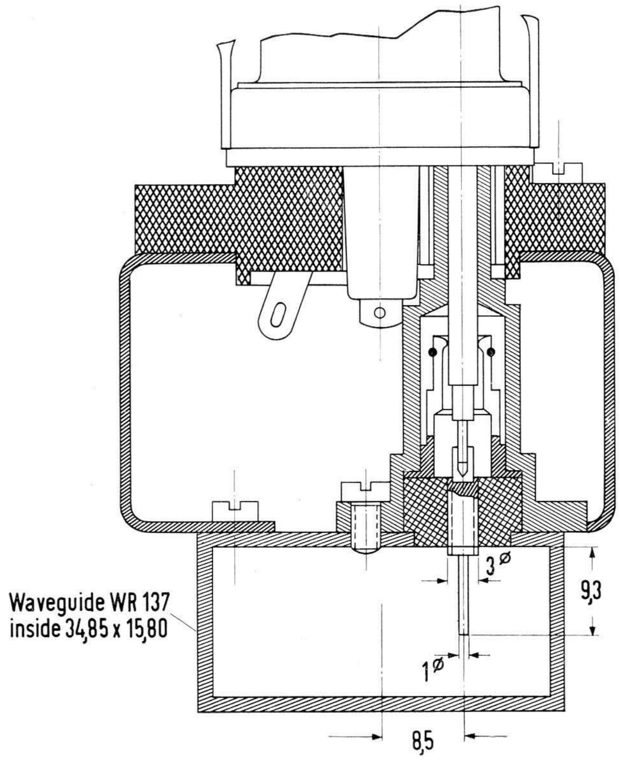

Fig. 4 Example for coupling tube **TK 6** to a square waveguide

Fig. 4 shows a method of coupling the tube with a square wave-guide. The dimensions of the various parts required can be seen from Fig. 5. In order that maximum power can be derived from the tube at all frequencies, it is necessary to match the load to the generator, in this case the reflex klystron. For this purpose a waveguide stub fitted near the input coupling is suitable whose electrical length can be varied, by a sliding shunt contact for example. For a fixed frequency it is quite sufficient to mount tuning screws as quarter-wave transformer near the input coupling.

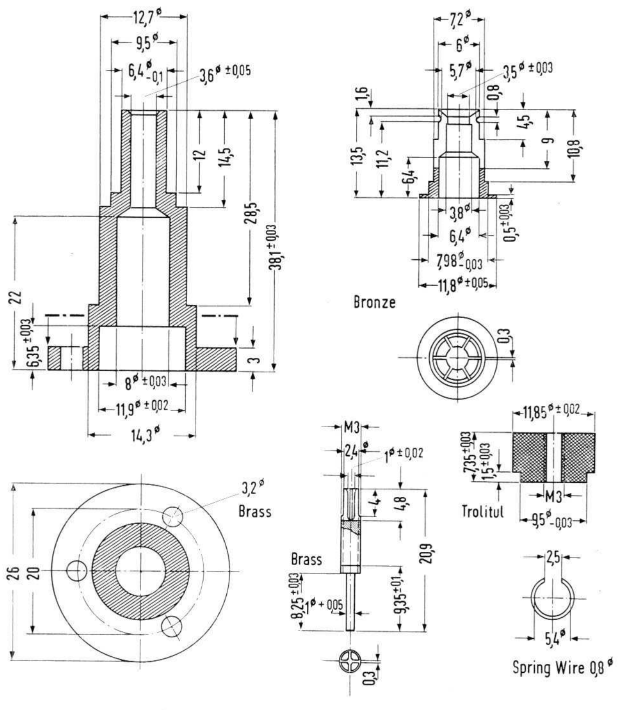

Fig. 5 Components of waveguide coupling

3. ELECTRICAL PROPERTIES

After leaving the gun the electrons travel through the radio frequency field across the resonator gap. The electron beam thus velocity-modulated passes into the negative field of the reflector space and is reflected there. At the same time the velocity-modulated beam is converted into a beam with periodic variations of current density. If the reflector DC voltage is selected so that the electrons enter a retarding phase of the control field when they return to the gap, they give up energy and the klystron is excited. After giving up power the reflected electrons strike the front surface of the anode and are thus prevented from reentering the reflector.

3.1 Output

As with all reflex klystrons, the RF output power of the **TK 6** is dependent on frequency (Fig. 6). At about 7.4 Kmc/s the tube reaches its maximum output of approx. 200 mW corresponding to an approximate efficiency of 2.5 %.

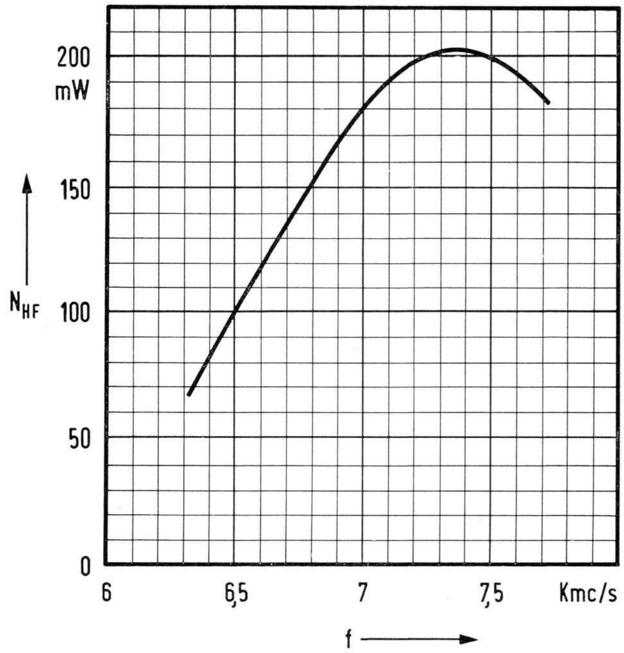

Fig. 6 RF output as a function of frequency

3.2 Optimum Reflector Voltage

At each mechanically adjusted frequency there is a definite reflector voltage at which the tube supplies its optimum RF output. In Fig. 7 this voltage is shown as a function of frequency.

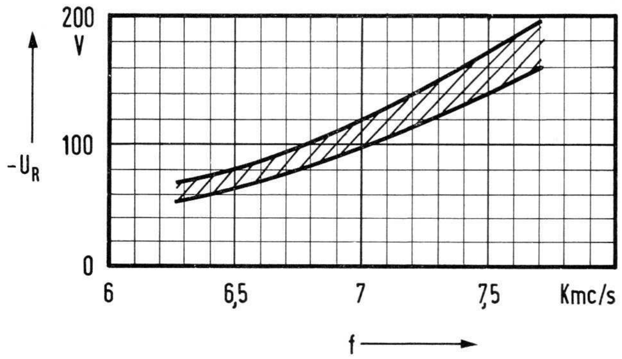

Fig. 7 Optimum reflector voltage as a function of frequency

3.3 Electronic Bandwidth

The electronic bandwidth, i. e. the difference in frequency between half-power points, is wider than 20 Mc/s and is maximum 50 Mc/s (Fig. 8) in the entire frequency range covered by the **TK 6**. If the tube shall be employed as directly modulated transmitter oscillator a wide electronic bandwidth is important. Furthermore, it permits electronic retuning of the oscillator when temperature or voltage fluctuate and when the slightest difference arises between transmitting and receiving frequencies in radio equipments.

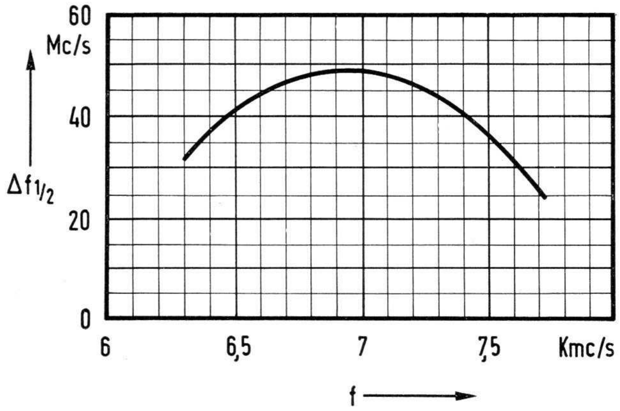

Fig. 8 Electronic bandwidth as a function of frequency

3.4 Modulation Characteristic

The modulation characteristic (Fig. 9) shows the dependence of klystron frequency on the reflector voltage. At the optimum reflector voltage this characteristic bends and, therefore, follows an almost straight line in the vicinity of the bend. This range is exploited for the direct modulation of the klystron.

By connecting an additional load dependent on frequency the modulation characteristic of a reflex klystron can be made linear to a great extent. Arrangements similar to pass-band filters designed as resonant lines and waveguide resonators are used which are interconnected by means of pins, loops or diaphragms. Optimum results are obtained when the circuit contains only the load resistance and unavoidable resonance resistances as effective resistances [4], [5].

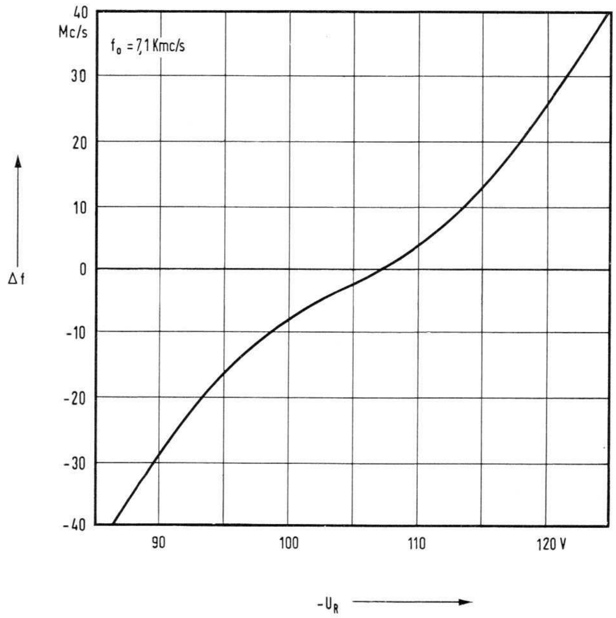

Fig. 9 Modulation characteristic of the **TK 6**

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Fig. 10 shows the slope of the modulation characteristic at the bend as a function of the klystron frequency.
The modulation characteristic indicates the necessary variation of reflector voltage required for a given change in frequency. In respect of the **TK 6** it is 1 Mc/s/V at the upper frequency limit and rises to 2 Mc/s/V at the lower frequency limit.

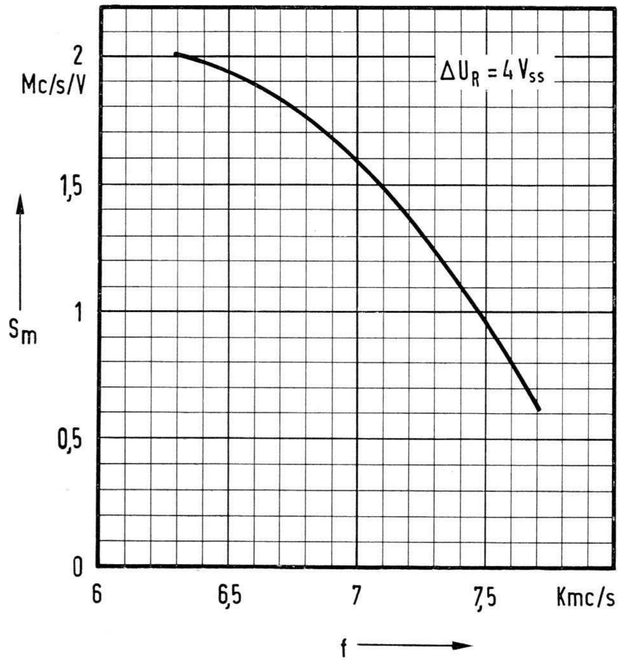

Fig. 10 Modulation characteristic as a function of frequency

3.5 Hysteresis

Hysteresis is a phenomenon that often causes interference, particularly in klystrons of earlier design. By hysteresis one understands rapid fluctuations of frequency and amplitude as a function of the reflector voltage and the direction in which the beam travels through the reflector voltage. One of the possible causes of hysteresis is that, after giving up power, the electrons are reversed again and pass through the gap a third time.
By suitably designing the electron gun, the reflector and the anode front surface, hysteresis in the TELEFUNKEN Klystron **TK 6** has been kept very low (Fig. 11).

3.6 Noise

Due to static fluctuations of the electron velocity and the number of electrons in the reflector gap and the reflector space, the RF power and the frequency of a reflex klystron are modulated. This effect is called noise modulation.

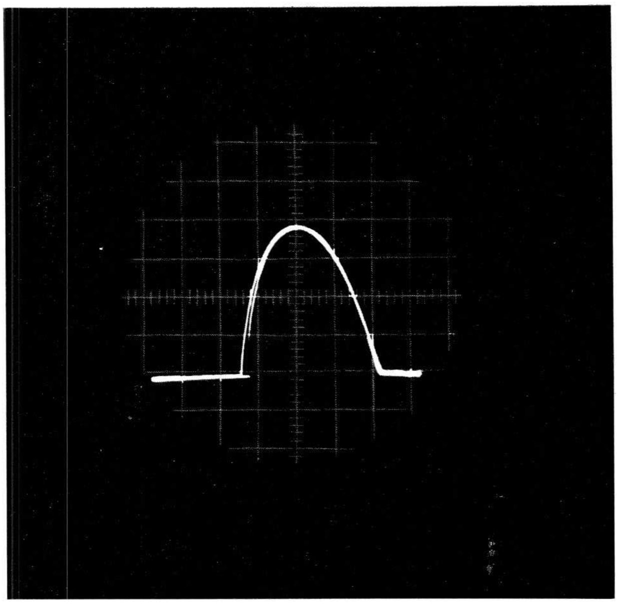

Fig. 11 RF power output as a function of the reflector voltage. The oscillogram shows the low hysteresis when the reflector voltage is wobbled as a difference in RF output at increasing and decreasing reflector voltage.

The so-called frequency noise is disagreeable in frequency-modulated radio link systems because the signal-to-noise ratio is reduced in consequence. The root of the average square fluctuation is used as a measure for this frequency noise. In the following it will be called noise level. In the **TK 6** this noise level has an approximate value

$$\sqrt{\overline{\Delta f^2}} \approx 50 \text{ c/s}$$

referred to 3.4 kc/s bandwidth and measured at a base frequency of 100 kc/s. As a function of the reflector voltage the noise level reaches an optimum value near the maximum output (Fig. 12) and then increases on both sides of the optimum value. From this it can be seen that electronic frequency

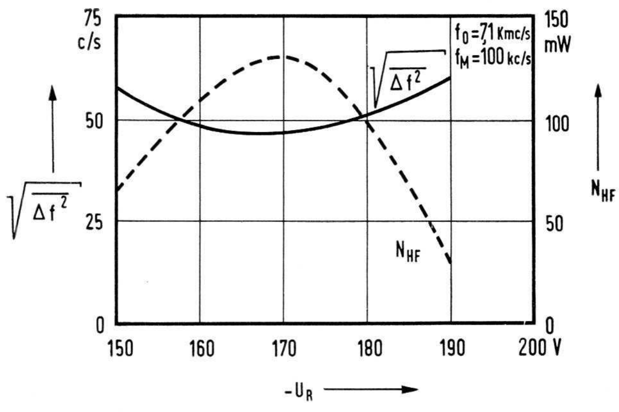

Fig. 12 Noise level and RF energy as a function of reflector voltage

retuning also influences the frequency noise of the tube.

Fig. 13 shows the noise level of the **TK 6** as a function of the resonator or acceleration voltage. At a resonator voltage of approx. 200 to 250 V the function shows a very flat minimum.

In Fig. 14 the dependence of the noise level on the klystron operating frequency is shown. Here in the centre frequency range, i. e. at about 7 Kmc/s, the noise level reaches a maximum that is most pronounced in the 2nd and 4th modes. In the operating mode (n = 3) the dependence of the noise level on the klystron operating frequency is low and at approx. 7 Kmc/s the noise level reaches a maximum value of about 80 c/s.

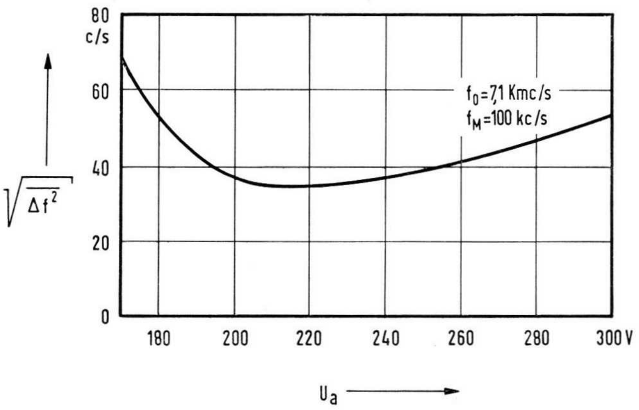

Fig. 13 Noise level as a function of acceleration voltage

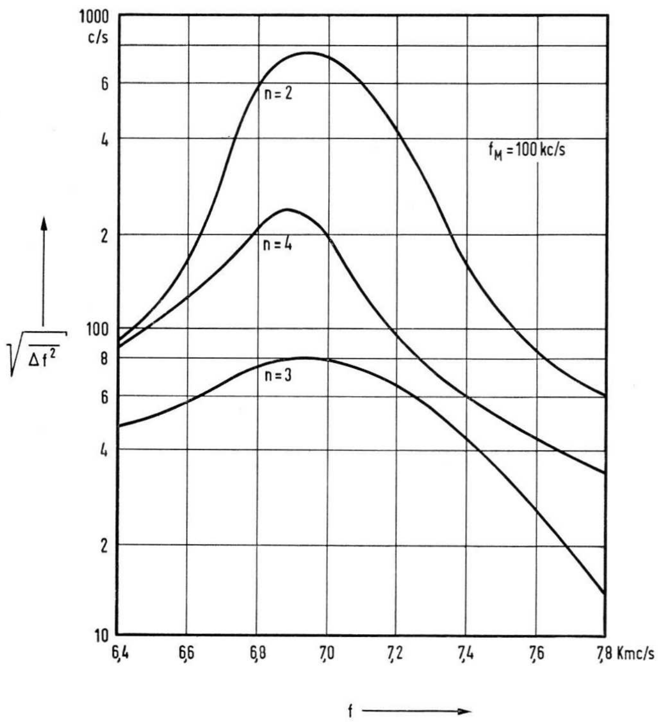

Fig. 14 Noise level as a function of frequency for the modes n = 2,3,4

4. OPERATING INSTRUCTIONS

The tube can be mounted in all positions. However, if necessary, precautions must be taken to prevent it falling out of the socket. This can be done, for example, by means of spring clips that press on the lower edge of the body. Particular attention must be paid to good contact between the coaxial terminal and the waveguide coupling. There must be no strong magnetic fields near the tube because they vary the beam direction. If required adequate shielding must be provided.

If special requirements are stipulated in respect of transmitter frequency stability, then it is recommended to stabilize all operating voltages, viz. heater, resonator and reflector voltages. Since the tube body conducts the resonator potential (+300 V) it is advisable to ground the resonator, the cathode then being negative against ground. If the heater filament is coupled with the cathode, then a heating transformer resistant to HT must be used.

Before the resonator and reflector voltages are applied, the tube must first be heated for 1.5 mins. with U_f = 6.3 V. The reflector voltage must never drop to zero or even become positive against the cathode because the reflector current then flowing would overload the reflector and destroy the tube. Therefore, the resonator voltage must not be applied until the nominal voltage is connected to the reflector. One method of achieving this is by means of a relay controlled by the reflector voltage that switches on the resonator voltage (Fig. 15). By means of the diode connected in parallel to the relay winding, any reflector voltage that is incorrectly poled by error will be short-circuited and the resonator voltage disconnected via the relay. If, in order to modulate the klystron frequency, the reflector DC voltage is superposed on an AC voltage, the diode prevents the momentary value of the reflector voltage becoming positive at a too high amplitude of this AC voltage. Henne, Lind

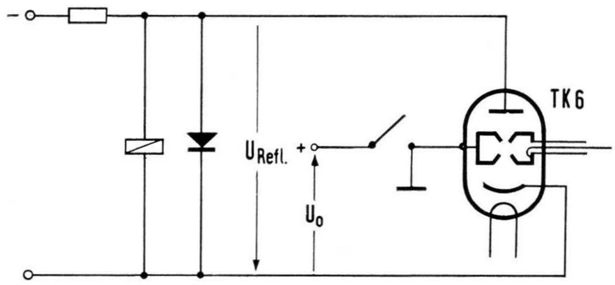

Fig. 15 Proposed circuit for the automatic disconnection of the resonator voltage when there is no, or a positive, reflector voltage

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Mains operated tube for
DC/AC heating
Indirectly heated
Parallel feed

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TK 6

Inner cavity reflex klystron
Frequency 6.3 to 7.7 Kmc/s

Provisional Technical Data

Before the resonator voltage is connected the tube must be heated for 1.5 mins. at U_f = 6.3 V.

The resonator voltage must not be connected before the reflector voltage.

U_f	**6.3** V ± 5%
I_f	400 mA

Static Measuring Values

Resonator voltage	U_o	**300**	V	
Reflector voltage	U_R	**—50**	V	
Frequency	f	**7**	Kmc/s	
Resonator current	I_o	18 to 30	mA	(not oscillating)
Reflector current	i_R	< 3	μA	

Operating Values

Frequency	f	**6.5**	**7**	**7.5**	Kmc/s
Mode	n		**3**		
Resonator voltage	U_o		**300**		V
Resonator current	I_o		28		mA
Reflector voltage	U_R	—74	—110	—145	V
Electronic bandwidth (Δf between half-power points)	Δf ½ *)	39	49	37	Mc/s
Modulation characteristic	$S_m = \left\| \frac{\Delta f}{\Delta U_R} \right\|$	1.95	1.65	0.95	Mc/s/V
RF output power	N_{HF}	100	180	200	mW
Temperature coefficient			0.12 ± 0.05		Mc/s/°C

*) Referred to a VSWR of $s = \frac{U_{max}}{U_{min}} < 1.05$

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Absolute Maximum Values

Resonator voltage	U_o	**330**	V
Resonator current	I_o	**35**	mA
Resonator load	Q_o	**9**	W
Reflector voltage, positive	U_R	**0**	V
negative	U_R	**− 400**	V
Voltage between filament and cathode	U_{fk}	**50**	V
Surface temperature			
at hottest point of the tube	t_K	**160**	°C
Temperature of output coupling	t_{Kop}	**75**	°C

The cathode is reference point for all voltage values.

The tube can be mounted in any position. If necessary precautions must be taken to prevent the tube falling out of the socket.

Frequency stability

If the tube frequency shall be kept constant within very narrow limits, it is recommended to derive all voltages from stabilized mains connecting units: furthermore, it must be ensured that the tube fits securely in the socket. The frequency deviation for a frequency of 7 Kmc/s is

$\frac{\triangle f}{\triangle U_R}$ approx. 1.3 Mc/s/V

$\frac{\triangle f}{\triangle U_o}$ approx. 0.4 Mc/s/V

$\frac{\triangle f}{\triangle U_f}$ approx. 2.5 Mc/s/V

Coupling the tube to the waveguide

Care must be taken that excellent contact is provided between the klystron output terminal and the transmitter input coupling. Additional matching of the tubes to the load can be effected by means of a sliding shunt contact in the waveguide.

Fittings

Socket	Octal, No. 4 bore, extended to 7 mm diam.
Reflector connection	Connector 6.35 mm in accordance with German standard DIN 41 535

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