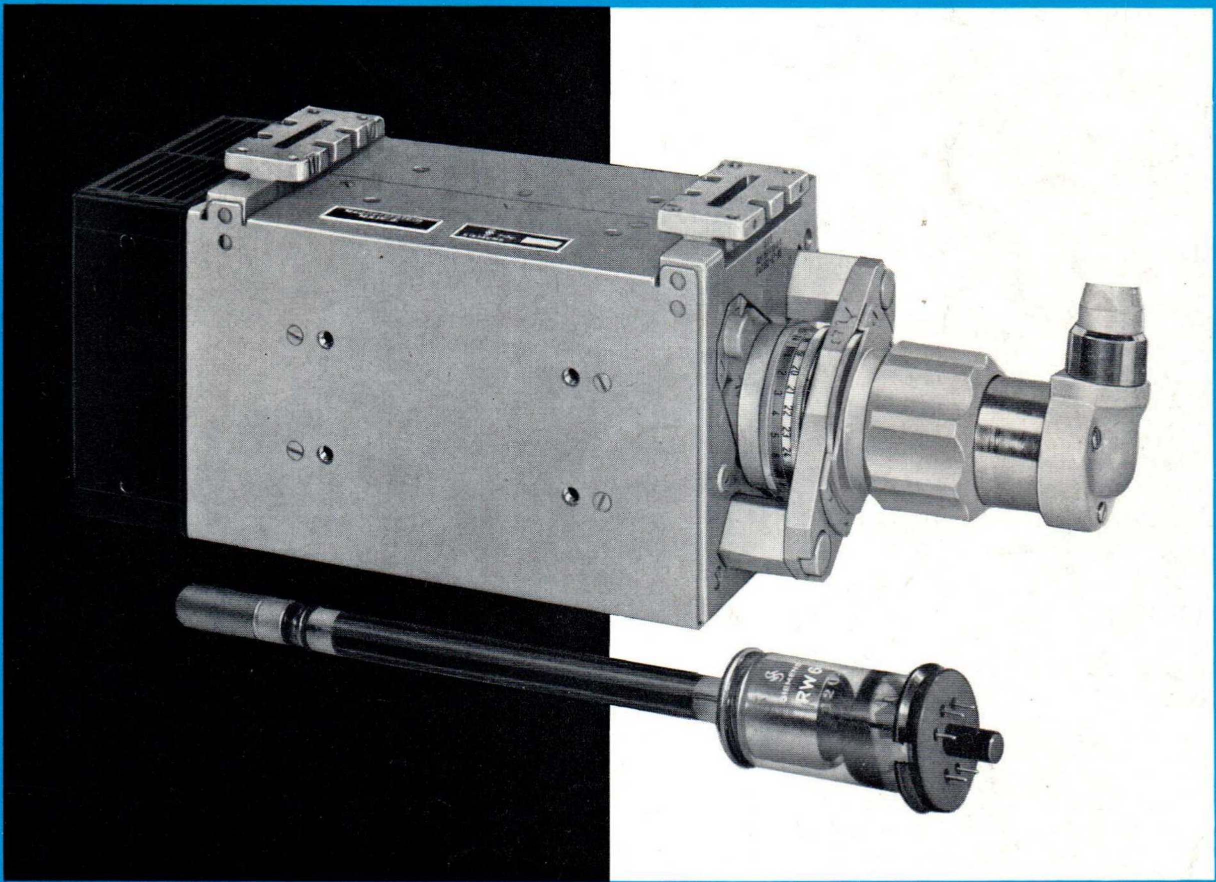
SIEMENS

The Siemens Traveling-Wave Tubes RW 6 and RW 80

Modern output tubes
for microwave link systems
in the frequency range 5.8 to 8.5 Gc.



SIEMENS & HALSKE AKTIENGESELLSCHAFT
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1. Introduction

With gridded tubes producing very little amplification over wide bands at microwave frequencies, the development of velocity-modulated devices has represented a considerable advance. The traveling-wave tube in particular is ideally suited as a power amplifier at such frequencies, with gains of around 40 db over bandwidths up to an octave. The gain-bandwidth product is thus several orders of magnitude higher than that obtainable from gridded tubes.

In addition to these advantages the traveling-wave tube is also capable of producing high output powers and is therefore now widely used as an output device in communications systems, especially in microwave link equipment.

The principle of operation of the traveling-wave tube is based on the exchange of energy between the moving electrical charges of an electron beam and an electromagnetic wave propagated in the same direction. The interaction between beam and wave over a large number of wavelengths produces the high gain, while the wide bandwidth, which is virtually only limited by the quality of the input and output matching, has its origin in the dispersionless nature of the delay line.

In view of the ever increasing importance of microwaves the Siemens Tubes Division has developed and now manufactures a series of modern traveling-wave tubes for a wide variety of applications. These devices are presently capable of delivering powers from 5 W to 3 kW and cover the frequency range 0.5 Gc. to 8.5 Gc. Further types are in preparation including tubes designed to extend the frequency coverage up to 12.5 Gc.

The two tubes described in this article are designed for the frequency bands 5.8 Gc to 7.3 Gc (RW 6) and 5.8 Gc to 8.5 Gc (RW 80), and at an approximate average gain of 40 db the nominal output powers range from 10 W to 15 W. The saturation powers are 18 W (RW 6) and 29 W (RW 80) respectively. The tubes are operated in periodic permanent magnet (PPM) circuits, and are replaceable in these magnets as a plug-in match. Particular advantages of the type of magnet system used are low weight, small stray field, insensitivity to temperature and a compact construction which results in a unit of remarkably small dimensions. Provision is made either for conduction or convection cooling as required.

2. Principles of Operation the Traveling-Wave Tube

2.1. The helix as a delay line

An electromagnetic wave is propagated along a straight filamentary conductor at the velocity of light. Fig. 1 shows the instantaneous distribution of the lines of electric force around such a wire.

If the wire is wound in the form of a helix, the electromagnetic wave again travels along it at approximately the velocity of light. When the wave has traveled a distance πD or one turn along the helix, where D is the diameter of the helix, it has covered a distance in the axial direction equal to the pitch d of the helix. The velocity in the axial direction is then

$$v_p = c \cdot \frac{d}{D \cdot \pi}$$

The velocity of propagation (phase velocity) along the axis of the helix can thus be reduced to a value to which electrons can also be accelerated by reasonable technical means. At beam voltages of about 2500 V, electrons can be accelerated to approximately $^1/_{10}$th the velocity of light and the synchronization between the velocities of the electron beam and electromagnetic wave which is then possible is a prerequisite for the functioning of a traveling-wave tube.

In order to understand the interaction with the electron beam one must consider the electric field inside the helix as shown schematically in fig. 2. There are strong components in the axial direction which can interact with the electron beam flowing within the confines of the helix.

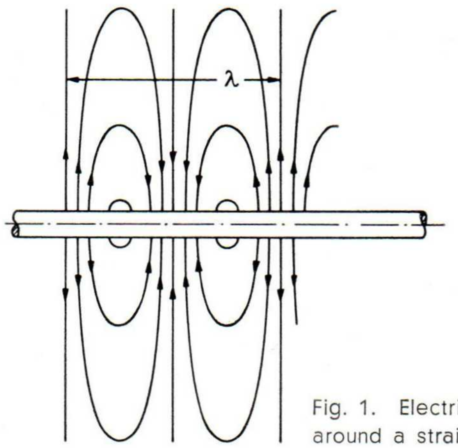


Fig. 1. Electric field pattern around a straight wire.

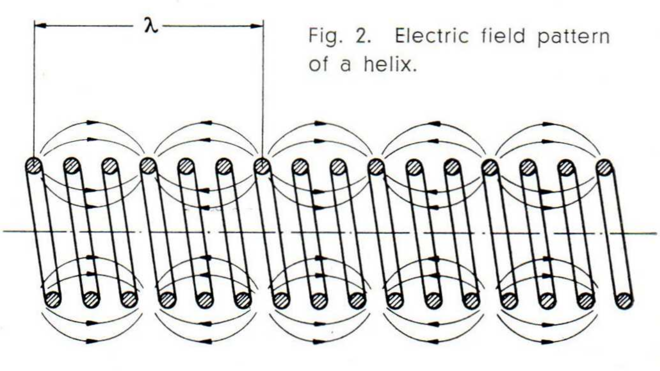


Fig. 2. Electric field pattern of a helix.

2.2. Exchange of energy between the electric field and the electron beam

When an electric field interacts with freely moving charge carriers such as electrons, an exchange of energy between the field and the electrons occurs. This can be clearly shown by taking a simple example (fig. 3).

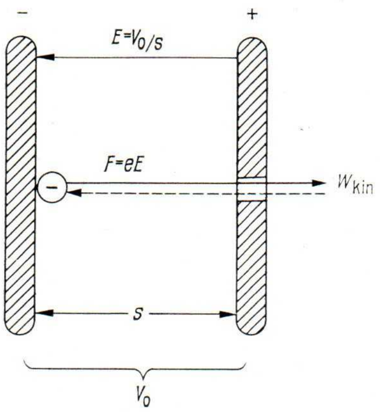


Fig. 3. Illustration of the exchange of energy using the example of the parallel-plate capacitor.

A plate capacitor with a hole is charged to a certain potential. An electric field E therefore exists between the plates. The force on a electron between the plates is

$F = e\,E.$

This force sets the electron in motion towards the positive plate, and the electron can emerge through the hole in the plate into a field-free space. In this space the electron travels further with constant velocity since no force is present. Let the distance between the plates be s and assume the electron starts from the negative plate. According to the conservation of energy, the work done in accelerating the electron is equal to the kinetic energy it gains, so that

$$W = \int F ds = e \int E ds = eV_o$$

The kinetic energy is $\frac{1}{2}\,mu_o^2$, therefore

$$eV_o = \frac{1}{2} mu_o^2$$

The average velocity of the accelerated particle is therefore

$$u_o = \sqrt{2 \frac{e}{m} V_o} = 6.10^7 \sqrt{V_o}$$

where V_o is in volts and u_o in cm/sec.

The electron has gained its energy from a capacitor field having a finite energy content. Each time electrons are accelerated the capacitor looses electrostatically-stored energy and will eventually be discharged. The field strength in the capacitor therefore decreases continuously with the result that the electrons are accelerated less and less. The field energy is therefore converted to kinetic energy. If this process is reversed, and the electrons injected with such a velocity into the electric field that they are decelerated, kinetic energy will be converted into field energy. The capacitor therefore charges up. This assumes that the electrons possess sufficient kinetic energy to reach the negative plate otherwise they will be reflected.

The interaction process in a traveling-wave tube involves the transfer of kinetic energy from the decelerated electrons of an electron beam to the energy of the electric field of an electromagnetic wave traveling along a delay line.

2.3. Amplification process

The interaction between the electron beam and electromagnetic wave which produces the amplification, will now be explained in more detail with the help of fig. 4.

The electron gun produces an electron beam of uniform density which is injected into the helix at point A. An r. f. signal is applied to the input of the helix and travels along it as an electromagnetic wave in the axial direction. Fig. 4 shows the instantaneous electric field and corresponding electron distribution.

For reasons of simplicity it will initially be assumed that the beam and wave velocities have the same value. The electrons in section A—B encounter an accelerating field and those in B—C a decelerating field. This is analogous to the behavior along the remainder af the helix. After one period, when electrons originally at B have reached point D, a slight bunching already forms at this point. On average there is as yet no energy exchanged between the helix and the beam.

The transfer of energy from the beam to the helix necessary for the process of amplification is achieved by making the beam velocity somewhat higher than that of the wave by choosing the helix voltage accordingly. The electron bunches, which initially form at the points of zero field strength of the axial electric field, move ever increasingly

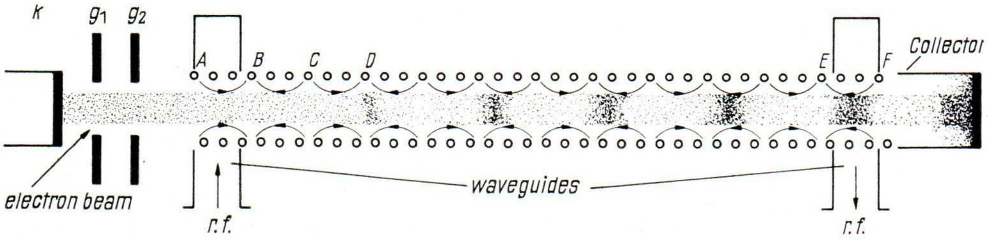


Fig. 4. Schematic presentation of the amplification process in a traveling-wave tube.

towards the right relative to the field pattern into the decelerating field preceding them. When the electrons are decelerated, kinetic energy is then transferred to the r. f. field and the amplitude oft his field increases in the axial direction exponentially. The modulation of the beam is thus further increased.

At the tube output between E and F, the electron bunches have a phase which leads the original phase relative to the electromagnetic wave due to their higher velocities, and lie in the decelerating r. f. field. Under these conditions the maximum energy is transferred to the field, and the amplified electromagnetic wave is coupled out into the output waveguide.

ond half of the helix and will be further amplified. This process cannot occur in the reverse direction since any wave reflected from the output can only reach the attenuating layer and no further. The attenuating layer must absorb over the complete range of amplification, and must be practically reflection-free.

The interaction length is usually measured in line wavelengths and in conventional tubes is about 25. If the gain of the tube is expressed in logarithmic units (e. g. db), a linear relationship between gain and line length — with the exception of the first section — is obtained (see fig. 6). The wave propagated by the r. f. signal applied to the input remains at a constant energy level until the

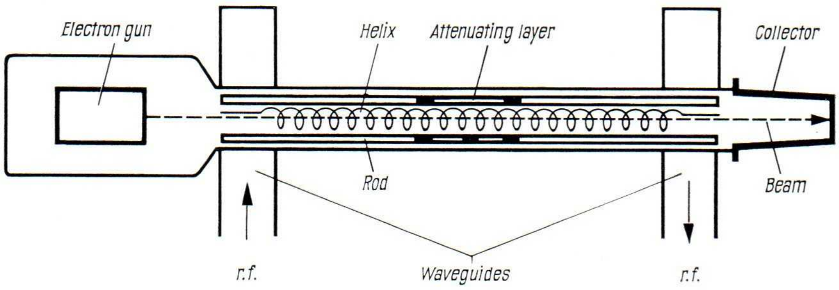


Fig. 5. Schematic of a practical traveling-wave tube.

Fig. 5 shows the schematic of a practical traveling-wave tube, consisting of an electron gun, the helix (generally supported by dielectric rods), the collector and a vacuum envelope. The dielectric rods must have the lowest possible r. f. losses and a low dielectric constant, otherwise the attenuation of the r. f. fields will be too high. The r. f. energy is generally coupled out by way of waveguides. An attenuator is built into the middle of the tube to decouple the output from the input and prevent any reflection at the output reaching the input unattenuated and producing self-oscillation. The attenuation must always be larger than the gain of the tube, and is usually greater than 70 db. The attenuator also absorbs the forward-wave on the helix, but the modulation of the electron beam remains, so the wave is again excited in the sec-

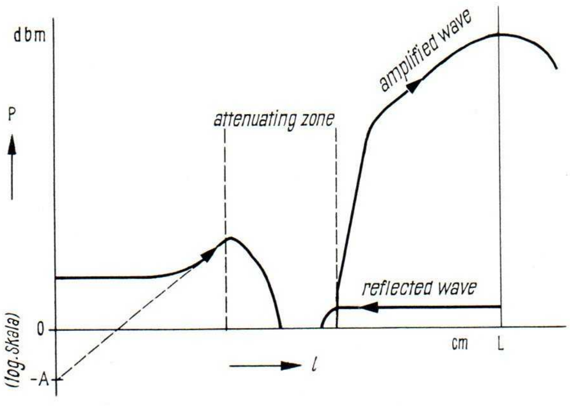


Fig. 6. Behavior of the axial electromagnetic wave inside a traveling-wave tube.

electron beam, which enters the helix as d. c., is sufficiently modulated to permit transfer of energy. Then the energy content of the wave increases exponentially up to the attenuating layer. Beyond the attenuating layer the modulated beam again excites a wave, the energy content of which increases exponentially up to a value corresponding to the output power.

The energy corresponding to the output power is taken from the electron beam resulting in a reduction of electron velocity. If the tube is driven hard the velocity of the beam at the output decreases to such an extent that the beam can no longer keep up with the wave. The tube is now said to be saturated. As the input power is further increased the output power starts to decrease. The conditions for synchronism are no longer fulfilled, and for this reason the gain falls drastically in the saturation region.

3. Construction of the RW 6 and RW 80

Fig. 7 shows the basic layout of the RW 6. Since the RW 80 construction varies only very slightly from this, both types will be discussed together in this section. The assembly is carried by two discs 1 and 2, the outer rims of which ensure that the tube is correctly centered in the magnet. These discs also form the r. f. contact with the input and output waveguides. They are manufactured from a magnetic material (Kovar) and also complete the main magnetic field along the helix correctly.

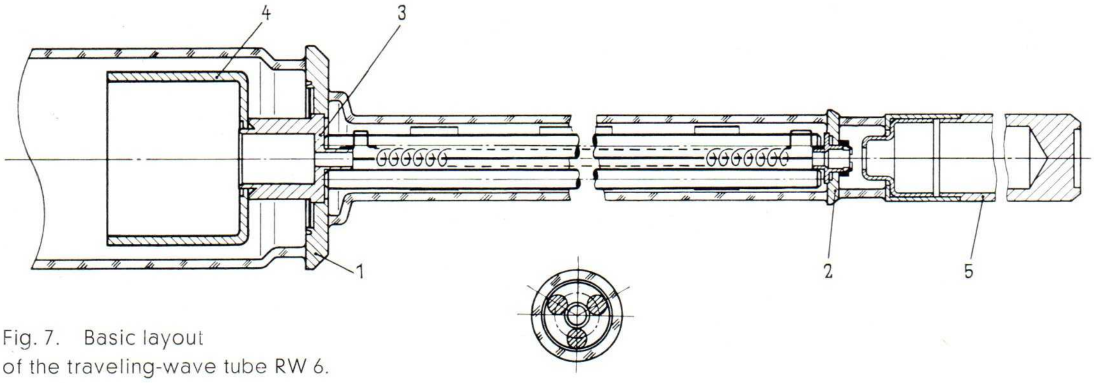


Fig. 7. Basic layout
of the traveling-wave tube RW 6.

The ends of the helix are connected through small coupling loops to two antennae fixed in the center holes of the discs. With the help of these antennae the r. f. energy is transferred from the input waveguide to the helix and similarly from the helix to the output waveguide (fig. 7). The helix itself is supported by three quarz rods, two of which carry the attenuating layer necessary [1]. The r. f. attenuation of the helix assembly in the reverse direction is better than 70 db.

A cylinder 4 attached to the cathode side of the input antenna 3 provides a magnetic screen for the electron gun. The collector 5 is separated galvanically from the helix.

The beam is produced by a magnetically-focussed electron gun [2] as shown in fig. 8. The gun consists of a dispenser cathode with a diameter of 3 mm, a cylindrical control grid g_1 and two parallel apertured electrodes g_2 and g_3 Grid No. 1 is the beam-forming electrode, and is generally at a fixed potential depending on the beam current required. The actual value of the beam current is set by the potential on g_2. The accelerating electrode g_3 is at helix potential.

The electron gun is centered in the input antenna and fixed.

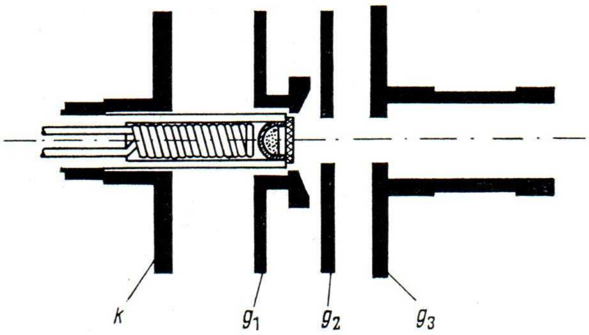


Fig. 8. Electron gun of the traveling-wave tube RW 6.

4. Beam Focusing and the Magnet System

The electron beam is focused by an axial periodic magnetic field, the variation of which is shown in fig. 9. This so-called periodic focusing field has the advantages over conventional permanent magnet systems that the beam stiffness is higher, the stray field is considerably lower and the weight of the magnet system is less.

There are three distinct regions of the magnetic field: The initial field with amplitudes B_1 and B_2,

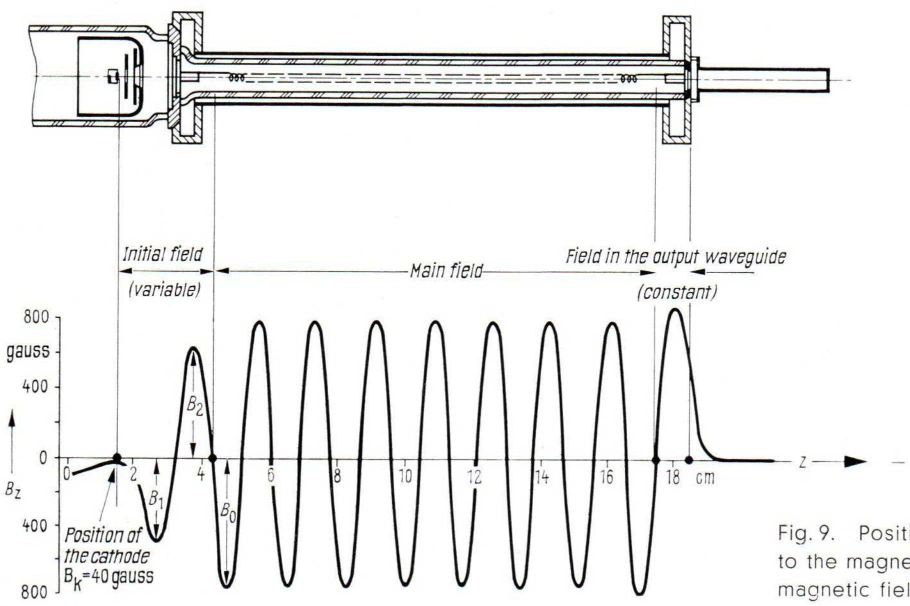
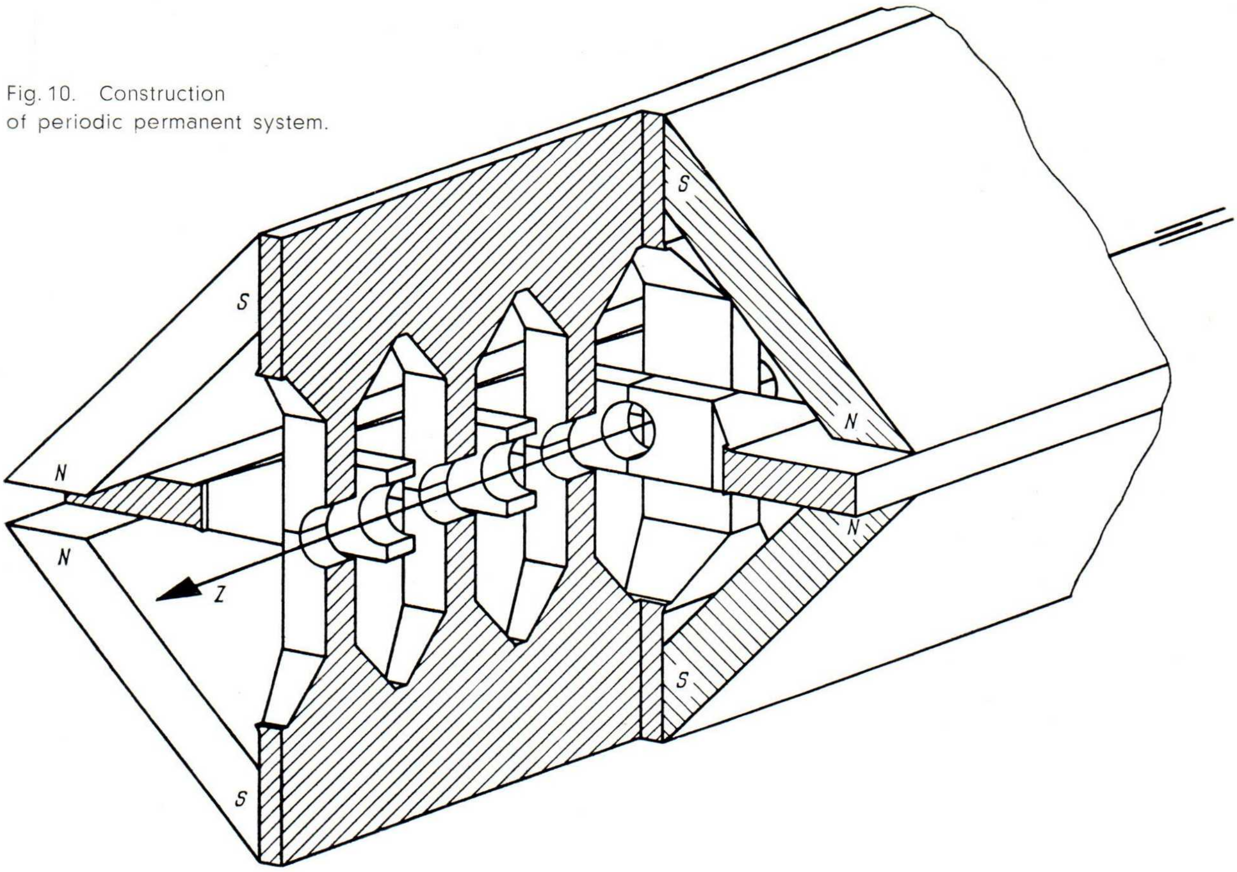


Fig. 9. Position of the traveling-wave RW 6 to the magnetic field and axial variation of the magnetic field.

Fig. 10. Construction
of periodic permanent system.



the main field with constant amplitude B_0 and the field in the output waveguide.

The main field is produced by two vertical rows of individual pole pieces stacked one on top of the other as illustrated in fig. 10. The four Alnico V bar magnets are arranged such that the two rows of pole pieces are uniformly magnetized. Magnetic fields therefore exist in the gaps between the pole pieces, the polarities of which vary periodically along the z axis. The peak field strength is approximately 800 Gauss and the period is 17.5 mm.

Since all the pole pieces of like polarity are interconnected and therefore have the same magnetic potential, the peak field strengths are very uniform.

The layout selected and the type of magnetic material employed results in a magnetic focusing circuit which is virtually insensitive to temperature. The mechanicallyrugged unit is also used as a mounting base for the waveguides.

The magnetic field strength in the output waveguide is somewhat higher to counteract the tendency of the beam to diverge due to the alternating space charge when the tube is operating with r. f. The magnetic field at the collector is negligible. Temperature measurements taken along the collector with the tube operating under pulsed conditions have shown that the impact of electrons over the inner surface is practically uniform.

The amplitudes B_1 and B_2 of the initial field, which itself is coupled to the main field, can be set individually for optimum focusing. B_2 is preset in the factory by shifting the magnetic shunts shown in fig. 12 within the focusing field. The amplitude B_1, however, can be individually set externally for each tube. This is carried out with the help of the "axial" field correction adjusting ring (fig. 11), which when turned shifts the soft iron cylinder shown in fig. 12 in a axial direction.

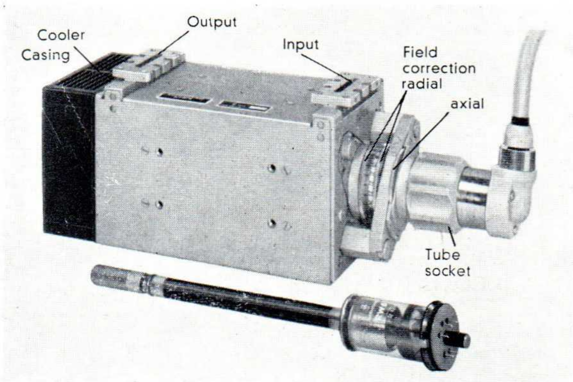


Fig. 11. Magnet system MRW 6 b 12 with traveling-wave tube RW 6 and connector socket (bend in direction D) in place.

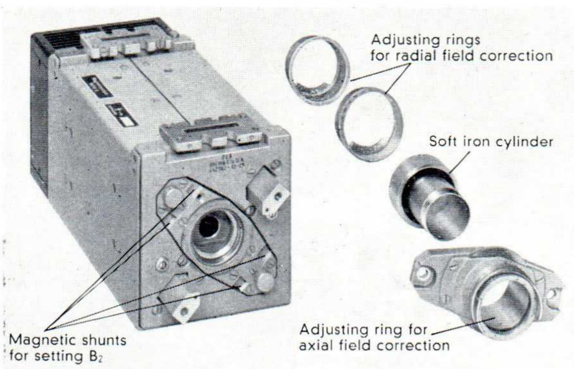


Fig. 12. Adjusting elements of the magnet system MRW 6.

Small asymmetries in the tube are compensated with the aid of the two "radial" field correction adjusting rings (see fig. 12). Each ring has a segment of soft iron attached to its inner surface, and both segments can be rotated in a plane normal to the axis either in opposite directions or as a unit in the same direction. The position of the segments determines the location and direction of the compensating field.

Optimum focusing is realized when the helix current is reduced to its lowest value, and it is generally necessary to adjust the various correcting rings alternately to achieve this.

An axial magnetic field of approximately 40 Gauss is left at the cathode since this affects the noise properties favorably when the tube is operating under r. f. signal conditions.

5. The Medium-Power Traveling-Wave Tube RW 6

The RW 6 is discussed in the following paragraphs, and in principle the majority of the remarks also apply analogously to the RW 80. The RW 80 data is then summarized in section 6.

The Technical Service Department of Siemens & Halske is always available to answer any questions which may arise in connection with the use and operation of traveling-wave tubes. In order to save expense and time-consuming experiments it is often advisable to consult this Department of the Tubes Division when the tube is required to operate under conditions which vary from those given here.

The RW 6 has an average gain of approximately 39 db at a power output of about 10 W, and is especially suitable for use in wideband microwave link systems operating in the frequency band 5.8 to 7.3 Gc.

The tube is focused by a low stray field periodic permanent magnet circuit MRW 6 and is a plug-in match in this system. The RW 6 is designed to operate with a depressed collector.

The magnet system is available for conduction cooling (MRW 6a) or convection cooling (MRW 6b) as required. With the tube and supply connectors in place it is fully screened to r. f. The tube is designed for use with waveguide input and output circuits.

5.1. Technical data

Tube dimensions	See fig. 13
Dimensions of the magnet system	See fig. 14
Tube socket	Similar to continental socket [1])
Weight of the tube	approx. 100 gm net
Weight of the magnet system	approx 7.5 kg
External dimensions of the magnet system	100 mm × 112 mm × 338 mm
Dimensions of the tube packing	170 mm × 170 mm × 460 mm
Waveguide	F 70 DIN 47302, 34.85 mm × 5 mm
Flange	NF 70 DIN 47303
Mounting position	Any (see cooling, section 7.4)

[1]) The appropriate connector socket with 1.1 m cable is supplied as required either straight or with a 90° bend on the socket assembly.

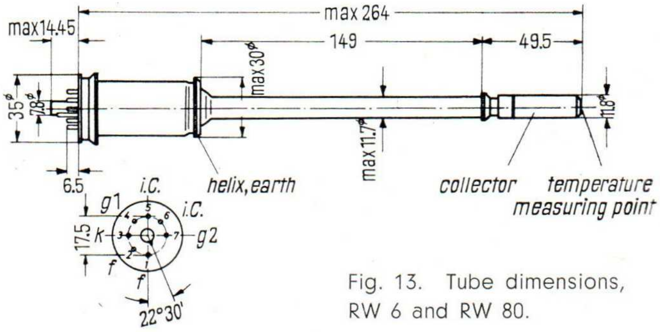


Fig. 13. Tube dimensions, RW 6 and RW 80.

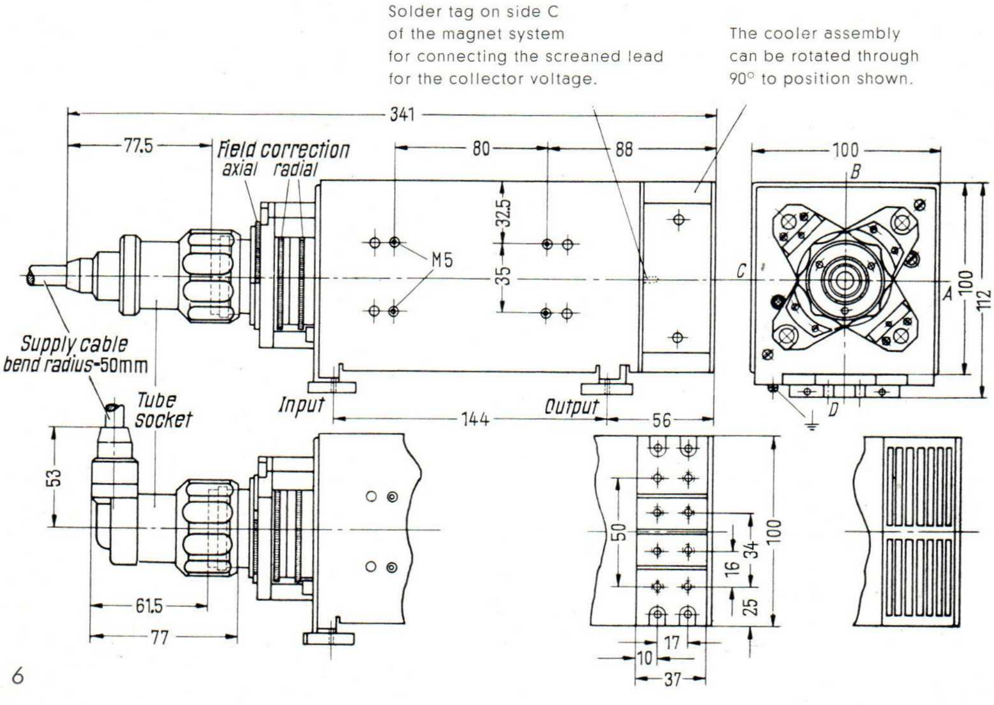


Fig. 14. Dimensions of the magnet system.

Technical data

Heating

Heater voltage	E_f	=	6.3	V[1]
Heater current	I_f	=	0.8	A
Preheating time	t_h	≧	2	min

Method of heating: indirect a. c. parallel fed
Cathode : dispenser (metal capillary)

Characteristics

Frequency range	f	=	5.8 ... 7.3	Gc
Saturation power	P_{sat}	=	18	W
Average gain	G (P_o = 10 W)	=	39	db
Small-signal gain	G (P_o = 1 W)	=	40.5	db[2]
VSWR	s	<	1.5	[2]
Magnetic flux density	B_z	=	800	Gauss[3]

Operating data (f = 6.2 G_c)

Output power	P_o	=	10	5	W[4]
Gain	G	=	39.5	40	db
Collector voltage	E_c	=	1300	1150	V[5]
Helix voltage	E_h	≈	2480	2480	V
Grid No. 2 voltage	E_{g2}	≈	550	550	V
Grid No. 1 voltage	E_{g1}	=	−20	−20	V[5] [6]
Cathode current	I_k	=	45	45	mA[6] [7]
Helix current	I_h	≈	2	2	mA
Grid No. 2 current	I_{g2}	≦	0.1	0.1	mA
Noise factor	F	≦	25	25	db
AM-PM conversion	k_p	≈	4.5	2.8	°/db[8]
PM- sensitivity	$\Delta\varphi / \Delta E_h$	≈	1.7		°/V[9]

Operating data (f = 6.6 Gc)

Output power	P_o	=	10	5	W[4]
Gain	G	=	38.5	39	db
Collector voltage	E_c	=	1300	1150	V[5]
Helix voltage	E_h	≈	2460	2460	V
Grid No. 2 voltage	E_{g2}	≈	550	550	V
Grid No. 1 voltage	E_{g1}	=	−20	−20	V[5] [6]
Cathode current	I_k	=	45	45	mA[5] [7]
Helix current	I_h	≈	2	2	mA
Grid No. 2 current	I_{g2}	≦	0.1	0.1	mA
Noise factor	F	≦	25	25	db

Operating data (f=7.0 Gc)

Output power	P_o	=	10	5	W[4]
Gain	G	=	37	37.5	db
Collector voltage	E_c	=	1300	1150	V[5]
Helix voltage	E_h	≈	2440	2440	V
Grid No. 2 voltage	E_{g2}	≈	550	550	V
Grid No. 1 voltage	E_{g1}	=	−20	−20	V[5] [6]
Cathode current	I_k	=	45	45	mA[5] [7]
Helix current	I_h	≈	2	2	mA
Grid No. 2 current	I_{g2}	≦	0.1	0.1	mA
Noise factor	F	≦	25	25	db

All voltages are referred to the cathode.

[1] Variations of more than ± 2 % (absolute limits) in the heater voltage impair tube performance and life.

[2] At input and output of cold tube.

[3] Crest value of the periodic magnetic field in the axial direction.

[4] For a lower output power than 10 W the cathode current can be reduced down to 25 mA by changing the grid voltages. This causes a decrease in gain and the linearity deteriorates. If such operation is desired the manufacturer should be consulted. (See also section 5.2.2)

[5] Setting-up value.

[6] It is advisable to set the grid No. 6 voltage E_{g1} by using a cathode resistor.

[7] When the cathode current I_k changes by 1 mA in the range 42 mA to 47 mA, the gain changes by approximately 0.5 db.

[8] AM-PM conversion is the phase shift of the r.f. output signal caused by a change in input power of 1 db.

[9] Phase change of the r.f. output signal when the helix voltage E_h is varied by 1 V.

Operating data (with reduced beam current, f =6.6 Gc)

Output power	P_o	=	7.5	5	W
Gain	G	=	39.5	32	db
Collector voltage	E_c	=	1200	1150	V
Helix voltage	E_h	=	2460	2430	V
Grid No. 2 voltage	E_{g2}	=	560	580	V
Grid No. 1 voltage	E_{g1}	=	−40	−70	mA
Cathode current	I_k	=	40	35	mA
Helix current	I_h	≈	2	2	mA
Grid No. 2 current	I_{g2}	=	0.1	0.1	mA
Noise factor	F	=	25	25	db
AM-PM conversion	k_p	=	4.0	3.4	°/db

Any deviations from the normal operating data should only be made in consultation with the manufacturer (see also section 5.2.2, page 11).

Maximum ratings (absolute values)

Cold collector voltage	E_{co}	max	1600	V
Collector voltage	E_c	max	1500	V
Collector dissipation	P_c	max	65	W
Helix voltage	E_h	max	2700	V
Helix voltage	E_h	min	2200	V
Helix current	I_h	max	4	mA[1])
Helix dissipation	P_h	max	10	W[1])
Grid No. 2 voltage	E_{g2}	max	700	V
Grid No. 2 dissipation	P_{g2}	max	0.2	W
Grid No. 1 voltage	E_{g1}	min	−100	V
Grid No. 1 voltage	E_{g1}	max	0	V
Cathode current	I_k	max	50	mA
Load reflection factor	r_L	max	33	%
Collector temperature	t_c	max	270	°C[2])
Ambient temperature	t_{amb}	min	−20	°C
Ambient temperature	t_{amb}	max	+55	°C[3])

[1]) During switch-on mains surges the helix current I_h may rise momentarily to 6 mA. This value is also recommended as the cutout value of the over-current protection relay.

[2]) If the carrier signal fails, the collector temperature may rise up to 300 °C for a maximum duration of 3 days.

[3]) See cooling, section 7.4.

5.2. Gain and power output

The gain is defined as the ratio of the r. f. output power P_o to the r. f. input power P_i applied to the tube. This ratio is usually expressed in db.

If the beam current is fixed and a low-level signal is applied to the input, the output power is directly proportional to the input power (see fig. 15). As the input level is increased, the gain falls off somewhat, since the beam modulation increases and the transfer of energy to the r. f. field therefore reduces the beam velocity. In order to obtain sufficient velocity for the transfer of energy in spite of the decrease in velocity at the output, the beam velocity at the input is increased by raising the helix voltage. If the input signal is even further increased the tube saturates. Under such conditions the output power is at its maximum value, and when the tube is driven beyond the saturation point the output power falls again since the conditions for synchronism are no longer fulfilled.

For a particular output power the phase velocity can in principle be matched to the beam velocity by using a variable-pitch helix, the pitch becoming progressively smaller towards the output. The tubes discussed here employ a smaller but constant pitch helix section on the output side which to a certain degree compensates for the decrease in beam velocity. The pitch changes in the attenuating zone, and since no r. f. energy exists here this change cannot cause any undesired reflections. This measure results in an improved linearity of the characteristics, and the gain remains practically constant up to the nominal output power.

5.2.1. Operation at nominal power

Fig. 15 shows the output power as a function of the input power at three characteristic frequencies. The gain in db can also be read from the graph. The helix voltage is adjusted for optimum, i. e. maximum gain in each case. The decrease of gain with increasing frequency is caused by the lower coupling between wave and beam as the wavelength becomes shorter, i. e. the lines of force of the electric field do not penetrate so far into the beam. This effect is partially compensated by the increase in the number of wavelengths in the tube.

The gain and optimum helix voltage as a function of the output power is shown in fig. 16. As already explained in section 5.2 the optimum helix voltage increases with the output power.

In fig. 17 the gain with constant helix voltage is shown as a function of the output power. The helix voltage is optimized for $P_o = 10$ W.

The dependence of the gain on helix voltage is more clearly illustrated in fig. 18, where the small-signal gain is presented as a function of the helix voltage at various cathode currents. The maximum possible gain is obtained at the "synchronous" helix voltage. At lower helix voltages many electrons no longer have sufficient velocity to reach the decelerating phase of the field. If the helix voltage is higher than the synchronous value, the electrons travel beyond the decelerating phase of the field, and are no longer able to give up the full energy.

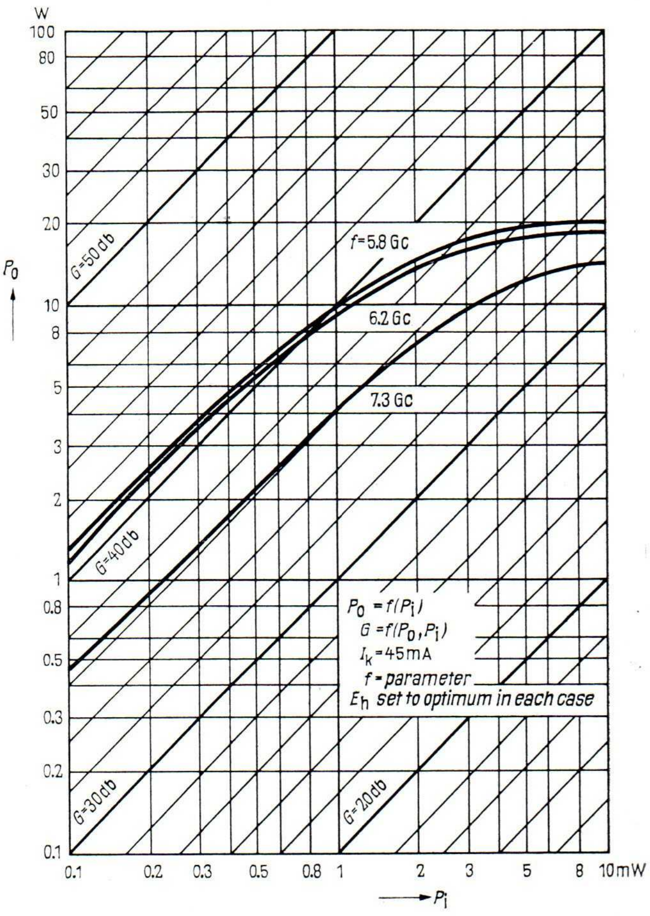


Fig. 15. Output power as a function of input power at various frequencies.

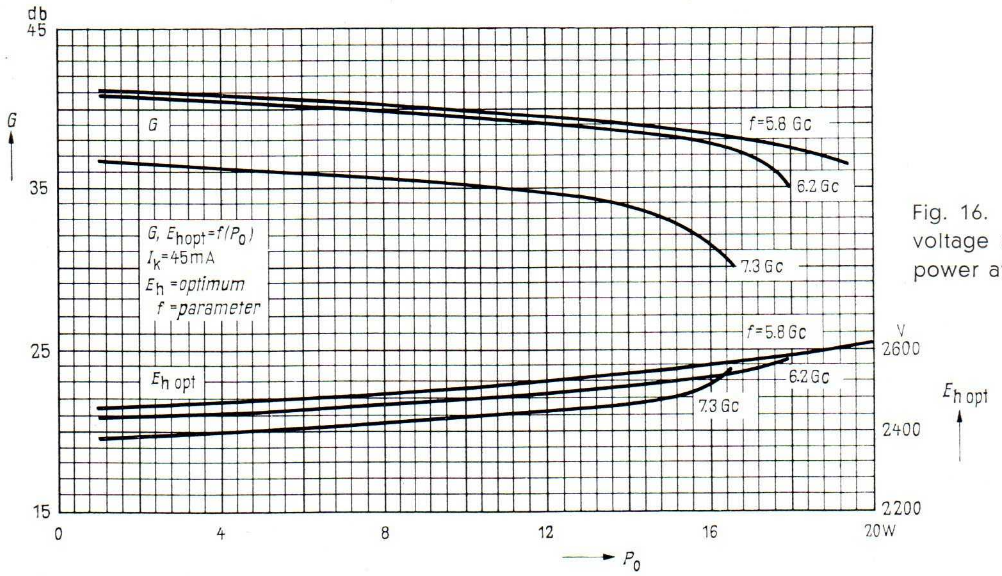


Fig. 16. Gain and optium helix voltage as a function of the output power at various frequencies.

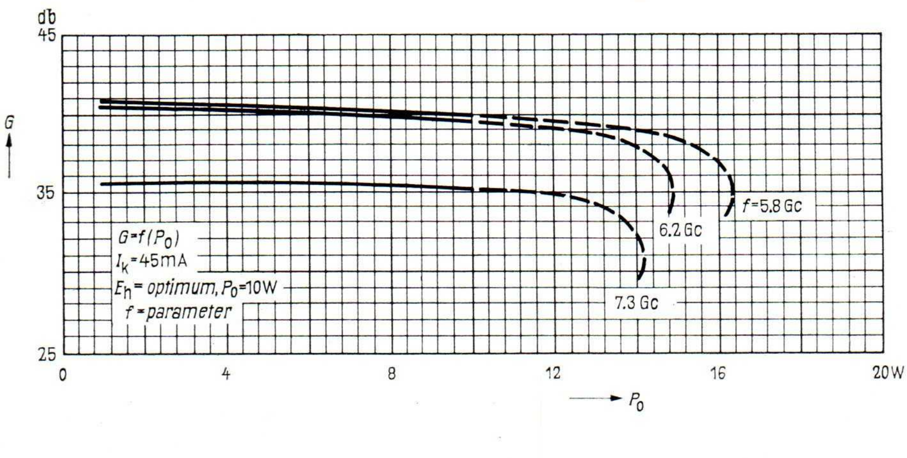


Fig. 17. Gain as a function of the output power at various frequencies.

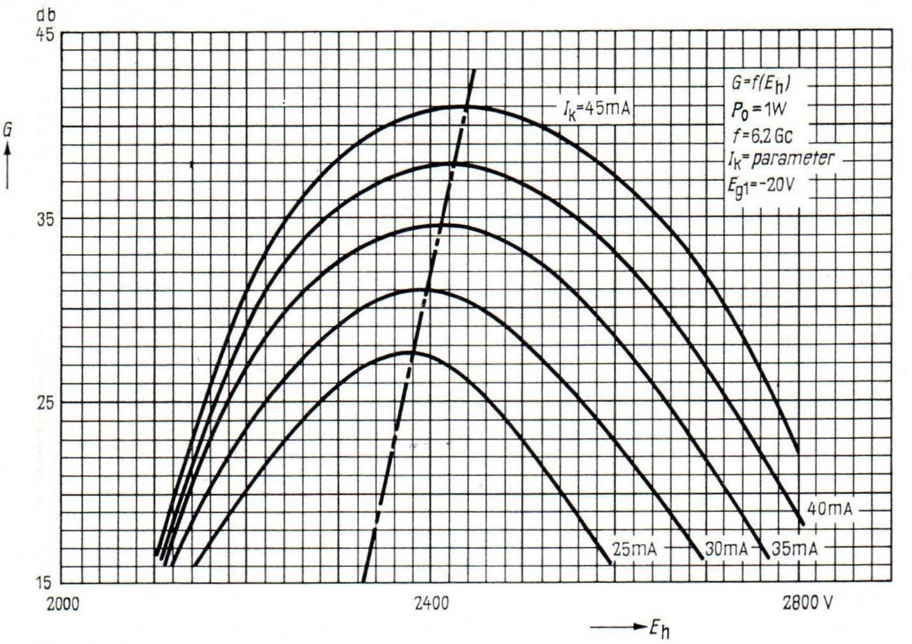


Fig. 18. Gain as a function of the helix voltage at various cathode currents.

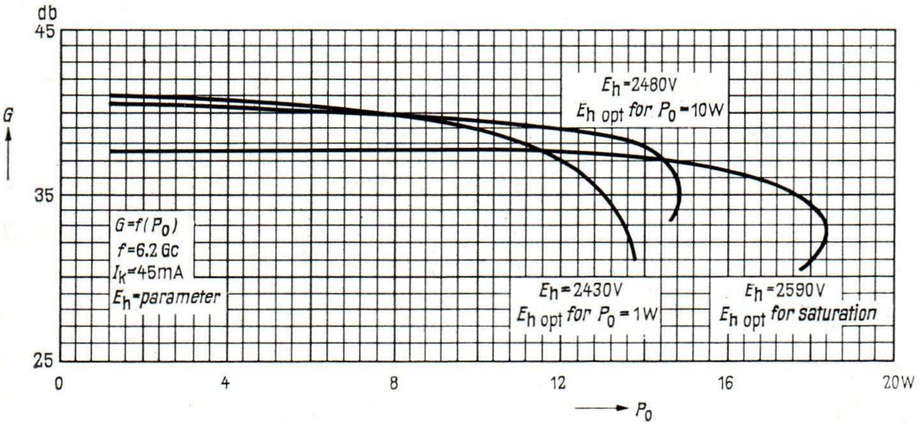


Fig. 19. Gain as a function of output power at various helix voltages.

At the normal working point ($I_k = 45$ mA) a change in helix voltage of ± 150 V about the optimum value causes a fall in gain of approximately 3 db.

As can be seen from fig. 18 the optimum helix voltage decreases as the cathode current is lowered.

The gain-output power characteristic at three fixed values of helix voltage is reproduced in fig. 19. Three typical cases are represented:

a) Optimum helix voltage for maximum small-signal gain ($E_h = 2430$ V). The maximum obtainable output power is only 13 – 14 W.

b) Helix voltage for optimum gain at $P_o = 10$ W ($E_h = 2480$ V). The maximum obtainable output power is approximately 15 W. This setting is generally used for wideband FM microwave link systems.

c) Helix voltage optimized for saturation power ($E_h = 2590$ V). The maximum output power obtainable at 6.2 Gc is achieved (saturation power approximately 18 W). In this case the gain is practically constant between 0 and 12 W, in other words the amplifier operates as a linear amplifier at low signal levels. This setting is usually employed for the transmission of amplitude-modulated or TV signals.

Since certain spreads in helix voltage occur from tube to tube, it is advisable to set the helix voltage to its optimum value at a low output power level and then raise it by a particular value, in this case 160 V.

Fig. 20 shows the influence of frequency on the gain at output powers of 1 W and 10 W respectively with the helix voltage optimized in each case.

The gain-frequency characteristic for two fixed values of helix voltage (E_h optimized at 5.8 Gc and 7.3 Gc respectively) is given in fig. 21.

The saturation power P_{sat} over the frequency range 5.8 Gc to 7.3 Gc is shown in fig. 22. The saturation power decreases approximately linearly from 20 W to 16 W with increasing frequency.

From figs. 18, 24, and 25 several factors can be obtained which are of interest when calculating the stability of the supply voltages:

Variation of gain with cathode current $\frac{\Delta G}{\Delta I_k} \approx 0.5$ db/mA

Transconductance of grid No. 1 $\frac{\Delta I_k}{\Delta E_{g1}} \approx 0.4$ mA/V

Transconductance of grid No. 2 $\frac{\Delta I_k}{\Delta E_{g2}} \approx 0.1$ mA/V

These values are valid for the normal 10 W operating point ($I_k = 45$ mA).

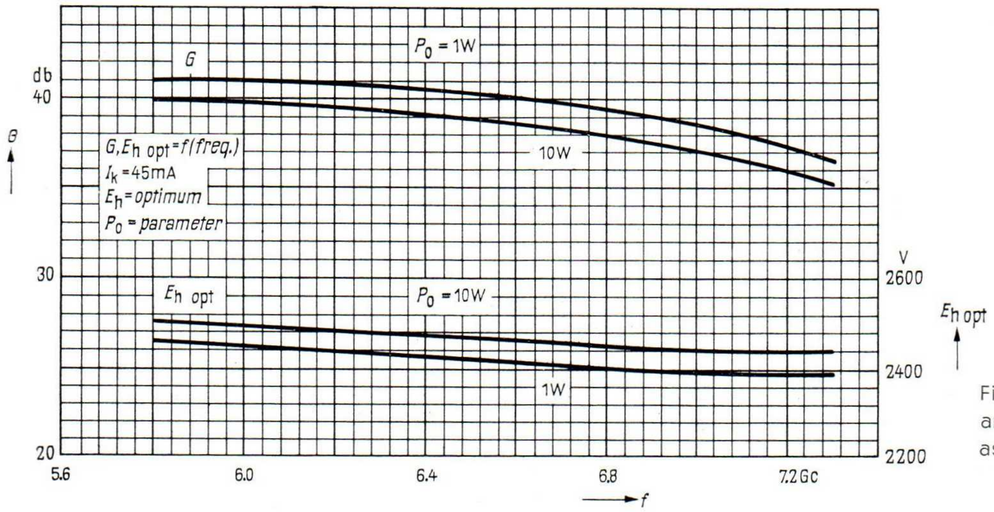


Fig. 20. Gain and optimum helix voltage as a function of frequency.

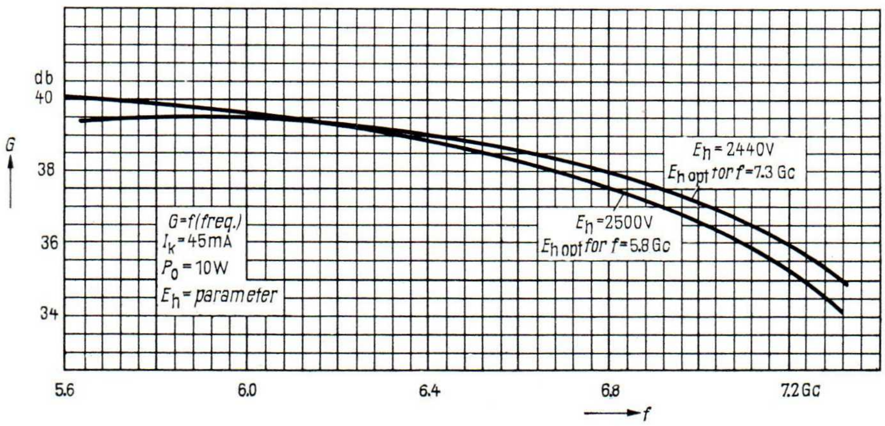


Fig. 21. Gain as a function of frequency at various helix voltages.

5.2.2. Operation at reduced power

If a traveling-wave tube is operated at an output power considerably lower than the nominal value, the operational efficiency can be improved by correcting the operating values. There are two principle possibilities:

a) If good linearity is required (e. g. a low value of AM-PM conversion) the normal beam current should be retained. The collector voltage may be reduced more the lower the output power required. However, operation in the knee of the helix current curve (see fig. 23 and section 5.3.3) must be avoided. If the collector voltage is too low the slowest electrons cannot reach the collector, and return to the helix. The proportion of "slow" electrons is larger the higher the amout of energy transferred from the beam to field.

   All other electrode voltages E_{g1}, E_{g2} and E_h remain at their normal values.

b) If a certain relaxation in linearity and output power is acceptable, the operational efficiency can be further improved in comparsion to a above by decreasing the cathode current and collector voltage. This type of operation can also be used when it is required that the output power should vary with gain for a constant input power.

If the tube is operated at a considerably reduced cathode current the manufacturer should be consulted. It may be necessary to correct the preset magnetic focusing carried out in the factory.

The following may be used for guidance purposes when operating at cathode currents down to a minimum of 35 mA:

The cathode current can be influenced both by the grid No. 1 and grid No. 2 voltages. The corresponding relationships are shown in figs. 24 and 25. The most practical combination of these two voltages depends on the helix current. The more negative the grid No. 1 voltage is made the lower the minimum helix current. Optimum helix currents can be obtained at the individual current values by re-adjusting the focusing (see also figs. 26 to 28). In figs. 26 to 28 the gain, cathode current and helix current are shown as a function of the grid No. 2 voltage at grid No. 1 voltages of −20 V, −40 V and −70 V. The helix current is measured in each case with optimum focusing at a cathode current of 45 mA and with optimum focusing at the given cathode currents for 0 and 1 W.

In the table section 5.1 "Operational data with reduced beam current" two operating points for I_k = 40 mA (P_o = 7.5 W) and I_k = 35 mA (P_o = 5 W) are given. The recommended guiding values of E_{g1} here are −40 V and −70 V respectively.

Fig. 29 shows the gain and helix current plotted against output power at $I_k = 35$, 40 and 45 mA. The saturation power increases with beam current due to the increase in beam energy. The gain and helix voltage at a cathode current of 35 mA are shown as functions of output power at three different frequencies in fig. 30.

5.3. Distortion

5.3.1. AM-PM conversion k_p

Because of non-linear distortions, the phase shift of an r. f. signal between input and output of a traveling-wave tube depends on the drive. An amplitude-modulated signal applied to the input will therefore also be phase-modulated as it passes through the tube (AM-PM conversion).

The AM-PM conversion is expressed as the phase change in degrees per db change in amplitude and has been given the symbol k_p. Here it is assumed that the change in input signal is so small that a further decrease in this change has no noticeable effect on the result.

$$k_p = \frac{\Delta \varphi^\circ}{10 \log \dfrac{P_i + \Delta P_i}{P_i}}$$

where P_i is the input power in Watts

ΔP_i is the change in input power in Watts

$\Delta \Phi$ is the change of the phase angle in degrees between input and output when the input power is changed from P_i to $P_i + \Delta P_i$.

If $\Delta P_i \ll P_i$

$$\log \left(1 + \frac{\Delta P_i}{P_i}\right) = 0.434 \ln \left(1 + \frac{\Delta P_i}{P_i}\right) = 0.434 \frac{\Delta P_i}{P_i}$$

so that $$k_p = 0.23 \frac{\Delta \Phi}{\dfrac{\Delta P_i}{P_i}} \text{ with } \Phi \text{ in degrees}$$

or $$= 13.2 \frac{\Delta \Phi}{\dfrac{\Delta P_i}{P_i}} \text{ with } \Phi \text{ in radians}$$

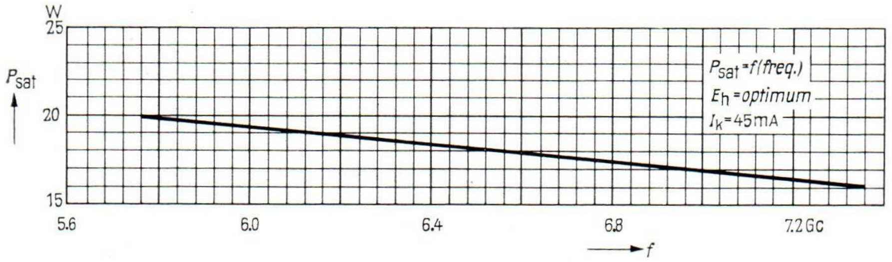


Fig. 22. Saturation power as a function of frequency.

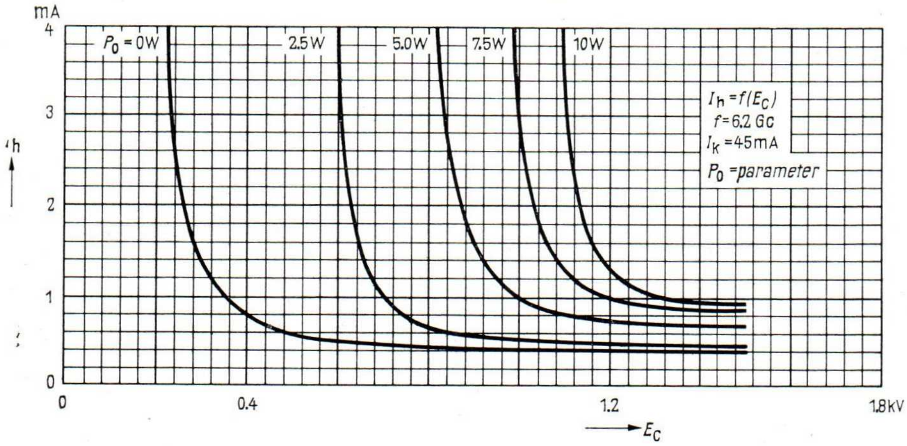


Fig. 23. Helix current as a function of the collector voltage at varios output powers.

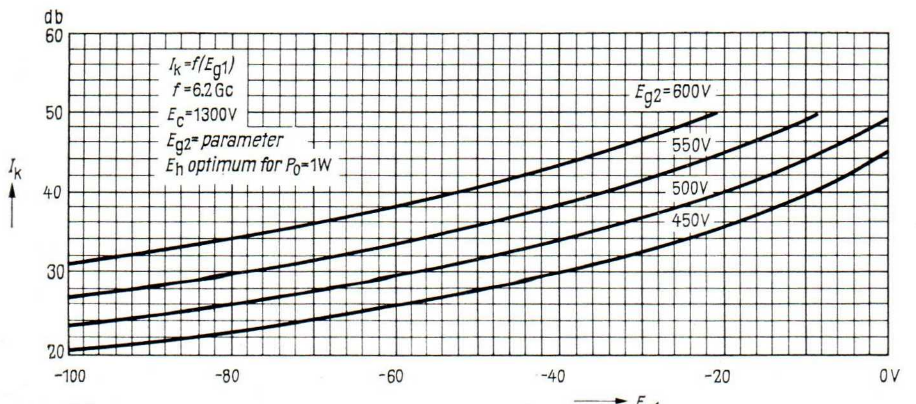


Fig. 24. Cathode current as a function of the grid No. 1 voltage at various grid No. 2 voltages.

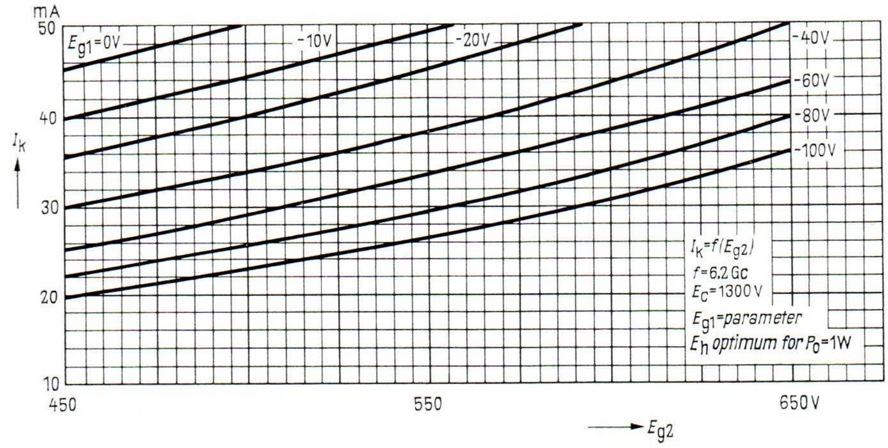


Fig. 25. Cathode current as a function of the grid No. 2 voltage at various grid No. 1 voltages.

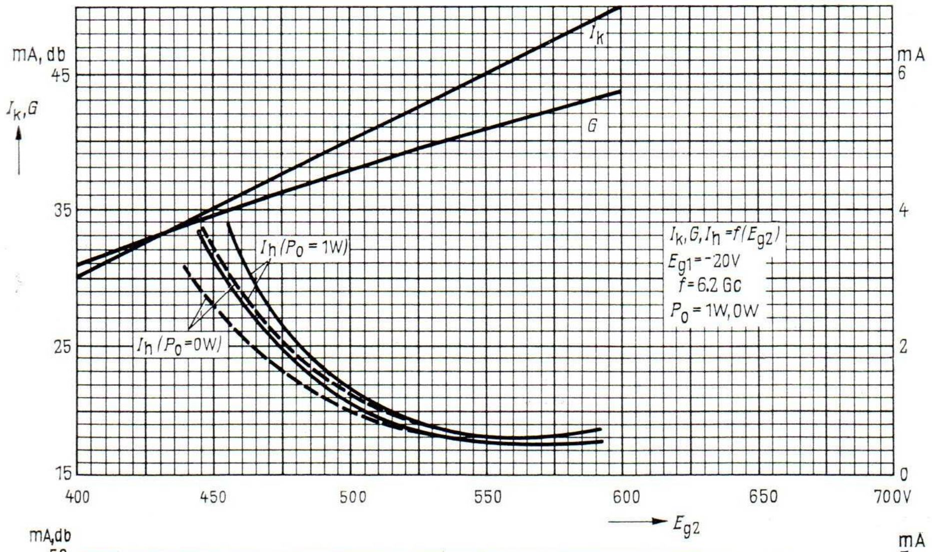


Fig. 26. 27. 28.
Cathode current, gain and helix current as functions of the grid No. 2 voltage

Fig. 26.
——Optimum focusing of tube for I_k = 45 mA
– – –Optimum focusing of the tube in each case

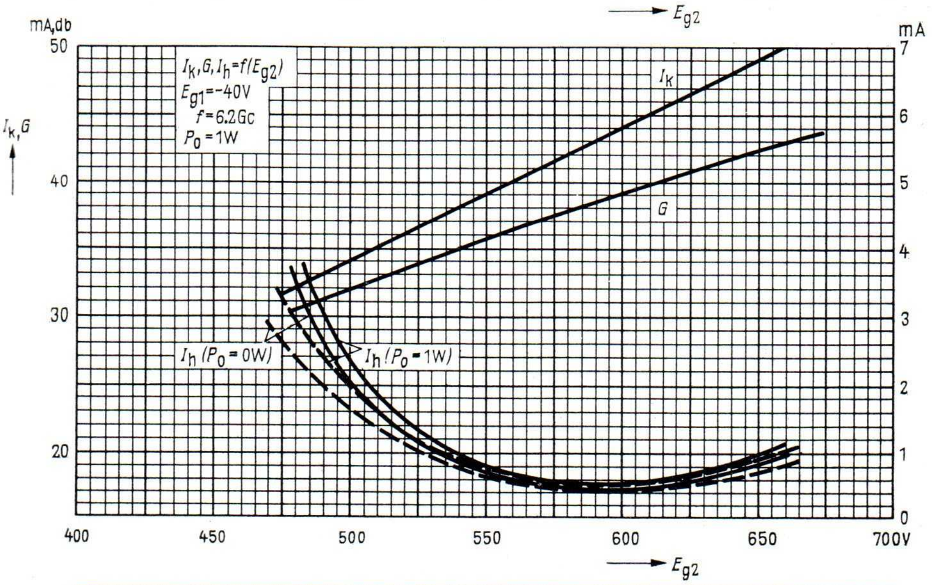


Fig. 27.
——Optimum focusing of tube for I_k = 45 mA
– – –Optimum focusing of the tube in each case

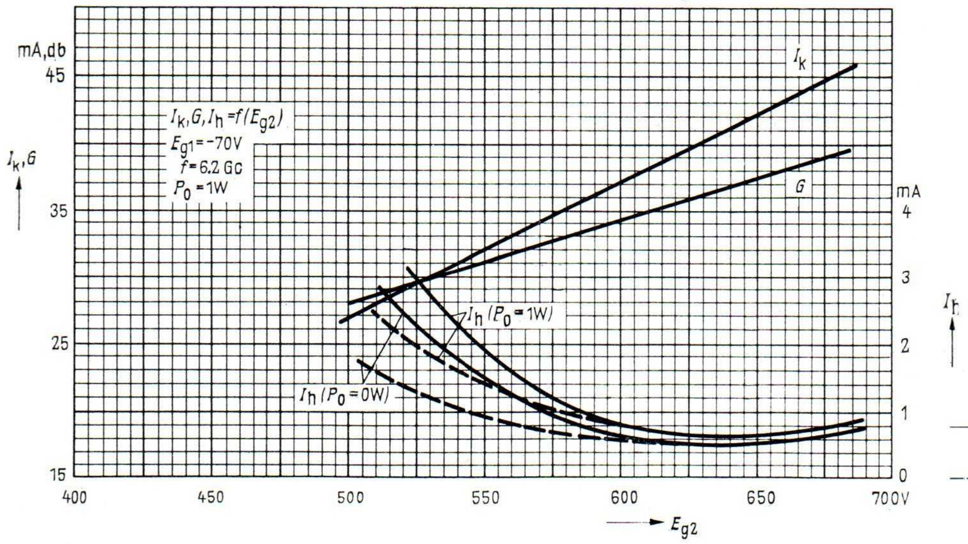


Fig. 28.
——Optimum focusing of tube for I_k = 45 mA
– – –Optimum focusing of the tube in each case

Since the AM-PM conversion varies with the drive, its value should always be quoted in conjunction with the corresponding input or output power.

Methods of measuring AM-PM conversion are described in [3, 4, 5]. The value of AM-PM conversion depends on various factors. The influence of the helix voltage at the nominal working point (P_o = 10 W) is shown in figs. 31 and 32. In fig. 31 the output power is constant, whereas in fig. 32 the input power remains unchanged. The tendency for k_p to increase with helix voltage can be clearly seen. However, the change is relatively small in the region of the highest power gain. In practice, the setting of the helix voltage E_h for optimum small-signal gain has proved the best. The loss in gain at 10 W power output is still relatively low and the difference between the nominal output and saturation powers is sufficiently large. The average value of k_p is 4.2 °/db.

Lower values of AM-PM conversion within the steep region of the k_p curve can only be utilized in certain cases, namely when a lower gain and the correspondingly lower saturation power are acceptable, and furthermore when the helix voltage can be highly stabilized. The increase of k_p with output power is virtually linear as long as the maximum power for a given helix voltage is not exceeded (fig. 33).

As the tube is driven beyond saturation, k_p falls again, and this is accompanied by a considerable fall-off in power gain.

The variation of k_p with frequency can be seen in fig. 34, where k_p is shown as a function of output power at three different frequencies. In each case the helix voltage is set for optimum small-signal gain.

Fig. 35 shows k_p as a function of the output power with the cathode current as parameter, the helix voltage E_h again being set for optimum small-signal gain. As can be seen, the value of k_p decreases as the cathode current is increased.

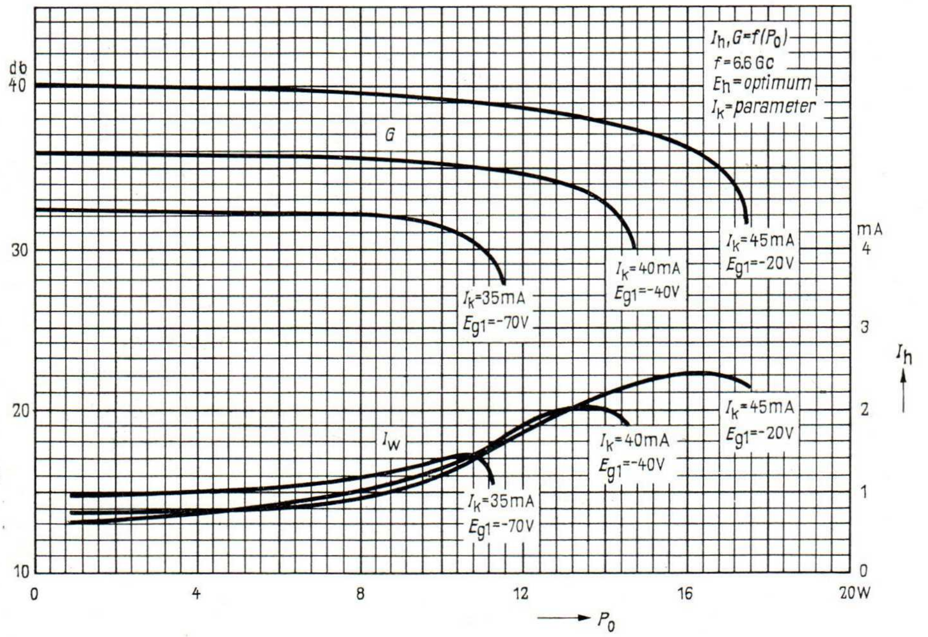


Fig. 29. Helix current and gain as functions of the output power at various cathode currents.

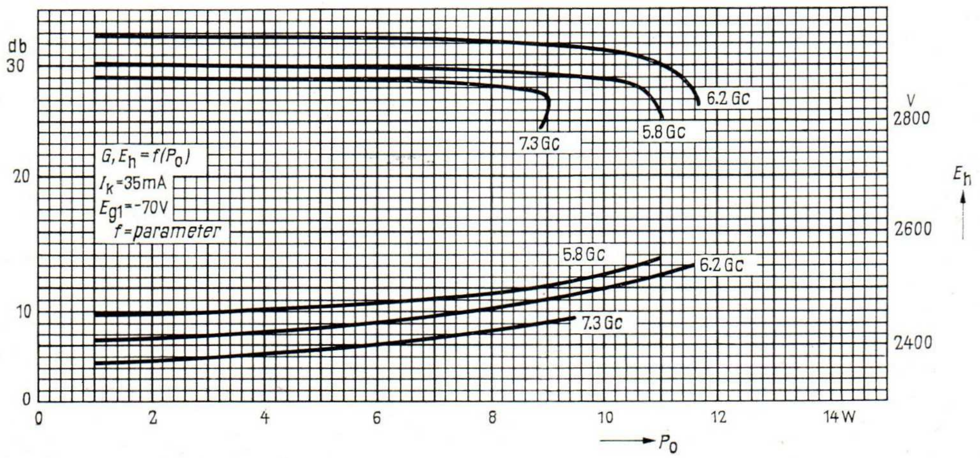


Fig. 30. Gain and helix voltage as functions of the output power at various frequencies.

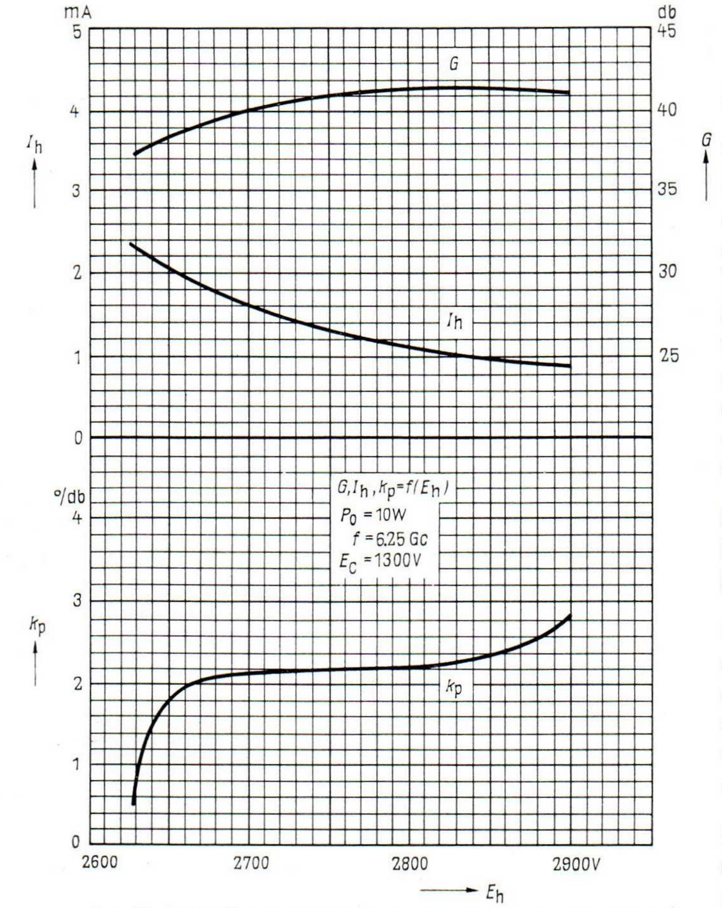


Fig. 31. AM-PM conversion as a function of the output functions of the helix voltage.

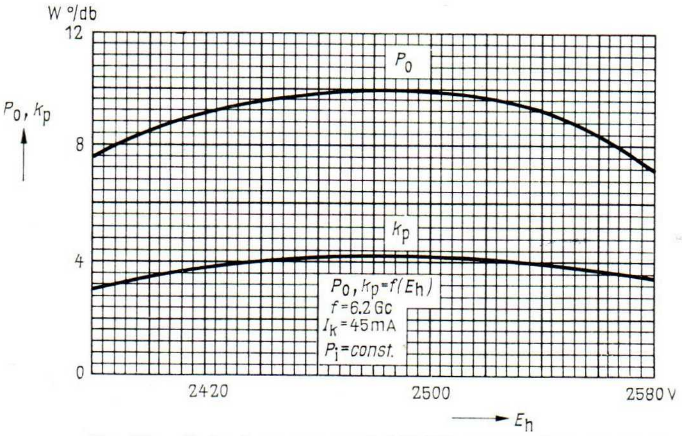


Fig. 32. Output power and AM-PM conversion as functions of the helix voltage at constant input power.

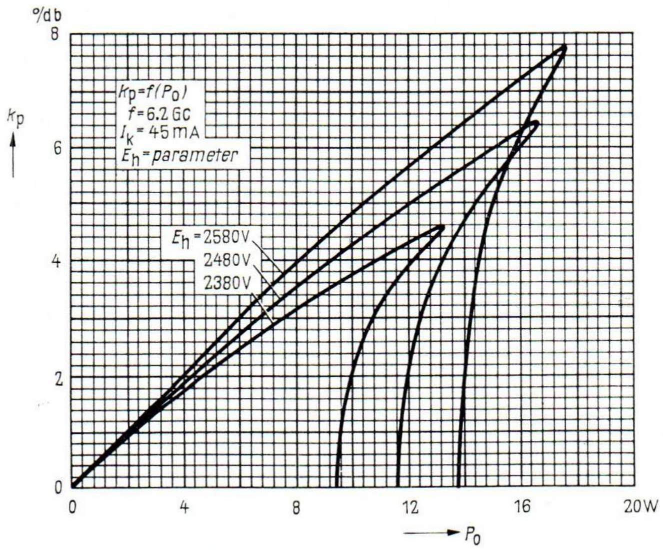


Fig. 33. AM-PM conversion as a function of the output power at various helix voltages.

5.3.2. ΔE-PM conversion

In comparison to normal gridded tubes, the interaction space of traveling-wave tubes is electrically very long, and the phase velocity of the wave can therefore be influenced by the electron beam. Thus even small changes in the operating voltages E_h, E_{g1} or E_{g2} cause detectable phase shifts at the output. This effect is described by the ΔE-PM conversion factor which is defined as the phase angle change between input and ouput per volt change in one of the electrode voltages. The appropriate values for the RW 6 are:

E_{g1}-PM conversion factor : 0.5 °/V
E_{g2}-PM conversion factor : 1.2 °/V
E_h -PM conversion factor : 1.7 °/V

If the phase modulation is undesired, as is for example the case when the tube is used as a power amplifier in FM microwave link systems, the above values can be used to determine the admissible spurious voltages and the necessary stability of the power supplies.

On the other hand, the voltage-dependent phase shift can be utilized to produce an intentional phase modulation. For example, it is possible to use the helix voltage to produce a phase modulation in a certain range without simultaneous amplitude modulation.

5.3.3. Harmonics in the output

As in most active four-pole networks, certain nonlinearities also occur in traveling-wave tubes. This leads amongst other things to the output power containing 2nd and 3rd Harmonic components. In tube types such as the RW 6 the harmonic power is about 30 db below the fundamental or useful power, but at individual frequencies this figure can sink to approximately 16 db.

5.4. Noise

5.4.1. Noise factor

The noise factor F is a measure of the noise of a tube, and from its definition the signal- to -noise ratio at the output of a tube is immediately obtained:

$$\frac{S}{N} = \frac{P_o}{GFBkT_o}$$

where S = signal power, N = noise power,
P_o = output power, G = gain, F = noise factor,
B = bandwidth, $kT_o = 4 \times 10^{-21}$ Ws.

Under normal operating conditions (I_k = 45 mA) the noise factor of the RW 6 is approximately 23 db. A reduction of cathode current results in only a small increase in the noise factor, for example at a cathode current of 35 mA, the noise factor is approximately 23.5 db.

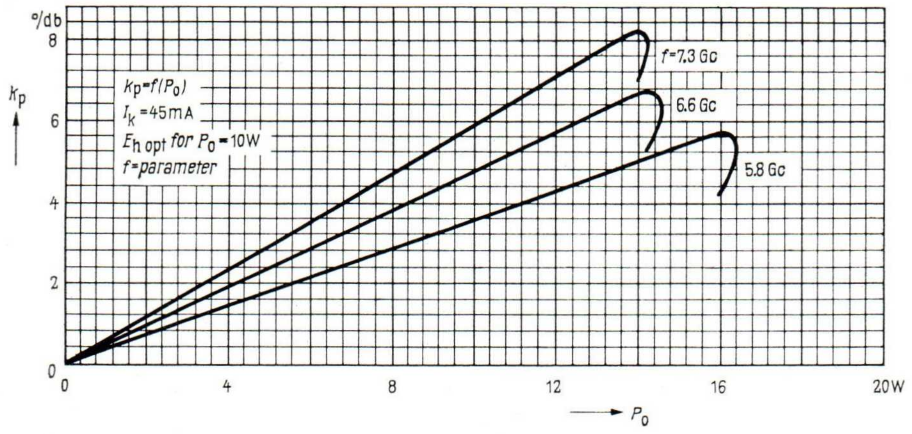


Fig. 34. AM-PM conversion as a function of the output power at various frequencies.

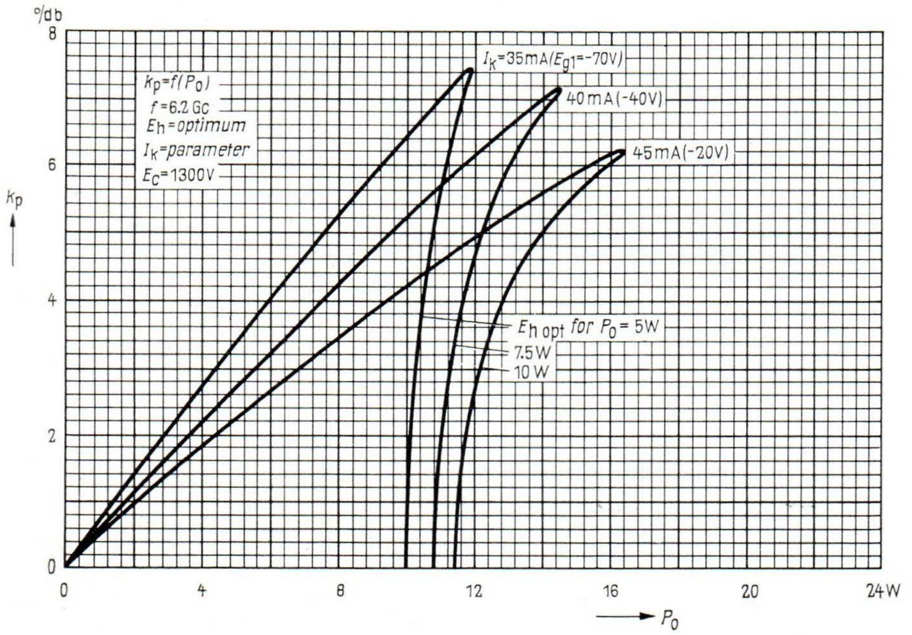


Fig. 35. AM-PM conversion as a function of the output power at various cathode currents.

5.4.2. FM noise

The following considerations are valid for frequency-modulated systems. An effective frequency deviation in the base band is allotted to a speech power of 1 mW per speech channel. This deviation is standardized:

$\Delta f_{eff} = 200$ kc for 600 and 960 channel systems

$\Delta f_{eff} = 140$ kc for 1800 channel systems

Theoretical considerations show that the square of the average value of the noise phase deviation is derived from the signal-to-noise ratio:

$$\Delta \Phi^2 = \frac{N}{S} = \left(\frac{S}{N}\right)^{-1}$$

Now

$$\Delta \Phi = \frac{\Delta f}{f}$$

where Δf is the frequency deviation and f is the modulating frequency,

so that

$$\Delta \Delta f_{eff} = f \cdot \sqrt{\frac{N}{S}}$$

The noise power per channel is therefore

$$P_N = \left(\frac{\Delta \Delta f_{eff}}{\Delta f_{eff}}\right)^2 \text{ mW}$$

$$= \frac{f^2 G F k T_o}{\Delta f^2{}_{eff} P_o} . 10^{-3} \text{ W}$$

It can therefore be seen that the noise power per channel increases with the square of the modulating frequency. When appraising a tube, the highest modulating frequency in the particular system must therefore be considered:

600 channels	$f_{max} = 2{,}4$ Mc
960 channels	$f_{max} = 4$ Mc
1800 channels	$f_{max} = 8$ Mc

The bandwidth is the speech bandwidth which is the channel bandwidth of 3.1 kc less 2.7 db ear rating. B is therefore 1.7 kc.

With this analysis all values with the exception of the product of gain and noise factor ($G \times F$) are fixed. It is the prerogative of the tube manufacturer to find a rational relationship between gain and the noise factor. For the RW 6 with $P_o = 10$ W, 1800 channels, $G = 39$ db and $F = 23$ db the noise power in the highest channel is 3.6 pW.

In conventional FM systems, the channel deviation is decreased at the lower frequencies and raised at the higher frequencies (pre-emphasis). This improves the signal-to-noise ratio in the higher channels. 5 db decrease or increase is usual, so that the signal-to-noise ratio calculated for the RW 6 is increased by 5 db.

5.5. Matching

The large bandwidth of a traveling-wave tube can only be fully utilized when it is also possible to provide a wide-band match at the input and output of the tube. Within a limited range the VSWR can be made extremely small for each tube by using variable matching elements. In practice, however, individual alignment usually meets with difficulties, and it appears more advisable to avoid special matching elements and in their place to aim at a wide-band matching. The traveling-wave tubes RW 6 and RW 80 are plug-in matches.

The VSWR at the input and output of the "cold" tube is less than 1.5. When the tube is operating, this figure is generally below 1.6.

The matching can be considerably improved by using isolators, and in order that all the advantages of the wide-band characteristics be utilized, it is in fact particularly advisable to make use of such circuit elements. These isolators should be connected directly to the input and output waveguide flanges of the magnet system to prevent the "long-line effect".

5.6. Helix attenuator

Any signal reflected from the output of a traveling-wave tube must be attenuated to prevent it reaching the input. This attenuation is achieved by depositing a resistive layer on the helix support rods. As already mentioned in section 2.3, this layer prevents signals reflected at the output from reaching the input and causing self-oscillation. The degree of helix attenuation is determined by applying a definite power to the tube output and measuring the power at the input with a beat receiver.

The cold helix attenuation is approximately 80 db which is some 40 db down on the gain. This indicates that practically no feedback occurs.

5.7. Effects of temperature

Traveling-wave amplifiers must also function properly under the adverse ambient conditions which can arise in microwave link systems. Thorough tests have therefore been conducted on the RW 6 to establish the behavior of helix current, gain and operational VSWR in the temperature range −20 °C to +55 °C.

The amplifiers were placed in an environmental room, and all other equipment required for the tests, such as power supplies, power meters, isolators etc. were left outside.

It was found that the power gain falls only slightly with increasing temperature (fig. 36). The variation of ±0.3 db. is hardly greater than the normal measuring accuracy. The helix current also increases slightly as shown in fig. 37. The low sensitivity to temperature is a result of using Alnico V as magnetic material and of the type of magnetic circuit configuration employed. The hot VSWR also varies very little with temperature.

The variation of collector temperature with ambient temperature is shown in fig. 38. The temperature difference between collector and ambient remains constant at 180 °C. The r.f. power taken

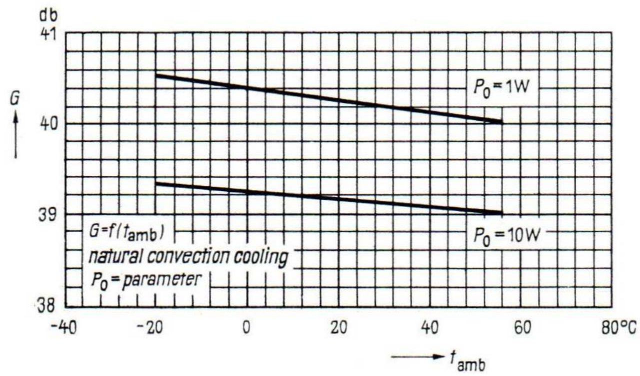


Fig. 36. Gain as a function of the ambient temperature. Convection-cooled version (MRW 6b) arranged horizontally with natural air circulation in a vertical direction through the radiator.

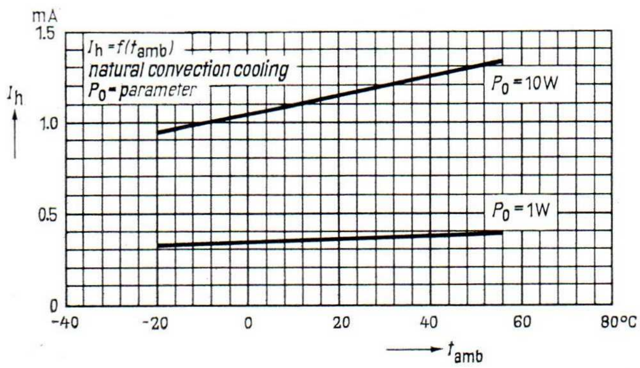


Fig. 37. Helix current as a function of the ambient temperature. Convection-cooled version (MRW 6b) arranged horizontally with natural air circulation in the vertical direction through the radiator.

from the electron beam has a noticeable effect on the collector temperature; without r. f. drive the collector temperature is approximately 35 °C higher. The temperature of the magnet system casing is about 15 °C above ambient at all temperatures. The amplifiers tested also functioned satisfactorily at –20 °C.

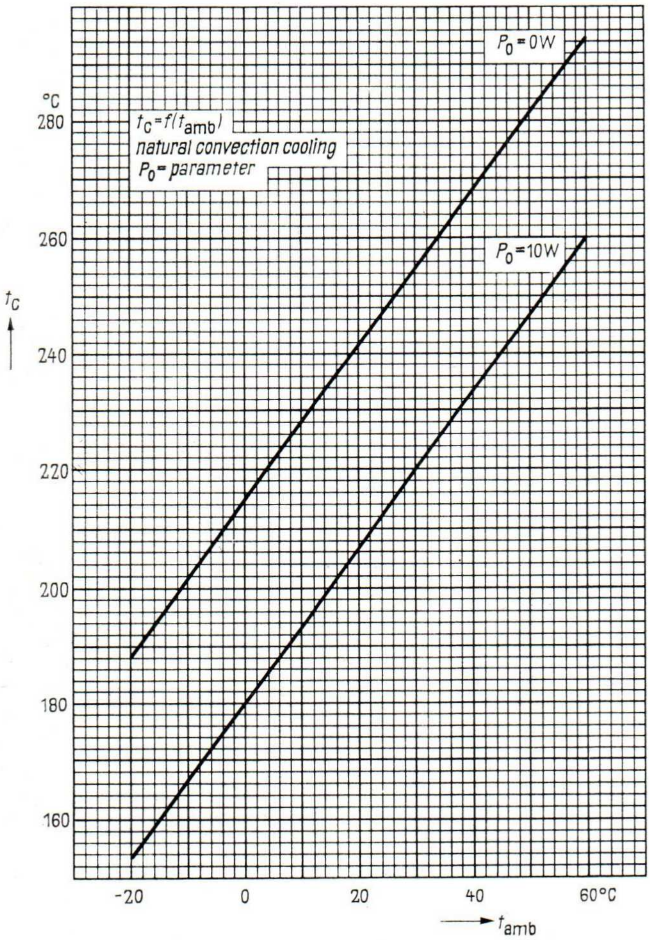


Fig. 38. Collector temperature as a function of the ambient temperature. Convection-cooled version (MRW 6b) arranged horizontally with natural air circulation in a vertical direction through the radiator.

5.8. Stability

Traveling-wave tubes normally work into a well-matched load at the operating frequency. However, filters connected between the traveling-wave tube and antenna can still produce total reflections at immediately adjacent frequencies. In such cases relatively small mismatches inside the tube can cause self-oscillation in view of the high gain of the tube.

The RW 6 is subjected to a stability test as outlined in fig. 39. Variable short-circuit waveguide sections are connected to the input and output of the tube and the helix voltage is wobbled over a definite range. If the position of either of the short-circuit sliders is changed independent of the other one, no self-oscillations must occur in the tube, and the background noise must not increase.

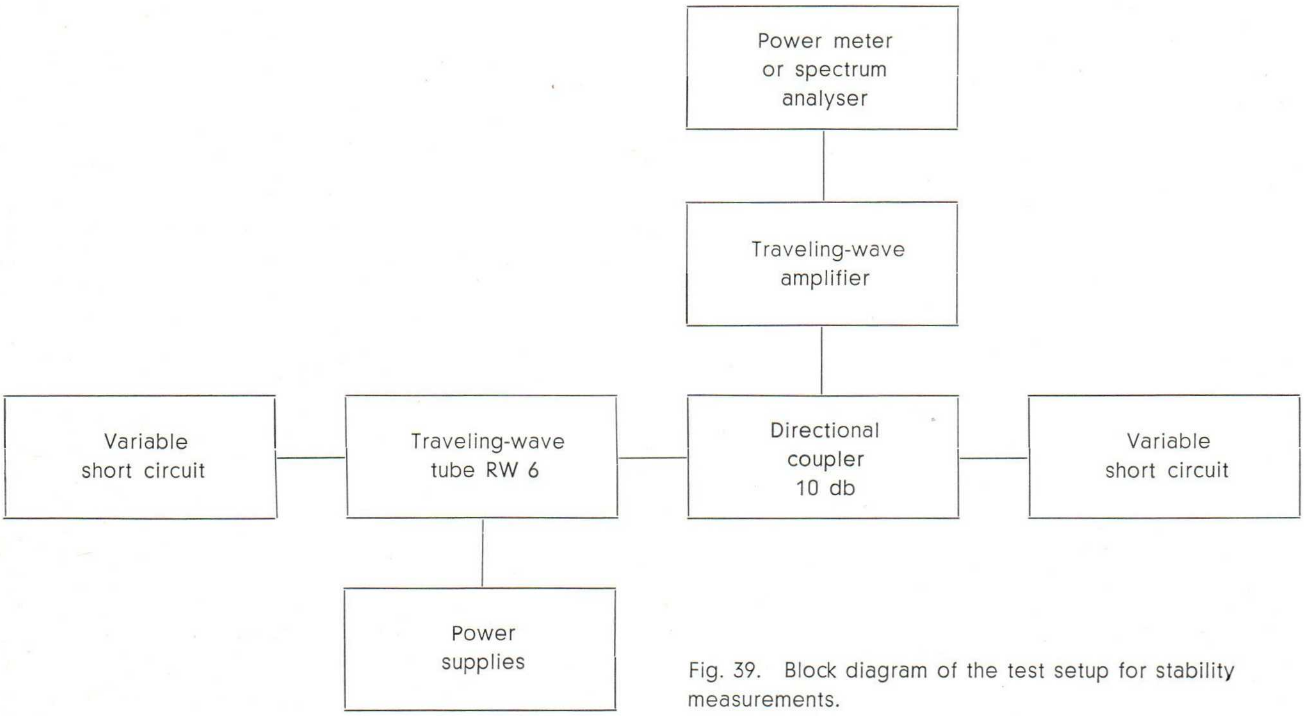


Fig. 39. Block diagram of the test setup for stability measurements.

6. The Medium-Power Traveling-Wave Tube RW 80 for the Frequency Band 5.8 to 8.5 Gc

The medium-power traveling-wave tube RW 80 is especially suited for use in wide-band microwave link systems and has an average gain of 39 db with an average output power of 15 W up to 7.0 Gc and 10 W up to 8.5 Gc. The tube is focused by a periodic permanent magnet circuit MRW 80 and is a plug-in match in this system which has a low stray field. It is designed to operate with depressed collector.

The magnet system is available for conduction cooling (MRW 80a) or for convection cooling (MRW 80b), and with the tube and supply cable in position is fully screened to r. f. The tube is designed for use with waveguide input and output circuits.

6.1. Technical data

Tube dimensions	See fig. 13
Dimensions of the magnet system	See fig 14
Tube socket	Similar to continental socket[1])
Weight of the tube	approx. 100 gm net
Weight of the magnet system	approx. 7.5 kg
External dimensions of the magnet system	100 mm x 112 mm x 338 mm
Dimensions of the tube packing	170 mm x 170 mm x 460 mm
Waveguide	F 70 DIN 47302, 34.85 mm x 5 mm
Flange	NF 70 DIN 47303
Mounting position	Any (see cooling, section 7.4)

[1]) The appropriate connector socket with 1.1 m cable is supplied as required either straight or with a 90° bend on the socket assembly.

Heating

Heater voltage	E_f	=	6.3	V[1])
Heater current	I_f	=	0.8	A
Preheating time	t_h	≧	2	min

Method of heating : indirect a. c. parallel fed

Cathode: dispenser (metal capillary)

Characteristics

Frequency range	f	=	5.8 . . . 8.5	Gc
Saturation power	P_{sat}	=	30 . . . 16	W
Average gain	G	≈	39	db
Small-signal gain	G ($P_o = 1$ W)	≈	40	db
VSWR	s	<	1.5	[2])
Magnetic flux density	B_z	≈	800	Gauss[3])

Operating data ($f = 6.0$ Gc)

Output power	P_o	=	15	10	5	W[4])
Gain	G	=	40.5	41	41	db
Collector Voltage	E_c	=	1500	1300	900	V[5])
Helix voltage	E_h	≈	2850	2850	2850	V
Grid No. 2 voltage	E_{g2}	≈	580	580	580	V
Grid No. 1 voltage	E_{g1}	=	− 40	− 40	− 40	V[5]) [6])
Cathode current	I_k	=	50	50	50	mA[5]) [7])
Helix current	I_h	≈	2	<2	<2	mA
Grid No. 2 current	I_{g2}	≦	0.1	0.1	0.1	mA
Noise factor	F	≈	22	22	22	db

All voltages are refered to the cathode.

[1]) Variations of more than ± 2 % (absolute limits in the heater voltage impair tube performance and life.)

[2]) At input and output of cold tube in the frequency band 5.8 Gc to 8.5 Gc.

[3]) Crest value of the periodic magnetic field in the axial direction.

[4]) For an output power lower than 15 W the cathode current I_k can be reduced down to 35 mA by changing the grid No. 2 voltage E_{g2}. This causes a decrease in gain and the linearity also deteriorates. If such operation is desired the manufacturer should be consulted.

[5]) Setting-up value.

[6]) It is advisable to set the grid No. 1 voltage by using a cathode resistor.

[7]) When the cathode current I_k changes by 1 mA in the range 48 to 55 mA, the gain changes by approximately 0.5 db.

[8]) For an output power lower than 10 W the cathode current I_k can be reduced down to 35 mA by changing the grid No. 2 voltage E_{g2}. This causes a decrease in gain and the linearity also deteriorates. If such operation is desired the manufacturer should be consulted.

Operating data ($f = 7.0$ Gc)

Output power	P_o	=	15	10	5	W[1])
Gain	G	=	40	40.5	40.5	db
Collector voltage	E_c	=	1450	1300	1050	V[2])
Helix voltage	E_h	≈	2800	2800	2800	V
Grid No. 2 voltage	E_{g2}	≈	580	580	580	V
Grid No. 1 voltage	E_{g1}	=	− 40	− 40	− 40	V[2])[3])
Cathode current	I_k	=	50	50	50	mA[2])[4])
Helix current	I_h	≈	2	<2	<2	mA
Grid No. 2 current	I_{g2}	≦	0.1	0.1	0.1	mA
Noise factor	F	≈	22	22	22	db

Operating data ($f = 8.4$ Gc)

Output power	P_o	=	10	5	W[5])
Gain	G	=	37.5	37.5	db
Collector voltage	E_c	=	1300	1100	V[2])
Helix voltage	E_h	≈	2750	2750	V
Grid No. 2 voltage	E_{g2}	≈	580	580	V
Grid No. 1 voltage	E_{g1}	=	− 40	− 40	V[2])[3])
Cathode current	I_k	=	50	50	mA[2])[4])
Helix current	I_h	≈	2	<2	mA
Grid No. 2 current	I_{g2}	≦	0.1	0.1	mA
Noise factor	F	≈	22	22	db

All voltages are referred to the cathode.

Operating data (with reduced beam current, $f = 7.0$ Gc)

Output power	P_o	=	10	7.5	W
Gain	G	=	37	34	db
Collector voltage	E_c	=	1300	1200	V
Helix voltage	E_h	=	2840	2830	V
Grid No. 2 voltage	E_{g2}	≈	590	580	V
Grid No 1 voltage	E_{g1}	=	− 60	− 80	V
Cathode current	I_k	=	45	40	mA
Helix current	I_h	≈	2	2	mA
Grid No. 2 current	I_{g2}	≦	0.1	0.1	mA
Noise factor	F	=	22	22	db

Any deviations from the normal operating data should be made only in consultation with the manufacturer (see also section 5.2.2, page 11).

Maximum ratings (absolute values)

Cold collector voltage	E_{co}	max	1700	V
Collector voltage	E_c	max	1600	V
Collector dissipation	P_c	max	75	W
Helix voltage	E_h	max	3000	V
Helix voltage	E_h	min	2400	V
Helix current	I_h	max	3.5	mA[6])
Helix dissipation	P_h	max	10	W
Grid No. 2 voltage	E_{g2}	max	700	V
Grid No. 2 dissipation	P_{g2}	max	0.2	W
Grid No. 1 voltage	E_{g1}	max	0	V
Grid No. 1 voltage	E_{g1}	min	−100	V
Load reflection factor	r_L	max	33	%
Cathode current	I_k	max	55	mA
Collector temperature	t_c	max	270	°C[7])
Ambient temperature	t_{amb}	min	−20	°C
Ambient temperature	t_{amb}	max	+55	°C[8])

[1]) For an output power lower than 15 W the cathode current I_k can be reduced down to 35 mA by changing the grid No. 2 voltage E_{g2}. This causes a decrease in gain and the linearity also deteriorates. If such operation is desired the manufacturer should be consulted.

[2]) Setting-up-value

[3]) It is advisable to set the grid No. 1 voltage by using a cathode resistor.

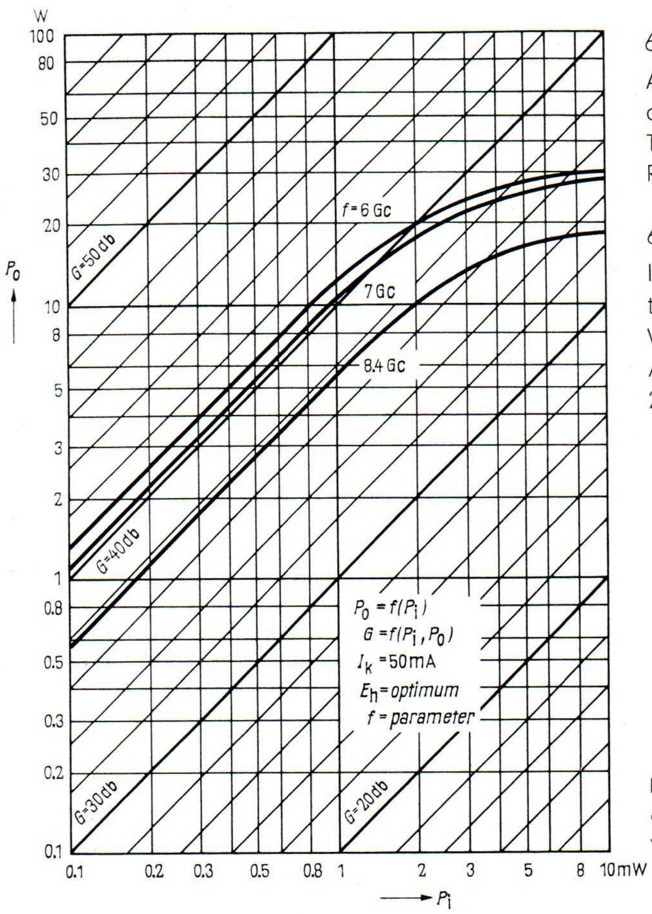
[4]) When the cathode current I_k changes by 1 mA in the range 48 to 55 mA, the gain changes by approximately 0.5 db.

[5]) For an output power lower than 10 W the cathode current I_k can be reduced down to 35 mA by changing the grid No. 2 voltage E_{g2}. This causes a decrease in gain and the linearity also deteriorates. If such operation is desired the manufacturer should be consulted.

[6]) During switch-on or mains surges the helix current I_h may rise momentarily to 5 mA. This value is also recommended as the cutout value of the over-current relay.

[7]) If the carrier signal fails, the collector temperature may rise up to 300 °C for a maximum duration of 3 days.

[8]) See cooling, section 7.4.



6.2. Gain and output power

As for the RW 6, the most important characteristics of the RW 80 are shown similarly in figs. 40 to 57. The general remarks made in section 5 for the RW 6 are also applicable in principle to the RW 80.

6.3. AM-PM conversion kp

In fig. 58 k_p, G and I_h are shown as a function of the helix voltage E_h at an output power of 10 W. Within a helix voltage range of about $\pm$ 75 V the AM-PM conversion is approximately constant at 2.2 °/db.

Fig. 40. Output power as a function of input power and gain as a function of input and output powers at various frequencies.

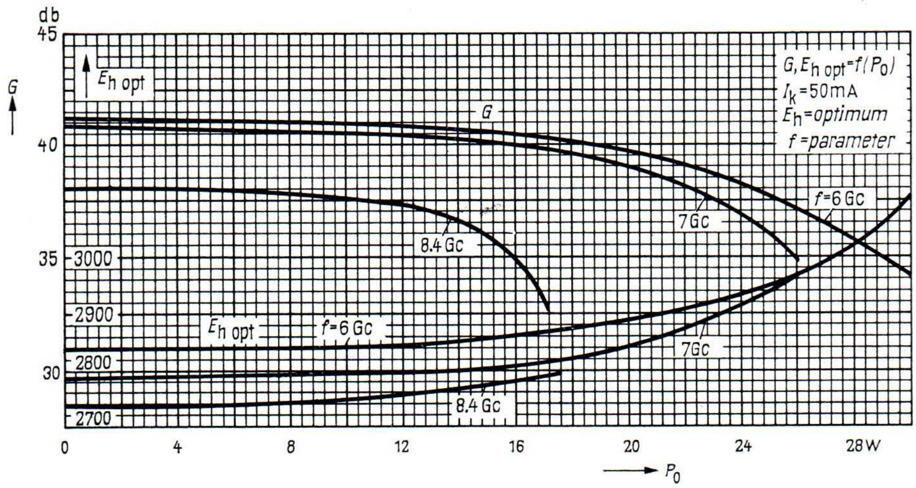


Fig. 41. Gain and optimum helix voltage as functions of the output power at various frequencies.

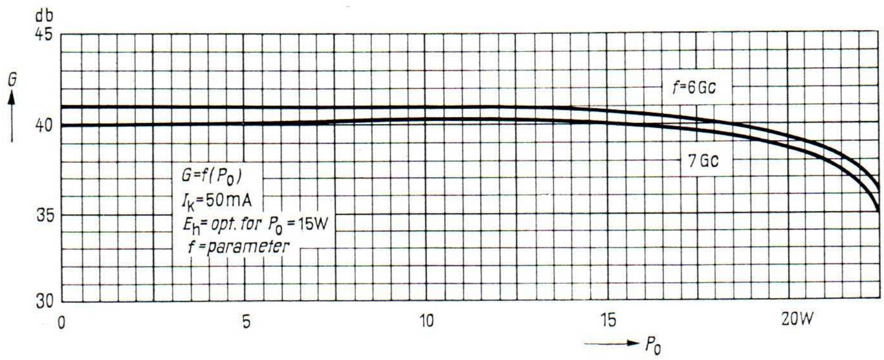


Fig. 42a. Gain as a function of the output power at two frequencies.

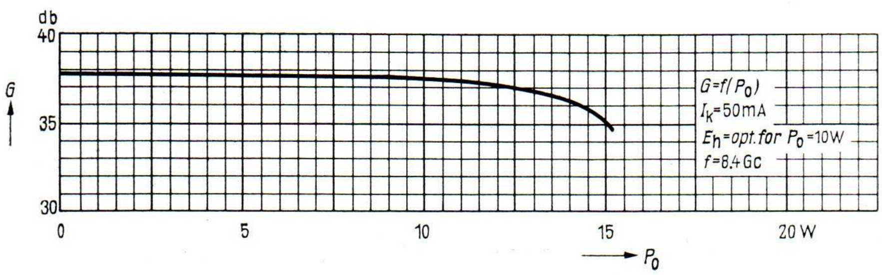


Fig. 42b. Gain as a function of output power at f = 8.4 Gc.

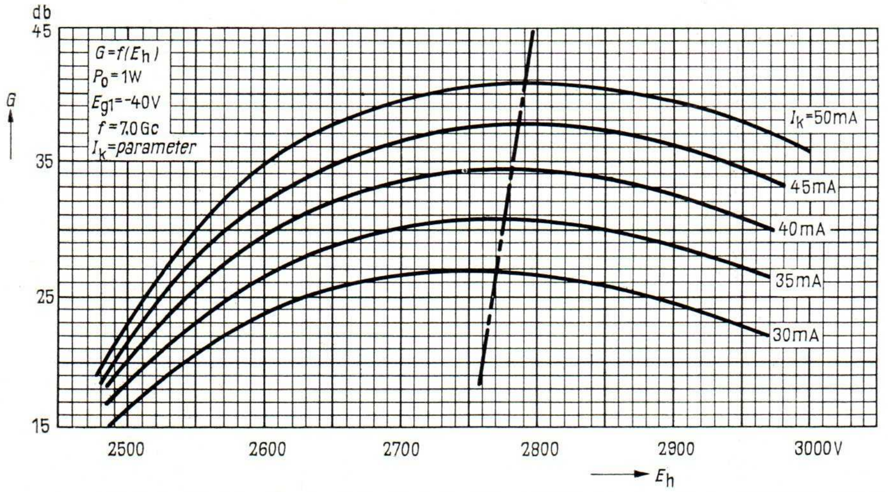


Fig. 43. Gain as a function of the helix voltage at various cathode currents.

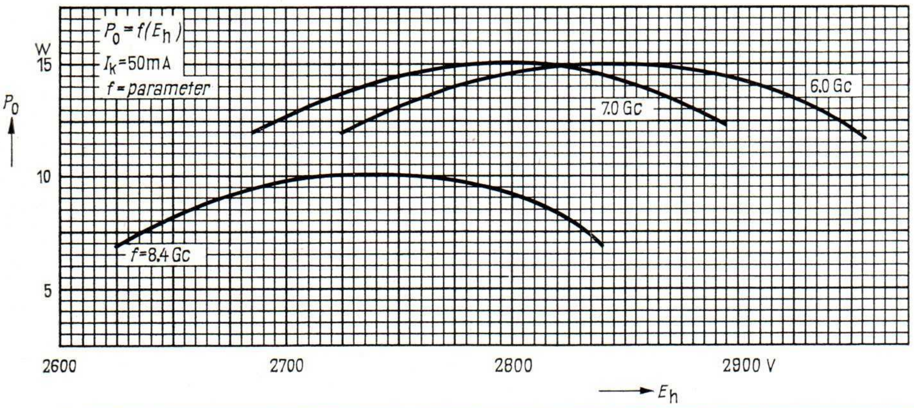


Fig. 44. Output power as a function of the helix voltage at various frequencies.

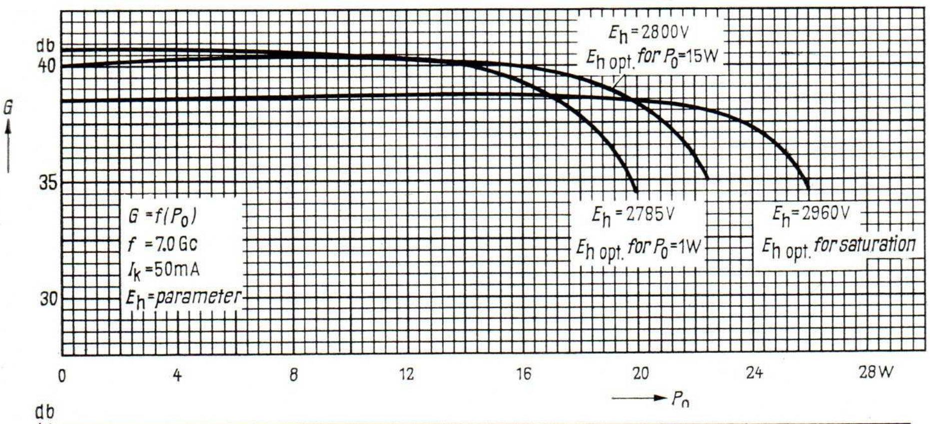


Fig. 45. Gain as a function of the output power at various helix voltages.

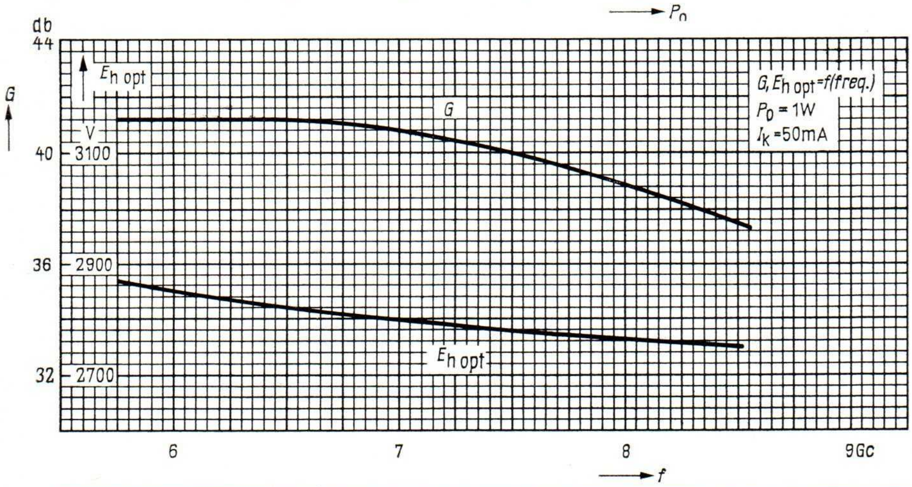


Fig. 46. Gain and optimum helix voltage as functions of frequency.

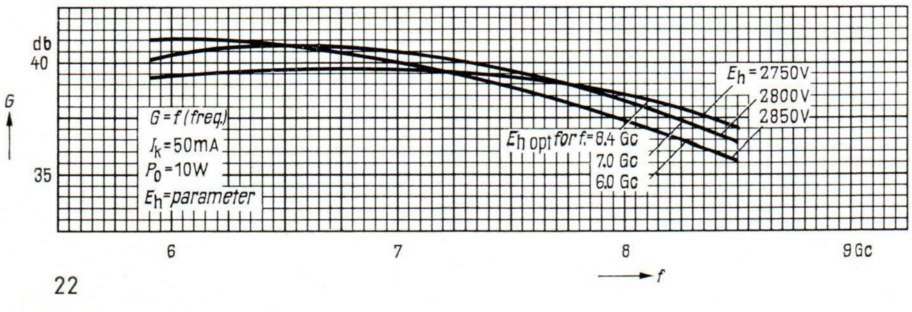


Fig. 47. Gain as a function of frequency at various helix voltages.

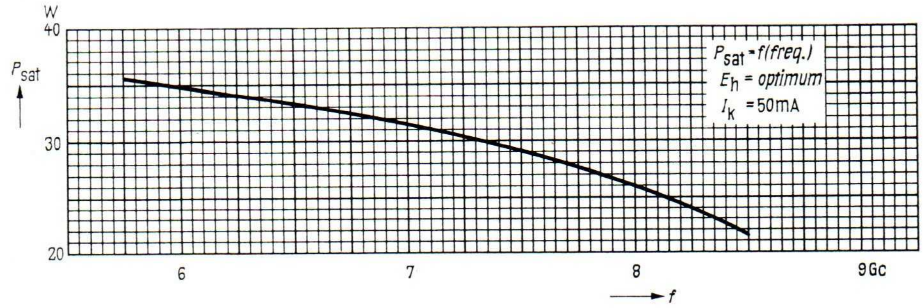


Fig. 48. Saturation power as a function of frequency.

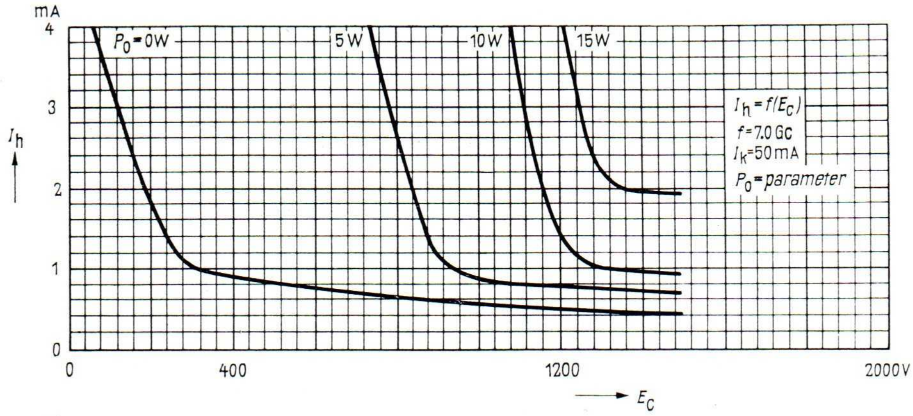


Fig. 49. Helix current as a function of the collector voltage at various output powers.

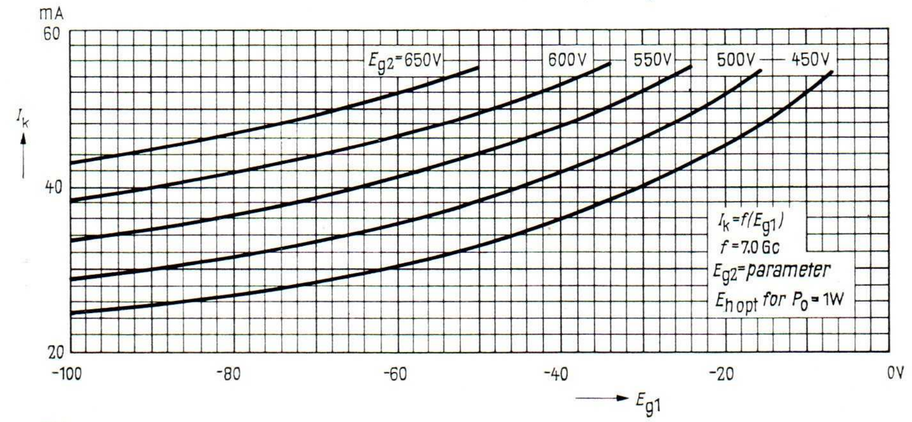


Fig. 50. Cathode current as a function of the grid No. 1 voltage at various grid No. 2 voltages.

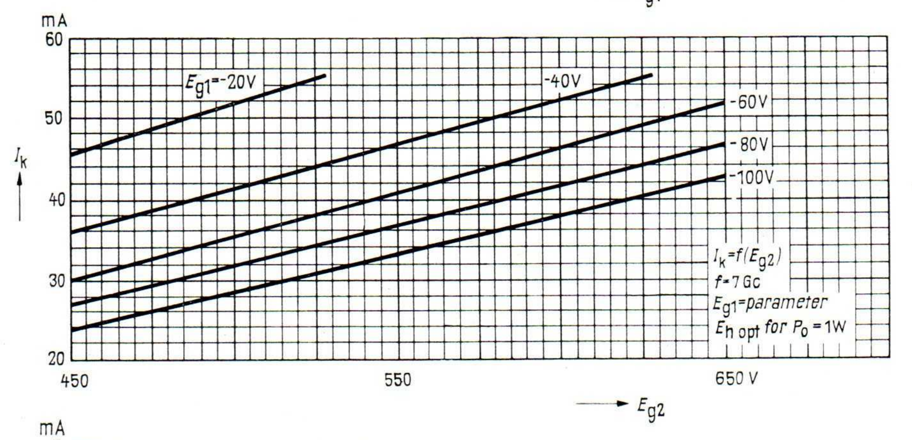


Fig. 51. Cathode current as a function of the grid No. 2 voltage at various grid No. 1 voltages.

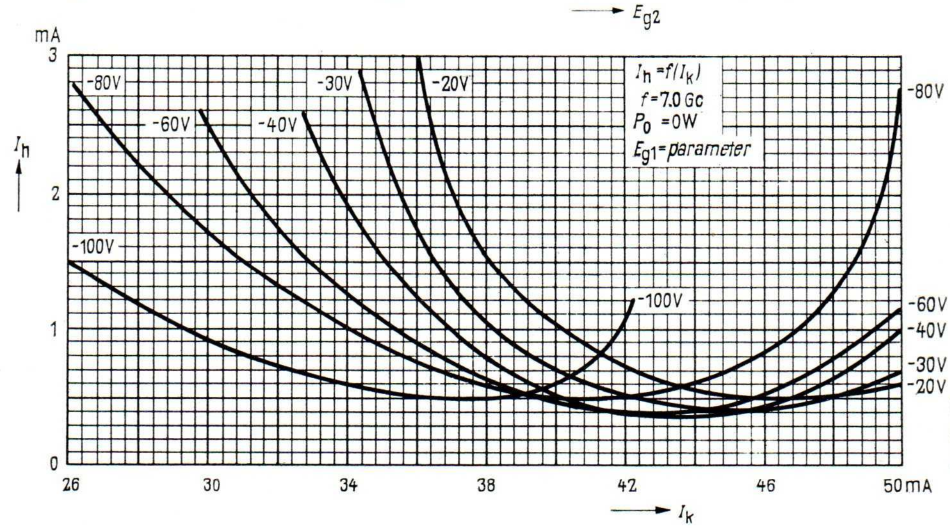


Fig. 52. Helix current as a function of the cathode current at various grid No. 1 voltages.

Fig. 53. 54. 55. cathode current, gain and helix current as functions of the grid No. 2 voltage

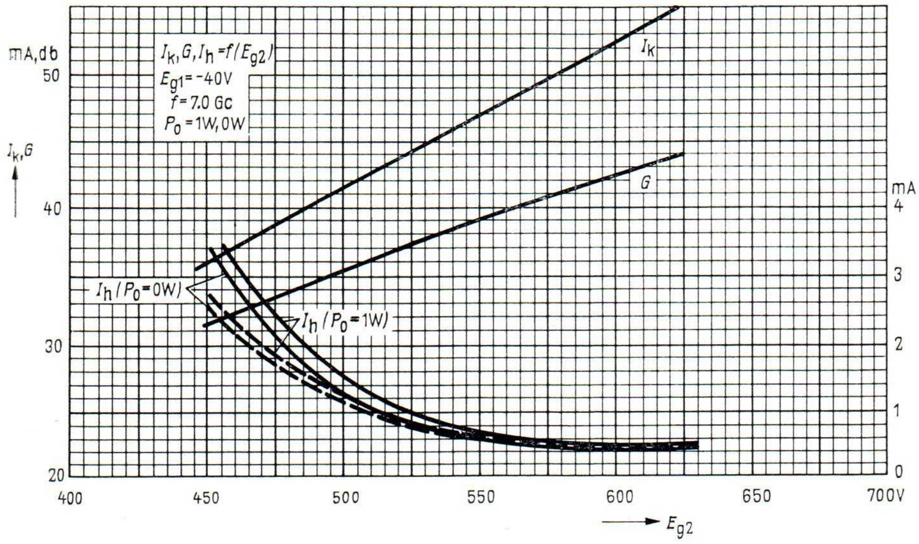


Fig. 53.
____Optimum focusing of tube at $I_k = 50$ mA
_ _ _Optimum focusing of tube in each case

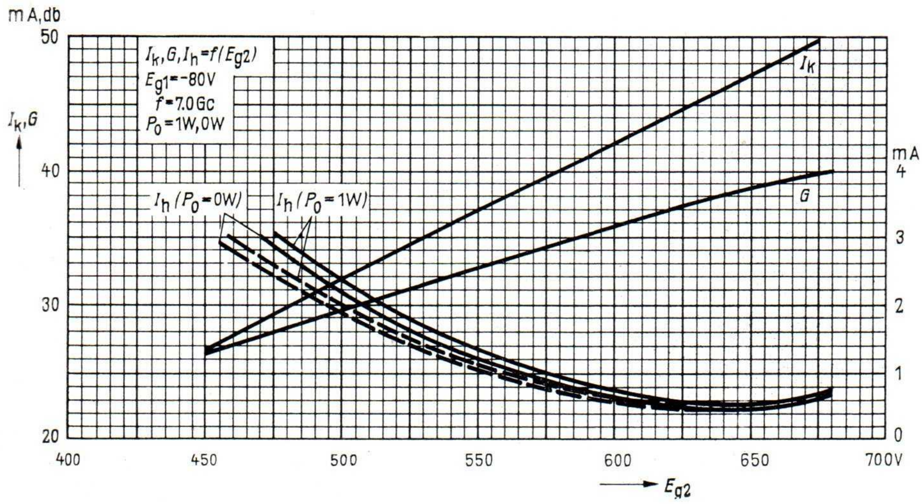


Fig. 54.
____Optimum focusing of tube at $I_k = 50$ mA
_ _ _Optimum focusing of tube in each case

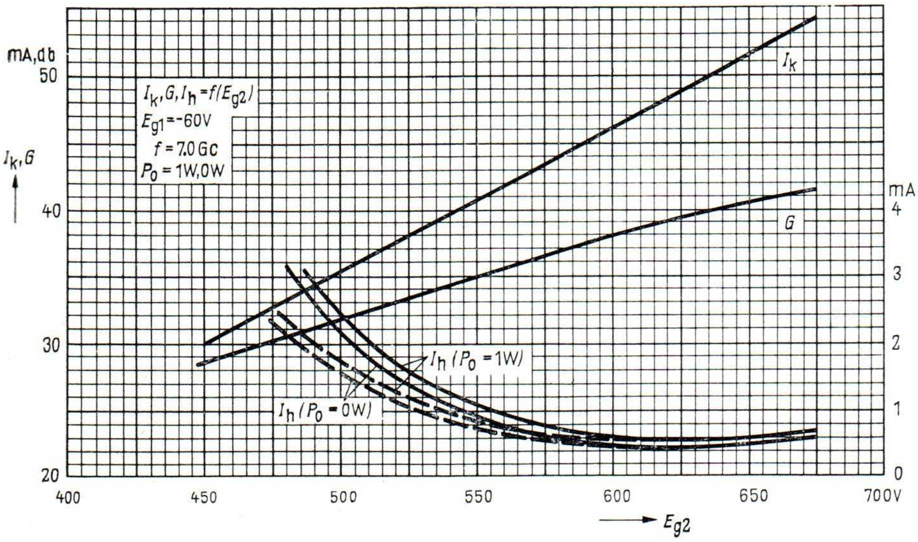


Fig. 55.
____Optimum focusing of tube at $I_k = 50$ mA
_ _ _Optimum focusing of tube in each case

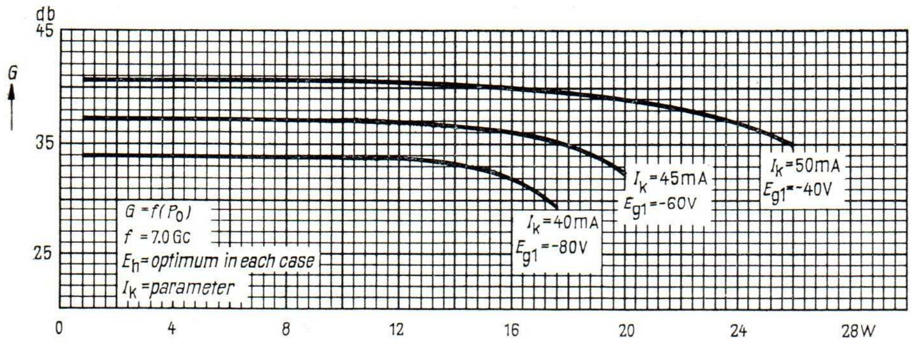


Fig. 56. Gain as a function the output power at various cathode currents.

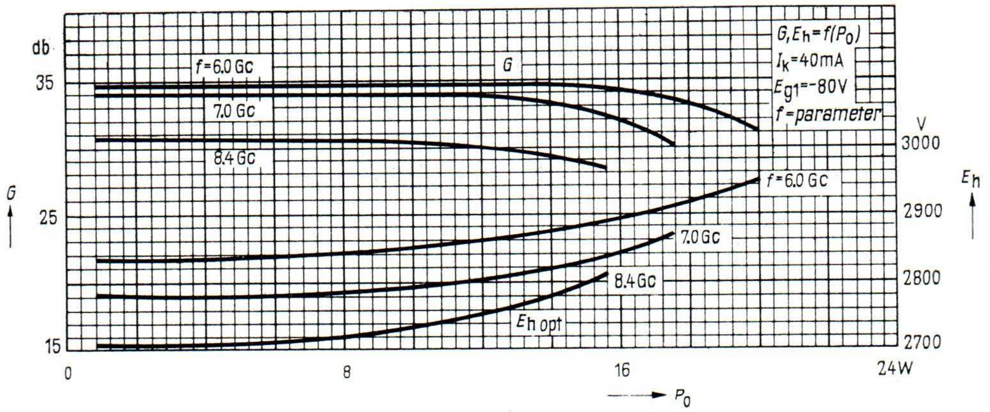


Fig. 57. Gain and helix voltage as functions of the output power at various frequencies.

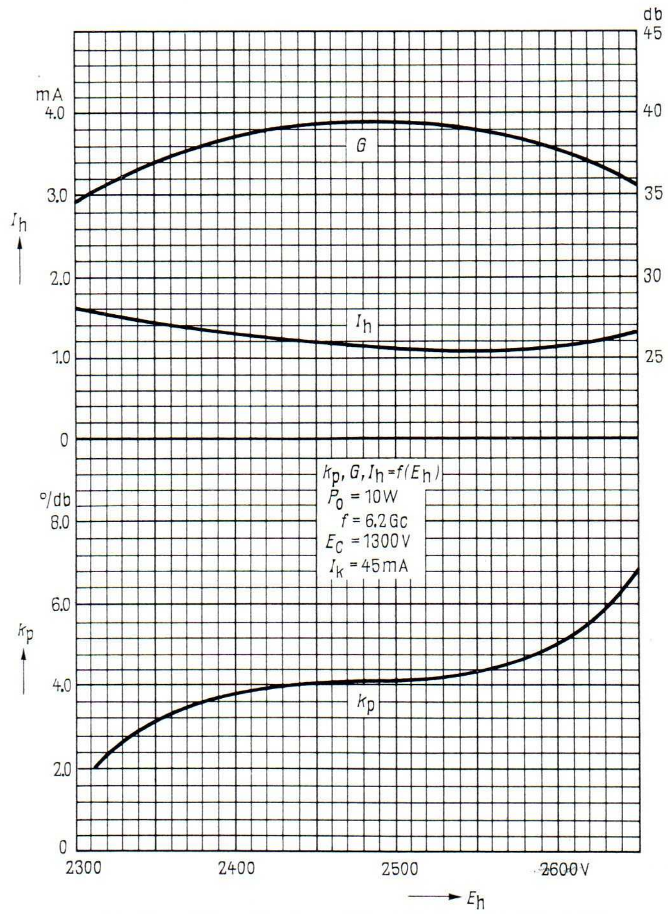


Fig. 58. Gain, helix current and AM-PM conversion as functions of the helix voltage.

7. Operating Instructions

The traveling-wave tubes RW 6 and RW 80 can only be used in conjunction with their respective magnet systems MRW 6 and MRW 80. All voltages quoted in the data are referred to the cathode.

7.1. Power supplies

The block diagram of a typical traveling-wave tube power supply is shown in fig. 59. The positive terminal of the helix voltage supply is earthed and therefore the cathode and heater are at a negative potential of maximum 3000 V during operation. The heater transformer and all components in the cathode circuit must therefore be insulated accordingly. Since the voltage on the collector is lower than that on the helix, the collector generally has a negative potential. It should be noted, however, that before the helix and grid No. 2 voltages are applied, the collector voltage is at + 1300 V compared with earth, and only when the helix voltage (e.g. 2400 V) is applied does the collector voltage come to its final and correct value of say −1100 V. When setting the heater voltage to exactly 6.3 V (at the heater pins of the tube), the voltage drop in the supply cable must be taken into consideration. If the supply cable and socket supplied with the tube are used, the total voltage drop in the standard length of 1.1 m is 0.1 V.

The grid No. 1 voltage E_{g1} is normally produced by the cathode resistor R_k, but it may of course be obtained from a separate source if so desired. The grid No. 2 voltage must be variable between 400 and 650 V for the RW 6 and between 450 and 700 V for the RW 80. It can be derived from a potential divider R_1 as shown in fig. 59, the total resistance of which must not exceed 2.5 MΩ.

The helix voltage E_h of the RW 6 must be adjustable between 2200 and 2700 V, and similarly for the RW 80 between 2500 and 3000 V. The helix voltage source must be capable of supplying at least 7 mA, included in which is the current through the potential divider. The necessary filtering and stabilization can be calculated from the "Operational data" and various characteristics according to the particular equipment specifications.

It is not necessary to stabilize the collector voltage E_c but precautions must be taken to ensure that the maximum ratings, in particular the admissible collector dissipation P_c, are not exceeded. The collector voltage source is best designed such that the voltage given in the operating data, for example 1300 V in the case of the RW 6, is produced at the intended collector current with nominal mains voltage. The helix voltage E_h of the RW 6 may vary down to 1150 V, but if the collector is depressed even further, the helix current will rise in the RW 6 as illustrated in fig. 23. The same reasoning is also valid for operation at reduced ratings.

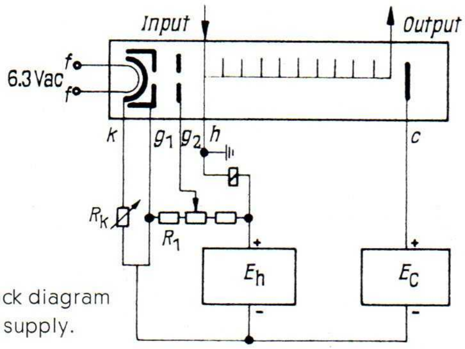


Fig. 59. Block diagram of a power supply.

The helix voltage supply lead must incorporate a protection relay which automatically operates when the helix current rises above 6 mA, and switches off the helix and grid No. 2 voltages. Switch-on surges of up to 40 Ws occuring within the first two seconds can be absorbed by designing the time-constant of the over-current relay accordingly. If the grid No. 2 voltage is supplied from a separate source, this source must have a contact in an interlock circuit which cuts out the grid No. 2 voltage immediately the helix voltage fails. If the collector voltage fails, the helix and grid No. 2 voltages must be switched off, either by the over-current relay in the helix voltage supply line, or by another interlock circuit.

7.2 Setting-up procedure

7.2.1. Connection of the supply voltages

To ensure safe operation, the magnet system must be correctly earthed.

The power supplies should be connected as follows:

a) supply cable leads

		color	
		old	new
Heater	f,f	brown	brown, brown-yellow
Cathode	k	yellow	yellow
Grid No. 1	g_1	green	green
Grid No. 2	g_2	blue	blue
Helix, earth	h	red	black

b) collector lead

The collector connection is situated inside the cooling case, and can be reached by removing the slotted cover plate. The supply lead is soldered to the tag on side C of the magnet system (see fig. 14). The lead used must be capable of carrying 3000 V.

c) The helix connection and earthing point for the magnet system are joined to the same terminal.

7.2.2. Insertion of the traveling-wave tube into the magnet system

1. Unscrew the retaining nut and remove the connector socket.
2. Insert the tube into the magnet system. The periodic magnetic field causes some noticeable resistance. Any difficulty in pushing the collector into the cooling vanes can be cured by rotating the tube slightly.
3. Rotate the tube such that the guiding pin on the magnet system engages in the lateral slot on the tube.
4. Slide on the tube socket with supply cable.
5. Screw on the retaining nut cautiously up to the stop. During this procedure the socket must on no account be canted due to the danger of breaking the tube!

7.2.3. Switch-on and switch-off procedure

1. Switch on the following voltages either simultaneously or in any sequence:
   Heater voltage E_f, Collector voltage E_c
   Grid No. 1 voltage E_{g1} } if present
   Blower for cooling } or intended
2. Allow at least 2 minutes for warm-up.
3. Switch on: Helix voltage E_h
   Grid No. 2 voltage E_{g2}
   either simultaneously and to their full values (do not run up slowly), or first E_h then E_{g2}. The condition that the two voltages are applied simultaneously is definitely fulfilled when, as is customary, E_{g2} is derived from the potential divider in the helix voltage supply line.
   It is advisable to set the values of E_{g2} and E_h to those given on the card accompanying each tube. If no card is at hand, E_{g2} should be set to approximately 500 V for the RW 6 and 550 V for the RW 80, and E_h to the relevant value given in the operating data.
4. Set the required cathode current I_k by adjusting the grid No. 2 voltage E_{g2}.
5. Set the helix current I_h to a minimum with the aid of the pair of radial field correction rings and the axial field correction ring (a single ring which can be slid along the axis of the tube) located at the input end of the magnet system.
6. Apply the r.f. signal to the input, if necessary at a reduced level, and adjust alternately with the helix voltage to obtain optimum gain at the required output power.
7. Repeat the field correction as under 5 above.

If under adverse conditions the tube cannot be run up because the helix current is too high and the over-current relay continuously operates, the grid No. 1 voltage should be increased to approximately -100 V, or the value of the cathode resistor raised to several thousand ohms. In this way the electron beam is strongly bundling when the tube is operating. The helix current I_h is then set to a minimum with the aid of the axial and radial field correction rings. E_{g1} or R_k can then be reduced and the focussing process repeated. This procedure should be repeated as often as is necessary to return to the normal values of E_{g1} or R_k.

The tube can be switched off by removing all voltages simultaneously. If this is difficult first the voltage E_{g2} on the beam-accelerating electrode (possibly together with the helix voltage) and then shortly afterwards the remaining voltages should be switched off. **Under no circumstances must the collector voltage E_c be switched off before the helix voltage E_h as long as the grid No. 2 voltage is still on,** otherwise the helix will carry the full beam current. Similarly grid No. 2 would be overloaded if the helix voltage were switched off before the grid No. 2 voltage.

7.2.4. Safety precautions

The traveling-wave tubes described here are operated at high voltages up to approximately 3000 V, and the following conditions must therefore be observed:

1. The appropriate safety regulations applicable to the use of high-voltage equipment must be observed.
2. The amplifier and power supplies must be properly earthed.
3. The tube may only be replaced in its magnet system when all electrode voltages are switched off. For reasons of safety it is generally necessary to provide some from of interlock circuit which only permits the tube to be removed if the electrode voltages have been automatically switched off.

7.3. Installation

The amplifier may be mounted in any position in the rack, but the points on cooling covered in section 7.4 must be taken into consideration.

In spite of its small dimensions, the magnet system fully screened and is not influenced by external fields. Furthermore the stray field is so small that ferromagnetic materials located near the magnet system are not influenced.

The magnet system can be mounted on iron parts without impairing the focusing properties, and several magnet systems may also be mounted side by side. It is advisable to attach the isolators directly to the waveguide flanges on the magnet system.

7.4. Cooling

The heat developed at the collector can be convected away by an air stream or conducted away by a good heat-conducting material. The magnet systems of the RW 6 and RW 80 are designed for both types of cooling, and are available as required.

7.4.1. Convection cooling

At ambient temperatures up to +40 °C and collector dissipations up to 65 W no particular measures are required for cooling the RW 6 and RW 80 provided the tubes are mounted horizontally and air can circulate naturally through the radiator in a vertical direction. The collector dissipation is given by:

$P_c = I_c E_c - P_o$

where $I_c = I_k - I_h$ is the collector current and P_o is the output power.

For any other mounting positions, increased ambient temperatures or higher dissipation powers, additional cooling in the form of a weak forced-air stream is necessary.

In this case the decisive factor is that the maximum admissible collector temperature under contінous operation of 270 °C should not be exceeded. Since the collector dissipation increases when the signal fails or is switched off, a collector temperature of maximum 300 °C is admissible for short periods under such vonditions (c. f. pages 8 and 20, footnote 2 under „Maximum ratings").

The required volume of air for various dissipation powers can be obtained from fig. 60. The collector temperature quoted assumes an ambient tem-

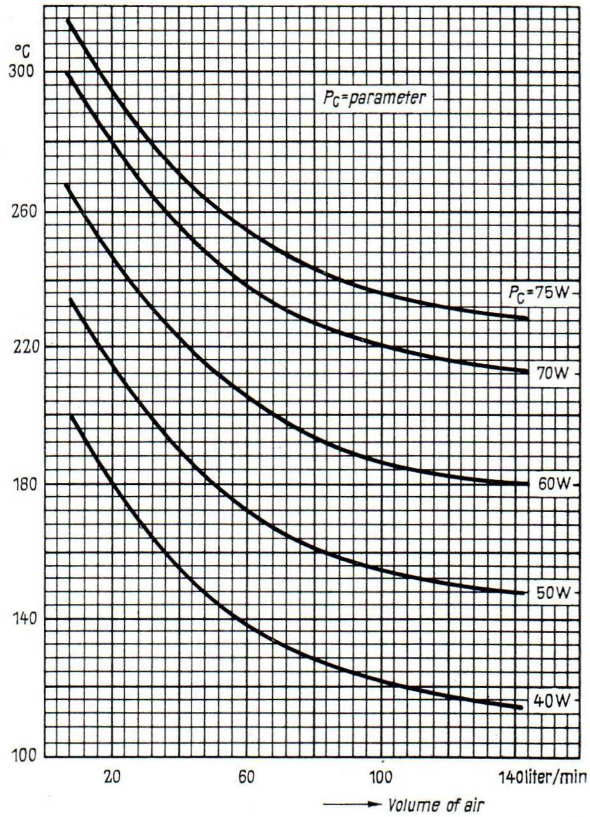


Fig. 60. Temperature of the collector end as a function of the volume of cooling air at various collector dissipation powers.

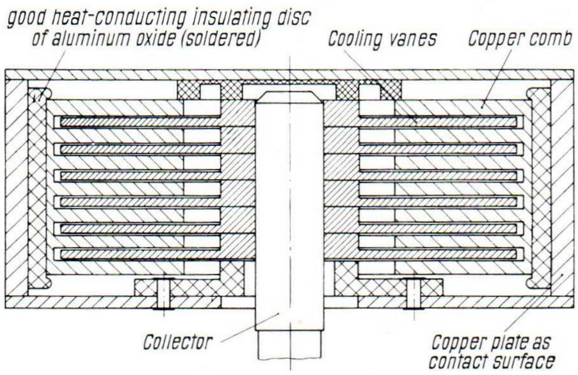


Fig. 61. Construction of the conduction cooler.

perature of 25 °C. If the ambient temperature has another value, the scale is shifted by the temperature difference, i. e. the excess temperature remains approximately constant. The curves end at about 10 liters/min which corresponds to the air flow with natural convection.

The external design of the convection cooling system can be seen in fig. 11. Six pairs of cooling vanes (for cross-sectional view see fig. 61) are located in the cooler attached to the magnet system, and these provide a flexible contact with the collector itself.

The cooling vanes are insulated from the casing by two ceramic supports on their outer edges.

When no forced-air cooling is used, the natural convection then being sufficient, the sets of slots in the two opposite sides of the casing must be located one above the other in a vertical direction. If required the cooler casing can be rotated through 90° compared to the position shown in fig. 14, but this must be specified when ordering (see section 8).

7.4.2. Conduction cooling

The conduction-cooled version has the same external dimensions as the air-cooled variant, and to a great extent uses the same parts. The basic construction is illustrated in fig 61.

Two copper combs are inserted from opposing sides between the cooling vanes. The individual teeth of the comb are slightly narrower than the distance between adjacent vanes to permit safe insertion of the collector into the vanes. In spite of this air gap, the heat transfer is still good due to the large surface area, and the temperature gradient is small.

Both copper combs are joined with two copper plates through good heat-conducting insulating layers of aluminum oxide. From these contact surfaces on the exterior of the magnet system the heat can either be conducted away through the equipment rack or be dissipated into the surrounding air by additional radiator vanes attached to them. Liquid cooling is also possible.

The copper surfaces should be connected to the equipment rack by flexible copper bands to prevent any large forces from being transferred to these surfaces. Further, care should be taken when tightening the fixing screws not to subject the contact surfaces to any turning moments. If necessary, the connecting strip should be subdivided into single elements. The same remarks are also applicable to the mounting of radiator vanes, and here it is also recommended that the complete radiator be subdivided into separate vanes.

The temperature of the copper contact plates must not exceed 100 °C to prevent any undesired effects on the magnet system. The heat resistance between the collector and the two contact surfaces is approximately 1.6 °/W. With the RW 6 operated under nominal conditions without r. f. (I_c =44 mA, E_c =1300 V) the temperature gradient is approximately 90 °C.

The conduction-cooled system has proved to be operationally safe, and because there is no air circulation, the collector contacts do not foul.

7.5. Associated waveguide circuit elements for the RW 6 and RW 80

7.5.1. Waveguide transition elements

The input and output waveguides of the RW 6 and RW 80 are of the flat-profile type (34.85 mm x 5 mm).

Since, however, the use of flat-profile waveguides is unusual internationally, waveguide transition elements are necessary to connect the amplifier to the normal WR 137 waveguide (34.85 mm × 15 mm).

7.5.2. Isolators

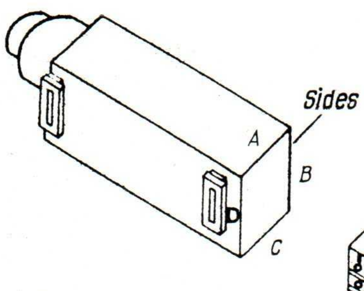
It is advisable to connect isolators to the input and output to protect the tube if the load develops a fault and to suppress reflections and thus additional noise in the speech channels when the tube is used in microwave link applications. Due to the long line effect, these isolators should be located as near as possible to the input and output (c. f. section 5.7, page 18).

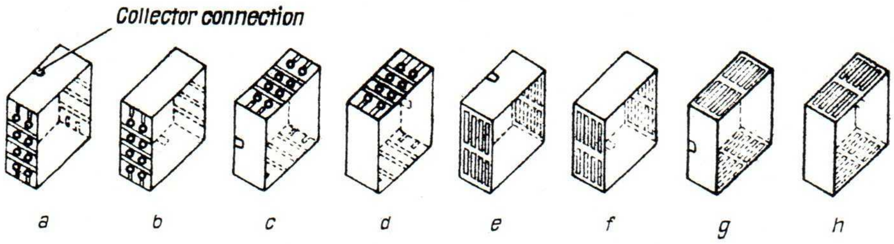
7.5.3. Filters for harmonics

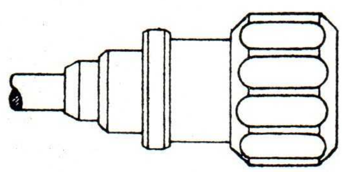
Harmonics which are present at the output of a traveling-wave tube due to non-linearity of the characteristics can be suppressed, for example by using a low-pass filter.

8. Ordering Numbers

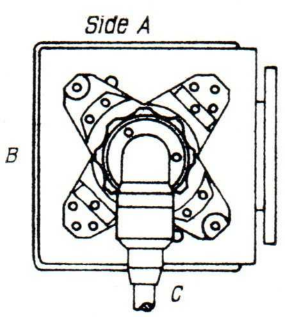
When ordering tubes, magnet systems and accessories, the following ordering numbers should be used. The various types of magnet system including cooling assembly and connector sockets are shown in fig. 62. The length of the screened cable supplied with the connector socket has been standardized at 1.1 m.







Form and direction of the connector socket



Shown in direction C

Fig. 62. Possible arrangements of the cooling assembly and collector connection.

8.1. RW 6

Traveling-wave tube RW 6	Q00041 - X3254
Magnet system MRW 6 a 11 Type: conduction-cooled, direction B—D Collector connection side A	Q00043 - X2341
Magnet system MRW 6 a 12 Type: conduction-cooled, direction B—D Collector connection side C	Q00043 - X2345[1])
Magnet system MRW 6 a 21 Type: conduction-cooled, direction A—C Collector connection side D	Q00043 - X2342[1])
Magnet system MRW 6 a 22 Type: conduction-cooled, direction A—C Collector connection side B	Q00043 - X2346
Magnet system MRW 6 b 11 Type: convection-cooled, direction B—D Collector connection side A	Q00043 - X2343
Magnet system MRW 6 b 12 Type: convection-cooled, direction B—D Collector connection side C	Q00043 - X2347[1])
Magnet system MRW 6 b 21 Type: convection-cooled, direction A—C Collector connection side D	Q00043 - 2344[1])
Magnet system MRW 6 b 22 Type: convection-cooled, direction A—C Collector connection side B	Q00043 - X2348
Connector socket Form: straight	Q00081 - X2301
Connector socket Form: 90° bend direction A	Q00081 - X2302
Connector socket Form: 90° bend direction B	Q00081 - X2303
Connector socket Form: 90° bend direction C	Q00081 - X2304
Connector socket Form: 90° bend direction D	Q00081 - X2305

[1]) The magnet systems MRW 6 a 12, MRW 6 a 21, MRW 6 b 12 and MRW 6 b 21 are preferred types.

8.2. RW 80

Traveling wave tube RW 80	Q00041 - X3255
Magnet system MRW 80 a 11 Type: conduction-cooled, direction B—D Collector connection side A	Q00043 - X2361
Magnet system MRW 80 a 12 Type: conduction-cooled, direction B—D Collector connection side C	Q00043 - X2365[1])
Magnet system MRW 80 a 21 Type: conduction-cooled, direction A—C Collector connection side D	Q00043 - X2362[1])
Magnet system MRW 80 a 22 Type: conduction-cooled, direction A—C Collector connection side B	Q00043 - X2366
Magnet system MRW 80 b 11 Type: convection-cooled, direction B—D Collector connection side A	Q00043 - 2363
Magnet system MRW 80 b 12 Type: convection-cooled, direction B—D Collector connection side C	Q00043 - X2367[1])
Magnet system MRW 80 b 21 Type: convection-cooled, direction A—C Collector connection side D	Q00043 - X2364[1])
Magnet system MRW 80 b 22 Type: convection-cooled, direction A—C Collector connection side B	Q00043 - X2368
Connector socket Form: straight	Q00081 - X2301
Connector socket Form: 90° bend direction A	Q00081 - X2302
Connector socket Form: 90° bend direction B	Q00081 - X2303
Connector socket Form: 90° bend direction B	Q00081 - X2304
Connector socket Form: 90° bend direction D	Q00081 - X2305

[1]) The magnet systems MRW 80 a 12, MRW 80 a 21, MRW 80 b 12 and MRW 80 b 21 are preferred types.

9. Example for ordering

The ordering numbers of tubes, magnet systems and connector sockets must be given separately.

For example:

Traveling-wave tube RW 6

with magnet system MRW 6 b 11 (convection-cooled, direction B—D collector connection side A)

and connector socket with cable, direction D

10. References

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