A TRANSMITTING TRIODE FOR FREQUENCIES UP TO 900 Mc/s

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*New designs have made it possible to use triodes as amplifiers or oscillators at unprecedently high frequencies. This was recently illustrated by an article in this Review on the EC 57 disc-seal triode *), which delivers a power of several watts at 4000 Mc/s. Considerable progress has also been made with triodes for appreciably higher power ratings. The transmitting tube TBL 2/300 discussed in the present article — also a disc-seal triode, but with a cylindrical electrode system as opposed to the planar electrodes of the EC 57 — has an output of about 400 W at 470 Mc/s and about 150 W at 900 Mc/s. It meets a need that has become increasingly pressing of late.*

In recent years the frequency range from about 450 to 900 Mc/s (wavelengths from some 7 to 3 dm) has come more and more into prominence. To give only a few examples, decimetric waves have acquired great significance in aviation for the purposes of communication and navigation; mobilophone communications at frequencies between 460 and 470 Mc/s are growing rapidly in number; in television more and more interest is being shown in bands 4 and 5 (470-585 and 610-960 Mc/s); high-frequency heating with dm waves is steadily gaining ground in industry; and in Germany a frequency range in the neighbourhood of 461 Mc/s has recently been reserved for diathermy, in connection with investigations being carried out into the therapeutic value of dm waves. In addition, numerous military applications might be mentioned.

Triodes of conventional construction are, for various reasons, unsuitable for decimetric waves. If we attempted to use such tubes at such wavelengths we should find in the first place that the electron transit time — the time taken by the electrons to travel from cathode to anode — would be too long in relation to the period of the oscillation to be generated or amplified. In the second place, the wavelength would no longer be large compared with the length of the electrodes, so that the voltages at different points of the same electrode would show phase differences; this effect becomes noticeable as soon as the wavelength drops to about 10 times the effective electrode-length. In the third place, at frequencies of several hundred Mc/s the dielectric losses in the insulating parts of the tube would be considerable, and finally, the self-inductance of the lead-in wires would exercise an adverse influence [1]). These four effects (transit-time effect, phase shift along the electrodes, dielectric losses and stray self-inductance) are, as regards transmitting triodes, the main reasons for the loss of efficiency at higher frequencies; at a certain limiting frequency the efficiency finally becomes too low for the tube to be of any practical use.

In the course of the years several tubes of an entirely different type have been developed, tubes whose operation is based upon the finite transit time of the electrons. The most important of these "velocity-modulated" tubes are magnetrons, klystrons and travelling-wave tubes. These are the tubes that have been mainly responsible for opening up the decimetric, centimetric and even the millimetric wave-ranges for radio engineering. Most of these tubes contain one or more cavity resonators, so that in principle each type is suitable for use at only one frequency. There are, it is true, various methods of varying this frequency to a slight extent [2]), but only over a small range (a few %). By the use of external cavity resonators and by very accurately adjusting the supply voltage, it is possible to extend the frequency range of klystrons and travelling-wave tubes, but none of these types can be employed as a universal tube for covering the entire frequency range up to, say, 900 Mc/s.

By contrast, the more conventional tubes (triodes, tetrodes) all operate with external oscillator circuits (e.g. cavity resonators) which can, in principle, be designed for any frequency (provided it is lower than the limit frequency of the tube) and which can be tuned as required.

There has naturally been no lack of attempts to raise the limit frequency of triodes by improvements in design. As regards tubes capable of a power output of several hundred watts, we may take as an example the TB 2.5/300 transmitting triode, described in this Review in 1949 [3]), which at 200

*) G. Diemer, K. Rodenhuis and J. G. van Wijngaarden, Philips tech. Rev. **18**, 317-324, 1956/57 (No. 11).

[1]) M. J. O. Strutt and A. van der Ziel, Philips tech. Rev. **3**, 103-111, 1938.

[2]) See, for example, Philips tech. Rev. **14**, 92, 1952/53.

[3]) E. G. Dorgelo, Philips tech. Rev. **10**, 273-281, 1948/49.

Mc/s delivers 200 W with an efficiency of about 60%. In the present article we shall describe some new developments in this field, which have led to the design of the triode TBL 2/300 (*fig. 1*). The limiting frequency of this tube has been raised to

Fig. 1. The transmitting triode TBL 2/300.

900 Mc/s. With a D.C. supply the TBL 2/300 can deliver more than 400 W at 470 Mc/s and about 150 W at 900 Mc/s [4]), with an efficiency of about 63 and 34% respectively. With A.C. supply — which is permissible in diathermy, for example — the power output is about 200 W at 470 Mc/s. Other favourable electrical properties are: good power gain and suitability for wide-band amplification with a relatively low supply voltage (2500 to 1300 V, according to the frequency).

In view of the diverse fields of application of the tube, its mechanical properties have to be taken into consideration. From an electrical point of view it is desirable to have short electrodes, small tube-capacitances, low self-inductance in the leads and short transit times. The first two requirements, calling for electrodes of small dimensions, entail heavy current densities and high specific loading, which adversely affect the tube's useful life. Lower self-inductance calls for leads with a large surface area, e.g. disc electrode leads (see below) and for a planar or a cylindrical electrode system. For short transit times the inter-electrode spacing must be small, and this threatens to conflict with the requirement of mechanical strength. It was therefore necessary to find a compromise. The fact that a favourable compromise was found is due, among other things, to the special construction of the cathode and to the use of a new material for the grid.

Description of the transmitting triode TBL 2/300

The article cited under [3]) gives a number of reasons why, from the electrical point of view as well as from the mechanical and thermal points of view, a cylindrical arrangement of the electrodes in a transmitting tube is preferable to a planar arrangement; among other things, it allows the use of a helical cathode and allows easy alignment of the electrodes. As may be seen from the cross-section in *fig. 2* and from the exploded view in *fig. 3*, a cylindrical arrangement has been adopted for the TBL 2/300. The directly heated cathode, marked *7*

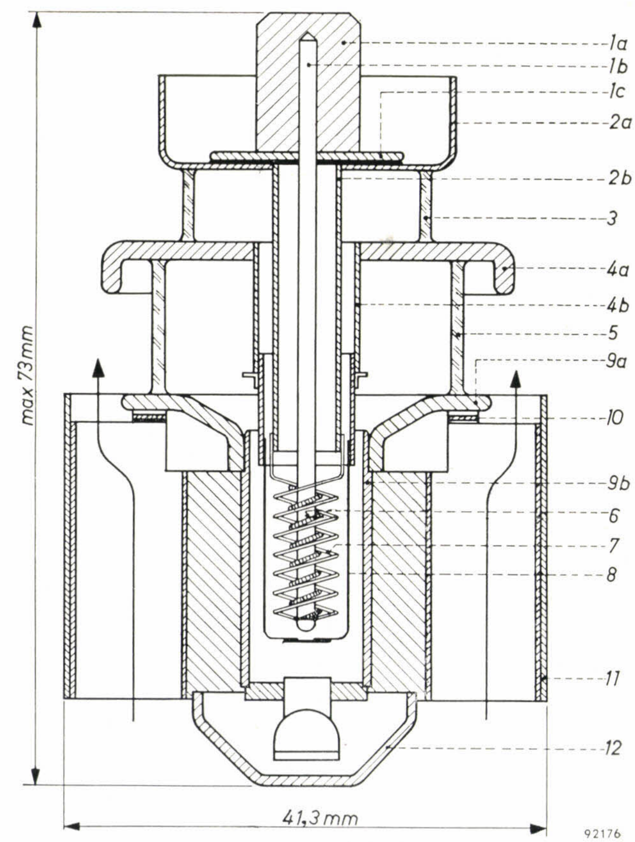


Fig. 2. Cross-section of the tube. *1a*, *2a* filament current connections. *1b*, *2b* mounting pieces for filaments *7* (two coils of thoriated tungsten wire in parallel). *1c*-*2a* shunt capacitor (sandwich seal). *3*, *5* glass insulating rings. *4a* grid disc. *4b* grid mounting tube. *6* getter (zirconium wire). *8* cage-type grid. *9a* anode disc. *9b* anode. *10* corrugated metal washer. *11* jacket around cooling fins. *12* protective cap.

[4]) For an improved version, still in course of development, which is capable of a somewhat higher power output, see the end of this article.

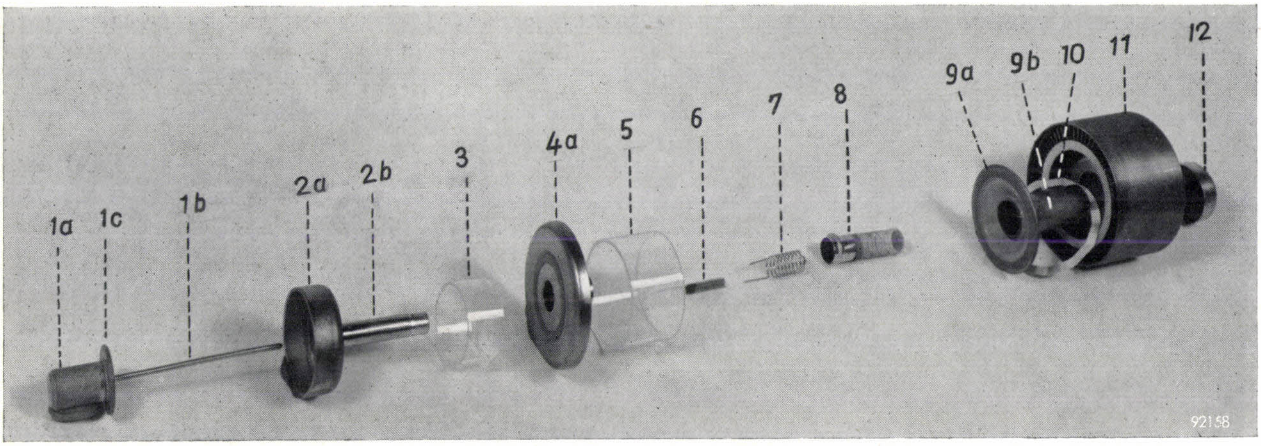
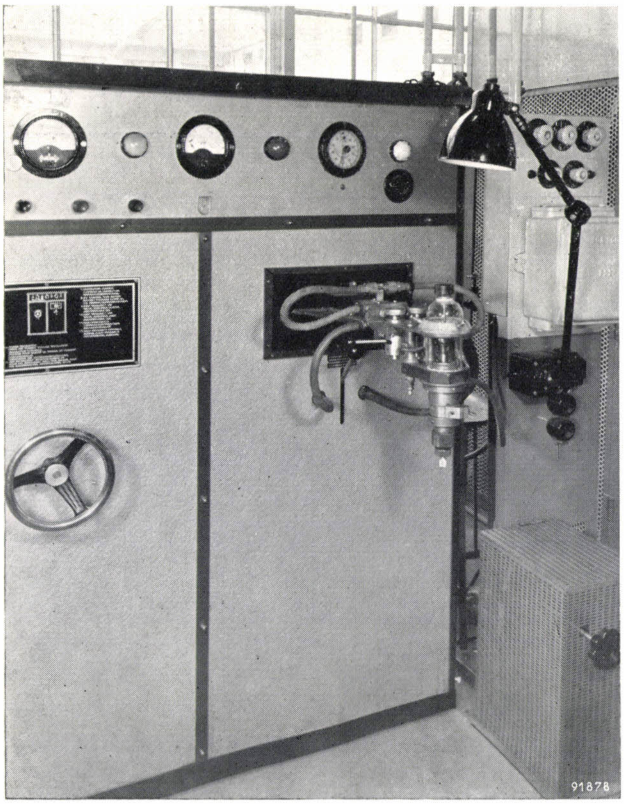


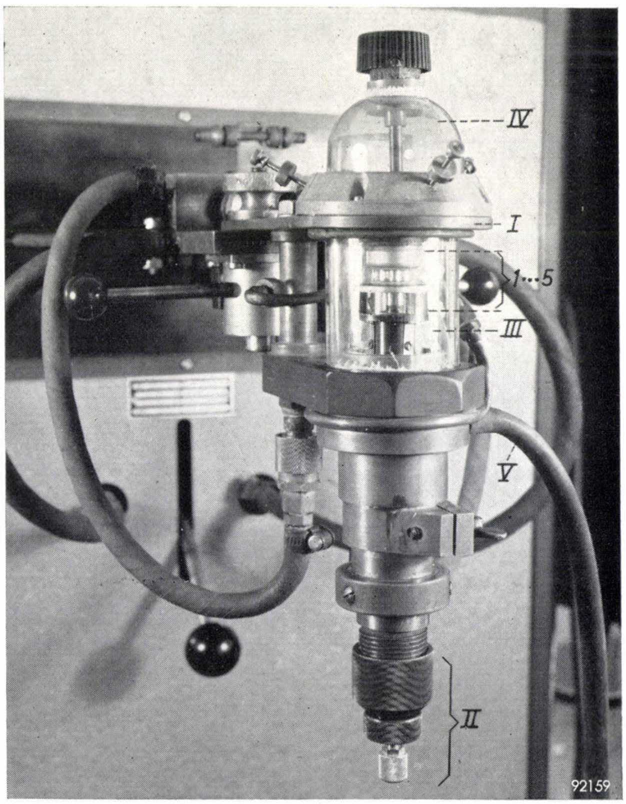
Fig. 3. Exploded view of the TBL 2/300 tube. Symbols as in fig. 2.

in both figures, consists of 2 parallel helices of thoriated tungsten (of which more later). Around the cathode are assembled the cage-type grid *8* and the anode *9b*. The metal parts *2a*, *4a* and *9a* are commonly called discs (although their shape is rather more intricate) and hence the tube is referred to as a disc-seal triode. This design allows the tube to be connected to an external coaxial system. The filament connections consist of the central contact *1a* and disc *2a*, which are connected to the filament via rod *1b* and bush *2b* respectively, both of molybdenum. The rod supports the filament and is partially wound with zirconium wire *6*, which functions as getter. The discs *1c* and *2a*, with a layer of glass between (sandwich seal) constitute a capacitor, the purpose of which will be described later.

Disc *4a* serves as the grid connection. It is



a



b

Fig. 4. *a*) High-frequency induction heater, used for sealing together the components of the TBL 2/300.
b) The sealing of components *1-5* (see fig. 3). *I* applicator coil, flat in order to concentrate the heating. *II* adjusting screws, for adjusting the height of the components. *III* glass envelope with glass cap *IV*, containing protective gas fed in by hose *V*.

insulated from discs *2a* and *9a* by rings *3* and *5*, which are of hard glass with a high melting point. The discs are of fernico — an alloy of iron, nickel and cobalt, whose coefficient of expansion is close to that of the glass. All external metal parts are silver-plated, to reduce skin-effect losses and also to ensure good contact with the external circuits.

The anode itself (*9b*) is also of fernico. Heat is dissipated via a thick-walled copper cylinder to a large number of cooling fins surrounded by a copper jacket *11*. The cooling surface is 380 cm^2, and the maximum dissipation is 380 W (300 W anode dissipation, 15 W grid dissipation and 65 W from the filament). Air is blown in through the cooling fins preferably in the direction of the arrows shown in fig. 2, since in that case, owing to the upper extension of the jacket *11*, the emergent air can also pass over and cool the glass ring *5*. If the incoming air is no warmer than 45 °C, an air flow of 0.45 m^3 per minute is sufficient, the pressure drop across the assembly then being 24 mm water. The air current required for two tubes can be provided by a small centrifugal fan, driven by a 70 W motor. For a total dissipation of 380 W per tube the temperature of the air passing the cooling assembly rises by about 30 °C.

The jacket *11* also serves as the electrical connection for the anode. The corrugated metal washer *10* ensures good electrical contact via disc *9a*.

The exhaust stem is located at the base of the anode, and is protected by a cap *12*.

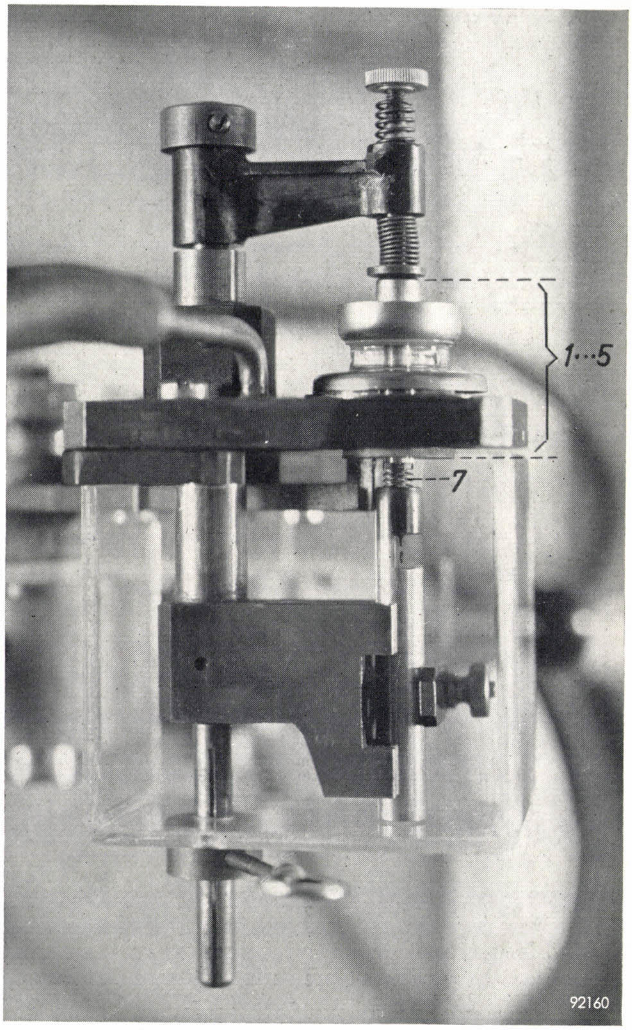


Fig. 5. The filaments *7* are brazed to the assembly *1-5* by high-frequency heating.

Manufacture

Parts *1*, *2*, *3*, *4* and *5* (fig. 3) are placed in a jig and sealed together by high-frequency heating (*fig. 4a*). A flat applicator coil *I* (fig. 4*b*) concentrates the heating in the fernico components, the height of which is accurately adjusted by means of screws *II*. The glass is softened by the radiation from the hot fernico components. All this is done in a protective gas atmosphere, for which purpose the jig is mounted in a glass cylinder *III* with a glass cap *IV*. To the assembly so produced (*1 . . 5*) the cathode filaments are now connected. *Fig. 5* shows how the filaments are brazed to bush *2b* (cf. figs. 2 and 3) by concentrated high-frequency heating. This is also done with the aid of a jig and in a protective gas. To improve their emission properties, the thoriated tungsten filaments are subsequently "carbonized", that is to say, annealed in a carbonaceous gas in order to reduce the thorium oxide. Finally, the getter is introduced.

The grid is accurately brazed concentric to the assembly by a method similar to that used for connecting the filaments. The next process is the sealing-in of the anode, the protective gas now being present only in the tube. After exhausting the tube and cutting off the stem, the cooling-fin assembly is soldered on and the external metal parts silver-plated.

The cathode

As stated, the cathode is of thoriated tungsten. In the article cited under [3]) it was explained that two objections had for a long time precluded the use of this material. The first was grid emission, caused by the thorium evaporating from the cathode and forming a deposit on the grid, and the second was the fact that tantalum, which is costly, was the only metal suitable to be used for the anode, no other metals being known with a sufficiently low gas emission to prevent poisoning of the cathode by traces of oxygen. It was not until the discovery of the gas-absorbing properties of zirconium [5]) that the thoriated cathode could be used on a wider scale in conjunction with an anode of less costly material; graphite, for example, was sometimes used [3]). As we have seen, the anode in the TBL 2/300 is of fernico. In telecommunications, as in industrial applications, it has been found that the thoriated tungsten cathode, with zirconium as getter, has a long useful life. We shall deal with the question of grid emission presently.

In the design of a cathode for a tube required to operate at frequencies of hundreds of Mc/s, certain other difficulties arise. The first is that, owing to the transit time, the emitted electrons do not pass through the grid in exactly the right phase and some of them therefore return to the cathode. The electron bombardment so produced causes extra heating of the cathode, which can be very damaging in that it gives rise to atomization of the oxide layer. Another reason for the over-heating of the oxide cathode during emission is the poor electrical conductivity at the boundary plane between the nickel and the oxide layer. This does not occur with the thoriated tungsten cathode; moreover, this type of cathode appears to be much better able to withstand electron bombardment, even at current densities from 1 to 1.5 A/cm². A familiar method of reducing the influence of electron bombardment, at frequencies where the transit-time effect is noticeable, is to make the filament voltage lower than at lower frequencies. In the TBL 2/300 the filament voltage need only be slightly lowered. In wide frequency ranges it may even remain constant. The following values are specified:

Frequency	Filament voltage
≦ 600 Mc/s	3.4 V
600-750 Mc/s	3.3 V
750-900 Mc/s	3.2 V

The second difficulty is connected with the requirement that the cathode — where no special measures are adopted — must be very short compared with the shortest wavelength $\lambda_{\min}$ at which the tube is required to operate. To illustrate this, *fig. 6* shows a schematic cross-section of the tube with its associated circuits. Coaxial resonant systems are connected to the cathode K, the grid C and the anode A; the tube is tuned by shifting the shorting-pistons p-p and q-q. We shall now consider the situation in which the distances of p and q to the end m of the diode proper are both $\frac{1}{4}\lambda_{\min}$ (approx. 8 cm at 900 Mc/s).

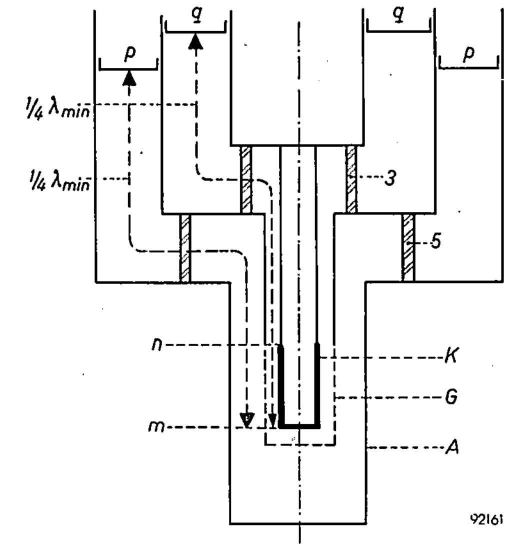


Fig. 6. Schematic cross-section of TBL 2/300 and coaxial resonant system. K cathode. G grid. A anode. *3*, *5* glass rings. p-p annular shorting-piston for anode circuit. q-q annular shorting-piston for grid circuit. The triode proper lies between m and n. The distances mp and mq are $\lambda/4$.

Fig. 7 shows how the high-frequency anode-grid voltage V_{ag} and cathode-grid voltage V_{kg} vary from the end m to the shorting-pistons p and q. In fig. 7*a* it is assumed that the cathode is a small tube (directly or indirectly heated). The length mn of the triode proper is about $\frac{1}{4}$ of the length $mp = mq = \frac{1}{4}\lambda_{\min}$, and consequently the alternating potential differences V_{ag} and V_{kg} along the anode and cathode respectively are small. However, a thin-walled tube, as would be needed for a cathode, cannot be drawn from thoriated tungsten. In practice, therefore, we are obliged to adopt a (directly heated) wire cathode. If a very high filament current is to be avoided, the wire must be fairly thin and long. For this reason a helical form is to be preferred (fig. 7*b*). In this case, however, ultra-high frequency operation is impossible because if the length of the filament is about $\frac{1}{2}\lambda_{\min}$, a voltage node will occur in the middle of the cathode. At that point V_{kg} will be zero and thus there will be no net anode alternating current, while on either side of the node the anode currents will be in anti-phase; the total anode alternating current will then be almost zero and the tube will be unable to operate.

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[5]) J. H. de Boer and J. D. Fast, Rec. Trav. chim. Pays-Bas 55, 459-467, 1936; J. D. Fast, Philips tech. Rev. 5, 217-221, 1940.

The solution of this difficulty is to take two helices, connected in parallel and each with a length of 7.5 cm ($\approx \frac{1}{4}\lambda_{\min}$), and to shunt them with a capacitor C of such a capacitance that the end m (fig. 7c) is at almost the same high-frequency potential as the end n. The result is that V_{kg} is practically constant over the entire length of the cathode, so that the cathode at high frequencies is almost an equipotential surface. The form of V_{kg} shown in fig. 7c was measured on an enlarged model (designed by J. M. van Hofweegen) with a correspondingly larger wave length.

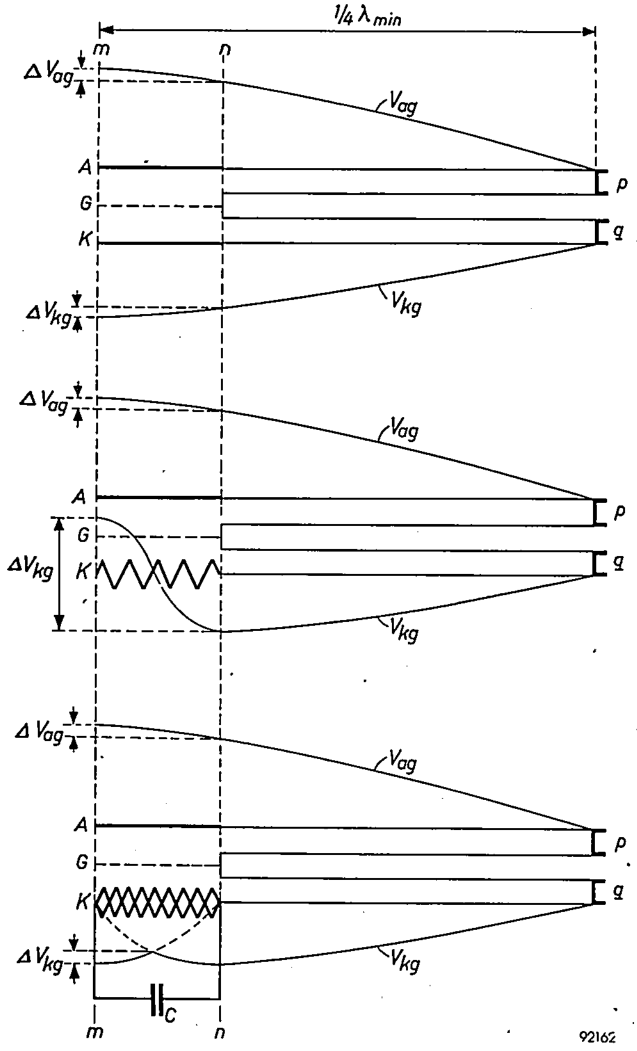


Fig. 7. K cathode, G grid and A anode of triode (schematic) showing the variation of the alternating voltages V_{ag} between anode and grid, and V_{kg} between cathode and grid, along the length of the anode and cathode respectively. ΔV_{ag} and ΔV_{kg} potential differences between the ends of these electrodes. p, q shorting-pistons (cf. fig. 6). $mp = mq = \frac{1}{4}\lambda_{\min}$.
a) Cylindrical cathode. ΔV_{ag} and ΔV_{kg} are small if the electrodes are short compared with $\frac{1}{4}\lambda$. The cathode is then an almost equipotential surface.
b) Helical wire cathode, with wire length $\frac{1}{2}\lambda$. The two halves are in anti-phase and therefore work in opposition.
c) The cathode consists of two coils, each $\lambda/4$ in length, connected in parallel and shunted by the capacitor C. The potential difference ΔV_{kg} is about as small as in (*a*).

Fig. 8 shows the connections to the cathode (the two helical filaments are drawn side by side for clarity). Capacitor C is formed by the sandwich seal already mentioned (fig. 2), the capacitance of which is about 50 pF. At a filament voltage of 3.4 V the filament current is about 19 A.

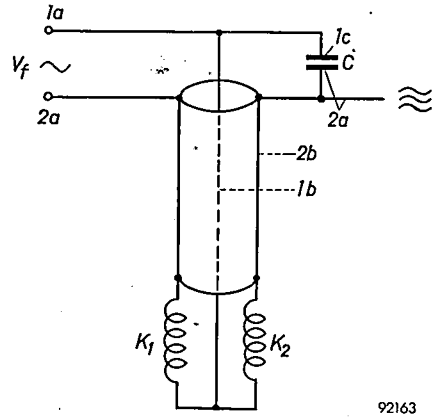


Fig. 8. The two coiled filaments K_1 and K_2 (shown side by side for clarity) and the capacitor C. For *1a*, *1b*, *1c*, *2a* and *2b*, see figs. 2 and 3. The filament voltage V_f is applied between *1a* and *2a*. *2a* is also the connection for the high-frequency current.

The grid

The cage-type grid consists of a large number of thin rods interconnected by 5 rings. The grid thus adequately approximates electrically to a conducting, entirely enclosed, surface, which is necessary in order to produce the V_{kg} distribution shown in fig. 7c.

An old problem encountered with transmitting tubes is grid emission. Substances evaporating from the cathode (in this case thorium) can, if they settle on the grid, cause the grid to emit electrons quite profusely. These electrons constitute a current in opposition to the normal grid current. If the negative grid voltage is produced by means of a leak resistor, the drop in the total grid current can result in instability. The risk of instability is particularly great if the tube is suddenly fully loaded after the filament has been switched on for a long period without any potential on the anode: during such a period a great deal of cathode dust will have settled on the grid, and when the load is applied the grid becomes hot and hence strongly emissive.

Several substances, such as zirconium oxide and platinum are known to have a low emission when used as grid material. These substances have been thoroughly tested in experimental TBL 2/300 tubes, both in new tubes and in tubes that had already operated 1000 hours with the high specific grid load of 15 W/cm². The results are set out in *fig. 9*, in which the specific grid emission current is logarith-

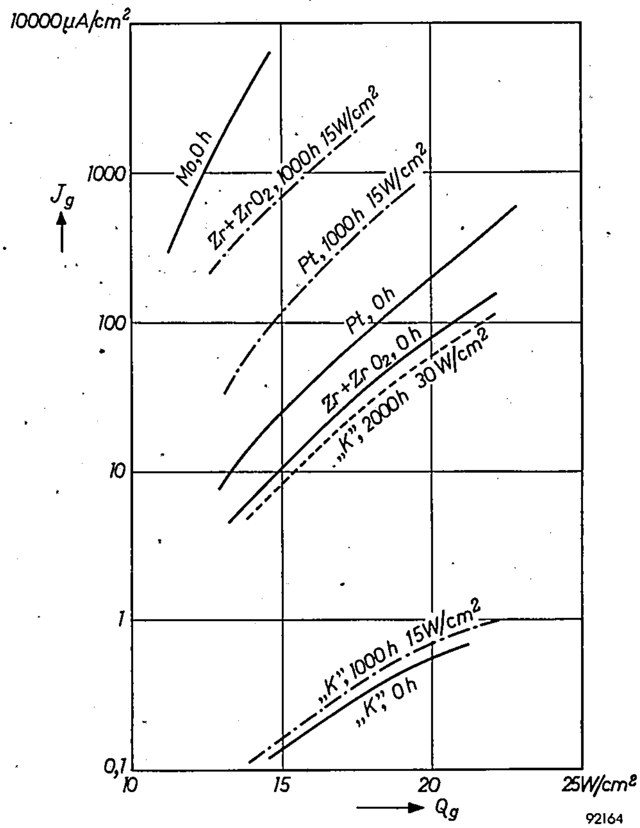
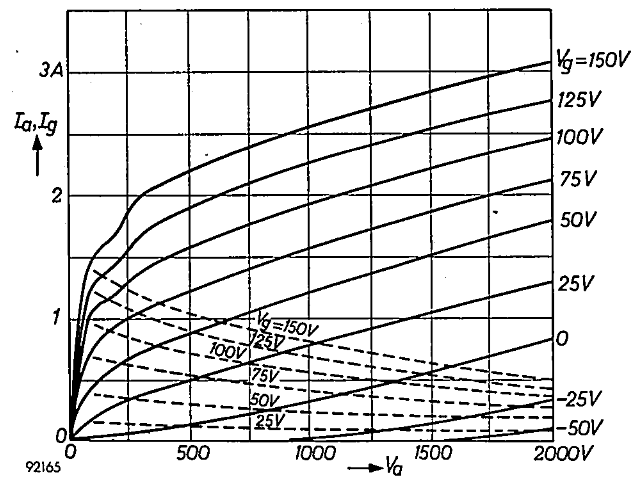


Fig. 9. Specific grid emission J_g (on a logarithmic scale) of experimental TBL 2/300 tubes, with grids of different materials as a function of specific grid dissipation Q_g. The fully-drawn curves apply to new tubes. The dot-dash curves are measurements made after 1000 hours at $Q_g = 15$ W/cm². The dashed curve refers to K material, measured after 2000 hours at $Q_g = 30$ W/cm². *Mo* = molybdenum. *Pt* = platinum on molybdenum. $ZrO_2 + Zr$ = zirconium oxide and zirconium on molybdenum. "*K*" = K material.

mically plotted as a function of specific grid load. It can be seen that of all materials tested, molybdenum is the least suitable, having by far the strongest emission. Platinum, when fresh (plated on a molybdenum core), is appreciably better, and zirconium oxide (mixed with zirconium and also coated on Mo) is slightly better still. After 1000 hours at 15 W/cm², however, the emission from the latter material has become greater than that of Pt and approaches fairly closely the emission of uncoated Mo.

A substantial improvement is obtained with a new material, referred to as "K material". Its emission is about 1/100 of that of $ZrO_2 + Zr$ or of Pt when fresh, and after 1000 hours at 15 W/cm² it shows hardly any increase. Not until after 2000 hours at 30 W/cm² (four times higher than the specified load) does the emission approach that of fresh $ZrO_2 + Zr$. Owing to its great ductility, the use of K material for the grids makes the tube well able to withstand shocks and vibrations. This is an important point, having regard to the uses of the TBL 2/300 in mobile equipment and in industry. This favourable combination of electrical and mechanical properties prompted the use of K material for the grid of the TBL 2/300. The geometry of the electrodes is such that the specific grid dissipation during normal operation lies far below 15 W/cm². The ultimate limiting power loading of the grid, i.e. the loading at which the grid is immediately destroyed, lies at about 60 W/cm². The wide margin between this limiting value and the normal loading of the grid is



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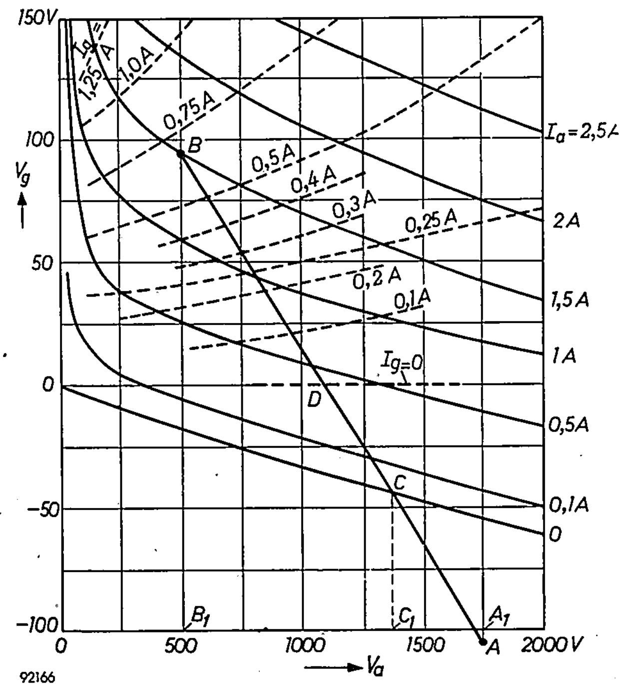


b

Fig. 10. Static characteristics of the TBL 2/300.
a) Anode current I_a (full) and grid current I_g (dashed) as a function of anode voltage V_a, with grid voltage V_g as the running parameter.
b) V_g as a function of V_a for constant I_a (full) and for constant I_g (dashed).

an important practical advantage in the adjustment of an oscillator in course of construction or development.

Electrical properties

Static characteristics

In *fig. 10a* the anode current I_a and the grid current I_g are plotted as a function of the anode voltage V_a, with the grid voltage V_g as the running parameter. Fig. 10*b*, which is derived from fig. 10*a*, represents V_g as a function of V_a; the fully-drawn curves hold for constant I_a, the dashed curves for constant I_g. This diagram has the advantage that the working line is straight, which simplifies the calculations for the biassing of the tube.

As may be derived from fig. 10*a*, the slope S is approximately 18 mA/V and the amplification factor μ about 32.

Use in oscillator circuits

Extensive measurements and life tests (several thousands of hours) have been carried out on many tubes of type TBL 2/300 in different oscillator circuits. One of these oscillators operates at 840 Mc/s: some constructional details are given in *fig. 11*, the actual arrangement is shown in *fig. 12*. In *fig. 13* the frequency of this oscillator is plotted as a function of the height H of the interchangeable anode cavity resonator, for diameters D = 90 and 180 mm. Furthermore, TBL 2/300 tubes are being used in an experimental television transmitter which has been in operation at Eindhoven for some considerable time (picture 772.25 Mc/s, sound 777.75 Mc/s).

The tests have shown that the H.T. supply may permissibly be 2500 V at frequencies up to 200 Mc/s,

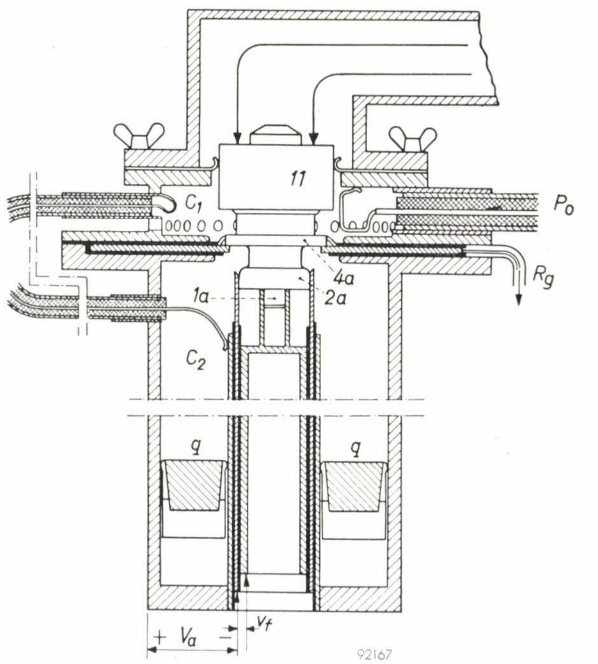


Fig. 11. Section through the coaxial system of an oscillator used for testing TBL 2/300 tubes at 840 Mc/s. *1a*, *2a* filament contacts, *4a* grid disc and *11* anode disc. C_1 interchangeable anode cavity resonator. C_2 grid cavity resonator, tuned by shorting-piston *q*. *Left*: the coaxial cable which provides for feed-back between the two cavity resonators. *Right*: the cable which takes off the output power P_o, and the connection for the grid resistor R_g. Connections for filament voltage V_f and the H.T. supply V_a are brought in from below. Air is blown in through the top.

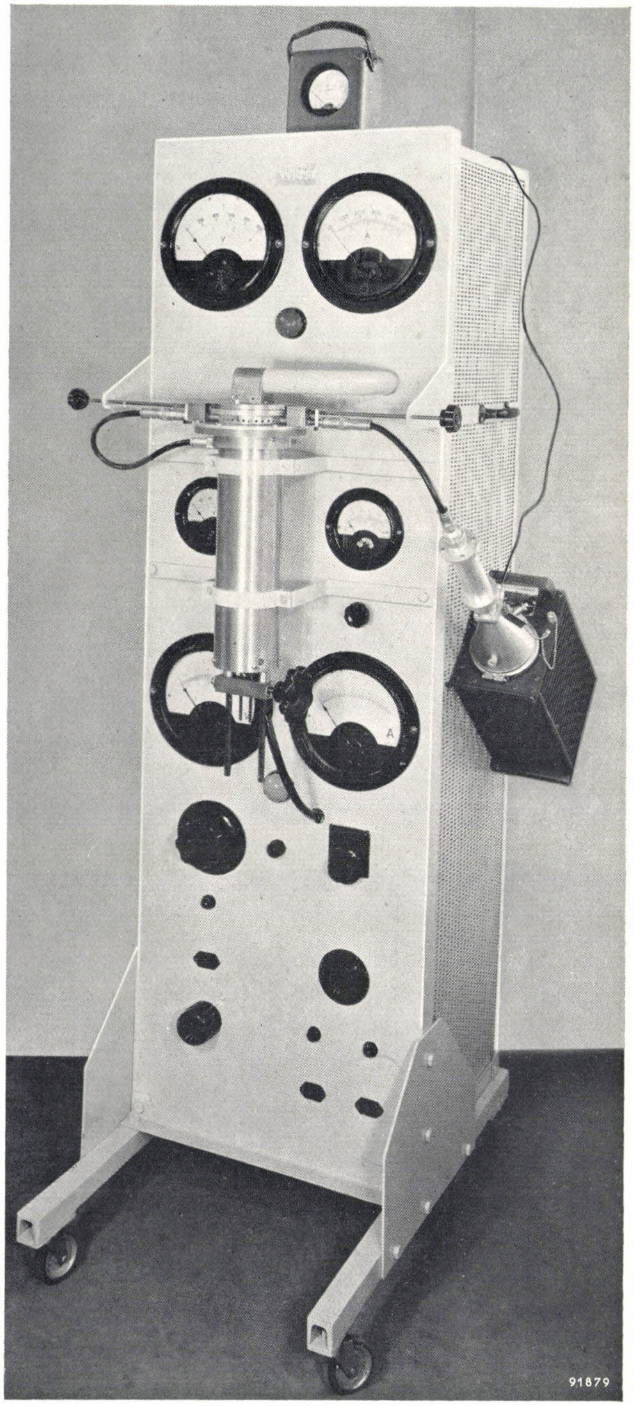


Fig. 12. Test oscillator operating at 840 Mc/s. The tube TBL 2/300 is mounted in the metal cylinder in the foreground; the load is shown on the right.

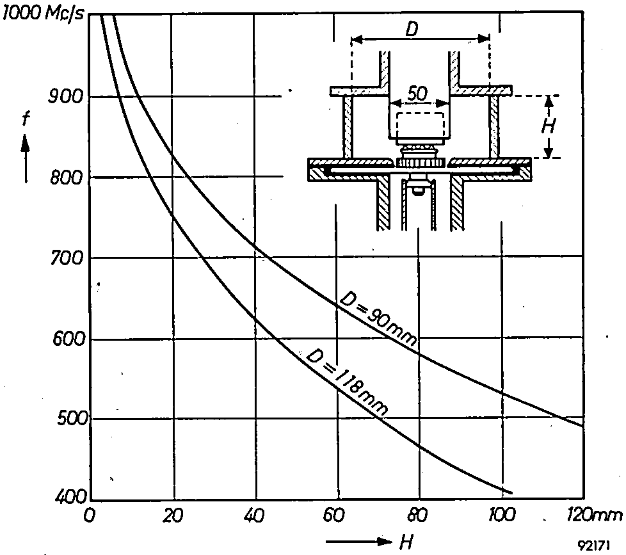


Fig. 13. The frequency f as a function of the height H of the anode cavity resonator, for two different diameters D. Inset: schematic cross-section of cavity resonator (cf. fig. 11).

but that it must be lowered according as the frequency rises (to 1300 V at 900 Mc/s) in view of dielectric losses in the glass. Partly as a result of this, the maximum power output P_o falls from 475 W at 200 Mc/s to some 150 W at 900 Mc/s. *Table I* gives the values measured for normal operation and the maximum values; see also *fig. 14*.

With regard to the grid dissipation, it should be added that apart from the dissipation P_g of about 6 W caused by electron bombardment, heat is also generated in the grid rods owing to the skin effect. The contribution which this makes to the total grid dissipation is, in proportion, quite considerable, being about 6 W at 470 Mc/s and about 8 W at 900 Mc/s. The grid may thus have altogether about $6 + 8 = 14$ W to dissipate. The grid surface area being 2 cm², the total specific grid load is 7 W/cm², which is far below the specific load of 15 W/cm² at which the K material has been life-tested, and even further below the ultimate limit of 60 W/cm². (These values do not include the (constant) radiation heating of the grid by the filament.)

As already remarked, it is often permissible in diathermy (and also in industrial high-frequency heating) to operate the tube on alternating voltage. This saves the costs and electrical losses entailed by the use of a rectifier and a smoothing filter. Fed by alternating voltage of 1900 V r.m.s. and a mean anode current of 166 mA, the tube consumes a power of $(\pi/2\sqrt{2}) \times 1900 \times 0.166 = 350$ W; at a frequency of 460 Mc/s, the power output is then 227 W, the efficiency being 65%. Of this output a part is lost in the tuned circuit. That part can amount

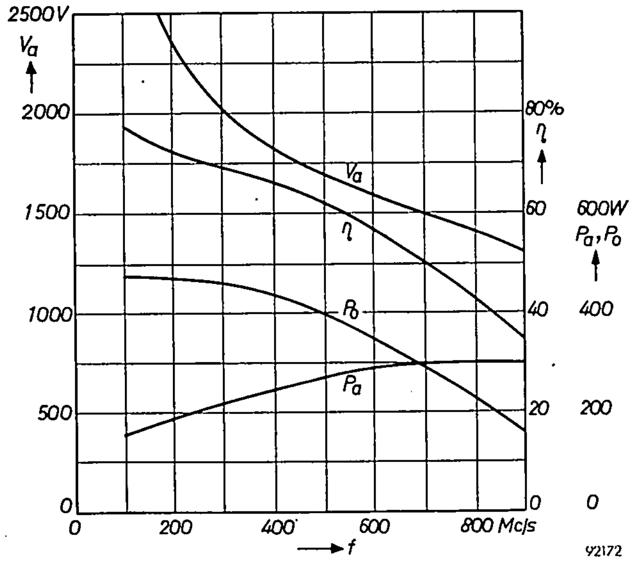


Fig. 14. Maximum permissible H.T. voltage V_a, maximum permissible dissipation P_a, power output P_o and efficiency η of an oscillating TBL 2/300 tube, as a function of frequency f.

Table I. Voltages, currents, powers and efficiency of TBL 2/300 tubes in an oscillator circuit. The values between brackets are the maximum permissible values.

Frequency	(Mc/s)	175		470		900	
Wavelength	(cm)	172		64		33	
Filament voltage	(V)	3.4		3.4		3.2	
Anode supply voltage	(V)	2500	(2500)	1750	(1750)	1300	(1300)
Anode direct current	(mA)	260	(400)	380	(400)	350	(400)
Grid D.C. voltage	(V)	—200	(—300)	—105	(—300)	—60	(—300)
Grid A.C. voltage (peak)	(V)	275		190		—	
Grid direct current	(mA)	100	(120)	100	(120)	100	(120)
Input power P_i	(W)	650	(1000)	665	(700)	455	(520)
Anode dissipation P_a	(W)	175	(300)	260	(300)	300	(300)
Grid dissipation P_g	(W)	~6	(15)	~6	(15)	~6	(15)
Power output P_o	(W)	475		405		155	
Efficiency P_o/P_i	(%)	73		61		34	

to about $\frac{1}{3}$, so that about 150 W useful output remains. In diathermy and heating applications, the load is not usually continuous. The tube, which goes on oscillating when the load is removed, then takes a high grid current, which increases from, say, 65 to 95 mA, while the supply voltage increases from 1900 to 1950 V. Even in these conditions, however, the tube life was found to be satisfactory.

Power gain and bandwidth

The power gain obtainable with the TBL 2/300 at 470 Mc/s is about 15 with grounded cathode and about 5 with grounded grid.

The tube capacitances are:

Anode-grid:	C_{ag} = approx. 4	pF
Anode-cathode:	C_{ak} = approx. 0.12	pF
Grid-cathode:	C_{gk} = approx. 9	pF

For wide-band amplification it is important that C_{ag} should be small, as follows from the expression for the bandwidth B:

$$B = \frac{1}{2\pi R_a C_{ag}}.$$

In this expression R_a is the load resistance (the ratio of the alternating voltage of the anode to the fundamental of the anode current). With C_{ag} = 4 pF and R_a = 2000 Ω, the bandwidth is 20 Mc/s, which is more than adequate for all existing television systems and can also accommodate a large number of telegraphy and telephony channels.

For the power gain G_k in the grounded cathode arrangement we may write:

$$G_k = \frac{P_o}{P_{ig}} = \frac{\frac{1}{2}V_{a1}I_{a1}}{\frac{1}{2}V_{g1}I_{g1}}.$$

P_{ig} is here the input power to be amplified, applied between grid and cathode, V_{a1}, I_{a1}, V_{g1} and I_{g1} represent the peak values of the fundamentals of anode voltage, anode current, grid voltage and grid current, respectively.

By way of example we shall take a case in which the frequency is 470 Mc/s and the maximum permissible anode supply voltage 1750 V. Half of the selected load line (AB) is shown in fig. 10*b*. The centre A of the load line lies at V_a = 1750 V, V_g = –105 V; end B lies at $I_{a\,max}$ = 1.5 A. The maximum grid current $I_{g\,max}$ is 0.7 A, the minimum anode voltage $V_{a\,min}$ is 500 V. The amplitude V_{a1} of the anode alternating voltage is thus 1750 – 500 = 1250 V.

The amplitude I_{a1} of the fundamental of the anode alternating current may be found by first determining the "conduction angle" $2\Theta_a$: the part of the period in which anode current flows, i.e. when the tube is conducting, is $2\Theta_a/2\pi$ (*fig. 15a*). It follows from fig. 15*a* and *b* that:

$$\cos\Theta_a = \frac{A_1C_1}{A_1B_1}.$$

According to fig. 10*b* this is equal to AC/AB, the value of which can be found from this figure to be

$$\cos\Theta_a = \frac{AC}{AB} = 0.325,$$

so that $$\Theta_a = 72°.$$

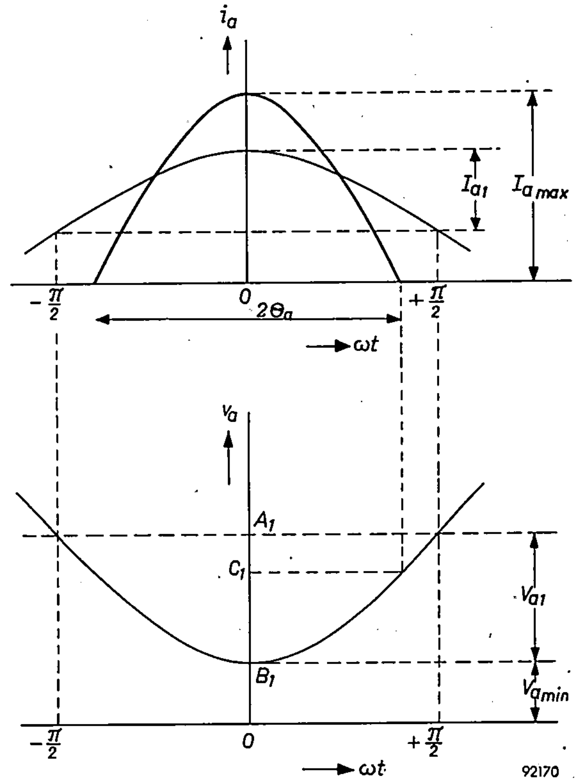


Fig. 15. *a*) Anode current i_a, (*b*) anode voltage v_a of an oscillating tube, as functions of ωt (ω = angular frequency, t = time). $2\Theta_a$ = conduction angle. Thin curve in (*a*): the sum of the fundamental of i_a (amplitude I_{a1}) and the D.C. component.

From the conduction angle we can derive the ratio $I_{a1}/I_{a\,max}$ [6]); for Θ_a = 72°, the value of $I_{a1}/I_{a\,max}$ is 0.43, so that

$$I_{a1} = 0.43\times1.5 = 0.65 \text{ A}.$$

With this we find for the anode resistance $R_a = V_{a1}/I_{a1}$ = 1250/0.65 = 1930 Ω (in the foregoing this was rounded off to 2000 Ω), and for the output power P_o:

$$P_o = \tfrac{1}{2}\times1250\times0.65 = 405 \text{ W}.$$

V_{g1} (the difference between the ordinates of B and A in fig. 10*b*) is seen to be 200 V. For half the conduction angle Θ_g of the grid current we may write:

$$\cos\Theta_g = \frac{AD}{AB} = 0.52,$$

hence $$\Theta_g = 58°.$$

6) J. P. Heyboer, Transmitting Valves, Philips Technical Library 1951, fig. 19, p. 38.

The corresponding value of $I_{g1}/I_{g\,max}$ is

$$\frac{I_{g1}}{I_{g\,max}} = 0.38\,,$$

so that

$$I_{g1} = 0.38 \times 0.70 = 0.27\ \mathrm{A}$$

and

$$P_{ig} = \tfrac{1}{2} \times 200 \times 0.27 = 27\ \mathrm{W}.$$

The power gain is therefore:

$$G_k = \frac{405}{27} = 15\,.$$

In grounded-grid arrangement the power gain G_g is:

$$G_g = \frac{P_o + P_d}{P_{ig} + P_d}\,,$$

in which P_d is the power directly transferred from input to output, equal to $\frac{1}{2} V_{g1} I_{a1}$. In the above example $P_d = 65$ W. Thus

$$G_g = \frac{405+65}{27+65} = 5.1.$$

Ceramic version of the tube

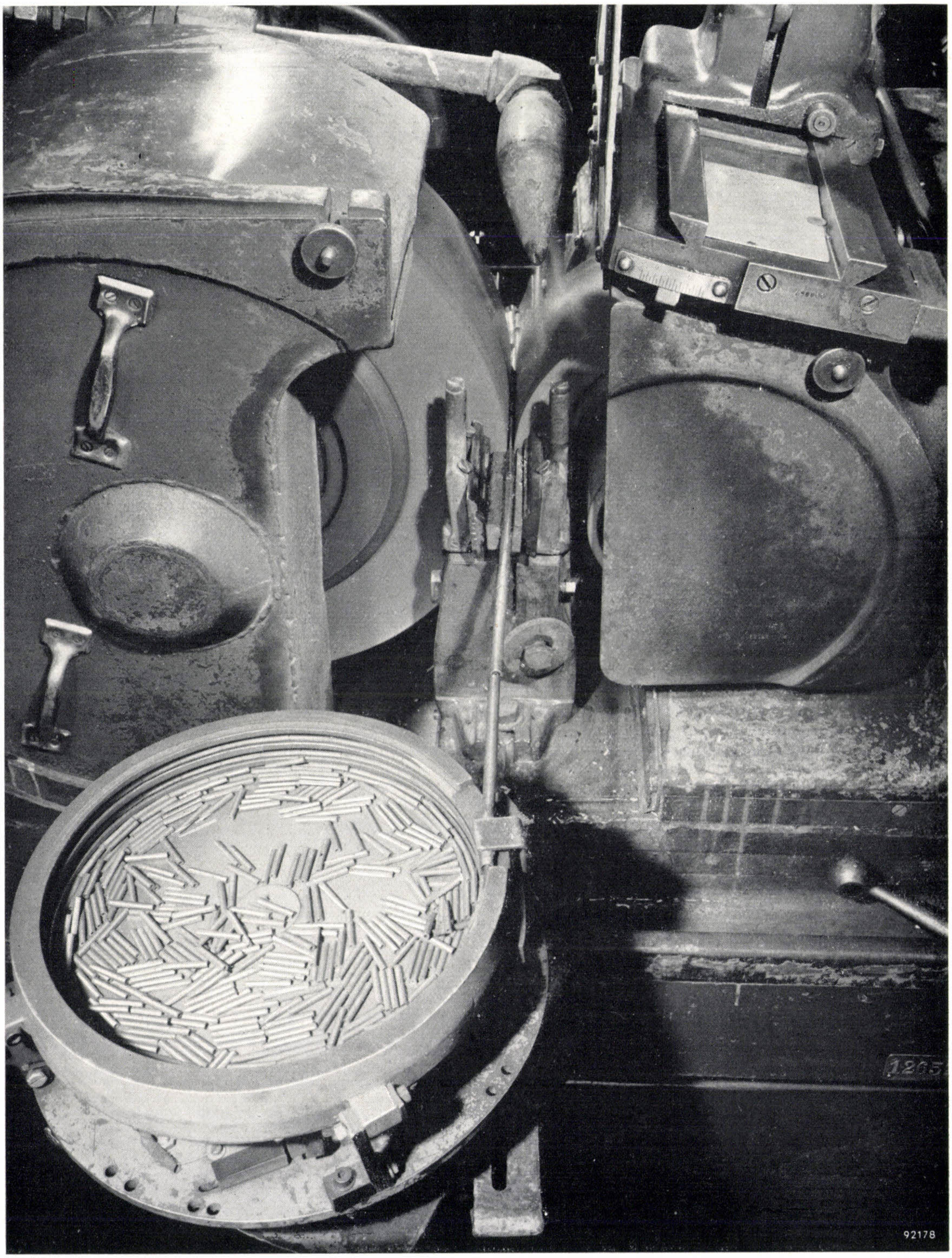
Finally, a few words about the latest version of the TBL 2/300, which is still in course of development. In this version the glass rings *3* and *5* (see figs. 2 and 3) have been replaced by ceramic rings. The ceramic material has an appreciably lower loss factor tan δ than the best types of hard glass suitable for fusion to fernico. Consequently, the supply voltage does not have to be lowered so much as the frequency rises, which means that the tube has a higher power output at the highest frequencies.

The ceramic-metal seal was an initial difficulty. A satisfactory ceramic-metal seal evolved by Radioröhrenfabrik Valvo in Hamburg will be described in a subsequent article in this Review.

Summary. The TBL 2/300 transmitting tube for frequencies up to 900 Mc/s is a disc-seal triode with a directly heated cathode of thoriated tungsten, a cage-type grid and an air-cooled anode. The cathode consists of two helical filaments connected in parallel, each with a wire length of about 1/4 of the shortest wavelength and shunted by a capacitor, the capacitance of which (50 pF) is such that at high frequencies the cathode is almost equipotential. The capacitor is formed by a so-called sandwich seal. The grid is made of a new material ("K material"), which has extremely low emission properties, even after the tube has operated for a long period with high grid dissipation; this material also has good mechanical strength. The slope of the tube is about 18 mA/V, the amplification factor about 32. In oscillator circuits it delivers a power of 405 W at 470 Mc/s, and 155 W at 900 Mc/s, with an efficiency of 61% and 34% respectively. The power gain is about 15 with grounded cathode and about 5 with grounded grid (both at 470 Mc/s). Owing to its low grid-anode capacitance (about 4 pF), the tube still amplifies efficiently at bandwidths up to 20 Mc/s.

A new version in course of development, in which a ceramic is used instead of glass for the insulating rings, has a somewhat higher output.

CENTRELESS GRINDING OF CERAMIC SLEEVES



Ceramic sleeves of various types and sizes are used on a large scale in the electronics industry. The photograph shows such sleeves undergoing centreless grinding down to a certain external diameter. A circular vibratory hopper (foreground) feeds the sleeves via a metal tube to the grinding wheel and pressure roller.