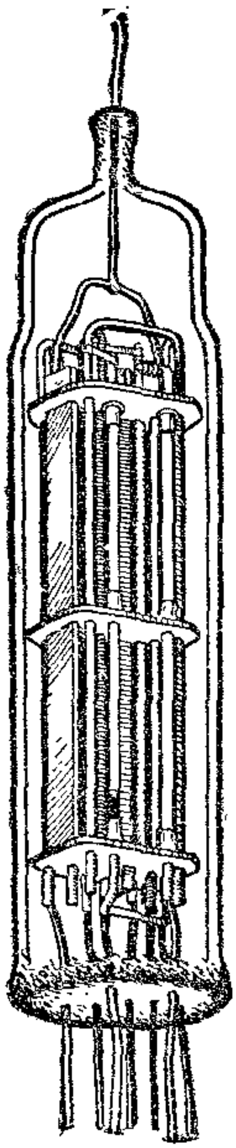

ROD TUBES

PRINCIPLE AND DESIGN

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Several years ago, when the semiconductor devices appeared on the market, some radio specialists were inclined to immediately "bury" vacuum tubes. Vacuum tubes, which for decades brought the triumph of Electronics, suddenly acquired a lot of disadvantages, such as "low economy", "poor mechanical strength", "short service life", "unsuitability for the automated production", etc.

The vacuum tube, when compared with the transistor, undoubtedly has several disadvantages, but in fact there are well-known remarkable advantages of vacuum tubes, due to which they remain in many areas of technology and will undoubtedly remain the main device for amplification and conversion of electrical signals.

In addition, vacuum tube technology does not stand still; it creates electronic devices not only of increasingly high performance, but also exhibiting a number of new principal features.

Such new devices, described here for the first time, are rod tubes. The main feature of rod tubes is the absence of grids for the formation of electron flow and its control: instead of grids, they use rigid metal rods specifically located between the anode and cathode.

Unfortunately, it must be noted that the scope of application, and hence the production level of rod tubes is not developing fast enough, despite the fact that these tubes have been around for many years and have received high appraisal.

The editors plan to publish another article about the application features of rod tubes in "Radio" Monthly later this year.

The domestic electro-vacuum industry has developed new sub-miniature vacuum tubes with direct heating, with electron-optical focusing, or, as they are called, vacuum tubes with rod electrodes. Compared with conventional grid-based tubes (Such as 2ZH27L, 2ZH27P, etc.) these tubes have a number of valuable benefits that allow engineers to design separate units and equipment in general, satisfying today's requirements regarding the reduced size and weight of the equipment while improving its key technical characteristics (frequency stability, sensitivity and selectivity of radio receiving devices, efficiency in energy consumption and reliability, operation in a high-frequency VHF band).

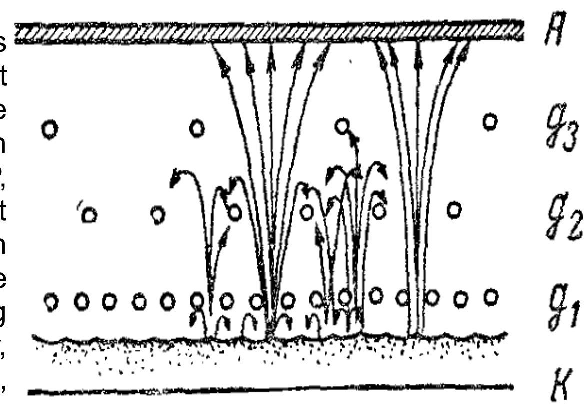

Fig.1 Distribution of currents in grid-based vacuum tube

Vacuum tubes with an electron-optical focusing are completely different from grid-based tubes, and their design and physical processes in these tubes have some specifics relating primarily to the control of electron’s flow.

Fig. 1 shows a schematic of cross-section of a pentode with direct heating in a conventional design. Arrows show the trajectories of electrons from filamentary or heater cathode K to the anode A. Some of the electrons, emitted from the cathode area are “shaded” by the control grid wires with a negative potential and return back to the cathode and into the space charge domain, while with a positive potential on the control grid, these electrons create current flow into the control grid. Another part of the electrons, emitted from sections of the cathode which are “shaded” by “screening” (g2) and “suppressor” (g3) grid wires, are spent uselessly to form the screen grid current Ig2, and the suppressor grid current Ig3. The remaining electrons reach the anode, forming the anode current Ia of vacuum tube.

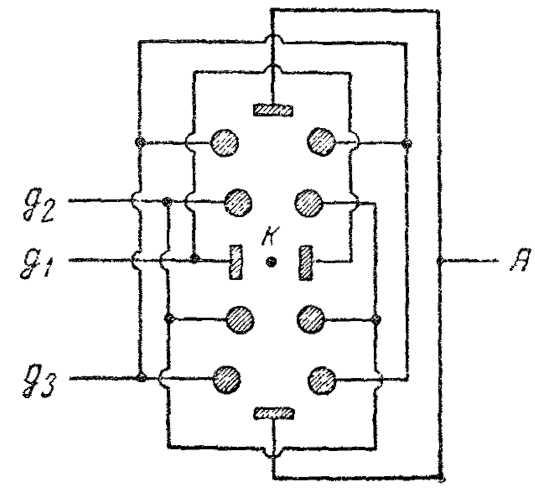

Fig.2 Location of electrodes inside rod tubes (cross section)

Grid wire layers [of a conventional vacuum tube], having different potentials with respect to the cathode, “arrange” the flow of electrons between the grid's wires to the anode. Therefore, a section of the cathode with the grid wires directly above it, and a section of the anode also above it, can be regarded as an “elementary” vacuum tube.

Analysis of such an elementary vacuum tube allows considering the possibility of electron flow control not only by spiral wound grids, but rather with the help of parallel wires or “rods”. Indeed, if the stream of electrons from the cathode “element” is restricted not by two adjacent turns of wires in conventional grids, but rather by pairs of parallel rods, and at the end of electron flow we put the anode as a single rod, and after doing this we assign to these rods (g1, g2, g3, A) the appropriate voltages (Eg1, Eg2, Eg3, Ea), we obtain a complete analogy to an elementary section of the grid-based vacuum tube. Now, by placing the rods parallel to the wire filament K (instead of an elementary area of the cathode), we will have a directly heated vacuum tube with rod electrodes, the schematic cross section of which is presented at Fig. 2.

Although the functions performed by electrodes with the same name behave the same for both types of vacuum tubes, the principle of operation of a vacuum tube with rod electrodes is significantly different from that of a conventional tube.

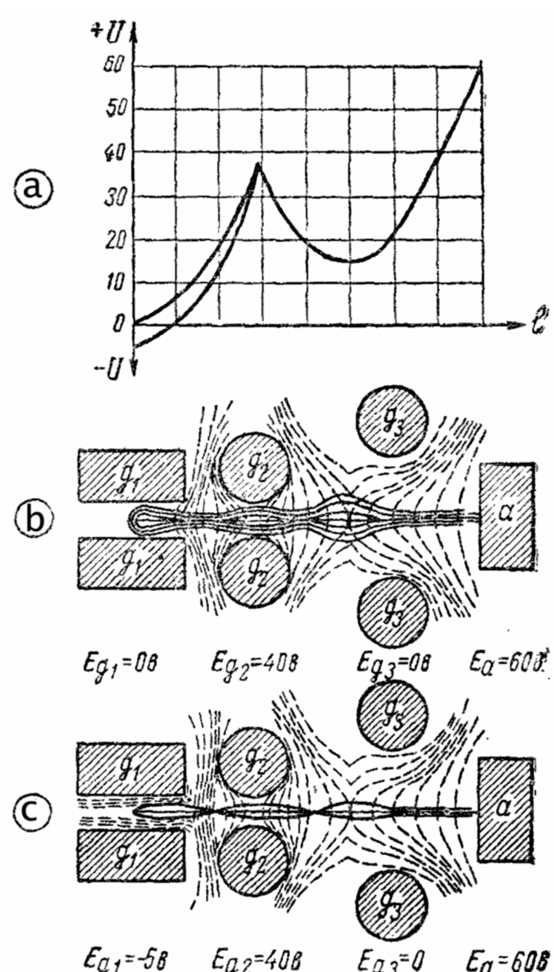

Fig. 3. Location of equipotential lines and voltage graph between the electrodes in a rod tube.

Fig 3a shows the graph of the electric field between the electrodes of a rod tube at two different control grid voltages, while at Fig 3b and 3c one can see the approximate location of the lines of equal potentials, corresponding to the electric field for two values of voltage at the control grid electrode. Fig 3b and 3c show only the “right half” of the rod tube because the rod tube is structurally symmetrical with respect to cathode and to the control "grid" rod.

Considering the location of the equipotential lines of the field in the vacuum tube with rod electrodes, we come to the following conclusion: The field lines form two electronic lenses - one focusing, which is located in the area of the control and screening rods, and another one – the collimator lens, located in the area of the suppressor rods and the anode. The focal length of the focusing lens is greatly affected by the potential at the control rod electrodes.

With negative potential at the control rods, the curvature of the electric field lines near the control rod electrode decreases, and field lines come closer to the screening electrode rods and move away from the control electrode rods (Fig 3c).

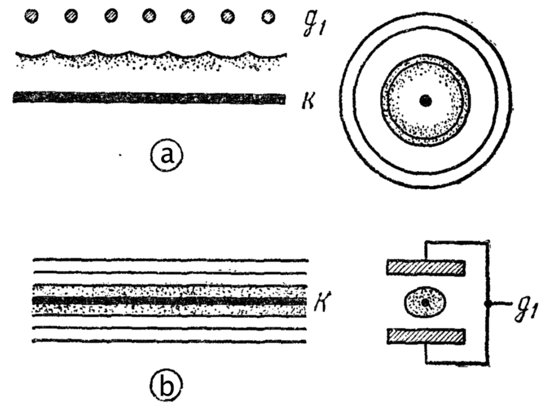

Fig. 4. Schematic illustration of the spatial charge: a) tubes with wound grids, and b) tubes of rod structure

On the other hand, with a negative potential at the control electrode, the electronic cloud, which is formed by electrons emitted from the cathode, comes closer to the filament and away from the control electrodes (Fig. 3c). The space charge around the filament takes the form of a squeezed ellipse (Fig. 4). As a result, the radiating surface of the space charge decreases, thereby reducing the cathode current of the rod tube.

With increasing negative potential at the control electrode, the radiating surface of the spatial charge becomes even smaller, and at a certain value of negative potential the active surface of the cathode itself starts to decrease. With a further increase of negative potential on the control rods, the operating cathode surface decreases to such an extent that the cathode current of the rod tube completely stops.

With a positive voltage on the control electrodes, the curvature of the equipotential field lines at the screening electrodes increases. At the same time, this increases the radiation surface of the space charge. Both these conditions contribute to an increased cathode current.

Further increase in the positive potential at the control grid electrodes causes a drastic redistribution of the electron beam - the share of the anode current decreases, but at the expense of increasing the currents of the control and shielding electrodes.

The anode current rise stops completely above a certain positive potential at the control grid electrodes.

Thus, in contrast with the grid-based vacuum tubes, where the value of cathode current is determined only by the potential at the electrodes affecting the space charge, the control of electron flow in tubes with rod electrodes is performed differently, namely by the influence of the potential of control electrode rods onto the radiation surface field of the space charge domain. In addition, the cathode current depends on the existing active surface of the cathode and the focal length of lenses in the electron-optical system of the rod tube. In this case, the high density electronic flow from the working surface of the cathode is directed towards the anode between the bars of the screening and suppressing electrodes. Due to such an electrode design and to this particular method of electron flow control, the rod based vacuum tube effectively uses almost the entire cathode lamp current, creating the conditions for improved efficiency of the rod tube with respect to the electric power consumed by its filament.

The efficiency of the use of cathode current in vacuum tubes is estimated by the ratio of anode current Ia to the cathode current Ik. This ratio in conventional grid-based tubes is in the range 0,65-0,85. In tubes with rod electrodes, it reaches 0.98, i.e. practically the entire cathode current in these new vacuum tubes is effectively used. High efficiency usage of cathode current in receiving-amplifying rod tubes made it possible to reduce (for the same parameters compared with grid-based tubes such as S factor and anode current) by the factor of two the power consumed by tube filament. For low-power oscillator-type rod tubes, the power savings get even more pronounced.

Electron-optical focusing of the electron beam used in the rod tubes streamlines the motion of electrons in the tube and reduces lateral scattering. Because of this, the current in the screening electrodes of rod tubes is substantially (5-7 times) lower in comparison with grid-based tubes. The magnitude of this current is 5-10% of the anode current, while in grid-based tubes with a conventional distribution of the electron beam, the current of the screening grid reaches 25-30% of the anode current. Therefore, rod tubes are not only economical in terms of power consumption for filament heating, but also in their high voltage circuits.

However, it should be noted that despite the very small currents in the rod tube screening grids, the standard deviation of the values of these currents is relatively large. For example, although the 1ZH24B screening grid current does not exceed 0.09 mA, at the same time, many tubes of this type have this current at the level of about 0.02 mA or even less. Therefore, the screening grids of rod tubes used in electronic equipment should be powered via a resistive voltage divider. This stabilizes rod tube operation, and is particularly useful at low voltage levels on the screening rods (with Eg2<<Ea/2), which is the typical case for voltage amplifiers.

When the voltage on the screening rods is close to the anode voltage, the slope characteristics (S-factor) of the rod tube has a maximum value and varies only slightly with the change of anode (screen grid) voltage. In this case, voltage to the screening electrodes can be supplied via the decoupling 5k to 10k resistor.

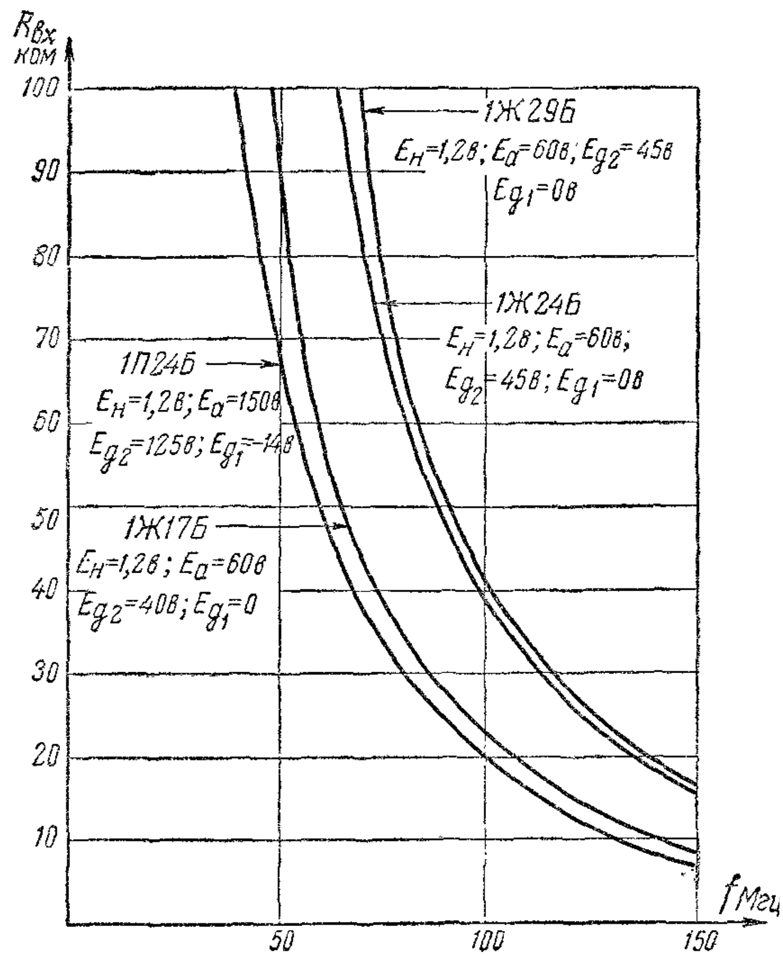

Fig. 5. Dependence of the input impedance of rod tubes on frequency.

Rod tubes work well in the VHF frequency range. In this, they differ advantageously from grid-type tubes. Difficulties in improving high-frequency properties in grid-type tubes are, to some extent, explained by the chaotic motion of electrons on the way from the cathode to the anode when electrons pass through artificial barriers in the form of metal grids randomly placed in their path, which control the electron flow. The electron's trajectories are bent, lengthened, and path lengths become different for different electrons that are simultaneously emitted from the cathode. This circumstance significantly affects the value of the input resistance of the tubes. Thanks to the “ordering” of the electron beam in rod tubes, the input resistance of vacuum tubes with rod electrodes is several times higher compared to conventional grid-based tubes.

Frequency dependence of input resistance of rod tubes is given in Fig. 5. For rod tubes, as well as for conventional grid-based tubes, we have a quadratic dependence of the input impedance on the frequency:

$$R^1_{вх} = \frac{R_{вх}}{\left(\frac{f'}{f}\right)^2},$$

where $\mathbf{R_{BX}}$ – is the input impedance at the frequency **f** (taken from tube reference tables), and **f'** is the frequency at which we have to calculate $\mathbf{R^1_{BX}}$.

The input impedance of rod tubes with two filaments (1ZH29B, 1P24B), in the regime when they are powered by a voltage of 2.4V (two filaments working in series) is almost two times lower than in the case when the filament is powered from 1.2V source. This is explained by the increased length of the filament (cathode) wire. To increase the input resistance of these tubes the midpoint of the filament should be grounded by high frequency bypass capacitors.

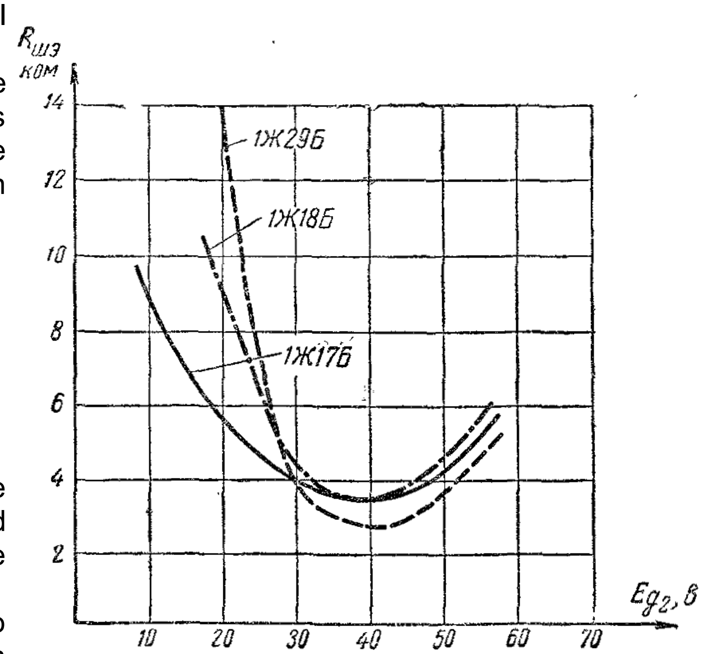

Fig. 6. Dependence of the equivalent resistance of the internal tube noise on the voltage on the screening rods.

The equivalent value of "noise resistance" of the amplifier ("small signal") type rod tubes is almost 1.5-2.5 times lower than that of the grid-based tubes of similar purpose. This is explained by the fact that the current of screening electrodes of rod tubes is a very small part of the anode current. The equivalent resistance of noise of a pentode tube is determined by the formula:

$$R_{ш} = \frac{I_a}{I_a + I_{g2}} \left[\frac{2{,}5}{S} + \frac{20 I_{g2}}{S^2}\right],$$

which implies that, when the current in the screening electrodes goes down, the second term in square brackets decreases faster than the ratio **Ia/(Ia+Ig2)**, which characterizes current distribution inside the tube. Therefore, the decreased current in the screening electrodes leads to a reduction of internal noise in the tube. The lowest noise in vacuum tubes with rod electrodes is achieved when the voltages at the electrodes are equal to 30-50V at the screen grid, to 60-80V at the anode, and to 0 to-0, 5V at the control grid.

The small value of equivalent noise resistance in a vacuum tube with rod electrodes, and a large input resistance allows them to almost double the sensitivity of a receiver in cases where these tubes are used at the receiver front end stages, as compared with conventional tubes.

In the new type of vacuum tube, the inter-electrode capacity (Cinput, Coutput, Cag, Cak) is less than that in tubes with wound grids. The output capacitance Coutput and transition capacitance Cag are particularly reduced, which is beneficial when using these tubes at high frequencies. Large input resistance and small inter-electrode capacitance allowed rod tubes to expand into a high frequency range, which is approximately doubled in comparison with conventional grid-based vacuum tubes.

Due to the electron-optical focusing of electron flow from the cathode to the anode and, consequently, small screen rod currents, the anode characteristics of the new tubes have a kind of sloping curve with a very small slope at the horizontal section. The inflection in the anode characteristics of a vacuum tube with rod electrode structure occurs at low anode voltages - for most tubes about 15-25V. This allows high efficiency in power amplification stages and high-frequency oscillators in generators. The methods of calculating the electronic circuits for tubes with rod electrodes are, therefore, more rigorous and accurate than for grid based tubes. It should be noted that the grid characteristics of rod tubes are characterized by an inflection in the region of small positive voltages at the control electrode, which accounts for the redistribution of the flow of electrons between the electrodes. For receiving and amplifying tubes at the recommended modes of operation, this inflection point begins at 1,0-1,5V. Because of proximity to the cathode and a relatively large surface of the control rods, at large positive potentials, a strict focus of the electron beam is violated. In such a situation, the redistribution of the electron beam takes place (increasing current into the control electrode, so the tube switches into signal cutoff or limiting mode).

For the transmitting tube 1P24B, the instantaneous positive driving voltage amplitude should not exceed 5-7V. Therefore, tubes with rod electrodes can be used to amplify and oscillate only at negative control electrode voltages. For small input signals (Ug1<=0,5 V) rod tubes are allowed to work without an initial grid bias at the control grid.

Fig. 7 shows rod tubes in comparison with directly heated vacuum tubes [with 2 V filaments].

The terminals of rod electrode tubes are made of flexible platinum [*in early versions - DF]* wires passing through a flat glass stem. The anode wire goes out separately at the top of the glass shell. Such a separation of terminals between the anode and the control electrode is made with a view to reducing capacitance in the tubes. The use of a flat bottom tube makes it possible to reduce the height of the tubes and to reduce the inductance and capacitance of the terminals.

Rod tubes are designed for direct soldering in place without the use of traditional connectors. The high mechanical strength of rod tubes, their long service life [*typically at least 5,000 hours – DF]* and small size justify such a construction.

Large tolerances in filament voltage levels allow powering the rod tubes from silver-zinc rechargeable batteries and from dry cell batteries with their large voltage drop (to use batteries to full extent). Operating conditions of rod tubes are chosen by designers of radio electronic equipment in relation to a particular scheme, based on the maximum allowable operating conditions. However, in all cases, the designer of vacuum tube schemes should keep in mind that the use of vacuum tubes in operating conditions that are close to the permissible maximums, leads to a reduction in the reliability of the tubes. For vacuum tubes with rod electrodes, it is particularly dangerous to operate them at a filament voltage close to the minimally acceptable, and at the same time at the maximum-permissible tube anode current.

If it is necessary to use the rod tubes in triode mode, a prerequisite is to connect the suppressor electrode (*g3*) with the tube cathode (or chassis), otherwise focusing of the electron flow in the tubes is violated. For the same reason, it is not allowed to apply a positive voltage on the suppressor electrode in pentode mode, as is sometimes suggested for some types of conventional grid based tubes in oscillator configurations.

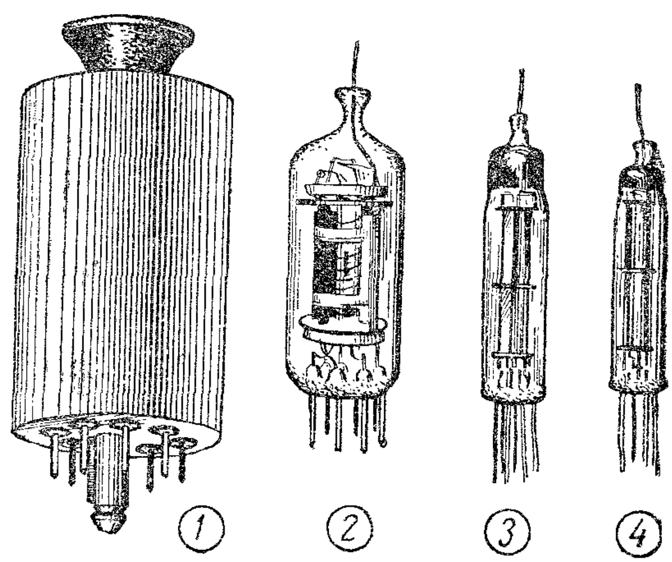

Fig. 7. Comparative sizes of rod tubes and tubes with wound grids 1-2ZH27L, 2-2ZH27P, 3-1P24B, 4-1ZH29B, 1ZH17B, 1ZH18B, 1ZH24B.

When designing equipment with rod tubes, avoid placing these tubes in magnetic fields (both permanent and variable). Failure to do so may impair operation.

* * *

The rod tube features outlined here show that these tubes, while being very economical, at the same time, have high efficiency with good electrical parameters and improved high-frequency properties: low internal tube noise, high input resistance and low values of inter electrode capacitance. This allows the efficient use of rod tubes at frequencies of up to 250 Mhz.

ROD TUBE PARAMETERS

A. Azatyan, N. Parol

Receiving and amplifying rod tubes (1ZH17B, 1ZH18B, 1ZH29B, 1P24B) look almost the same as conventional subminiature vacuum tubes.

In most tubes with rod electrodes, their filaments operate at the voltage of 1.2V. For 2.4V filament tubes (1ZH29B and 1P24B) the two identical electrode systems with single filaments are used, which can be connected in series (2.4V) or in parallel (1.2V).

Basic electrical parameters of rod tubes, their specifications and pinouts are placed at the third cover page [of this magazine].

Table 1 shows the maximum allowed [voltage and current] limits of the rod tubes.

Table 2 shows the ratios of S-factor to anode current, S/Ia (*transconductance/amp*), S-factor to power consumption (*transconductance/Watt*), and anode to cathode currents of rod tubes.

Rod tubes are characterized by high values of the coefficients of current distribution (Ia/Ik), which is due to low secondary electrode currents.

Anode characteristics [of rod tubes] are very beneficial. The change between regimes of current distribution (inflection characteristics) occurs at low values of anode voltage, located within 10-20V. This feature allows the use of rod tubes at reduced anode voltage, without significant reduction in the S-factor.

In addition, such characteristics allow the realization of oscillators and transmitters with large output power and high efficiency. For example, tube types 1ZH29B and 1P24B, when used in a class "C" oscillator at a frequency of 45 MHz, deliver output power of 0.8W and 2.5-3W, respectively. In this mode, the efficiency of the anode-screen circuits reaches 80%. However, it should be kept in mind that when entering the area of positive drive to the control electrode, grid currents soar, because this electrode has a large surface and is located very close to the cathode. Even with zero bias at the control electrode, the current can reach more than 20 uA.

Due to the low noise level, high input resistance and low transit capacitance rod tubes can be used at frequencies significantly greater than 100 Mhz. For example, the 1ZH24B pentode operates at a frequency of 200 MHz with the LC circuits of a satisfactory quality, delivering power gain of 8-10 times.

The decreased internal tube noise in rod tubes is mostly due to the small values of currents at the second electrodes. It is worth mentioning that when the negative bias at the control electrode of a rod tube is reduced (i.e. goes closer to zero), the noise factor of the rod tube does not change because the second electrode current stays the same.

TABLE1 Maximum permissible operation of rod tubes

Lamp type	Minimum Voltage filament, V	Maximum Voltage filament V	Anode voltage V	Voltage on second electrode V	Voltage on first electrode V
1ZH17B	1.08	1.32	90	60	0
1ZH18B	1.08	1.32	90	60	0
1ZH24B	1.05	1.32	120	90	-
1ZH29B	1.08/2.16	1.32/2.64	150	120	-
As oscillator or power amplifier in class “B” 1P24B	1.08/2.16	1.32/2.64	300	200	-
For DC operation 1P24B	1.08/2.16	1.32/2.64	300	200	-

TABLE1 (continued)

Lamp type	Cathode current, mA	Bias resistance first electrode MegOhm	Power dissipation on anode, W	Power dissipation screen grid, W
1ZH17B	5	1		
1ZH18B	5	1		
1ZH24B	1.4	2.2		
1ZH29B	8	1	1.2	0.35
As oscillator or power amplifier in class “B” 1P24B	40	0.5	4	1.5
For DC operation 1P24B	25	0.5	2.75	1

Table 2

Lamp type	S/Ia (mS/mA)	S/P (mS/mW)	Ia/Ik
1ZH17B	0.7	7	0.91
1ZH18B	0.71	8.4	0.92
1ZH24B	0.82	10.8	0.96