ROD TUBES
Application Notes
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In the seventh issue of this magazine we gave the description of the internal design, and also have shown the parameters of subminiature vacuum tubes with rod electrodes. Their operating principle is different from that of conventional vacuum tubes with wound grids due to the special configuration of the electrodes of rod tubes. The distinctive design of rod tubes also allows manufacturing them with relatively small inter-electrode capacitances.
These tubes are particularly suitable for use in portable battery operated equipment, not only due to their high efficiency, but also because they are able to withstand high shock loads (*DF: this is a clear statement of intended military applications of rod tubes, published in a civilian “Radio” magazine back in 1960, around the time when the first mass produced narrow FM rod tube field radio R-126 was designed and made in the USSR. It is quite clear that the authors of this article may have been actively involved in the design of this one, and of other types, of military radios of those past times, which makes this article a particularly interesting document of its time, showing Russian engineering mentality and education level, as well as their “up to the point” practical style in general. Western readers should have in mind that rod tubes were almost never used in the civilian radio electronics in the USSR, and probably the only exception to this “rule” was a portable AC operated HF band UV air sterilizer “Foton”, in which the 1-watt free running 40 MHz oscillator, made with just one 1p24b-type rod tube, was used to directly “ignite” a small gas-filled glass sphere placed in the center of the anode RF coil of the oscillator*).
The advantages of rod tubes, as compared to conventional “grid-would” vacuum tubes, are particularly pronounced when rod tubes are used in portable battery operated equipment operating in VHF band. This article discusses the design principles of various modules of such VHF equipment made with rod tubes.
However, this does not mean that rod tubes cannot be used in equipment operating at long and medium wave bands, and even more so at audio frequencies.

RF voltage gain.

All existing types of rod tubes are equally suitable for small-signal amplification in the VHF band.

However, for portable battery operated equipment it makes particular sense to use the 1ZH17B, 1ZH18B and 1ZH24B rod tubes.

The main requirement for these tubes when they are used in the front stages of receivers is a minimized internal noise level factor. This noise factor of receiving rod tubes is usually observed when rod tubes are used in the following regime: Ua = 60 V, Ug2 = 35-45 V, and Eg1 = -0.5 to 0V.

To simplify the schematics of small-signal UHF stages, as a rule, no negative bias is applied to control (g1) electrodes (see Fig. 1). (*DF: the authors have in mind the VHF FM applications of rod tubes (as they stated in the Preface), i.e. applications which do not require AGC loops: see R-126 schematic diagram for reference. Obviously, in SW band rod tube radios, such as the R-326 or the R-309, do have AGC loops that are used both at front end and in IF amplifier stages*). In this case, the use of rod tubes of 1ZH17B type is not recommended due to the resulting relatively high (around 2 mA) anode current at zero g1 bias. As a result, at frequencies of up to 50-70 MHz it is advisable to use at the front stages of a receiver the rod tubes 1ZH18B or 1ZH24B. These tubes, when operated at Eg1 = 0 and Eg2 = 40 V, consume at the anode plus screening circuit an electric current of about 0.75 mA, and their S-factor in this mode is about 0.7 mA / V (compared with about 1 mA / V for the tube 1ZH17B), while the 1ZH24B filament consumes just half of the electric power (compared with 1ZH18B).

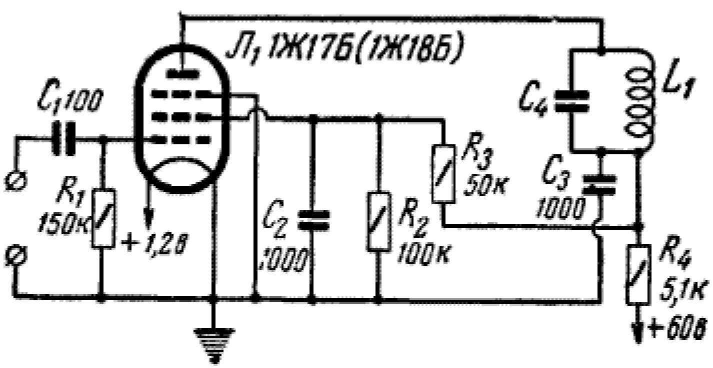

Рис. 1

The real gain in sensitivity, that is achieved in the radio receiving device by using rod tubes at its input, instead of the grid-wound tubes (such as 2ZH27P), is estimated at 30-40 % at a frequency of 50 MHz. With increasing frequency, this advantage further increases due to lower internal noise factor and the higher values of input impedance of rod tubes at high frequencies.

At frequencies of 100 MHz and higher, due to small values of inductance, the resonant impedance of LC circuits, and hence the gain of amplification stages, is reduced. To provide the necessary gain at such frequencies it is advisable to use rod tubes with higher S-factor, such as 1ZH17B or 1ZH29B, so that the loss in power consumption efficiency pays off by increased gain, compared with 1ZH18B or 1ZH24B rod tubes.

Frequency conversion.

The stages of frequency converters operating at “meter” wavelengths (*DF: i.e. at frequencies above 30 MHz*) with directly heated vacuum tubes, are usually implemented using two separate tubes, one for mixer, and another one for local oscillator.
As a rule, both tubes in such case are pentodes. Such a design of a frequency converter provides virtually independent LC circuit tuning and high stability of the device during operation.
The mixing stage with rod tubes can be designed using the “one-grid” or “two-grid” frequency conversion scheme. In the first case, when both the incoming signal and the local oscillator RF voltage are applied to the same control “grid” (i.e. to the control rods of a rod tube) all types of rod tubes, such 1ZH17B, 1ZH18B, and 1ZH24B can be used. The required local oscillator voltage level in such case should not exceed 1.5-2 V eff [rms]. At larger local oscillator voltages, due to “clipping” of the anode current at the right-hand side of the [Eg1 to Ia] graphs, the higher harmonics of the [principal mode] of the signal may appear.

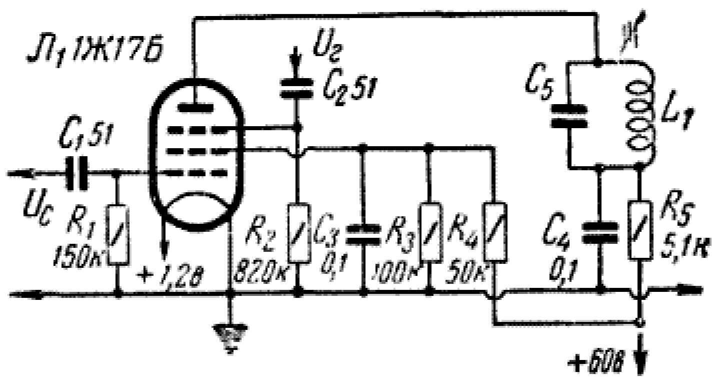

Рис. 2

The second scheme of frequency conversion can be used only with tubes 1ZH17B and 1ZH29B, which have a separate g3 electrode [not connected with filament inside the tube]. (*DF: according to my detailed vacuum tube reference book published by “Energoizdat” in Moscow in 1981, only the 1ZH18B rod tube does not have a separate g3 electrode, which in this tube is internally connected to the “left hand” (negative potential) filament electrode inside the tube. According to this reference book, all other rod tubes, including the 1ZH24B, do have a separate g3 electrode. It is possible that back in 1960 some rod tubes may have been designed in a slightly different way, hence the comment made by the authors regarding the g3 electrode connection*).
Under this scheme, the incoming signal is fed to the control “grid” (g1), while local oscillator voltage is applied to g3 (Fig. 2). In this case, in order to obtain optimum conversion efficiency the local oscillator should have at least 12-15 V eff [rms] voltage, fed to g3.
It should be noted that the design of rod tubes, in principle, allows the construction of a special mixing tube with two separate control rod wires [from each one of two control rods], and therefore implement dual control of electron flow. (*DF: this is an amazing comment made by the authors: here they point to the future mixing rod tubes 1ZH37B and 1ZH42A with two separate control grids, same as in dual gate MOSFETs, which rod tubes were not yet available in 1960!)*

IF voltage amplification.

Rod tubes type 1ZH18B and 1ZH24B are specifically designed for multistage IF amplifiers. A typical IF circuit used in portable VHF radios is usually a three-stage amplifier with two LC circuits in the anode load of each stage. This scheme obtains high selectivity and required signal gain. (*DF: the authors clearly point here to R-126 schematics, which was developed the same year 1960*) The gain at each stage in this case should not be less than 25. However, such an amplification in one stage with two LC circuits suggests using the regime for rod tubes, in which each stage draws around 1.0 to 1.2 mA of anode current, or about 3.5 mA for the IF amplifier. In order to reduce the overall consumption of energy used to power up the receiver in cases where physical size is of lesser importance, it is more rational to use a four stage IF amplifier with the same two LC bypass filters [in each stage], and with economical [energy saving] mode for each stage (Ea = 40-45 V, Eg2 = 20 – 25 V, Eg1 = 0). In this scheme, the Ia + Ig2 current of each stage is reduced to 0.30-0.35 mA, and at the same time overall IF amplifier stability increases because individual gain at each stage of IF amplifier in the 4-stage variant will be less than 50% of gain per stage in the 3-stage IF amplifier. The actual circuit diagram of one cascade of such an IF amplifier with the 1ZH18B rod tube is shown in Fig. 3.

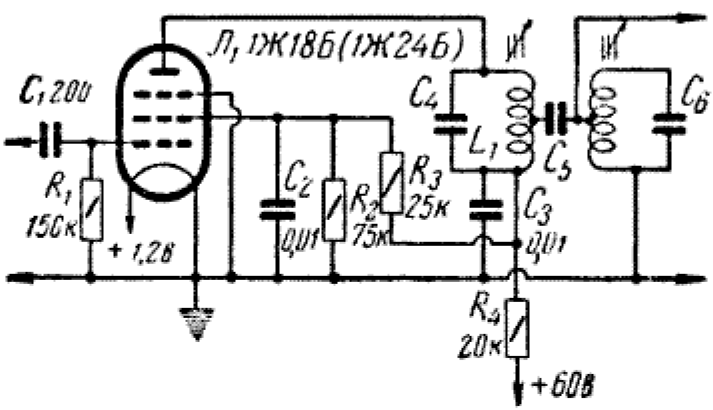

Рис. 3

Amplitude limiting.

Rod tubes 1ZH17B, 1ZH18B, and 1ZH24B can be used as amplitude limiters for FM receivers. For example, the rod tube 1ZH17B operating in the mode of Ea = 35 V, Eg2 = 40 V, and Eg1 = -1.5 V gives a sharp “threshold limiting” for the intermediate frequency voltage at the input of the tube with no more than 1 V. Such a low threshold limit for rod tubes allows reducing the overall gain of IF amplifier by 2-3 times, compared with the case when the amplitude limiter is implemented on conventional directly heated tubes with wound grids. In the 4-stage “energy saving” IF amplifier used for FM receivers it is sometimes possible to abandon the use of special amplitude limiter altogether, and to use for this purpose a conventional (fifth) IF amplifier stage.

At low anode-screen voltages on rod tubes, and with small signal at the input of the receiver, the role of the amplitude limiter is performed by last (fifth) stage. When the input IF signal increases, the function of amplitude limiter goes to stage 4, then to stage 3, etc. In this way, a very efficient signal limiting is achieved, while the entire IF tract consists of five identical stages.

Generation of high-frequency oscillations.

Three variants of RF oscillators are commonly used in practice: a scheme with grounded cathode, a scheme with grounded control grid, and a scheme with grounded anode.

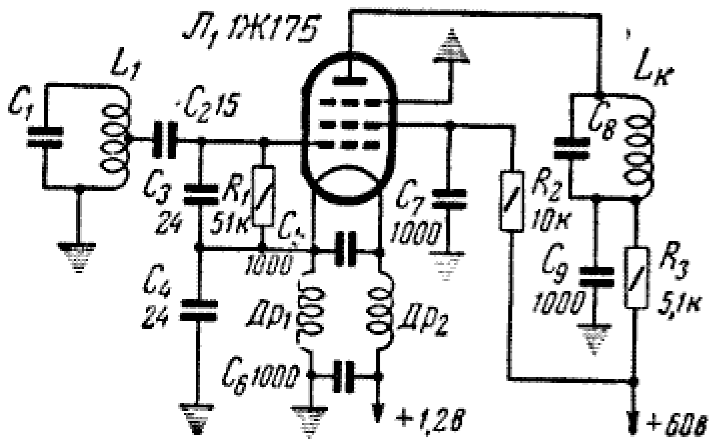

Рис. 4

Each one of these schemes can be subdivided further by the type of feedback used in it.
In radio amateur practice, the circuit with grounded cathode is commonly used in SW and HF bands. For VHF, the most commonly used scheme is the one with grounded control grid. Much less used, is the scheme with grounded anode, although for VHF frequencies this particular scheme is of greatest interest. Fig. 4 shows the circuit diagram of the RF oscillator with grounded anode and with a tank circuit in the anode of the rod tube. The anode LC circuit is connected with the LC circuit in the control grid only through a shared (common) electron beam: the first harmonic of the anode current, passing sequentially through the external (anode) LC circuit, and then through the cathode part of the internal (control grid) LC circuit, creates a voltage drop on both circuits.
The oscillation frequency in this circuit is determined by the LC circuit in the control grid, while the anode LC circuit is used as a buffer from which the RF signal is taken for further amplification, or is injected into the mixer tube. Voltage on the “internal” LC circuit only serves to maintain oscillations in this scheme. Due to the absence of the external coupling between the LC circuits in this scheme, the influence of the load connected to the external LC circuit does not affect overall frequency stability of such an oscillator. Therefore, such a dual-oscillator circuit essentially combines in it a conventional vacuum tube oscillator and a "buffer stage" that separates the oscillator part and the output load section of the RF oscillator. This oscillator, known as the "two-circuit oscillator with electronic coupling," imposes special requirements on vacuum tubes used in it. First, only shielded tubes can be used in it, and secondly, the inter-electrode capacitance between control grid and anode, and between cathode and anode of the tube, should be as small as possible (smaller than 0.03 pF).
Rod tubes 1ZH17B, 1ZH29B, and 1P24B, having relatively small values of these capacitances, meet this criterion, allowing stable operation at 100 MHz and above. In this case, the dual-circuit configuration of the oscillator can be used in frequency-doubling mode, when the anode LC circuit is tuned to the desired frequency range, while the inner (grid) circuit is used to generate a frequency twice as low.
This feature of the oscillator with electronic coupling can be well used to generate frequencies of 100-300 MHz.

Power gain.

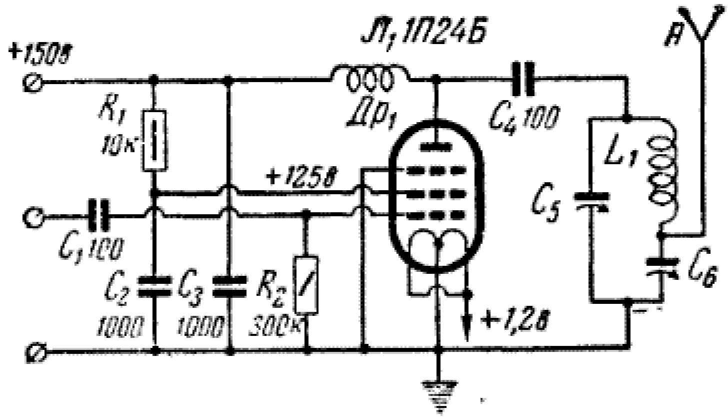

Рис. 5

The low power 1P24B pentode is designed for use in the output stages of small-sized radio transmitters. Fig. 5. shows a variant of a VHF transmitter output stage, in which this rod tube is used.

Despite its small size, the 1P24B rod tube provides output power in its anode load of about 2.5W. The maximum (peak) anode current in such case can be in the range of 90-100 mA. Cathode current in this mode can be up to 30-35 mA, which results in an additional heating of the rod tube filament.

Therefore, in a typical mode of operation (Ea = 150 V, Eg2 = 125 V), and especially in the maximum permissible operating mode (Ea = 300 V, Eg2 = 200 V), we recommend parallel connection of two filaments [as shown on Fig.5]. In this case, the filament current equals 240 mA and, therefore, the additional heating of the filament is not dangerous. Such a mode of operation for the filament of the tube is also more advantageous from the standpoint of increasing the input impedance of the tube.

Fig. 6 shows the load characteristic of the 1P24B rod tube, taken at a frequency of 45 MHz using the stage shown at Fig. 5.

As can be seen from the curves, during the transition to overloading mode (when Roe > Roe-optimal) *[Roe is the plate load impedance in kΩ]* the output RF power in the anode circuit of the tube decreases sharply, while power dissipation at anode and screen rods goes up, and overall efficiency of the output amplifier drops dramatically.

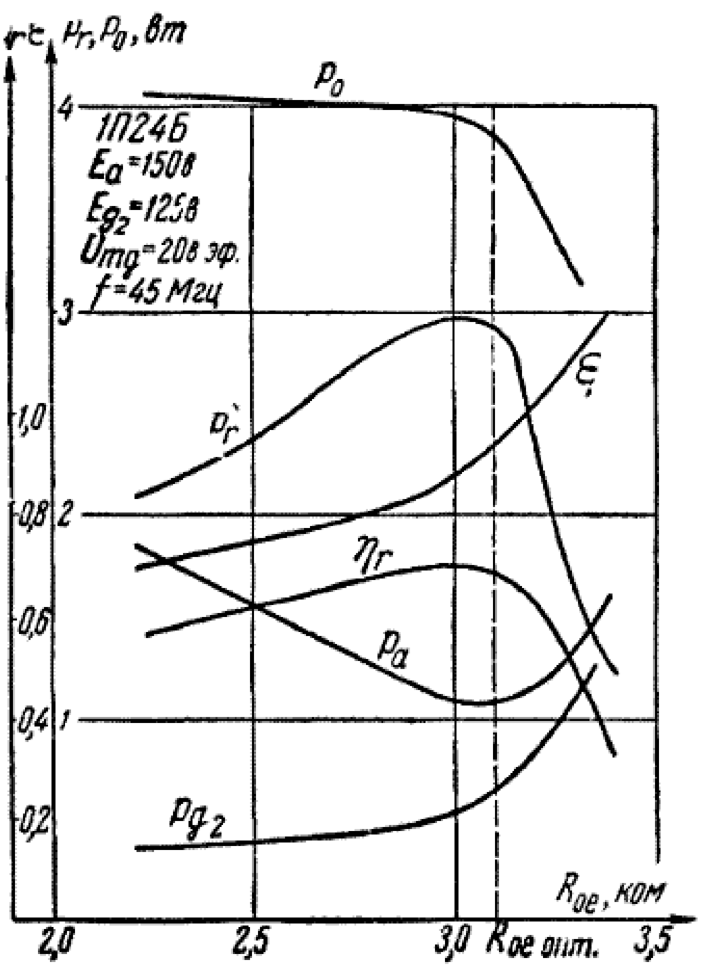

Рис. 6

This is explained by the fact that during the transition to the overloaded regime, because of pronounced inflection of the anode characteristics at low residual voltage on the anode, the utilization

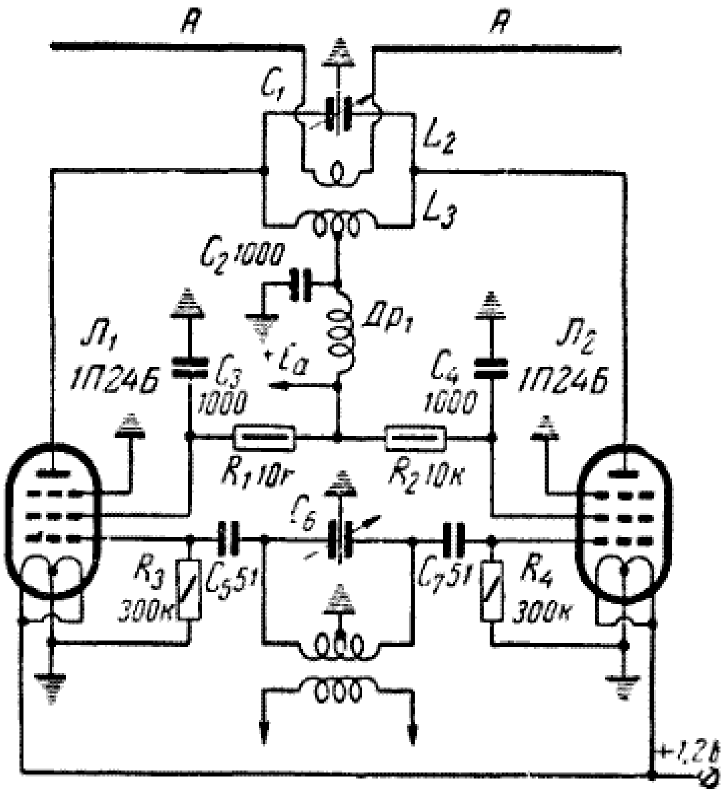

Рис. 7

ratio of the anode voltage e = U max / Ea comes close to 1. At this moment, the residual voltage on the anode is equal to zero or is negative, and the voltage on the anode shielding rods is higher than anode voltage. The result is a redistribution of electron flow: the instantaneous value of the anode current is zero, and the current of screening electrodes is at a maximum; in the pulse of anode current a “deep dip” is formed, and therefore the RF output power [of the stage] is dramatically reduced.

Consideration of the different modes of operation shows that the rod tube 1P24B can be used successfully in the under-power mode, i.e. with the anode load [*impedance*] being less than optimal.

This feature of the tube can be advantageously used at frequencies of 200-250 MHz, in which case it is usually quite difficult to have an optimal value of anode load, and therefore most of the input power is [uselessly] dissipated at the electrodes of the tube.

At frequencies above 100 MHz in the output stages with 1P24B rod tubes, it is advantageous to use the push-pull scheme. Because the input and output capacitances of tubes in this case are added into the LC circuits in series, the initial capacitance of the LC circuit is less than in the previous scheme.

As a consequence, the LC circuit in this case will have a larger equivalent impedance.

Circuit diagram of push-pull transmitter for frequencies above 100 MHz with tubes 1P24B is shown at Fig. 7.

Obviously, for a push-pull circuit the identical pair of rod tubes should be selected (with the same values of the anode current Ia, the S factor, and inter-electrode capacitances).

Super-regeneration.

Due to their simplicity and high sensitivity, super-regenerative receivers were widely used in amateur practice.
Of all the existing super-regenerator schemes, the best results by sensitivity and gain are achieved in the scheme with an external suppressing voltage source injected into the screen grid circuit. Such scheme with rod tubes 1ZH17B is shown in Fig. 8. High-frequency oscillations in this scheme are created by so-called "soft" mode excitation, and terminated by changing the steepness of the characteristics of the anode current of the circuit screen grid. The source of quench (interrupt) is the ultrasonic voltage harmonic sine oscillator for which the second tube is used. The magnitude of suppressing voltage in this case should be around 20-25 V eff [rms]. Increasing this voltage does not improve the sensitivity of the receiver, and only leads to an expansion of its bandwidth.
When size, weight and cost of radio receiver are of crucial importance, RF oscillator and high-frequency ultrasonic can be performed on the same tube (for example 1ZH17B). In this case, the RF oscillator is implemented by using the two-circuit scheme [Fig.4], while the suppressing oscillator is implemented as a circuit with a grounded cathode *(JS. This hints at a single tube super regeneration circuit where the quenching is not due to the usual squegging instability of the RF oscillator, but driven independently in the same tube by a super-sonic oscillator circuit with grounded cathode)*.

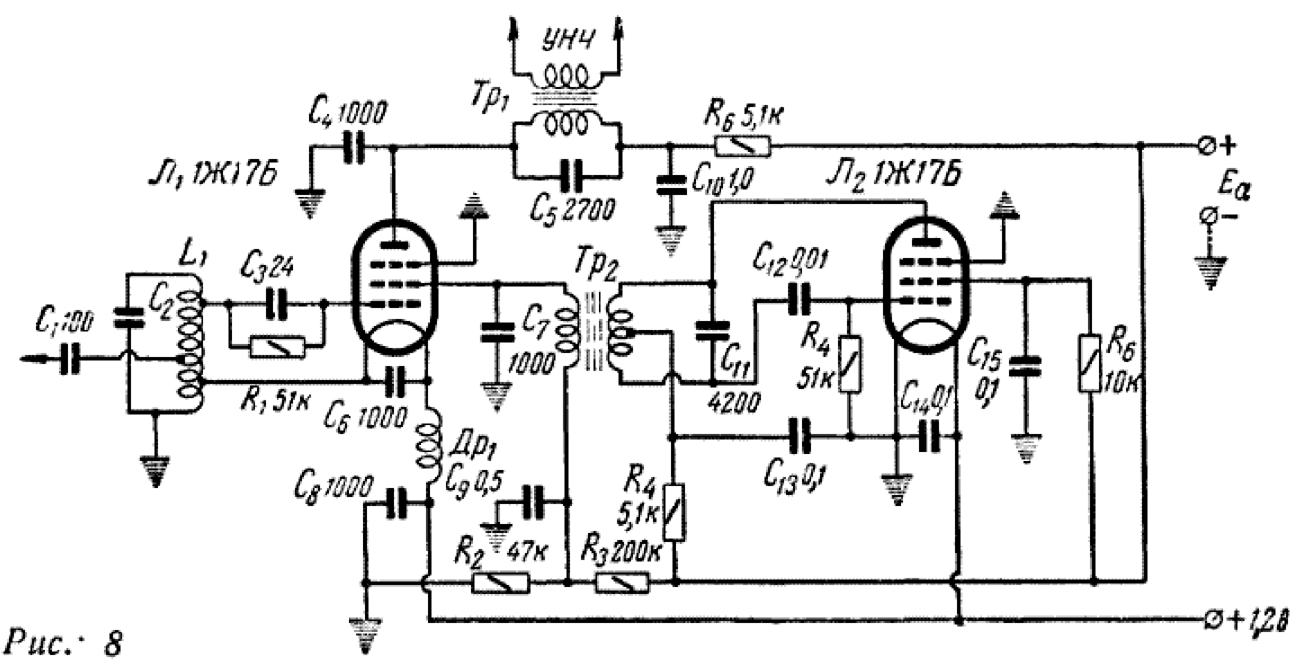

Рис.· 8

The construction of devices with rod tubes.

The peculiarity of the design of equipment with rod tubes is connected mainly with the fact that these tubes are designed for direct soldering into the device. For a long time, vacuum tubes were interchangeable pieces of equipment. The possibility of replacing the defective tube is achieved by using an intermediate part between the tube and the rest of the assembly – a tube socket. However, the tube socket inevitably affects the parameters of the tube itself and of the devices, by increasing the capacitances and introducing additional losses.
Contact resistance changes in the tube socket (especially under the condition of bumps and vibrations), and also, as a result of oxidation of the surface of the of tube socket contacts and of tube pin contacts, can grow up to the point of breaching electrical contact. Also, the glass around tube electrodes often develops cracks.
Due to the wide use of the VHF range, these shortcomings of tube sockets are very noticeable. At such high frequencies, the wires become so short that the tube becomes "incorporated" into the rest of the circuit, i.e. it becomes a part of it, and therefore the capacitance and inductance of the tube make up a significant proportion of capacitance and inductance of the oscillatory circuit.
Long operational life of rod tubes (more than 2,000 hours for small signal amplifying tubes, and more than 1,000 hours for power oscillator tubes), as well as their high mechanical strength based on the use of metal rods as electrodes, and small size of rod tubes eliminates the need for tube panels, and to directly solder rod tubes into the circuit together with other components. Reliability of the equipment is, in this way, significantly increased.
From the schemes presented here it is clear that the main elements of amplifying stages and of RF oscillators are the rod tube and the resonant circuit. The remaining elements of the device (mainly resistors and capacitors) are used to create the desired operation mode of the tube, and these components are usually smaller in their size and therefore can be grouped around each tube.
As a consequence, it seems appropriate to place rod tubes with all the necessary components included in this or that stage, in a separate board. Components are placed in close proximity to the tube, and are soldered to the PCB or to metal pins on the board. This improves the overall stability of the circuit.
In cases where the size of the inductor and capacitor circuit is small (for example, the 1 MHz IF amplifier) these components can also be placed on the same PCB.
Practice shows that the individual modular design of equipment in the form of individual functional units is preferable compared with using a common PCB.
In the latter case it is rather difficult to avoid unwanted parasitic coupling caused by the imperfection of the dielectric properties of the material of the board, resulting in reduced stability of the equipment.