IMPROVING THE EFFICIENCY OF HIGH-POWER RADIO-FREQUENCY AMPLIFIERS

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One of the fundamental operating characteristics of a high-power radio-frequency amplifier is its energy efficiency; the maximum value is characteristic of class C amplification. The energy efficiency is a decisive factor determining the possibility of miniaturizing devices using high-power amplifiers, as well as the cost of operation. Thus, there have been numerous studies of the problem of increasing the efficiency. The concept behind the methods that have so far been proposed for improving efficiency amounts to so choosing the voltages at the amplifier-element input and output as to minimize the power losses in this element. As an example, for a vacuum-tube triode power amplifier it is necessary to try to obtain an operating characteristic similar in form to that shown in Fig. 1a by the broken line ONS and to shift the instantaneous operating point along the line referred to as the boundary line [1].

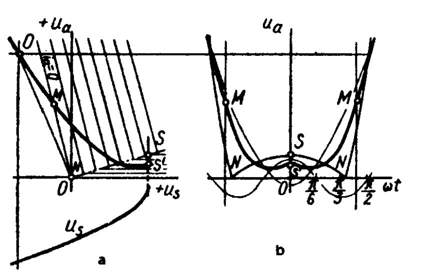

Fig. 1

One way of realizing the required output voltage is to use additional resonant circuits tuned to odd harmonic components and connected together with the main tank circuit [2-8]. For simplicity, practical devices frequently utilize just the third-harmonic voltage in the appropriate phase. The operating characteristic that can be obtained in this case is shown in Fig. 1b (curve OMS'). Such a method may be used for power amplifiers operating at fixed frequency under fixed load, for example, in broadcast transmitters. The realization of such a method involves significant difficulty for tunable devices or devices with variable load.

The efficiency can also be increased by an appropriate transformation of the input voltage [9]; if, in particular, we excite the amplifier by a voltage in the form of rectangular pulses, the output current of the amplifier element also becomes close in form to rectangular pulses; in this connection the current-pulse duration is shorter than that of a conventional cosinusoidal pulse. Thus, it is possible to reduce the losses in the amplifier element. The results obtained here are poorer than with the first method, but simplicity of tuning is preserved.

It is also possible to employ the concept of the two preceding methods and use an approach based on simultaneous transformation of the input and output voltages. This can be done in practice, for example, through the use of additional resonant circuits tuned to the third harmonic and connected into the plate or cathode circuit of the tube [10].

A still different principle for improving efficiency has been proposed in [11,12] and is associated with the departure from the conventional use of a high-Q parallel tank circuit. In place of this circuit, the tube is coupled to the load by a line with characteristic impedance that can be varied.

The new approach to raising the efficiency of an RF high-power amplifier is based on the

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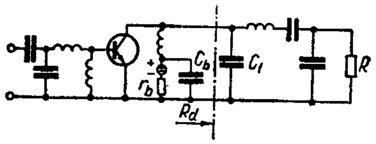

Fig. 2

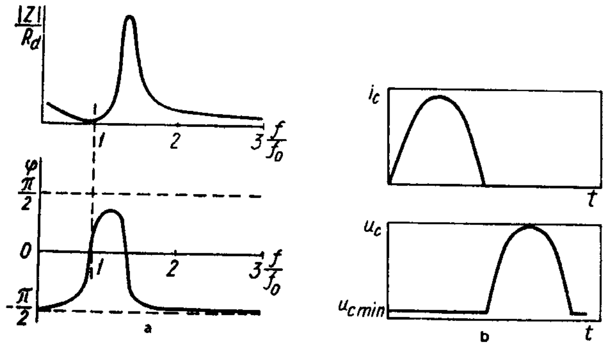

Fig. 3

theoretical and experimental investigation of two amplifiers: a classical circuit with parallel tank circuit and a "dual" circuit with series tank circuit [13-15]. In the "dual" amplifier sinusoidal current with pulse voltage flows at the output of the amplifier element. The efficiency may be increased [16,17] by so modifying the device as to cause the current variations that correspond to the change in voltage in the dual parallel circuit to approach the shape obtained in an amplifier with parallel circuit. To do this we constructed an amplifier with selective circuit whose characteristics are intermediate between those of parallel and series circuits (Fig. 2). From the input-terminal end such a circuit may be characterized by the ratio of the equivalent resistance R_d to the reactance of the capacitor C, called the reactance factor:

$$q_D = \frac{R_d}{X_1}.$$

If $q_D \gg 1$, then the characteristics of the coupling circuit from the input end are close to the characteristics of the parallel circuit. At the same time, if $q_D \ll 1$, the circuit will have characteristics close to those of the series circuit.

Figure 3 shows the frequency characteristics of the absolute value and phase of the input impedance of the given circuit for $q_D = 0.2$. With circuit characteristics of this form and an amplifier-element output current in the form of a pulse train, the voltage across the amplifier output will have the form shown in Fig. 3b. As we see, the current flows during the time intervals when the instantaneous voltage U_c across the terminals of the circuit is nearly zero. On the other hand, large instantaneous voltages correspond to the time intervals in which there is no current. As a result, the conditions for high device efficiency exist.

To make an experimental check on the proposed device we assembled a transistor amplifier; its analysis fully confirmed the realistic nature of the time characteristics shown in Fig. 3b and the closeness of the actual characteristics (Fig. 4) to the ideal ones.

The energy efficiency was determined by measuring the thermal loss power in the transistor with the aid of a transistor. During the experiment the efficiency reached better than 95%. It has therefore been established that the collector-circuit efficiency depends on the ratio of the working frequency f_w and the limiting transistor frequency f_t.

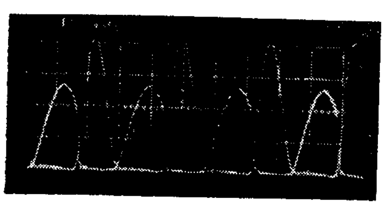

Fig. 4

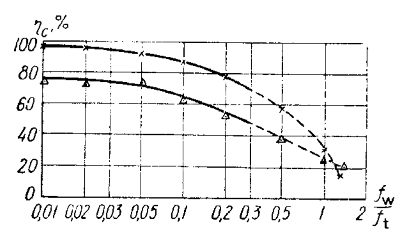

Fig. 5

Figure 5 shows the typical dependence of collector-circuit efficiency on the ratio f_w/f_t for an amplifier with a classical tank circuit (lower curve) and the improved-efficiency amplifier.

The advantage of the given type of amplifier lies in its simplicity. It is also simple to tune the amplifier over the band, as in a conventional device, with the output-current maximum corresponding to tuning to the input-signal frequency. Neither tuning nor the value of the coefficient q_D is critical. Good harmonic filtering is achieved at moderately low values of circuit Q. It is also easy to realize a selective circuit with high efficiency. The restrictions on the proposed method for increasing efficiency are connected with the output parameters of the active element. In the RF region its output reactance may be so small that it will be impossible to attain a small enough value of q_D.

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