$$\tau_H = (a^2/(2,4)^2\kappa)(n_e(T_e + T_i)/T_i).$$

At low concentrations, the experimentally measured $1/\tau_H$ is much larger than the theoretical one, but at $n_e \sim 3 \times 10^{13}$ the two values coincide.

It should be noted that the greater rate of loss from the plasma at low concentrations cannot be attributed to ionic thermal conductivity within the framework of classical theory, for in Coulomb collisions the energy transferred from the electrons to the ions is too low (see curve 3 of Fig. 2). The classical electronic thermal conductivity is also small. A plasma with low concentration apparently is characterized by the presence of nonclassical processes. The anomalous resistance observed under these conditions [5] may also be evidence of the development of instabilities.

On the other hand, we have assumed throughout that there are no impurities in the plasma. The presence of an appreciable impurity content at low electron densities can greatly increase the classical transport coefficients.

The fact that at sufficiently large concentrations the rates of energy loss from a real plasma agree with the calculated ones cannot, likewise, serve as evidence of the existence of classical transport coefficients, since the functional relations predicted by the theory are not observed. Only the absence of a dependence of the transport coefficients on the longitudinal magnetic field agrees with the theory. It is probable that both the classical mechanisms and the instability are equally responsible for the loss, thus greatly hindering the interpretation of the experimental results.

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[1] L. A. Artsimovich, G. A. Bobrovskii, S. V. Mironov, et al., Atom. Energ. 22,259 (1967).
[2] L. L. Gorelik et al. Plasma Physics and Controlled Nucl. Fusion Res., Vienna, 2, 647 (1966).
[3] Ē. I. Kuznetsov, Atom. Energ. 25, 315 (1968).
[4] A. A. Galeev and R. Z. Sagdeev, Zh. Eksp. Teor. Fiz. 53, 348 (1967) [Sov. Phys.-JETP 26, 233 (1968)].
[5] G. A. Bobrovskii et al., Paper at II European Conference on Plasma Physics, Stockholm, 1967.

PULSED PARAMETRIC GENERATION IN DISTRIBUTED SYSTEMS

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Distributed parametric generators of electromagnetic radiation were first realized in optics [1]. In view of the large dimensions of the resonant system (compared with the wavelength), it is possible to generate in such systems in principle, just as in lasers, radiation with a large discrete spectrum - at a number of modes simultaneously. An important factor in this case is the possibility of controlling the process by means of mode synchronization, which leads, in particular, to the production of short pulses. However, these phenomena have not yet been observed in parametric generators.

We present here the results of an experimental investigation of multimode parametric generation in the radio band. We note that the distinctive features of multimode systems is utilized most effectively, in a certain sense, in the radio band. Indeed, the maximum width of the generated spectrum (and accordingly the minimum pulse duration) is the determined in the various bands by the frequency properties of both the resonator and the working medium. In optical systems, the emission spectrum is narrow compared with the average frequency ($\Delta\omega << \omega$). At lower frequencies (in the radio band) it is possible to generate a spectrum of maximum width, where $\Delta\omega$ and ω are comparable in magnitude. As a result, the energy of the harmonic pumping is converted in the self-oscillation energy of a video-pulse type, the waveform of which is far from sinusoidal.

The construction of such systems in the radio band entails considerable difficulties because the available nonlinear materials (ferrites, ferroelectrics, etc) are not transparent enough in a frequency band wide enough to permit excitation of a large number of modes at reasonable system dimensions. The best frequency properties is possessed by parametric semi-. conductor diodes, but they cannot be regarded as distributed elements up to very high frequencies.

The first compromise of a sort were "artificial" one-dimensional resonators in the form of networks (filters) consisting of a large number (10 - 20) elements with lumped inductances and capacitances, the latter being parametric diodes.

Pulsed generation was obtained also in a "genuinely" distributed system - a distributed parametric diode. The latter is a strip line up to 14 cm, in which the space between the metallic conductors is filled with semiconducting material containing a p-n junction (details of the diode construction are described in [2]). When the diode bias is negative, waves close to transverse can propagate in the diode, and a segment of the diode is used as a nonlinear resonator with a nearly-equidistant natural-frequency spectrum. It can be shown that under certain conditions the electric energy is concentrated mainly in the region of the barrier layer, with width $d \approx 1\ \mu$, and the magnetic energy is distributed over the entire thickness of the semiconductor, $D \approx 400\ \mu$, as a result of which the principal wave in the system is decelerated by a factor $\sqrt{\varepsilon D/d}$ (ε is the dielectric constant of the semiconductor). As a result, the lowest natural frequency F_0 of a resonator 14 cm long amounts to 37 - 45 MHz (when the bisas is changed from 4 to 10 V).

It is interesting to note that in these systems mode synchronization requires no special internal or external control element (as in lasers), but is effective directly by the pump field, owing to its appropriate spatial distribution. In the simplest case, a standing pump wave of frequency f close to F_0 is excited by a harmonic source in a resonator open on both ends. The generated short pulses are synchronized with the pump; their maximum duration τ is determined by the nonlinear dispersion properties of the system, and the repetition period at the end of the resonator coincides with the pump period, whereas at the center this period is smaller by one-half (Figs. 1a, c).

The shortest pulses obtained in the distributed diode had a duration $(5 - 7) \times 10^{-9}$ sec and an amplitude 8 V (Fig. 1c). In systems made up of artificial lines, the width of the generation spectrum is smaller ($\tau \sim 10^{-7} - 10^{-8}$ sec, $T \sim 10^{-6}$ sec). However, such systems allow

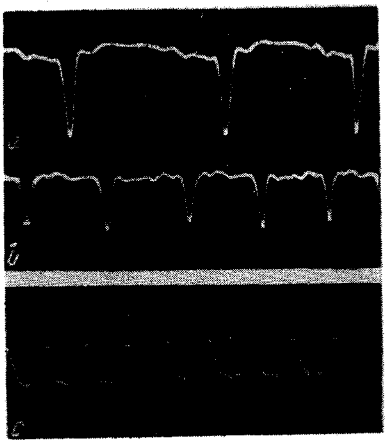

Fig. 1

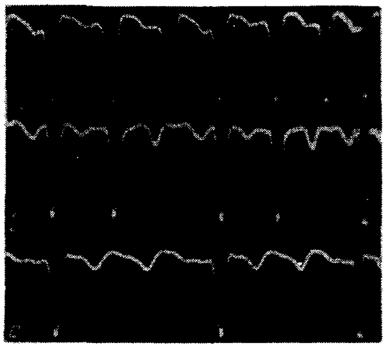

Fig. 2

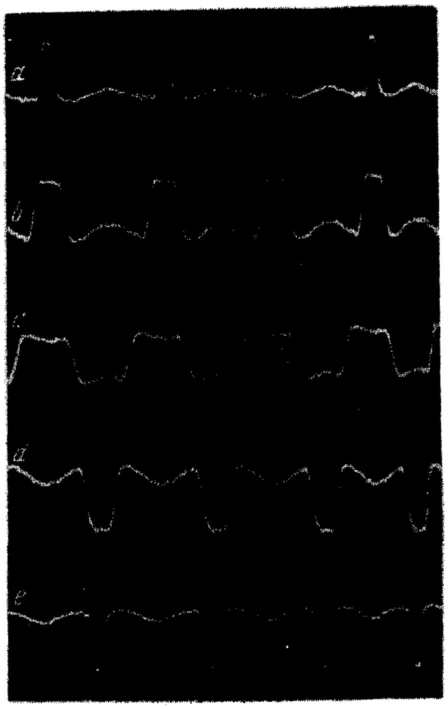

Fig. 3

Fig. 1. a) Oscillogram of voltage at end of one-dimensional resonator with parametric diodes (f = 1.6 MHz). b) The same at center of the resonator. c) Voltage at the end of a parametric germanium diode 14 cm long (f = 37 MHz).

Fig. 2. Various generation regimes at $f = 3F_0$ (a - 4.7 MHz, b - 4.77 MHz, c - 4.85 MHz).

Fig. 3. Oscillograms of pulses at various points of a closed resonator (a, e - near ends, c - at center)

a more detailed investigation, since it is easy to change their construction and operating conditions. Interesting features are produced when the pump frequency is increased. Thus, at $f \simeq 3F_0$ there are three possible different regimes (stable states), in which pulse sequences are produced with omission of one or two pump periods (Fig. 2). The transition from one regime to the other is effected by changing the bias or by a slight (several per cent) change of f; hysteresis phenomena may also occur in this case.

Finally, it is possible to obtain an entirely different result of mode synchronization. Figure 3 show oscillations in a resonator with closed ends. The picture here is qualitatively different and on the whole can be represented by a superposition of two opposing waves with a short (shock) increasing part and a gently decreasing part.

The described systems may be not only of physical but also of considerable practical interest from the point of view of conversion of sinusoidal oscillations into pulses, in view of a number of advantages in the sense of energy loss and flexibility of control.

In conclusion we note that mode synchronization of parametric generators in optics can be based on a similar principle. To this end, the working medium should occupy a smaller part of the resonator, and the pump phase should be modulated with a period equal to double the time required for the pulse to travel between the resonator mirrors1).

The authors thank A. V. Gaponov for a discussion of the results.

[1] S. A. Akhmanov and R. V. Khokhlov, Radiotekhnika i elektronika 12, 2052 (1967)
[2] V. N. Shabanov and V. A. Tolomasov, ibid. 11, 772 (1966).
[3] S. E. Harris, IEEE, QE-2, 701 (1966).

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1) The mode synchronization method for parametric generators, discussed in the literature [3], is connected with amplitude and not phase modulation of the pump.