NEWSLETTER

of the International Consortium "Development of High-Power Terahertz Science & Technology"

February 2022 № 20

CONTENT

EDITORIAL: HOW TO CONTRIBUTE TO THE NEWSLETER

Dear Reader,

We are inviting contributions to the following rubrics:

- Research highlights (annotations) presenting the projects pursued by the members of the Consortium.
- Short regular and invited papers.
- Proposals for collaborative research work.
- News from the participating institutions.
- Information about conferences, symposia, workshops, seminars.
- Programs and frameworks for an exchange of visits and mobility of researchers. Job opportunities (especially for young researchers, e.g. postdoctoral positions, specializations, internships).
- Annotations of books, conference proceedings, software and internet resources. Additions to the list of the recent scientific publications and conference reports at the website of the Consortium (http://fir.ufukui.ac.jp/Website_Consortium/publist.html).
- Information and announcements about awards and nominations.
- Short presentations of laboratories and research groups belonging to the participating institutions.

Please submit your contributions to the Newsletter as well as requests for information to:

Professor Masahiko Tani
Director of FIR UF – Facilitator of the International Consortium
FIR UF
tani@fir.u-fukui.ac.jp

Dr. Svilen Sabchevski
Editor of the website and the Newsletter
Institute of Electronics of the Bulgarian Academy of Sciences
sabch@ie.bas.bg

Investigation of Mode Interaction in Harmonic Sub-THz Gyrotron

M. Glyavin[1], A. Gashturi[1], A. Malkin[1], I. Zheleznov[1], Y.Tatematsu[2] and I. Zotova[1]

[1]Institute of Applied Physics RAS, Nizhny Novgorod, Russia
[2]Research Center for Development of Far-Infrared Region, University of Fukui, Japan

glyavin@ipfran.ru

Abstract

Within the frame of a non-stationary self-consistent model, we have investigated the regimes of simultaneous oscillations at two different modes, which are resonant with the first and second cyclotron harmonics of electron oscillations, respectively. Simulations were carried out for parameters of a sub-THz gyrotron developed at FIR UF (Fukui, Japan). It was shown that the hard self-excitation at the second cyclotron harmonic is possible in the presence of generation at the first one. Simulations also predict the possibility of simultaneous generation at two harmonics in the excitation zone of the second harmonic modes at relatively high beam currents. Furthermore, it was demonstrated that in this case, the axial structure of the generated field can vary in the process of nonlinear interaction.

The gyrotron has established itself as one of the most efficient high-power generators of microwave and millimeter waves. The most powerful gyrotrons reach 1–2 MW power in long-pulsed and continuous-wave regimes. Such gyrotrons operate at the fundamental cyclotron harmonic. In order to advance into the submillimeter-wave band under conditions of a limited magnetic field, it becomes imperative to generate radiation at the second (or higher) harmonic of the gyrofrequency. However, operation at cyclotron harmonics complicates the problem of mode selectivity in gyrotron cavities. This problem becomes severe with an increase in the radiation frequency when the mode spectrum becomes denser. In this case, the rotating electron beam, which represents a nonlinear medium, can interact with several modes at different cyclotron harmonics [1, 2] that may lead to their simultaneous excitation [3-6].

This article is devoted to simulations of mode interaction for the parameters of the sub-terahertz multi-frequency FU CW GVII gyrotron [7], which was recently developed at FIR UF (University of Fukui, Japan). The gyrotron should operate at frequencies from 274 to 422 GHz (9 fixed modes) at the second harmonic of the gyrofrequency. At the same time, the differences between the observed regimes and regimes predicted in calculations were found in experiments. In particular, simultaneous excitation of two modes at the first and the second cyclotron harmonics took place in the area of parameters where the observation of single-mode second-harmonic generation was expected. Figure 1 shows one of such regimes when, instead of one Gaussian beam corresponding to the excitation of the $TE_{5,5}$ mode at the frequency of 353 GHz, two wave-beams were recorded. One of such beams corresponds to expectations, but the second corresponds to the $TE_{0,3}$ mode generated with high efficiency at the first cyclotron harmonic. This discrepancy was most likely caused by the use of a model with a fixed axial field structure for preliminary calculations of the indicated gyrotron. Note that the importance of self-consistent modification of the axial profile of the excited field for mode competition at the front of beam voltage was pointed out in [8] for the case of fundamental-harmonic gyrotrons. Here we extend this approach to the case of interaction of modes excited at different harmonics.

Further, we study in detail the generation regimes of the FU CW GVII gyrotron within the framework of the more complicated model with a self-consistent field structure. First, the performed simulation demonstrates the impossibility of selective excitation of the $TE_{5,5}$ mode in the calculated zone with the maximum efficiency. Second, the simultaneous excitation at two cyclotron harmonics is predicted with an increase in the beam current when a change in the axial structure of the field in the process of nonlinear interaction becomes essential.

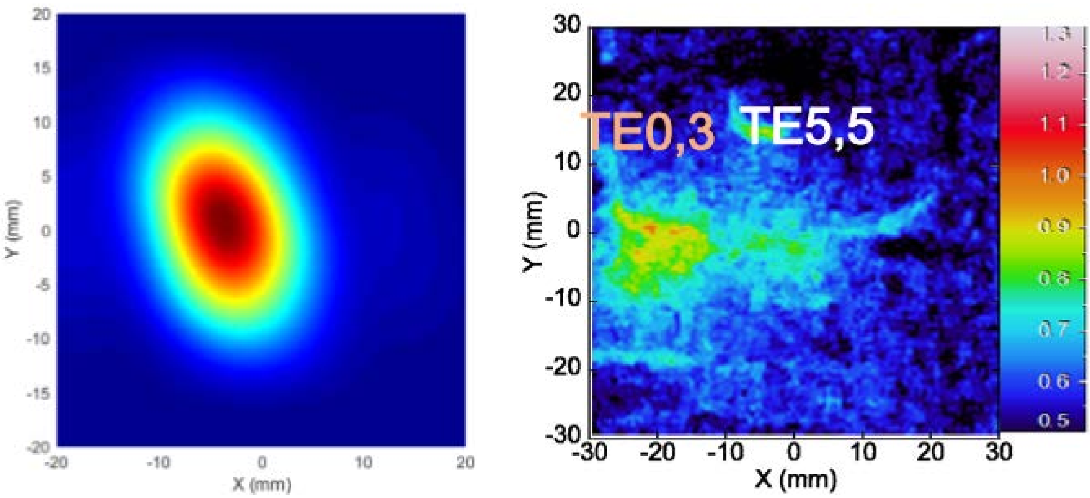

Fig. 1. Calculated (left) and measured (right) distribution of the output wave-beams of the FU CW GVII gyrotron at 353 GHz for the case of calculated excitation of the $TE_{5,5}$ mode at the second cyclotron harmonic. The mode $TE_{0,3}$ is excited at the fundamental resonance.

We will consider the interaction regimes in the gyrotron based on the self-consistent multimode model [9], which has already demonstrated its effectiveness in comparison with experimental data. This model is based on the following system of equations (cf. [10,11]):

$$i\frac{\partial^2 a_n}{\partial Z^2}+s_n\frac{\partial a_n}{\partial \tau}+is_n\left(\delta_n(Z)-\chi\Delta_n\right)a_n=i\frac{I_n}{4\pi^2}\int_0^{2\pi}\int_0^{2\pi}p^{s_n}e^{i(m_n-s_n)\varphi}d\theta_0 d\varphi,$$
$$\frac{\partial p}{\partial Z}+\chi^{-1}\frac{\partial p}{\partial \tau}+ip\left(|p|^2-1\right)=i\sum_n a_n\left(p^*\right)^{s_n-1}e^{-i(m_n-s_n)\varphi}. \qquad (1)$$

with the non-reflection boundary conditions in the following form (cf. [10]):

$$a_n(\tau,0)-\frac{1}{\sqrt{i\pi s_n}}\int_0^{\tau}\frac{e^{-i(\delta_n(0)-\chi\Delta_n)(\tau-\tau')}}{\sqrt{\tau-\tau'}}\frac{\partial a_n(\tau',0)}{\partial Z}d\tau'=0, \qquad (2a)$$

$$a_n(\tau,L)+\frac{1}{\sqrt{i\pi s_n}}\int_0^{\tau}\frac{e^{-i\chi\Delta_n(\tau-\tau')}}{\sqrt{\tau-\tau'}}\frac{\partial a_n(\tau',L)}{\partial Z}d\tau'=0, \qquad (2b)$$

where L is the normalized length of the interaction space with the physical length l.

Simulations were carried out for parameters close to the experimental data [7]: operating frequency of 353 GHz; accelerating voltage of 14.4 kV; electrons pitch-factor of 1.7; radius and length of the regular part of the gyrotron cavity of 2.78 and 20 mm, respectively; injection radius of 1.2 mm. Interaction of the above-mentioned pair of modes, namely, co-rotating with electrons $TE_{0,3}$ mode at the first cyclotron harmonic and counter-rotating $TE_{5,5}$ mode at the second harmonic, were taken into account. Note that we considered the case of non-degenerate modes with $m_2 \neq m_1 s$; thus, observed regimes do not include the effect of frequency multiplication.

Figure 2 shows zones of generation regimes of the gyrotron under study in the plane of parameters "beam current versus magnetic field", temporal evolutions of the mode's amplitude and the axial field structures established in the steady-state generation are shown in Fig. 3.

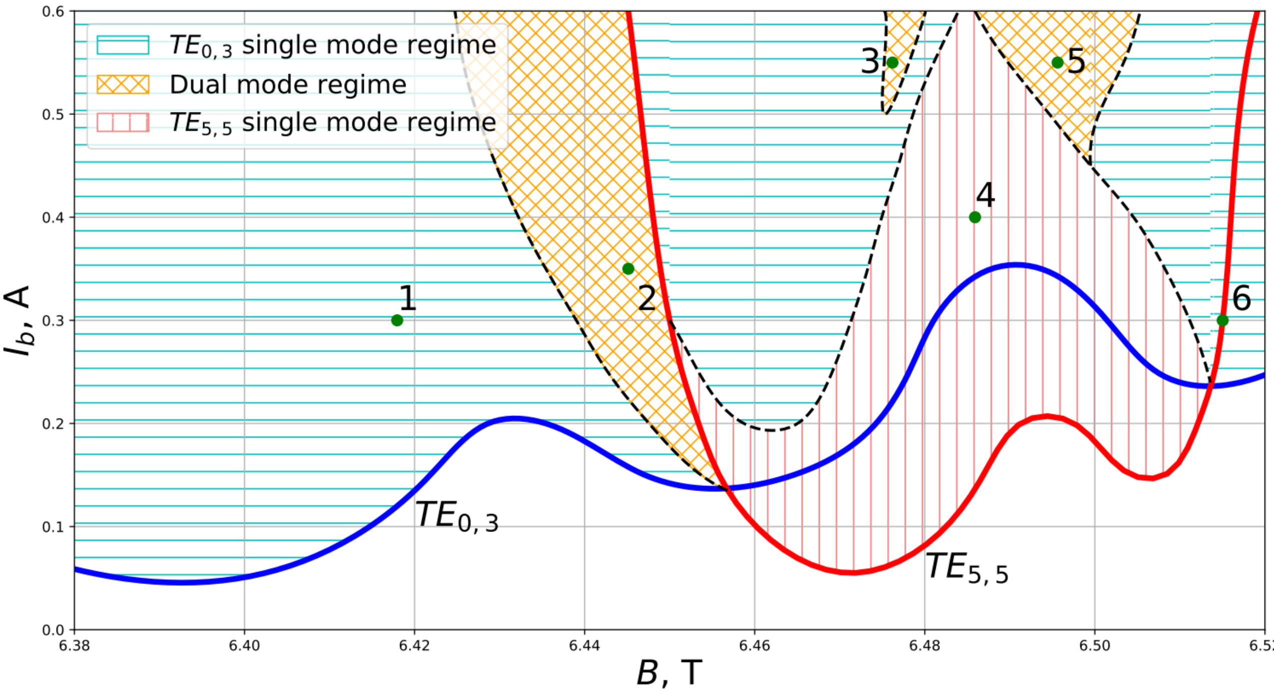

Fig. 2. Zones of different generation regimes for competition of $TE_{5,5}$ (second harmonic) and $TE_{0,3}$ (first harmonic) modes.

In the case of the second harmonic mode, this mode has one axial variation, when the magnetic field is in the range of 6.45-6.49 T, and two axial variations (as will be shown later) when the magnetic field is in the range of 6.50-6.52 T. The parasitic mode at the fundamental has one axial variation when the magnetic field varies from 6.38 T to 6.43 T that follows by the zone with two variations when the magnetic field varies from 6.43 T to 6.49 T and so on.

The simulations also predict the occurrence of small zones where these modes at both harmonics coexist at high currents. These zones contain points 3 and 5 shown in Fig. 2. As shown in Fig. 3, at the point 3 the second harmonic mode has one axial variation that agrees with its axial structure in the solo self-excitation regime at low currents. Correspondingly, at the point 5 this mode has only one axial variation in the presence of the competitor, instead of two variations in the solo regime. Such coexistence - excitation of the second harmonic simultaneously with the first one - was not found in the previous studies of harmonic gyrotrons.

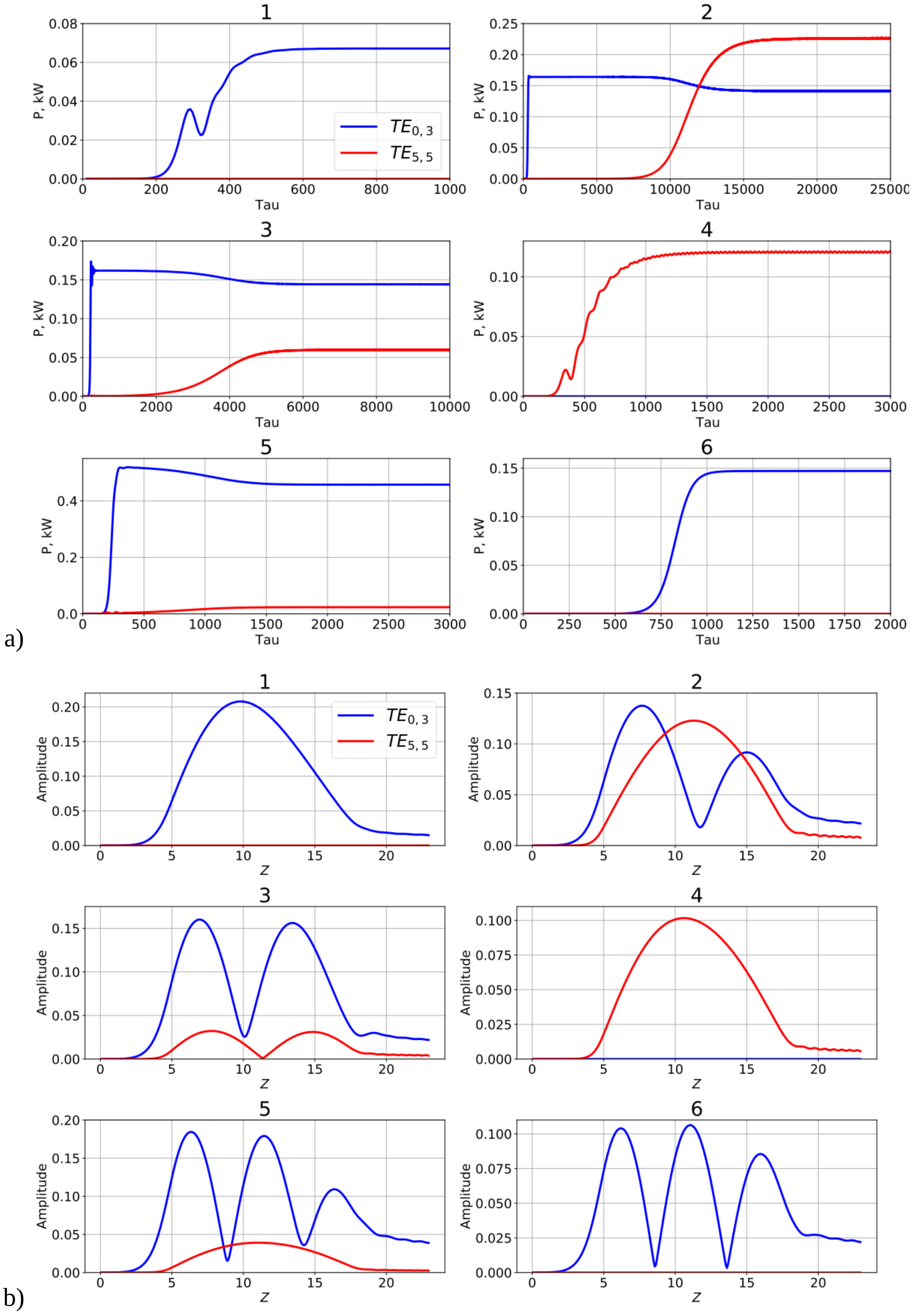

Fig. 3. Establishment of steady-state regimes for the selected cases shown in Fig.2 (a) with an estimate of the powers of the generated modes, and their axial HF field structures (b). Blue and red lines correspond to the first and the second harmonics, respectively.

The experimental situation described in [7] corresponds (for the operating current of 0.3 A) to the point 2 in Fig. 2. This point lies in the region of hard self-excitation for the second harmonic mode. For realizing efficient oscillations in this zone, when just only this mode is considered, it is necessary to vary gyrotron parameters in such a way that, first, the oscillations are excited in the zone of soft self-excitation (where the beam current exceeds the start current) and, then, this gyrotron is driven in the zone of hard excitation. If we consider the excitation of two modes just at this point, we find that, first, the mode at the fundamental is excited and, then, this mode induces excitation of the second harmonic mode. In simulations, output power at both modes is close. Decreasing the power of second harmonic generation obtained in the experiments (see Fig.1) may be explained by higher ohmic losses for higher frequency and the axial mode with one variation.

In the present study, the self-consistent non-stationary theory was used, which takes into account the evolution of axial structures of modes under the beam influence. By using this theory it was possible to find the zones of the coexistence of modes at two different cyclotron harmonics. This fact indicates that such a theory should be used for accurate predicting the generation regimes in harmonic gyrotrons.

The authors are grateful to Prof. G.S. Nusinovich for his interest in this work, stimulating discussions, and numerous valuable comments.

References

[1] V.E. Zapevalov, G.S. Korablev, and Sh.Ye. Tsimring, Radio Eng. Electron. Phys., vol. 22, n. 8 (1977) 86-94.

[2] V.E. Zapevalov, I.G. Zarnitsyna, and G.S. Nusinovich, Radiophys Quantum Electron, vol. 22 (1979) 254–258. DOI:10.1007/BF01034911.

[3] V.L. Bratman, A.E. Fedotov, and T. Idehara, Int. J. Infrared Milli. Waves, vol. 22 (2001) 1409.

[4] G.S. Nusinovich, IEEE Transactions on Plasma Science, vol. 27, n. 2(1999) 313-326. DOI:10.1109/27.772257.

[5] A.P. Gashturi, G.S. Nusinovich, I.V. Zotova, E.S. Semenov, S.P. Sabchevski, and M.Yu. Glyavin, Physics of Plasmas, vol. 27 (2020) 063304. DOI10.1063/5.0010593.

[6] Yu.K. Kalynov, I.V. Osharin and A.V. Savilov, IEEE Transactions on Electron Devices **67**, 3795 (2020); doi:10.1109/TED.2020.3009617.

[7] Y. Tatematsu, Y. Yamaguchi, M. Fukunari, et al., Journal of Infrared, Millimeter, and Terahertz Waves, vol. 41 (2020) 576–589. DOI:10.1007/s10762-020-00681-7.

[8] E.M. Khutoryan1, G.S. Nusinovich, and O.V. Sinitsyn, Physics of Plasmas, vol. 21 (2014) 093114. DOI: 10.1063/1.4896709.

[9] M. Glyavin, I. Zotova, R. Rozental, A. Malkin, A. Sergeev, A. Fokin, V. Rumyantsev, and S. Morozov, Journal of Infrared, Millimeter, and Terahertz Waves, vol. 41 (2020) 1245. DOI:10.1007/s10762-020-00726-x.

[10] N.S. Ginzburg, G.S. Nusinovich, and N.A. Zavolsky, International Journal of Electronics, vol. 61, n. 6 (1986) 881-894. DOI:10.1080/00207218608920927 .

[11] N.A. Zavol'skii, and G.S. Nusinovich, Radiophys Quantum Electron, vol. 33 (1990) 627–632. DOI:10.1007/BF01048496.

More detail in: Glyavin M., Gashturi A., Malkin A. *et al.* “Investigation of Mode Interaction in Harmonic Sub-THz Gyrotron,” *Journal of Infrared, Millimeter, and Terahertz Waves*, vol. 42 (2021) 843–850. DOI:10.1007/s10762-021-00818-2.

The Concept of Phase-Locking of Second-Harmonic Gyrotrons for Providing MW-Level Output Power

G.G. Denisov, I.V. Zotova, I.V. Zheleznov, A.M. Malkin, E.S. Semenov, M.Yu. Glyavin

Institute of Applied Physics of the Russian Academy of Sciences, 603950, Nizhny Novgorod, Russia

Abstract: We propose the method of providing MW-level output power in CW or long-pulse second-harmonic (SH) gyrotrons using phase-locking by a weak external monochromatic signal. Typically, the power of harmonic gyrotrons is hindered due to excitation of spurious fundamental-harmonic modes at the front of the accelerating voltage and the beam current. Injection of a seeding signal at the operating SH mode (priming) can suppress the spurious generation during the start-up process. Within the frame of a self-consistent multi-mode model, we demonstrate the applicability of this approach to provide ~1 MW radiation in a 230 GHz SH gyrotron with the high order $TE_{34,14}$ operating mode which is standardly unattainable for harmonic operation.

At present, the gyrotrons are the most powerful sources of coherent millimeter and sub-millimeter waves capable of operating in long-pulse and continuous wave (CW) regimes with megawatt power levels. The important application of high-power gyrotrons is plasma heating and current drive in controlled thermonuclear fusion installations. Such systems typically use gyrotrons of the short-wavelength part of the millimeter range (the generation frequency of 110-170 GHz) operating at the first (fundamental) cyclotron harmonic. The modern challenge in the development of high-power gyrotrons is associated with a significant increase in their operating frequency, which is in demand, for example, in next generation of tokamaks with a strong magnetic field planned for construction. Some progress in these studies was achieved recently in fundamental-harmonic (FH) gyrotrons. However, presently, this progress is restrained by the problem of creating strong magnetic fields in volumes, sufficient for installing high-power gyrotrons equipped with a large-diameter cathode.

Undoubtedly, it is attractive to use generation at the second cyclotron harmonic for increasing the frequency, which provides proportional reduction of the guiding magnetic field. According to the theoretical considerations, the maximum electron efficiency of second-harmonic (SH) gyrotrons in the single-mode approximation is close to that of gyrotrons based on the fundamental cyclotron resonance. However, the output power of experimentally implemented high-frequency SH gyrotrons does not exceed several tens of kilowatts with efficiency restricted by 20%. The main problem that hinders obtaining a high power of SH radiation is competition with modes excited by the beam at the fundamental resonance. Moreover, spurious FH modes can be excited at the smooth front of the accelerating voltage and the beam current and, then, continue to exist in the steady-state regime suppressing the operating SH mode.

It should be noted that there are some approaches to solving the described problem aimed at increasing the starting currents of parasitic FH modes, as well as selecting the gyrotron start-up scenario for earlier excitation of the operating SH mode. However, these methods were mainly considered for sufficiently low transverse modes. At the same time, for high-power high-frequency generation, operation at high-order transverse modes is needed for reducing the Ohmic load. Note that the requirement for high power in CW or long pulse regimes makes it highly undesirable electrodynamics selection methods using irregularities in the gyrotron cavity. Simultaneously, electronic selection methods based on axis-encircling or additional absorbing electron beams contradict the requirement for high efficiency.

At the same time, the well-known and currently actively investigated method of spurious modes suppression for fundamental-harmonic gyrotrons is associated with locking by an external weak monochromatic signal with the frequency and structure of the operating mode. In the start-up process, such a signal can provide priming the desired mode and helps this mode to suppress the competitors. Moreover, according to recent studies, frequency-locking also provides a noticeable increase in efficiency, radiation power, and improvement of generation stability of fundamental-harmonic gyrotrons. This paper proposes applying this method to second-harmonic sub-THz gyrotrons to provide single-mode single-frequency generation with megawatt-level output power. This way does not require any essential modification of the device or a complicated start-up scenario. Note, however, that the situation with the 2nd harmonic priming is complicated by the inherent for such gyrotrons nonlinear effect, when the excited harmonic facilitates the excitation of parasitic modes at the fundamental frequency. Nevertheless, for considered area of parameters this effect was not observed; thus, as will be shown below, weak external signal may provide priming of the desired mode, and its oscillations will remain stable with respect to all possible competitors.

In this paper, we describe the basic multi-mode model of electron-wave interaction, taking into account the start-up process and priming by an external signal. Since the quality factors of high-power gyrotrons' cavities are fairly low, the model with the self-consistent axial profile of the RF field is used in contrast with previous considerations. Then, as an example of applicability of the proposed approach, we consider a possibility of megawatt-level second-harmonic generation in a 230-GHz gyrotron with the $TE_{34,14}$ operating mode.

Theoretical analysis presented further is based on the model of low-Q cavity gyrotrons with nonfixed axial mode structures. Such gyrotron can be described by the following self-consistent system of partial differential equations, which describes competition of many transverse modes excited at different cyclotron harmonics (cf. [1]):

$$
\begin{aligned}
& i\frac{\partial^2 a_n}{\partial Z^2} + s_n\frac{\partial a_n}{\partial \tau} + \left(i\varepsilon_n(Z) + i\Delta_n + \rho_n\right)a_n = \\
& \qquad = i\frac{\alpha_I \alpha_\perp^{s_n}}{\alpha_\parallel}\frac{I_n}{4\pi^2}\int_0^{2\pi}\int_0^{2\pi} p^{s_n} e^{i(m_n - s_n)\varphi}\, d\theta_0\, d\varphi, \\
& \frac{\partial p}{\partial Z} + \frac{\overline{g}^2}{4\alpha_\parallel}\frac{\partial p}{\partial \tau} + i\frac{\alpha_\perp^2}{\alpha_\parallel} p\left(|p|^2 - 1\right) = \\
& \qquad = i\sum_n \frac{\alpha_\perp^{s_n - 2}}{\alpha_\gamma \alpha_\parallel} a_n \left(p^*\right)^{s_n - 1} e^{-i(m_n - s_n)\varphi}.
\end{aligned}
\tag{1}
$$

Here p is the complex transverse momentum of electrons normalized to its absolute value at the entrance of interaction space, $Z = \overline{\beta}_\perp^2 \overline{\omega}_g z / 2c\overline{\beta}_\parallel$ and $\tau = \overline{\beta}_\perp^4 \overline{\omega}_g t / 8\overline{\beta}_\parallel^2$ are dimensionless axial coordinate and time,

$a_n = \frac{eA_n}{m_e c\bar{\omega}_g} \frac{s_n^{s_n}}{2^{s_n-1} s_n!} \frac{\bar{\beta}_\perp^{s_n-4}}{\bar{\gamma}} J_{m_n-s_n}(\nu_n R_b)$ is the normalized amplitude of the n-th mode TE_{m_n,q_n} excited at the cyclotron harmonic with number s_n at the frequency $\bar{\omega}_n^c \approx s_n\bar{\omega}_g$ where $\bar{\omega}_g$ is the relativistic gyrofrequency in the operating point chosen as the reference frequency, $\bar{\beta}_\perp = \bar{V}_\perp / c$ and $\bar{\beta}_{||} = \bar{V}_{||} / c$ are normalized electrons velocities, $\bar{g} = \bar{\beta}_\perp / \bar{\beta}_{||}$ is the pitch-factor, $\bar{\gamma} \approx 1 + e\bar{U} / m_e c^2$ is the relativistic factor, $\bar{U}$ is the accelerating voltage in the operating point (at the end of the start-up process),

$$\bar{I}_n = 64 \frac{e\bar{I}_b}{m_e c^3} \frac{\bar{\beta}_{||}\bar{\beta}_\perp^{2(s_n-4)}}{\bar{\gamma}} s_n^3 \left(\frac{s_n^{s_n}}{2^{s_n} s_n!} \right)^2 \frac{J_{m_n-s_n}^2(\nu_n R_b)}{\left(\nu_n^2 - m_n^2\right) J_{m_n}^2(\nu_n)}$$

is the normalized current parameter, $\bar{I}_b$ is the operating electron current, R_b is the injection radius, $J_{m_n}(x)$ is the Bessel function of the first order, m_n is the azimuthal index of the n-th mode, ν_n is its eigenvalue, $\rho_n = s_n^2 4\beta_{||0}^2\beta_{\perp 0}^{-4} \big/ Q_n^{ohm}$ is the parameter of Ohmic losses, $Q_n^{ohm} = Rd_n^{-1}\left(1 - m_n^2\nu_n^{-2}\right)$ is the Ohmic Q-factor, d_n is the frequency-dependent skin depth. The function $\varepsilon_n(Z) = 8\bar{\beta}_{||}^2 s_n^2 (\bar{\omega}_n^c - \omega_n^c(Z)) / \bar{\omega}_n^c \bar{\beta}_\perp^4$ describes the variation of the cut-off frequency $\omega_n^c(Z) = \nu_n c / R(Z)$ along z-axis, $R(Z)$ is the profile of the smoothly tapered gyrotron cavity, $\bar{\omega}_n^c$ is the cut-off frequency in its regular part.

Unlike [1], the gyrotron start-up is taken into account in Eqs.(1) by slow variation of electron beam parameters (energy, current, axial and transverse velocities) in the process of the accelerating voltage rising $U(\tau)$:

$$\begin{gathered} \alpha_\gamma = \frac{\gamma(U(\tau))}{\bar{\gamma}}, \quad \alpha_I(\tau) = \frac{I_b(U(\tau))}{\bar{I}_b}, \\ \alpha_{||}(\tau) = \frac{\beta_{||}(U(\tau))}{\bar{\beta}_{||}}, \quad \alpha_\perp(\tau) = \frac{\beta_\perp(U(\tau))}{\bar{\beta}_\perp}, \end{gathered} \tag{2}$$

The function $\Delta_n(\tau) = 8\bar{\beta}_{||}^2 s_n^2 (s_n\bar{\omega}_g\alpha_\gamma^{-1} - \bar{\omega}_n^c) / \bar{\omega}_n^c \bar{\beta}_\perp^4$ describes start-up variation of the cyclotron resonance detuning.

For diode-type magnetron-injection guns, the temporal dependence of the pitch-factor and the current-voltage characteristic taking into account the Schottky effect are given by relations [2]:

$$g(U(\tau)) = \bar{g}\sqrt{\frac{U(\tau)}{\left(1+\bar{g}^2\right)\bar{U} - \bar{g}^2 U(\tau)}}\,, \tag{3}$$

$$I_b(U(\tau)) = \bar{I}_b e^{B\left(\sqrt{U} - \sqrt{\bar{U}}\right)}. \tag{4}$$

Equations (3),(4) allow us to calculate the functions (2) introduced above. The coefficient B in (4) is found based on experimental current-voltage characteristics of modern high-power gyrotrons (see, for example, [3]).

The equations (1) have to be supplemented by proper boundary conditions. For the equations of motion, we apply standard conditions corresponding to electrons uniformly distributed over the cyclotron rotation phases at the entrance of the interaction space: $p(Z=0) = e^{i\theta_0}, \theta_0 \in [0, 2\pi)$. Note, that we consider here interaction with a thin electron beam without velocity spread. For modes' amplitudes, boundary conditions are written in the form:

$$a_n(\tau,0)-\frac{1}{\sqrt{i\pi s_n}}\int_0^{\tau}\frac{e^{-i\Phi_n(\tau,\tau',0)}}{\sqrt{\tau-\tau'}}\frac{\partial a_n(\tau',0)}{\partial Z}d\tau'=0, \tag{5a}$$

$$a_n(\tau,L)+\frac{1}{\sqrt{i\pi s_n}}\int_0^{\tau}\frac{e^{-i\Phi_n(\tau,\tau',L)}}{\sqrt{\tau-\tau'}}\frac{\partial a_n(\tau',L)}{\partial Z}d\tau'= =2\delta_{n,N}F_0 e^{i\Omega_n\tau+i\Phi_n(\tau,0,L)}, \tag{5b}$$

where $\delta_{n,N}$ is the *Kronecker delta*, $L=\bar{\beta}_{\perp 0}^2\bar{\omega}_H l_z/2\bar{\beta}_{||0}c$ is the normalized length of the gyrotron cavity with the physical length l_z, $\Phi_n(\tau,\tau',Z)=s_n^{-1}\int_{\tau'}^{\tau}(\Delta_n(\tau'')+\varepsilon_n(Z)-i\sigma_n)d\tau''$, F_0 and $\Omega_n=8\bar{\beta}_{||}^2 s_n(\omega_0-\bar{\omega}_n^c)/\bar{\omega}_n^c\bar{\beta}_{\perp}^4$ are the normalized amplitude and the frequency of the external monochromatic signal. In order to write the boundary condition Eq.(5b) at the gyrotron output (see [4] for details), we assume that the transverse structure and direction of rotation of the external signal are the same as that of the operating mode with $n=N$. For high-power gyrotrons it can be realized based on a novel quasi-optical convertor proposed in [5]. Note that some modifications of Eq.5b (compared to the form obtained in [4]) are caused by the fact that the gyrofrequency changes during the gyrotron start-up.

Based on the developed model, we performed simulations of a high-power second-harmonic gyrotron with an operating frequency of 230 GHz. With the megawatt power level in mind, the fairly high transverse mode $TE_{34,14}$ was chosen as the operating one to provide an acceptable Ohmic load. In the simulation, it was assumed that the gyrotron cavity was made of copper, taking into account the possible surface roughness (i.e., the value of the skin depth was taken twice as much as that given by the known formula $d_n=(2\pi)^{-1}\sqrt{c\lambda_n/\sigma}$, where $\sigma=5\cdot 10^{17}$ is the copper conductivity).

The optimized profile of the gyrotron cavity with the radius of the regular part of 18.34 mm and the length of 12 mm is shown in Fig.1a. Figure 1b demonstrates the extremely dense spectrum of competing modes near the operating frequency. Note that for the injection radius of 7.17 mm (which corresponds to the maximum of the coupling coefficient for the operating SH mode), there are several dangerous competitors at the fundamental resonance, including modes of the equidistant spectrum $TE_{\pm 15,8}$, $TE_{\pm 16,8}$ with higher coupling coefficients and the nearest in the magnetic field modes $TE_{18,7}$ and $TE_{\pm 6,12}$.

Note that the length of the regular part of the gyrotron cavity was significantly shortened in comparison with the value optimal for achieving the maximum SH efficiency; thus, diffractive Q-factor of the desired mode was of 2500. It was done in order to decrease the diffraction Q-factors of competing FH modes and, accordingly, to increase their starting currents [6]. Nevertheless, for the accelerating voltage of 100 kV and the pitch-factor of 1.3, the generation zone of the operating SH mode is almost completely overlapped by zones of competing FH modes (Fig.2); thus, selective gyrotron excitation with high power at the second harmonic in the free-running regime is not possible. However, as shown below, efficient excitation of the second harmonic with sufficiently high efficiency and power can be provided in the regime of frequency-locking by a weak external signal.

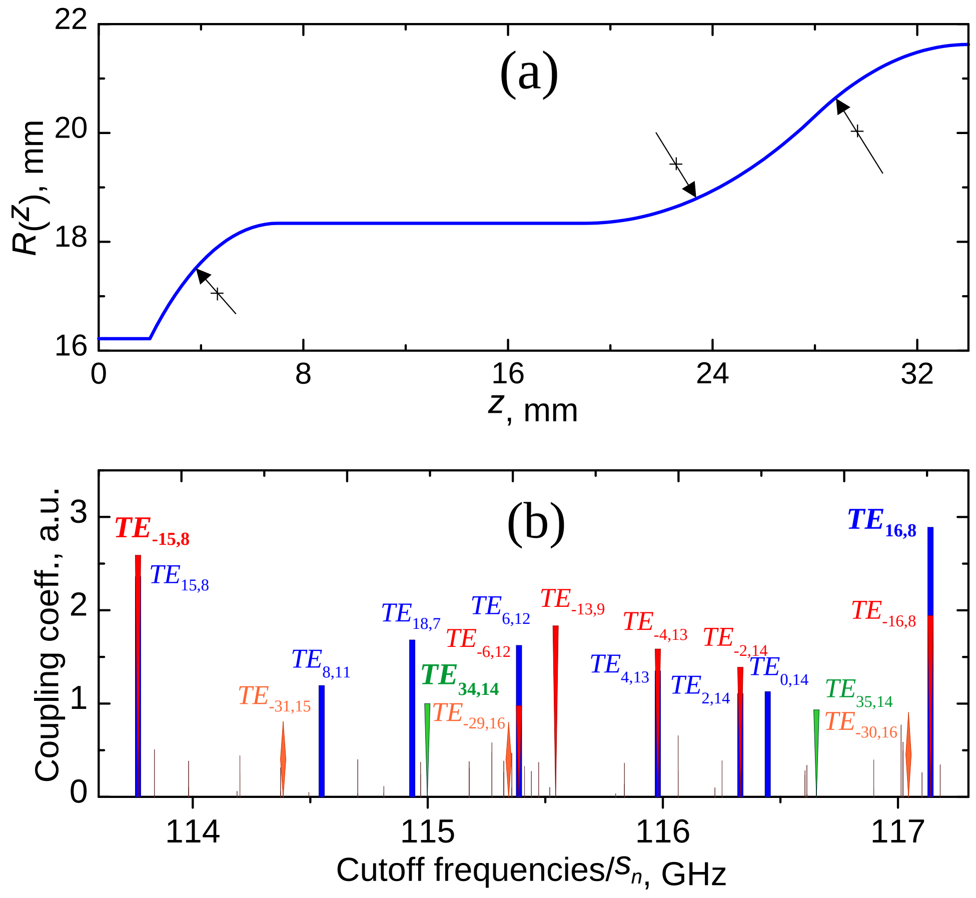

Fig.1 (a) The optimized cavity profile of the simulated 230-GHz gyrotron. (b) Normalized coupling coefficients of the operating and competing modes (modes spectrum) for the injection radius of 7.17 mm. Blue and red lines correspond to FH modes of direct and opposite rotation. Differently rotating SH modes are marked by green and orange lines, respectively. Black lines show modes which are not important for competition.

For further simulations, the operating current was chosen equal to 50 A, since for this value, the megawatt level of SH generation can be reached at the $TE_{34,14}$ mode. The simplest start-up scenario with a linear voltage rise in time from 75 to 100 kV was considered (Fig.3). Note here, that in practice, the voltage rise time in long-pulse gyrotrons is on the order of milliseconds. However, a typical cavity fill time is on the order of nanoseconds. Therefore, the choice of 300 ns for describing the start-up scenario looks like a reasonable scale, which is fast enough for saving the time of simulations and, at the same time, sufficiently slow for studying the physics of nonlinear processes.

In the free-running regime, the $TE_{16,8}$ fundamental-harmonic mode (blue line in Fig.3) is the first which is excited on the rising front of the accelerating voltage, suppresses all other competitors, and continues to exist in a steady-state generation regime (Fig.4) with an output power of about 1.1 MW. As a result, transverse efficiency $\eta_\perp = 1-(2\pi)^{-1}\left\langle |p|^2 \right\rangle_{\theta_0}$ is 35%; total efficiency is 22% taking into account the Ohmic losses. Untypical low FH efficiency is explained by using the shortened cavity.

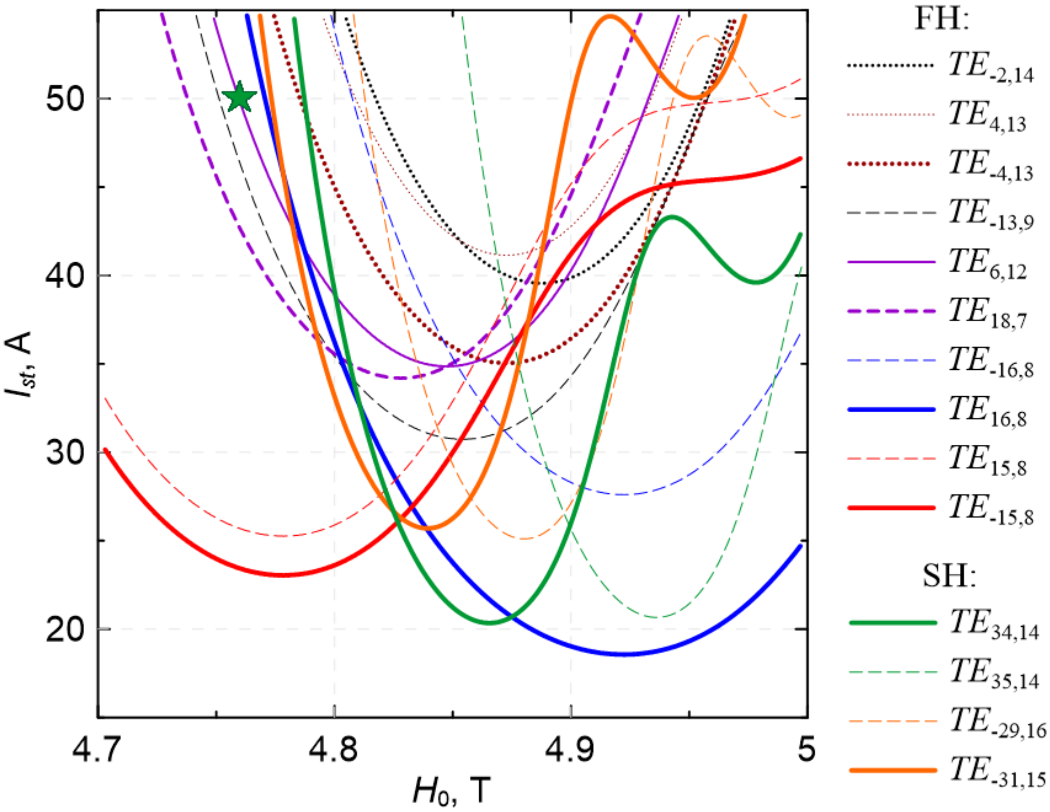

Fig.2 Excitation zones for competing modes: the operating voltage $\bar{U}$ =100 kV, the pitch-factor $\bar{g}=1.3$. The operating point with the maximum efficiency is marked by the green star (the guiding magnetic field of 4.76 T).

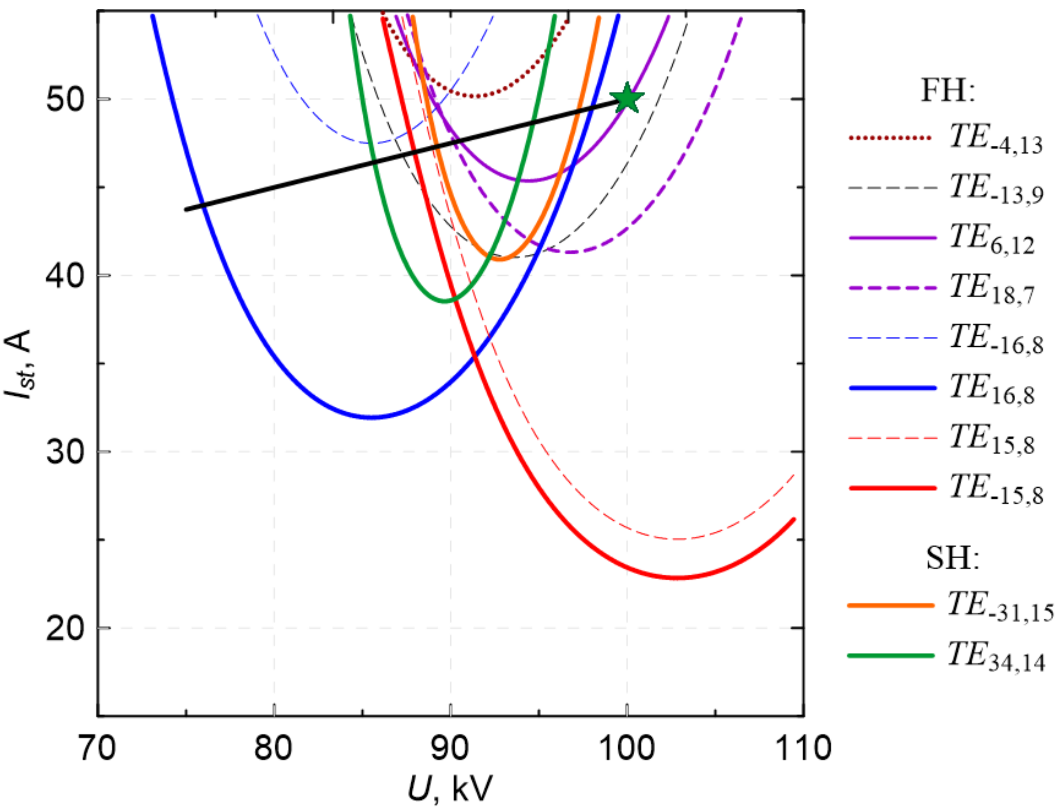

Fig.3 Modes' excitation zones depending on the accelerating voltage for the guiding magnetic field of 4.76 T. Black line shows the current-voltage characteristics in the start-up process. The operating point with maximum efficiency is marked by the green star

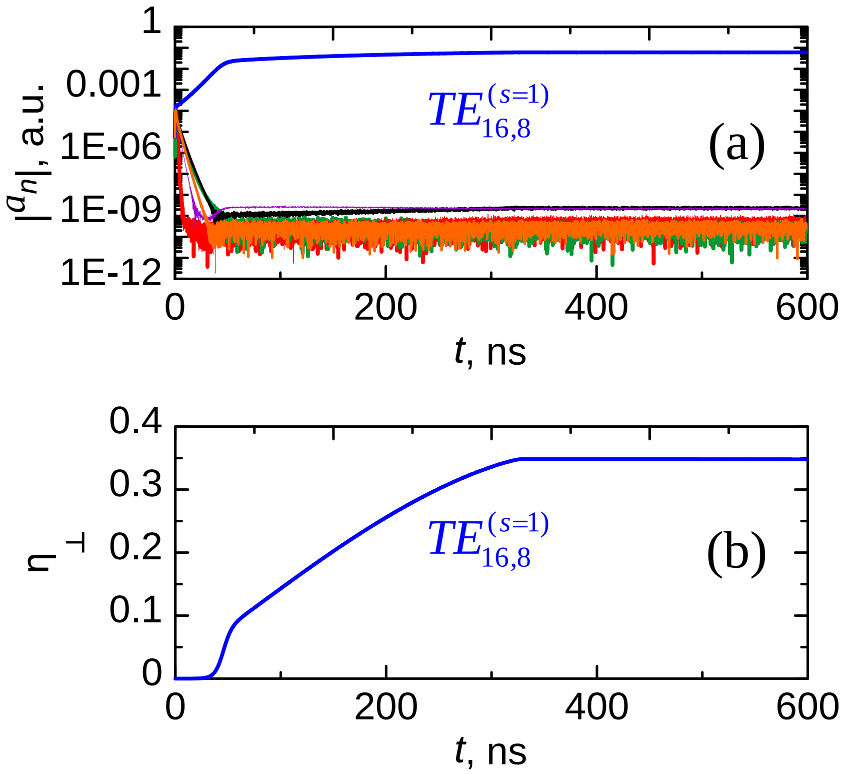

Fig.4. Results of simulations for the free-running (autonomous) regime. Temporal dependences of amplitudes of competing modes (a) and the transverse efficiency (b) are shown. The start-up process ends at 300 ns

The situation is principally different in the frequency-locking regime. In simulations, we use the external signal with a power of 50 kW (about 5% of the desired output level of 1 MW), which for the given frequency can be generated by a FH gyrotron [7]. Such signal provides priming the desirable SH mode $TE_{34,14}$ (Fig.5), which, as a result, wins in the competition. The zone of efficient priming corresponds to hard self-excitation at the second harmonic (Fig.2). Note, that in the operating point, the gyrotron should remain locked by the external signal the switching off of which leads to the excitation of the parasitic FH $TE_{-15,8}$ mode.
According to simulations, the output power of second harmonic generation reaches 0.95 MW (total efficiency is ~20%); the Ohmic loads on the cavity walls is of ~2.5 кВт/см^2 which is still acceptable for water cooling.

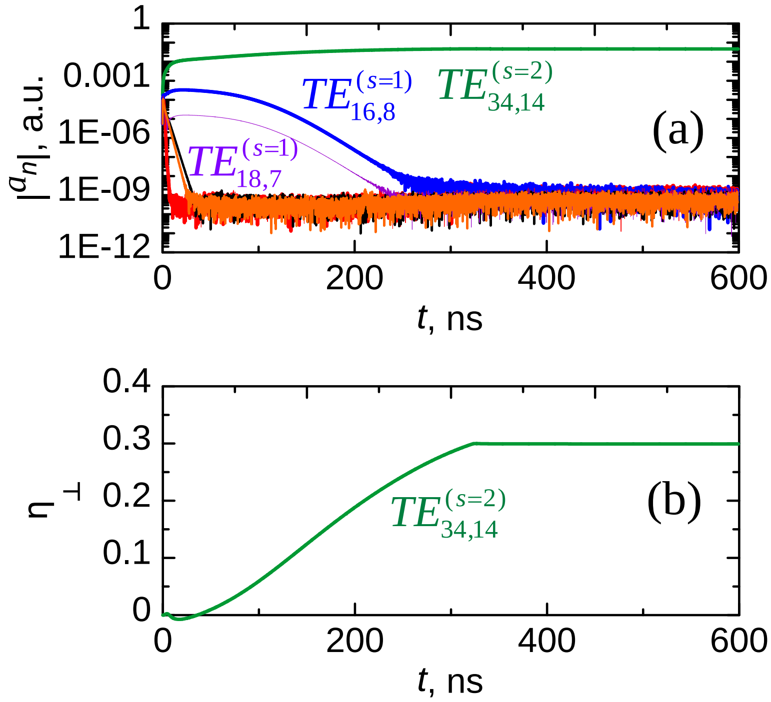

Fig.5. Results of simulations for the frequency-locking regime. Temporal dependences of amplitudes of competing modes (a) and the transverse efficiency (b) are shown. The start-up process ends at 300 ns.

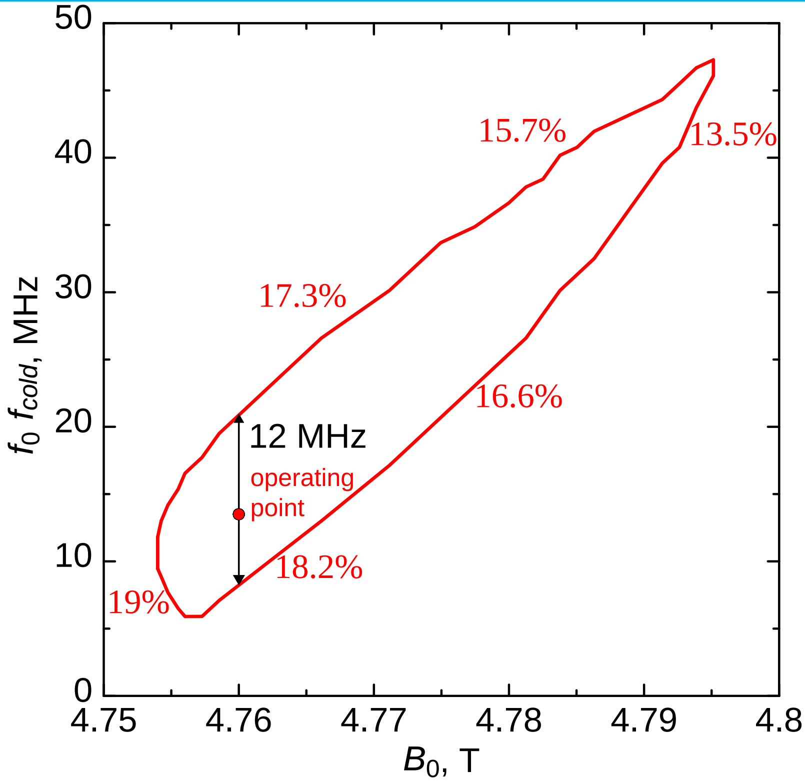

Fig.6. Frequency-locking band vs. guiding magnetic field. The output efficiency at the boundaries of the band is marked.

In Fig.6, the dependence of frequency-locking bandwidth on the guiding magnetic field is shown. For the operating point, the frequency-locking bandwidth is about 10 MHz. This value can be doubled when the current is reduced to 45 A. However, in this case, the generation efficiency decreases to 16%, and the power, respectively, is 0.7 MW.

Note that the calculated bandwidth value is limited by competition with FH modes and, as a result, it is two times smaller than that 20 MHz given by the well-known Adler formula. Moreover, this zone is at least twice as narrow as compared with the simulations at a given voltage, i.e., not taking into account the gyrotron start-up.

Thus, with a specific example, we have shown that the locking a gyrotron with an external monochromatic signal makes it possible to provide selective excitation of second-harmonic generation at the very high-order transverse mode (much higher than in the currently known record experiments [10]). In such a way, it is possible to significantly increase in SH gyrotrons output power. However, the efficiency of SH generation remains strongly limited by competition with fundamental-harmonic modes. Nevertheless, the proposed method may ultimately allow gyrotrons to move at a high-power level to a range of higher frequencies based on existing superconducting magnets.

Refreences

[1] M. Glyavin, I. Zotova, R. Rozental, A. Malkin, A. Sergeev, A. Fokin, V. Rumyantsev, and S. Morozov, "Investigation of the frequency double-multiplication effect in a sub-THz gyrotron," J Infrared Milli Terahz Waves, vol. 41(2020) 1245-1251. DOI: 10.1007/s10762-020-00726-x.

[2] M.Yu. Glyavin, and V.N. Manuilov, "Synthesis of current-voltage characteristics of 670 GHz gyrotron magnetron injection gun and calculation of the parameters of a helical electron beam at the leading edge of a high-voltage pulse", Journal of Infrared, Millimeter, and Terahertz Waves, vol. 34, n. 2 (2013) 119-126. DOI: 10.1007/s10762-012-9953-3.

[3] M.Yu. Glyavin, A.L. Goldenberg, A.N. Kuftin, V.K. Lygin, A.S. Postnikova, and V.E. Zapevalov, “Experimental studies of gyrotron electron beam systems,” IEEE Transactions on Plasma Science, vol. 279, n. 2 (1999) 474-483. DOI: 10.1109/27.772276.

[4] N.S. Ginzburg, A.S. Sergeev, and I.V. Zotova, “Time-domain self-consistent theory of frequency-locking regimes in gyrotrons with low-Q resonators,” Physics of Plasmas, vol. 22 (2015) 033101. DOI: 10.1063/1.4913672.

[5] A.V. Chirkov, G.G. Denisov, and A.N. Kuftin, “Perspective gyrotron with mode converter for co- and counter-rotation operating modes,” Appl. Phys. Lett., vol. 106 (2015) 263501. DOI: 10.1063/1.4923269.

[6] V.E. Zapevalov, S.A. Malygin, and S.E. Tsimring, “High-power gyrotron at second harmonic of cyclotron frequency,” Radiophys. Quantum Electron., vol. 36 (1993) 346-353. DOI: 10.1007/BF01038234.

[7] G.G. Denisov, M.Yu. Glyavin, A.P. Fokin, A.N. Kuftin, A.I. Tsvetkov, A.S. Sedov, E.A. Soluyanova, M.I. Bakulin, E.V. Sokolov, E.M. Tai, M.V. Morozkin, M.D. Proyavin, and V.E. Zapevalov, “First experimental tests of powerful 250 GHz gyrotron for future fusion research and collective Thomson scattering diagnostics,” Review of Scientific Instruments, vol. 89 (2018) 084702. DOI: 10.1063/1.5040242.

More detail in: G. G. Denisov *et al*., "Phase-Locking of Second-Harmonic Gyrotrons for Providing MW-Level Output Power," in *IEEE Transactions on Electron Devices*, vol. 69, n. 2 (2022) 754-758. DOI: 10.1109/TED.2021.3134187.

FORTHCOMING EVENTS

The Organizing Committee of the 47th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz 2022) has announced Call for Abstracts. The message of the Conference Chair reads:

“Following two consecutive years of Covid-triggered online-only venues, we are extremely pleased to be able to plan a hybrid event in 2022 from 28th August to 2nd September to take place in Delft, Netherlands on the campus of the Technical University of Delft (www.tudelft.nl).

The in-person conference will be held at the upscale and modern Aula Conference Center (https://www.tudelft.nl/en/about-tu-delft/our-campus/conferences-and-events), centrally located on the Delft University of Technology campus and only a 10-minute walk from the historic Delft city center. The Aula Center has excellent facilities with an auditorium for the Plenary sessions that can accommodate up to 1100 people and many in-center breakout rooms for our smaller technical sessions. It also has wonderful poster presentation and exhibition space. We plan to have a live exhibition, where you can meet our sponsors and talk with our exhibitors in person. The online portion of the conference will take place using the Whova platform (as in Chengdu), where you can attend all the technical sessions and also gather information about our sponsors and exhibitors.

Our abstract submission process officially opens on 1st February 2022 at: https://www.irmmw-thz2022.tudelft.nl/abstract.html. All the relevant conference information and the detailed abstract submission guidelines are already posted on the conference website (http://www.irmmw-thz2022.org).
The deadline for your abstract submission is 25thMarch 2022.”

The Twenty-Third International Vacuum Electronics Conference (IVEC) will be held in Monterey, California, on April 25-29, 2022. This year the conference will be a hybrid event under the sponsorship of the IEEE Electron Devices Society (EDS). The in-person meeting will be held at the Marriott Conference Center. The hybrid event will permit remote attendance and conference presentations as well. For detail information about the event, please visit the website of the conference.

ICTSTA 2022: 16. International Conference on Terahertz Science, Technology and Applications

September 15-16, 2022 in Amsterdam, Netherlands

The International Research Conference is a federated organization dedicated to bringing together a significant number of diverse scholarly events for presentation within the conference program. Events will run over a span of time during the conference depending on the number and length of the presentations. With its high quality, it provides an exceptional value for students, academics and industry researchers.

International Conference on Terahertz Science, Technology and Applications aims to bring together leading academic scientists, researchers and research scholars to exchange and share their experiences and research results on all aspects of Terahertz Science, Technology and Applications. It also provides a premier interdisciplinary platform for researchers, practitioners and educators to present and discuss the most recent innovations, trends, and concerns as well as practical challenges encountered and solutions adopted in the fields of Terahertz Science, Technology and Applications.
For more information, please follow the link.

ICTS 2022: 16. International Conference on Terahertz Science

June 27-28, 2022 in London, United Kingdom

International Conference on Terahertz Science aims to bring together leading academic scientists, researchers and research scholars to exchange and share their experiences and research results on all aspects of Terahertz Science. It also provides a premier interdisciplinary platform for researchers, practitioners and educators to present and discuss the most recent innovations, trends, and concerns as well as practical challenges encountered and solutions adopted in the fields of Terahertz Science.
For more information, please follow the link.

ICTRSIS 2022: 16. International Conference on Terahertz Radiation Sources for Imaging and Sensing

July 21-22, 2022 in Tokyo, Japan

International Conference on Terahertz Radiation Sources for Imaging and Sensing aims to bring together leading academic scientists, researchers and research scholars to exchange and share their experiences and research results on all aspects of Terahertz Radiation Sources for Imaging and Sensing. It also provides a premier interdisciplinary platform for researchers, practitioners and educators to present and discuss the most recent innovations, trends, and concerns as well as practical challenges encountered and solutions adopted in the fields of Terahertz Radiation Sources for Imaging and Sensing.

For more information, please follow the link.

LIST OF SELECTED RECENT PUBLICATIONS

Bibliography and links to selected recent publications on topics related to the research field of the International Consortium and published after October 2021, i.e. after issuing the previous Newsletter #19. This cumulative list is in chronological order as collected from various bibliographical and alert services

A. Publications by authors from the institutions participating in the International Consortium

N. Kumar, A. Abhishek, Vishant, K. Singhal, N. Gurjar, S. Jain, A.V. Starodubov, N.M. Ryskin, “Pseudospark-Driven High-Current Miniaturized Voltage-Tunable Sheet-Electron-Beam Source," in IEEE Transactions on Electron Devices, (2021). DOI:10.1109/TED.2021.3119555.
https://ieeexplore.ieee.org/document/958531

S.V. Samsonov, G.G. Denisov, A.A. Bogdashov, I.G. Gachev, "Cyclotron Resonance Maser with Zigzag Quasi-Optical Transmission Line: Concept and Modeling," in IEEE Transactions on Electron Devices, vol. 68, n. 11 (2021) 5846-5850. DOI:10.1109/TED.2021.3114141.
https://ieeexplore.ieee.org/document/9552432

A.B. Adilova, M.I. Balakin, S.A. Gerasimova, N.M. Ryskin, "Bifurcation analysis of multistability of synchronous states in the system of two delay-coupled oscillators," Chaos, vol. 31 (2021) 113103. DOI:10.1063/5.0065670.
https://aip.scitation.org/doi/10.1063/5.0065670

Omrani A,, Yadav R., Link G., Lähivaara T., Vauhkonen M.,, Jelonnek J., "An Electromagnetic Time-Reversal Imaging Algorithm for Moisture Detection in Polymer Foam in an Industrial Microwave Drying System," Sensors, vol. 21, n. 21 (2021) 7409. DOI:10.3390/s21217409.
https://www.mdpi.com/1424-8220/21/21/7409

Yuriy K. Kalynov, Andrey V. Savilov, and Eugeny S. Semenov, "Parasitic excitation of fundamental-cyclotron-harmonic waves in high-harmonic gyrotrons," Physics of Plasmas, vol. 28 (2021) 113105. DOI: 10.1063/5.0071351.
https://aip.scitation.org/doi/10.1063/5.0071351

Vakhin A.V., Khelkhal M.A., Tajik A., Ignashev N.E., Krapivnitskaya T.O., Peskov N.Y., Glyavin M.Y., Bulanova S.A., Slavkina O.V., Schekoldin K.A., “Microwave Radiation Impact on Heavy Oil Upgrading from Carbonate Deposits in the Presence of Nano-Sized Magnetite,” Processes, vol. 9. n. 11 (2021). DOI:10.3390/pr9112021.
https://www.mdpi.com/2227-9717/9/11/2021

Hosseini M., Kaasinen A., Aliyari Shoorehdeli M., Link G., Lähivaara T., Vauhkonen M., “System Identification of Conveyor Belt Microwave Drying Process of Polymer Foams Using Electrical Capacitance Tomography,” Sensors, vol. 21, n. 21 (2021) 7170. DOI:10.3390/s21217170.
https://www.mdpi.com/1424-8220/21/21/7170

Manfred Thumm, “State-of-the-Art of High-Power Gyro-Devices. Update of Experimental Results 2021,” KIT SCIENTIFIC REPORTS 7761 (20210. DOI: DOI 10.5445/KSP/1000136043. ISSN 1869-9669.
https://library.oapen.org/bitstream/handle/20.500.12657/51438/KIT-SR_7761.pdf?sequence=1

C. Wu, G. Aiello, K.A. Avramidis, A. Bruschi, et al. “Basic design considerations for a frequency step-tunable electron cyclotron wave system to suppress NTMs in DEMO,” Fusion Engineering and Design, vol. 173 (2021) 112931. DOI:10.1016/j.fusengdes.2021.112931.

https://www.sciencedirect.com/science/article/pii/S0920379621007079

Krasilnikov A.V., Konovalov S.V., Bondarchuk E.N. et al. “Tokamak with Reactor Technologies (TRT): Concept, Missions, Key Distinctive Features and Expected Characteristics,” Plasma Phys. Rep., vol. 47 (2021) 1092–1106. DOI:10.1134/S1063780X21110192.
https://link.springer.com/article/10.1134%2FS1063780X21110192

Belousov V.I., Denisov G.G., Shmelev M.Y., “System of Electron Cyclotron Heating at the TRT Tokamak,”Plasma Phys. Rep., vol. 47 (2021) 1158–1168. DOI:10.1134/S1063780X21110143.
https://link.springer.com/article/10.1134%2FS1063780X21110143

V.N. Manuilov, M.V. Morozkin, “Suppression of parasitic secondary emission in a magnetron-injection gun of a 24-GHz technological gyrotron,” Results in Physics, vol. 31 (2021) 105034. DOI:10.1016/j.rinp.2021.105034.
https://www.sciencedirect.com/science/article/pii/S2211379721010275

Ginzburg N.S., Samsonov S.V., Denisov G.G., Vilkov M.N., Zotova I.V., Bogdashov A.A., Gachev I.G., Sergeev A.S., Rozental R.M., “Ka-Band 100-kW Subnanosecond Pulse Generator Mode-Locked by a Nonlinear Cyclotron Resonance Absorber,” Physical Review Applied, vol. 16, n. 5 (2021) 054045. DOI: 10.1103/PhysRevApplied.16.054045.
https://journals.aps.org/prapplied/abstract/10.1103/PhysRevApplied.16.054045

A.G. Luchinin, V.A. Malyshev, E.A. Kopelovich, K.F. Burdonov, M.E. Gushchin, M.V. Morozkin, M.D. Proyavin, R.M. Rozental, A.A. Soloviev, M.V. Starodubtsev, A.P. Fokin, J. Fuchs, and M.Yu. Glyavin, "Pulsed magnetic field generation system for laser-plasma research", Review of Scientific Instruments, vol. 92, (2021) 123506. DOI:10.1063/5.0035302.
https://aip.scitation.org/doi/10.1063/5.0035302

Savoldi, Laura, Konstantinos A. Avramidis, Ferran Albajar, Stefano Alberti, Alberto Leggieri, and Francisco Sanchez.. "A Validation Roadmap of Multi-Physics Simulators of the Resonator of MW-Class CW Gyrotrons for Fusion Applications," Energies, vol 14, n. 23 (2021). DOI:10.3390/en14238027.
https://www.mdpi.com/1996-1073/14/23/8027

A. Likhachev, Yu. Kovshov, S. Kishko, S. Ponomarenko, S. Vlasenko, A. Ivanov, A. Kuleshov , "Supply voltage control for guaranteed performance of compact terahertz vacuum electron devices", Review of Scientific Instruments, vol. 92 (2021) 124704. DOI:10.1063/5.0070533.
https://aip.scitation.org/doi/10.1063/5.0070533

N.A. Zavol’Sky, V.E. Zapevalov, M.A. Moiseev, “Numerical Modeling of the Processes of Electron-Wave Interaction in the Cavities of High-Power Gyrotrons with a Frequency of 300 GHz,” Radiophysics and Quantum Electronics, (2021) 1-12. DOI: 10.1007/s11141-021-10121-8.
https://link.springer.com/article/10.1007%2Fs11141-021-10121-8

M.L. Kulygin, I.A. Litovsky, A.V. Chirkov, I.N. Shevelev, G.I. Kalynova, M.Y. Shmelev, "Terahertz Active Nanosecond Gigawatt Compressor Thermal Feasibility," 2021 IEEE International Conference on Microwaves, Antennas, Communications and Electronic Systems (COMCAS), 2021, pp. 99-102. DOI: 10.1109/COMCAS52219.2021.9629071.
https://ieeexplore.ieee.org/abstract/document/9629071

M.L. Kulygin, D.Y. Schegolkov, V.I. Belousov, A.V. Chirkov, I.N. Shevelev, I.A. Litovsky, "Nanosecond Gigawatt Compressor Excitation Dynamics," 2021 IEEE International Conference on Microwaves, Antennas, Communications and Electronic Systems (COMCAS), 2021, pp. 473-476. DOI:10.1109/ COMCAS52219.2021.9629100.
https://ieeexplore.ieee.org/abstract/document/9629100

Rozental R.M., Samsonov S.V., Bogdashov A.A. et al. "Multifrequency Radiation at the Kilowatt Power Level in a Continuous Helical Gyroresonance K-Band Backward Wave Oscillator with External Reflections," Tech. Phys. Lett. (2021). DOI:10.1134/S1063785021030299.
https://link.springer.com/article/10.1134%2FS1063785021030299

Tsvetkov A.I., Vodopyanov A.V., Mansfel'd D.A. et al., "Preparation of a Highly Dispersed Powder of Tin Monoxide by the Evaporation/Condensation Method under Heating with Focused Radiation of a Subterahertz Gyrotron," Tech. Phys. Lett. (2021). DOI:10.1134/S1063785021030147.
https://link.springer.com/article/10.1134%2FS1063785021030147

Ruess, Tobias, Gantenbein, Gerd, Ioannidis, Zisis, Rzesnicki, Tomasz, Wagner, Dietmar, Thumm, Manfred and Jelonnek, John. "Frequency and mode measurement techniques for megawatt-class gyrotrons" tm - Technisches Messen, (2021). DOI:10.1515/teme-2021-0039.
https://www.degruyter.com/document/doi/10.1515/teme-2021-0039/html

I.V. Bandurkin, Y.K. Kalynov, A.V. Savilov, "Single-Cavity Gyromultipliers with Asymmetric Electron Beams," in IEEE Transactions on Electron Devices, (2021). DOI:10.1109/TED.2021.3130856.
https://ieeexplore.ieee.org/abstract/document/9642401

Tsvetkov A.I., Vodopyanov A.V., Mansfel'd D.A. et al. "Preparation of a Highly Dispersed Powder of Tin Monoxide by the Evaporation/Condensation Method under Heating with Focused Radiation of a Subterahertz Gyrotron," Tech. Phys. Lett. (2021). DOI:10.1134/S1063785021030147.
https://link.springer.com/article/10.1134/S1063785021030147

Barabin, S.V., Kropachev, G.N., Lukashin, A.Y. et al. "Emittance Measurements of a Gasdynamic Electron Cyclotron Resonant Ion Source,"Tech. Phys. Lett. (2021). DOI:10.1134/S1063785021050199.
https://link.springer.com/article/10.1134/S1063785021050199

G.G. Denisov et al., "Phase-Locking of Second-Harmonic Gyrotrons for Providing MW-Level Output Power," in IEEE Transactions on Electron Devices, (2021). DOI:10.1109/TED.2021.3134187.
https://ieeexplore.ieee.org/document/9656818

Sidorov A.V., Veselov A.P., Razin S.V., Barmashova T.V., et al. "Gas discharge sustained by powerful THz and sub-THz gyrotrons in the mixtures of noble gases with nitrogen," Journal of Physics: Conference Series, vol. 2103 (2021) 012211. DOI:10.1088/1742-6596/2103/1/012211.
https://iopscience.iop.org/article/10.1088/1742-6596/2103/1/012211

N.S. Ginzburg, A.M. Malkin, V.Y. Zaslavsky, A.E. Fedotov, A.S. Sergeev, "Relativistic Sub-THz Surface-Wave Sheet-Beam Amplifier With Transverse Energy Input and Output," in IEEE Transactions on Electron Devices, (2021). DOI: 10.1109/TED.2021.3134197.
https://ieeexplore.ieee.org/document/9659820

Tsvetkov A.I., Mansfeld D.A., Vodopyanov A.V. et al. "Experimental Evaluation of the Temperature Dependence of the Absorption of Metal Oxide Powders Heated by a 527-GHz Gyrotron Radiation," Tech. Phys. Lett. (2021). DOI:10.1134/S1063785021080277.
https://link.springer.com/article/10.1134/S1063785021080277

I.A. Navrotsky, N.M. Ryskin, "Electron-Optic System with High Compression of a Multiple Elliptic Electron Beam for a Miniaturized THz-band Vacuum Electron Device," in IEEE Access, (2021). DOI: 10.1109/ACCESS.2021.3138963.
https://ieeexplore.ieee.org/document/9663398

Zuev A.S., Fokin A.P., Ananichev A.A. et al. Realization of an Octave Frequency Step-Tuning of Sub-terahertz Gyrotron for Advanced Fusion Research. J Infrared Milli Terahz Waves (2021). DOI:10.1007/s10762-021-00832-4.

https://link.springer.com/article/10.1007%2Fs10762-021-00832-4

M.M. Melnikova, N. M. Ryskin, "Influence of reflections on mode-competition processes in a high-power multimode gyrotron," Physics of Plasmas, vol. 29 (2022) 013104. DOI:10.1063/5.0071210.
https://aip.scitation.org/doi/10.1063/5.0071210

Denisov G., Kuftin A., ManuilovV., Chirkov A., Popov L., Zapevalov V., Zuev A., Sedov A., Zheleznov I., Glyavin M, "Concept design of the megawatt power level gyrotron stabilized by a low-power signal for DEMO project," Nuclear Fusion, (2022). DOI: 10.1088/1741-4326/ac4946.
https://iopscience.iop.org/article/10.1088/1741-4326/ac4946

S. Adya, S. Yuvaraj, M. Rawat, M. V. Kartikeyan, M.K. Thumm, "Investigations on RF Behavior of a V-Band Second Harmonic Gyrotron for 100/200 kW Operation," in IEEE Transactions on Plasma Science, (2022). DOI:10.1109/TPS.2022.3140350.
https://ieeexplore.ieee.org/document/9681477

Zapevalov V.E., Zuev A.S., Parshin V.V., Semenov E.S., Serov E.A., "Reduction of Ohmic Losses in the Cavities of Low-Power Terahertz Gyrotrons," Radiophys Quantum El (2022). DOI:10.1007/s11141-021-10127-2.
https://link.springer.com/article/10.1007%2Fs11141-021-10127-2

Rozental R.M., Samsonov S.V., Bogdashov A.A. et al. "Multifrequency Radiation at the Kilowatt Power Level in a Continuous Helical Gyroresonance K-Band Backward Wave Oscillator with External Reflections," Tech. Phys. Lett. (2021). DOI:10.1134/S1063785021030299.
https://link.springer.com/article/10.1134%2FS1063785021030299

Manuilov V.N., Zaslavsky V.Y., Kuftin A.N. et al. "Optimization of the Magnetron-Injection Gun for a High-Power Planar Millimeter-Wave Gyrotron," Radiophys Quantum El., (2022). DOI:10.1007/s11141-021-10126-3.
https://link.springer.com/article/10.1007%2Fs11141-021-10126-3

S. Ponomarenko, S. Kishko, A. Likhachev, E. Khutoryan, A. Kuleshov, "Electromagnetic sources for THz imaging and DNP NMR spectroscopy," In: Electromagnetic Waves and Antennas for Biomedical Applications, 2021. DOI: 10.1049/PBHE033E_ch3.
https://digital-library.theiet.org/content/books/10.1049/pbhe033e_ch3

M.S. Gitlin, S.A. Bulanova, A.P. Fokin, M.Yu. Glyavin, et al., "Imaging of a High-Power Millimeter Wave Beam Using a Millimeter Wave-Induced Gas Breakdown Initiated by a Metal-Dielectric Screen," in IEEE Transactions on Plasma Science, (2022). DOI:10.1109/TPS.2022.3142902.
https://ieeexplore.ieee.org/document/9694494

I.V. Bandurkin et al., "Frequency-Tunable Second Harmonic Gyrotron with Selective Cavity: Design and Simulations," in IEEE Transactions on Electron Devices, (2022). DOI:10.1109/TED.2022.3142657.
https://ieeexplore.ieee.org/document/9693990

Novak E., Samsonov S., Savilov A., "Klystron-like Cyclotron Amplification of a Transversely Propagating Wave by a Spatially Developed Electron Beam," Electronics, vol. 11, n.3 (2022) 323. DOI: 10.3390/electronics11030323.
https://www.mdpi.com/2079-9292/11/3/323

M.S. Gitlin et al., "Imaging of a High-Power Millimeter Wave Beam Using a Millimeter Wave-Induced Gas Breakdown Initiated by a Metal-Dielectric Screen," in IEEE Transactions on Plasma Science, (2022). DOI: 10.1109/TPS.2022.3142902.
https://ieeexplore.ieee.org/document/9694494

V.E. Zapevalov, A.S. Zuev, O.P. Plankin, E.S. Semenov, "New Gyrotron Concept: Multi-barrel Gyrotron," 2021 Photonics & Electromagnetics Research Symposium (PIERS), (2021) 1527-1530. DOI: 10.1109/PIERS53385.2021.9695109.
https://ieeexplore.ieee.org/abstract/document/9695109

A.S. Zuev, A.P. Fokin, A.A. Ananichev, A.N. Kuftin, V.E. Zapevalov, M.Y. Glyavin, "Broadband Frequency Tuning in a Powerful Gyrotron for Fusion," 2021 Photonics & Electromagnetics Research Symposium (PIERS), 2021, pp. 1605-1607. DOI:10.1109/PIERS53385.2021.9695026.
https://ieeexplore.ieee.org/abstract/document/9695026

I.V. Bandurkin et al., "400-GHz Frequency-tunable Second-harmonic Gyrotron with Irregular Cavity," 2021 Photonics & Electromagnetics Research Symposium (PIERS), 2021, pp. 1060-1065. DOI: 10.1109/PIERS53385.2021.9694686.
https://ieeexplore.ieee.org/abstract/document/9694686

S.V. Samsonov, G.G. Denisov, A.A. Bogdashov, I.G. Gachev, "Gyro-TWT and Gyro-BWO with a Microwave Circuit in the Form of Zigzag Quasi-optical Transmission Line," 2021 Photonics & Electromagnetics Research Symposium (PIERS), 2021, pp. 2790-2799. DOI: 10.1109/PIERS53385.2021.9695051.
https://ieeexplore.ieee.org/abstract/document/9695051

Y.K. Kalynov, G.I. Kalynova, I.V. Osharin, A.V. Savilov, D.Y. Shchegolkov, "Terahertz Gyrotrons with Azimuthally-asymmetric Cavities," 2021 Photonics & Electromagnetics Research Symposium (PIERS), 2021, pp. 1073-1077. DOI:10.1109/PIERS53385.2021.9695016.
https://ieeexplore.ieee.org/abstract/document/9695016

R.M. Rozental, Y.Y. Danilov, A.N. Leontyev, A.M. Malkin, D.Y. Shchegolkov, V.P. Tarakanov, "Spatial Synchronization of TE-Modes in a Slit-Type Gyrotron Cavity," in IEEE Transactions on Electron Devices, (2022). DOI: 10.1109/TED.2022.3146218.
https://ieeexplore.ieee.org/abstract/document/9704869

Louksha O.I., Trofimov P.A., Manuilov V.N. et al. "Trajectory Analysis in a Collector with Multistage Energy Recovery for a DEMO Prototype Gyrotron. Part II. Toroidal Magnetic Field," Tech. Phys. (2022). DOI:10.1134/S1063784221070082.
https://link.springer.com/article/10.1134/S1063784221070082#citeas

D. Mondal, S. Yuvaraj, M. Rawat, M.K.A. Thumm, M.V. Kartikeyan, "Realistic Design Studies on a 300-GHz, 1-MW, DEMO-Class Conventional-Cavity Gyrotron," in IEEE Transactions on Electron Devices, (2022). DOI: 10.1109/TED.2022.3146101.
https://ieeexplore.ieee.org/document/9705496

Rumyantsev V.V., Maremyanin K.V., Fokin A.P. et al. "Generation of Terahertz Radiation in InP:Fe Crystals Due to Second-Order Lattice Nonlinearity," Semiconductors (2022). DOI:10.1134/S1063782621090189.

B. Publications by other authors worldwide

Guan X., Zhang J., Fu W., Lu D., Yang T., Yan Y., Yuan X., "Frequency Tuning Characteristics of a High-Power Sub-THz Gyrotron with Quasi-Optical Cavity," Electronics, vol. 10, n. 5 (2021) 526. DOI:10.3390/electronics10050526.
https://www.mdpi.com/2079-9292/10/5/526

K. Nawata, Y. Takida, T. Notake and H. Minamide, "Over 200 W Peak-Power Cascaded Backward Terahertz-Wave Parametric Oscillator at 0.3 THz," 2021 46th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz), 2021, pp. 1-2. DOI:10.1109/IRMMW-THz50926.2021.9567609.
https://ieeexplore.ieee.org/abstract/document/9567609

V. Vdovin et al., "An estimation of high-power sub-THz gyrotron based system for space debris detection and Moon scanning," 2021 46th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz), 2021, pp. 1-2. DOI:10.1109/IRMMW-THz50926.2021.9566913.
https://ieeexplore.ieee.org/abstract/document/9566913

X. Guan et al., "A Broadband Quasi-Optical Mode Converter for Sub-Terahertz Confocal Gyrotron Devices," in IEEE Transactions on Electron Devices, (2021). DOI:10.1109/TED.2021.3119911.
https://ieeexplore.ieee.org/document/9585056

Sun-Hong Min, Ohjoon Kwon, Matlabjon Sattorov, Seontae Kim, In-Keun Baek, Seunghyuk Park, Ranjan Kumar Barik, Anirban Bera, Dongpyo Hong, Seonmyeong Kim, Bong Hwan Hong, Chawon Park, Sukhwal Ma, Minho Kim, Kyo Chul Lee, Yong Jin Lee, Han Byul Kwon, Young Joon Yoo, Sang Yoon Park, Gun-Sik Park, "Cell-type continuous electromagnetic radiation system generating millimeter waves for active denial system applications," Defence Technology, (2021). DOI:10.1016/j.dt.2021.10.014.
https://www.sciencedirect.com/science/article/pii/S2214914721001987

R. Shatalova, S. Gurova, V. Revkova, I. Ilina, D. Sitnikov, "Influence of Powerful Non-Ionizing Terahertz Radiation on Healthy and Tumor Human Cells of Neural Origin," Medical Radiology and radiation safety, vol. 66, n. 5 (2021) 5-10. DOI: 10.12737/1024-6177-2021-66-5-5-10.
https://naukaru.ru/en/nauka/article/46725/view

J. Ren et al., "An Easy-to-Fabricate Circular TE_{21}/TE_{01} Mode Generator," in IEEE Transactions on Electron Devices, (2021). DOI:10.1109/TED.2021.3123149.
https://ieeexplore.ieee.org/document/9600005

Fan-Hong Li, Chao-Hai Du, Zi-Wen Zhang, Si-Qi Li, Zi-Chao Gao, Juan-Feng Zhu, Guo-Wu Ma, Qi-Li Huang, Hong-Ge Ma, Liang Zhang, Adrian W. Cross, Pu-Kun Liu, "Development of a Magnetic Cusp Gun for a 1-THz Harmonic Gyrotron," IEEE Transactions on Electron Devices, (2021). DOI: 10.1109/ted.2021.3120699.
https://ieeexplore.ieee.org/document/9610103

Mitra Mirsalehi, Zahra Kavehvash, Mehdi Fardmanesh, "Two Effective methods for improving the quality of THz spectroscopy systems," Optik, (2021) 168276. DOI:10.1016/j.ijleo.2021.168276.
https://www.sciencedirect.com/science/article/pii/S0030402621017964

Batanov G.M., Borzosekov V.D., Kolik L.V. et al. "Plasmoid Generation behind the Front of a Subthreshold Discharge in Air under the Self-Action of a Microwave Beam," Plasma Phys. Rep., vol. 47 (2021) 1042–1048. DOI:10.1134/S1063780X21100019.
https://link.springer.com/article/10.1134/S1063780X21100019

Shadi Shahedipour-Sandvik et al, "(Invited) Defect Microstructural Evolution of Co-Implanted and Gyrotron Microwave-Annealed GaN," Meet. Abstr. MA2021-02 (2021) 998. DOI: 10.1149/MA2021-0234998mtgabs.
https://iopscience.iop.org/article/10.1149/MA2021-0234998mtgabs/meta

S.C. Schaub, Z.W. Cohick, W. Hoff, "Laser requirements for the design of fast laser-driven semiconductor switches for THz and mm-waves," Review of Scientific Instruments vol. 92 (2021) 113106. DOI:10.1063/5.0062711.
https://aip.scitation.org/doi/full/10.1063/5.0062711

Ilgisonis V.I., Ilyin K.I., Novikov S.G. et al. "On the Program of Russian Research in the Field of Controlled Thermonuclear Fusion and Plasma Technologies," Plasma Phys. Rep., vol. 47 (2021) 1085–1091. DOI:10.1134/S1063780X21110179.
https://link.springer.com/article/10.1134/S1063780X21110179

Minxing Wang, Zewei Wu, Xiaoyi Liao, Ran Zhang, Yong Luo, “Selective mode filtering for gyrotron traveling-wave tube systems,” Journal of Electromagnetic Waves and Applications, (2021). DOI: 10.1080/09205071.2021.2004558.
https://www.tandfonline.com/doi/abs/10.1080/09205071.2021.2004558

C.R. Donaldson et al., "8-Fold Helically Corrugated Interaction Region for High Power Gyroresonant THz Sources," in IEEE Electron Device Letters, vol. 42, no. 10 (2021) 1544-1547. DOI: 10.1109/LED.2021.3105435.
https://ieeexplore.ieee.org/document/9514920

PengCheng Yin, Jin Xu, ShuanZhu Fang, RuiChao Yang, JinJing Luo, Jian Zhang, DongDong Jia, HaiRong Yin, LingNa Yue, GuoQing Zhao, Guo Guo, Lin Xu, WenXiang Wang, and YanYu Wei, "Electron optical system with integrated PCM for sheet electron beam devices", Physics of Plasmas, vol. 28(2021) 123101. DOI:10.1063/5.0076651.
https://aip.scitation.org/doi/full/10.1063/5.0076651

N. Kumar, Vishant, A. Bera, "Particle-in-Cell Algorithm-Based Computation of Time-Dependent-Multimode Behavior of 42-GHz Gyrotron," in IEEE Transactions on Plasma Science, (2021). DOI: 10.1109/TPS.2021.3130276.
https://ieeexplore.ieee.org/abstract/document/9635719

X. Gu, S. Hemour, K. Wu, "Far-Field Wireless Power Harvesting: Nonlinear Modeling, Rectenna Design, and Emerging Applications," in Proceedings of the IEEE, (2021). DOI:10.1109/JPROC.2021.3127930.
https://ieeexplore.ieee.org/abstract/document/9628167

C.R. Donaldson et al., "Fivefold Helically Corrugated Waveguide for High-Power W-Band Gyro-Devices and Pulse Compression," in IEEE Transactions on Electron Devices, (2021). DOI: 10.1109/TED.2021.3130846.
https://ieeexplore.ieee.org/abstract/document/9640243

Chen C., Chai M., Jin M., He T., “Terahertz Metamaterial Absorbers,” Adv. Mater. Technol. (2021) 2101171. DOI:10.1002/admt.202101171.
https://onlinelibrary.wiley.com/doi/abs/10.1002/admt.202101171

O.I. Louksha, P.A. Trofimov, B.D Usherenko “New possibilities of collectors with azimuthal magnetic field for multistage energy recovery in gyrotrons,” Journal of Physics: Conference Series, vol. 2103 (2021) 012058. DOI:10.1088/1742-6596/2103/1/012058.
https://iopscience.iop.org/article/10.1088/1742-6596/2103/1/012058

Minxing Wang, Zewei Wu, Xiaoyi Liao, Ran Zhang, Yong Luo, “Selective mode filtering for gyrotron traveling-wave tube systems,” Journal of Electromagnetic Waves and Applications, (2021) DOI: 10.1080/09205071.2021.2004558.
https://www.tandfonline.com/doi/abs/10.1080/09205071.2021.2004558?journalCode=tewa20

Kaiqing Zhang, Yin Kang, Tao Liu, Zhen Wang, Chao Feng, Wencheng Fang, Zhentang Zhao, “A Compact Accelerator-Based Light Source for High-Power, Full-Bandwidth Tunable Coherent THz Generation,” Applied Sciences, vol. 11 (2021) 11850. DOI: 10.3390/app112411850.
https://www.mdpi.com/2076-3417/11/24/11850

Rakesh Kumar, Manoj Kumar, Jasgurpreet Singh Chohan, Santosh Kumar, “Overview on metamaterial: History, types and applications,” Materials Today: Proceedings, (2021). ISSN 2214-7853, DOI:10.1016/j.matpr.2021.11.423.
https://www.sciencedirect.com/science/article/pii/S2214785321074435

Arteaga, H., León-Roque, N., Oblitas, J., “The frequency range in THz spectroscopy and its relationship to the water content in food: A first approach,” Scientia Agropecuaria, vol. 12. n. (2021) 625-634. DOI:10.17268/sci.agropecu.2021.066.
https://revistas.unitru.edu.pe/index.php/scientiaagrop/article/view/3794

Zhang Luqi, Yi Jiang, Wenqiang Lei, Rui Song, Peng Hu, Guowu Ma, and Yanyu Wei, "Analysis of W-band traveling-wave tube based upon slotted sine waveguide slow wave structure", AIP Advances, vol. 11 (2021) 125214 . DOI:10.1063/5.0075447.
https://aip.scitation.org/doi/full/10.1063/5.0075447

A. Miyazaki, et al. “Proof-of-principle of the ultra-narrowband detection scheme at 30GHz toward weakly interacting slim particle search,” FREIA Report (2021).
https://www.diva-portal.org/smash/record.jsf?pid=diva2:1619986

N.V. Grigorieva, “Study of gyrotron synchronization by an external harmonic signal based on a modified quasi-linear theory”, Izvestiya VUZ. Applied Nonlinear Dynamics, vol. 29, n. 6 (2021) 905–914.
DOI:10.18500/0869-6632-2021-29-6-905-914.
http://www.mathnet.ru/php/archive.phtml?wshow=paper&jrnid=ivp&paperid=455&option_lang=eng

Yao Hsin-Yu, Wei Cheng-Hsiung, Chang Tsun-Hsu, “Nonlinear and self-consistent single-mode formulation for TM-mode gyrotrons,” Physical Review E, vol. 104, n. 6 (2021) 065205. DOI: 10.1103/PhysRevE.104.065205.

https://journals.aps.org/pre/abstract/10.1103/PhysRevE.104.065205

Sun, D., Huang, Q., Hu, L. et al. “A CW, 94 GHz Second Harmonic Gyrotron with a Continuous Operation Solenoid Cooled by Water,” J Infrared Milli Terahz Waves (2021). DOI:10.1007/s10762-021-00811-9.
https://link.springer.com/article/10.1007%2Fs10762-021-00811-9

X.Chen et al., "Mode Excitation in Gyrotrons With Triode-Type Electron Guns," in IEEE Transactions on Electron Devices, (2022). DOI:10.1109/TED.2021.3137760.
https://ieeexplore.ieee.org/document/9668923

Jianwei Liu, Junwei Guo, Lina Wang, Xinjian Niu, Xu Sun, "A method for synthesis of quasi-optical transmission line for the 45 GHz/20 kW electron cyclotron resonance ion source", Review of Scientific Instruments, vol. 93 (2022) 014704. DOI:10.1063/5.0062610.
https://aip.scitation.org/doi/10.1063/5.0062610

Chen J., Maly T., “Compact, tunable polarization transforming reflector for quasi-optical devices used in terahertz science,” Review of Scientific Instruments, vol. 93 (2022) 013102. DOI: 10.1063/5.0036292.
https://aip.scitation.org/doi/10.1063/5.0036292

Zewei Wu, Ran Zhang, Minxing Wang, Ruilin Liao, Huan Gao, Shuai Huang, Youlei Pu, Wei Jiang, Guo Liu, Jianxun Wang, Yong Luo, "Circular TE_{0n} Mode Content Analysis Technique for High-Power Gyro-TWT System," in IEEE Transactions on Microwave Theory and Techniques, (2022). DOI:10.1109/TMTT.2021.3136178.
https://ieeexplore.ieee.org/abstract/document/9674741

Raktim Guha, Xin Wang, Xianfeng Tang, Amit Kumar Varshney, Sanjay Kumar Ghosh, Subrata Kumar Datta, Michael A. Shapiro, Edl Schamiloglu, Zhaoyun Duan & B. N. Basu, “Metamaterial assisted microwave tubes: a review,” Journal of Electromagnetic Waves and Applications, (2021). DOI: 10.1080/09205071.2021.2016499.
https://www.tandfonline.com/doi/abs/10.1080/09205071.2021.2016499?journalCode=tewa20

Pazynin V.L., “Sparseness of Natural Oscillations Spectrum for Double-Mirror Open Resonator Using Mode-Selective Scatterers on One of Mirrors Surface,” Radioelectron. Commun. Syst., vol. 64 (2021) 525–534. DOI:10.3103/S0735272721100010.
https://link.springer.com/article/10.3103%2FS0735272721100010

Lan F., He G., Mazumde, P. et al. “Broadband Nonuniform Terahertz Multimode Conversion Series with Compactness and Pure Pattern, J Infrared, Millimeter, and Terahertz Waves (2022). DOI:10.1007/s10762-022-00840-y.
https://link.springer.com/article/10.1007/s10762-022-00840-y

Nowak K., “The Gyrotron for DNP-NMR spectroscopy: A Review,” BULLETIN OF THE POLISH ACADEMY OF SCIENCES TECHNICAL SCIENCES (2022). DOI: 10.24425/bpasts.2022.140354.
https://journals.pan.pl/Content/122222/PDF/_00_02581_Bpast.No.70(1)_18.01.22_EA_.pdf

X. Wang, D. Gao, Y. Wang and J. Yang, "Design and Thermal Analysis of Magnetron Injection Gun for Dual-Band Gyroklystron," in IEEE Transactions on Plasma Science, (2022). DOI:10.1109/TPS.2021.3139427.
https://ieeexplore.ieee.org/abstract/document/9690087

Hur M.S., Kumar M., Song H.S. et al. “Terahertz emission from a plasma dipole oscillation,” J. Korean Phys. Soc. (2022). DOI:10.1007/s40042-021-00390-x.
https://link.springer.com/article/10.1007%2Fs40042-021-00390-x

Mengshi Ma, Qixiang Zhao, Kunshan Mo, Shuquan Zheng, Lin Peng, You Lv, Jinjun Feng, “Design of a Dual-Mode Input Structure for K/Ka-Band Gyrotron TWT,” Electronics., vol. 11, n. 3 (2022) 432.
https://www.mdpi.com/2079-9292/11/3/432

Yu Wang, Guo Liu, Yingjian Cao, Weijie Wang, Wei Jiang, Jianxun Wang, Yong Luo, “Influence of the Output Window Reflection on the Performance of W-Band Gyrotron Traveling Wave Tubes,” IEEE Transactions on Electron Devices, (2022). DOI: 10.1109/TED.2022.3144239.
https://ieeexplore.ieee.org/document/9696167

Budhiraja R., Saini J., “TM Mode Dispersion Characteristics in Cylindrical Waveguide Loaded with Metal Vanes,” International Journal of Microwave and Optical Technology, vol. 17, n. 1 (2022) 24-34.
https://www.ijmot.com/VOL-17-NO-1.aspx.

X. Chen et al., "Mode Excitation in Gyrotrons With Triode-Type Electron Guns," in IEEE Transactions on Electron Devices, vol. 69, no. 2 (2022) 785-791. DOI:10.1109/TED.2021.3137760.

NEW BOOKS

“High Power Microwave Sources and Technologies Using Metamaterials,” John W. Luginsland (Editor), Jason A. Marshall (Editor), Arje Nachman (Editor), Edl Schamiloglu (Editor). ISBN: 978-1-119-38444-1 December 2021 Wiley-IEEE Press 320 Pages.
https://www.wiley.com/en-us/High+Power+Microwave+Sources+and+Technologies+Using+Metamaterials-p-9781119384441

“THz Communications: Paving the Way Towards Wireless Tbps,” Editors Thomas Kürner, Daniel M. Mittleman Tadao Nagatsuma. Series Title: Springer Series in Optical Sciences Series. DOI:10.1007/978-3-030-73738-2.
https://link.springer.com/book/10.1007/978-3-030-73738-2#about

Khanna, Vinod Kumar, "Solid-state devices and vacuum tubes, Practical Terahertz Electronics: Devices and Applications, Volume 1 (2021) IOP Publishing. DOI:10.1088/978-0-7503-3171-5.
https://iopscience.iop.org/book/978-0-7503-3171-5/chapter/bk978-0-7503-3171-5ch8

Lulu Wang (Editor), "Electromagnetic Waves and Antennas for Biomedical Applications." (Healthcare Technologies, 2021). DOI: 10.1049/PBHE033E. ISBN: 9781839531675, e-ISBN: 9781839531682 (338 pages).
https://digital-library.theiet.org/content/books/he/pbhe033e

"Electromagnetic Vortices: Wave Phenomena and Engineering Applications," Editors: Zhi Hao Jiang, Douglas H. Werner. First published:19 November 2021, Wiley). Print ISBN:9781119662822 |Online ISBN:9781119662945 |DOI:10.1002/9781119662945.
https://onlinelibrary.wiley.com/doi/book/10.1002/9781119662945

NEWS FROM THE NET (OUR BROADER HORIZONS)

Japan seeks nuclear fusion reactor prototype by midcentury

On 9 Jan 2022 NikkeiAsia reported "Japan aims to hammer out its very first research and development strategy for nuclear fusion by summer, Nikkei has learned, with the goal of achieving a prototype reactor by around 2050". In another report, it has been announced that Kyoto Fusioneering (KF), the first fusion energy startup in Asia and Japan, has raised 1.33 billion yen (US$ 11.7 million) in its latest round of funding. In particular, KF will use funds for the concentrated development of its plant engineering technologies for plasma heating (**gyrotrons**) and heat extraction (blankets), which are required for fusion reactor projects currently under development worldwide. The company can also accelerate its global expansion to recruit talented engineers and business professionals globally, whilst at the same time furthering its reach by leveraging existing industrial capabilities unique to Japan.

A leap forward for terahertz lasers

In a recent report by Leah Burrows it is announced that researchers have taken a major step towards bringing terahertz frequencies out of their hard-to-reach region of the electromagnetic spectrum and into everyday applications. In a new paper, the researchers demonstrate a first-of-its-kind terahertz laser that is compact, operates at room temperature and can produce 120 individual frequencies spanning the 0.25 - 1.3 THz, far more range than previous terahertz sources. The laser could be used in a range of applications, such as skin and breast cancer imaging, drug detection, airport security and ultrahigh-capacity optical wireless links. The research, conducted by a team from at the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS), in collaboration with the DEVCOM Army Research Lab and DRS Daylight Solutions, is published in APL Photonics (Open Access). "This is a leap-ahead technology for generating terahertz radiation," said Federico Capasso, the Robert L. Wallace Professor of Applied Physics and Vinton Hayes Senior Research Fellow in Electrical Engineering at SEAS and senior author of the paper. "Thanks to its compactness, efficiency, wide tuning range, and room temperature operation, this laser has the potential to become a key technology to bridge the terahertz gap for applications in imaging, security, or communications." This radiation source is a quantum cascade laser-pumped molecular laser (QPML) tunable over 1 THz spanning the range from 0.25 to 1.3 THz. The authors of the paper say "Thanks to its large permanent dipole moment and large rotational constants, methyl fluoride (CH3F) as a QPML gain medium combines a lower threshold, larger power efficiency, and a wider tuning range than other molecules. These key features of the CH3F QPML, operated in a compact cavity at room temperature, pave the way to a versatile THz source to bridge the THz gap". For further reading on this topic see the report "Terahertz Lasers Are About to Have a Moment", published by Payal Dhar in IEEE Spectrum.

Physicist Solves Century Old Problem of Radiation Reaction

On its website, the Lancaster University announces: “A Lancaster physicist has proposed a radical solution to the question of how a charged particle, such as an electron, responds to its own electromagnetic field. This question has challenged physicists for over 100 years but mathematical physicist Dr. Jonathan Gratus has suggested an alternative approach - published in the Journal of Physics A- with controversial implications.” The author claims: “In this letter we have presented the case why Maxwell–Lorentz without self-interaction is the best model for the dynamics of charged particles. It has many advantages.” The history of attempts to calculate this radiation reaction (also known as radiation damping) date back to Lorentz in 1892. Major contributions were then made by many well-known physicists including Plank, Abraham, von Laue, Born, Schott, Pauli, Dirac, and Landau. Active research continues to this day with many articles published every year.
Reference: “Maxwell–Lorentz without self-interactions: conservation of energy and momentum” by Jonathan Gratus, 21 January 2022, Journal of Physics A Mathematical and Theoretical. DOI: 10.1088/1751-8121/ac48ee. (Open Access)

Slow waves on long helices

In a recent paper, the authors report: “Slowing light in a non-dispersive and controllable fashion opens the door to many new phenomena in photonics. As such, many schemes have been put forward to decrease the velocity of light, most of which are limited in bandwidth or incur high losses. In this paper we show that a long metallic helix supports a low-loss, broadband slow wave with a mode index that can be controlled via geometrical design. For one particular geometry, we characterize the dispersion of the mode, finding a relatively constant mode index of ~ 45 between 10 and 30 GHz. We compare our experimental results to both a geometrical model and full numerical simulation to quantify and understand the limitations in bandwidth. We find that the bandwidth of the region of linear dispersion is associated with the degree of hybridisation between the fields of a helical mode that travels around the helical wire and an axial mode that disperses along the light line. Finally, we discuss approaches to broaden the frequency range of near-constant mode index: we find that placing a straight wire along the axis of the helix suppresses the interaction between the axial and high index modes supported by the helix, leading to both an increase in bandwidth and a more linear dispersion.”
Reference: Barr, L.E., Ward, G.P., Hibbins, A.P. et al. Slow waves on long helices. Sci Rep 12, 1902 (2022). DOI:0.1038/s41598-022-05345-1. (Open Access)

When Light Loses Symmetry, It Can Hold Particles

A post at PhysOrg presents a paper devoted to optical trapping. The annotation says: “Optical tweezers use light to immobilize microscopic particles as small as a single atom in 3D space. The basic principle behind optical tweezers is the momentum transfer between light and the object being held. Analogous to the water pushing on a dam that blocks the stream, light pushes onto and attracts objects that make the light bend. This so-called optical force can be designed to point to a certain point in space, where a particle will be held. In fact, the optical trapping technique has so far won two Nobel Prizes, one in 1997 for holding and cooling down single atoms, a second in 2018 for offering biologists a tool to study single biomolecules such as DNA and proteins. Researchers led by Prof. Yuanjie Pang at Huazhong University of Science and Technology (HUST), China, are interested in the use of fiber optical tweezers, where light and particles are manipulated at the tip of an optical fiber. This technique eliminates the requirement of conventional, bulky, optical accessories such as microscopes, lenses and mirrors. Their idea is to start with a perfectly annular symmetric light mode that can only be transmitted in the optical fiber and will not leak into the surrounding space through the fiber tip, and have a particle to break the mode symmetry and thereby scatter light into the space. This way, by changing the symmetry and the momentum of the light, the particle receives a reactive force that holds it at the fiber tip. he researchers predict potential applications such as performing an in-vivo single bioparticle-manipulating experiment by using the fiber optical tweezers as an endoscope in the interior of a living animal.
Reference: Lou, Y., Ning, X., Wu, B. et al. Optical trapping using transverse electromagnetic (TEM)-like mode in a coaxial nanowaveguide. Front. Optoelectron. 14, 399–406 (2021). DOI:10.1007/s12200-021-1134-3.