High quality operation of gyrotron aiming toward the convenient radiation source in the submillimeter wave length range

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Abstract
Output power and frequency of a submillimeter wave gyrotron (GYROTRON FU IV) have been stabilized by putting a smoothing circuit in cathode and anode lines. It consists of a resistor, an induction coil and a capacitor. As a result, the fluctuations of both the cathode and the anode potentials decrease to ΔV_k~0.6V and ΔV_a~0.2V, respectively. For the regime characterized by output power P~20 W and frequency f=301 GHz, we have achieved stability of the output power $\Delta P/P \sim 10^{-2}$ and frequency $\Delta f/f \sim 1.7\times10^{-7}$. Using a phase-lock control, stability of the frequency of radiation increases up to $\Delta f/f < 3.3\times10^{-9}$. A carefully designed cavity resonator with nonlinear up-taper has been developed and implemented in Gyrotron FU VA. The measurements of the radiation patterns have confirmed high-purity mode operations.

1. Introduction
Up to the present, molecular vapour lasers [1, 2] and backward-wave oscillators [3, 4] have been used as the principal power sources in the submillimeter wavelength range. However, their output powers are lower than 0.5 W. High frequency gyrotrons have many advantages such as moderately high power and frequency tunability which other conventional sources never possess.

For many applications of gyrotrons, the stabilization of the output power and frequency is very important. It can be achieved by decreasing the fluctuations of the cathode potential and the anode potential. As long as the gyrotron is a voltage controlled oscillator [5], a high frequency stability can be attained by phase lock control.

Unlike the molecular vapor lasers, the gyrotrons generate diverging beam of radiation with TE_{mn} mode structure. It is therefore necessary to convert the output radiation into a Gaussian beam (TEM_{00} mode), which is suitable for an effective transmission and can be used as a well-collimated probe beam. In this respect, a high purity mode operation is a prerequisite for effective conversion of the output radiation into the Gaussian beam. We have constructed a new gyrotron, namely, Gyrotron FU VA, which has a carefully designed resonant cavity. It is developed in collaboration with Stuttgart University and the Institute for High Power Pulse and Microwave Technology at the Research Center Karlsruhe (FZK).

2. Stabilization of output power and frequency
We have achieved cw operation of the submillimeter wave gyrotron, Gyrotron FU IV. This gyrotron consists of sealed-off tube and magnet system. The superconducting magnet produces the main field in the cavity region whose intensity can be raised up to 12T. Three subsidiary copper coils are used in the electron gun region. Both fields can be adjusted independently to control the formation of the electron beam produced by the MIG. The cw operation (TE_{03} mode, f=301GHz, P=20W) is obtained under the following conditions: magnetic field intensity in the cavity region B_0=10.8T, cathode potential V_k=-16kV, anode potential V_a=-2.9kV. The output power of cw operation was not stable ($\Delta P/P$~several percent) due to the fluctuation of the cathode potential (ΔV_k~40V). The evolution of operation parameters with time is shown in Fig.1. The fluctuation of the output power ΔP correlates with that of the cathode potential ΔV_k. In order to suppress the fluctuation level of the cathode potential and the anode potential, high voltage power supplies are equipped with smoothing circuits consisting of a resistor, an induction coil and a capacitor (Fig.2). The fluctuation level was decreased (ΔV_k~0.6V and ΔV_a~0.2V). Accordingly, the fluctuations of the output power were decreased from 4 % to 1 % (Fig.3).

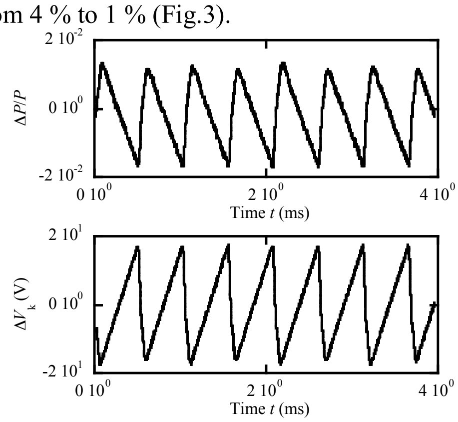


Fig.1 Time evolution of fluctuations of gytotron output power ΔP, cathode potential ΔV_k.

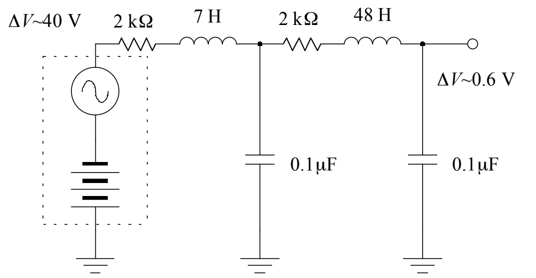


Fig.2 A smoothing circuit to suppress output voltage fluctuations.

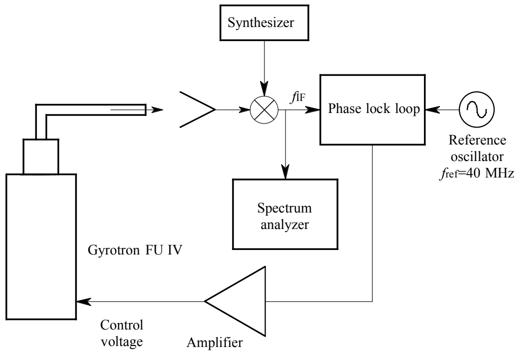


Fig.4 Block diagram of a phase lock system.

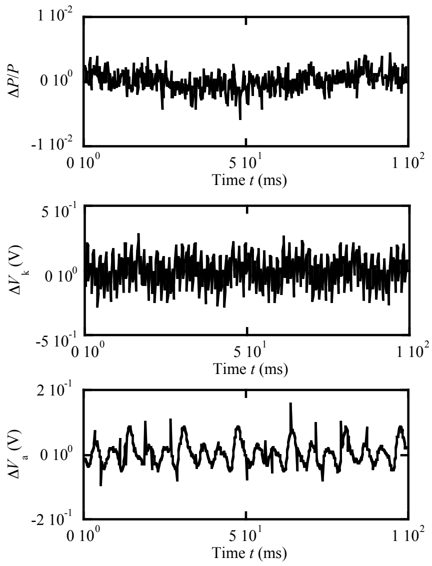


Fig.3 Time evolution of fluctuations of gytotron output power ΔP, cathode potential ΔV_k and anode potential ΔV_a.

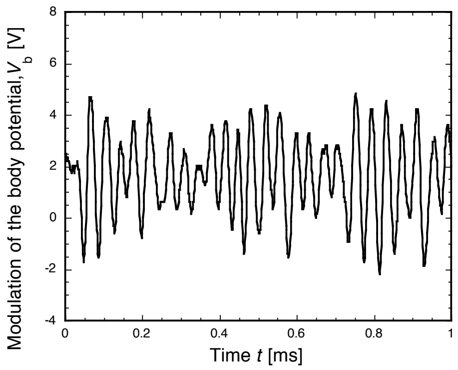
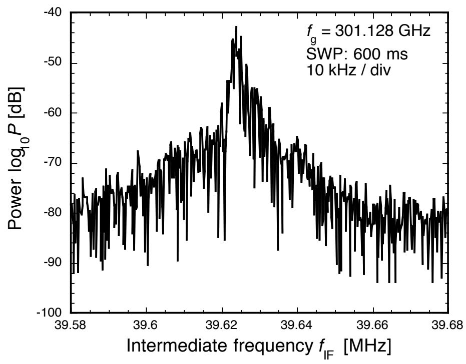


Fig.5 The phase lock signal.

(a)



(b)

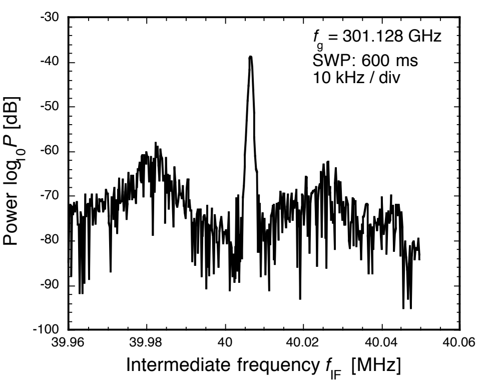


Fig.6 Frequency spectra of intermediate frequency signal. (a) without phase-locked stabilization and (b) under phase-locked stabilization.

3. Stabilization of output frequency using phase lock control

The fluctuation of output frequency is removed by smoothing circuits and gyrotron functions as a voltage controlled oscillator. This enables us to attain a high stability of output frequency by introducing a phase lock control. Compared to conventional sources (Gunn oscillator, BWO), gyrotron has a small frequency modulation sensitivity (0.016 MHz/V). In order to compensate the mismatch of modulation sensitivity, we introduce an amplifier between a phase lock module for gunn oscillator and a control electrode (Fig.4). The phase lock signal is fed back to gyrotron body electrode across a load resister of 1kW (Fig.5). Frequency stabilization is effectively improved by introducing phase lock control from Δf~10kHz (Fig.6(a)) to Δf<1kHz (Fig.6(b)).

4. High purity mode operation of a gyrotron

Gyrotron FU VA (Fig.7) is constructed using a helium-free superconducting magnet. This magnet can produce a magnetic field up to 8 T without using liquid helium. The tube is demountable, because we will try to optimize all components, the cavity, the transmission waveguide and the output window. The window is made by quartz plate with the thickness of 3.175 mm and relative dielectric constant of 3.83.

In order to avoid conversion of the cavity mode to spurious modes, the cavity (Fig.8) has an optimized design with nonlinear up-tapers and a rounded iris at the output. The resonance calculation using a scattering matrix formalism (SM-code) was performed taking into account the complete gyrotron geometry including the pumping sections (slots) and the window [6]. The radiation patterns are measured by two-dimensionally (x-y plane) moving pyro-electric detector array over the gyrotron window. The intensity profiles of radiation pattern for TE_{03}-, TE_{13}- and TE_{32}-mode are shown in Fig.9. These patterns are not so affected by the diffraction at the output aperture of waveguide because they are measured in the far-field region ($z > z_f = ka_w^2 \sim 200$ mm).

The patterns for these modes agree well with the intensity profiles calculated. This demonstrates that Gyrotron FU VA can produce outputs of high purity mode. As can be seen from Figs.9 (b) and (c), this gyrotron does not produce a rotating mode but a non-rotating mode. Such a feature is favorable for converting gyrotron output into a Gaussian beam, because a quasi-optical antenna is available for a set of TE_{0n} mode outputs and non-rotating TE_{1n} mode outputs.

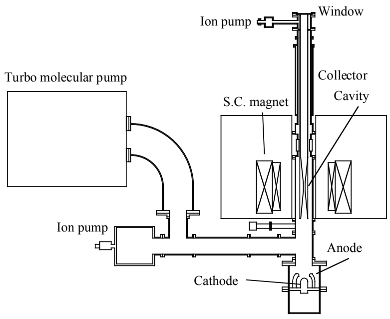


Fig.7 Schematic drawing of Gyrotron FU VA.

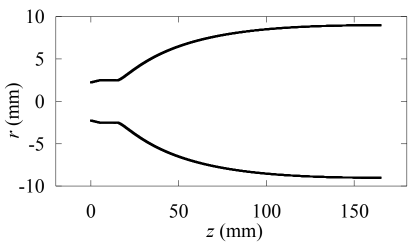


Fig.8 Configuration of the cavity and up-taper.

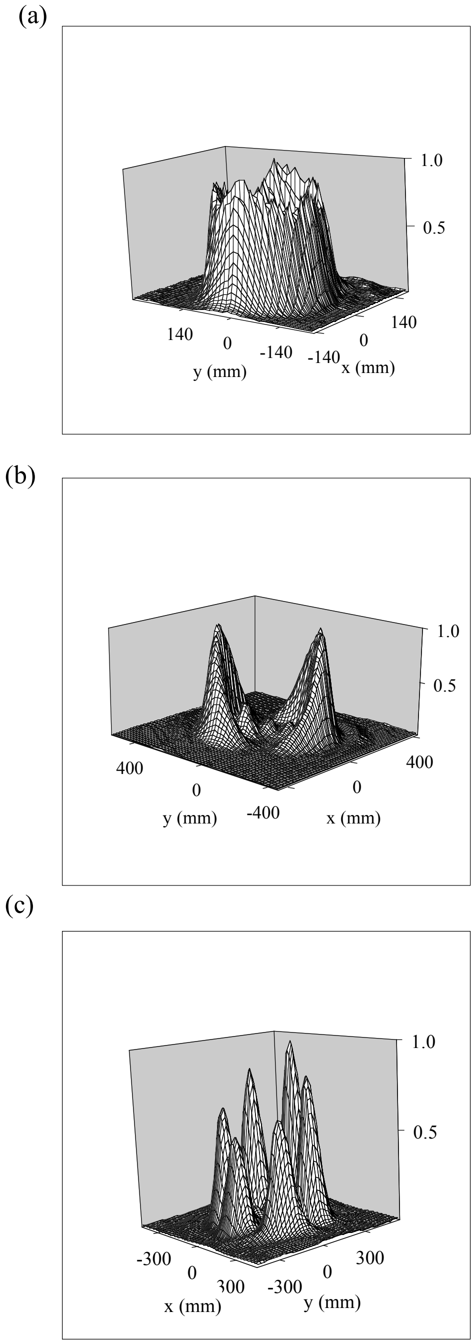


Fig.9 Intensity profiles of radiation pattern.
(a) intensity profile for TE_{03} mode
(b) intensity profile for TE_{13} mode
(c) intensity profile for TE_{32} mode

5. Conclusions

The output of the Gyrotron FU IV (f=301 GHz, P~20 W) obtained by cw operation is stabilized up to 1 % and 10 kHz by decreasing the fluctuations of the potentials ($\Delta V_k \sim 0.6$V, $\Delta V_a \sim 0.2$V), via introducing a smoothing circuit consisting of a resistor, an induction coil and a capacitor. As a result of phase lock loop, we succeeded to reduce the frequency fluctuation within 1 kHz.

To produce high purity mode outputs, a

carefully designed cavity is installed in Gyrotron FU VA. The measurement of radiation patterns demonstrates high purity non-rotating mode operations. The resonance calculation for a complete gyrotron geometry using scattering matrix formalism (SM-code) was carried out and the results were compared with the measurement.

References

[1] A.Semet, A.Mase, W.A.Peebles, N.C.Luhmann Jr. and S.Zweben, Phys. Rev. Lett. **45**, 445 (1980).

[2] K.Kawahata, T.Tetsuka, J.Fujita, M.Nagatsu, H.Ohnishi, S.Okajima and T.Iwasaki, Int. J. of Infrared and Millimeter Waves **9**, 655 (1988).

[3] I.Morino, M.Fabian, H.Takeo and K.Yamada, Journal of Molecular Spectroscopy, **185**, 142 (1997).

[4] F.Lewen, R.Gendriesch, I.Pak, D.G.Paveliev, M.Hepp, R.Schieder and G.Winnewisser, Rev. Sci., Instrum., **69**, 32 (1998).

[5] T.Idehara, M.Pereyaslecets, N.Nishida, K.Yoshida and I.Ogawa, Phys. Rev. Lett., **81**, 1973 (1998).

[6] D.Wagner et al., Int. J. of Infrared and Millimeter Waves **19**, 185 (1998).