Vacuum Electron Sources of Terahertz Radiation

V.L. Bratman
Institute of Applied Physics, Russian Academy of Sciences, 46 Ulyanov Str., Nizhny Novgorod, Russia 603950
bratman@appl.sci-nnov.ru

Abstract-**Capabilities of vacuum devices in creation of compact and powerful terahertz sources will be discussed. Main attention will be focused on orotrons (or Generators of Diffraction Radiation) and on several varieties of gyrodevices (fundamental and second harmonic gyrotrons, high harmonic Large Orbit Gyrotrons, gyromultipliers). These generators can be available for many laboratories.**

I. Introduction

In principle, vacuum electronics allows production of coherent Terahertz radiation practically at any power level. The most widespread electron devices of this frequency range – low-voltage Backward Wave Oscillators (BWOs) – enable CW radiation with output power $1\text{-}10^{-3}$ W at the frequencies of 0.1-1.0 THz with a broad frequency tuning. Gyrotrons enable a fantastic high power up to 1 MW at the frequency of 0.17 THz in quasi-CW regime. Gyrotrons with strong pulse magnetic field demonstrate tens kW of output power at the frequencies up to 0.65 THz. The highest frequency achieved in gyrotrons is close to 1.0 THz. Free Electron Lasers (FELs) demonstrate very high pulse and average power along with a possibility of broadband frequency tuning within entire Terahertz range and even at many times higher frequencies.

It should be, however, noticed that gyrotron operation at THz waves requires very strong magnetic field: 36 T at the frequency of 1 THz when generating at the fundamental cyclotron resonance. This is possible in pulse regime only. An alternative way is generation at high cyclotron harmonics that practically is possible at the 2nd harmonic and sometimes at the 3rd one. Gyromultipliers can operate at higher harmonics. With account of this, low-voltage and compact gyrotrons with magnetic field of 5-12 T can provide $1\text{-}10^{4}$ Watt at the frequencies up to 1 THz. As for Terahertz FELs, they use basically very high electron energy 2-12 MeV that can be only produced in large accelerators.

Many new applications appearing last years require Terahertz devices with power higher than it can be generated in BWOs. In this presentation, two types of promising devices that can satisfy needs in such power will be discussed. These are Orotrons [1], or Diffraction Radiation Generators [2], and varieties of gyrodevices which basically operate at high cyclotron harmonics. Both types of devices are now under intensive development in the Institute of Applied Physics (orotrons - in collaboration with "VNIIFTRI", Mendeleevo and Institute of Spectroscopy, Russian Academy of Sciences, Troitsk, Moscow region) [3].

II. Orotrons

Operation of the Orotron is based on the stimulated Smith-Purcell radiation of a rectilinear electron beam moving over or inside a periodic structure that serves as a mirror of an open cavity. Due to high selectivity of the cavity, utilizing significantly broader electron beams with higher currents and generation of higher output power in comparison with BWOs is possible in Orotrons. Broad electrical-mechanical frequency tuning is also realized in Orotrons. At the moment, a series of the developed low-voltage (0.5-5 kV) orotrons can generate in the frequency range of 0.1-0.4 THz with output power of 1.0-0.1 W and typical electrical-mechanical frequency tuning within an octave.

III. Gyrodevices

Both conventional and Large-Orbit Gyrotrons [4] are also under development in the Institute of Applied Physics. Being based on the same mechanism of stimulated cyclotron radiation of electrons, the Large Orbit Gyrotrons have an important advantage over conventional gyrotrons in lower currents and possibility of more selective operation at higher cyclotron harmonics; respectively, they work at lower magnetic fields. At the same time significantly more complicated electron guns are needed for them to provide appropriate axis-encircling electron beams. Such beams with electron energy 50-250 keV and high compression have been obtained and selective generation at 1st-5th cyclotron harmonics have been demonstrated at millimeter and submillimeter waves. When operating at the 3rd cyclotron harmonic, generation with power level of 10 kW has been obtained in the range of 0.3-0.42 THz [3].

Another prospective way for developing Terahertz sources, that will be also discussed, is realization of gyromultipliers with an external signal (e.g. from Orotron) or with a self-exciting low-frequency section.

References

[1] F.S. Rusin, G.D. Bogomolov, "Device for generation and amplification of microwaves in an open cavity", *JETP Letters*, vol. 4, pp. 236-239, 1966.

[2] V.P. Shestopalov, *Diffraction Electronics*, Kharkov: Vischa shkola, 1976.

[3] V.L. Bratman, I.V. Bandurkin, B.S. Dumesh, A.E. Fedotov, Y.K. Kalynov, F.S. Rusin et al., "Sources of coherent Terahertz radiation", in *High Energy Density and High Power RF*, AIP Conference Proc. 2006, pp. 356-367.

[4] H.R. Jory, Research and Development Technical Report ECOM-01873-F, Varian Associates, Palo Alto, California, 1968.