doi: 10.56761/EFRE2024.S3-O-017701

Diagnostic system to measure parameters of high-power sub-mm/THz radiation fluxes at pulse duration 0.1–5 μs

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Abstract. Currently various approaches to create sources of electromagnetic (EM) radiation in frequency range 0.1–10 THz are developing. Accordingly, a task on developing diagnostic systems to measure properties of the generated radiation especially of megawatt or higher power level becomes of high importance. In given report considered different diagnostic systems applied at experiments on generation of THz radiation pulse fluxes carrying out at Budker institute of nuclear physics (BINP). Among these diagnostics are: 1) eight channel polychromator for the range 0.15–0.5 THz, 2) a two-channel cryogenic detector for the range 0.6–1.2 THz, 3) a heterodyne system operating at frequency 75 GHz, 4) burning neon bulbs to visualize a radiation flux, and 5) a calorimeter for energy content measuring. In order to define requirements for the diagnostic systems of electromagnetic radiation, we briefly describe peculiarities of the EM-flux generation and of study approaches at various generation facilities at the BINP. Then, the prospects of current diagnostics usage and their development necessity will be discussed in accordance to the parameters of constructed novel facilities.

Keywords: free-electron devices, THz radiation, powerful radiation flux, quasi-optical instrumentation.

1. Introduction

Creation of a radiation source with sub-gigawatt power in a submillimeter/THz frequency ranges is an actual problem of modern scientific research. Accompanying tasks to be solved are development of diagnostic systems to measure parameters of such electromagnetic radiation fluxes. The activity on the development of each individual diagnostic system depends on properties of radiation flux generated by any radiation source. Given paper devoted to describe of submillimeter radiation diagnostic complex that is currently used at the Budker Institute of Nuclear Physics of Siberian Branch of Russian Academy of Science (BINP) for research on generation of electromagnetic radiation in frequency range from 70 GHz to 0.9 THz. In this paper, there is established limitations of the current diagnosis complex operation in frame of its use in future research and possibility to perform its developing for solving this task. Necessity of comprehensive analysis of diagnostic complex is caused by developing of two new facilities and planning of further experimental research at the existing ones. All these operating and under construction facilities intended to generate radiation fluxes in sub-THz/THz frequency ranges are require diagnostics for measuring the radiation parameters. To begin with, all these facilities and approaches to generate THz generation will be presented briefly. Then, diagnostic complexes used at the BINP to measure the properties of radiation fluxes at mentioned up facilities will be described. These complexes description will be done taking into account requirements for measurement peculiarities of the radiation fluxes generated at these facilities.

2. Experimental study on generation of sub-mm/THz radiation

Several approaches to studying of submm wave generation are realized at the Budker Institute of Nuclear Physics. One of the way to generate radiation fluxes in the submm/THz frequency range is to use an intense interaction of a relativistic electron beam (REB) with a magnetized plasma column. Such research activity is carried out at the GOL-PET facility [1, 2]. The feature of this generation mechanism is providing high-power (~10 MW) pulsed (~3 μs) radiation fluxes in wideband spectrum (0.1–0.5 THz) (see [1, 2]). Another way is to use a planar free electron maser (FEM) with two dimensional distributed feedback on the base of ribbon electron beam (0.9 MeV / 2–3 kA / 5 μs) as it was done at the ELMI facility in the BINP in collaboration with Institute of Apply Physics (IAP, Nizhniy Novgorod) [3]. In frame of these experimental studies, the producing of 40 MW pulses of narrowband 75 GHz radiation fluxes has already achieved [4]. Besides that, the project on the creation of a short-wavelength Cherenkov maser of planar geometry [5] on the base of the mentioned ribbon beam is realized at the ELMI facility in the BINP in collaboration with IAP, as well. Moreover, the project of a new free electron lase (FEL) using the intense REB (5 MeV / 2 kA / 100 ns) from the linear induction accelerator (LIA) [6–7] being built at the BINP will advance long-pulse FEL-generators into a THz range at a gigawatt power level. A few key parameters of radiation fluxes generated at the mentioned up facilities are given in the Table 1.

Table 1. Facilities for THz generation in BINP.

Facility name	**Frequency**	**Pulse duration**	**Pulse Power**	**Status**
GOL-PET	0.1–0.5 THz	1–5 us	~ 10 MW	Operating
ELMI (2D feedback)	75 GHz, 1 THz	100–150 ns	40MW, 40kW	Operating
ELMI (Cherenkov maser)	75, 150, 300 GHz	150 ns	up to 0.5 GW	Operating
LIA-FEL	0.3, 0.6, 1.2 THz	80–120 ns	up to 0.5 GW	Under construction
LIA-PET	0.3–0.9 THz	80–120 ns	1–100 MW	Under construction

3. Diagnostic complexes

These diagnostic complexes are intended to study submm-radiation fluxes with the pulse duration of 0.1–1 us in the frequency range 75–1000 GHz. The single pulse power is varied from 1MW to 0.5 GW in depend on facility type and generation regime.

3.1. Multi-channel radiometric complex

One of the tasks solved at experimental studies on generation of THz radiation in beam-plasma system is measuring spectral composition power density of the radiation flux. It is for this purpose that a radiometric wideband complex based on an assembly of individual THz sensors is used. The complex consists of eight-channel polychromator based on Schottky barrier diode (SBD) sensors for broadband spectral analysis in the range (0.15–0.5 THz) [8] and two-channel detector using two cryo-bolometers of SCONTEL Company, type “HEB 1” for the range 0.3–3 THz [9]. The scheme of these two parts compose the complex are presented in Fig. 1. We discuss only main features of this multi-channel radiometric complex.

In eight-channel polychromator, a quasi-optical system creates 8 individual radiation beams by dividing an initial radiation flux entered in this diagnostic. Each individual flux propagates to sensor of each registration channel through quasi-optical system. That system is based on polarizing beam-splitters and sensitive to incoming flux polarization. In order to ensure sufficient resolution of the polychromator channels band-pass FSS-filters are used. FSS-filters have the relative bandwidth (FWHM) of 12–14% and are distinguished by the high out-of-band suppression (> 40 dB) and low insertion losses (about 10%) in the transmission maximum. Hence, final responsivity of each channel is determined as multiplication of the transmission function of the correspond filter with self-responsivity of the sensor. The advantage of this system is a possibility to optimize responsivity based on a number of filters. Time resolution for sensors in use is about 1 ns that actually sufficient for current and future research. It should be noted that given approach allows independently decrease radiation power in different channels in order to provide acceptable level for each sensor. We also apply a diagnostics with much higher frequency resolution, such heterodyne system.

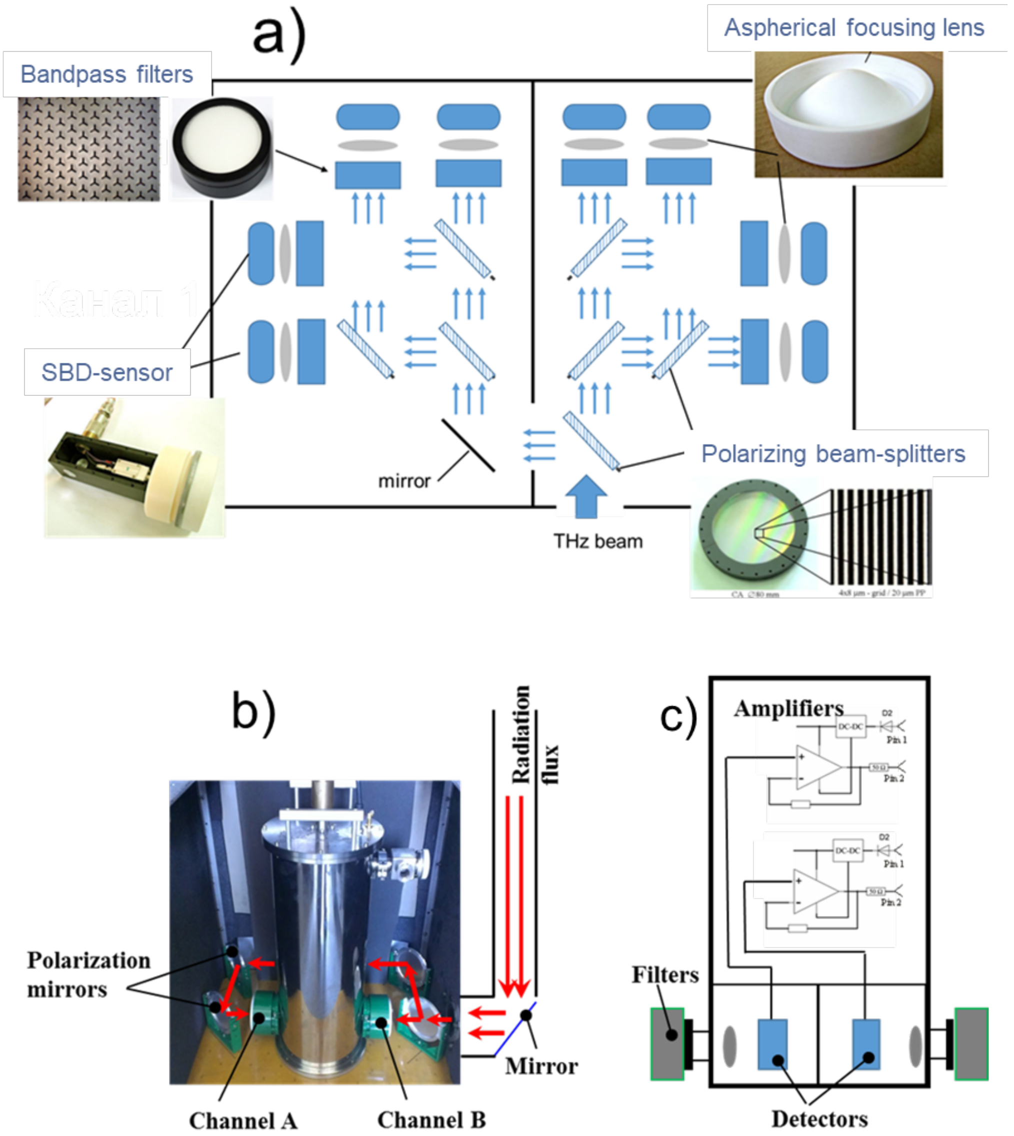

Fig. 1. Scheme of eight-channel polychromator (a), operation schematic of cryo-bolometers detector (b) and its electrical scheme (c).

3.2. Heterodyne system

Example of the system for precise spectrum analysis in the vicinity of the allocated frequency is a heterodyne system. It provides two input signals combining in a nonlinear signal-processing device. As a result, the frequency of the output signal is difference between the frequencies of two input signals. This diagnostic is used at the ELMI facility for analysis of the radiation spectrum in experiments on radiation generation in electrodynamic system with two-dimensional distributed feedback [4]. It should be noted that investigated and referenced radiation should be inside operating range of heterodyne. Moreover, bound of this frequency range is limited by frequency band of the receiver. Scheme of heterodyne system at the ELMI facility is shown in Fig. 2. It was developed in order to provide detailed spectrum study at frequency range 73–77 GHz. It should be noted that effective heterodyning is possible with comparable power of the studied and reference signals. Hence, in experiments additional measurements of radiation power and flux attenuation are required.

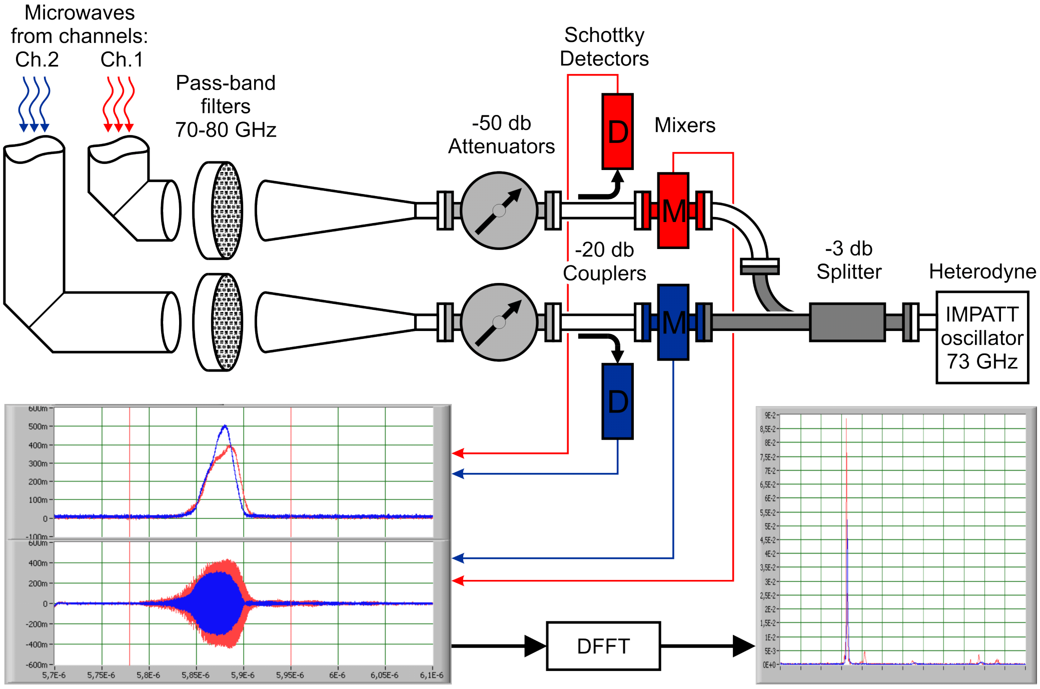

Fig. 2. Scheme of heterodyne measuring system with signal example.

3.3. Calorimeter

One of the important characteristics of single radiation pulse is its energy content. For measuring this radiation parameter at the GOL-PET facility experiments, we use a calorimeter created in Institute of Apply Physics (Nizhniy Novgorod) [10]. The calorimeter operation is based on the absorption of EM-radiation in a thin-walled shell and on recording the change in its temperature by a set of large number thermocouples. Scheme of the calorimeter and example of the signal measured in experiments at GOL-PET facility presented in Fig. 3. This device allows one to measure energy content over wide frequency range but it has time resolution about 10 s. Strictly speaking, the calorimeter responsivity varied in depend on radiation frequency due to change in efficiency of its absorption for different frequencies. Calibration experiments for measuring the calorimeter sensitivity gave the following results: 70 μV/J at a frequency of 10 GHz and 90 μV/J at a frequency of about 100 GHz. Thus, it was used at experiments on THz generation in beam-plasma system under assumption that responsivity change in frequency range 0.1–0.5 THz is less then 20%. Results of these measurements presented in [2]. In addition, this calorimeter is also used in order to measure energy content in radiation flux generated at experiments at the ELMI facility.

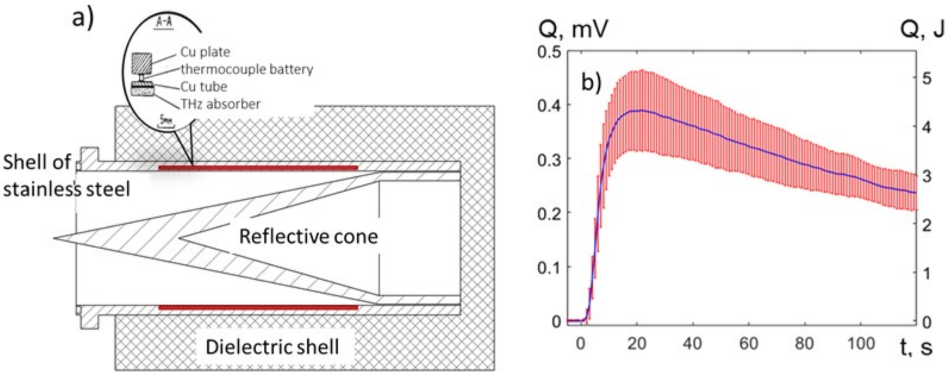

Fig. 3. Scheme of the calorimeter (a) and example of the measured signal (b).

3.4. Neon bulbs panel

If power density in a radiation flux exceeds certain value, the glowing of gas-discharge bulbs may be used to visualize the flux cross-section as it shown in Fig. 4. This method allows one to obtain spatial power distribution of the radiation flux. The bulb glowing may be recorded by image recording with fast CCD-camera or by measuring current flow through the bulbs during discharge. In experiments at GOL-PET facility used only photography of panel glowing that allows us to estimate cross-section of the power radiation flux outgoing in atmosphere. Such way, it has been established in experiments at the GOL-PET facility that a high power flux submm- radiation propagates in atmosphere over 3-meter [11].

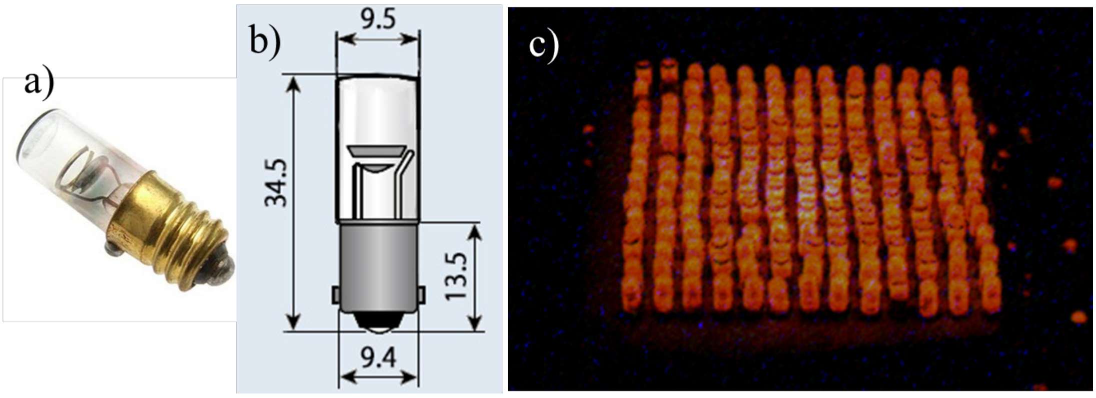

Fig. 4. Example of the THz radiation flux visualization based on neon bulbs panel. Bulb photo (a) and scheme (b). Photo of the panel glowing in experiment (c).

4. Conclusion

So, various methods to measure properties of the megawatt power level radiation in frequency range from 70 GHz to 0.9 THz is described shortly in this paper. The use of multi-channel radiometric system is justified for study of spectral power density in broadband frequency range. Responsivity of the sensors usually decrease with frequency growth. Nevertheless, current technological level allows one to create registration complex of such type for measurements up to 1 THz frequency range. In addition, it should be noted that spectral resolution mostly depend on characteristic of bandpass filters and could be improved. The use of heterodyne system is more suitable for detailed measurements of the radiation spectrum in narrowband frequency range. These systems provide high time and spectral resolution in measurements. Unfortunately, its broad use in subTHz/THz range is limited by limitations of individual component frequency properties. Measurements of energy content in radiation pulse could be performed with use of the calorimeter. The most disadvantage of this diagnostic is low time resolution. The precision of the calorimeter measurements depend on device calibration at varying frequencies in wide frequency band. The use of neon bulbs panel allows easily obtain on qualitative level supplementary characteristic of the radiation flux e.g. spatial power density distribution over flux cross section. With due effort, this approach of measurement radiation parameters can be improved to obtain quantitative characteristics. To sum up, current diagnostics used at experiments on radiation generation in frequency range from 70 GHz to 0.9 THz are provide satisfactory possibility to measure radiation parameters. Moreover, there are some possibilities to perform additional development of the diagnostic complex described in the paper.

Acknowledgement

The activity on creation and development of diagnostic system of the radiation is supported partially by the Russian Science Foundation (grant No. 23-1900370).

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