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Martin-Puplett interferometer for studying THz and subTHz radiation

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Abstract. The design of a portable terahertz and subterahertz interferometer, manufactured according to the Martin-Puplett scheme, is presented. The possibility of using film polypropylene polarizers in interferometers of this type has been demonstrated. The provided possibility of using various types of radiation detectors makes it possible to perform measurements in high-performance or high-sensitivity modes. The presented interferometer is proposed to be used to measure the spectra of terahertz and subterahertz radiation produced during the interaction of bunched and continuous beams of charged particles with solid targets.

1. Introduction

Terahertz radiation is electromagnetic radiation, the frequency range of which is between infrared and microwave radiation (from 100 GHz to 10 THz) [1]. Interest in this frequency range is due to the ability of THz waves to penetrate deep into media like X-rays. But unlike X-rays, the energy of THz photons is not enough to ionize the atoms of the medium, which makes the use of THz radiation completely safe. Since many substances are transparent to THz waves, they can be used to solve applied problems in medicine [2], biology [3], and spectroscopy of materials [4].

Despite all the advantages of using THz radiation, its generation is a difficult task. To create a source of broadband and incoherent radiation with low intensity in this frequency range, it was necessary to use large-sized and expensive equipment [5]. For example, these could be free electron lasers or thermal sources. The use of THz radiation is also complicated by the fact that it is quite difficult to detect [6]. Due to the lack of suitable sources, sensitive detectors and other components, this frequency range came to be called the “THz gap” [7]. Due to the great prospects for the use of THz radiation, many methods have been developed to effectively generate and detect THz radiation. For example, to generate THz radiation, it was proposed to use Smith-Purcell radiation [8], Cherenkov diffraction radiation [9], and coherent transition radiation [10].

One of the ways to register THz radiation is the use of interferometric methods [11]. An interferometer is a common tool in many areas of physics that works by combining multiple coherent radiation sources to create an interference pattern that can be measured and analyzed. Many types of interferometers used for visible light have also been tested in the THz frequency range, such as the Mach-Zehnder interferometer [12], the Michelson interferometer [13–14], and the Fabry-Perot interferometer [15].

This work presents an interferometer for studying radiation in the THz and sub-THz frequency range manufactured according to the Martin-Puplett scheme [16]. A special feature of

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this interferometer is the use of polarization beam splitters. Such interferometers have been successfully used to measure the characteristics of relativistic bunched beams of charged particles [17–19].

2. Interferometer design

The scheme of the interferometer manufactured in Belgorod National Research University is shown in figure 1. The interferometer consists of three polarizers, a movable and fixed corner reflector, and a detector that allows one to measure the radiation intensity. Unpolarized radiation, the spectrum of which needs to be determined, passes through the first polarizer with the plane of polarization oriented vertically and becomes linearly polarized. Next, the polarized radiation hits the beam splitter (a polarizer with a polarization plane rotated by 45° relative to the first polarizer) and is evenly distributed between the two arms of the interferometer, limited by corner reflectors made of Al-Cu 2124 alloy. Reflecting from the corner mirrors, the polarization plane of the radiation rotates 90°, which allows the beam splitter to collect radiation from the interferometer arms together and direct it to the detector. In this case, the radiation interferes and finally passes through the third polarizer, which acts as an analyzer. The result of interference will depend on the radiation wavelength and the difference in the interferometer arms lengths. To measure the radiation spectrum using such an interferometer, it is necessary to determine the dependence of the radiation intensity recorded by the detector on the position of the movable corner reflector. Reconstruction of the spectrum of the primary radiation occurs when performing the Fourier transform operation on the resulting interferogram.

To measure the intensity of terahertz and subterahertz radiation, broadband detectors Terasense TSH [20] and Tydex GC-1P [21] were used, the main characteristics of which are shown in table 1. To provide the operation of the detectors, a Torlabs MC2000B optical modulator (chopper) was used, which is a rotating metal disk with slots [22].

Changing the position of the movable reflector with a step of 2.5 microns was carried out using a motorized linear translation stage Standa 8MT193-100 [23]. The interferometer is placed in a metal box with dimensions 650 × 800 × 250 mm (WLH), on the walls of which panels with ZIPSIL 607 [24] pyramidal radiation absorbers were installed.

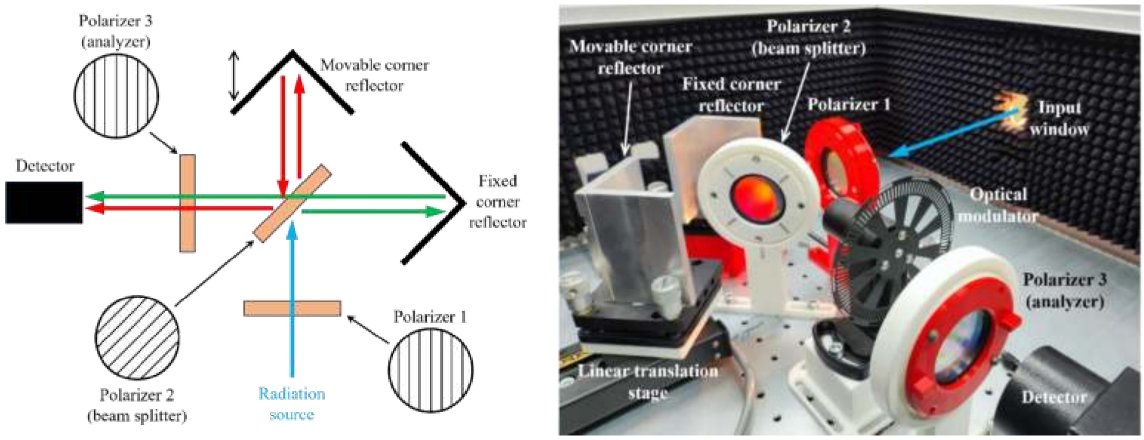

Figure 1. Schematic (left) and photograph (right) of a THz and subTHz interferometer made using the Martin-Puplett scheme.

Table 1. Main characteristics of the terahertz and subterahertz radiation detectors used.

Detector characteristics	Terasense TSH	Tydex GC-1P
Operating radiation frequency	0.05–0.70 THz	0.04–20 THz
Operating radiation wavelength	0.4–6.0 mm	0.015–8.000 mm
Responsivity	10 V/W	100 kV/W
Response time	1 µs	30 ms

One of the main parts of the presented interferometer is Tydex PP-CA38-OD60-T10 film polypropylene polarizers with an operating frequency range of 0.4–20 THz (15–700 µm) according to the manufacturer [25]. The measured transmission and reflection characteristics of these polarizers depending on the angle between the planes of polarization are presented in figure 2. During test measurements, an incandescent lamp was used as a broadband radiation source. The power of transmitted or reflected radiation was measured with the GC-1P detector. It is important to note that to eliminate the influence of visible light and infrared radiation on the

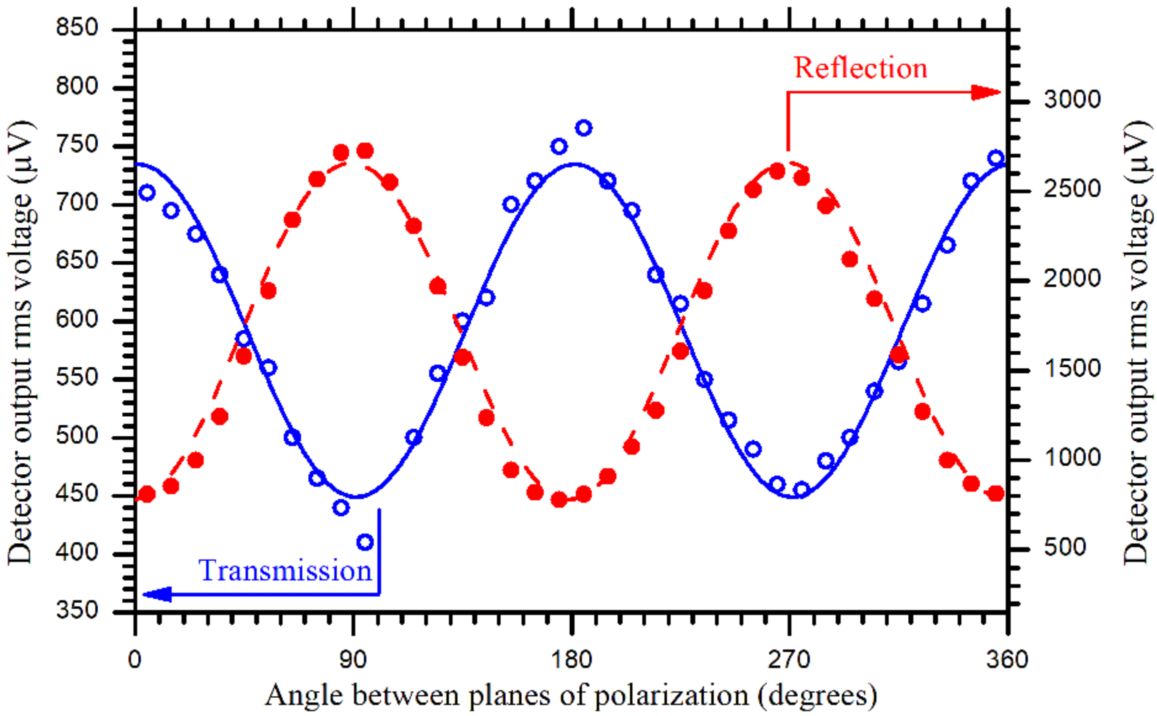

Figure 2. Dependence of the voltage at the output of the GC-1P detector on the angle between the planes of polarization in the case of transmission (open circles and solid curve) and reflection (filled circles and dashed curve) of radiation by a polarizer PP-CA38-OD60-T10 (points are measured values, lines are the result of fitting the measured values with the cosine-squared function according to Malus's law).

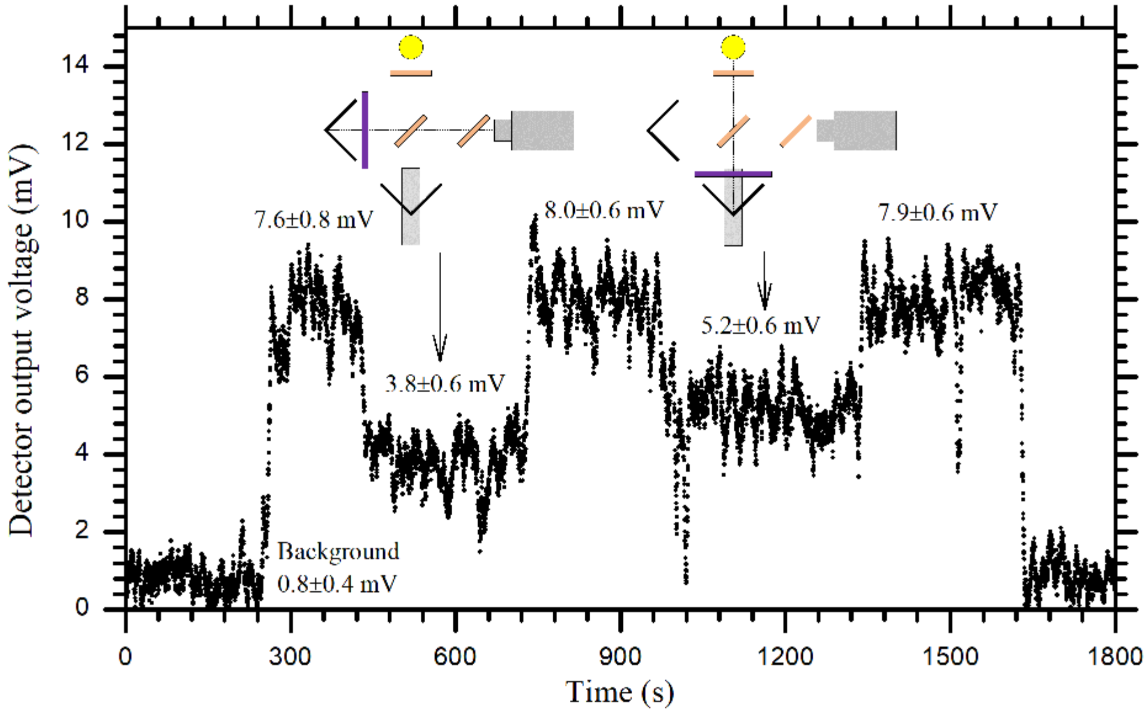

Figure 3. Dependence of the voltage at the output of the GC-1P detector on time when installing an absorbing screen in front of the fixed (area about 600 s) and movable (area about 1200 s) corner reflectors.

measurement results, a 2 mm thick Teflon (PTFE) filter was installed in front of the detector input window.

The interferometer elements were adjusted using a laser level. Figure 3 demonstrates how the detector responds to alternate blocking of the interferometer arms by a radiation-absorbing screen. It can be seen that (taking into account errors) radiation propagating in different arms of the interferometer affects the registered signal level approximately equally. This confirms the possibility of using a polypropylene film polarizer as a beam splitter.

3. Conclusion

At the moment, the presented interferometer is ready for use in experimental facilities to study the interaction of radiation or fast charged particles with matter. The interferometer will become the starting point for the development of a diagnostic system at stations for generating terahertz radiation. Due to the lack of availability of a calibration monochromatic source of terahertz radiation, calibration and measurement of the main characteristics of the device are planned to be performed using bunched relativistic electron beams at the Röntgen-1 facility [26] (electron energy 7 MeV) and LINAC-200 [27] (electron energy from 26 to 200 MeV). The possibility of integrating an optical modulator (chopper) into the design of the interferometer allows it to be used also with continuous beams of charged particles, including low energies [6, 28]. It is also important to note that the created interferometer allows the use of two different types of detectors with high responsivity or high performance, which will make it possible to easily adapt the measurement system to the experimental conditions.

CRediT authorship contribution statement

R M Nazhmudinov: Methodology, Validation, Formal analysis, Investigation, Writing - Original Draft, Visualization; **I A Kishin**: Software, Investigation, Resources, Writing - Original Draft, Visualization, Supervision; **E Yu Kidanova**: Formal analysis, Investigation, Resources, Writing - Original Draft, Visualization; **P Yu Karataev**: Conceptualization, Methodology.

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