Capillary quasioptical highpass filter

Valerian S. Edelman, Mikhail A. Tarasov, Artem M. Chekushkin

***Abstract*— A series of capillary matrix highpass filters with different diameters and lengths of capillaries has been fabricated and experimentally studied. Transmission was measured in the frequency range of 150-550 GHz. For inner diameter of capillary of 0.54 mm and length of 3 mm the attenuation of such filter was over 40 dB at frequencies below 200 GHz. At frequencies above 350 GHz attenuation was below 5 dB.**

***Index Terms*— Below cut-off circular waveguide, cryogenic systems, high-pass filters, millimeter and submillimeter waves,**

I. Introduction

THE terahertz radiation is a region of the spectrum between far infrared and microwaves (0.1–10.0 THz). Detectors for balloon and space projects should operate at temperatures below 1K. For calibration of sensitive bolometers using black-body radiation source we need band-depending filters for cryogenic setup Fig.1.

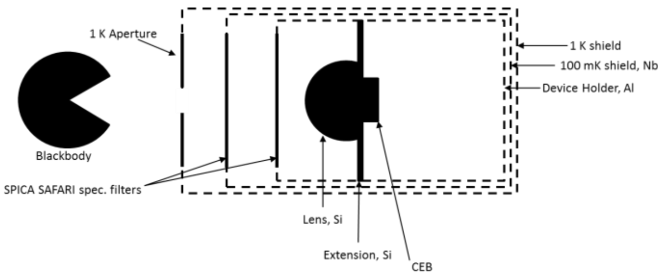

Fig. 1 Example of setup for cryogenic calibration of bolometer (CEB), two filters (SPICA SAFARI filters), black body source and 1 K aperture)

At the different temperatures black body radiation source has spectral maximum at different frequencies Fig.2. And level of out-of-band radiation can be more than in the required band (1).

$$\mathrm{P} = \frac{8 \cdot f \cdot h}{2 \cdot \pi \cdot \left(\exp\left(\frac{2 \cdot h \cdot f}{k \cdot T} \right) - 1 \right)} \tag{1}$$

In this case for correct calibration it is necessary to have high suppression at the frequencies below signal. Such filter should have a sharp cut-off frequency.

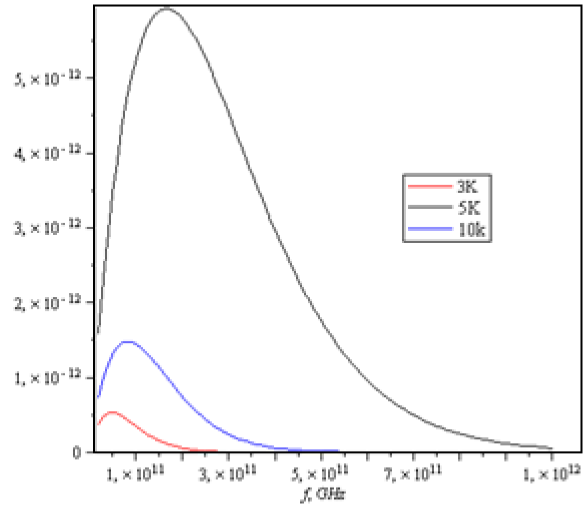

Fig. 2 Radiation spectra of black body source at temperatures 3 K, 5 K, 10 K.

II. Theory

There are different types of high pass filters. One of them is a metal mesh filter [1]. High-quality filters are fabricated of several layers of mesh filters. Multi-mesh filters are rather expensive and difficult in fabrication. And such filters still have some disadvantages, like Wood anomaly -loses due to substrate mode; and losses at edges of metal film due to skin effect.

Another type is a waveguide filter. The specifications of below cut-off circular waveguides were studied in detail in [2]. The suppression of the long-wave part of radiation in this filter can be rather high. Another important advantage of the below cut-off circular waveguide as a filter is the sharpness of the transmission cut-off. In this case characteristics of the filters can be chosen within wide range by varying the diameters and lengths of waveguides. The amplitude of the wave propagating in waveguide is (2)

$$|\vec{\mathrm{E}}|(\mathrm{Z}) = |\vec{E}_0| \exp(i\gamma Z) \tag{2}$$

where Z is the coordinate along the waveguide, $\vec{\mathrm{E}}$ is the intensity of the electric field at point Z, $\vec{E}_0$ is the intensity of the electric field at the initial point, and γ is the propagation constant, described as (3).

$$\gamma = \frac{2\pi}{\lambda_{\mathrm{cr}}} \sqrt{\left(\frac{\lambda_{cr}}{\lambda} \right)^2 - 1} \tag{3}$$

In the case when $\lambda < \lambda_{cr}$ we have ordinary propagating wave, but if $\lambda > \lambda_{cr}$ then the propagation constant will be

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imaginary and incoming wave will be exponentially attenuated inside waveguide. These properties allow fabricating filter with a very sharp cut-off frequency, high suppression of radiation below cut-off frequency and uniform transmission.

III. Fabrication and Constructions

Single below-cutoff circular waveguide as a high-pass filter was studied earlier in [2], in which was obtained attenuation of 6-12 dB in the pass-band and attenuation of 30-60 dB in the stop-band. Such filter requires input and output horns and adapters (Fig.3) if using in quasioptical systems and makes construction rather complicated, of big size, with nonuniform spectral characteristics.

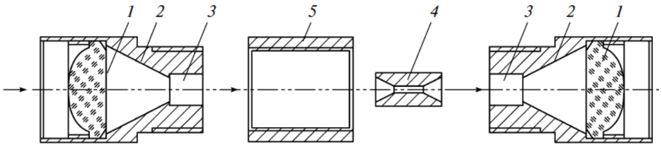

Fig.3 Filter construction: 1- Polyethylene lenses (13mm diameter), 2- Waveguide horns, 3- Apertures for sleeve, 4- Sleeve (internal diameter: 1.5, 1.2, 0.48, 0.4, 0.24 mm), 5- Metal coupling for fastener.

Matrix of many capillaries each like element (4) in Fig.3 can operate as a high-pass filter at millimeter and submillimeter waves without additional adapters. At lower frequencies each capillary can be viewed as a below-cutoff circular waveguide. Array of capillaries do not need any adapters, they are thin and can be inserted in any quasioptical beam-guide. They can be alternative to perforated plates (grids) that should be arranged as 4-6 parallel layers and this pseudo high pass filter is rather a bandpass filter with a bandwidth of about one octave [3]. Industrial manufacturers of multimesh terahertz filters such as QMC Instruments [4] and TYDEX [5] do not offer high performance highpass filters that are required for cryogenic radiation sources intended for calibration of superconducting bolometers.

We fabricated series of capillary matrix filters with different diameters and lengths of capillaries. Fabrication consists of following steps: electroplating of stainless with Ni or nickel-copper capillaries, filling short piece of 10 mm inner diameter tube with as many capillaries as possible, soldering of such package with tin-lead alloy, electroerosion cutting pieces of 1, 2, 3, 4 mm long, final cleaning in ultrasonic bath. Fig.4

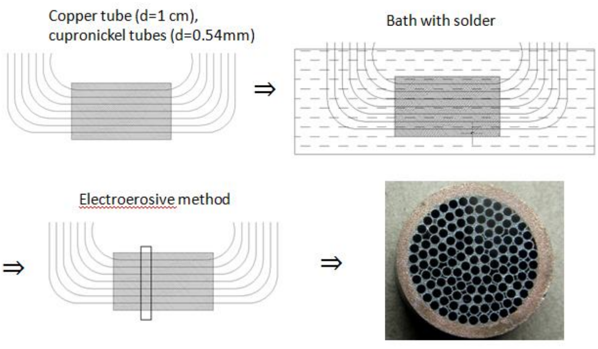

Fig. 4 The main steps in filter fabrication.

IV. Measurements

Filters were placed in the waist of a quasioptical gaussian beam-guide comprising Backward Wave Oscillator (BWO) radiation source, modulator, corrugated horn, four teflon lenses (focal length 20 cm and 40 cm), and Goley cell detector. Fig.5 Transmission was measured in the frequency range 150-550 GHz. BWO is not uniform radiation source. Due to that we measured the filter transmission at each spectral point by dividing transmitted signal with filter by transmission of blank aperture.

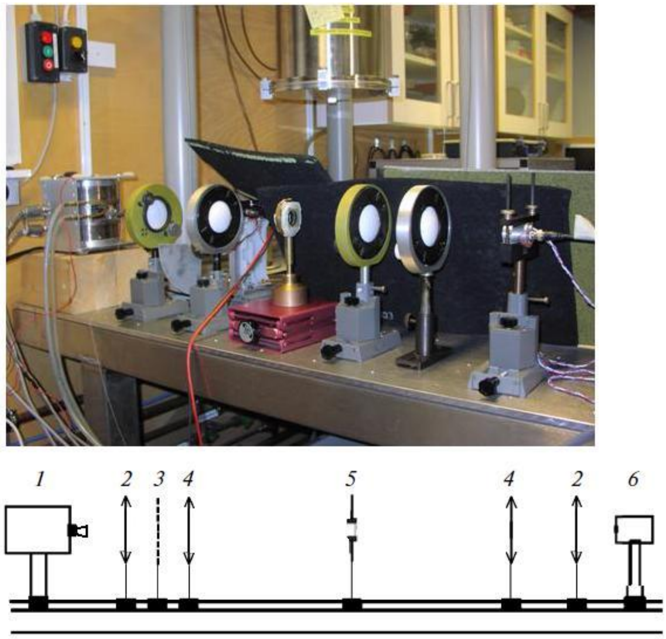

Fig. 5 Measurement setup: 1-BWO, 2,4 –teflon lenses, 5-HPF under test, 6 -Golley cell detector.

V. Results and Discussions

For inner diameter of capillary of 0.54 mm and length of 3 mm the attenuation of such filter was over 40 dB at frequencies below 200 GHz. At frequencies above 350 GHz attenuation does not exceed 5 dB Fig.6.

Theoretical transmission at operating range determined by ratio of open area S(open) to the whole area of filter S(whole). In our filter this ratio should be about 60%. Experimental results measured in configuration of Fig. 5 showed 33%. This difference could be explained with nonideal optical beam shape. We use Gaussian beam and put our filter in the waist of beam, but after that Gaussian beam will not spread in the same condition. Beam at the output is wider. If we take the whole output beam this value approaches theoretical value of 0.33.

If we return to theory [3], we can compare our filter with very similar [6]. But they have some differences. For [6] it is a band-pass filter. Fig.7, contrary to our case of high-pass filter. In [6] it was essentially an array of round holes (0.29 mm dia.) drilled in a 1-mm-thick Cu plate. The waveguide structure provides an extremely sharp cut-off below f=620 GHz. This filter type is important for controlling the blackbody power in the Wien limit, where the spectral density of the radiation power decreases exponentially with

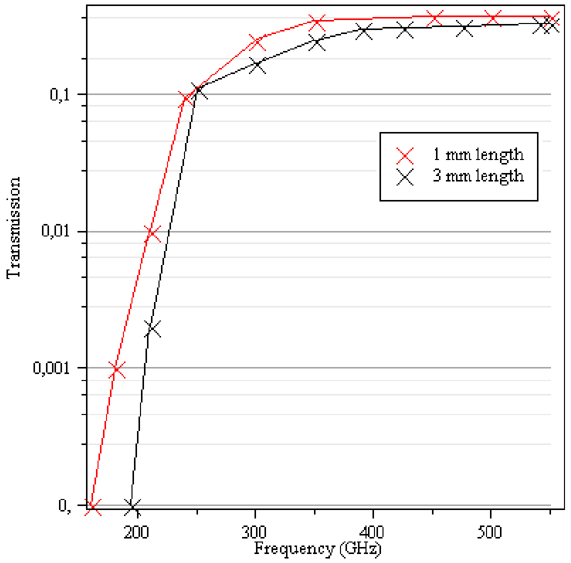

Fig. 6 Experimental results for 1 mm and 3 mm length of filters.

frequency. This filter could be compared with cross-shaped band-pass filter.[7]. The key question in this geometry is distance between crosses or circles. The main advantage in our filter is uniform transmission above cutoff frequency, low cost and simple fabrication.

VI. Conclusion

A novel type of sharp highpass filter of terahertz and subterahertz electromagnetic radiation based on frequency selectivity properties of below cut-off circular waveguide, is developed. Experimental results show that the filters provide a sharp cut-off in the transmission band with the efficient radiation suppression below the transmission band. The filter transmission in the pass band was at a level of 30–40%. Small size allows using such filters at cryogenic measurement setup.

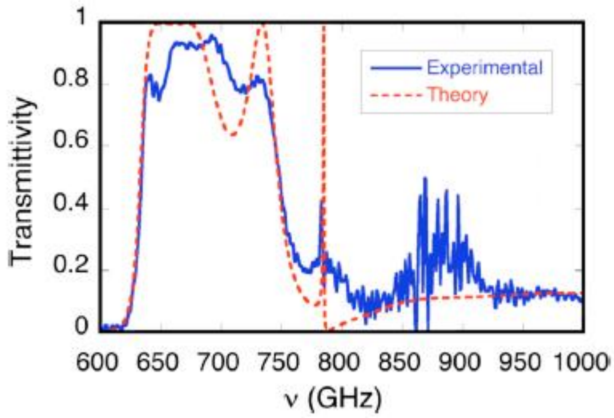

Fig.7 Transfer function of the frequency selective surface filter in comparison with theory of [3]. A noisy bump around 900 GHz is due to a large data error in the vicinity of the Fourier transform spectrometer beamsplitter node. [4]

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