of KBr measured with this technique at 300 and about 200 K. In each case, one set of four interferograms has been used with an integration time of 1 s/sampling point.

CONCLUSION

A technique is described for measuring the amplitude- and phase-reflection spectra of solids in the far infrared without precise mechanical replacement of reflecting surfaces. The technique is illustrated with measurements at 5-cm^{-1} resolution on a KBr crystal at 300 and 200 K. Using this technique, amplitude- and phase-reflection spectra can be measured at low temperatures with the same precision as at room temperature. More careful cryogenic engineering will enable the measurements to be extended to lower temperatures.

The technique has the disadvantage that four interferograms are required for each spectrum, but it is found that by using phase modulation on the moving mirror a satisfactory signal-to-noise ratio can be obtained with a Golay detector on samples of area greater than about 1 cm^2.

The accuracy of the phase measurement is limited by the backlash error in the moving-mirror micrometer screw which amounts to $\sim\pm 0.15$ μm. However, because of the ease with which one can switch from the specimen to the reference mirror, backlash errors can be eliminated by reflecting from each surface in turn on a single scan of the moving mirror.

ACKNOWLEDGMENT

The authors wish to thank P. Heaver, J. Oliver, J. Beadle, and M. Curati for their valuable technical assistance. They also wish to thank Dr. J. F. Angress for his useful discussions.

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Atmospheric Noise in the Far Infrared (300–3000 μm)

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***Abstract*—Noise measurements in the frequency regions 5–200 Hz and 5.2 $\times$ 10^{-4}–8.3 $\times$ 10^{-3} Hz have been performed in the wavelength region between 300 and 3000 μm from the high altitude observatory of Testa Grigia, Italy (3.500 m).**

In the high frequency region a specially designed Ge bolometer operating in background-limited-infrared-photoconductor conditions matched to a 1.5-m telescope has been used, while at low frequency a radiometer designed for atmospheric transmittance measurements was employed.

In both regions no excess noise with respect to the photon noise relative to 300-K blackbody has been detected.

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I. INTRODUCTION

ANY further development in ground based far infrared (FIR) astronomy requires a better knowledge of low frequency noise which may be introduced by atmospheric fluctuations.

While measurements in the near infrared (NIR) (8–14 μm) performed by various authors have shown that the noise produced by the surrounding background is sometimes larger than the intrinsic noise of the best available detectors [1], up to now no measurements are listed in literature relative to FIR ($\lambda > 300$-μm) atmospheric noise, except for an indication of no white noise in the submillimeter region observed at sea level [2].

This situation induced us to perform this type of measurement at a 3.500-m-above-sea-level observatory. High altitude is in fact required in IR astronomy in order to detect the faint emission from celestial sources.

II. HIGH FREQUENCY MEASUREMENTS

In order to compare the atmospheric noise to the quantum noise expected from a room temperature blackbody ($\simeq$300 K) we have developed a special detector operating in background-limited-infrared-photoconductor conditions. The detector used was a Ge bolometer, made by Infrared Laboratory, mounted in a liquid helium Dewar,[1] and modified as follows in order to meet our needs.

For a thermal detector with a cold high pass filter in front of it the detectivity D^* versus wavelength is plotted in Fig. 1 [3].

It can be seen that above 300 μm, intrinsic D^* must be larger than $5\cdot10^{12}$ $W^{-1}\cdot Hz^{1/2}\cdot cm$ in order to detect the quantum noise of the atmosphere assuming that it emits as a 300 K blackbody. This fact is equivalent to a noise equivalent power (NEP) of $2\cdot10^{-13}$ $W\cdot Hz^{-1/2}$ for a collecting area of 1 cm² and a field of view of 1 sr.

Our bolometer initially has an area A of 0.36 cm² and a solid angle of view Ω of 1/16 sr, so that its NEP produced by background was defined by

$$\text{NEP} = 2\cdot10^{-13}\,(\Omega A)^{1/2} = 2\cdot10^{-14}\ \text{W}\cdot\text{Hz}^{-1/2}.$$

We have made some changes to the setting of the instrument (namely, the bolometer was put inside an integrating sphere plus a condensing cone as can be seen in Fig. 2) so that the product $A\Omega$ becomes equal to $3.14 \times 1/4$ cm²·sr and the NEP produced by background results equal to 1.8×10^{-13} $W\cdot Hz^{-1/2}$ which is nearly twice the intrinsic noise.

A Yoshinaga-type filter 3 mm thick is in front of the detector, cutting off all the radiation shorter than 300 μm with a rejection factor greater than 10^5. Finally this detector was mounted in a telescope in order to diminish the field of view, maintaining constant the product $A\Omega$ and consequently the NEP of the instrument. The $f/2$ telescope has a diameter of 1.5 m so that the field of view was given by

$$\Omega_T = \frac{A_R\Omega_R}{A_T} = \frac{3.14 \times 0.25}{1.77 \times 10^4} = 4.4 \times 10^{-5}\ \text{sr} = 20'.$$

This small field of view is required in order to isolate the small atmospheric discontinuities which can produce an excess of noise in IR.

[1] Texas Instruments, Incorporated.

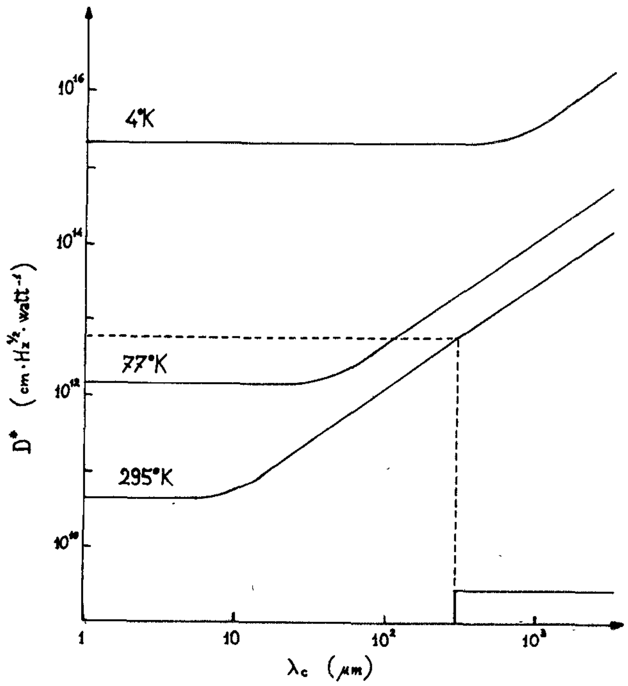


Fig. 1. D^* of a thermal detector (normalized at 1 sr) versus wavelength for various background temperature. In the bottom the wavelength cutoff of the cold high pass filter in front of the detector is indicated.

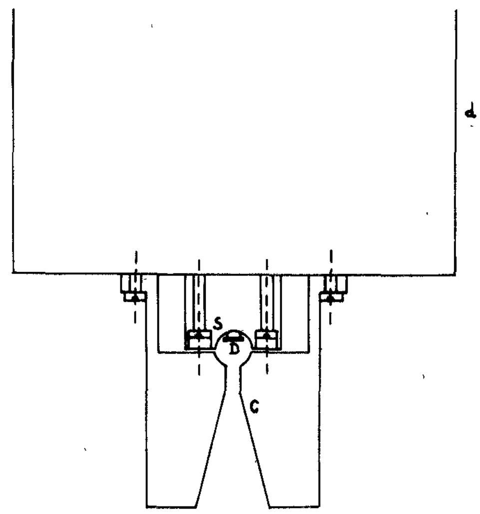


Fig. 2. Detector mounting. The detector D is mounted into an integrating sphere S. A condensing cone C ensures an equivalent area of 3.14 cm² and an f number equal to 2. d indicates the inside part of Texas Dewar.

The detector was calibrated in the laboratory using a mercury lamp coupled to a parabolic mirror. The output signals were detected on a lock-in amplifier and plots of them versus the angle of incidence α and versus the collecting area are given in Figs. 3 and 4.

The frequency range of the recorded noise spectrum is defined by the cutoff of the preamplifier at low frequency ($\sim$5 Hz) and by the cutoff of the detector itself at high frequency ($\sim$200 Hz).

Fig. 5 shows a typical night-time noise spectrum in the above specified frequency range with a resolution of about 0.3 Hz.

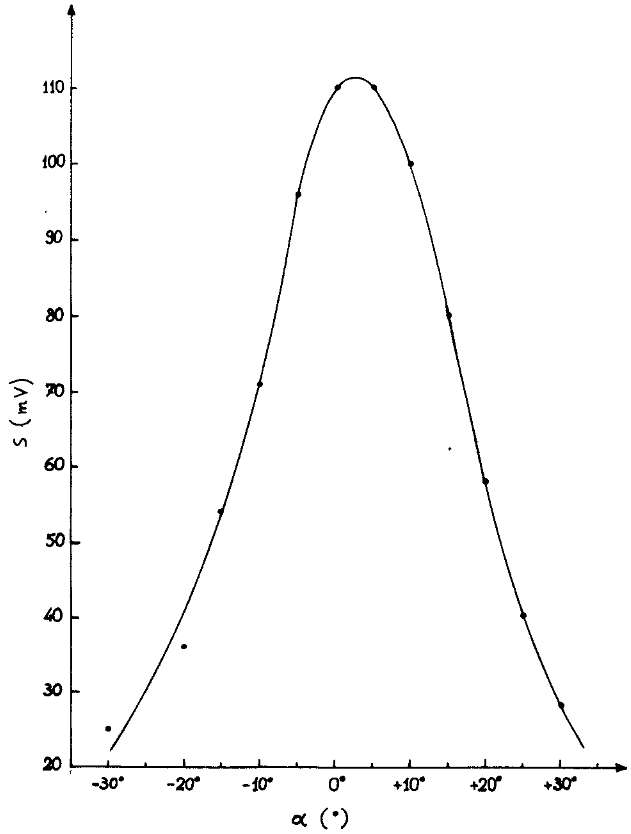


Fig. 3. Output signal S of the modified detector versus the angle of incidence α of the incoming radiation.

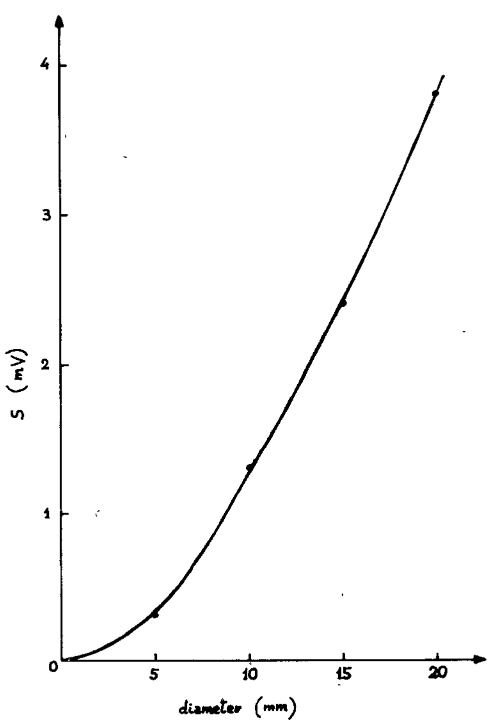
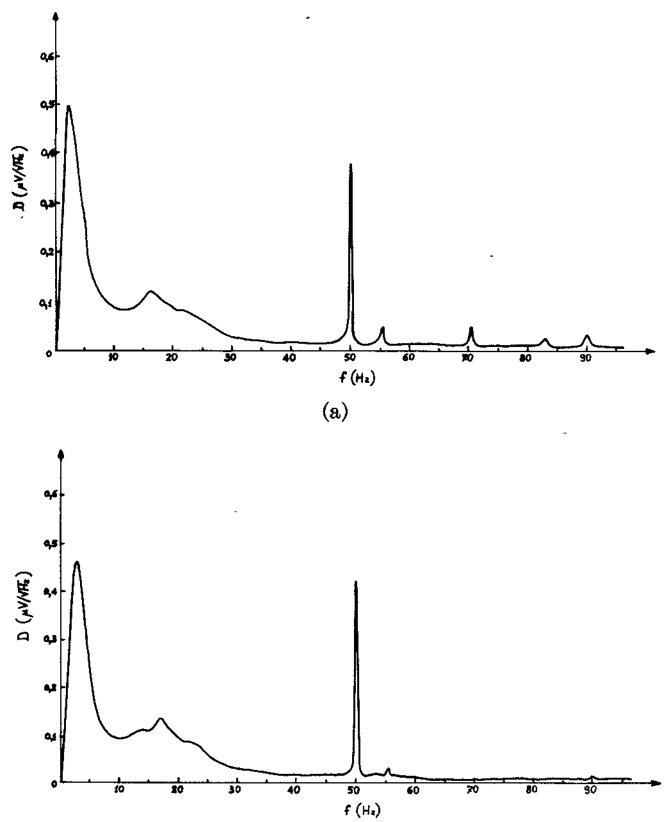


Fig. 4. Output signal S versus the different diameters of the diaphragms set in front of the detector. From this we are able to evaluate the effective area of the detector.



(b)

Fig. 5. (a) Night-time noise spectrum obtained with the dome open. (b) With dome closed.

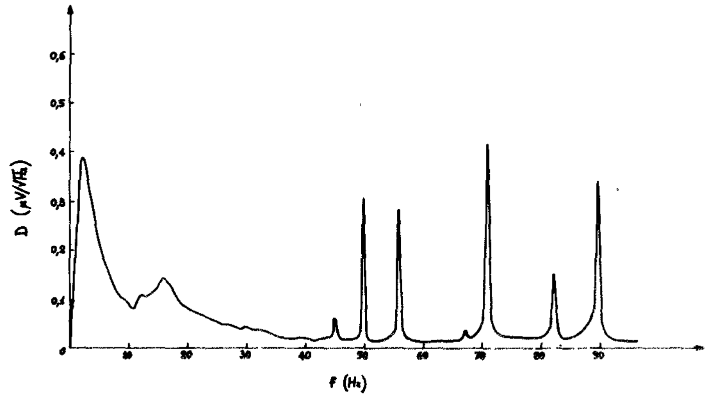


Fig. 6. Noise spectrum obtained with the telescope pointing at 20° from the zenith.

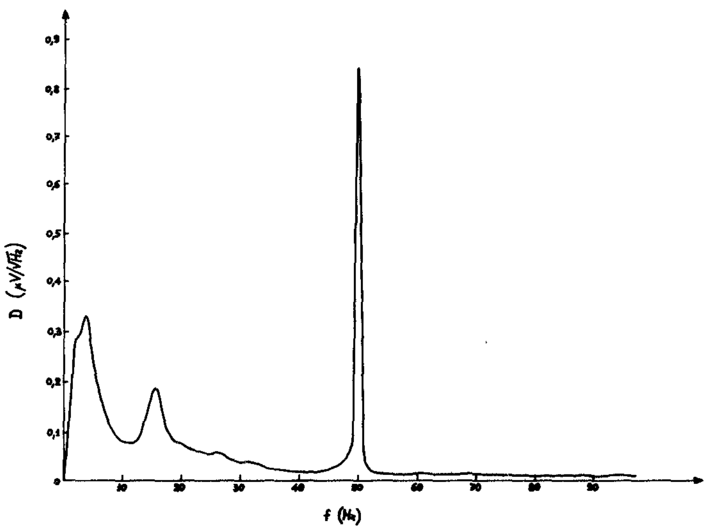


Fig. 7. Noise spectrum obtained with the telescope pointing at 30° from the zenith.

The main sources of noise appear to be as follows.

1) The $1/f$ noise of the detector and of electronics for $f < 10$ Hz.

2) The noise induced by the pressure fluctuations due to the pumping system between 10 and 20 Hz.

3) The large noise at 50 Hz induced by mains.

No substantial difference appeared in the noise spectrum when the dome was open or closed as can be seen in Fig. 5(a) and (b). In some cases a small decrease has been observed in the noise when the dome was open. We wish though to point out that unexpected peaks were found for some elevations (see Figs. 6 and 7); there is no evidence of instrumental effect responsible for this feature.

III. LOW FREQUENCY MEASUREMENTS

Fig. 8(a)–(c) shows the experimental setup for low frequency noise measurements.

The radiation coming from the sky I_s is reflected by the mirror M of the celostat and chopped at 30 Hz by the chopper C, whose blades reflect the radiation I_b coming from a 77-K blackbody reference source.

The radiation is collected by the TPX lens L on the detector which is a Ge bolometer cooled down to liquid helium temperature. The detector has an equivalent area of 6×6 mm², an f number equal to 5, and a NEP of 10^{-13} W·Hz$^{-1/2}$. The collecting lens has a diameter of 5 cm and 20 cm of focal length.

The optical system has the following characteristics: field of view: ±1°; equivalent area: 16 cm².

The output signal of the detector is given by

$$S = R(I_1 - I_2) \qquad (1)$$

where I_1 is the radiation falling on the detector when the chopper is open, I_2 the radiation when the chopper is closed, and R is the detector responsivity.

Let us discuss now in detail I_1 and I_2:

$$I_1 = R_m I_s + I_m + I_l \qquad (2)$$

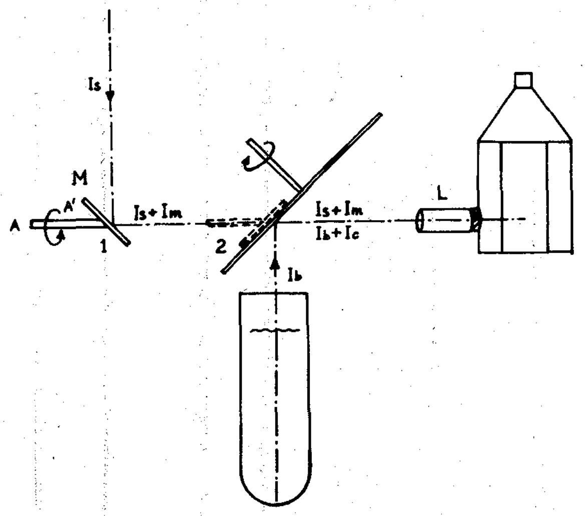
$$I_2 = I_c + R_c I_b + I_l \qquad (3)$$

where R_m and R_c are the reflectivities of the mirror M and of the chopper blades; I_m, I_c, and I_l are, respectively, the radiation emitted by the mirror M, by the chopper C, and by the lens L.

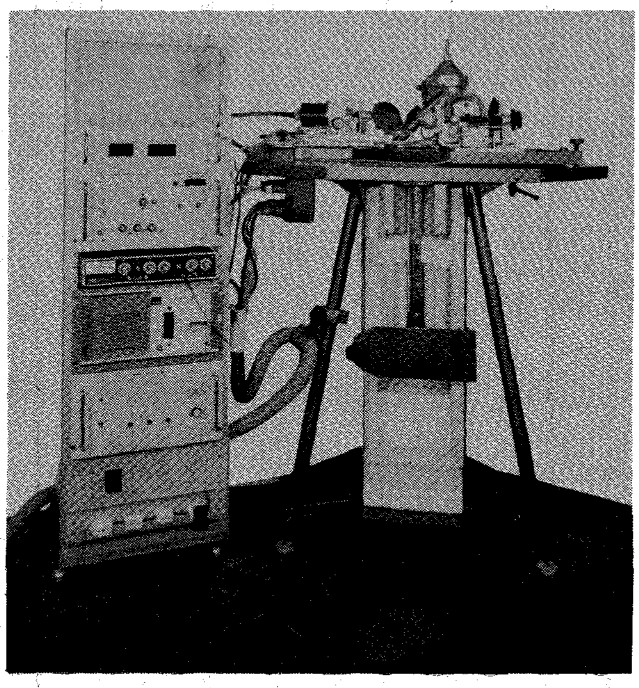
We finally get from (1)–(3)

$$S = R(I_s R_m + I_m - I_c - I_b R_c).$$

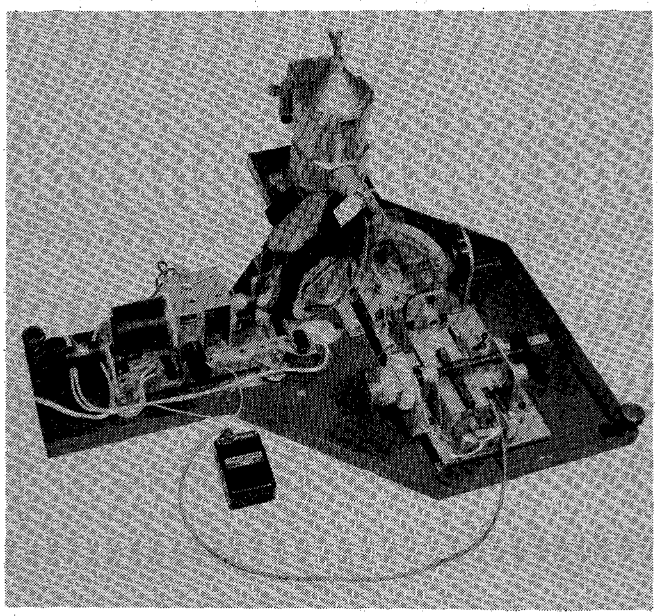
In the reasonable assumption that I_m, I_c, and I_b are constant during the experiment and that, in FIR, $R_m =$



(a)



(b)



(c)

Fig. 8. (a) Experimental setup. (b) and (c) Pictures of the radiometer.

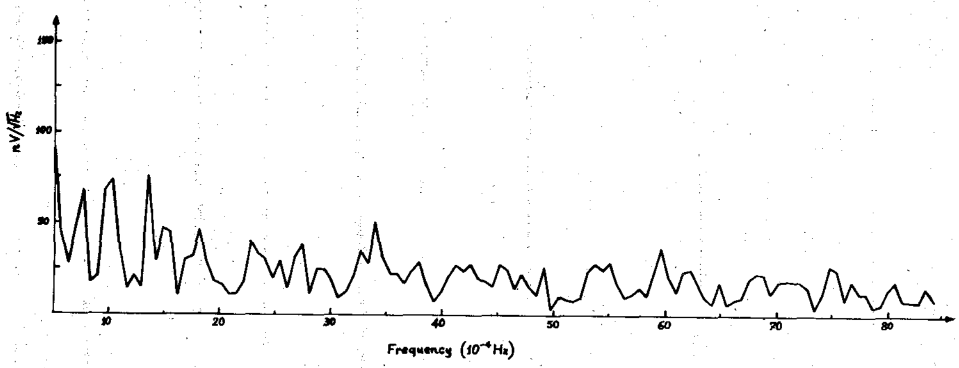


Fig. 9. Computed spectrum in the frequency range 5.2×10^{-4}–8.3×10^{-3} Hz.

$R_c = 1$, we get

$$S = R(I_s - I_b + K)$$

where $K = I_m - I_c$.

Since we are interested only in the variations of S, K can be neglected and the variations are proportional to the difference between I_s and I_b.

Fig. 9 shows the computed spectrum in the frequency range 5.2×10^{-4}–8.3×10^{-3} Hz. The results have been obtained during a clear night, pointing to the zenith for about 4 h. No excess noise can be observed in the spectrum with respect to the intrinsic noise of the detector.

IV. CONCLUSIONS

According to these preliminary results one may conclude that there is no excess of low frequency noise due to atmospheric fluctuations in the submillimeter wavelengths.

Since the best available detectors optically matched with optimized IR telescopes show an intrinsic noise more than ten times larger than the corresponding photon noise, our results suggest that IR astronomy can gain in the near future about a factor of ten in the minimum detectable signal by developing better detectors (see, for instance, [3, Fig. 5]).

In the high frequency region other measurements are required in order to clarify the existence of special frequencies at which a strong noise excess has been detected.

ACKNOWLEDGMENT

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Submillimeter Spectroradiometers with n-InSb Detectors

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***Abstract*—The optimal characteristics of amplitude splitters for submillimeter radiation beams are determined. Versions of optical schemes with large light gathering power (LGP) utilizing such splitters are proposed. Using them, high sensitivity receiving devices for the 2–0.2-mm waveband region with Fabry–Perot interferometers (FPI) and Michelson interferometers (MI) and n-InSb immersion detectors (spectroradiometers) are constructed.**

I

THE investigation of receiving devices of the short millimeter and submillimeter waveband region using n-InSb detectors cooled with liquid helium [1] have caused the development of various broad-band radiometers [2]–[4] and spectrometers with grating monochromators [5], [6] utilized in radioastronomy and spectroscopy for various purposes. The increase of signal-to-noise ratio of spectral measurement apparatus using such receiving devices is made possible by improving detector sensitivity, thus increasing the light gathering power (LGP)[1] of the spectral scheme. The LGP of n-InSb detectors, especially immersion detectors, is much more than the LGP of submillimeter monochromators. For this reason the first stage of development of receiving devices was the construction of spectroradiometers based on a combination of immersion n-InSb detectors and spectral devices having high LGP of the Fabry–Perot interferometer (FPI) or Michelson interferometer (MI) type. The main results of the corresponding investigation and development are given in this paper.

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[1] We mean that LGP is value $L = \tau U = \tau S \Omega$, where U is the geometric factor of the optical device, S is the operating aperture, τ is the transparency, and Ω is the solid angle of the beam.

II

The advantage of spectroradiometers using the FPI is the compactness of construction and the possibility of the direct recording of spectra [7]. The increasing of LGP of the FPI can be reached either by increasing the operating surface of reflectors or by increasing the beam divergence angle.

The consideration of conditions of optimal matching of the FPI with the n-InSb detector [8] has shown that the divergence beam quality of the FPI $\tilde{Q} = \nu/\Delta\nu$ is connected with parallel beam quality $Q = \pi(R)^{1/2}/(1-R)$, where R is the reflectivity, by the expression

$$1/\tilde{Q}^2 = 1/Q^2 + (\Omega/2\pi)^2. \quad (1)$$

The maximum transparency of the interferometer with the divergence beam is

$$\tau_m = \frac{2\pi\tau_0}{Q\Omega} \arctan \frac{Q\Omega}{2\pi} \quad (2)$$

where τ_0 is the transparency of the ideal FPI which is