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Scientific Motivation and Requirements for Future Space Astronomy and Solar System Science Missions (1)

Author: Mr. Giuseppe Cataldo
Massachusetts Institute of Technology (MIT), United States, giuseppe.cataldo@nasa.gov

Prof. Jeffrey Hoffman
Massachusetts Institute of Technology (MIT), United States, jhoffma1@MIT.EDU
Dr. Samuel Harvey Moseley
NASA, United States, samuel.h.moseley@nasa.gov
Dr. Edward J. Wollack
NASA, United States, edward.j.wollack@nasa.gov

MICRO-SPEC: AN INTEGRATED, DIRECT-DETECTION SPECTROMETER FOR FAR-INFRARED AND SUBMILLIMETER ASTRONOMY

Abstract

Micro-Spec (μ-Spec) is a high-sensitivity, direct-detection spectrometer working in the far-infrared and submillimeter (450–1000-μm) wavelength range. It has two antenna arrays, one for transmitting and one for receiving, superconducting microstrip transmission lines for power division and phase delay, and an array of microwave kinetic inductance detectors (MKIDs). The instrument is integrated on a 100-millimeter-diameter silicon chip. This size reduction is accomplished by using single-mode microstrip delay lines, which can compactly folded on the silicon wafer. Because silicon has a refraction index three times that of vacuum, these transmission lines are shorter than in vacuum by a factor of three. For all these reasons, -Spec can become an important capability under the low background conditions provided by space telescopes such as the space infrared telescope for cosmology and astrophysics SPICA and high-altitude balloons. This paper first presents the optical design of μ-Spec, with particular attention to its two-dimensional diffractive region where the light of different wavelengths is focused on the different detectors. The method, based on the stigmatization and minimization of the light path function in this bounded region, results in an optimized geometrical configuration. A point design with an efficiency of about 90% was developed for initial demonstration, and will be the basis of future instruments. Design variations on this implementation are shown to lead to lower efficiencies (about 30%) because of losses to higher diffraction orders. The paper then describes the analysis performed on some superconducting materials which with their extremely low losses have been identified as candidates for providing μ-Spec with the required background-limited sensitivity (noise equivalent power, NEP, less than 3 x 10^{-21} W/$\sqrt{\text{Hz}}$) at a resolution of about 1200. A novel semi-empirical model is therefore proposed for extracting the quality (Q) factors of arrays of superconducting MKIDs and for computing the loss in the materials. The method enables the simultaneous analysis of multiple interacting discrete resonators with the presence of a complex spectral baseline arising from reflections in the system. The results of this model applied to transmission data of arrays of coplanar waveguide (CPW) and microstrip Mo_2N resonators readout on superconducting CPW transmission lines is illustrated and discussed. It will be shown that the model recovers such data with a deviation of less than 1% and provides the required Q values. In addition, verification and validation of the proposed method will be described and compared to prior art.