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DEVELOPMENT OF LOW-TEMPERATURE TRANSISTOR MODULES TO IMPROVE THE MSFC MID-INFRARED ARRAY

Center Director's Discretionary Fund Final Report

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM

DEVELOPMENT OF LOW-TEMPERATURE TRANSISTOR MODULES TO IMPROVE THE MSFC MID-INFRARED ARRAY

I. INTRODUCTION

We have developed in the MSFC Space Science Laboratory a unique detector system containing a spatial array of 20 germanium bolometer detectors for use in the wavelength region 8 to 40 μm. The purpose of the task described here was to improve this detector system through the development of more effective methods of mounting and accessing cooled transistors that must be physically close to the detectors and are vital to their proper operation. The detector system (see Ref. 1 for a detailed description), which was developed with Center Director's Discretionary Funds, permits highly efficient imaging of astronomical sources using ground-based observatories. The bolometer detectors and optical design of this imaging system were carefully chosen to permit very sensitive observations under the high-thermal background conditions encountered near 10 μm. In the short time since it became fully operational, the mid-infrared array system has been used to make important and unique contributions to the study of comets [2,3] and star-forming galaxies [4].

Twenty junction-field-effect transistors (JFETs), one JFET for each bolometer, are crucial components of the infrared array. Both the bolometers and JFETs are kept cold within a cryogenic dewar using liquid nitrogen and superfluid liquid helium. The bolometer/JFET geometry is shown schematically in Figure 1. The stream of incident infrared radiation is focussed onto the heat-sensitive bolometer. The signal from each bolometer, which has a high impedance (typically 10 MΩ), is applied to the gate of a nearby JFET. The signal is then sensed at the JFET source with substantially reduced impedance and transferred out of the cold interior of the camera for further processing by external warm electronics. The JFETs act as impedance transformers, permitting most of the signal path to be at low impedance and hence much less susceptible to noise pickup. The JFETs are therefore crucial to the achievement of acceptably low noise and high sensitivity in the IR camera.

II. TASK REQUIREMENTS

Within the cryogenic dewar, the JFETs are grouped into four modules, each module containing five transistors. The bolometers are also grouped into four modules of five bolometers each, and each bolometer module operates with one JFET module (Fig. 1). The essential goal of this CDDF task was to develop a mounting geometry for the JFETs that met the following requirements. Each JFET module must be both rigidly attached to the same surface as the bolometers and within a few centimeters of them. However, to function properly, the bolometers are operated at the temperature of superfluid helium (1.5 K), whereas the JFETs must be at the temperature of liquid nitrogen (77 K). The JFETs must therefore be carefully insulated from the much colder helium-cooled surface, and an efficient thermal link must be provided between the JFETs and the 77 K surface. Because of the need to service the bolometers and JFETs, the JFET module solder pins and wiring must be conveniently accessible while not compromising module compactness. In addition, the geometry must permit convenient replacement of individual malfunctioning JFETs. We incorporated these requirements into a module design that was fabricated, tested, and fully implemented into the MSFC mid-infrared array.

III. PROCEDURE

The JFETs in each module are attached directly to an insulating substrate (shown schematically in Fig. 1). After consideration of several substrate materials, we decided that Teflon was the most promising based on availability, ease of use, and low thermal conductance. However, Teflon is malleable, and it "flows" when acted upon constantly by even a modest force. Although this potential lack of physical stability concerned us initially, we concluded that the physical stress encountered by the Teflon modules would be small enough not to compromise module stability. Our subsequent tests showed this conclusion to be correct.

We considered several generations of module design, eventually evolving to the one described below. The approach was to machine a Teflon module and attach the JFETs and solder pins using low-temperature epoxy. During operation, the JFET temperature was maintained near 77 K by using a thermal link, or cold strap, between the JFETs and the 77 K liquid-nitrogen-cooled radiation shield. In the various tested prototypes, the flat copper cold strap was attached to the module either directly to the JFETs with epoxy or to an intermediate copper surface with solder. After a module was constructed, one of the old manufacturer-supplied JFET modules was replaced in the infrared array with the new one. The performance was evaluated side by side with the remaining old modules. Monitoring the physical and electrical properties of each test module through several temperature cycles ("cooldowns") permitted evaluation of the long-term stability and integrity of epoxy joints and the mechanical support of the JFETs.

IV. RESULTS

Figure 2 shows a sketch of the final JFET design that best met our requirements. In Figure 3 a JFET module (white component at figure left) is shown attached to the copper substrate containing the field mirrors, bolometers, and electrical connector (see, also, Fig. 1). In the following description, we refer to Figure 2.

The five JFETs for each module are epoxied to the top surface of a thin copper disk and around the disk perimeter. The JFETs are epoxied in an inverted orientation, with the epoxy applied to the flat JFET surface on the opposite side of the JFET from the three metal leads. The circular copper disk containing the JFETs is then lowered into a circular depression on the Teflon module "shelf." This depression has a concentric circular hole in the bottom with a slightly smaller diameter than the depression. Thus, the copper disk, which has the clearance diameter of the depression, rests on a thin Teflon ridge at its perimeter. The bottom perimeter of the copper disk is epoxied to the Teflon ridge, which is roughened for adequate epoxy adhesion. The copper cold strap is soldered to the bottom of the copper disk and protrudes through the hole in the bottom of the Teflon shelf.

Soldering wires to the JFETs is straightforward, since the JFET leads are conveniently accessible at the top of the module. Wires to and from the JFETs are "woven" through holes in the Teflon to keep them relatively rigid. A malfunctioning

JFET can be easily removed with needle-nosed pliers, with a replacement inserted and epoxied. Readily accessible solder pins are press-fit into the Teflon module on the side of the lower support structure. Two holes in the end of the lower horizontal support structure are used to attach, with screws, the JFET module to the copper bolometer/mirror assembly (Fig. 3).

After initial testing of the final module design described above, the new JFET modules were fully implemented into the MSFC mid-infrared array. Temperature cycling through dozens of cooldowns and prolonged use at the nominal operating temperature have demonstrated that both the long-term integrity of the epoxy joints and the physical stability of the JFETs and the Teflon structures are maintained. Repeated removal of the modules from the array, done as part of the regular maintenance and testing of the array system, has shown that, as intended, the modules are conveniently accessible and a vast improvement over those used initially. Therefore, the goal of this CDDF task has been accomplished and has substantially improved the operation and maintenance of the MSFC mid-infrared array.

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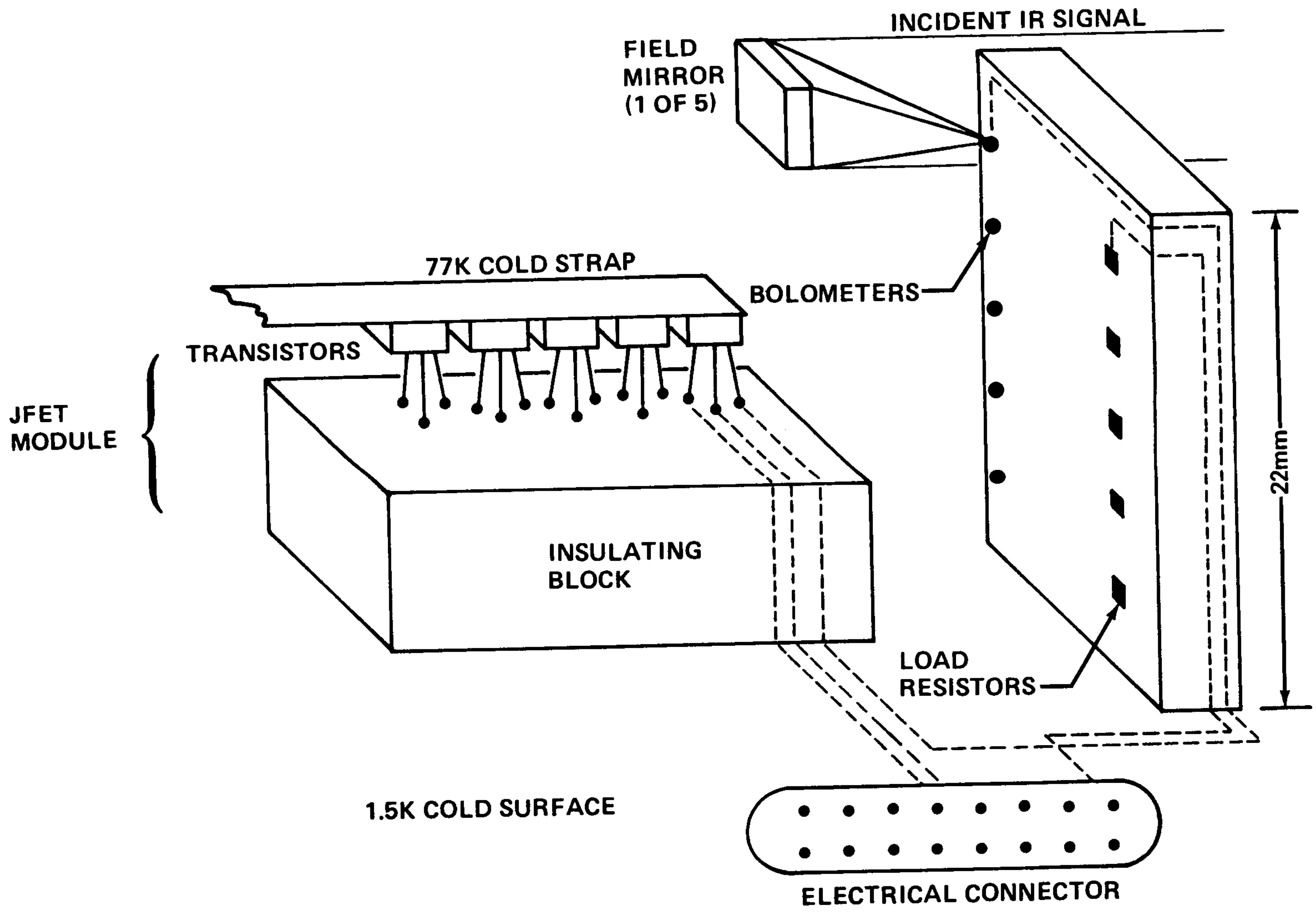

Figure 1. Schematic diagram of a JFET module shown in relation to field optics, bolometers, and electrical connectors.

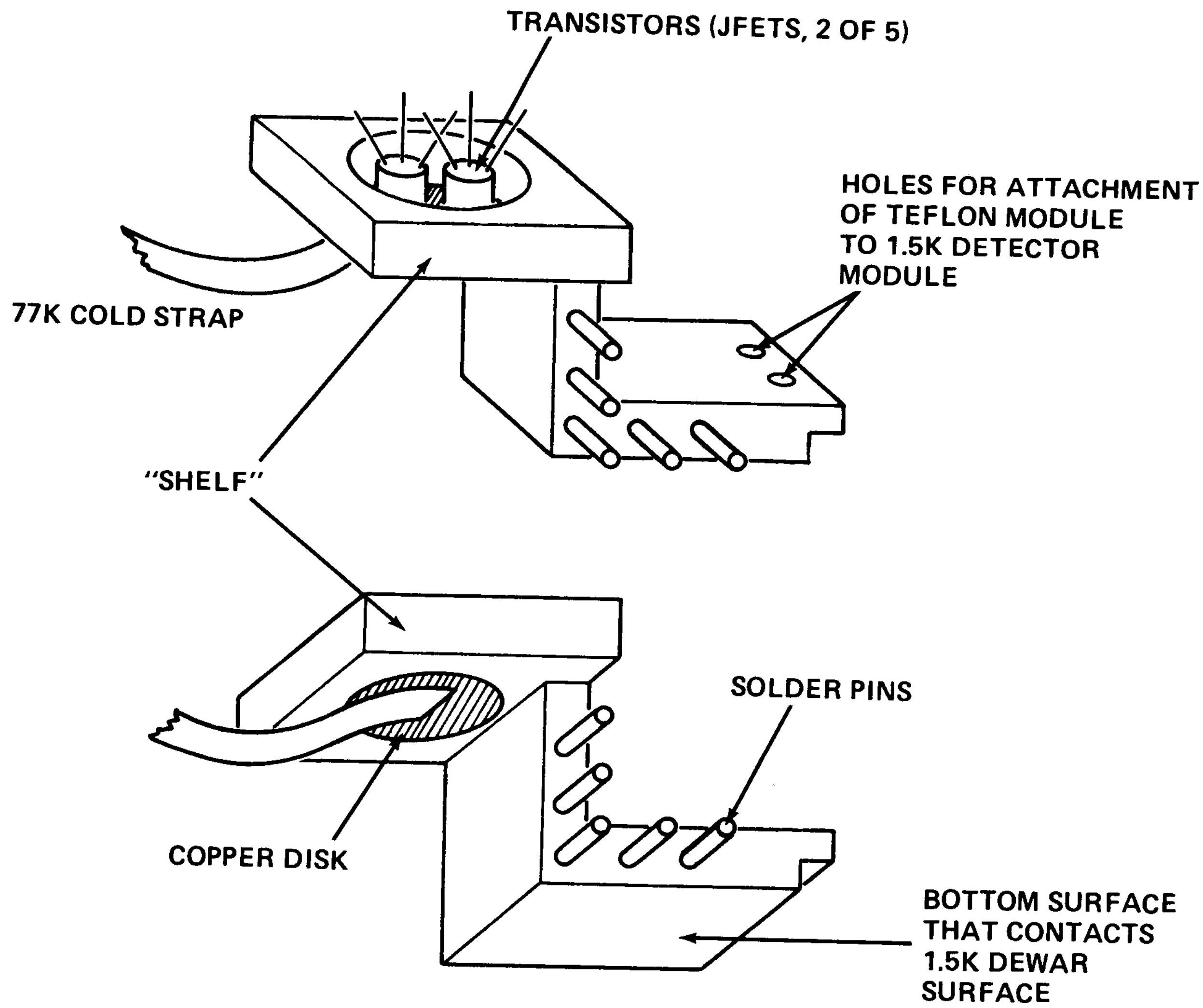

Figure 2. The final version of the JFET module.

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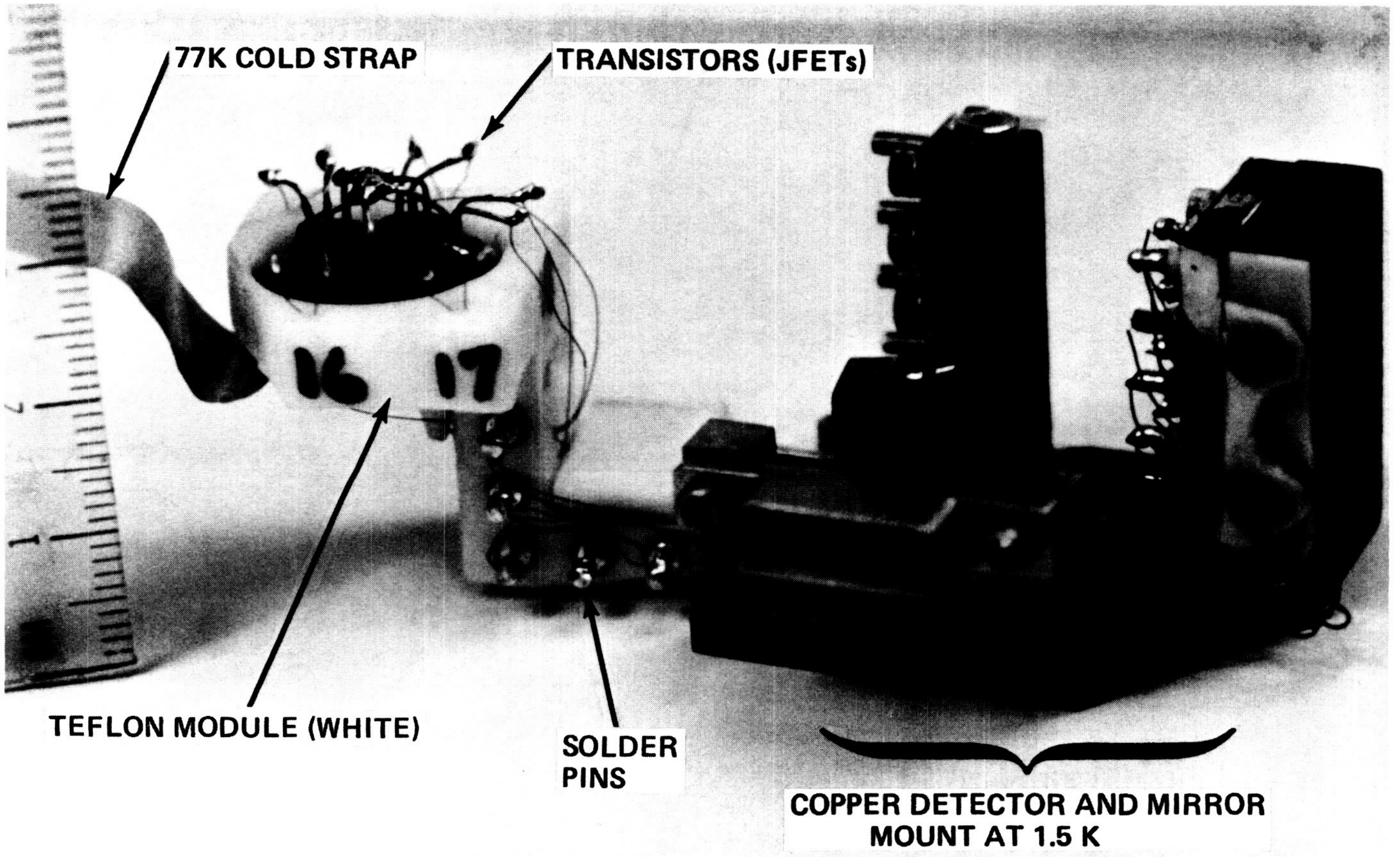

Figure 3. A JFET module attached to a detector/mirror substrate.

APPROVAL

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

E. A. Tandberg-Hanssen

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16. ABSTRACT

This report describes the low-temperature transistor modules designed for use with the MSFC mid-infrared array. The modules were developed in the Space Science Laboratory at Marshall Space Flight Center with Center Director's Discretionary Funds. The transistors (JFETs), which operate at a temperature of 77 K, are epoxied to a copper surface attached to a Teflon substrate. The module substrate insulates the JFETs from the 1.5K detector work surfaces and provides a convenient mounting structure for additional components such as solder pins. These modules have maintained their structural integrity during repeated temperature cycling, and they have proven to be convenient during maintenance and servicing of the infrared array.

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