DDF annual report

Title of Investigation:

Low-Power Solid-State Microwave Switch

Principal Investigator:

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Other In-house Members of Team:

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Other External Collaborators:

None

Initiation Year:

FY 2005

Aggregate Amount of Funding Authorized in FY 2004 and Earlier Years:

$0

Funding Authorized for FY 2005:

$45,000

Actual or Expected Expenditure of FY 2005 Funding:

In-house: $45,000

Status of Investigation at End of FY 2005:

Existing RTOP from ROSES-APRA

Expected Completion Date:

February 2006

Purpose of Investigation:

The goal of this investigation is to develop an instrument switch that would help to measure differences in the Cosmic Microwave Background (CMB), the remnant radiation of the primordial Big Bang. To measure the differences, scientists need to change the connections between a set of detectors and a pair of sensitive antennas. Because the CMB is just 3 degrees above absolute zero, the detectors need to be cooled to less than 3 Kelvin so that they can detect the background microwave radiation. The switches also must operate at the same temperature and use extremely low amounts of power; otherwise, the heat from the switches will interfere with the detectors. In a space mission, the switches would have to cycle on and off about a hundred times a second for several years without wearing down. This investigation studies a switching concept in which power dissipation is zero and no moving parts are involved. The technology would be useful for NASA's Beyond Einstein Inflation Probe mission.

Accomplishments to Date:

The switch concept proposed here is based on the tunable reactance of a Josephson junction in its zero-voltage superconducting state. As a dc-bias current is increased below the junction's critical current, the junction's effective inductance increases, and the "plasma oscillation" frequency of its inductance in parallel with its capacitance drops. If an appropriate series capacitance connects the junction between the microstrip transmission line and ground, then the device looks like a reflecting short or an open circuit that lets signals pass depending on the dc-control current. For CMB polarimetry applications, one would like switches for several measurement frequency bands within the range 30 to 300 GHz. For our initial demonstration, we chose to design for a 30 GHz center frequency where the required junction area is larger and the critical current density is lower and more reproducible. Testing is easier.

Our main accomplishments included the design of a suitable switch geometry using electromagnetic-simulation software, the design of a transition structure to couple microwave signals to a thin-film superconducting microstrip transmission line from coaxial input and output connections, fabrication of prototype switches and calibration lines, and calibration measurements of the microwave transmission through the transition structures and a microstrip line without the switches connected.

Figure 1 shows a micrograph of one of the prototype devices we fabricated. After depositing and patterning a niobium ground plane and microstrip dielectric layer on silicon wafers, we used a commercial foundary (STAR Cryoelectronics) to deposit a niobium-aluminum-oxide-niobium ($Nb/Al/Al_2O_X/Nb$) "trilayer" on the wafers. We then patterned the trilayer with dry-etch processes, added an additional insulting layer, etched contact vias, and completed the devices with a niobium-wiring layer. Our design put three switches in series on one microstrip to increase the fractional bandwidth to 25 percent, as shown in the SONNET software simulation of the transmission matrix element S12 (Figure 2).

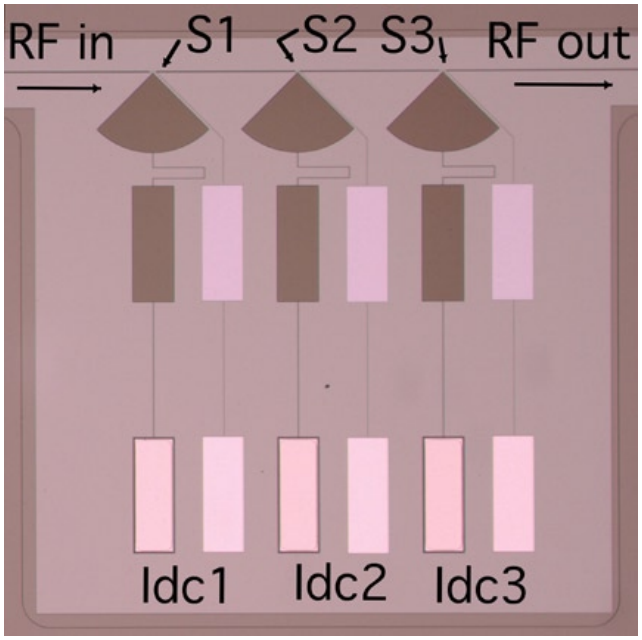

Figure 1. Photograph of a prototype microwave switch device fabricated on a silicon chip. Microwave signals traveling on a microstrip line from "RF in" to "RF out" are either passed or reflected by three switch elements S1, S2, S3 place in series along the microstrip. The switches are controlled by dc currents supplied from pads Idc1, Idc2, and Idc3 via bias leads with RF-choke filters.

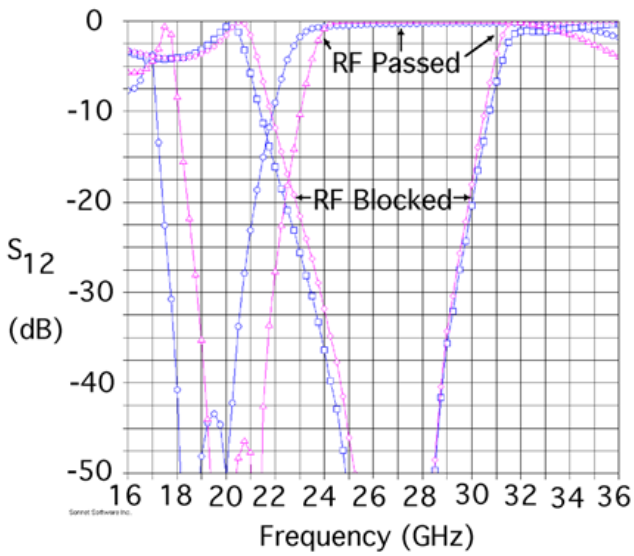

Figure 2. Simulated performance of the three-junction switch. In one state of the switch, microwave transmission is high, while in the other state transmission is < -20 dB from 23 to 30 GHz.

Measurements of dc behavior showed that our first batch of devices had faulty insulation at the edges of the junctions. Microwave measurements were made on some chips that had the wiring layer intentionally omitted to give a microstrip line without switches. These calibration chips were mounted in a fixture with K-connector launchers pressed against small pads on the chip (Fig. 3). When cooled with liquid helium, the transmission in the range 25 to 30 GHz was -5

dB, which was less than hoped for, but consistent with deviations in the actual contact geometry from what had been designed (Figure 4).

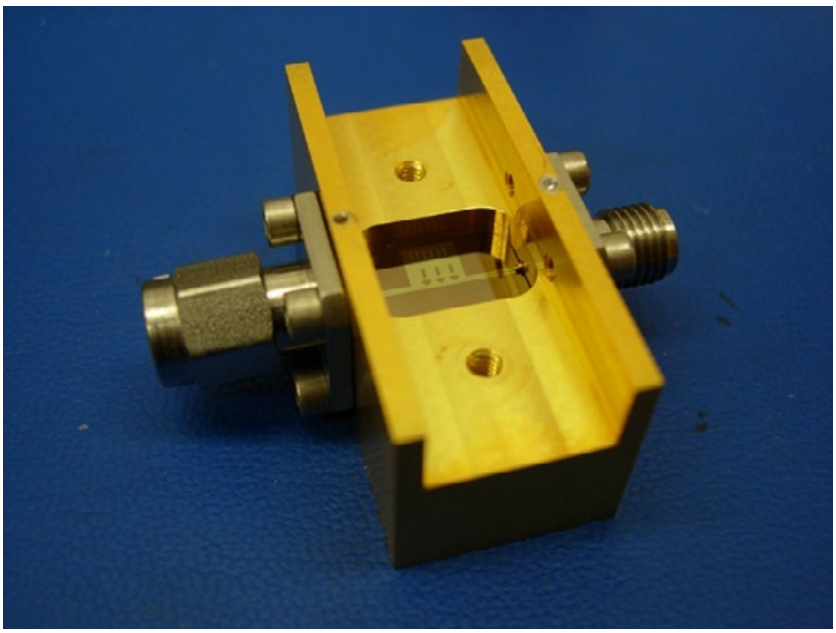

Figure 3. Chip with superconducting transmission line mounted in package ready for microwave measurements at low temperatures.

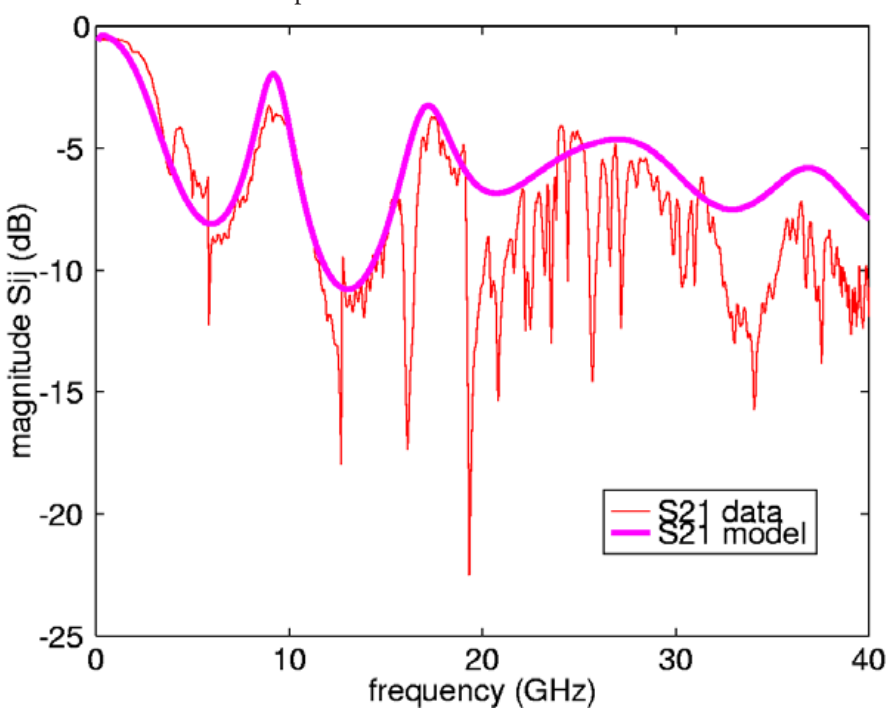

Figure 4. Measured microwave transmission through the calibration line as a function of frequency (red curve). Revised model describing the actual contact and transition geometry fits the data (magenta).

Planned Future Work:

Two wafers coated with the commercially prepared trilayer material were reserved. They are available for a second fabrication run that incorporates process improvements based on the difficulties

encountered in the first batch. Support is from an existing RTOP award (Principal Investigator Al Kogut). The results reported here, and any additional results, will be used in support of ROSES NRA proposals in 2006.

Key Points Summary:

Project's innovative features: Success in this investigation will provide a method of manipulating the path taken by low-power microwave wave signals in an instrument to study the Cosmic Microwave Background (CMB). The approach taken in this investigation would provide microwave switches that can be integrated with highly sensitive detectors without dissipating heat that would interfere with the measurement.

Potential payoff to Goddard/NASA: Success will improve Goddard's competitiveness on proposals to build detector arrays that precisely measure variations in the CMB. Possible future space missions include the Beyond Einstein Inflation Probe or nearer-term suborbital flights aimed at maturing technology.

The criteria for success: Develop the required device fabrication technology and demonstrate switching behavior at an initial design frequency of 30 GHz.

Technical risk factors that might have, or that in fact have, prevented achieving success: The primary risk factors involve device fabrication challenges. The devices are very small and are made from delicate material. More time than anticipated was needed to develop various fabrication steps. An additional risk factor was the need to successfully model both the microwave behavior of the switching device and of structures for getting microwave signals on and off the chip for testing.