Multiplexed RF-SET Readout Amplifiers for Superconducting Detector Arrays

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INTRODUCTION:
Several types of superconducting detectors are being developed for NASA applications, including transition edge sensors (TES)[1], superconducting tunnel junctions (STJ)[2], and photon-counting direct detectors (SQPC)[3]. Despite the complexity of cryogenic operation, such detectors are desirable because of capabilities such as *single-photon spectroscopy*, or *extreme levels of sensitivity*, which cannot be obtained with uncooled detectors.
Large format detector arrays will be facilitated by sensitive, fast, compact, low-power, multiplexable, on-chip amplifiers. For high impedance detectors such as the STJ and SQPC, the Radio Frequency Single Electron Transistor (RF-SET) seems to be an ideal readout amplifier.

RF-SET:
Single electron transistors (SET) are cryogenic quantum-effect devices which utilize quantization of charge on a small conducting "island" to yield a very high performance electrometer (Fig. 1) SETs are the electrostatic "duals"[4] of the better known SQUIDS, which are the most sensitive magnetometers and current amplifiers[5]. With picowatt power dissipation and sub-femtofarad input capacitance, SETs are well-suited as on-chip amplifiers for detectors with high resistance and low capacitance.

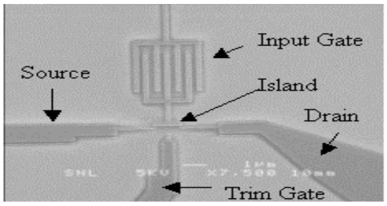

Figure 1. SET with input gate.

In an RF-SET[6](Fig. 2), an rf readout technique is employed to give amplifier bandwidths as large as 100 MHz. When an SET is connected to a high-frequency tank circuit and a carrier signal applied at the resonance frequency, the reflected power is modulated by signals at the SET input gate. Wavelength Division Multiplexing (WDM) of 20 - 50 amplifier outputs on one coax can be done by placing RF-SETs with different resonance frequencies in parallel.

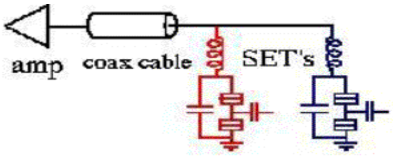

Figure 2. Schematic of two RF-SETs multiplexed onto one coaxial cable leading to an rf following amplifier.

TWO-CHANNEL WAVELENGTH DIVISION MULTIPLEXING:

We have successfully demonstrated the first two-channel wavelength division multiplexing of RF-SETs using discrete components wirebonded together (Fig. 3).

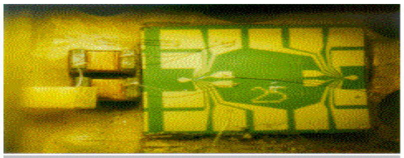

Figure 3. Two-channel WDM with SETs, inductors, and coaxial launcher wirebonded together. Chip is 7 mm square; SETs are at confluence of optical traces.

The rf power reflected from the parallel combination of the two tank circuits had nulls near two well-separated resonance frequencies (Fig. 4). By applying carrier waves at those two frequencies and monitoring the amount of reflected power for each, the input charge signals on each of the two SETs were reconstructed (Fig. 5).

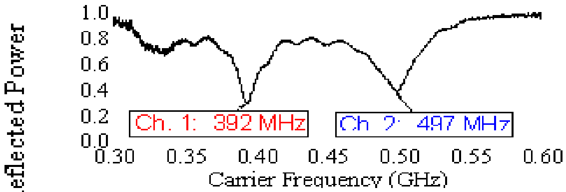

Figure 4. Reflected power versus frequency shows resonance frequencies for two parallel RF-SET tank circuits.

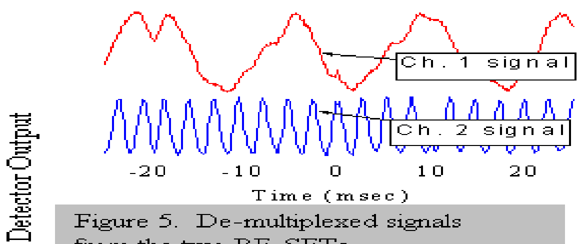

Figure 5. De-multiplexed signals from the two RF-SETs.

LITHOGRAPHIC TANKS:

We have made progress in miniaturizing tank circuits to allow larger arrays of multiplexed RF-SETs. On optically patterned substrate chips for our next generation prototype submillimeter detectors (Fig. 6), we have integrated a set of inductor coils and bonding pads which form tank circuit arrays when connected together with wire bonds. Each chip has sixteen inductors.

Figure 6. 8x10 mm substrate for SETs and submillimeter detectors. Chip has 16 rf tank circuits.

Planar 3D electromagnetic modeling software (SONNET [7]) was used to design the circuit elements to minimize unwanted cross inductance and capacitance, and to give the desired resonance frequencies and impedance transforming properties. For example, Fig. 7 shows a calculation of the capacitance matrix of the pad array. The capacitance of a pad dominates the total capacitance of its tank circuit. Calculations indicated that independent WDM channels with negligible cross coupling would be obtained if bonding pads used for tank circuits were alternated with pads tied to ground.

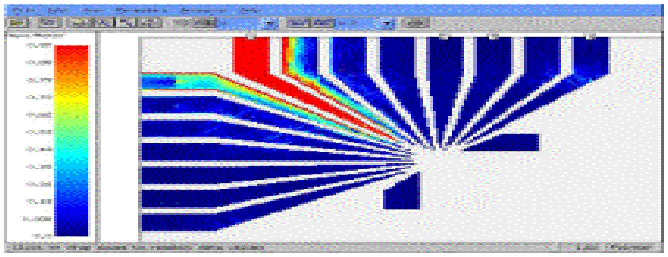

Figure 7. Charge density for cross capacitance calculation: voltage on one pad induces charges on all.

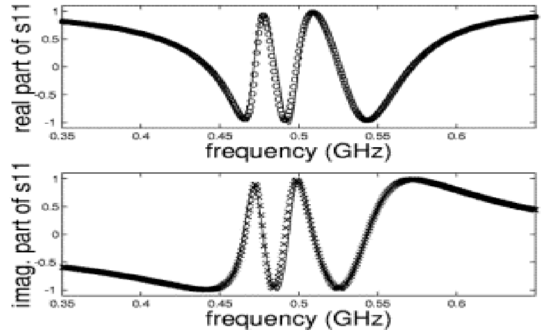

Figure 8. Reflection coefficient for three tank circuit array. Data (points) and parametric model (curves).

We tested this by measuring the reflection coefficient of tank circuit arrays in the superconducting state (Fig. 8). We found excellent qualitative agreement between the data and a parametric model assuming no cross couplings. Values derived for capacitances, inductances, and frequencies agreed with SONNET predictions to about 10% or better.

CONCLUSIONS:

We have demonstrated the wavelength division multiplexing concept for RF-SETs, and have shown that we have the rf engineering tools and fabrication technology for scaling up the number of multiplexed channels. WDM will be a valuable multiplexing technique for applying RF-SETs as on-chip readout amplifiers for superconducting detectors.

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