Radio Frequency Reflectometer for Single Electron Transistors as Multiplexers in Bolometer Array Detectors

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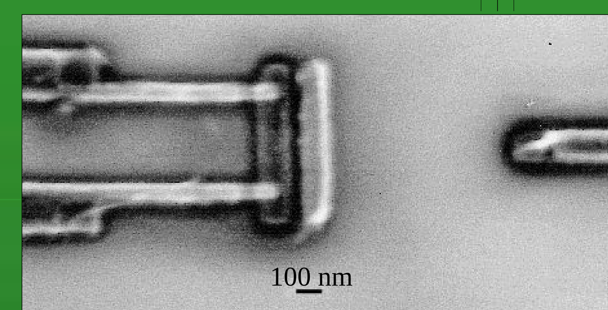
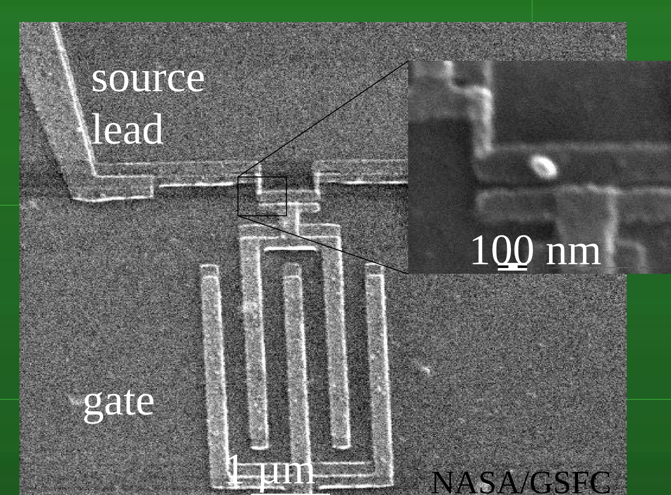


The SET device:

• The Single Electron Transistor has junctions approximately 60nm by 60 nm in size, with a 1 µm island. The total capacitance of the island to ground is so small (< 1 fF) that electrons are prevented from tunneling onto the island through the junctions by a "Coulomb blockade" energy $e^2/2C >> kT$. Applying a gate voltage turns the transistor on, and allows tunneling to occur, and current to flow.

• SETs have applications in detecting small changes in charge (on the order of one electron sensitivity in a few nanoseconds of measurement time).

• We are using the SET as an electrometer for the following advantages:
- faster readout
- low noise device
- multiplexing capabilities
- can be integrated on chip with detector

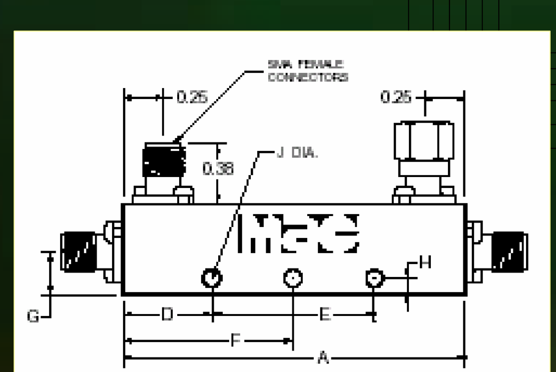


The Directional Coupler:

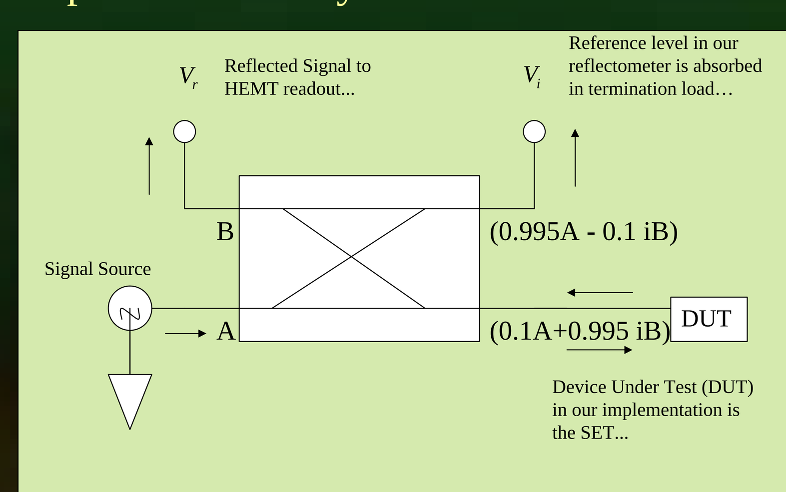
• A reflectometer, which measures the reflection coefficient of a device, will be used to monitor changes in the SET output in response to a changing input voltage on the SET gate.

• A directional coupler allows an RF carrier wave to be incident on the SET and resonant circuit, while the reflected wave is directed to the input of a High Electron Mobility Transistor (HEMT) amplifier for measurement of the reflected power level.

• After amplification, the reflected RF signal will be analyzed with an RF spectrum analyzer at room temperature.



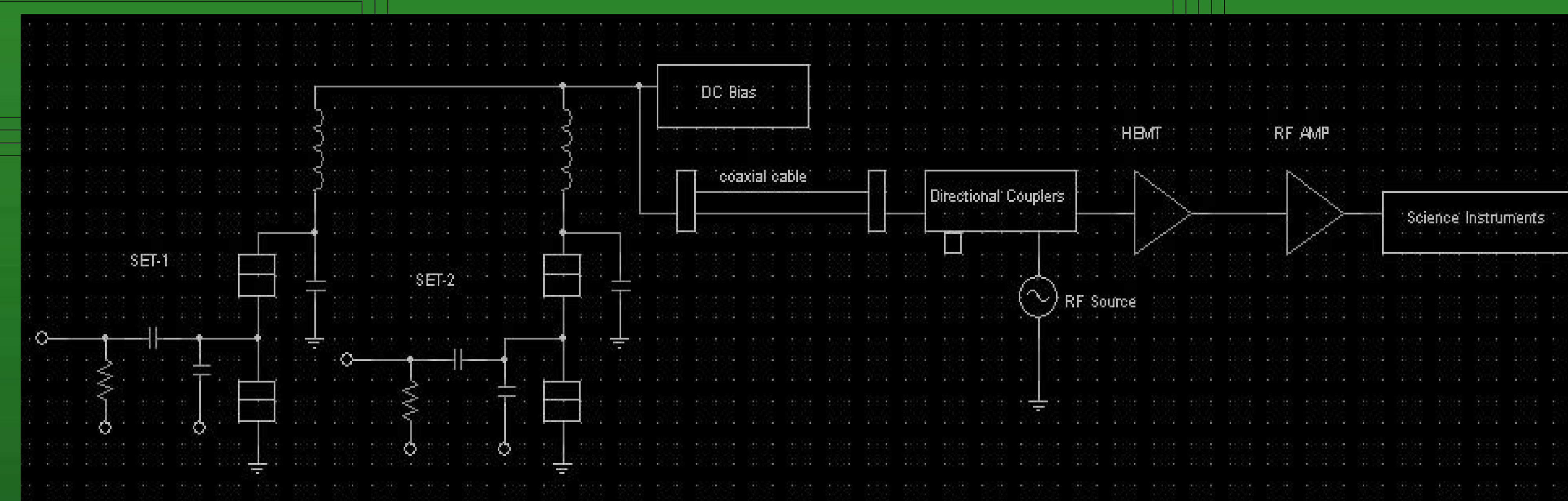
A Simple Scalar Analyzer:



Applications:

Our goal is to advance detector technology by reducing the noise equivalent power in a multiplexible architecture. Future missions will need Noise Equivalence Powers (NEP) as small as 10^{-20} W/√Hz and array sizes up to 10^4 pixels.

Spectrum	NASA mission	NEP GOAL	Detector and Multiplexor
X ray	Constellation X	Energy Resolution 2eV at 6 keV (NEP ~10 Š18 W/rt(Hz) for 1 ms time constant)	TES micro cal Š SQUID Silicon Thermister Š RF-SET
Far IR Sub mm	SAFIRE	NEP ~ 10 Š20 W/rt(Hz)	TES bolometer Š SQUID Silicon Hot Electron bolometer Š RF SET
Millimeter	CMB Polarization	NEP ~ 10 Š18 W/rt(Hz)	Antenna Coupled Superconducting Tunnel Junctions Š RF-SET



Reflectometer Circuit and RF Multiplexing:

• By putting a capacitor in parallel with each SET, and an inductor in series, resonant circuits are formed that transform the high output impedance of an SET (˜ 50 k?) to match the 50 ? HEMT amplifier. The reflectometer circuit, with directional coupler, can simultaneously read reflected signals from resonant circuits that each have a unique resonance frequency. This provides a form of multiplexing of many RF-SET signals onto one coaxial cable.

Following Amplifiers:

• Following the SET is an amplification chain. The first stage after the SET is a cryogenic low noise GaAs HEMT amplifier designed by the NRAO. Additional gain is provided by ZFL 1000 LN and ZFL 1000 amplifiers from Mini-Circuits.

• Amplifiers were selected to provide a gain which would increase the signal to a conveniently measurable level without adding significant extra noise.

Testing the Amplifiers:

• To test the design of the system, the amplifier's scattering matrix is measured.

• Calibrated S-parameter measurements at 300K were made with a vector network analyzer.

• The ZFL 1000 LN and ZFL 1000 were characterized. At -25 dBm input power, respective gains of 20 and 25 dB were obtained.

The Scattering Matrix provides a complete description of the device as seen from its ports. We can obtain direct magnitude and phase measurements of the incident, reflected, and transmitted voltage waves using a Network Analyzer. Below is the derivation of the S-parameters.

$V^- \equiv$ reflected Voltage

$V^+ \equiv$ incident Voltage

$$[V^-] = [S][V^+]$$

$$S_{ij} = \frac{V_i^-}{V_j^+}$$

$$S_{21} = \frac{V_2^-}{V_1^+}$$

$|S_{21}|^2 \Rightarrow$ gain ; $|S_{12}|^2 \Rightarrow$ reverse isolation

$|S_{11}|^2 \Rightarrow$ input return loss ; $|S_{22}|^2 \Rightarrow$ output return loss

Detector:

•This Project is for development of a reflectometer for Single Electron Transistors as Multiplexers for Large Format Semiconducting Bolometer Arrays.

• A bolometer is a small absorber of heat with a very sensitive thermometer that measures the change in temperature caused by absorbed radiation.

• A multiplexer reduces the amount of leads on the detecting chip by its ability to combine signals that would otherwise require separate readout devices.

Current Status & Future Work :

• Current work to analyze the HEMT and RF Amplifiers' gain and noise at 300K is being conducted in order to test the current design of the reflectometer.

• Band-pass filters and amplifiers which make up the RF Amplifier chain have been analyzed over a wide frequency at 300K using scattering matrix techniques.

• Hardware to rack-mount room temperature amplifiers and bias circuitry was designed and machined.

• Noise of the amplifiers will be characterized by the Y-factor method.

• After proper testing, the reflectometer will be used in conjunction with the SET circuit for further analysis with science instruments to measure the detector sensitivity.

Measuring Noise - The Y factor technique:

• It is assumed that the power output of the amplifier is proportional to the gain and the system temperature.

• We measure the output power as a function of the changing brightness temperature of the input load

• The x-intercept from a plot of the system temperature on the load vs. the output power will be the negative temperature noise of the amplifier.

$$P_{out} \propto k_B T_{sys} \Delta n_{BW}$$

$$P_{out} = \frac{\partial P}{\partial T} T_{sys} = \frac{\partial P}{\partial T}(T_{Load} + T_{Noise})$$

Above: The gain of the Mini-Circuits ZFL 1000 LN amplifier was measured with a network analyzer from 20 MHz to 6 GHz at -25 dBm (dB vs. Hz).