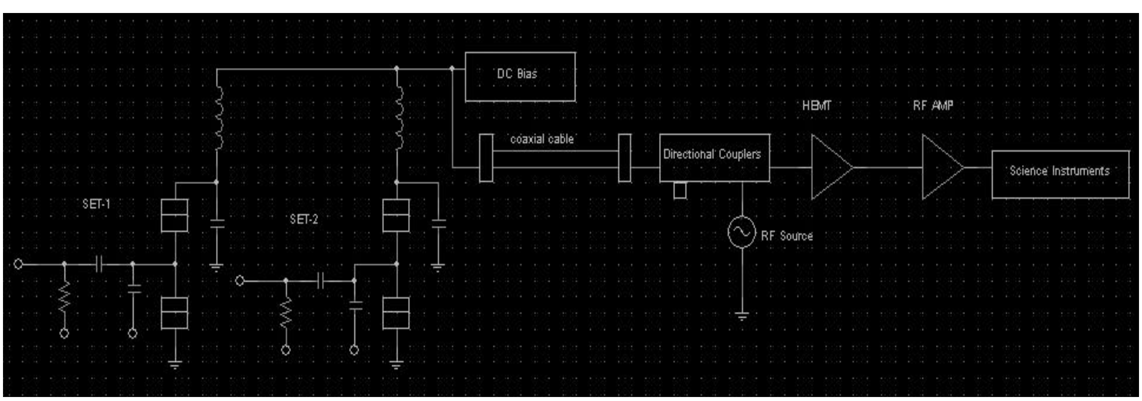
Radio Frequency Reflectometer for Single Electron Transistors as Multiplexers in Bolometer Array Detectors

Research Associate : Christina Pelzer
PI: Dr. Harvey Moseley*
Co I: Thomas Stevenson** and Ed Wallock*
NASA Goddard Space Flight Facility
* Infrared Astrophysics Branch (685)
** Detector Systems Branch (553)

- ## 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 $10^{-20}\ {}^{W}/_{\sqrt{Hz}}$ 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^{-18} W/rt(Hz) for 1 ms time constant)	TES micro cal – SQUID Silicon Thermister – RF-SET
Far IR Sub mm	SAFIRE	NEP ~ 10^{-20} W/rt(Hz)	TES bolometer – SQUID Silicon Hot Electron bolometer – RF SET Antenna Coupled Superconducting Tunnel Junctions – RF-SET
Millimeter	CMB Polarization	NEP ~ 10^{-18} W/rt(Hz)	

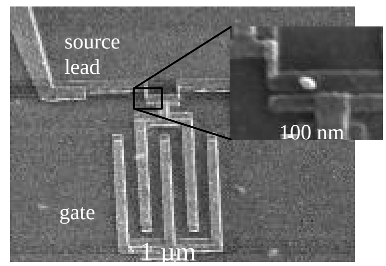
  - This Project is for development of a reflectometer for Single Electron Transistors as Multiplexers for Large Format Semiconducting Bolometer Arrays.
  - A bolometer is a small absorber of heat with a very sensitive thermometer that measures the change in temperature caused by absorbed radiation.
  - A multiplexer reduces the amount of leads on the detecting chip by its ability to combine signals that would otherwise require separate readout devices.



The detector device is shown in the schematic above. The first resistor represents a bolometer which is connected to the Single electron transistor at 0.24 Kelvins. 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 (50k?) 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 the directional coupler is a series of amplifiers selected to increase the signal to measurable level without adding significant noise. The signal will then be analyzed with an RF spectrum analyzer at 300K.

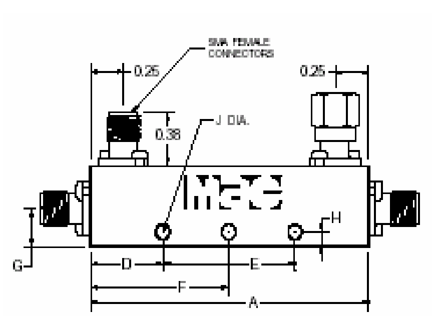
• Detector Components:

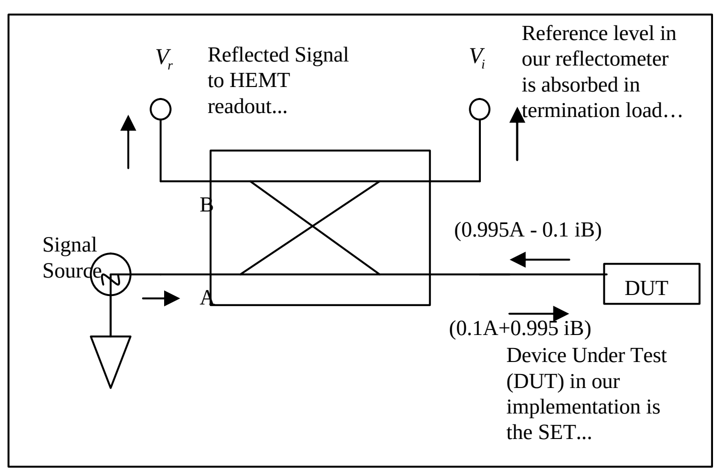
- The SET
  - The Single Electron Transistor has junctions approximately 60nm by 60 nm in size, with a 1 μm island. The total capacitance of the island to ground is so small (< 1 fF) that electrons are prevented from tunneling onto the island through the junctions by a "Coulomb blockade" energy $e^2/2C >> kT$. 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.





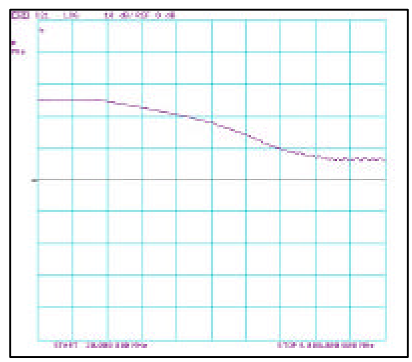
- # Following Amplifiers:
  - Following the SET is an amplification chain. The first stage after the SET is a cryogenic low noise GaAs HEMT amplifier designed by the NRAO. Additional gain is provided by ZFL 1000 LN and ZFL 1000 amplifiers from Mini-Circuits.
  - Amplifiers were selected to provide a gain which would increase the signal to a conveniently measurable level without adding significant extra noise.

– Testing the Amplifiers:

– Testing Gain

- 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.

Right: 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).



– 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.

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

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

- # 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.