Modelling of electronic noise in a cryogenic bolometer detector

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Introduction

A tin cryogenic bolometer detector (*TIN.TIN*-The INdia-based TIN detector) [1] is being developed to search for NDBD process in ^{124}Sn. The bolometric detector is preferred in rare decay searches due to its high energy resolution, in principle limited only by thermal fluctuations. Operationally, the noise contributed from other sources like components in the bolometer readout circuit, is a limiting factor. For TinTin detector, readout circuit consists of a Neutron Transmutation Doped (NTD) Ge sensor at mK temperature, a current source for sensor biasing and a front-end preamplifier. A noise analysis of the bolometer readout circuit is presented to understand the effect of noise from various sources. Such a model is also useful for the design and optimization low noise readout circuits.

Analytical noise model

For a bolometer readout circuit, the noise at the input of the amplifier consists of four components [3]- the johnson noise from bias resistor (R_L) and sensor resistors (R_S), the current and noise density of the amplifier e_{ni} and the voltage noise density of the amplifier e_{na}. These can be described as

$$|e_j| = \sqrt{4kT_jBR_{\mathrm{j}}}\frac{1}{R_j}\frac{R_{\mathrm{eq}}}{\sqrt{1+(\omega R_{\mathrm{eq}}C_{\mathrm{L}})^2}} \quad (1)$$

$$|e_{\mathrm{ni}}| = i_{\mathrm{na}}\sqrt{B}\frac{R_{\mathrm{eq}}}{\sqrt{1+(\omega R_{\mathrm{eq}}C_{\mathrm{L}})^2}} \quad (2)$$

$$|e_{na}| = e_{white}\sqrt{\left[1+\left(\frac{f_c}{f}\right)^n\right]B} \quad (3)$$

T_j is the temperature of sensor R_j, where $j = S, L$ refer to sensor and bias resistor, respectively and R_{eq} refers to their parallel equivalent combination. The resolution bandwidth B is set to 0.1 Hz and k is the Boltzman constant. The i_{na}, e_{white} and f_C represent input current noise density, white noise fluctuation and flicker corner frequency of the amplifier. Total noise at output will be rms addition of individual noise components convoluted with the amplifier gain and bandwidth response.

Data analysis and Results

Noise Measurements for NTD Ge sensors and SMD (Surface Mount Devices) resistors were carried out in the CFDR-1200 setup at TIFR [2] in multiple runs. For measurements four indigenously fabricated, identical NTD Ge sensors and SMD ressitors were directly coupled to the copper holder using GE varnish and the setup was mounted on the mixing chamber stage. SMDs with negative temperature coefficient (i.e. non-metallic behaviour)

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were chosen for noise measurements as a close match to NTD Ge for resistance variation with temperature. The SMD resistors were also mounted on a similar copper holder. A train of square wave pulses were used for R_S measurements while C_L was estimated from fitting an exponential decaying function at falling edge of the square waves. Noise measurements were done in temperature range of 20 - 70 mK with bias voltage close to zero.

For optimizing the model, a subset of NTD Ge sensor data spanning range of $R = 1 - 50$ MΩ and $T = 40 - 70$ mK were carefully selected to enhance sensitivity to different noise contributions. Analysis was done in the frequency domain and from the fit to the data (excluding $f \leq 0.1$ Hz, to remove influence of residual DC offsets) the model parameters f_c,i_{na} and e_{white} were extracted. Fig. 1 shows a typical comparison between simulated and experimental noise spectra for one of the NTD Ge sensors. It is observed that optimal value of f_c is much lower than the amplifier specification, while other two parameters are found to be similar. These optimized parameters were used to calculate the noise of NTD Ge sensors at $T = 20 - 70$ mK and of SMD resistors at $T = 3 - 13$ K. The good agreement between the simulated noise and data over a range of R_S ($\sim 0.1 - 4000$ MΩ) and T_S is evident from Fig. 2. It is observed that the amplifier noise (current and voltage) is the dominant factor. This can be improved by using the amplifier at the cold stage. Further, employing the model, it can be seen that for $R_{NTD} > 1$ GΩ, the amplifier current noise will be significantly large. Hence, from noise considerations, R_{NTD} should be less than 1GΩ. Since the sensitivity of R_{NTD} is better for high values, the optimal R_{NTD} is suggested to be $\sim 0.5 - 1$ GΩ.

In summary, an analytical model for bolometer readout circuit with optimized parameters has been presented. The optimized model has been verified for NTD Ge sensors over a wide range of $R_S = 130$ kΩ - 4.1 GΩ in 20 - 70 mK and for SMD resistors in the range $T = 3$ - 13 K. Further, the model can be used for voltage noise predictions. From noise considerations, the desired range for R_{NTD} is shown to be 0.5 - 1 GΩ.

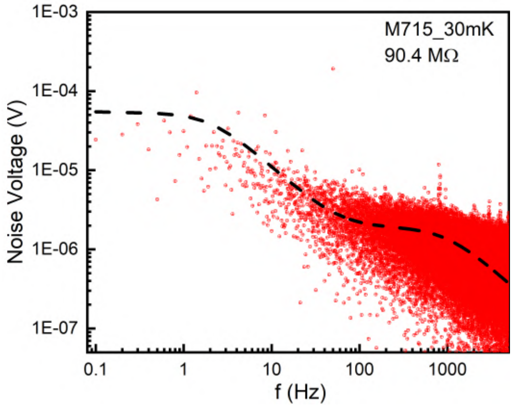

FIG. 1: A comparison of simulated noise and data.

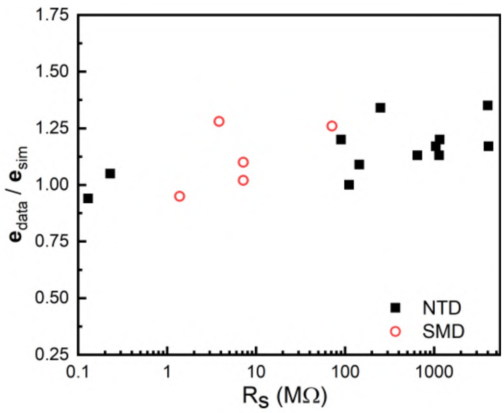

FIG. 2: Ratio e_{data}/e_{sim} over a range of R_S.

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