# Calibration Procedure for Cryogenic Noise Measurements

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***Abstract*—Cryogenic noise measurement using Tunnel Junction Shot Noise Source(TJSNS) is one way to address measurement uncertainties associated with thermal gradients. However, for this technique to work, the insertion loss between the TJSNS and the input of amplifier must be known. In this project, a two-tiered VNA calibration procedure, based on Thru-Reflect-Line(TRL) and Short-Open-Load(SOL) calibration techniques, is developed for determination of each component's gain at cryogenic temperatures.**

***Index Terms*—TJSNS Noise Measurement, Cryogenic TRL and SOL Calibration, Microwave Switches.**

## I. INTRODUCTION

SEVERAL cryogenic noise measurement techniques are in use, but each has its own limitations. The variable-temperature load method is challenging to perform accurate calibration due to uncertainties result from thermal gradients. The alternative cold attenuator method is suitable for characterizing Device Under Test(DUT) with less than 10 K noise temperature, while one further step calibration by using a device, whose noise property has been fully characterized, is required. This increases the complexity of the noise measurement [1]. One approach to reduce the effects of uncertainties without introducing multicycle cooldown calibration is using TJSNS [2].

In TJSNS Noise measurement, the output power $P_{out}$ is measured as different bias voltages $V_{bias}$ are applied to the noise source. After one step data fitting between $P_{out}$ and $V_{bias}$, following parameters can be determined:

$$T_m = \frac{T_e}{\eta} + \frac{T_a(1-\eta)}{\eta} \quad (1)$$

$$T_e = \eta T_m - T_a(1-\eta) \quad (2)$$

$$G_m = \eta G \quad (3)$$

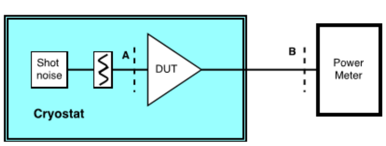


Fig. 1. Block diagram of TJSNS based noise measurement setup.

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where $T_a, T_m, G_m$ are ambient temperature, measured noise temperature, and measured gain [1]. $\eta$, in equation (3), is the gain between TJSNS and DUT, shown in Fig.1. When its value is derived, equivalent temperature $T_e$ of DUT capable of being obtained from equation (2). The goal of this research is to develop a methodology to systematically determine the value of $\eta$, by carrying out calibration procedure to calculate the gain $G$, along the path between plane A and B.

## II. BLOCK DIAGRAM

The block diagram, shown in Fig.2, composes of subsystems working at both room temperature and cryogenic temperatures. A suite of microwave switches, featuring low channel loss, low power consumption and high isolation, are employed to be driven systematically so that following calibration procedure can be achieved.

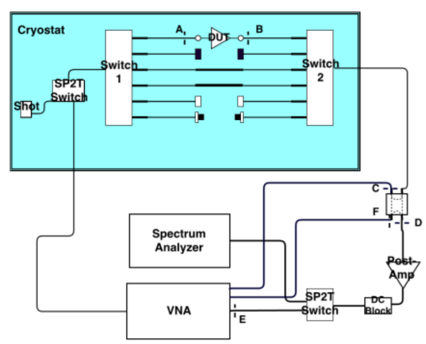


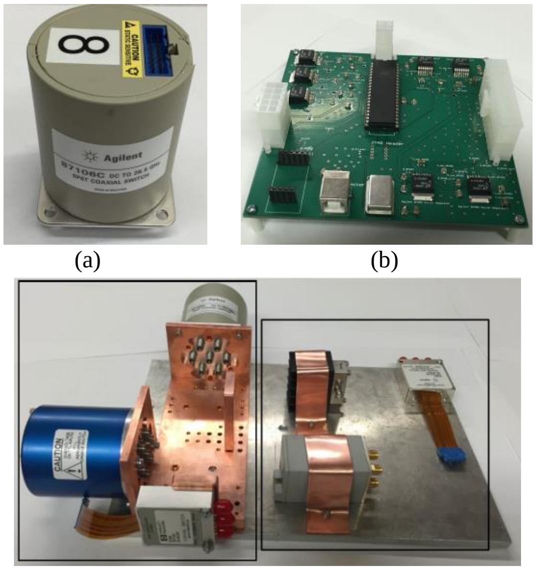

Fig. 2. Block diagram for the whole system.

Step1: TRL Calibration to reference plane A and B, and measures DUT S-parameters $S_1$(transmission parameters $T_1$).
Step2: SOL calibration to determine path B-C S-parameters $S_2$(transmission parameters $T_2$).
Step3: S-parameter measurement to determine path C-E S-parameters $S_3$(transmission parameters $T_3$).
Step4: S-parameter measurement to determine path C-F S-parameters $S_4$(transmission parameters $T_4$).

After cascading above T-matrices, $T = T_1 T_2 T_4^{-1} T_3$, and converting back to scattering parameter $S$, the gain from reference plane A to Spectrum analyzer is $G = |S_{21}|^2$ and $\eta = {G_m}/{G}$, which is used to determine $T_e$ of DUT.

## III. IMPLEMENTATION

The block diagram, shown in Fig. 2, is implemented by three parts: suite of mechanical relay switches with calibration standards, microcontroller interfaced for TTL driving Printed Circuit Board (PCB), and Oxygen Free High Conductivity (OFHC) mounting system.



(a) (b)

(c)

Fig. 3. (a) Agilent SP6T Switch. (b) Microcontroller interfaced PCB. (c) Mounting system: left box is OFHC mounting put inside cryostat and right box is room temperature switches setup.

## IV. MEASUREMENTS

The measurements are conducted at both room temperature and cryogenic temperatures. Performance evaluation and function verification of the calibration procedure are firstly finished at room temperature. After characterizing error of calibrated results, we apply this technique to TJSNS noise measurement to extract DUT's equivalent noise temperature and compare it with the noise temperature measured by using Spectrum Analyzer noise figure meter.

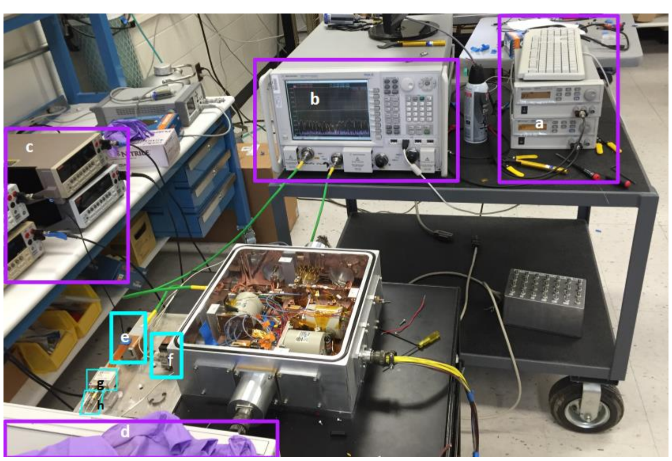
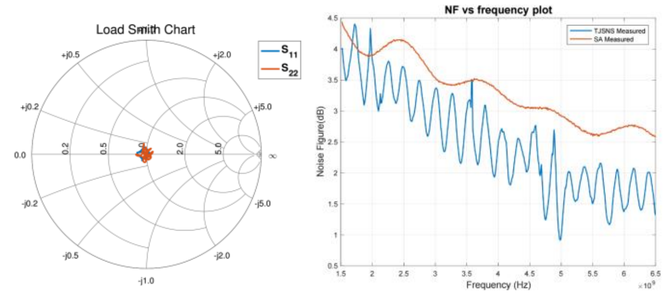



Fig.4. Measurement setup: (a) DC bias for switches. (b) Vector Network Analyzer(VNA). (c) DC bias for DUT. (d) Spectrum Analyzer. (e) Room Temperature Transfer Switch. (f) Post-amp. (g) Room Temperature SP2T Switch.

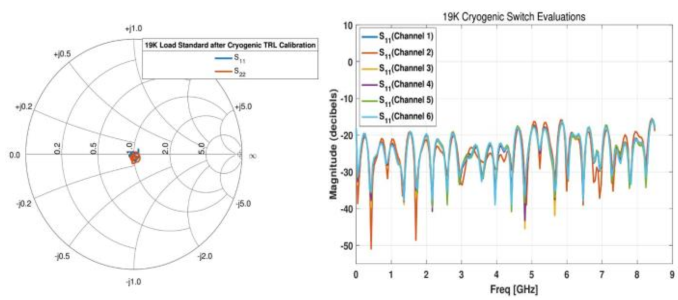



(a) (b)

Fig. 5. (a) Measured Load after TRL Calibration. (b) Noise Figure comparison between TJSNS noise measurement and SA noise figure meter measurement

As shown in Fig. 5, there are around 0.5dB ripples for TJSNS measured noise figure, but in general, it reaches good agreement with SA noise figure meter measured result.

For measurements at cryogenic temperatures, we evaluate the performance of switches at 19K, and then perform cryogenic TRL Calibration. The results are shown in Fig. 6.




(a) (b)

Fig. 6. (a) Measured Load after Cryogenic TRL Calibration. (b) Evaluation of SP6T channel connecting Load standards at cryogenic temperatures.

## V. CONCLUSION

The calibration procedure has been evaluated at both room temperature and cryogenic temperatures. Applying it to TJSNS noise measurement, measured noise figure reaches agreement with SA noise meter measured result at room temperature. At cryogenic temperatures, though some reasonable data of noise measurements is obtained, there are errors and further improvement is required.

## VI. FUTURE PLAN

This experience made me realize the importance of having a solid theory background. Hence, I decided to continue my graduate school study to dig deeper.

The trip to 2017 International Microwave Symposium was an excellent experience. In the future, I am excited to attend these conferences to catch the state-of-the-art research results.

## REFERENCE

[1] J. E. Fernandez, “A noise measurement system using a cryogenic attenuator.” JPL, Caltech, 1998.

[2] Chang, Su-Wei, Jose Aumentado, Wei-Ting Wong, and Joseph C. Bardin, “Noise Measurement of Cryogenic Low Noise Amplifiers Using a Tunnel-Junction Shot-Noise Source.” International Microwave Symposium 2016.