Design and performance of a signal processing system for CULTASK experiment

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Abstract

The CULTASK is an experiment to search for the cosmic Axion using resonant cavity, targeting to detect converted 1 ~ 8 GHz photon signal of 10^{-24} W from the Primakov effect in a very high magnetic field and ultra low temperature. To keep the high signal-to-noise ratio and detect very weak signal, a signal processing system has been designed and developed. Basic principle of the signal processing is radio frequency (RF) transceiver with the direct conversion to baseband, with a fast digitizer to read the amplified signal in real time for further Fourier transformation. The performance of cryogenic amplifier chain with cavity, room-temperature signal processing will be presented.

Introduction

A. CULTASK

- CULTASK : CAPP Ulutra Low Temperature Axion Search in Korea, Axion cavity experiment @ CAPP/IBS
- The axion is converted into 1 ~ 8 GHz, 10^{-24} W photon in high magnetic field.
- It is necessary to deal with RF signal. (signal processing system)

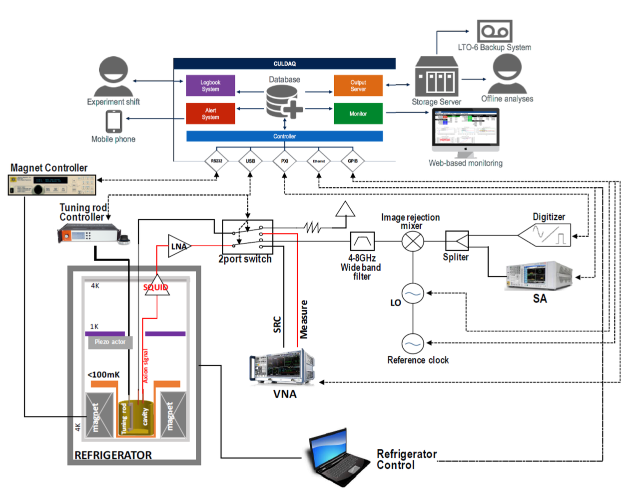


Fig. 1 Schematic of CULTASK

B. Signal processing system

- The high quality factor of cavity can increase the probability of axion signal detection
- Since the axion signal is vest small to detect, the noise of system which the signal goes through should be measured.

Measurements

A. Q factor

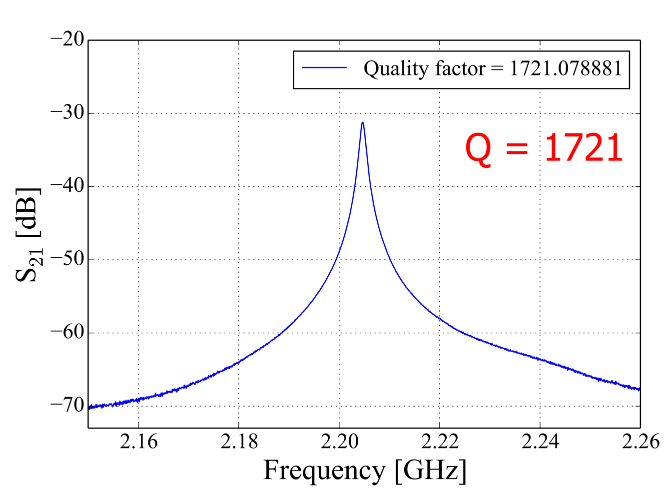


Fig. 2 Measurement of Q factor in frequency domain

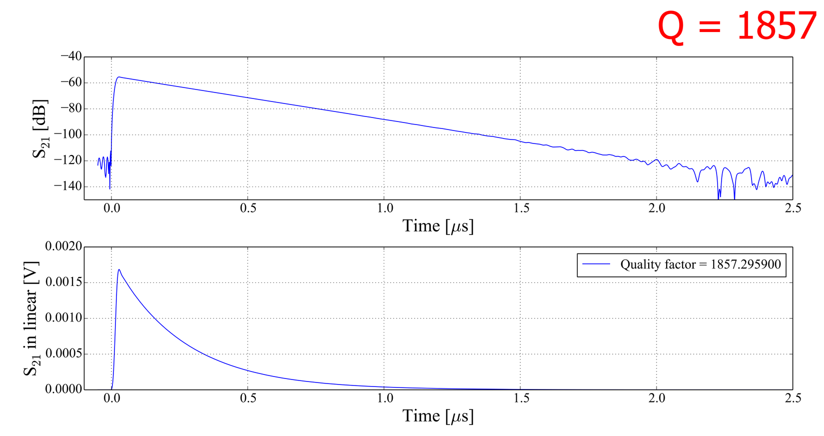


Fig. 3 Measurement of Q factor in time domain

- The high quality factor of cavity can increase the power of axion signal.
- Q factor can be measured in two ways : frequency domain and time domain

B. LNF-LNC1-12A (Cryo amp)

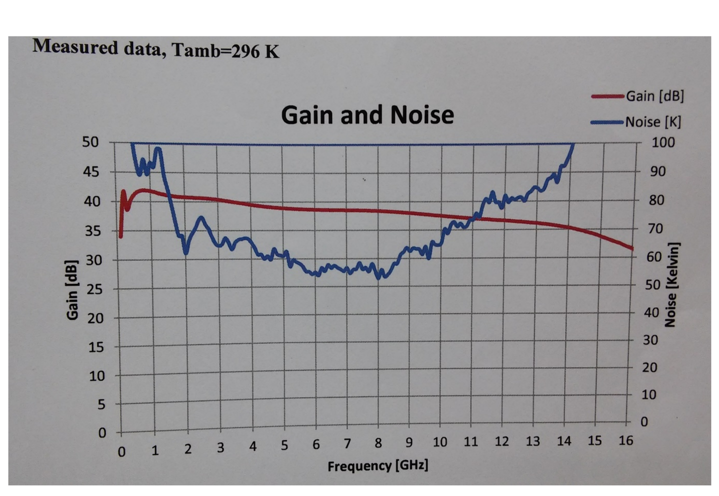


Fig. 4 Measurment of gain and noise : LNF-LNC1-12A s/n 505B @ 296 K

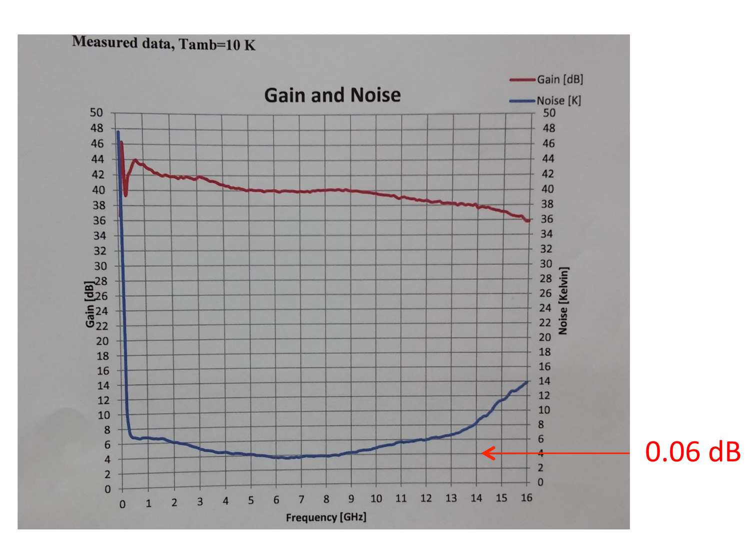


Fig. 5 Measurment of gain and noise : LNF-LNC1-12A s/n 505B @ 10K

C. Gain measurement

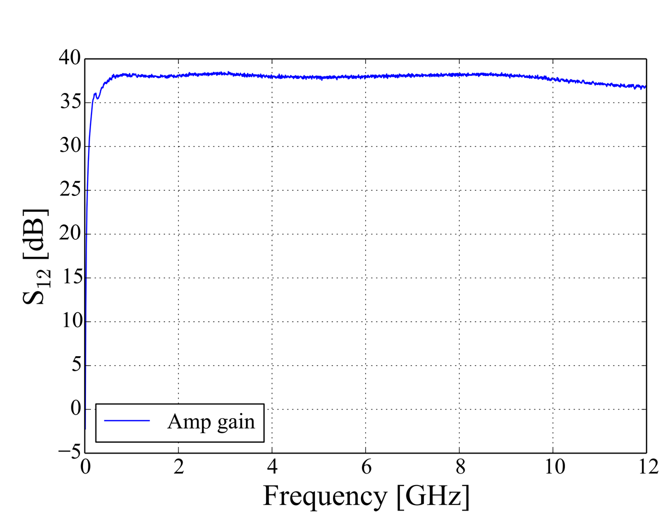


Fig. 6 Gain measurement using network analyzer @ room temperature

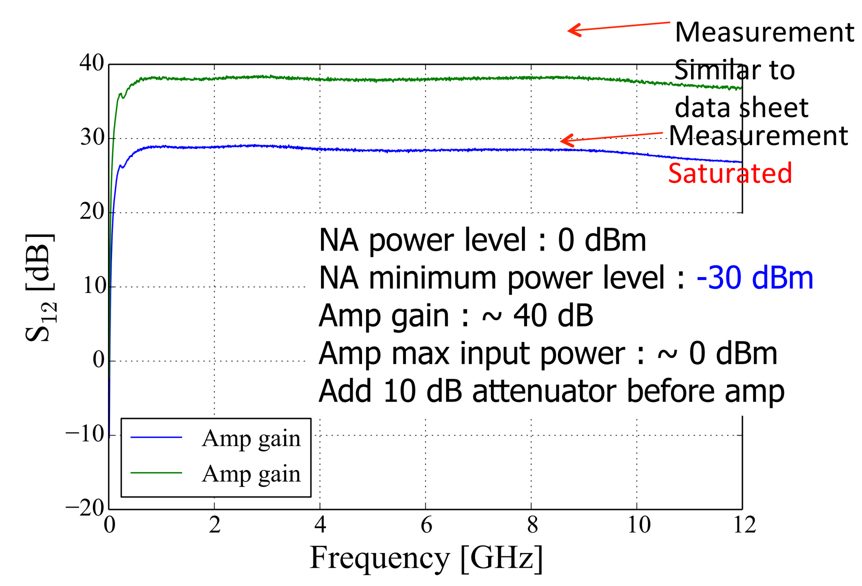


Fig. 7 Gain measurement using network analyzer @ room temperature : saturated measurement

D. Noise diode calibration

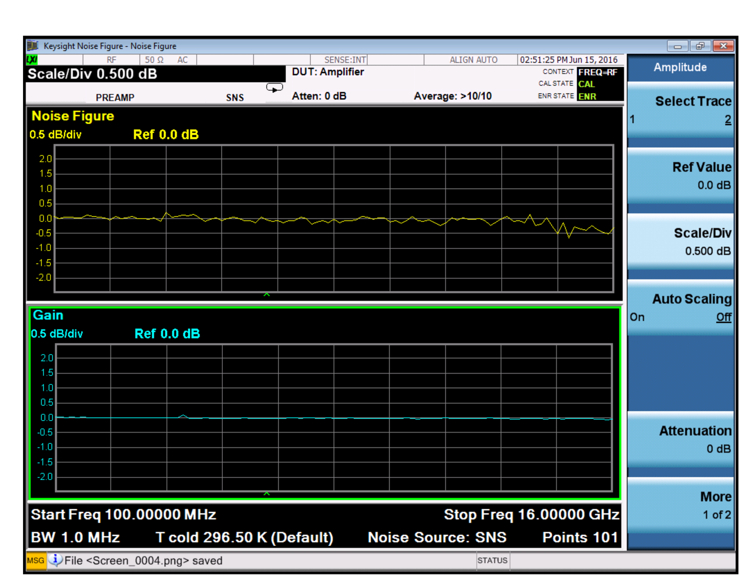


Fig. 8 Calibration

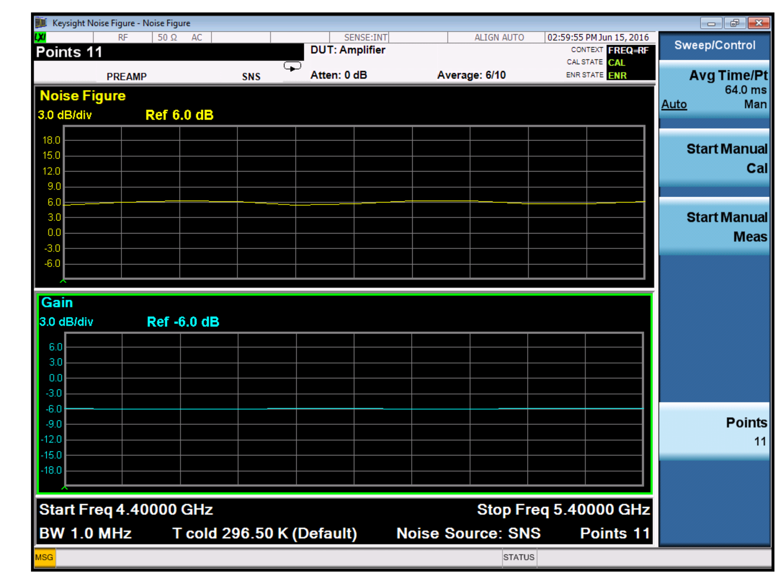


Fig. 9 Check the calibration quality using 6 dB attenuator

E. Y factor method

- Popular way to measure noise figure, an ENR (Excess Noise Ration) source is needed
- Y is the difference between the output noise power density when the noise source is on/off

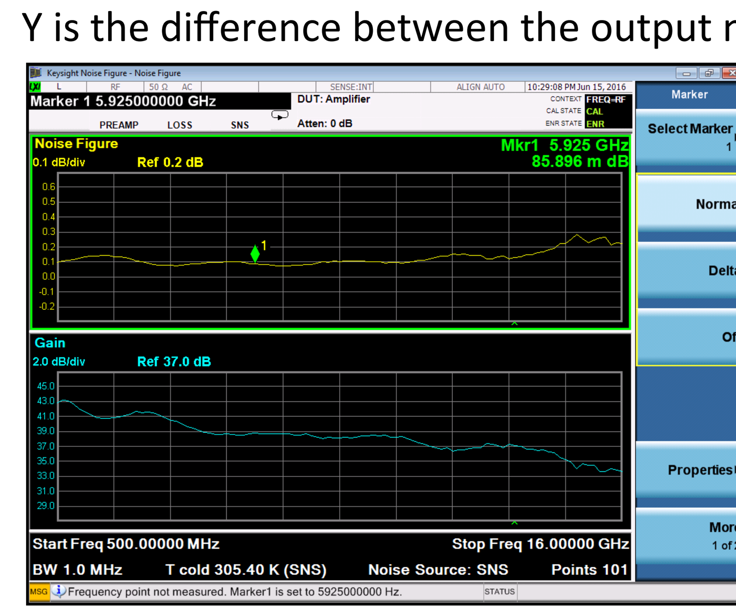


Fig. 10 Noise Figure and gain measurement at 4 K

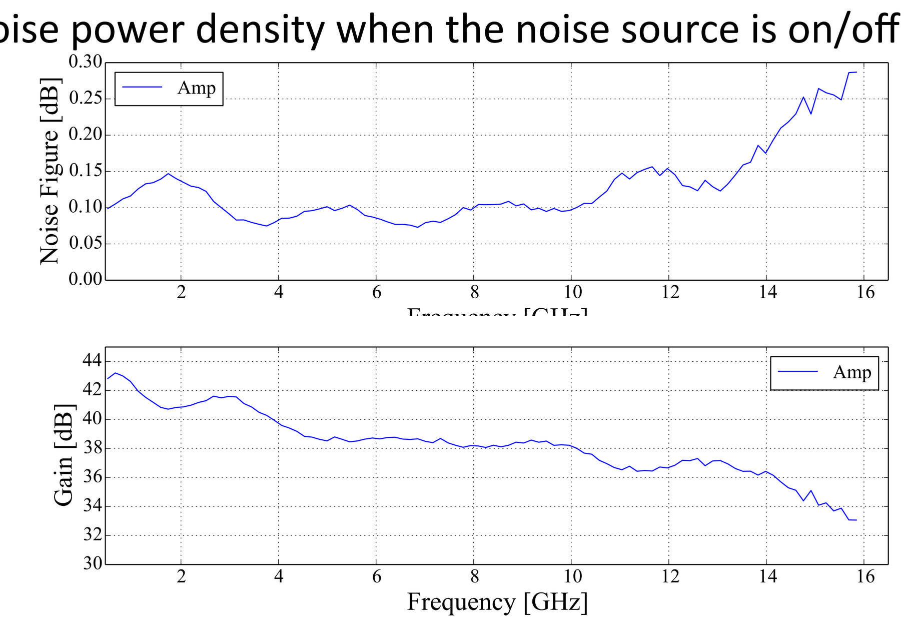
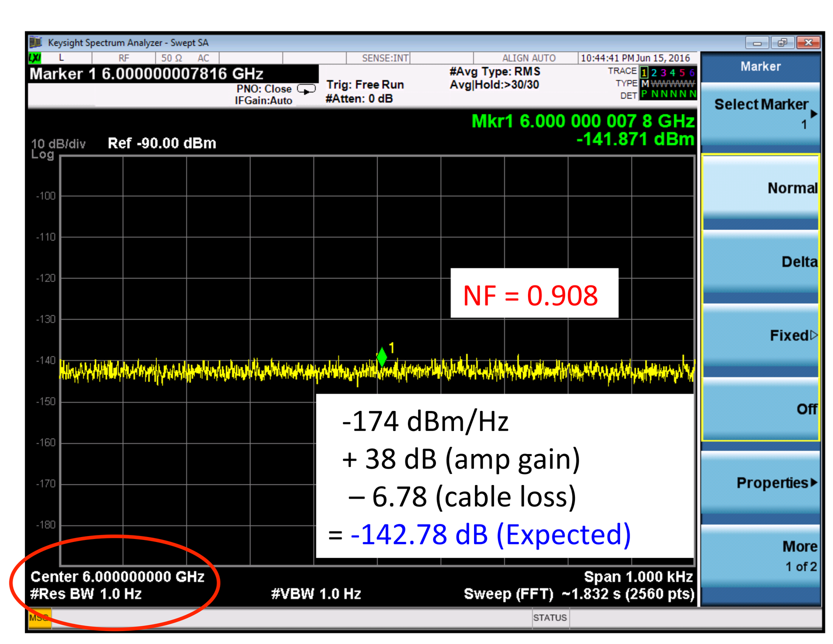


Fig. 11 Noise Figure and Gain measurement at 4 K

F. Gain method

- Involves more measurements and more calculation.
- BUT under certain condition, more convenient and more accurate



$$\text{Noise Factor (F)} = \frac{\text{Total Output Noise Power}}{\text{Output Noise due to Input Source Only}}$$

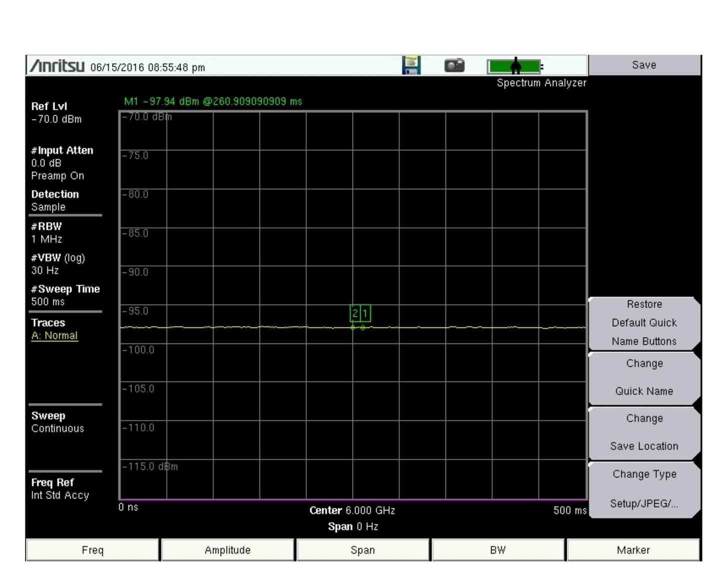
- Noise is due to two effects
- Interference comes to the input of a RF system in the form of signals that differ from the desired one
- Random fluctuation of carriers in the RF system (LNA, mixer, receiver, etc) – a result of Brownian motion

G. The signal generator twice-power method

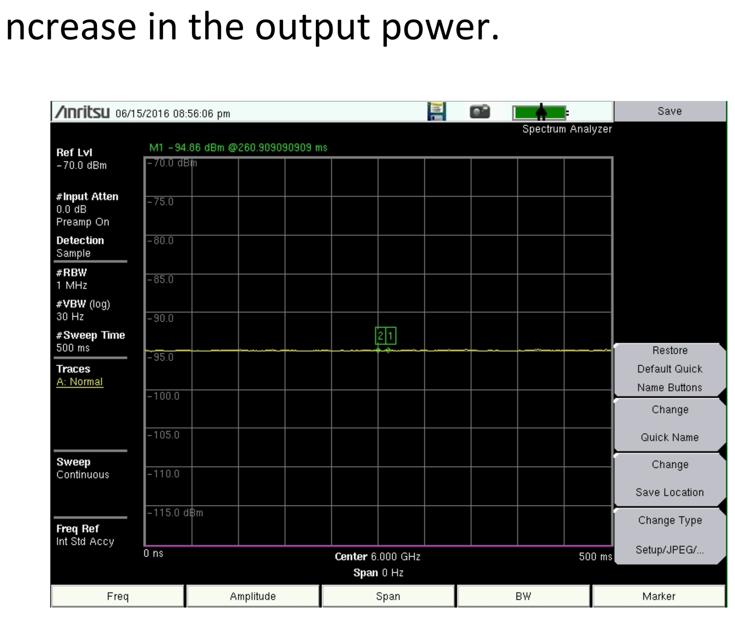
- Before noise sources were available this method was popular.

The output power is measured w/ the amp input terminated with a load

Signal generator (SG) is connected The generator output power is adjusted to produce a 3 dB increase in the output power.



-97.9 dBm – cable loss (6.78 + 2.13 dB) – 20 dB attenuator = -126.81 dBm



Amp output – cable loss (6.78 dB) = -94.9 dBm
Amp output : -88.12 dBm

-126.81 + amp G (38 dB) – amp output = 0.69 dB (NF)

Conclusion & Plan

- Important to know more than one method to make measurement to cross check
- Quality factor measurement can be done in both frequency and time domain
- Noise figure measurements are done with many methods, results are well agreed

Reference

[1] Efstathiadis, Efstratios, Y.y Lee, Jian-Lin Mi, Chien Pai, Jonathan M. Paley, B.lee Roberts, Ralph T. Sanders, Yannis K. Semertzidis, and David S. Warburton. "A Fast Non-ferric Kicker for the Muon (g−2) Experiment." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 496.1 (2003): 8-25. Web.
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[3] http://operafea.com