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June 14, 2023

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Subject: Initial Measurements of L-Band Ultra Low Noise Amplifier from CMT

### Summary

This document summarizes measurements of the L-Band Ultra Low Noise Amplifier (ULNA) from Cosmic Microwave Technology (CMT), serial number 342R, performed on June 6<sup>th</sup> 2023 at Haystack Observatory. Comparison is provided with the reported data for the unit from CMT. Additionally, measured levels required to activate the internal noise calibrator are included along with the impedance into which the calibrator control signal driver circuit must operate..

### Background

The ULNAs from CMT (depicted in Figure 1) were designed for the Deep Synoptic Array<sup>1</sup>, and were first described by Weinreb and Shi in 2021 [1]. These amplifiers achieve a noise temperature of about 7 Kelvin when operating at room temperature and are useable over essentially the entirety of the L-band. Ganesh Rajagopalan was able to ask CMT to donate four units for use by Tufts and MIT. Unfortunately, as these are not a commercial product we do not have a formal datasheet to work with and some information about them is lacking. Particularly, interface information for the built-in noise calibrator control circuit was quite cursory and not sufficient to provide confidence in producing a successful design to operate the LNA on the 6m dish or the Tufts SRT.



Figure 1. A ULNA from Cosmic Microwave Technology. The N Type connector on the left is the input, the SMA on the right is the RF output, as well as the input for DC bias and the calibrator control signal. A green indicator LED next to the SMA connector illuminates when the internal noise source is active.

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<sup>1</sup> <https://www.deepsynoptic.org/technology>

## Gain and Noise Measurements

Measurements of the gain and noise temperature of the LNA from 1 to 2GHz were performed in the instrumentation lab at Haystack Observatory using an Agilent N9030A and are shown in Figure 2 and Figure 3. The uncertainty of the noise figure measurement at Haystack is about 0.21dB (about 14.4 K), which is significantly larger than the noise of the amplifier, however, we can observe that the shape of the noise temperature curves very closely agrees with the data shared with Ganesh by CMT in October of 2022 [3].

One important difference is that the Haystack measurement shows the sampling density in the data from CMT is grossly insufficient to provide accurate calibration in the region around 1.2GHz, where the amplifier internal calibrator temperature varies rapidly. Based on the more precise measurements from CMT and the raw data from Haystack we should be able to provide a more accurate correction for the noise temperature measurements.

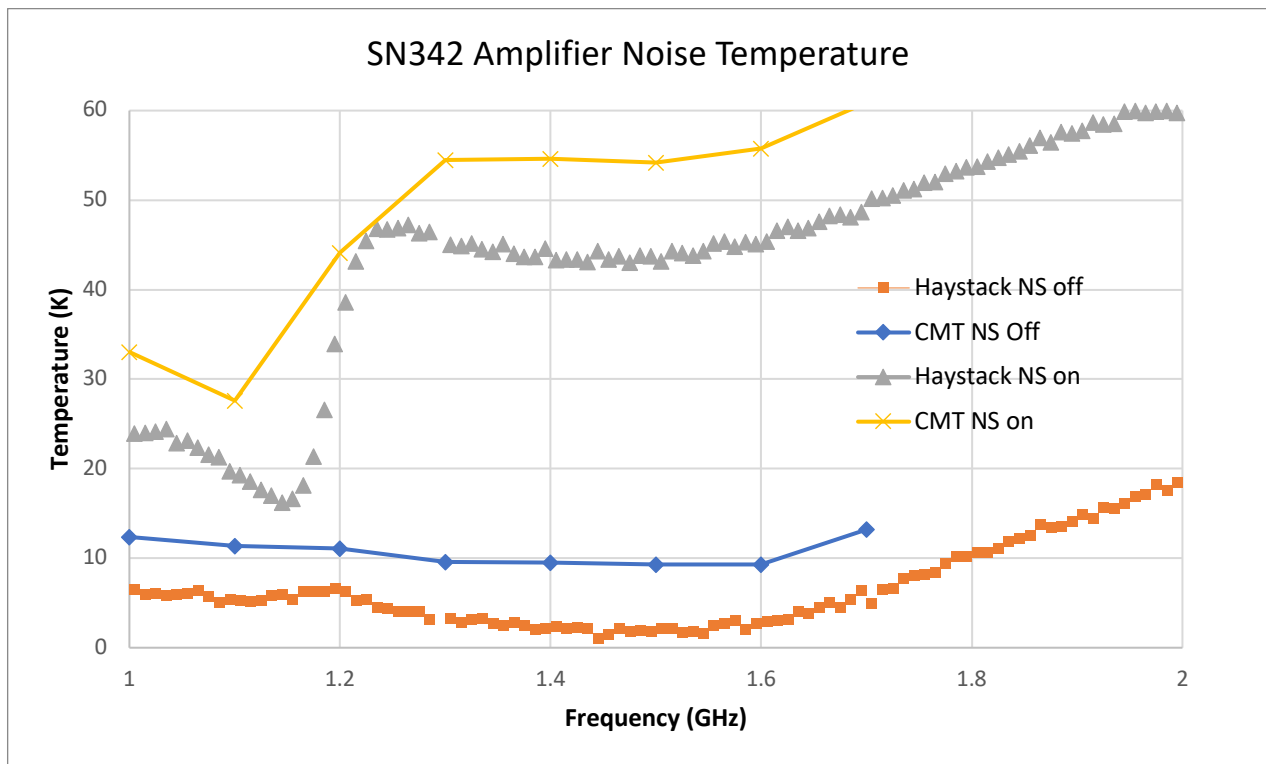


Figure 2. Amplifier noise temperatures as measured at Haystack and reported by CMT. Values are shown for the amplifier both with the noise calibrator off, and with the calibrator active.

The measured gain in Figure 3 shows extremely close agreement with the measurements from CMT. The full S parameters of the device were also measured using a Keysight N9917A FieldFox Network analyzer likewise show close agreement with reported values, however, the Haystack measurements do suffer from significant noise due to the use of a -40dB measurement level (Figure 4). The S21 measurement shown in Figure 5 very closely matches CMTs data, with some slight deviation in the vicinity of 1.3 GHz and 1.7 GHz. Additionally, while not examined in detail, a cursory sweep of the VNA output power suggests the reported 1dB compression point of -24dBm input is likely correct. Two tone tests for intermodulation performance will require a separate measurement setup.

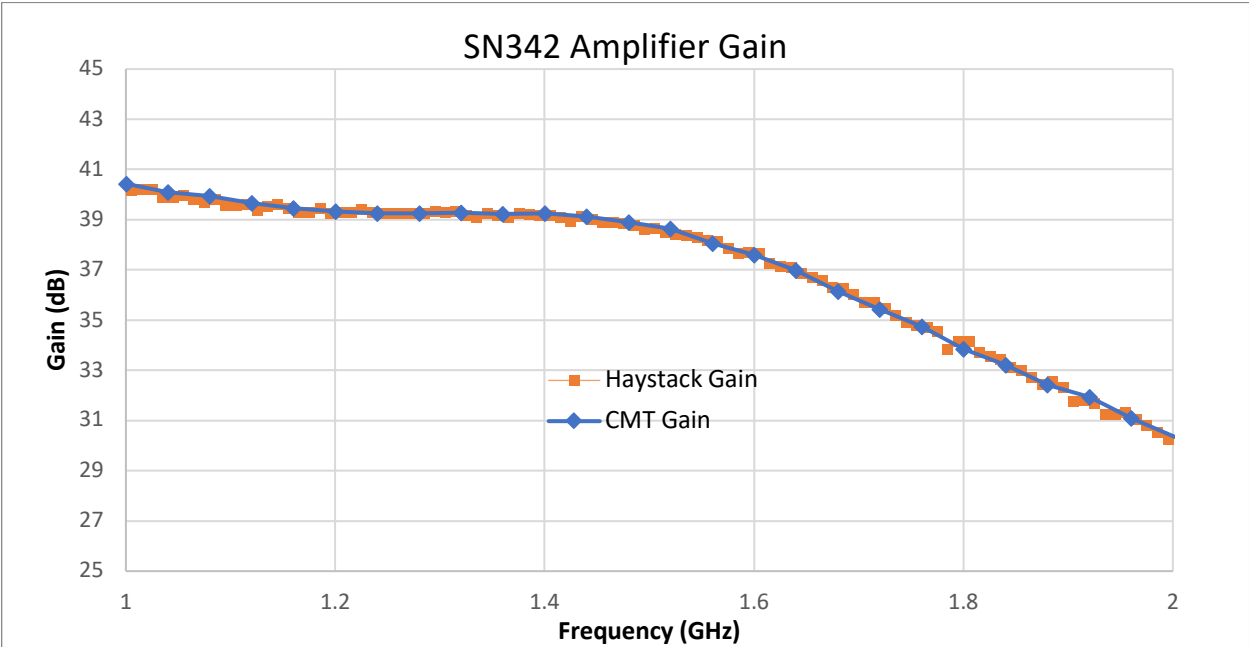


Figure 3. Measured gain values as reported by CMT and as measured at Haystack Observatory using an Agilent N9030A spectrum analyzer.

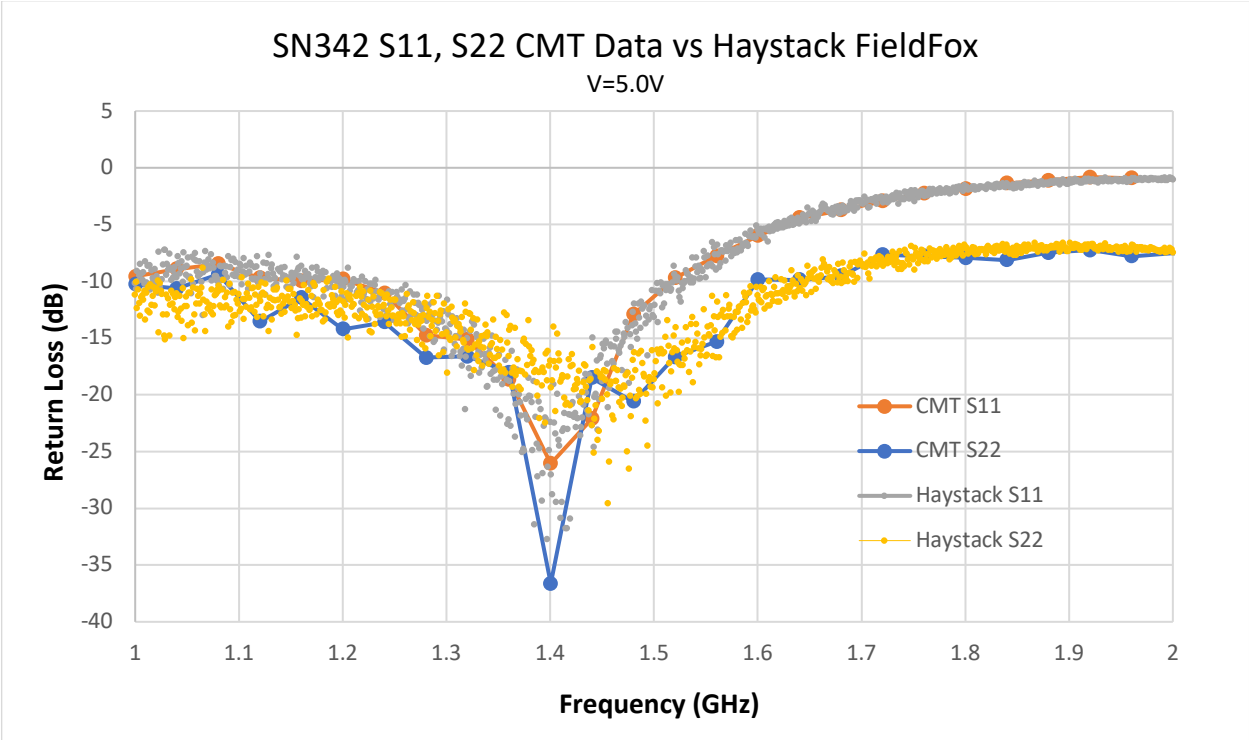


Figure 4. Measured S(1,1) and S(2,2) of the powered amplifier including the effect of the bias tee. Measurements at Haystack were performed using a Keysight N9917A FieldFox.

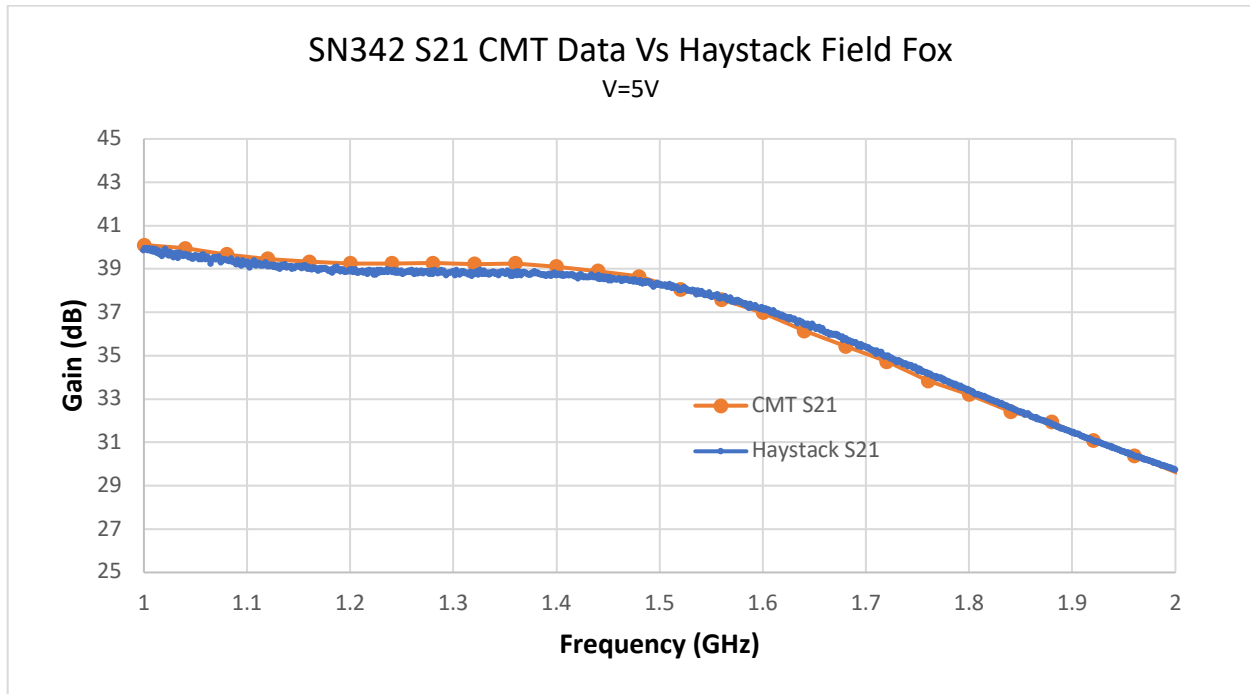


Figure 5. Gain measurement of the ULNA using the Haystack FieldFox

### Noise Calibrator Control Signal Testing

The highest priority in testing was to measure the signal characteristics needed to activate the internal noise calibrator, which according to [1] is activated by a 32kHz tone injected onto the RF output line. No details about the required signal level are provided in the paper. Further, the information provided by CMT to Ganesh via email lacked sufficient information about the impedance seen by the signal and raised more questions about the signal levels.

“The DC bias of the amplifiers is injected through the output SMA connector. We were using a minicircuits ZFBt-6GW-FT+ bias tee. The supply voltage is 5.0 V @ 60-70 mA. To turn on the noise diode, inject a 30 kHz sine wave (couple of volts p-p) into the output SMA connector through a second bias tee.”[2]

To test the actual levels required, the circuit of Figure 6 was assembled from discrete components on hand and a Mini Circuits dc bias tee purchased for the project. This circuit allowed separate injection of the DC Bias and the control signal. Under this configuration, the calibrator source was observed to activate with roughly 120mv peak to peak input to the network from a signal generator, and roughly 300mv peak to peak into the Mini Circuits bias tee with a 10 degree phase lead. The signal generator output was probed using a coax tee fed to the scope, the bias tee was probed using a 10:1 probe. Backing this out from the input network impedances (with C2 shorted by the power supply), it implies an impedance looking into the bias tee of about  $0.69+2.57j$  ohms.

Notably, this is quite close to the bias tee’s native input impedance of about  $0.9+3.5j$  at 32KHz when terminated in 50 ohms on both RF ports (simulated in Keysight ADS). We are also already

well into the rolloff of the bias tee’s passband, so we are likely primarily looking at its impedance rather than that of the LNA.

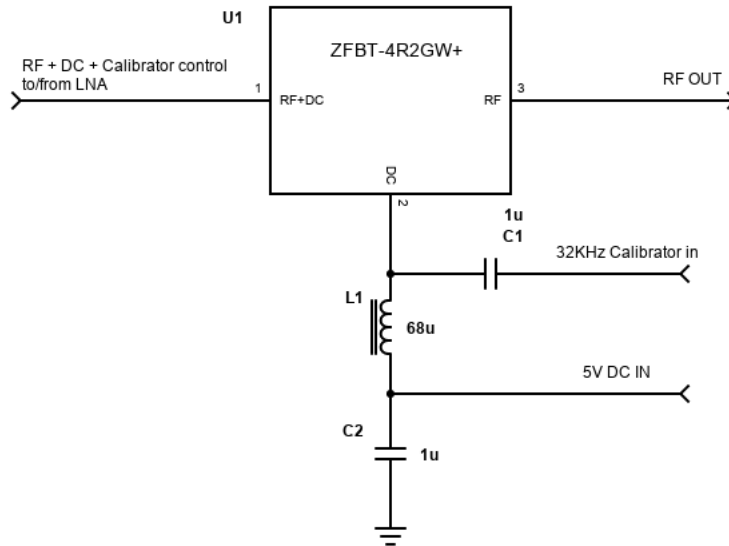


Figure 6. Test circuit for bias and control signal injection

Any circuit which can impose a 300mV peak to peak signal onto this input impedance should be sufficient to activate the calibrator. A simple opamp oscillator combined with a filter will be designed for this purpose.

**Summary Data for ULNA SN342**

Table 1 contains a combined summary of data on the amplifier form all available sources.

Table 1. Combined summary data for ULNA SN342

Parameter	Value	Source
Noise Temperature @ 1.4 GHz and 25 °C	9.5 K	[3]
Calibrator Noise temperature @ 1.4 GHz and 25 °C	45.1 K	[3]
Combined Noise temperature @ 1.4 GHz and 25 °C	54.6 K	[3]
Input Reflection Coefficient @ 1.4 GHz	-26.1 dB	[3]
Gain @ 1.4 GHz	39.3 dB, 39.2 dB	[2], Measurement
Input 1 dB compression point @ 1.4 GHz	-24 dBm	[1]
Power Supply Voltage	5.0 V	[1], [2]
Power Supply Current:		
Noise Source Off	58 mA	
Noise Source On	82 mA	[1]
Calibrator control signal frequency	32kHz	[1]
Calibrator control signal minimum amplitude <sup>2</sup>	300mV	Measurement
Calibrator control input impedance <sup>3</sup>	0.69+2.57j ohms	Measurement

<sup>2</sup> At bias tee input

<sup>3</sup> At bias tee input

## References

- [1] S. Weinreb and J. Shi, “Low Noise Amplifier with 7-K Noise at 1.4 GHz and 25 °c,” *IEEE Trans. Microw. Theory Tech.*, vol. 69, no. 4, pp. 2345–2351, 2021.
- [2] G. Rajagopalan, Private Communication. May 31, 2023.
- [3] G. Rajagopalan, Private Communication. October 3, 2022.