Application to Graduate with Honors

Student ID:

I plan to defend in: FALL/ [✓ SPRING] of 20 11

Personal Information:

Name: Clinton Bockstiegel
Address: 3315 Hickok Place
Boulder, CO 80301

CU E-mail: clinton.bockstiegel@colorado.edu
I am an: [✓ IN-STATE]/ OUT-OF-STATE student

Academic Information:

☒ I plan to graduate with *Departmental Honors* in: Physics

☐ I plan to graduate with *General Honors*

Cumulative GPA:

Please attach a brief **PROSPECTUS**, **BIBLIOGRAPHY**, and **TIMELINE** of your thesis project to this application. When summarizing your work, consider the following:

- What is the problem you are investigating?
- What is the hypothesis you are testing?
- What is the focus of your study?
- What is your goal in this study?

Primary thesis advisor: Name: Jason Glenn JASON GLENN Dept: APS

List the other members of your committee:
Name: Harvey Segur Dept: APPM Nov 19, 2010
Name: John Cumalat Dept: Phys
Name: Dept:
Name: Dept:

Departmental and General Honors Committee Checklist:

Applicant has a total of at least three committee members.
At least one Honors Council Representative is included on committee.
At least one committee member from an outside department.

APPLICATION CONTINUED ON BACK OF THIS SHEET

Please initial if you are pursuing Departmental Honors:

CB I have consulted with my department and have completed (or am completing) the requirements they have established.

For Honors Council Representative:

I have met with applicant and approve him/her for departmental honors.

Printed Name: John P. Cumalat Signature: John P. Cumalat

Please initial if you are pursuing General Honors:

_____ I have completed (or am completing) the requirements for graduating with General Honors.

Please list the courses you have or are taking toward General Honors:

For General Honors Council Member:

I have met with applicant and approve him/her for general honors. I agree to be on his/her defense committee.

Printed Name: ________ Signature: ________

For the Thesis Advisor:

I have met with the applicant to discuss the proposed work and agree to provide the necessary help and direction for this thesis project.

Printed Name: JASON GLENN Signature:

For the Student:

I have read the requirements for graduating with honors at the University of Colorado. I also understand that my designation will be sent to the CU email address that I have provided and will not be given out over the phone.

Signature: Date: 12/2/10

For additional graduation information including requirements, guidelines and deadlines, you can download them online at www.colorado.edu/honors

Characterization of HEMT Amplifiers

Clinton Bockstiegel
Advisor: Jason Glenn

Microwave Kinetic Inductance Detectors (MKIDs) are a new kind of sub-millimeter detector to be used as the main continuum light collection devices for the Caltech Submillimeter Observatory in the near future. Fundamentally, a MKID is a resonator circuit. The detection method utilizes a probe signal input to the resonator, and compares the phase shift and amplitude of the output to that of the input. Because MKIDs are superconductors, they must be operated at a temperature of a few hundred milli-Kelvin. However, most of the readout electronics can be kept at room temperature because of a set of cryogenic amplifiers called High Electron Mobility Transistors (HEMTs). My work is to characterize the properties of a set of HEMTs to determine ideal bias settings to maximize their gain and to minimize their noise, and to make sure that they have sufficiently low noise temperatures for our purposes at the CSO.

In order to make the needed measurements, it was necessary to construct a testbed for the amplifiers. We had a small cryostat sitting around in the lab that was a perfect size for our purposes. This cryostat is a vacuum chamber with a tank for liquid nitrogen (LN2) and a tank for liquid helium (LHe). The amplifiers are mounted at the 4K (the temperature of liquid helium at 1atm) stage in the cryostat. The cryostat has feed-throughs for the HEMT signal, the HEMT bias wiring, and thermometry wiring. I assembled the wiring and the coax cables for all electronics inside the cryostat.

The first type of measurement that I and the members of my group made was the gain of the HEMTs. This was accomplished with a network analyzer, measuring a quantity called S21. S21 is the voltage gain of the amplifier, measured over a range of frequencies specified by the user. The typical frequency range we measured over was 1-10GHz. The network analyzer outputs a signal at a known frequency from one port, and measures the received power at that same frequency in another port. HEMTs are hailed as very wide-band amplifiers, and can go up to 15GHz. We measured a larger range than we need as a check to see that the gain behaves the way we expect it to. The range the HEMTs will eventually be operated in is 3-5GHz.

HEMTs have two bias controls, the Gate (VG) and the Drain (VD). In order to measure the gain over a wide range of the two settings, we produced a grid. A typical grid would range from about 0.5V to 2.0V for both VG and VD. At each of these grid points, we would measure S21, and produce a contour plot of the gain values.

We also produce a similar grid for the white noise of the HEMT. The white noise at each point was measured with a spectrum analyzer, which measures the power vs. frequency. We expect the amplifier to add white noise (which has the same power at all frequencies), and 1/f noise at low frequencies. The noise contribution typically increases as VD or VG increase. However, the gain is also dependent on VD and VG, so in order to find the settings that are ideal for signal to noise it is necessary to normalize the white noise by the gain at each point on the grid.

Once we determine the best bias setting for signal to noise, we then find the HEMT's equivalent noise temperature at that setting. Basically, the noise temperature is a measure of the noise contribution, and the reason we care about this "temperature" is because the amplifier will be operating at 4K. If the equivalent noise temperature of the HEMT is significantly higher than 4K, then it is too noisy. A typical value for a HEMT is 3-5K. We can accomplish these noise temperature measurements in two ways.

The first way to measure the noise temperature is to heat up an attenuator that is placed immediately before the HEMT in the signal line. As the attenuator's temperature increases, the white noise floor measured by the spectrum analyzer should also increase linearly with temperature. By plotting the noise floor against the attenuator's physical temperature and examining the slope of the line and its intercept, we can calculate the noise temperature of the HEMT. This method is convenient because the loss and gain terms of the system and the HEMT drop out in the calculation, so we do not need to measure them precisely.

Timeline

January 2010-present	construction of HEMT test bed/updates and modifications of testbed/write measurement and analysis software
August-December 2010	data collection/analysis
January-March 2011	integration of HEMTs with MKIDs/write thesis
March 2011	defend

Bibliography

[1] Jason Glenn et al. A Microwave Kinetic Inductance Camera for Sub/Millimeter Astrophysics. SPIE. 2008

[2] James A. Schlearth et al. MKID Multicolor Array Status and Results from DemoCam. AIP. 2010

[3] Sander Weinreb. Noise Temperature Estimates for a Next Generation Very Large Microwave Array. IEEE. 1998

[4] S. Weinreb et al. W-Band InP Wideband MMIC LNA with 30K Noise Temperature. Symposium Digest, 1999 IEEE MTT-S International. p101-104 vol. 1

[5] J. J. Bautista et al. Cryogenic, X-band and Ka-Band InP HEMT Based LNAs for the Deep Space Network. Aerospace Conference, 2001, IEEE Proceedings. P2/892-2842 vol. 2

[6] Niklas Wadefalk. Cryogenic Wide-Band Ultra-Low-Noise IF Amplifiers Operating at Ultra-Low DC Power. Microwave Theory and Techniques, IEEE Transactions on. p1705-1711 vol. 51 issue 6