Small Rocket Measurements / Validation in Support of SABER

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**Abstract**—Small rocket measurements in the Mesosphere and lower Thermosphere / Ionosphere will serve to validate and improve measurements being made by the TIMED satellite’s SABER instrument. This validation can be made more cost-effective and versatile by developing a smaller, lighter, and less expensive radiometer module. Recent developments in technology have allowed us to proceed in developing this smaller, more lightweight radiometric instrument.

We are currently working on a miniature 2-channel radiometer that will interface with a Viper DART sounding rocket payload. Along with its support circuitry and housing, we estimate the 2-channel radiometer to weigh less than 1 1/2 lbs and be less than 8 inches long with a 2 1/8” diameter.

In this report we will discuss the development of this instrument, termed MINRAD, and our current standing.

I. INTRODUCTION

On December 7, 2001 the TIMED spacecraft was launched from Vandenberg Air Force Base, California. TIMED carried with it several scientific instruments for studying the least explored and understood region of Earth’s atmosphere – the Mesosphere and Lower Thermosphere / Ionosphere (MLTI). Among these was the Sounding of the Atmosphere using Broadband Emission Radiometry instrument, or SABER.

A. SABER

SABER is a 10-channel limb-scanning radiometer that measures near- to mid-infrared emissions in the range 1.27 to 17 μm (7865 to 650 cm⁻¹). It has a 2-km vertical instantaneous field of view (IFOV) for each channel and scans from the Earth to a 400-km tangent height. Analysis of two wide-band and one narrow-band CO₂ channel provide accurate pressure and altitude registrations. The telescope and baffle assembly are cooled to 240 °K, while the focal plane assembly is cooled to 75 °K. Since TIMED first entered orbit, SABER has been continuously sounding the atmosphere and returning excellent data about the MLTI.

B. MINRAD

MINRAD is a project by the Utah State University Space Dynamics Lab (SDL) that developed out of the early Viper DART / DUST payloads SDL built and launched in May of 2001 and 2002. MINRAD seeks to develop a new science section for these payloads. It will consist of two infrared radiometers and support circuitry. We expect to get MINRAD built and tested by December 2003.

II. MOTIVE FOR MINRAD

Since SABER was put in orbit, scientists have sought to launch several radiometers onboard sounding rocket platforms. With this combination of rocket and SABER data they would be able to quantitatively test temporal changes in atmospheric constituents, address the baseline chemistry of such constituents, derive turbulent velocity, energy dissipation rate, and eddy diffusion coefficients. By fusing SABER data with that of the rocket measurements, we would also be able to improve measurement of the atmosphere.

III. ADVANTAGES OF MINRAD

A. Cost

MINRAD seeks to exploit the relatively low cost of small launch vehicles. By designing for a Viper DART, we cut launch vehicle costs by at least 10, compared to the next largest launch vehicle, the Terrier Malamute, or 100 compared to the Black Brant. The advantage is that we can fly 10 of these 2-channel radiometers on Viper DART payloads for the same cost of one Terrier Malamute payload. You can also launch the DARTs from different stations and at different times to study various atmospheric optical characteristics. This is a significant advancement for reducing costs in science missions and is made possible by miniaturization technologies. These technologies are implemented fairly easily now and at low cost and risk. Figure 1 shows a picture of one of the detectors that we are using. It is less than 0.6” in diameter and 0.4” deep.

Fig 1: HTE-2642 Infrared Detector from EG&G Optoelectronics [1]
B. Weight

By building MINRAD for a Viper DART launch vehicle, we are also constrained to make it lighter. We estimate that, once built, the complete MINRAD unit will weigh less than 1 \( \frac{1}{2} \) lbs. Advances in miniaturization have also helped to make this possible. Surface mount technology and components will be implemented and used in MINRAD. This technology is commonplace in the commercial industry and has proven to be very reliable in sounding rocket applications. Surface mount components are much smaller and lighter than their through-hole counterparts.

C. Modular

The fact that we will be able to build a compact, working 2-channel radiometer will be very useful. These sections are modular. We will have the complete radiometer instrument, signal processing, and control circuitry built in to a single package. The modular nature of this allows you to easily swap MINRAD sections in and out of a payload. The interface will be simple and easy to design for, such that they could be placed on any kind of a payload.

D. Short Lead Time

Once MINRAD has gotten through the development phase and proven itself on a few rocket flights, the design can then be finalized. The units would be very easy to build and thus have short lead times. You could also easily and quickly make modifications to the optics and filtering so as to measure different spectral bands. This makes atmospheric multispectral time studies from rocket platforms realizable, without extraordinary costs or lead times.

E. Data Fusion

From early studies by Westwater and Grody, we have seen that fusion of data from satellite- and ground-based radiometers has improved the measurement of temperature profiles. They also took into account climatological models and improved the data further [5]. A sample of their results is shown in figure 2.

We seek to use that same approach here to improve data collected by SABER. By flying several MINRAD flights through the same scan area as SABER, we can fuse that data and improve upon the measurement. We could even take it a step further and fuse SABER and MINRAD data with that from ground-based radiometer and atmospheric models.

IV. DEVELOPMENT OF MINRAD

A. Beam-Splitting Method

In MINRAD, we were seeking to develop at least a 2-channel radiometer. That means that we had to have some way of separating out the incoming light into different wavelengths. When considering this, several methods presented themselves.

1) Dichroic Beamsplitter: The first method is to use a dichroic beamsplitter. The dichroic beamsplitter is often effective in many applications, but requires a high incidence angle. Because of our size constraints, this appeared to be very difficult to implement in MINRAD so, we decided not to use it.

2) Two Optical Barrels: The second method to separating the incoming radiation that we considered was to use two optical barrels. By using different optical filters in each barrel, we could separate out the two wavelengths that we wanted to measure. This method was very simple and easy to implement so, we decided to use it.

B. Chopping Method

The next thing we considered in developing MINRAD was whether to modulate, or 'chop', the incoming signal or not.

1) Unchopped: The first option was an unchopped signal. This was simple, inexpensive and required less volume for the instrument. But, the disadvantage is that it would be much more sensitive to noise. This seemed like too high of a risk to take, so we decided upon modulating or 'chopping' the incoming signal. By chopping the signal, we could improve the Signal-to-Noise Ratio (SNR) significantly.

2) Polarization Chopped: One way we could do this is by using liquid crystal polarization rotators. The incoming signal would be modulated by passing through these wheels. This seemed like a very elegant solution and had the advantage of no moving parts. But, we eventually decided against this because these rotators typically have less than 25% transmittance and the technology is relatively unproven with rocket-based radiometers.

3) Mechanically Chopped: The final method that we considered and decided upon was a mechanically chopped radiometer. The mechanical chopping is done by using a small dc motor to turn a metal wheel. The wheel has windows in it and is placed in the path of the incoming signal. The motor is monitored and controlled to spin the wheel at a constant frequency. The incoming signal passes through the wheel and is thus modulated.

This solution seemed to be the best fit for MINRAD. It had
been implemented and proven on several other rocket payloads so it had the lowest technology risk. And the chopping would greatly improve the SNR of the incoming signal. The only disadvantage to this method is the packaging. It would be a little difficult to put this into the MINRAD package. Proper design shouldn’t make this a problem, though.

So, the final radiometer design layout that we decided upon was double barreled and mechanically chopped. A diagram of our layout for this system is shown below in figure 3.

![Diagram of MINRAD science section](image)

**Fig. 3: Layout of the MINRAD science section**

### C. Channel Measurements

The two spectral bands that we selected to monitor with MINRAD are the $O_2$ (Δ) and OH (3, 1) bands that lie in the 1.263 – 1.290 μm and 1.568 – 1.727 μm region, respectively. The main reason for choosing these two bands is because they are also channels 9 and 10 of the SABER instrument. With MINRAD and SABER measuring emissions in these two bands together, we will be able to perform synergistic science studies and define temporal changes in the atmosphere. These two bands also allow us to test temporal changes in the relationship between $O_2$ (Δ) and $O_2$ concentration, address the baseline chemistry of OH, derive turbulent velocity, energy dissipation rate, and eddy diffusion coefficients in the middle atmosphere and study the relationship between eddy diffusion and airglow.

### D. Detectors

The detectors that we have chosen to use are model HTE-2642 from EG&G Optoelectronics. The HTE-2642 uses a InGaAs photodiode coupled with a thermoelectric cooler and low noise/high gain transimpedance amplifier. There is also a built-in 10kΩ thermistor for monitoring the temperature of the detector. Including all of this in the detector package makes controlling it a lot easier and we don’t have to supply all of this circuitry externally.

The HTE-2642 is specially designed to operate in near infrared regions 200 to 1800 nm, over a broad temperature range, and for spectroscopy and outdoor environmental monitoring techniques. These are all great qualities to have for small rocket application.

The HTE-2642 is also appealing because it is so small. The detector with housing is less than 0.6” in diameter and 0.4” deep. This allows us just enough room to fit two of them into our 2 1/8” science section housing and makes it possible to measure two channels, or wavelength bands, at once.

### E. Motor and Chopper Wheel

The motor that we are using is a DC, model 1319T-006 from MicroMo. It has the option to come with the encoder HEM 1319. The encoder fits on the back of the motor and, in all, the motor and encoder package is about is 1.3” long and 0.6” in diameter. Because it is so small, it can fit into our housing, mate to the chopper wheel, and perform the chopping that we need.

The encoder also allows us to easily monitor and control the speed of the motor. The signal must be chopped at a steady frequency of 150 Hz. To do this, the speed of the motor must be known at all times and adjusted accordingly. Without the encoder, this wouldn’t be possible.

### F. Motor Control

As was stated earlier, the motor speed had to be monitored in order to keep a steady chop frequency of 150 Hz. This required an active feedback control system. Building a working version of this was a lot more complicated than it first appeared to be.

1) **Analog Solution:** We had initially designed to control the motor with analog circuitry. This seemed very simple to do - just add a filter and differential op amp. The digital signal from the encoder would be passed through the filter and you would get an average voltage level corresponding to the frequency of the motor. A higher frequency would generate a greater voltage and lower, less. The differential op amp would then compare that voltage to a reference voltage. If the output from the filter was less than the reference, the voltage difference would turn on a transistor that would send more current to the motor thus increasing the chop frequency. If the output from the filter was less than the reference voltage, the difference would be negative, the transistor would not turn on and the motor would slow down. The reference voltage could be adjusted to keep the motor at 150 Hz.

Although this method, and several versions of it, seemed promising in simulation, they never worked in tests. They proved to be very unstable. Even a simple single pole filter and differential op amp wouldn’t work.

2) **Digital Solution:** So, we began to explore digital methods of controlling the motor. The first digital method that we explored was a phase detector. By generating a 150 Hz signal with an oscillator and then seeking to lock up the rising edge of the encoder with the rising edges of the 150 Hz signal, we could get the motor to operate at 150 Hz. This idea seemed promising, but once again, worked in simulation, not in actuality.

The solution that we finally came up with for this was a frequency counting digital method. We programmed up a system to count the clock cycles between the rising and falling edges of the encoder signal. By knowing the frequency of the clock, we knew how many cycles should occur between edges.
of the encoder signal. If there were too many cycles, the motor was running slow, and a high voltage signal (5V) would be sent out to a transistor that turned on power to the motor. If there were too few cycles, the motor was running too fast, and 0 volts was sent to turn the transistor off. Through constant monitoring of the encoder signal, the motor is kept at a steady 150 Hz.

This was a good solution to our problem. The system was very stable and didn't skip. It also operated well under loading.

Some other advantages to this system are that the motor frequency is directly monitored and already digitized so we can easily send this value down through the data stream. This accurate measurement of the motor frequency can also be used to control the radiometer signal demodulation.

**G. TE Cooler Control**

The control of the TE coolers has been successfully designed, tested and implemented. The control circuitry is set up such that the thermistor of the HTE-2642 is monitored and then compared to a potentiometer setting. The potentiometer setting controls the operating temperature of the detector. If the thermistor measurement is less than that of the potentiometer then a transistor is turned on and more current is sent to the TE coolers.

Control circuitry for several detector operating temperatures was built and investigated. We monitored the amount of power drawn from the power supply, the power dissipated in main components, and the time needed to reach normal operating temperatures. As a result of this investigation, we found that operating the detector at -20 °C would be the most beneficial. This causes more power to be drawn from the supply, but at -20 °C the sensor will be 10 times more sensitive than at -10 °C. This gives us greater accuracy with our measurements.

In addition, the transfer of power from the supply to the TE coolers is the most efficient with this design and normal operating temperature can be reached in the quickest amount of time. This is important considering the short flight of the rocket payload. We want to reach the normal operating temperature as quick as we can before the radiometer starts making critical measurements.

The drawbacks to this design are that more power is initially drawn from the supply and more wattage is dropped across the transistor. The transistor would need to be rated at 1-watt greater than it is with the -10 °C design. This needed 1-watt rating increase and increased initial power draw is negligible considering the parts available and the fact that we gain so much more sensitivity operating the detector at -20 °C.

**H. Size**

In order to mate the MINRAD instrument to a Viper DART payload it had to fit into housing 2 1/8" or less in diameter. It also couldn't be too long. The longest practical length was about 14". So, we started to design around these constraints.

First of all, we knew that we wanted to use the HTE-2642 EG&G detectors and we were able to fit two of them in the housing, given the 2 1/8" size constraint. Next, we designed the optical components. One complete set of lenses and filters ended up fitting into two 3/4" diameter tubes, one of length 2" and the other of length 3/4". We then decided upon the Micro Mo 1319T-006 motor and encoder for signal modulation. These and the chopper wheel would end up taking about 1 3/4" of length in the housing. The final components, the printed circuit boards, are estimated to take up about 3 1/2". In total, we should be able to fit the complete instrument into a 2 1/8" diameter section no longer than 8".

1. **Interface**

With the signal conditioning and control built with the instrument into the science section housing, our system will have a minimum number of interface signals. We will need general power lines of +12 volts, -12 volts and +5 volts. We will also need a separate +6 volts for the motor. A motor start signal will also need to be sent from the central processing unit of the payload. In return, the system will provide signal measurements of the temperature sensors, TE cooler voltages and currents, motor current, voltage and frequency, and radiometer detectors.

**V. CURRENT STATE OF DEVELOPMENT**

The work is going well. The design has been finished and is now progressing through the build-up stage. We have completed the assembly for one set of optics and the motor and chopper wheel. These have been installed into the main housing, shown below in figure 4. We will need to complete the assembly for the other set of optics and perhaps extend the main housing to accommodate the electrical control and processing circuit boards.

![Fig 4: Optical Element Assembly and Chopper Assembly Installed Into the Main Housing](image)

Much of the electrical sub-circuitry has been developed and tested extensively, but this circuitry has yet to be implemented on printed circuit boards and installed in the MINRAD housing. We are currently working on this. Once this is completed, we can test the whole system and make modifications where needed.

**VI. CONCLUSION**

If successful, this miniature radiometer will not only serve to validate and improve measurements made by the SABER
instrument, but it will significantly advance optical atmospheric exploration. With a smaller, more lightweight radiometer package, scientists will be able to make emissions measurements in the atmosphere from rocket platforms for a fraction of what the previous cost was.

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