Measuring the Microwave Background Radiation

Martin John Madsen†
Purdue University

(Dated: May 5, 2000)

The process of measuring the cosmic background radiation is described, along with the equipment needed to make the measurement. Initial results that were based on temperature measurements from furnaces used to calibrate the equipment are given. A process is proposed which will possibly yield accurate results for the actual temperature of the cosmic background radiation.

I. INTRODUCTION

One of the fundamental questions in cosmology relates to the origin of the universe. As has been shown, the temperature of cosmic black-body radiation is related to the formation of the universe.[1] One method used to measure the temperature of the cosmic black-body radiation is to detect the microwave radiation which is uniform in all directions of the sky. For long wavelengths, the power per unit bandwidth of incident microwave radiation received by an antenna observing an extended blackbody is proportional to the temperature[2]:

$$P_\nu = kT,\ (hc/\lambda\, kT) \ll 1.$$

The optimal frequency range to scan is determined by the intensity of various noise sources. As is explained by Roll and Wilkinson, there is an area of the spectrum where the noise from atmospheric water has dropped off significantly, yet before the noise from galactic sources increases. This range is from about 1 to 10cm.[3] This corresponds to a frequency range of 3GHz to 30GHz. Previous experiments have been done at λ=3.2cm and λ=7.35cm.[3,4] We chose to work at a range from λ=2.48cm to λ=2.59cm as is explained below.

The basic concept of this experiment was to use a spectrum analyzer to determine the magnitude of a microwave signal coming from various sources. These sources with known temperatures were used to calibrate the output of the spectrum analyzer. Knowing the output on the analyzer as a function of temperature, the analyzer was then used to determine the temperature of the microwave black-body radiation coming from the sky.

II. EXPERIMENTAL SETUP

The analyzer used in this experiment was an HP-8593EM EMC analyzer. This particular analyzer had an option to work as a spectrum analyzer, which we used throughout the experiment. The microwaves were detected using a metal horn (ATM part number 75-442-6, 20dB nominal) with a front opening of 4λ x 3λ with an effective range of 10.0GHz to 15.0GHz. The base of the horn was connected to a microwave detector that was part of an Astrotel Communications Corporation Precision PMJ-LNB KU, a digital compatible mini KU-Band LNB. The size of the opening that connected the horn to the LNB was 0.4λ x 0.8λ.

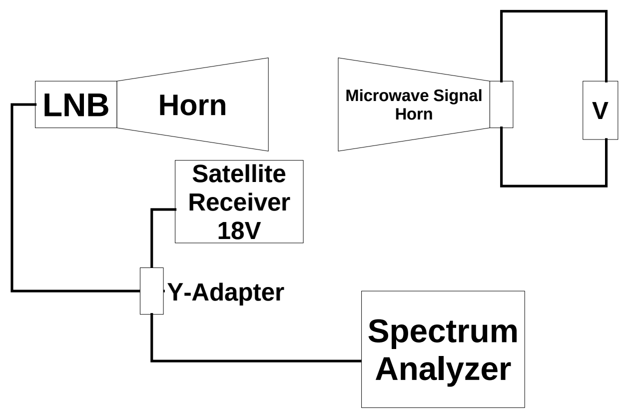

FIG. 1: Box diagram showing the experimental setup in configuration to calibrate the LNB subtraction term.

The LNB has an oscillator circuit that creates a beat pattern with the detected signal, effectively subtracting a frequency from the signal collected from the horn. The main reason that we used the LNB is because radiation from the 10GHz range does not propagate down co-axial cables. In order to use the equipment available, it is desirable to be able to connect the collecting horn with the spectrum analyzer using co-axial cables. So the signal from the LNB, which is below the actual signal on the spectrum, can more easily propagate down co-axial cables. The manufacturer of the LNB lists the effective range of the electronics as 950MHz to 1450MHz, which is why we looked at that range (λ=2.48cm to λ=2.59cm). The LNB is powered by a Uniden Ultra Videocipher RS satellite television receiver that provides a voltage of 18V to the LNB. Note that it was important to correctly bias the signal using a y-connector, the input connected to

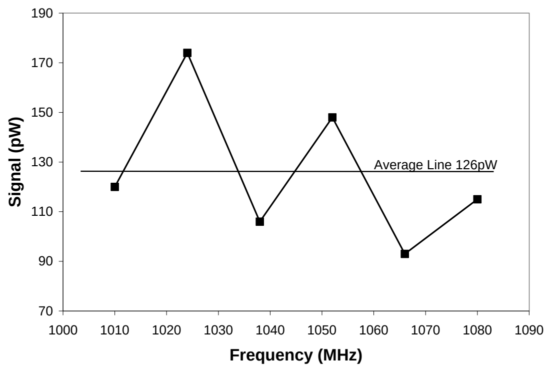

FIG. 2: Example of the calculation made in order to be able to compare the signal from different sources. The data points are from the 730°C oven.

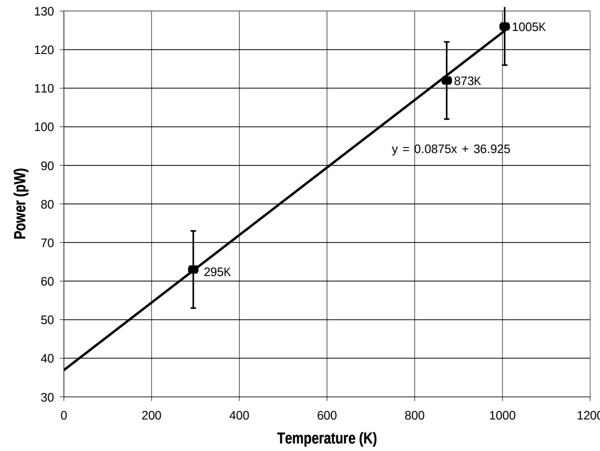

FIG. 3: The data used to calibrate the spectrum analyzer is shown. The linear fit was produced using the least squares statistical analysis.

the LNB, and the two outputs connected to the receiver and the analyzer.

The signal magnitude, as read from the spectrum analyzer, can be set in various units. This experiment was done with the units set to Watts. The mechanism that the analyzer employs to convert the signal to the output on the screen is not known due to the lack of a manual provided for the demo model that we used. For future experiments, this information should be understood.

III. CALIBRATION

The first step in calibrating the equipment was to determine the magnitude of the subtraction which the LNB provides to the signal. We used a microwave signal generator initially facing the spectrum analyzer input plug, without the horn/LNB attached. There was a small peak in the spectrum at 10.7GHz. Then, we attached the horn/LNB and faced the detection horn with the signal horn (see Fig.1). The signal that appeared on the spectrum analyzer had strong peak at around 50 ± 10MHz, with smaller peaks spaced at around 40MHz intervals. The smaller peaks are harmonics coming from the beat oscillator from the LNB. This indicates that the LNB is subtracting 10.65 ± 0.01GHz from the incoming signal.

The next step was to measure several different black-body radiators in order to find the relationship between temperature and output on the spectrum analyzer. We set the vertical axis of the spectrum analyzer to a liner scale (units of Watts). The bandwidth we looked at was from 800MHz to 1.5GHz, which is a little larger then the active range of the LNB. In order to reduce the signal noise, we used a function of the spectrum analyzer called "Vid Avg" set at 100. This appeared to take an average of 100 sweeps (sweep time 20.0msec). Because we did not have a means to record the scans, we looked at a much smaller region when actually recording the signal. We recorded the magnitude of the peaks and valleys of the signal within a bandwidth of 70MHz (1010MHz to 1080MHz). The average of the peaks and the valleys was used to gauge the magnitude of the signal (see Fig.2).

Three measurements were made to calibrate the signal. We measured the microwave radiation inside a room at about 295°K. Then we used two measurements of the microwave radiation from a Lindberg SolaBasic furnace. The oven was first set at 1003°K, and then the same oven was allowed to cool to 873°K. The temperature of the oven was measured using a pyrometer. We checked the microwave radiation of the oven with the door closed and it was not noticeably greater then the signal from different areas of the room. Given that measurement, we are assuming the oven to be a black-body radiator. In order to make the measurement we had to open the door, which allowed the oven to cool. This is a source of uncertainty because we do not have a measure of the temperature more accurate then about 10 degrees. The data from these three measurements were used to find the slope and y-intercept of the best fit line using a least squares statistical analysis. We calculated the slope to be m=0.875pW/°K with an intercept of 36.9°K(see Fig.3). The uncertainties in the measurements are due to several factors including uncertainty in the accuracy of the method of averaging the peaks/vally, as well as uncertainty in the temperature measurement of the oven and the room. The error bars shown in the plot are determined by the uncertainty in measuring the the exact signal from the spectrum analyzer. Given a better method of recording the signal and comparing two signals, the error bars would be much smaller. We also noticed that

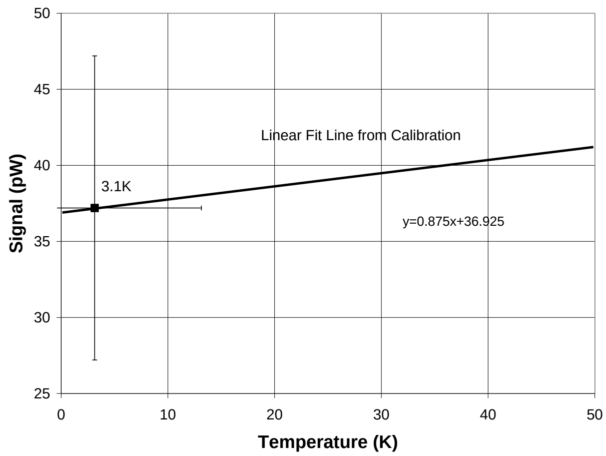

FIG. 4: Shown here is the measurement taken of the sky, along with the linear fit line from the calibration measurements. The error bars on the data point are due to the difficulty in making a precise measurement with the spectrum analyzer.

the signal decreased as the LNB electronics warmed up. This variation in signal due to the LNB temperature contributes to the uncertainty in our measurements.

IV. EXPERIMENTAL RESULTS

Our final measurement was to point the horn at a clear section of the sky on a clear day. We pointed the horn away from any buildings, but at an angle that was not perfectly vertical. The average of the peaks in the 1010MHz-1080MHz range was 37.2pW. Using the linear fit from the calibration data, we calculated that the temperature of the sky was $3.4 \pm 10°$K, assuming the same uncertainty in the calculation that we had for the calibration (see Fig. 4). In order to be able to determine how much of this temperature can be attributed to the cosmic back-ground radiation, it would be necessary to measure the temperature of the atmosphere. This can be done by tipping the horn at several different angles and comparing the temperature with the zenith temperature. This measurement has been found to be in the range of 3.2°K[3]. Total antenna temperature measurements made pointing at the zenith have been shown to be on the range of 6.7°K[4]. The cosmic background radiation temperature is then the total measurement minus the atmospheric measurement, minus any other losses or absorption of the horn.

$$T_{BACKGROUND} = T_{TOTAL} - T_{ATMOSPHERE} - T_{LOSSES}$$

Within the uncertainty of our measurement, we are in agreement with previous findings.

The point of this experiment was to show that it was possible to measure the temperature of the sky using the spectrum analyzer and the LNB. We showed that given an appropriate calibration, it should be possible to accurately measure the temperature of the sky. One possible way to accurately calibrate the spectrum analyzer would be to measure the microwave radiation coming from black-bodies at liquid nitrogen and liquid helium temperatures. In order to do this, it would be necessary to insure that no ambient microwave radiation reflected from the black-body container. Given this calibration, along with careful measurements of the furnace microwave emissions, it should be possible to get an accurate measurement of the microwave radiation from the sky. Note that it will be important to measure the changes in the radiation as a function of the angle that the horn is pointed from the vertical, in order to get an idea of the contribution of the atmosphere to the measurement.

REFERENCES

† mjmadsen@purdue.edu
1. R. Dicke et al., Astrophysics Journal **142**, 414 (1965).
2. R. Dicke, Review of Scientific Instruments **17**(7), 268 (1946).
3. P. Roll and D. Wilkinson, Annals of Physics **44**, 289 (1967).
4. A. Penzias and R. Wilson, Astrophysics Journal **142**, 419 (1965).