Measurements of Cosmic Background radiation

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A new simple experimental setup for measuring the equivalent temperature of the cosmic microwave background radiation is discussed. This paper describes the apparatus and the technique used for the measurements. The result of $T_{BG} = (3.0 \pm 0.5)°$ K, has been reported [Phys. Rev. Letters **16**, 405 (1966)] at a wavelength of 3.2 cm. Although a similar measurement for the temperature of the background was not successfully obtained, the experimental setup showed promising results.

I. INTRODUCTION

The interest of the cosmic background radiation began as an attempt to provide an answer about the beginning and the existence of the universe, as we know now. Several theories have been put to explain the existence of the universe[1], for example, the "Steady State Theory" and the "Big Bang Theory". The measurement of the equivalent temperature of the cosmic microwave background radiation pins the balance between the theories in favor of the Big Bang one. The cosmic background can be explained (according to the evolutionary picture) as a result of the thermal radiation when the universe was highly compressed and hot. As the universe expanded and cooled down, the cosmic radiation red-shifted from the γ-ray region to the μ-wave region of the spectrum, while retaining the blackbody spectrum properties[2]. Several experiments have been reported in an attempt to measure the temperature equivalent of the cosmic radiation at different μ-wave wavelengths[1, 2, 3]. The choice of the 3.2 cm wavelength is preferred for the following two of reasons[1]: a) at shorter wavelengths the atmospheric absorption would be problematic, b) at longer wavelengths galactic emission would be significant. The absorption window roughly appears between 1 and 20 cm[2], Figure 1. The choice of a specific wavelength within this range is partly dependent on the size convenience and the cost of the equipment used in the experiment.

Our experiment is a simplified setup of the one built by Roll and Wilkinson[2]. We have used microwave receiver (for a 3 cm wavelength) combined with a commercially available LNB converters. The emission signals from the different objects under study were recorded on a spectrum analyzer and then compared using commercially used spreadsheet software. In this paper, the experimental setup is discussed along with the results obtained for the emission signals of the ground, sky, and a reference source in liquid Nitrogen.

II. EXPERIMENTAL SETUP AND RESULTS

Figure 2 shows the setup used for the experiment. It consisted of: i) A 3-cm wavelength microwave receiver (horn) for detecting the cosmic signals. ii) Commercial

LNB's (used for TV-satellite dishes - Precision, model, PMJ-LNB KU, 0.5 dB, 650 MHz – 1500 MHz range) were used to down shift the frequency detected by the horn by 10.7 GHz. This shift is necessary to be able to transport the signal through F-Type TV cables instead of custom-made microwave guides and switches, for more cost-effective design. iii) A commercial TV signal receiver (UNIDEN, Ultra) was used to operate and bias the LNB's. iv) A spectrum analyzer (HP, model, E440713, 9KHz-26.5GHz range), was used to record the observed signals. v) A reference load (terminator along with a 3-cm wavelength wave-guide) was used to provide a signal at a known temperature. The TV-receiver, the spectrum analyzer, and either the horn or the reference load (depending on the signal needed to be observed) were connected together using a 3-way splitter (model, HFS-21, 900-2150MHz range), Figure 3.

Before running the experiment, a quick check needed to be done to insure that the system is running and giving reasonable signals. Signals were collected from the horn while having its end open and closed (using a metal slab). The horn was then disconnected from the LNB and the signals were collected from the LNB while having its end was open and closed. These tests were done to check the difference between the signals obtained by the horn and by the electronics (LNB). Figure 4 shows that there is an observed difference between the signals detected while the end of the horn was covered and while it was open. This indicates that the horn was detecting actual microwave waves floating in the lab. Similarly for the open and closed end LNB signals. The similar behavior between the horn and the LNB could be due to the fact that their ends have comparable cross sectional areas (1:16, LNB area: Horn area), which allows the LNB to pick up microwave signals directly as well. Figure 5 shows the signals obtained from the reference load at both room temperature (300°K) and when a part of it was immersed in the liquid nitrogen (reference temperature). This was done to check the effect of temperature on the signals detected by the load. The graph shows a slight shift between the signals at the two different temperatures. To insure that the signal obtained in Figure 5 was not due to instrumental noise, a couple of runs were done while the load is at room temperature, Figure 6. The graph shows almost an identical match between the two runs, which indicates that the signal in Figure 5 is a real one.

After the tests were done, the experiment was performed as follows: I) A signal is collected from the reference load that was partly submerged in liquid nitrogen (77°K) in the lab. II) The setup was then taken to a roof of a high building (to avoid interference with microwave emission from the surrounding buildings) on a clear day. The analyzer was set to "single shot" mode to avoid averaging problems. The signals were then collected while the open end of the horn was pointed at the sky at a vertical angle, at the sky at 45°, at the sky at 90° (pointing at the horizon), and at the ground (vertical). Finally the signal was collected from a closed end horn as well as for the analyzer by itself. Figure 7 shows the obtained signals relative to each other. The graph shows that the signal obtained from the sky is smaller relative to the one obtained from the ground. This gives an indication that the sky is lower in temperature than the ground. This is a promising result since it agrees with what was expected.

The signals obtained from the sky, as well as the load at both room temperature, and cooled terminator were then compared to each other, Figure 8. The graph shows that the signal obtained from the load at room temperature is the biggest, and the one from the sky is the smallest.

III. CALCULATIONS

In order to figure out the temperature of the sky, the obtained signals have to be treated as blackbody radiation signal[1]. Appendix A, shows the equation used to evaluate the value of the sky's temperature. It is done by evaluating the area under the curves of Figure 8, and then compare them to the blackbody radiation equation (for the range of 10.8 GHz to 13.8 GHz)[¥]. A value of the $I_{Sky}(T)$ can then be evaluated. By knowing the exact temperature of the reference load while at room temperature and while it is cooled, the temperature of the sky can then be determined numerically (Appendix A).

By assuming that the load was at 300°K while at room temperature, and it is at 77°K while it is cooled with the liquid nitrogen, the temperature of the sky was found to be approximately -325°K. This value is obviously erroneous. It is suspected that the main source of error in the calculation is the exact temperatures of the reference load while it is cooled with liquid nitrogen. This is due to the fact that the load was only partly immersed in liquid nitrogen (only 1/5 of its length). For example, if the effective temperature of the load was to be assumed 200°K under the conditions mentioned above, the calculated temperature of the sky would be approximately 10°K. This value is close to the expected value of (7 ± 1)°K due to radiation from both the atmosphere (3.5°K) and the cosmic background [(3.5 ± 1)°K][1].

IV. CONCLUSION AND RECOMENDATIONS

Although an acceptable measurement for the temperature of the background was not successfully obtained, the experimental setup showed promising results. The fact that the setup showed acceptable relative magnitudes of the signals obtained from the sky, load at room temperature, and at low temperature is an indication to possibility of obtaining acceptable results using this simple, low cost system. A few modifications needed to be done to the system in order to achieve that goal. The main one is measuring the exact temperature of the cold load at liquid nitrogen. This would significantly reduce the error in the calculation as discussed above. This can be done by attaching thermocouple to the different parts of the load to measure its temperatures. Also by fully immersing the load in the liquid nitrogen, it would be insured to a great extent that the temperature along the load is constant. Finally, using liquid helium might be better due to the fact that its temperature is relatively in the same order of magnitude as of equivalent temperature of the cosmic background.

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[¥] This is considered the "effective" region of the frequency, where the signals are different. Running integration above or below these limits would give the same results since the signals coincide, Figure 8. The integration was done for the LNB frequency range (0.95 – 14.5 GHz) and similar results were obtained.

References

1 A. A. Penzias and R. W. Wilson, Astrophys. J. **142**, 419 (1965).
2 P. G. Roll and D. T. Wilkinson, Annls of Phys. **44**, 289 (1967).
3 R. H. Dicke, Rev. Sci. Instr. **17**, 268 (1946).

APPENDIX A

$$u(f) = \frac{4h_{bar} f^5}{c^4\left(e^{2\pi h_{bar} fkT} - 1\right)}$$

The distribution as a function of frequency f at temp T

Let

$$I_T = \int_{f_a}^{f_b} df * \left(u(f,T)\right)$$

Let f_a and f_b be the corresponding frequencies over which the LNB is supposed to be sensitive.
These are frequencies before the LNB downshifts. (f^a and f^b are the refer to down shifted freq.).
Then I_{300} is approximately equal to that for the ground (assuming blackbody radiation from the ground).

$I_?$ is the integral corresponding to the sky.

Then I_{100} is approximately equal to that for the cold load.

Now the area under our graphs are A, B, and C for ground, sky, and cold load respectively.

The area under our graphs (from f^a to f^b) should be proportional to that of u(f,T) provided that we shift our graphs up or down correctly. Assuming that either the machine or we have shifted our graphs to a uniform offset ζ

$$I_{300} = \kappa\left[A - \zeta\left(f^b - f^a\right)\right]$$

$$I_? = \kappa\left[B - \zeta\left(f^b - f^a\right)\right]$$

$$I_{100} = \kappa\left[C - \zeta\left(f^b - f^a\right)\right]$$

Therefore:

$$I_? = \frac{[B-A]}{[A-C]}\left(I_{300} - I_{100}\right) + I_{300}$$

We should then be able to numerically solve for the T value of the sky because the left is a known function of frequency.