scattered to much higher frequencies. At redshifts greater than 10^8 the temperature is sufficiently high that electron-positron pair production and annihilation take place readily. In this regime a Planckian spectrum can be established on a time scale short compared to the expansion and cooling of the universe. We therefore can conclude that the CBR spectrum does not retain any information about the universe for times before a redshift of 10^7 to 10^8, except that it was hot (Illarionov and Sunyaev 1975, Danese and De Zotti 1977, 1978, and 1982).

The spectrum of the CBR contains information about the energy-releasing processes in the universe for the time period beginning about a year after the start of the Big Bang. A number of processes may have released energy into the universe during this period. These include large scale motions of the matter such as turbulence, shock waves, and fragmentation of protogalaxies or protoclusters, irregularities and inhomogeneities in the matter distribution, the annihilation of matter and antimatter, or the decay of long-lived particles. Accurate measurements of the CBR spectrum restrict any theory involving injection of energy into the radiation field, since energy release would have distorted the CBR spectrum from its initial blackbody distribution. These distortions are expected to have their maximum deviation from a blackbody spectrum in the wavelength range of a few centimeters.

Realizing that a significant ($\approx$15%) distortion could have gone undetected, we have undertaken a program to measure the low-frequency spectrum of the CBR. Previous results have been reported by Smoot *et al.* (1983, 1984). This paper presents the results of a new set of observations made with fixed-frequency radiometers at wavelengths of 0.33, 0.9, and 3.0 cm and with a new broadband radiometer which is tunable from 1.7 to 15 cm.

2. – CONCEPTS AND REQUIREMENTS OF THE MEASUREMENT

The intensity of the CBR is measured at each frequency by a radiometer, a device whose output voltage is proportional to the power intercepted by its antenna. The radiometer is calibrated in units of antenna temperature (a measure of intercepted power) per voltage output by measuring the change in output voltage for a known change in input antenna temperature. The calibration targets are microwave absorbers at ambient temperature and in baths of liquid nitrogen or liquid helium.

The antenna temperature T_A is proportional to the input power P according to the relation

$$P = kT_A B \tag{1}$$

and is related to the thermodynamic temperature T of a blackbody source covering the antenna aperture by

$$T_A = \frac{T_\nu}{(e^{T_\nu/T} - 1)}, \tag{2}$$

where $T_\nu = h\nu/k = 0.048\nu$ (K/GHz), h is Planck's constant, ν is frequency, k is Boltzmann's constant, and B is the radiometer bandwidth. At low frequencies ($T_\nu << T$) the antenna temperature is nearly equal to the thermodynamic temperature.

Each CBR measurement compares the antenna temperature of the zenith with that of an absolute-reference blackbody load of known temperature. The zenith antenna temperature can be expressed as

$$T_{A,zenith} = T_{A,load} + G(V_{zenith} - V_{load}), \tag{3}$$

where V_{zenith} and V_{load} are the output voltages produced when the radiometer views the zenith and reference load respectively, and G is the gain calibration of the radiometer. We use a liquid-helium-cooled reference load because the nearly equal antenna temperatures of the reference load and zenith minimize the effect of gain-calibration errors on the measured zenith temperature.

Radiation reaching a radiometer pointed at the zenith comes from a number of sources; we can approximate $T_{A,zenith}$ as the sum:

$$T_{A,zenith} = T_{A,CBR} + T_{galaxy} + T_{A,atm} + T_{ground} \tag{4}$$

or combining equations (3) and (4)

$$T_{A,CBR} = T_{A,load} + G(V_{zenith} - V_{load}) - T_{galaxy} - T_{A,atm} - T_{ground} \tag{5}$$