ON THE SUBSTITUTION MEASUREMENT OF SKY TEMPERATURE AT CENTIMETRE WAVES

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Abstract—The antenna towards the sky was replaced by a hot load, whose temperature was raised to about 300°C.

When a square-law detector is employed, direct comparison is possible by reversing the phase of either case in the low-frequency part of a radiometer. Uniform temperature rise of the hot load, rejection of substitution error and the loss of transmission circuits are chief points of discussion.

A result of measurement at 8 cm shows that the sky temperature is between 0° and 5°K.

I. Introduction

The sky temperature[1][2][3] may be defined as the equivalent antenna temperature when a high gain antenna with small side and back lobes is pointed towards the zenith. As the sky temperature is very low and almost always constant at microwave frequencies, it is useful as an ever ready noise standard associated with thermal noise at room temperature. For example, this low noise standard is indispensable to estimate the background noise in the case of observing solar radio noise.

Sky temperature at 10.7 cm wavelength was measured by substituting a cold resistive load for an antenna and was reported[1][2] as below 50°K. The experiment here is the measurement of the sky temperature at 8 cm wavelength by substituting a hot resistive load, whose temperature is raised to about 600°K for the horn antenna, about two metres in length, directed towards the zenith.

II. The Substitution Method

It is difficult to substitute a resistive load, whose temperature is near 0°K, for the antenna of a radiometer. So the antenna towards the zenith was replaced by a hot load, whose temperature was raised to about 600°K.

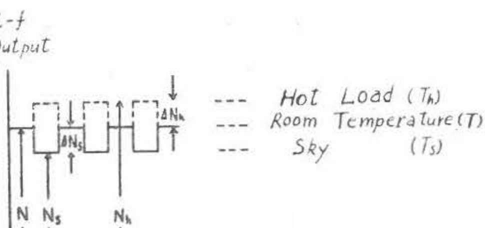

FIG. 1. *I-f* outputs of a radiometer corresponding to inputs of various temperatures.

If *i-f* outputs of a radiometer are denoted as shown in Fig. 1, following relations will be obtained:

$$N = FGkTB$$
$$N_s = (F-1)GkTB + GkT_sB$$
$$N_h = (F-1)GkTB + GkT_hB$$
$$\Delta N_s = N - N_s = GkB(T - T_s)$$
$$\Delta N_h = N_h - N = GkB(T_h - T)$$

where F is the overall noise figure of the receiver, k is Boltzmann's constant, G is the available gain, and B is the effective bandwidth. If $T-T_s=T_h-T$, $\Delta N_s=\Delta N_h$. So when a square-law detector is employed, direct comparison is possible by reversing the phase of either case in the low-frequency part of a radiometer.

III. Hot Load[4) 5) 6)]

The hot load used here is a conventional microwave resistive load, except that the waveguide is unsoldered and thermojunctions are inserted between two glass strips covered with carbon film in order to measure the temperature of termination. This load matches to the waveguide within 1.05 in V.S.W.R. up to about 300°C. The hot load is inserted into the oven as shown in Fig. 2, and is heated.

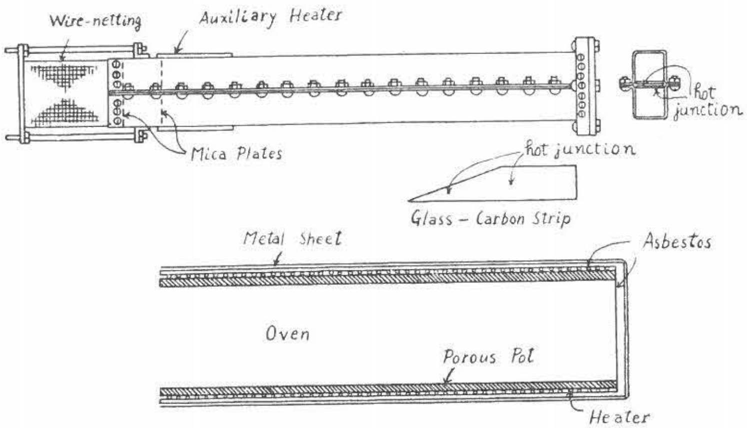

FIG. 2. A hot load.

To prevent cooling caused by heat-conduction, a wire-netting waveguide is used and against air-convection, two mica plates of negligible loss are inserted in the waveguide as shown in Fig. 2. In addition, an auxiliary heater is attached to the waveguide and can be so adjusted that the inner temperature rises uniformly; when two copper-constantan thermojunctions have the same e.m.f., the temperature of the termination is presumable to be uniform.

IV. Transmission Loss

Let L_1 be the transmission loss from the modulation wheel to the antenna, and L_2 from the antenna to the hot load. The equivalent noise temperature at the modulation wheel is,

$$T_s'=L_1T_s+(1-L_1)T$$

or

$$T_h'=L_1L_2T_h+(1-L_1L_2)T$$

where T_s' is the equivalent temperature when antenna is pointed towards the zenith, and T_h' is that when the hot load is substituted for the antenna. Accordingly, the receiver output is proportional to $T-T_s'=L_1(T-T_s)$ and $T_h'-T=L_1L_2(T_h-T)$ respectively. So, if $T-T_s=T_h-T$, $T-T_s'=(T_h'-T)/L_2$. Hence, if the hot load is substituted just in place of the antenna, L_2 becomes negligible, and so, $T_s'=2T-T_h'$.

V. Substitution Error

It is the most important problem in this measurement to remove the error due to substitution. If the impedance of the antenna is just equal to that of the hot load, this error could be neglected. But, as the difference in impedance is inevitable, the balanced mixer and the input circuit of the *i-f* amplifier must be carefully adjusted so that no error can be detected for a slight mismatch in the input impedance, such as below 1.1 in V.S.W.R.

VI. Error Based on the Square-Law Detecter

If the 2nd detector has not accurately the square-law response, error will arise. The detector must have a square-law response up to at least four times as large as the r.m.s. voltage of the noise to be detected. The detector utilizing the square-law characteristic of a beam tetrode is quite satisfactory for this purpose.

VII. Error due to Reversing the Phase of Signal or Reference Voltage in the Low-Frequency Part

As related in Sec. 2, it is necessary to reverse the phase of signal or reference voltage at the synchronous rectifier to make d.c. outputs equal in sense in both cases, when antenna is pointed towards the zenith and when the hot load is substituted for it. But if d.c. outputs of the synchronous rectifier change in absolute value when the phase of signal or reference voltage is reversed, error will arise.

If the synchronous rectifier is perfectly balanced and the phase relation between signal and reference voltage is correct, no error will arise. We found that it is preferable to reverse the phase of signal, in case the selective amplifier is omitted.

VIII. Measurements and Result Obtained

Measurements were carried out as follows: first, the paraboloidal reflector was directed towards the zenith and after the gain of the radiometer became stable, the hot load was substituted for the feeding antenna. Then the hot load was heated and the recorder reading vs. temperature was plotted as shown in Fig. 3.

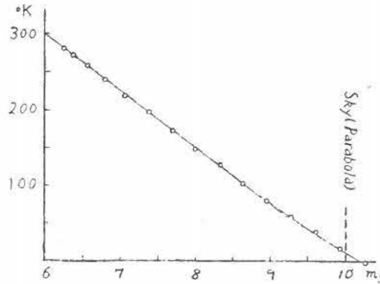

FIG. 3. Recorder reading obtained for various temperatures.

The equivalent antenna temperature, when our antenna was pointed towards the zenith, could be read 8~13°K as the results of several experiments carried out on different days.

As our paraboloidal reflector covered with wire-netting will have some leakages and losses, we cannot conclude that the above values correspond to the sky temperature. So we replaced the antenna by a horn about 2 m in length, and compared the equivalent antenna temperature with that in the previous case. The difference was about 10°K. Consequently, we have concluded that the sky temperature is 0~5°K.

IX. Conclusion

It may be permissible for practical use to conclude that the sky temperature is 0°K at 8 cm wavelength. For the antenna with appreciable losses or side and back lobes, equivalent antenna temperature, when it is pointed towards the zenith, may be a little higher than 0°K.

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