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ABSTRACT

The need for passive microwave radiometry using aperture synthesis and phased arrays for large apertures requiring more stability has generated several studies[1]. The in flight calibration and therefore the stability of such systems is an important design consideration. A 4.3 GHz laboratory radiometer operating in a balanced Dicke mode has been developed for making precise brightness (noise) temperature measurements. The stability of the noise diode source used in the noise-injection loop is of interest. A statistical Allan variance method to characterize the stability of the radiometer and the noise diode is presented in this paper. Noise measurements which demonstrate this approach are also included.

MEASUREMENT SYSTEM

The heart of the measurement system is a 4.3 GHz laboratory noise-injected radiometer which has an aluminum chassis enclosure with a heat sink to provide a low noise, temperature stable environment. A proportional temperature controller maintains the enclosure to 40.0 $\pm$ 1° C. Using calibrated RTD's (Resistive Thermal Devices) a data acquisition system monitors the internal temperature of the main assembly. The radiometer itself is controlled by a digital computer which also stores data. The noise injection switch is driven by the noise injection switch signal generated by the computer which sets the width of the noise injection pulse. The stored data represents the pulse width of the noise added to the antenna signal so that the zero or null output condition for the noise-injection loop is met. After a calibration is made with noise standards, a brightness temperature can be calculated from the data.

A noise diode fixture was developed for measuring a noise diode identical to the one found in the radiometer and can be seen in figure 1. The intent of these tests was to estimate the stability of the noise power at the output of the directional coupler. The PIN diode switch in the fixture allowed the noise diode output to be compared to the noise from the resistive termination. For radiometric purposes the radiometer input or the total noise power out of the directional coupler had to be less than the noise power from the reference termination within the radiometer. Since the noise diode used had an ENR of 30.59 dB at 4.3 GHz, a 30 dB directional coupler and a 3 dB attenuator were added for attenuation and to avoid saturating the front end of the radiometer. The attenuation provided by the directional coupler did not generate undesirable noise, characteristic of attenuators. With a cryogenic cold load attached to one port, the directional coupler lowered the noise level of the diode below the reference temperature of the radiometer. A PIN diode switch was used to switch between the noise diode and a 50 ohm reference termination and an isolator was added in line with the diode to compensate for any mismatches that would occur when the switch was active. All these devices were mounted on an aluminum slab and enclosed. A proportional temperature controller was used to maintain the temperature of the noise diode fixture. Tests normally ran over 24 hours and the cryogenic load had to be replenished every hour with liquid nitrogen.

STABILITY MEASUREMENT USING ALLAN VARIANCE

The stability of the noise diode was measured by comparing the excess noise level of the diode to the noise level of the 50 ohm termination. Since the noise we are measuring is from both the noise diode and the cryoload we must first correct for any variation in the noise power from the cryoload. This was done by continuously changing the switch position between the two devices every 8 seconds while making a radiometric measurement every second. By doing this the diode was essentially being turned on and off depending on the switch position. The measured noise with the diode off was then subtracted from the diode on data to remove any variation in the cryoload output.

The Allan variance has been used to investigate the stability of microwave noise sources in the past[2]. Not only does it have the ability to quantify instabilities in sources but it also can identify the instabilities as being flicker or 1/f, random walk, or white noise. Consider the noise diode fixture in figure 1 and the two outputs for switch positions $y_1(t)$ and $y_2(t)$ respectively. Define an average y_k

$$y_k = \frac{1}{\tau}\int_{t_k}^{t_k+\tau} y(t)dt, \qquad (1)$$

where τ is the integration time.

Then let the variance

$$\sigma_y^2(\tau) = \sum_{n=k}^{k+1} (y_n - \overline{y}_k)^2 \qquad (2)$$

where

$$\overline{y_k} = \frac{1}{2}(y_k + y_{k+1}). \qquad (3)$$

The Allan variance is the expected value of $\sigma_{y_k}^2(\tau)$ and can be written as

$$< \sigma_y^2(N,\tau) > \approx \frac{1}{N-1}\sum_{n=k}^{k+N-1}(y_n - \overline{y}_k)^2 \qquad (4)$$

(4)

where the brackets < > represent the ensemble average and N is the number of measurements[3]. By calculating the Allan variance for different integration times and plotting the results, different noise processes can be identified. For white noise the Allan variance σ_y^2 has a τ^{-1} dependence, for flicker or 1/f noise there is a τ^0 dependence, and for random walk noise there is a τ dependence.

EXPERIMENTAL RESULTS

In this section results of the noise diode measurements system will be presented using the 4.3 GHz laboratory radiometer. The stability of the noise diode and the radiometer measurement system was investigated. Data was collected for each switch position every second while the switch was switching every 8 seconds. The brightness temperature of the terminated measurement system, that is the noise from the 50 ohm termination held at 40° C and the measurement system was recorded. In addition $y_2(t)$, the brightness temperature of the noise diode plus the measurement system was also recorded. With data for both switch positions the noise contribution for the radiometer measurement system was eliminated by subtracting the noise measurements for the two switch positions $y_1(t)$-$y_2(t)$. It was assumed that the variations in the measurement systems were slower than the switch rate of 8 seconds. Brightness temperature data was averaged for approximately every minute and shown in figure 2 is the temperature difference between the noise diode and the 50 ohm termination for 1700 minutes (28.33 hours). The average brightness temperature difference varied less than .05 C. The Allan variance using equation 4 is shown in figure 3. The measured noise appears to be composed of a combination of white and flicker noise for integration times where τ < 8000 seconds and a random walk trend develops for τ > 8000 seconds. Another measurement was made for more than 2400 minutes (40 hours). The results are shown in figures 4 and 5. Notice the more definitive random walk component for τ > 8000 seconds for this longer measurement.

To verify that the random walk component of the noise is due to the noise diode and not thermal variation of the test fixture, data was collected in the same manner with the noise diode bias current off. Thus, only noise from the test fixture or uncorrected effects of the cryoload should be measured. The brightness temperature and Allan variance data are shown in figures 6 and 7 respectively. Since only white noise is present, these results suggest that the noise output of the noise diode does include the random walk component. Future testing will include an improved thermal control system for the noise diode and will investigate the importance of thermal variation and bias current variations on the diode stability.

Lastly, a direct measurement was made to determine the stability of the radiometer itself. The noise diode fixture was removed and a precision thermal termination was attached directly to the radiometer input. Since no switching was involved the data was not subtracted or improved as earlier. The Allan variance is presented in figure 8. Figure 8 represents the measured system noise including white noise and apparently a residual 1/f noise component with a noise temperature on the order of 30 micro Kelvin which begins to dominate the noise in the measurement for integration times in excess of 300 seconds. Without eliminating the variations in the measurements system as done earlier with the noise diode switching at a 8 second rate (see figure 7) and subtracting the data for the two switch positions, the measurement proved that the switching approach eliminated the residual 1/f noise.

CONCLUSION

A radiometric measurement at 4.3 GHz utilizing the Allan variance was developed to characterize the stability of noise diodes. The radiometric measurement system itself was estimated to be stable to within 30 micro Kelvin using a precision thermal termination. With noise diode data presented the noise processes in the measurement that cause instabilities were identified and quantified. The noise diode investigated appeared to have random walk noise. It appears that this measurement approach could be useful in determining the stability of various radiometer subsystems. Future efforts to improve the stability of the measurement system will be pursued.

References

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2. Lawrence, R.W., Scherner, M. and Grady, B.M., "Measurement of calibration stability of radiometer sensor systems," Proceedings of the SPIE, Vol. 1935, No. 25, April 1993

3. Allan, D.W., "Statistics of atomic frequency standards," Proceedings of the IEEE, Vol. 52, Feb. 1966

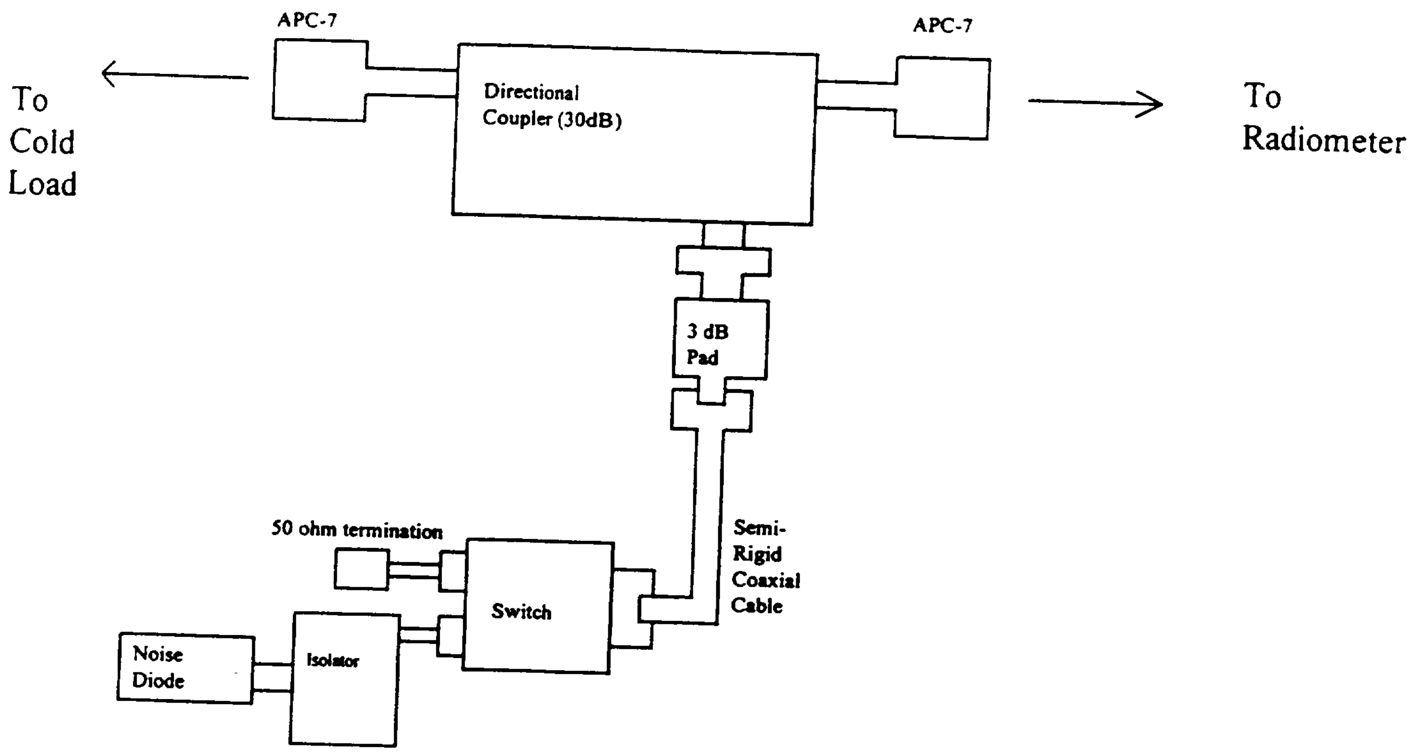

Figure 1 Noise Diode Test Fixture

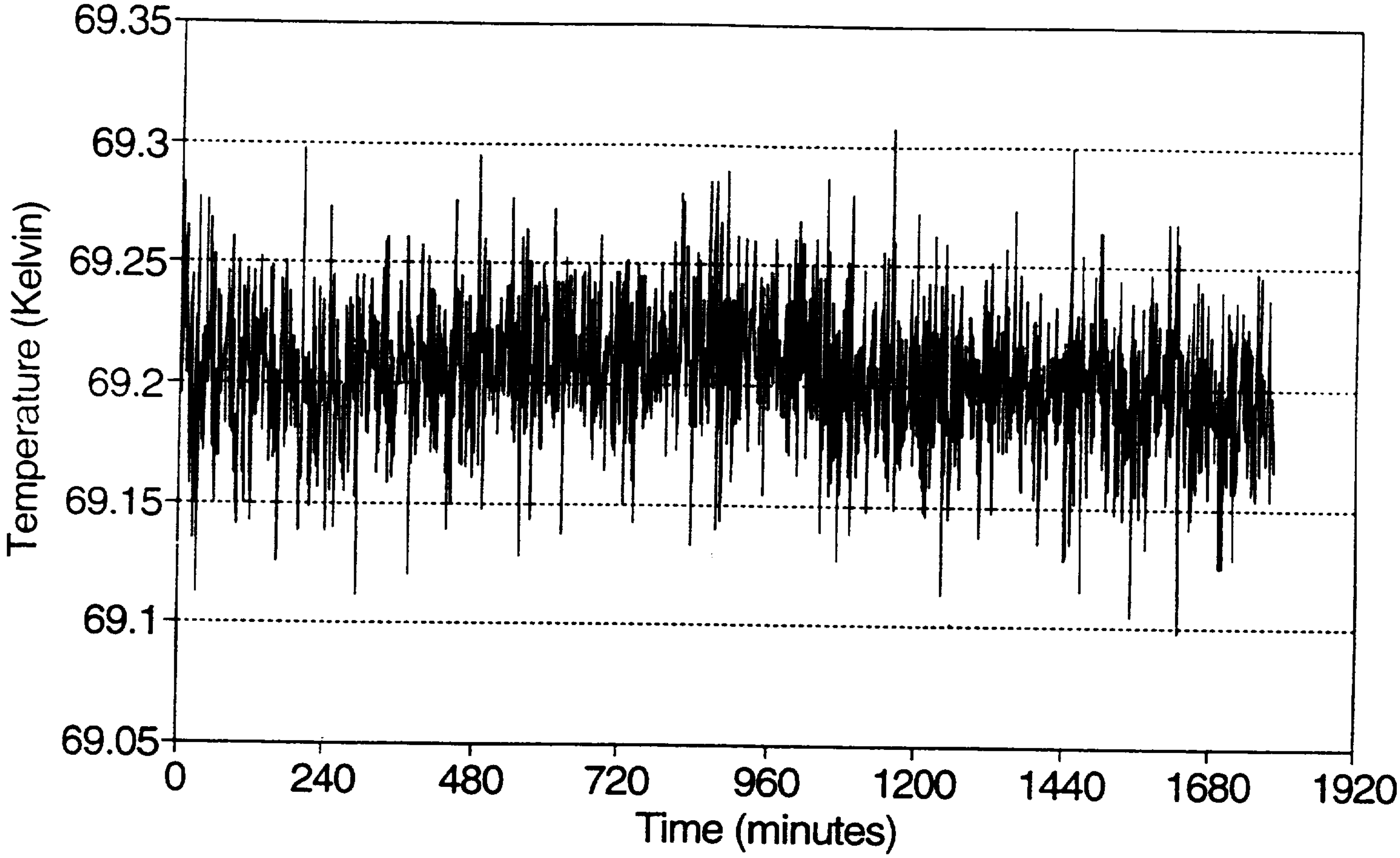

Figure 2
Noise Diode Brightness Temp Difference

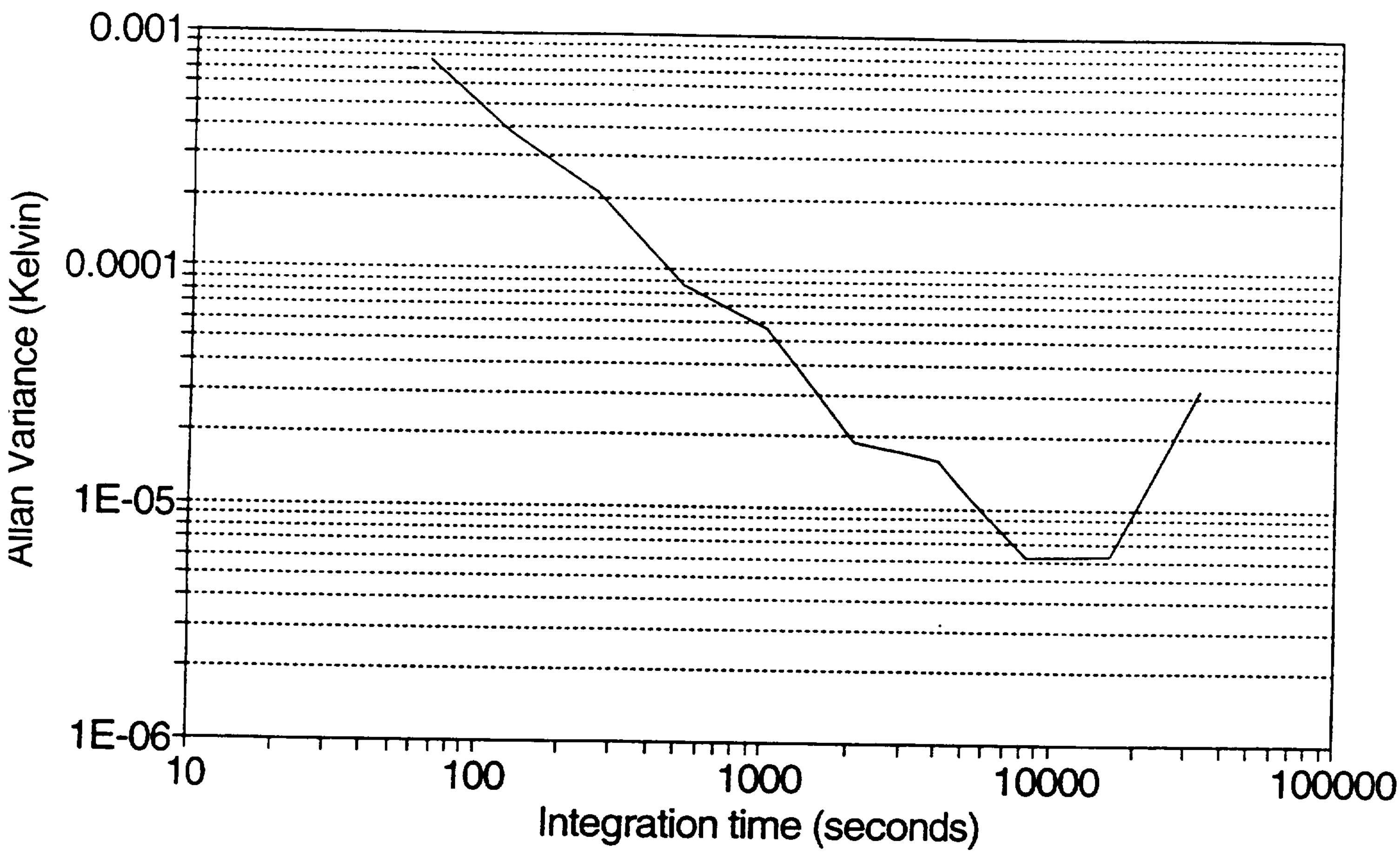

Figure 3

Allan Variance for Noise Diode

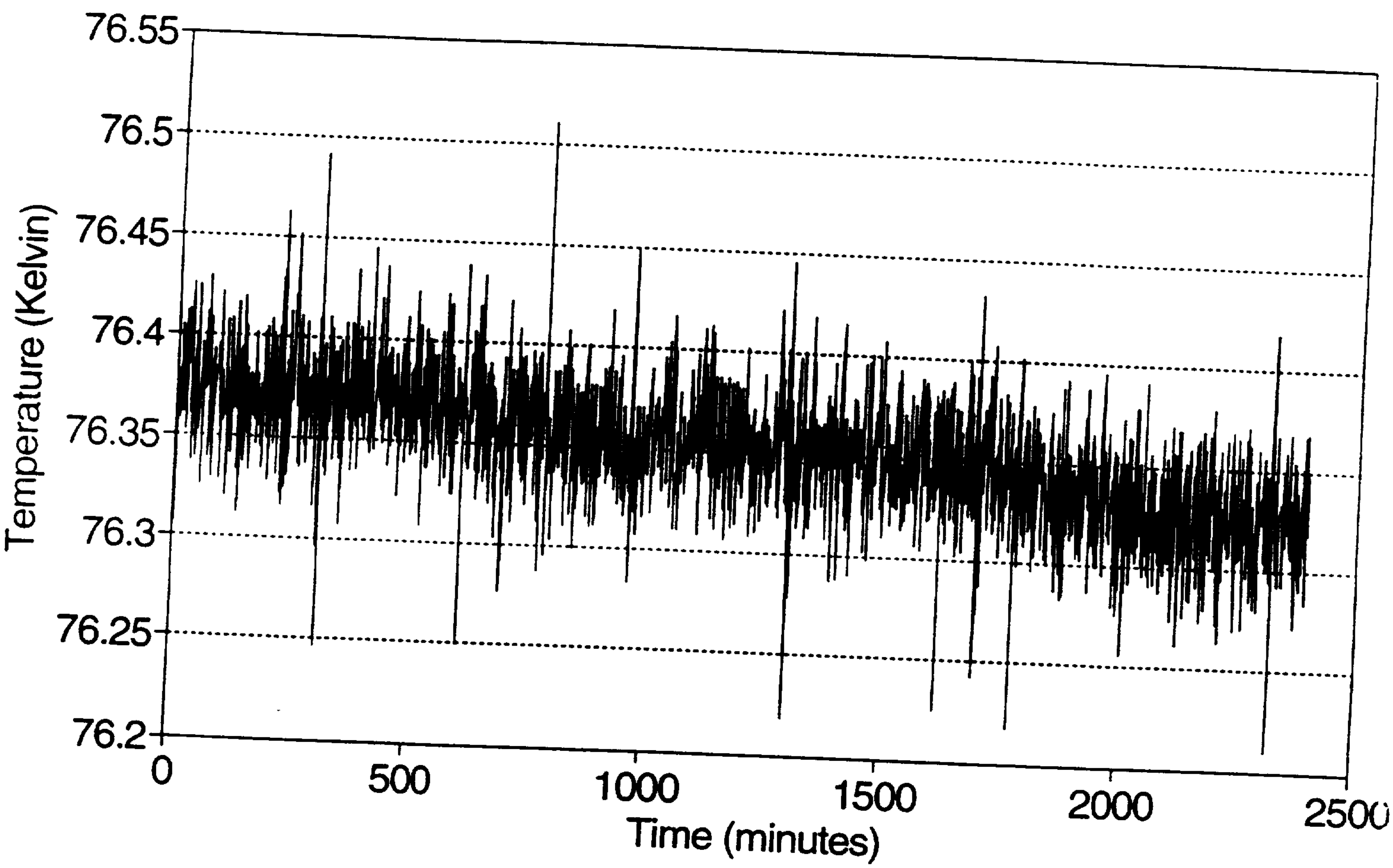

Figure 4
Noise Diode Brightness Temp Difference

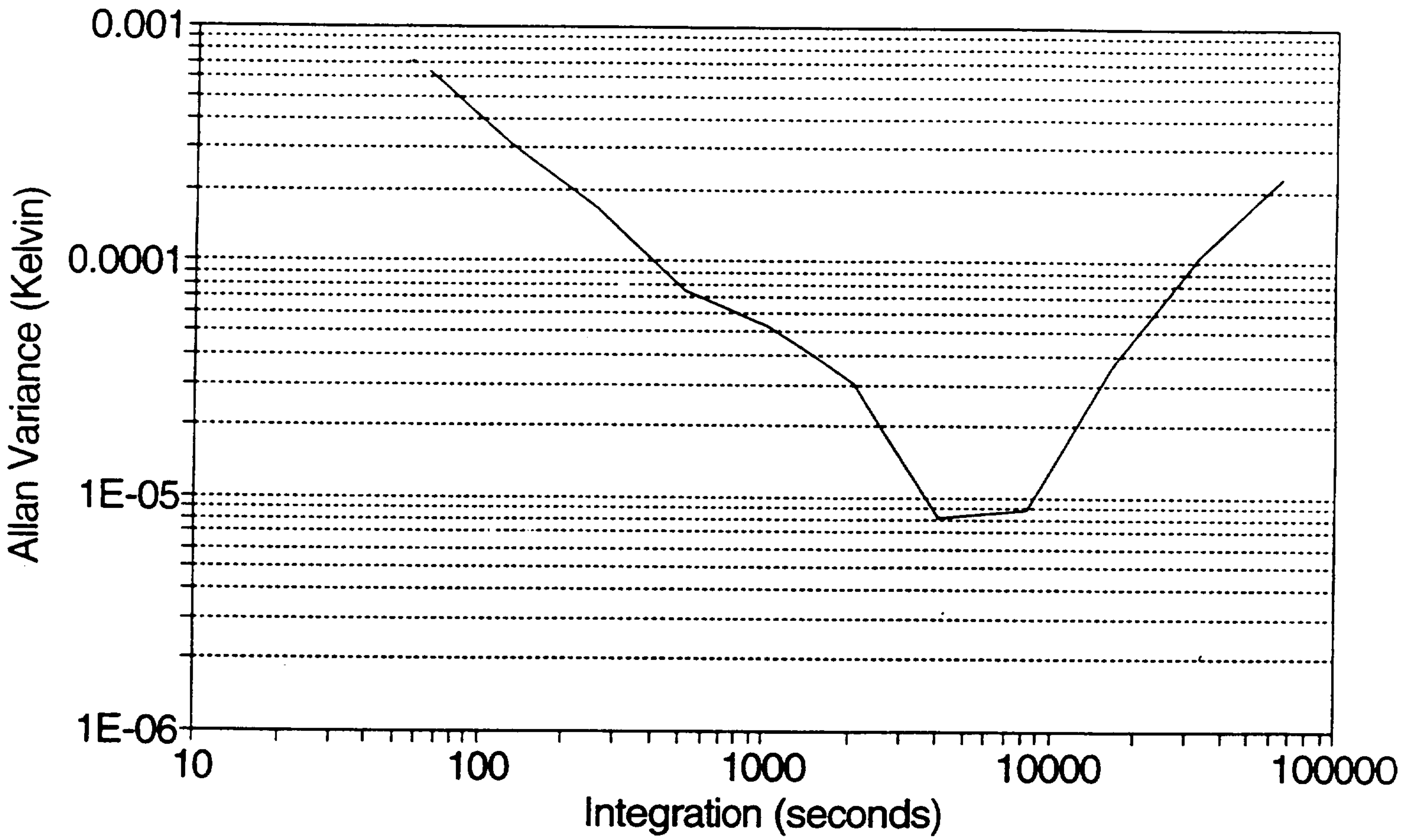

Figure 5
Allan Variance for Noise Diode

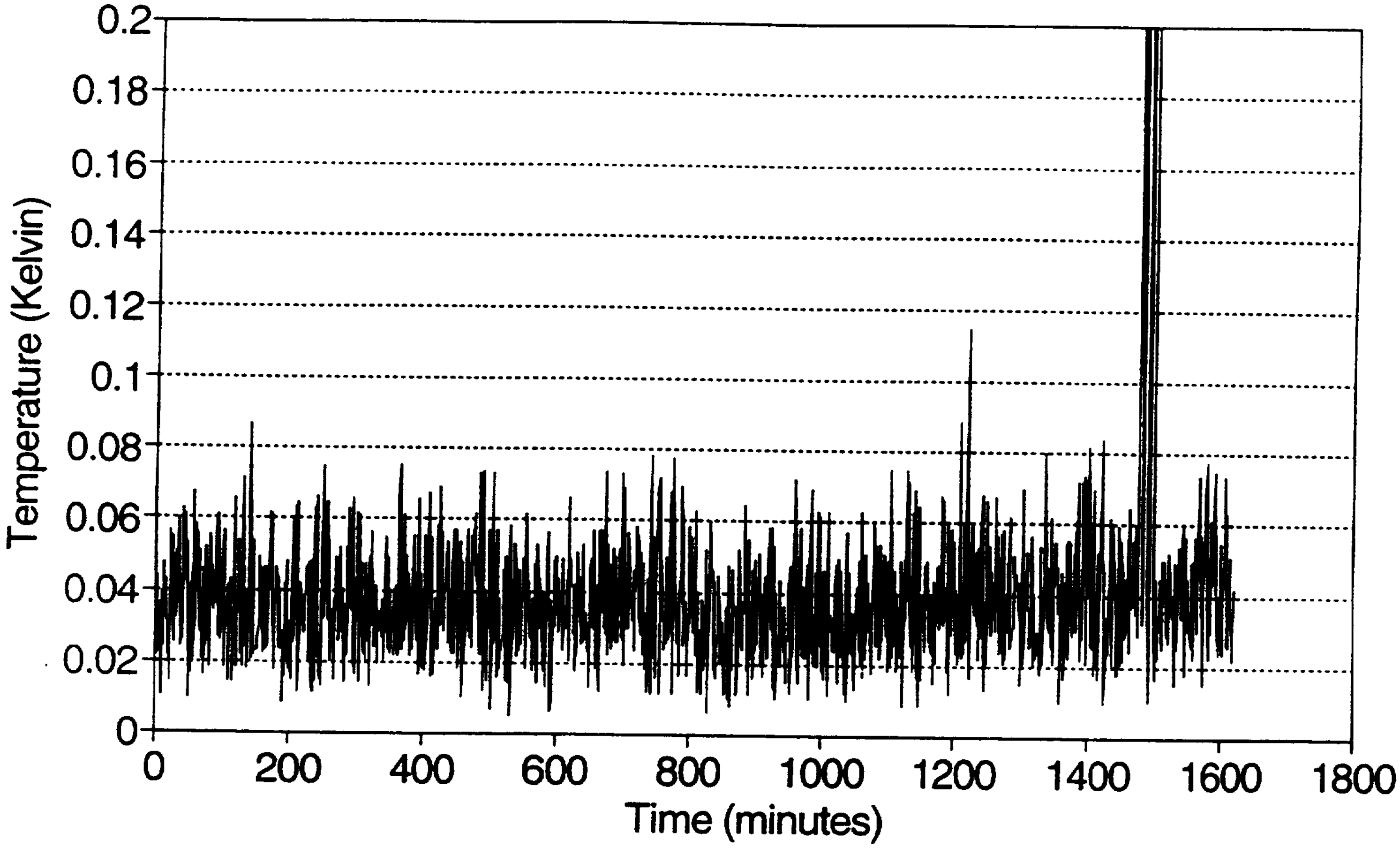

Figure 6
Noise Diode Brightness Temp Difference

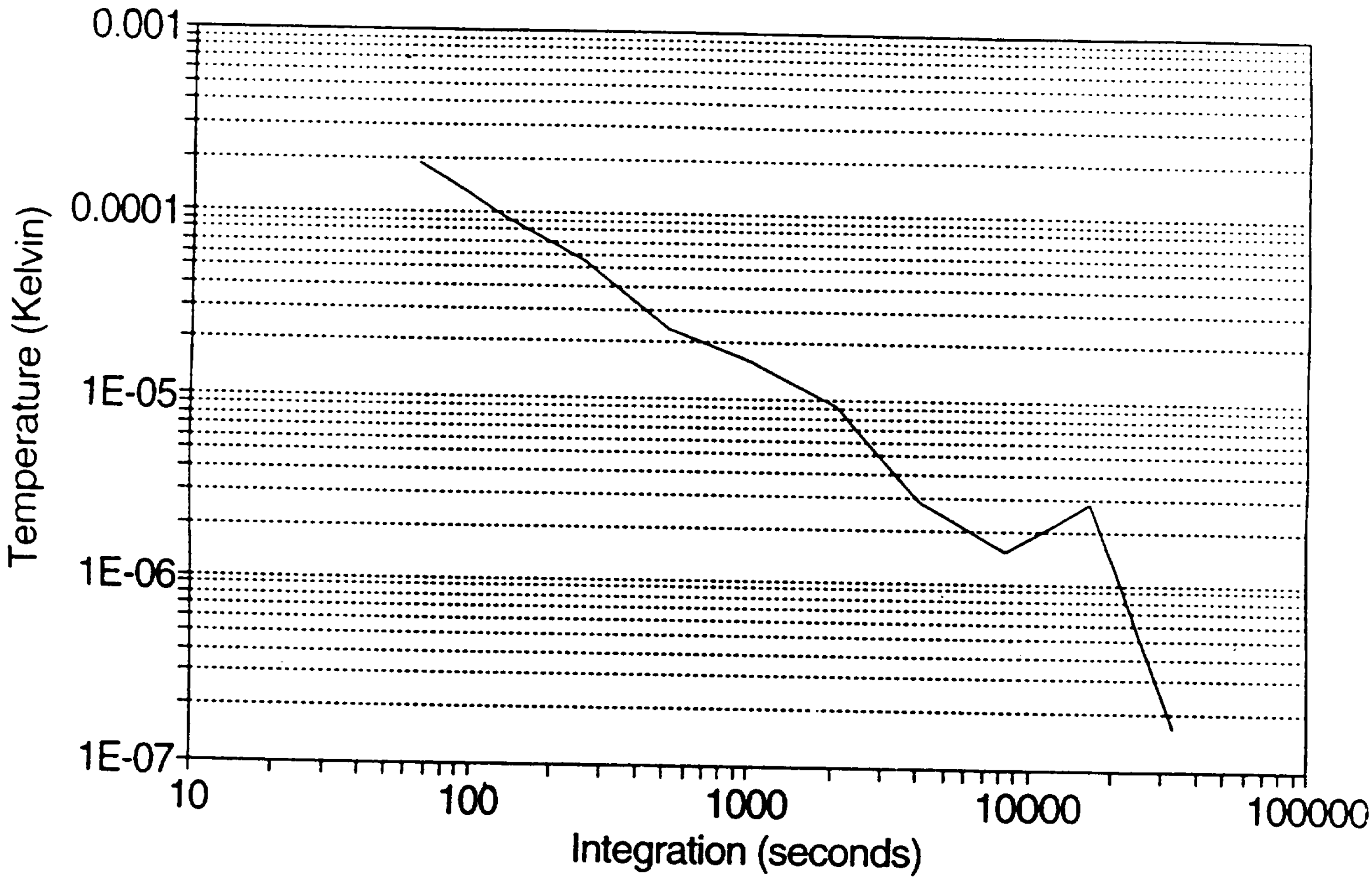

Figure 7
Allan Variance for Noise Diode

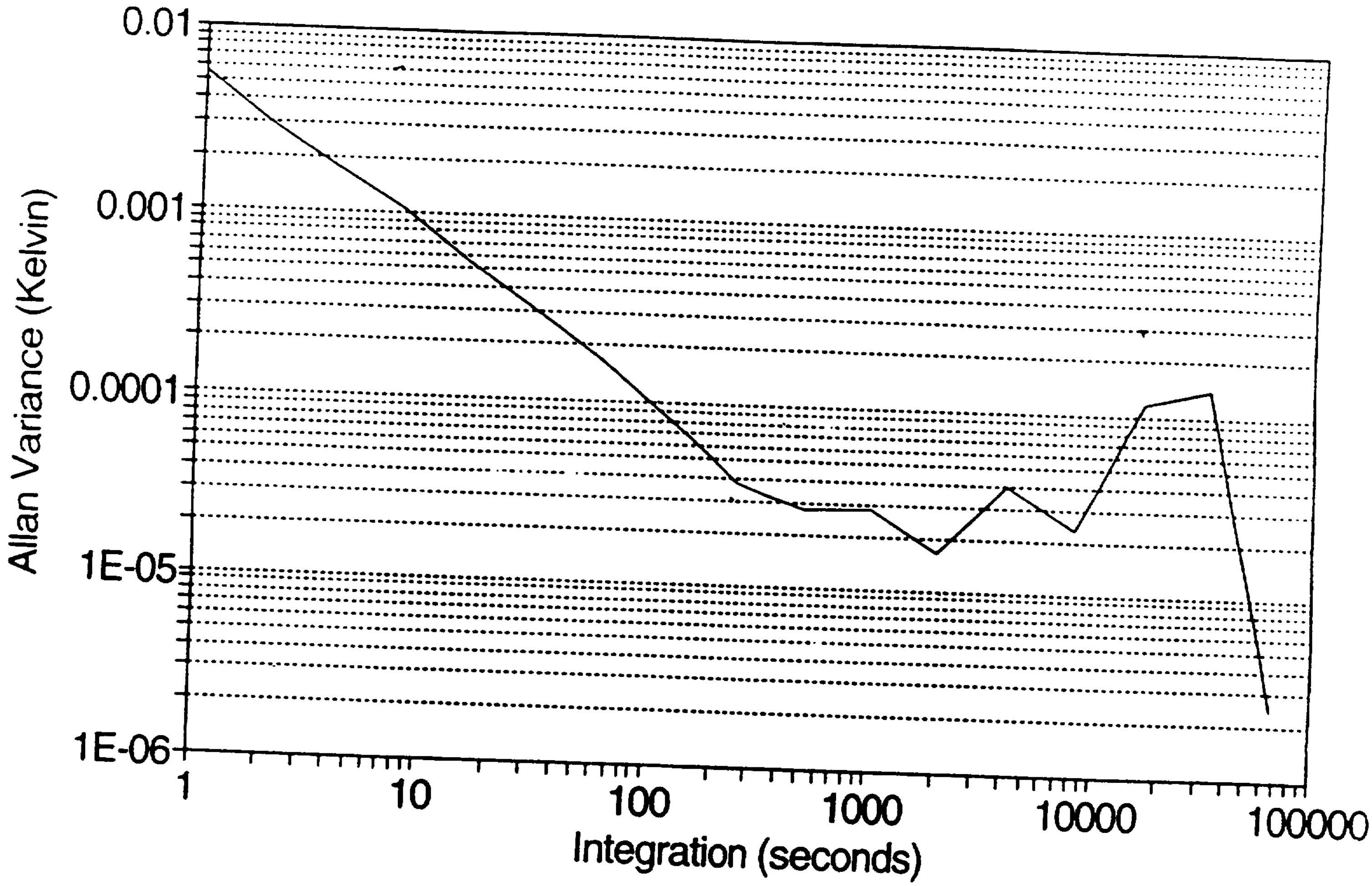

Figure 8
Allan Variance for Hot Load

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