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REQUIREMENTS FOR A LABORATORY INSTRUMENT FOR RADIOMETER STABILITY ANALYSIS

S. von Hoerner and M. Davis

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Baseline instability of a receiver is often a more serious radiometer defect than front-end noise, but at present there is no standard procedure providing for its quantitative measurement. The proposed instrument will provide this data in a form which can be easily interpreted in terms of the time scale of the instability.

Before describing the test instrument, it is interesting to illustrate with one common example the surprisingly high stability requirement on a radiometer, and the inadequacy of present testing methods. A 20 cm drift scan through an unresolved 0.4 flux unit source obtained with the 300-foot telescope last February is shown in Figure 1, together with its 10.0 f.u. calibration signal.

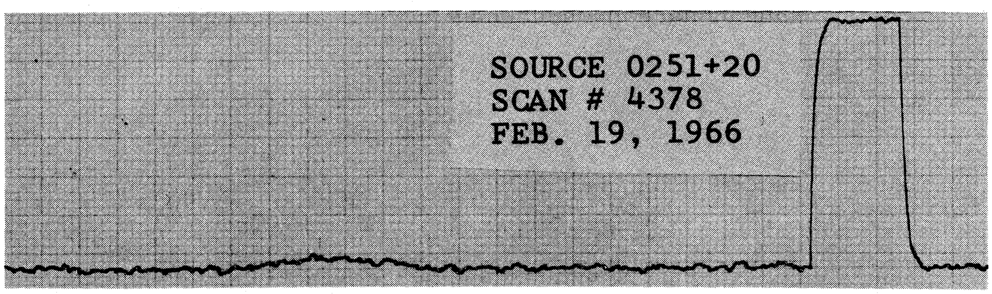

Figure 1

The peak-to-peak noise is ~ 1 mm, giving rms ~ 0.2 mm. The time constant was two sec. and the HPBW 40 sec., so that 20 independent measurements are available/HPBW. Hence, a least squares solution will determine the source flux with an rms error of $0.2 \text{ mm}/\sqrt{20} \approx 0.05$ mm. This is the thickness of one of the thin coordinate lines on the chart paper. The amplitude of the peak-to-peak instability over the length of the scan may not be greater than the thickness of one of the heavy coordinate lines, if it is not to be the limiting factor in determining the flux of the source. It is not possible to see whether such instabilities are present by visual inspection of the record.

Digital Methods

The instrument measures the rms fluctuation ΔT of the radiometer output as a function of integration time τ. It should

1) Integrate the receiver output, using finite integration for a time $\tau = 0.1$ sec. Call result P_1.

2) Repeat (1), obtain $\Delta_i = P_{i+1} - P_i$, $i = 1, 3, 5 \ldots, 255.$

3) Find $\Delta T\ (0.1) = \dfrac{1}{128\ \tau\ \sqrt{2}} \left(\sum_{i=1,3,5\ldots}^{255} \Delta_i^{\,2} \right)^{1/2}$

4) Repeat steps 1-3 for $\tau = 0.4,\ 1.6 \ldots, \tau_{max}$ seconds, where τ_{max} can be manually selected up to a maximum value of 409.6 seconds.

5) As a check: (a) obtain Δ (0.1) before each new value of τ is run and (b) repeat the entire series, decreasing from τ_{max} by factors of 4 down to 0.1 sec.

The total running time is $\sim$ 50 hours for $\tau_{max} = 409.6$ sec. Operation should be automatic during this time.

An alternative to the above instrument would be a facility in the laboratory for recording the radiometer output on magnetic tape at a sampling rate of 10 Hz for 50 hours. An autocorrelation program could then be written for the computer to do essentially what has been described above.

The test results $\Delta T(\tau)$ should be converted from counts to °K by calibration with a known noise source at $\tau = 0.1$ second, and be presented as a graph of ΔT (°K) vs. τ (sec) on log-log paper.

For uncorrelated noise (no instability), ΔT decreases a factor 2 for each factor of 4 in τ, while $\Delta T(\tau)$ = constant when significant instabilities of time scale τ are encountered. For example, test results for a radiometer with uncorrelated noise plus an instability level of 0.02 °K are shown schematically in Figure 2.

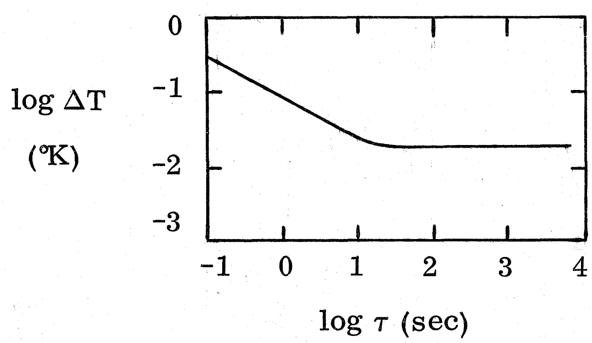

Figure 2

Such a graph should become part of the basic documentation of the radiometer.

Analog Method

An analog version of the above instrument can be used with some decrease in objectivity and accuracy. In this case the radiometer output is recorded with increasing (RC) time constants τ as described above. For each new τ the recorder speed is adjusted to $\sim$ 20 τ/inch, and the recorder gain is increased proportional to $\sqrt{\tau}$ (3 dB per factor of 4 in τ). About a foot of chart paper is recorded at each time constant.

The width of the trace will be constant as long as system noise dominates, but will start to increase as instabilities set in.

Typical Application

The 300-foot telescope 20 cm discrete source survey will use T_s = 130 °K, β = 20 MHz and τ = 8 sec to get ΔT = 0.02 °K. The mean error in flux on a point source is then 0.01 °K, since the HPBW = 40 sec of time, which gives $\sim \sqrt{5}$

improvement on the flux when a least squares fit is made. This means that the rms baseline instability with time scale $\sim$ 40 sec must be << 0.01 °K (say, 0.005 °K), if it is not to limit the survey. In fact, instabilities of this amplitude with time scales between 40 and 400 seconds are detrimental, since a scan length of $\sim$ 10 HPBW is used to determine the baseline under the source. It makes no sense spending a lot of money on reducing T_s to 60 °K if the radiometer is insufficiently stable.

A radiometer meeting these requirements would lie at or below the line drawn in Figure 3. If it is possible to keep the radiometer within 1 °K of balance while observing with it on the telescope, then the gain stability must be such that

$$\Delta G/G \leq 0.5\% \ (0.01 \text{ dB}).$$

300-ft. 20 cm Discrete Source Survey

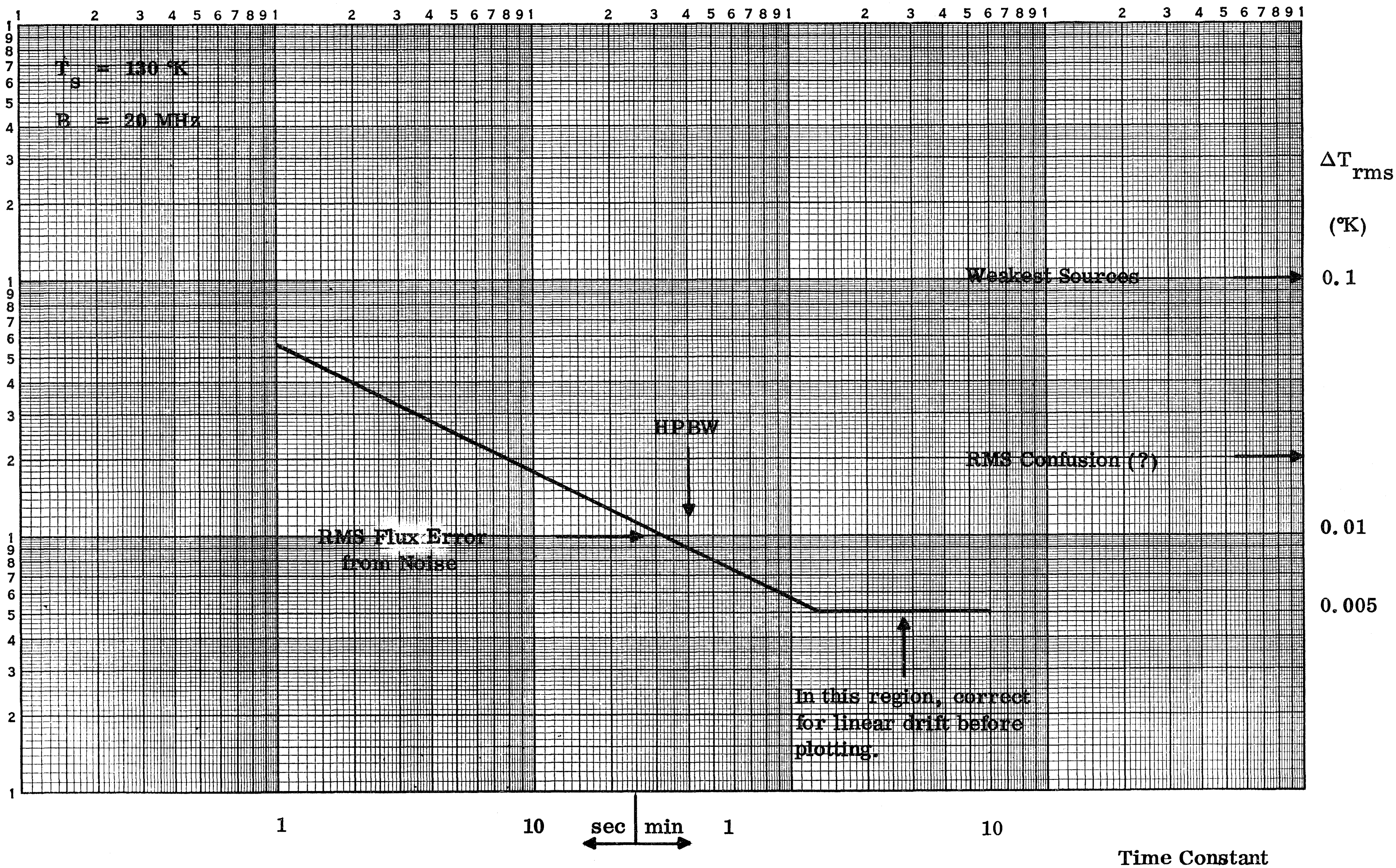

Figure 3 — Radiometer Noise and Stability Specifications