NATIONAL RADIO ASTRONOMY OBSERVATORY

TECHNICAL NOTE NO. 2

Calibration of Ewen Knight Model EK/HII-X2C X-band Radiometer Serial Number 101

by

F. D. Drake

National Radio Astronomy Observatory
Green Bank
West Virginia

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The purpose of this note is to provide observers at NRAO with the results of a fundamental calibration of the X-band travelling wave tube radiometer purchased from Ewen Knight Corporation.

1. Measurement of Calibration Step.

The radiometer possesses as a part of the front end plumbing a directional coupler through which a calibration noise signal is inserted into the antenna line when the appropriate switch is activated. An experiment was conducted to compare quantitatively this noise step with a temperature increment in a properly matched resistive termination to the antenna line. The experimental apparatus is shown in Figure 1. The VSWR of the RF structure attached to the radiometer was less than 1.03 over the frequency band 7.5-8.5 kmc, thus insuring that power reflection at the junction between structure and radiometer was less than .03 per cent. The radiometer noise tube current was maintained at 125 ma. Means were provided for making small changes in the thermal bath temperature, and for stirring constantly this bath to prevent stratification. A Central Scientific Company Type 23779 thermometer was permanently mounted in the bath, and was capable of giving directly the bath temperature to an accuracy of better than .01°K. It was found in practice that the temperature of the bath, and therefore the termination, could be maintained easily at any temperature within a few degrees of ambient to an accuracy of better than .01°K.

The experimental procedure was as follows: The radiometer was turned on and allowed to operate for several hours until the gain had become constant. The temperature of the thermal bath was set at a level near room temperature and maintained at this level to an accuracy of better than .01°K. for a period of at least 1/2 hour. Since the measured thermal time constant of the termination was 6^m, this insured that the load had stabilized at the temperature chosen. The calibration step was then energized for a period of about eight minutes, and turned off, thus giving a deflection which is a measure of the calibration step. The radiometer was allowed to run for about eight minutes to check the zero level. The temperature of the thermal bath was then elevated suddenly by 1.00°K., and was maintained at the new value for a period of 30 minutes. This was sufficient time for the termination to approach nearly a new thermal equilibrium with the thermal bath. The expected exponential curve was traced by the radiometer. The temperature was then abruptly lowered to the original value, and maintained there while the radiometer tracing continued another 30 minutes. The calibration step was then reactivated for a period of eight minutes, turned off, and the radiometer was allowed to recheck again the zero level for a period of eight minutes. This completed one experimental run.

In reducing the experimental data, the mean deflection given by the two calibration steps in a run was compared with the deflection that occurred due to the 1° temperature change. By comparing the mean of the two calibration step deflections with the deflection due to the change in load temperature, one is eliminating any effect due to linear changes with time in receiver gain. In measuring the deflection due to the temperature changes, the recorder tracings made from three to five thermal time constants after the abrupt temperature changes were used. These portions of the tracings were corrected to account for the fact that the final deflection had not been reached, using the well-known qualities of the exponential function. By using the data given after at least three thermal time constants, the exponential corrections were kept extremely small, so that errors due to improper correction will be insignificant. Such errors could result principally from making an incorrect assumption as to what the final deflection will be; in the actual reduction of data it was quite obvious that these errors were negligible. Assuming the radiometer to operate linearly, the data reductions give a measure of the strength of the calibration step, neglecting the small losses in the RF plumbing. The results of four measures of the calibration step gave:

$$\text{Calibration step} = 1.072 \pm .011 (\text{p.e.})\ ^\circ\text{K}.$$

It is necessary to insure that the termination is closely coupled thermally to the water bath, so that the step in bath temperature is truly the step in load temperature. To test this, the above experiment was repeated several times for different water levels in the thermal bath. It was found that as long as the water level was at least 5 inches above the bottom of the Hewlett Packard termination, the same measure of the calibration step was obtained to within 1 per cent. With lower water levels, measurable deviations began to occur in the data.

For practical reasons, we wish this calibration to refer to the input to the radiometer, rather than to the position of the termination at the end of the RF plumbing, as is the case in the above result. It is therefore necessary to correct for losses in the waveguide between termination and receiver input. The total length of the plumbing is about 20 inches. Assuming that the Waveline components, which have a high-conductivity plating, have a mean attenuation of 2.3 db/100 ft. over the frequency band, the attenuation is .038 db, or about 0.9 per cent. This gives as a final result for the value of the calibration step referred to the radiometer input, RF junction JM8:

$$\text{Calibration step} = 1.066 \pm 0.011 (\text{p.e.})\ ^\circ\text{K}.$$

It is suggested that, for uniformity in the reporting of results, all observers using this radiometer adopt the value $\Delta T = 1.066^\circ$K for the calibration step.

It should be noted that this calibration remains valid only as long as the noise diode installed during these tests continues to be the radiometer noise diode.

2. Radiometer Linearity.

The overall linearity of the radiometer was measured using the apparatus shown in Figure 2. Throughout this experiment the RF detector current was maintained at a value of 20 microamps. Tests were carried out as follows: The desired audio gain and recorder gain were set and noise tube turned on. The precision attenuator was then set to give maximum attenuation, and the recorder zero level adjusted to give a zero level nearly at the edge of the recorder grid. The attenuation was then reduced until a deflection of about three divisions was produced, and the setting of the attenuator recorded. This was repeated continuously until a full-scale deflection was reached, or the radiometer saturated. Straightforward treatment of the attenuator settings then produced a curve of deflection versus input temperature. A typical curve resulting from these measures is shown in Figure 3.

It was concluded from these measures that for antenna temperatures from 0 to 500°K, and for recorder gain settings of 2.5 or less, the radiometer is linear to better than 1 per cent. No larger antenna temperature inputs were attempted. as they would not be met in practice except with the sun, which is a special case. It was found that with recorder gain settings of 5.0 or greater, the radiometer remained linear, but went into saturation sharply at some level. This may be seen in Figure 3. This saturation occurs in the Kin Tel DC amplifier which immediately precedes the recorder amplifiers in the signal path. Observers should therefore use recorder gain settings of 5.0 or greater with caution.

Acknowledgements: Mr. B. L. Meredith assisted in the taking of the data regarding the calibration step, and in the measurement of the radiometer linearity. Mr. Dewey Ross took a large part of the data concerned with the radiometer linearity.

Figure 1.

Experimental Set-up for Measurement of Calibration Step

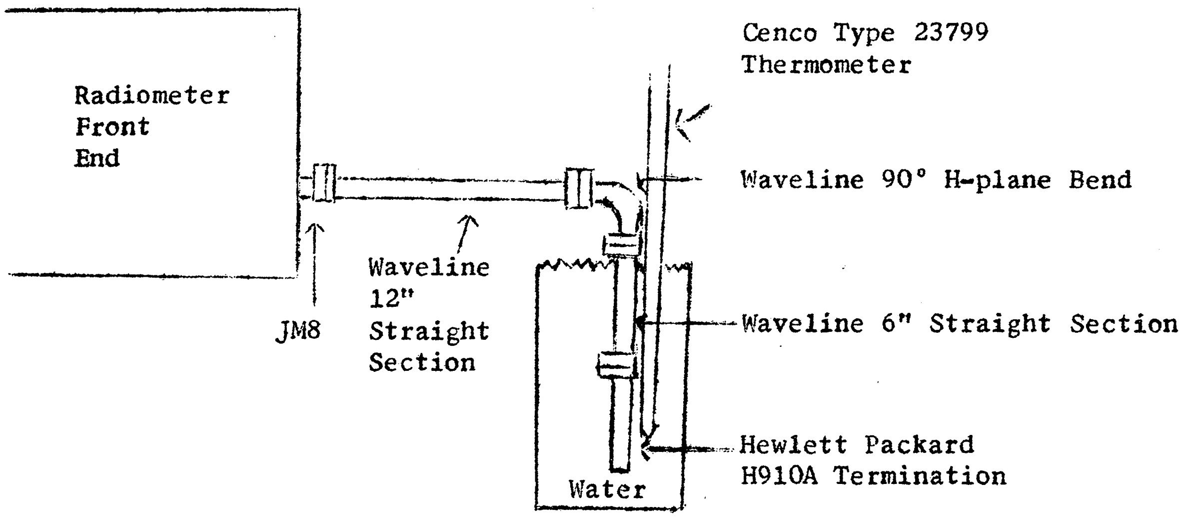


Figure 2.

Experimental Set-up for Measurement of Radiometer Linearity

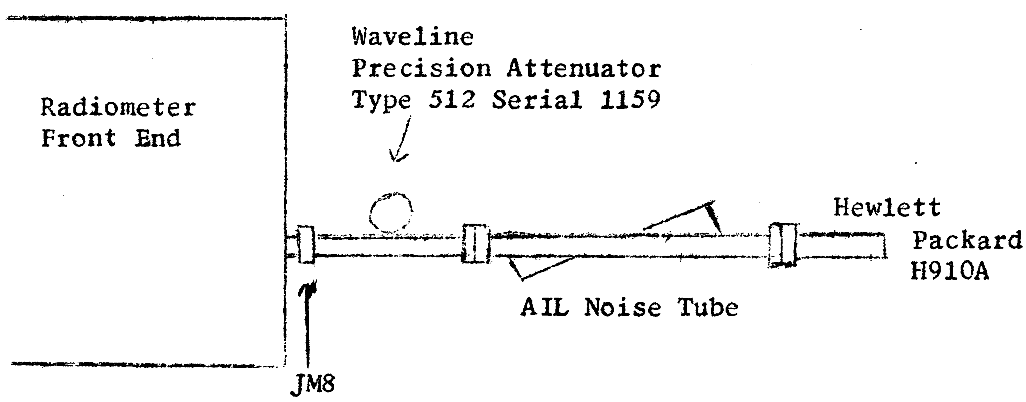
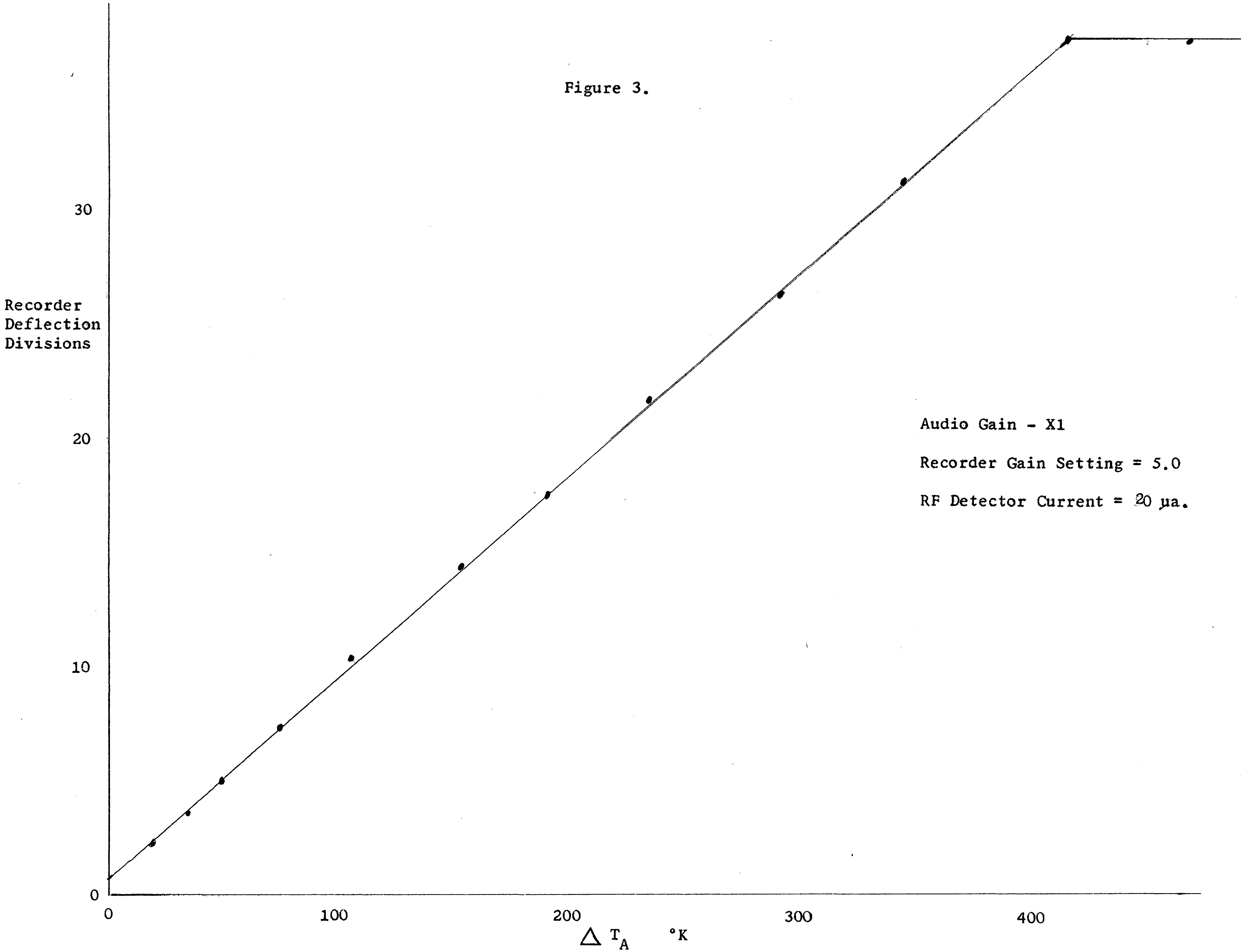


Figure 3.



Recorder
Deflection
Divisions
30
20
10
0
0
100
200
300
400
ΔT_A °K
Audio Gain - X1
Recorder Gain Setting = 5.0
RF Detector Current = 20 µa.