Stability Measurements on Noise Sources

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***Abstract*—We report results of stability and repeatability measurements performed on a selection of different noise sources for selected frequencies between 12 GHz and 26.5 GHz. Measurements cover intervals classified as intermediate term (about 1 week) and long term (about 1 year or more). Noise sources measured include a commercial diode source, a gas-discharge source constructed by NIST, a specially modified commercial diode source, and a variable-temperature FET-based source. All sources exhibit excellent stability, typically consistent with zero drift in noise temperature within the uncertainty of the tests.**

***Index Terms*—Noise, noise measurement, noise source, noise temperature, stability, thermal noise.**

I. INTRODUCTION

THE Noise Metrology Project at the U.S. National Institute of Standards and Technology, Boulder, CO (NIST) has recently conducted tests to determine the stability of several different noise sources over time periods of about one week and about one year. In addition, we have noise sources that are used as check standards for our noise–temperature calibration services. Some of these check standards have been in use for many years, and the histories of their measured noise temperatures provide a measurement of their stability over long time periods.

There are several reasons for interest in the stability of noise sources. Noise sources may be used in remote locations and in applications involving continuous or intermittent use. In such cases, it is important to know how much the noise temperature of the source may drift over the time it is in use. For sources used as secondary or transfer standards in calibration laboratories, the stability of the source is important in determining the interval between its recalibrations. The tests reported in this paper are not extensive enough to be used as the basis for choosing calibration intervals, but we shall see that they do provide support for relatively long intervals. Four very different types of noise sources were measured in this work, and so our results could be used to compare the stability of different types of noise sources, provided we bear in mind that we have tested only one or a few representative sources of each type.

The measurements were all performed on radiometers that are used in NIST measurement services. The stability of these measurement systems is also measured as a byproduct of the tests, and we shall discuss it below. All measurements were made in a calibration laboratory whose temperature is maintained at $23\,^\circ\mathrm{C} \pm 0.5\,^\circ\mathrm{C}$. For most of the sources, variations in the ambient temperature would be expected to induce corresponding changes in the noise temperature of the source.

In Section II, we describe the sources and the tests. Section III presents the results of the stability measurements on the noise sources, as well as the radiometer stability results. Section IV summarizes the work. An abbreviated report of this work was presented in [1].

II. SOURCES AND TESTS

A. Noise Sources

We have stability results for four different types of noise sources: gas tubes, diodes, a temperature-stabilized diode source, and an FET-based variable-temperature source. The NIST check standards that we measured were either gas tubes or diode sources. They will be referred to by their NIST identification numbers (*e.g.*, X1KZH1.098, or 098). Only a small representative subset of the available data on the NIST check standards is presented. The diode sources were all commercially manufactured. Of the gas tubes, some were constructed by NIST, and some are commercial units, but all share the same basic design. The other two types of sources are less familiar. One consists of a commercial WR-62 waveguide diode source that has been housed in a temperature-controlled box. The box maintains the source at a constant physical temperature (about $40\,^\circ\mathrm{C}$) preventing changes in the temperature of the environment from affecting the noise temperature of the source. The unit was designed and built by the Jet Propulsion Laboratory (JPL) to provide a very stable noise source under field conditions, where the ambient temperature may vary or may be quite different from the ambient temperature at which the source was calibrated. In our measurements, which were performed in a temperature-controlled laboratory, the temperature-controlled box does not provide any significant advantage. Consequently, we would not expect the JPL source to be significantly more stable than the other diode sources. Its advantage lies in the fact that its stability should remain the same when used outside the calibration lab. The fourth type of source that was measured was an FET-based variable temperature source (VTS) [2], [3]. Varying the gate and drain voltages varies the output noise temperature, which can be less than ambient, or cold, when observed at the gate side of the device. The stability of this source was measured for four different output temperatures, ranging from about 119 to about 240 K. This was the only cold source measured. All the other sources had noise temperatures in the range 8500–11 000 K.

B. Test Procedures

We shall use “intermediate term” to refer to time periods of a few days to a few weeks. “Long term” will refer to time pe-

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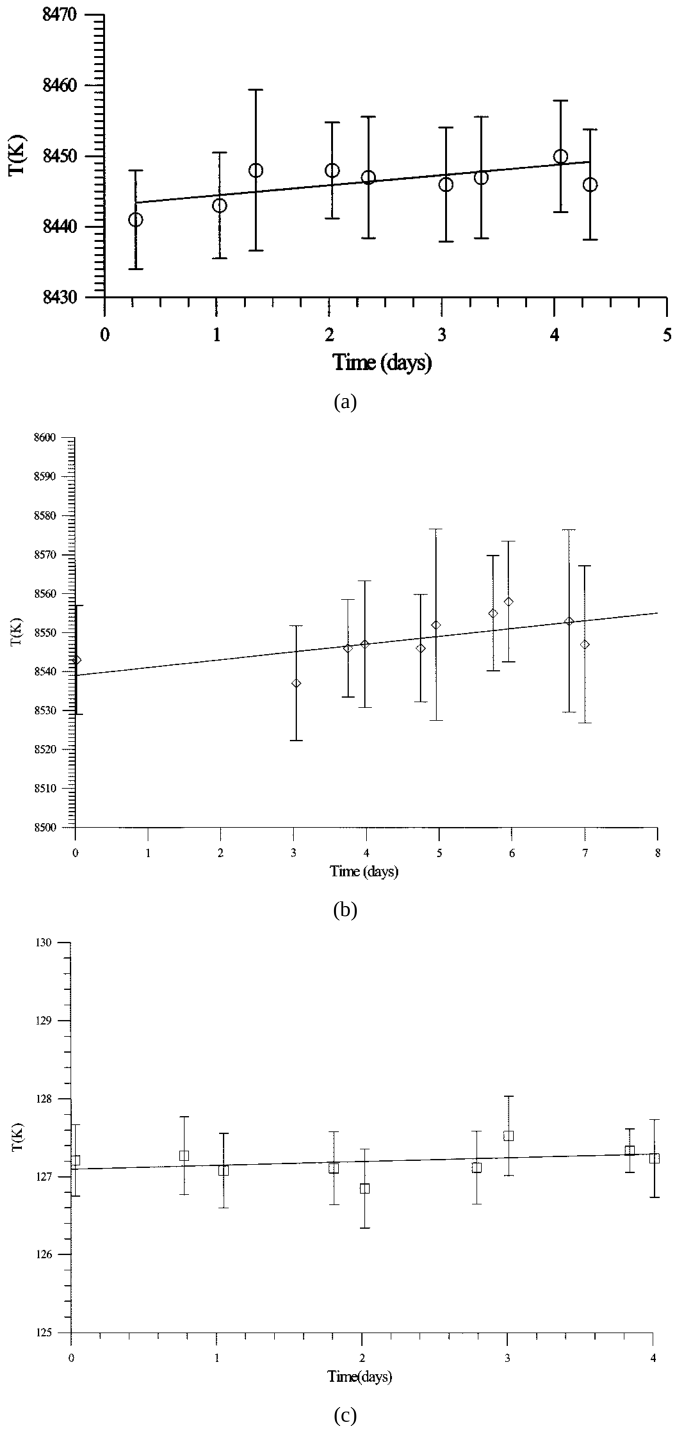

Fig. 1. (a) Intermediate-term stability results for JPL source at 13.402 GHz. Error bars correspond to the standard deviation of the mean of the 20 readings that went into each measurement value. (b) Intermediate-term stability results for diode source 098 at 18 GHz. Error bars are as in Fig. 1(a). (c) Intermediate-term stability results for VTS at 18 GHz for $V_{\rm ds} = 1$ V, $V_{\rm gs} = 0.4$ V. Error bars are as in Fig. 1(a).

riods from a month or two up to several years. We do not address short-term (a few hours or less) stability in this paper. The measurements were performed on the NIST coaxial [4], [5] and waveguide [6] radiometers. They are total-power radiometers with built-in six-port reflectometers to measure the relevant reflection coefficients. Before a noise–temperature measurement, a full system calibration is performed, comprising a six-port calibration and a measurement of the asymmetry between different measurement paths. In the noise–temperature measurement, the delivered powers from the ambient primary standard, the cryogenic primary standard, and the device under test (DUT) are read in succession, and a noise temperature is calculated from the radiometer equation [5], [6]. This cycle constitutes one "reading." It is repeated many times (20 for waveguide systems, 50 for coaxial), and the noise temperatures are averaged to yield one "measurement." With this procedure, we are effectively recalibrating the radiometer gain and noise temperature for each reading (one cycle). We are thus insensitive to drift in these system parameters except over the time interval of one reading cycle (one minute or less). The multiple readings or cycles increase the effective integration time and also allow us to measure the repeatability of the switch in each measurement.

The measurements of the intermediate-term stability can be performed in two different ways. One way is to perform a complete system recalibration before each measurement. This entails disconnecting and reconnecting the DUT for each measurement, and it therefore is subject to variations in the connection, as well as variations from one system calibration to the next. The other method is to perform a full system calibration only at the start, and then to leave the DUT connected to the system throughout the course of the tests. This method eliminates variations in system calibration and DUT connection, but it is susceptible to variations due to drift in the six-port calibration or the path asymmetry. It is our experience that this drift is less than the variations in connections and system calibration, and, consequently, we prefer to leave the DUT continuously connected for the intermediate-term stability tests and to not recalibrate the system before each measurement. We performed one set of measurements with a complete system calibration before each measurement as a check of our expectations. For the long-term stability tests it is not practical to leave the DUT continuously connected, and so we performed a full system calibration before each measurement. For the intermediate-term tests, measurements were made twice per day for four to seven days. For the long-term tests, measurements were made at irregular intervals over about one year.

As a byproduct of measuring the stability of the noise sources, we also obtain information about the radiometers. The stability measurements will provide a limit on the radiometer stability. In addition, the tests involving a new system calibration for each measurement provide a measurement of the repeatability of noise–temperature measurements on the radiometers involved.

III. RESULTS

A. Intermediate-Term Stability

We measured the intermediate-term stability of three noise sources. A commercial diode source (X1KZH1.098, or 098) and the VTS were measured at 18 GHz, and the JPL source was measured at three frequencies around 13 GHz. In the interest of space, we will present results for only one frequency for the JPL source and for only one of the four bias settings for the VTS. The results at the other frequencies and bias settings are qualitatively the same. For the JPL source, we use 13.402 GHz, which is the

TABLE I
SUMMARY OF INTERMEDIATE-TERM STABILITY TESTS

Noise Source	Mean T (K)	σ (K)	σ (%)	Slope (K/d)	Slope (%/d)
X1KZH1.098	8548	5.9	0.07	2.0±2.5	0.023±0.029
JPL	8446	2.7	0.03	1.4±2.0	0.017±0.024
VTS	127.2	0.18	0.14	0.05±0.11	0.039±0.086

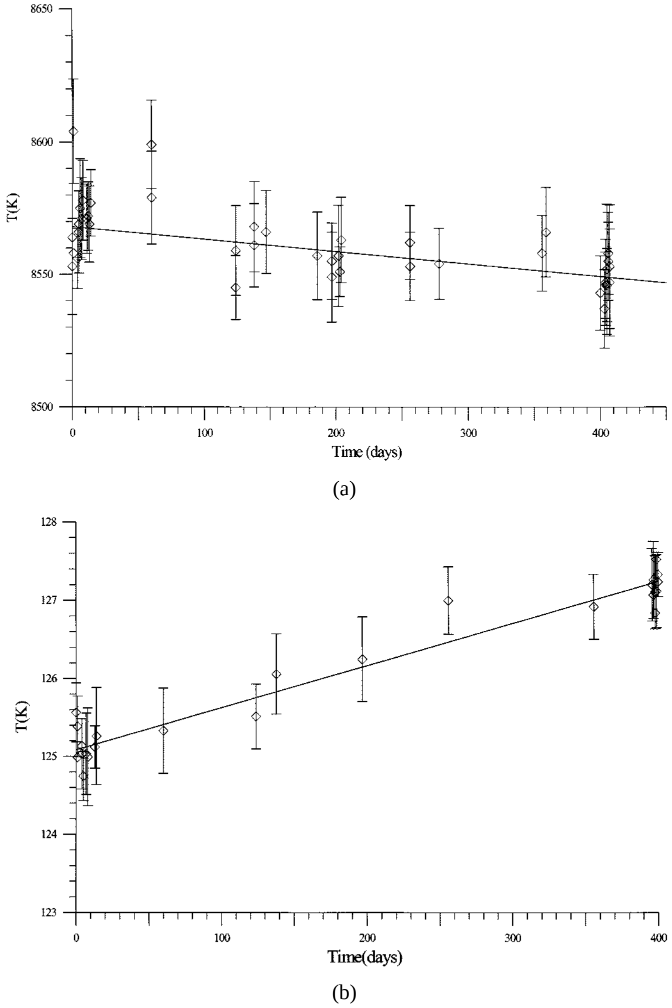

Fig. 2. (a) Long-term stability results for check standard 098 at 18 GHz. Error bars are as in Fig. 1. (b) Long-term stability results for VTS at 18 GHz for $V_{\rm ds} = 1$ V, $V_{\rm gs} = 0.4$ V. Error bars are as in Fig. 1.

middle of the three frequencies. For the VTS, the noise temperatures for the different bias settings range from about 119 K to about 240 K, and we use the results for $V_{\rm ds} = 1$ V and $V_{\rm gs} = 0.4$ V, corresponding to a noise temperature of about 127 K. The JPL measurements were performed on a WR-62 radiometer, whereas 098 and the VTS were measured on a WR-42 system. The VTS has a 3.5 mm coaxial connector, and so it was measured through an adapter.

Measured noise temperatures for the three sources are plotted in Fig. 1. The error bars correspond to the standard deviation of the mean of the 20 readings that went into each measured value. The straight lines are weighted least-squares fits to the data. From the graphs of Fig. 1, it is obvious that the three sources are all *very* stable. The stability can be quantified in many different ways, some of which are shown in Table I. The third column is the sample standard deviation (not the standard error or standard deviation of the mean) for the sets of points in the graphs. It reflects the spread of the random variations of the noise temperatures assuming no drift. The slopes are the results of weighted least-squares fits to the data. Uncertainties in the slopes are statistical (type-A) only, and correspond to 1σ. To facilitate comparison of sources with very different noise temperatures, we have given the fractional (relative to the mean) values for the sample standard deviations and the slopes. The intermediate-term slopes are consistent with zero for all the noise sources measured. They are generally about 0.04% per day or less, and the uncertainty is typically less than 0.1% per day. In addition, the standard deviations of the sets of measured noise temperatures are small, on the order of 0.1% of the noise temperatures.

B. Long-Term Stability and Repeatability

Long-term stability tests were performed at 18 GHz on the VTS and on the same solid-state check standard (098) used in the intermediate-term tests. Measurements were made at irregular intervals for a little over one year. The results are shown in Fig. 2. Again, only one bias setting is shown for the VTS, and the straight lines are weighted least-square fits. The quantitative information is given in Table II. In this case, there is a small but significant drift in the noise temperature of each device. Since 098 is used as a check standard in calibration services, we have additional historical data on it, which can be used to investigate the significance of the measured slope. The $098'$ entry in Table II is the result of a fit to data on 098 spanning a longer time, just over three years. The mean noise temperature is essentially the same as for the smaller sample, but the slope has decreased by a factor of almost 2. We can also investigate whether the observed drift is frequency dependent, and for this purpose we include in Table II results of a fit to six years of data on 098 at 26 GHz. In this case, there is no evidence of any drift. The final entry in Table II shows the results for a different check standard (X1PZH1.023, or 023) measured at 18 GHz on a different radiometer over a period of about six years. This source is a gas tube in a housing constructed by NIST. It has a WR-62

TABLE II
SUMMARY OF LONG-TERM STABILITY TESTS

Noise Source	Mean T (K)	σ (K)	σ (%)	Slope (K per year)	Slope (% per year)
VTS (18 GHz)	126.1	1.0	0.8	2.0±0.2	1.6±0.1
098 (18 GHz)	8561	13	0.16	-17±4	-0.20±0.05
098′ (18 GHz)	8562	13	0.15	-9.4±1.7	-0.11±0.03
098 (26 GHz)	10 247	25	0.25	-1.1±4.5	-0.011±0.044
023 (18 GHz)	10 962	14	0.13	1.4±1.7	0.013±0.015

output, and it was measured on a WR-62 radiometer. It shows no evidence of drift.

The long-term results show some evidence for drift in the commercial diode source at 18 GHz and in the VTS for the one set of bias conditions. (Other bias settings show more or less drift.) The effects are not large, particularly for the commercial source, and perhaps not even conclusive, but the long-term stability of these two sources bears watching.

C. Radiometer Stability

As we described in Section II-B, the measurements are relatively insensitive to radiometer drift for intervals longer than about a minute. We nevertheless take considerable pains to insure the stability of each radiometer. One of the principal measures is to control the temperature of the amplifiers and mixer by mounting them on metal plates through which room-temperature water is circulated. With each noise–temperature reading, a nominal (ignoring mismatch effects) system gain and noise temperature are computed from the powers measured from the two primary standards. This allows us to monitor the characteristics of the radiometers during use.

The noise temperature and gain of the system were recorded during the intermediate-term tests, and a weighted least-squares fit was performed on each set of data at 13.402 GHz. The resulting fits were $T_e = 507.97\ \mathrm{K} - 0.12\ \mathrm{K/d} \times t$ and $G = 7.611 \times 10^{10} + 1.411 \times 10^{7}/\mathrm{d} \times t$, where t is time. The (1σ) uncertainties on the slopes were 0.18 K/d for T_e and 2.0×10^{7}/d for G. The fractional drifts were thus ($0.023\% \pm 0.035\%$) per day for system noise temperature and ($0.019\% \pm 0.026\%$) per day for system gain. Both are very small and consistent with zero.

IV. SUMMARY

We have presented data on both the stability and the repeatability of several noise sources of differing design. Both intermediate-term (about one week) and long-term (a year or more) results were presented. The slopes of the linear fits measure the drift of the noise temperature of the source. The intermediate-term slopes were all consistent with zero. The type-A uncertainties were about 0.1 K/d for the cold source (VTS) and about 2 K/d for the hot sources, or between 0.024% per day and 0.9% per day. Long-term slopes were measured with type-A uncertainties between 1.7 K per year and about 5 K per year ($< 0.05\%$ per year) for the hot sources, and 0.2 K per year (0.1% per year) for the cold source. Some of the sources did exhibit nonzero, but small, long-term drift for some bias choice or for some frequencies. The fact that the unmodified diode noise source exhibited stability comparable to the temperature-stabilized JPL source is presumably due to the fact that the measurements were performed in a temperature-controlled laboratory. In an uncontrolled environment, we would expect the unmodified source to drift with environmental changes, whereas the JPL source should not.

Assuming no drift, the sample standard deviations are a measure of the repeatability of the noise–temperature measurements. In the intermediate-term tests the sample standard deviations were all less than 0.2% of the noise temperature, and as low as 0.03% for the JPL source. This corresponded to a few Kelvins for the hot sources and about 0.2 K for the VTS. Both noise source and measurement system contribute to these variations (presumably independently), and therefore the observed sample standard deviations represent bounds on the variations due to the respective noise sources. The noise-source variations are due not just to the noise source itself, but also to its power supply and the sensitivity of the source output to small variations in the power supply. The somewhat larger fractional standard deviations observed for the VTS could well be due to variations in setting the bias voltages because supplies with only manual analog controls were used. The long-term sample standard deviations are around 0.2% for the hot sources and 0.8% for the VTS. We expect the long-term repeatability to be worse than that observed in the intermediate-term tests because the long-term results include variability in the source connection and the system calibration. The intermediate-term results do not include these effects, since the source was not disconnected during the tests, and only one full system calibration was performed.

The effective noise temperature and nominal gain of the measurement system were also monitored during the intermediate-term tests. The fractional drifts in both were about 0.02% per day $\pm 0.03\%$ per day. For comparison, the standard (1σ) uncertainty in such measurements is typically 0.4%–0.5%.

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