Precision Measurement of Antenna System Noise Using Radio Stars

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***Abstract*—This paper reviews the National Bureau of Standards (NBS) preision noise measurements program for antenna systems which have been made using Cassiopeia A and the moon. The Earth Terminal Measurement System (ETMS) was developed by NBS to make measurements of figure of merit (G/T), and the noise equivalent flux (NEF). The accuracy of the noise measurements are, typically, between 5 and 15 percent for systems with antenna gains between 51 and 65 dB and frequencies between 1 and 10 GHz.**

***Key words*—antenna gain; antenna half-power beamwidth; atmospheric loss; Cassiopeia A; earth terminal measurement system; figure of merit; moon; noise equivalent flux; noise measurement; radio stars; satellite communication.**

I. INTRODUCTION

THE National Bureau of Standards (NBS) has been making precision noise measurements of antenna systems using radio sources for about ten years [1], [2]. Initially, the radio star Cassiopeia A (Cas A) was used [3]-[5], but recently, we have begun using the moon [6]. The accuracy of the noise measurements is, typically, between 5 and 15 percent for systems with antenna gains between 51 and 65 dB.

II. BACKGROUND

The noise that originates within, or enters into, a microwave communications antenna system is a basic characteristic of the system. There are four methods used to make system noise measurements in antenna systems. The first method is to make precision noise and gain (or loss) measurements for the various components of the system and combine these results in an appropriate manner to obtain an overall system noise. In evaluating the characteristics of the individual components, three keys to the overall accuracy for the system noise measurement are the accuracy of measuring a) the antenna gain [7]-[11] (NBS calibration services use near-field [12]-[14] or extrapolation [15] techniques, but one might also consider radio-astronomy [16], [17] techniques), b) the antenna noise [18], and c) the amplifier noise [19]-[21].

A second method is useful for large antenna systems that can "see" a radio star such as Cassiopeia A, or the moon. The noise from the radio star can be used as a "yard stick" to measure the system noise [11], [22]-[24].

A third method is to use the signal of known intensity from a satellite. This satellite signal can be used in a way not too different than that of a radio star [25]. Finally, a modified gain comparison technique can be used where one antenna is basically used to calibrate the strength of some radio source in order to then calibrate a second antenna.

This paper will discuss only the second method which, if applicable, is the most accurate method. It is applicable when a) the antenna system can "see" the radio source with a signal-to-noise ratio of better than 0.2, b) the half-power beamwidth (HPBW) of the antenna radiation pattern is greater than the diameter of the radio source being used, and c) the antenna can be pointed at the radio source to a resolution of better than 10 percent of the HPBW.

The radio star Cassiopeia A (Cas A) and the moon are used as calibration sources [3], [6] for the measurements described in this paper. For X-band antenna systems, Cas A is the source of choice for large, low-noise antenna systems (11- to 28-m diameter antennas). The moon is the better source for medium-sized antenna systems (4- to 5.5-m diameter antennas).

A. Noise Measures

There are several ways of specifying the noise in an antenna system. Some of them are confusing and misleading, but have a historical acceptance that keeps them in use. Discussed below are some of the noise measures in use, along with a warning about their shortcomings.

1) System Noise Temperature: System noise temperature (T) can be defined as the temperature of a fictitious noise source in a noiseless equivalent antenna system such that the output noise power from the idealized system equals the output noise power of the actual antenna system. For system noise temperature, the antenna is assumed to be pointing to the cold sky. The noise flux generated in the atmosphere that is collected by the antenna is included, so the atmospheric conditions (at least temperature and humidity), antenna location, and pointing are important and need to be specified. The choice of the reference plane for characterizing the system noise temperature is arbitrary, but if it is not explicitly stated, it is understood to be at the output of the antenna (wherever you choose that to be). Stated again, system noise temperature includes the noise coming into, or originating within the antenna system, when the antenna is pointed to the cold sky. Thus the magnitude of the system noise temperature depends on atmospheric conditions, antenna elevation, site elevation, and the internal reference plane selected.

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System noise temperature would be a poor parameter to really use to characterize noise in an antenna system. The double problem of stating (or wondering) what atmospheric conditions were assumed, and stating (or wondering) which reference plane was assumed, is too much. Rather, it is used as a concept for such things as the definition of figure of merit discussed below. One unfortunate difficulty related to system noise temperature is that it is not assigned a unique symbol. It is commonly represented by both the symbol T and also by the symbol T_s. Doubly unfortunate is the practice of also using the symbol T to refer to a different parameter (operating noise temperature as defined below) in the popular parameter C/kT (the ratio of the carrier power to noise power in a 1-Hz bandwidth). I think this practice presents a rather interesting challenge, and even the communications professionals forget and confuse the two.

2) Operating Noise Temperature: Operating noise temperature is defined the same as system noise temperature, except that the antenna is pointing at an operating satellite. Thus noise broadcast from the satellite contributes to the operating noise temperature.

3) Figure of Merit: One of the more popular specifications of antenna system noise is figure of merit, usually denoted as G/T [1], [3], [23], [25]-[32]. Figure of merit is defined to be the ratio of the antenna receive gain to the system noise temperature (referred to the antenna output port). The early papers talk about G as being the antenna gain [27], [30], [31], [33], but this is not technically correct because antenna gain (or power gain as defined by the IEEE) is the ratio of power density radiated in a given direction compared to the power density radiated by an isotropic radiator emitting the same total power [34], [35]. What is needed for the figure of merit is the ratio of the power received by the antenna compared with that received by an ideal isotropic antenna. The number is the same for reciprocal antennas, but for G/T, an amplifier can be considered part of the antenna and the power gain definition is not applicable. To emphasize that the antenna gain used in the definition of G/T is a receiving property, it is referred to as the receive gain [28].

Figure of merit has the advantage of being a relatively easy noise parameter to measure(for most antenna systems). It can be shown that the figure of merit does not depend on which internal reference plane is selected as being the output port of the antenna. Thus one can say that the figure of merit is the ratio of the system gain to the system noise temperature [28].

By definition, receive antenna gain does not depend on atmospheric loss. It is unfortunate that the definition of figure of merit does not account for the atmospheric loss in the numerator of G/T. Because of this oversight, the attractiveness of the figure of merit is diminished. The atmospheric loss is neither included nor excluded. For example, in the measurement of figure of merit using radio stars (as will be discussed in more detail later), one has to estimate and correct for the atmospheric loss. This complicated correction is a detriment both to the simplicity of the measurement, and to its usefulness. If no correction for loss were required, then the figure of merit would have been a more direct measure of the signal-to-noise ratio obtained using a satellite transmitting a known signal power. As it is, nothing "exactly" can be done with figure of merit until the atmospheric loss is put back in!

4) Noise Equivalent Flux (NEF): the Noise Equivalent Flux (NEF) density is a measure of the noise performance of the earth terminal analogous to effective input noise temperature for an amplifier [2]. NEF is the magnitude of an ideal white, random noise flux density [$\mathrm{W \cdot m^{-2} \cdot Hz^{-1}}$] incident normal to the aperture of a noiseless equivalent earth terminal operating in a lossless atmosphere such that the output noise power equals the output noise power of the actual earth terminal. Thus NEF characterizes only the hardware performance of the earth terminal.

B. Measurement Method

To determine G/T using radio sources, one measures the ratio (Y) of the output noise power when the earth terminal antenna is pointed at a radio "star" to the output noise power when the antenna is pointed to the nearby cold sky. The noise power out of the antenna system when the antenna is pointed to a radio source is the power at the output of the antenna times the gain (g) from the antenna output to the system output. Thus

$$\text{power out (on source)} = gk(\Delta T + T)B$$

where ΔT is the temperature rise due to the radio source at the antenna output port, and T is the system temperature expressed relative to the antenna output port, and

$$\text{power out (on sky)} = gkTB.$$

The ratio of these two measurable powers is

$$Y = (\Delta T + T)/T. \tag{1}$$

The temperature of the cold sky is included in T. The temperature rise ΔT caused by the star depends on its flux density $S(\mathrm{W \cdot m^{-2} \cdot Hz^{-1}})$ and on the effective area of the antenna A_e ($\mathrm{m^2}$)

$$\Delta T = (1/2)\kappa S A_e/k \tag{2}$$

where κ is the correction factor near unity that accounts for the atmospheric loss, star shape, antenna pointing, polarization effects, and instrumental effects; and k is Boltzmann's constant ($k = 1.38045 \times 10^{-23}$ J/K). The factor 1/2 in (2) accounts for the fact that only one polarization of radiation can be received from a star at any one time. To introduce the receive gain G, one uses the following relationship:

$$A_e = c^2 G/(4\pi f^2) \tag{3}$$

where c is the velocity of light (2.99793×10^8 m/s), f is the frequency; so

$$G/T = (Y - 1)(8\pi k f^2)/(\kappa c^2 S) \tag{4}$$

or expressed in decibels above one inverse kelvin

$$G/T(\mathrm{dB/K}) = 10 \log (G/T). \tag{5}$$

By replacing T by $(\mathrm{NEF}\, A_e)/(2k) + T_{\mathrm{sky}}\,(A_e/A_{e0})$, where T_{sky} is the noise power originating from the atmospheric losses plus the 3 K cosmic background temperature, and A_{e0} is the antenna effective area at the antenna aperture (i.e., no resistive antenna losses included), then the Y factor (1) becomes

$$Y = (\kappa S + 2kT_{\text{sky}}/A_{e0} + \text{NEF})/(2kT_{\text{sky}}/A_{e0} + \text{NEF}). \tag{6}$$

Boltzmann's constant k and the antenna effective area A_{e0} convert T_{sky} to a power density expressed in watts per square meter. Rearranging (6)

$$\text{NEF} = \kappa S/(Y - 1) - 2kT_{\text{sky}}/A_{e0}. \tag{7}$$

C. Broad Radio Sources

Our laboratory has never made a precision noise measurement using a broad radio source, but we have considered it. There are some pitfalls and problems that make using such noise sources impractical for precision measurements of system noise. From our own experience, and from talking with others, these limitations are not always immediately obvious. The purpose of this section is to bring the problems to light.

For the purposes of this paper, a broad source is one that is significantly broader than the HPBW of the antenna. By precision measurement, what is meant is that the magnitude of the measurement error can be estimated, and the measurement accuracy is somewhere near the state of the art.

To understand the difficulty of making precision measurements using broad sources, consider what happens to the measurement of G/T or NEF as the source size approaches the HPBW. Two effects erode the accuracy: first, the correction for the fact that the star is not a point source (called the star shape factor) becomes more and more difficult to estimate, and, secondly, the sensitivity of the measurement decreases.

The star shape factor for Cassiopeia A [3] and the moon [6] have been examined by NBS very carefully. To obtain a star shape factor, one has to know or assume the brightness distribution of the source and the antenna pattern, calculate the source–antenna convolution, estimate the errors caused by the limitations in the distribution/pattern assumptions, and obtain a practical algorithm to represent this convolution integral for different antenna HPBW's, the frequency ranges desired, and source conditions (i.e., secular decay, moon phase, moon–earth distance, etc.). In practice, the star–antenna convolution calculation results are not very dependent on the antenna pattern assumed nor the details of the star brightness distribution as long as the source is smaller than the antenna HPBW. That is, assuming that the antenna pattern is Gaussian does not give a significantly different result than using an actual measured antenna pattern. And, assuming some appropriate, simple brightness distribution (e.g., a disk distribution with the "best diameter and brightness) does not give a significantly different result than using the actual measured distribution.

This situation changes dramatically as the size of the source approaches and exceeds the HPBW of the antenna. Instead of the star shape correction factor depending on neither the details of the antenna pattern nor the star brightness distribution, it begins to depend heavily on both. In principle, if one had an accurately measured antenna pattern and a detailed brightness map for the source, the appropriate star shape correction factor could be calculated. This shifts the measurement from being an easy measurement to being a major undertaking. The antenna would have to be constructed or mounted so that the necessary measurements are feasible, and an adequate far-field source or adequate near-field measurement facility available. For example, for a point source, the star shape factor is unity and independent of the antenna pattern. For an ideal disk source equal to the HPBW of the antenna pattern, the star shape factor is near 0.7 and a 1-percent error in estimating the HPBW causes a 0.5-percent error in the star shape factor. But for a disk source equal to twice the HPBW, the star shape factor is only 0.3 and a 1-percent error in estimating the HPBW causes a 1.6-percent error in the star shape factor. The error in estimating the star shape correction factor quickly gets out of hand.

However, if the source size approaches or is larger than the HPBW, a new and very significant problem is encountered. Namely, (4) and (7) become inappropriate as κ (because of the star shape correction factor) becomes nearly inversely proportional to the receive gain. The physics of the situation is that the magnitude of the signal "on star" begins to depend only on the brightness temperature of the source and not on the shape of the antenna pattern. That is, if the antenna were defocused, the boresight gain would decrease, but the pattern widens so that the total radiation collected by the antenna is nearly the same (assuming that the brightness temperature of extended source is uniform). As κ becomes inversely proportional to G, the G dependence in (7) and (8) drops out, and the measurement error becomes unbounded (because NEF and G/T depend directly on G).

In principle, the measurement using an extended source can be used to monitor changes in system temperature (which can be measured better by other ways). But if the sun is used as the broad source, the errors will be doubly difficult to estimate because of its unpredictable brightness distribution.

On the other hand, if the source is much broader than the HPBW, one can measure the rate of change (derivative) of the signal as the antenna pattern enters the source region, and thereby determines some of the antenna parameters [16]. In principle, one could obtain noise information from an extension of this technique, but it appears to us to be too formidable a task. To our knowledge, the two techniques—correcting for star shape, and using the rate of change—are the only methods for using radio sources for measuring noise in an antenna system; so we conclude that broad sources are not suitable for making noise measurements.

III. NBS MEASUREMENTS

To measure the system noise in a large antenna system, NBS developed the Earth Terminal Measuring System (ETMS) [2], [36]–[39]. The ETMS is a computer-aided measuring system that calculates the pointing angle for the antenna. It also contains a very accurate noise power measuring system (0.1-percent accuracy) to measure the noise coming from the antenna system as the "radio star" drifts though the antenna pattern in five equally spaced declination cuts. The resulting antenna–star response is fit to a three-dimensional Gaussian curve.

For broad-beam antennas, e.g., 4- to 5.5-m diameter antennas in X-band, Cas A is too faint a source, but the moon has adequate intensity. However, for the moon to be useful as a

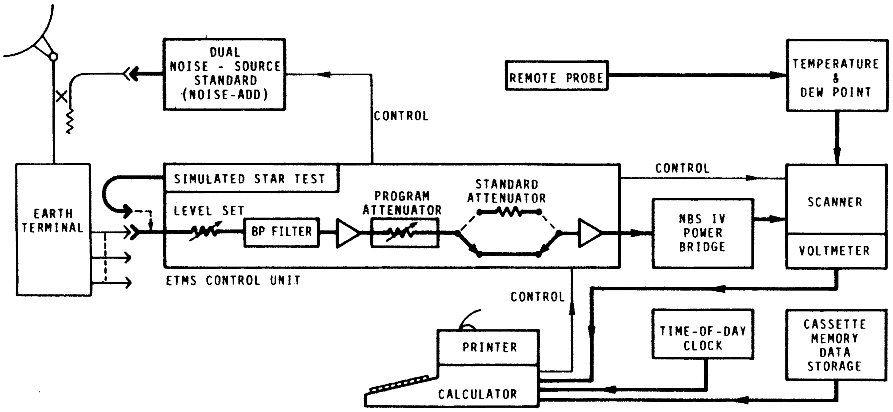

Fig. 1. Block diagram of the earth terminal measuring system.

TABLE I
STEPS IN THE MEASUREMENT PROCEDURE

STEP	PURPOSE
(PRELIMINARIES)	
1	Prepare daily data tapes, one for each measurement day
2	Validate hardware and tapes before shipping to antenna site
(DATA ACQUISITION)	
3	Validate hardware after arrival
4	Determine antenna offsets, sky profile
5	Collect data
(DATA ANALYSIS)	
6	Split multiple frequency data files into single frequency data files
7	Replace isolated bad data points
8	Obtain best fit parameters for data sets
9	Calculate G/T, etc. and plot results

source for accurate antenna system noise measurements, simple expressions for the effective lunar flux density and its shape factor are needed. This has recently been accomplished for the frequency range of 1-10 GHz, with errors in the flux density of less than 8 percent (for all phases of the moon, and for all seasonal variations in earth-moon distance), and errors less than 0.4 percent for the shape factor [6].

A. Measurement Instrumentation

The ETMS is an automated measurement system a simplified block diagram of which is shown in Fig. 1.

The ETMS contains nine subsystems: 1) a calculator which provides computation capability, a means of controlling each of the remaining subsystems under automatic sequence control, a means of storing the measurement results on magnetic tape in order to rework the data at a later time, and a keyboard to control the measurement procedures or to enter program modifications; 2) an external cassette which allows redundant recording of measurement data; 3) an NBS type-IV self-balancing power meter used to measure noise power; 4) a programmable voltmeter; 5) a multiplexer which connects the digital voltmeter to various measurement points of interest; 6) a digital clock to provide required time information to determine current star coordinates; 7) dual X-band solid-state noise source to provide a stable reference signal needed to eliminate the effects of gain fluctuations in the earth terminal; 8) an RF control unit which provides signal conditioning, system test signals, and the precision circuits which allow the calculator to control the various measuring instruments, and 9) a coaxial switch under computer control which allows the input of the RF control unit to be connected to any of three down-converters of the earth terminal.

B. Overview of Measurement Procedure

The measurement procedure of the ETMS is designed to measure G/T, NEF, and to estimate the antenna gain. The measurement procedure contains the nine steps listed in Table I.

Many of these steps are self-explanatory. In step 4, sky profile refers to a measurement of the sky temperature versus antenna elevation along the star trajectory. The sky profile is used as an additional check on the atmospheric loss.

In step 5, the measurement data are collected for G/T and NEF. A measurement set contains six cuts. For a cut, the antenna is pointed to a computed coordinate position; then a string of power measurements (typically 30) relative to a reference "noise add" signal are taken 6 s apart as Cas A or the moon drift through. One cut is taken on the cold sky about 2° away (in declination) from Cas A or the moon. The remaining cuts are spaced equidistant throughout the main beam of the antenna pattern. For the string of power measurements, the ETMS is sequentially connected to the outputs of one, two, or three different down-converters so that the information for one, two, or three frequencies are collected within one measurement set. The data are stored and G/T, NEF, antenna HPBW, and the updated antenna point offsets are calculated and printed out.

After all the data have been taken, the remaining steps may be done after leaving the measurement site. Any outliers are removed from the data sets. Then each data set is least squares fitted to a three-dimensional Gaussian curve and the values for G/T, NEF, and HPBW are calculated using the precision fit results. The last step is to plot and tabulate all of the results as a function of antenna elevation.

C. Accuracy Considerations

For the measurement of system noise, the noise from a radio star is used as a "yard stick." To obtain an accurate measurement, careful attention is given to atmospheric effects, antenna pointing, accurate noise power measurements, adequate characterization of the radio source, and careful calculation of the "star shape" correction factor. Most recently, the NBS measurements have been improved by including a more accurate procedure for measuring the increase of noise caused by the radio "star," and by developing an algorithm which enables the use of the moon as a precise noise source for broad-beam antennas.

1) Flux: Typically, the uncertainty in the accuracy of the flux of the radio "star" dominates the total measurement uncertainty unless the antenna system is just barely able to observe the radio "star" (i.e., signal-to-noise ratio of less than about 0.1) [3]. The accuracy of the flux of Cassiopeia A [4] and the moon [6] were studied is some detail by NBS.

The most careful measurement of the flux of Cas A was made at 2.3 GHz at the Jet Propulsion Laboratory [40]. This measurement of absolute flux density had an uncertainty of about 1.8 percent (1 sigma). Utilizing this result, combined with other results from the literature [41],[1] NBS uses the following algorithm for the flux density for Cas A in flux units (f.u.) [4], [5], [38], [39]:

$$S(\text{Cas}) = (3154)e^{-0.0097\tau} f^{\alpha} \tag{8}$$

where f.u. $= 10^{-26}\ \text{W}\cdot\text{m}^{-2}\cdot\text{Hz}^{-1}$, τ = the number of years since 1965.0, $\alpha = -0.792 + 0.0012\tau$, f is the frequency (GHz), k is Boltzmann's constant.

The flux density for the moon (f.u.) [6]

$$S(\text{moon}) = 7.349 f^2 T_b d_m{}^2 \tag{9}$$

where d_m is the apparent lunar diameters (deg) defined below, and T_b is the brightness temperature

$$T_b = T_{b0}\{1 - (T_{b1}/T_{b0}) \cos(\omega t - \zeta)\}$$

T_{b0} is the mean brightness temperature

$$T_{b0} = 207.7 + 24.43/f$$

$$T_{b1}/T_{b0} = (0.004212) f^{1.224}$$

$\omega = 12.19$ (deg/day), t = lunar age (days), lunar phase lag $\zeta = 43.83\ \text{deg}/(1 + 0.0109 f)$

$$d_m = 31.090/\{(r_0/a)/60.268 - 0.0166 \sin L\}$$

$$r_0/a = a_0 + (a_1/500\,000)(p - 0.5) + (a_2/500\,000)(p - 0.5)^2$$

where a_0, a_1, a_2 are coefficients given in the American Ephemeris and Nautical Almanac [42], p is the fractional number of hours from 0 hours UT to 24 hours UT on the same day.

2) Star Shape: The shape factor, denoted by k_2, corrects for the finite size of the "star." This factor is one of the multiplicative factors contained in κ of (2), which approaches unity as the "star" diameter becomes small compared with the antenna HPBW. The algorithm used by NBS to calculate k_2 for Cas A is as follows [38]:

$$k_2 = (1 - e^{-q})/(1.001\, q) \tag{10}$$

where

$$q = (D/(1.2012\, HPBW))^2$$

and $D = 0.0767°$ is the effective source diameter of Cas A.

For the moon [6]

$$k_2 = (1 - e^{-x})/x \tag{11}$$

where

$$x = 0.6441 (d_m/HPBW)^2$$

and where d_m is the apparent lunar diameter (deg) as noted above.

3) Atmospheric Effects: The atmospheric effects fall roughly into three categories; absorptive attenuation, diffusive attenuation, and refractive attenuation. These effects are small enough in the frequency range of 1–10 GHz that simple approximate algorithms for the losses, based only on local temperature, humidity, and the site elevation can be used [43]. Nevertheless, the atmospheric effects are important sources of measurement uncertainty. Particularly troublesome is the scarcity of experimental and theoretical information to predict the magnitude and the uncertainty of the diffusive attenuation [44], [45] of a signal passing through the atmosphere.

4) Curve-Fitting Accuracy: The ETMS measures the noise coming from the antenna system as the "radio star" drifts though the antenna pattern in five equally spaced declination cuts. The resulting antenna–star response is fitted to a three-dimensional Gaussian curve. The accuracy of the antenna system noise measurement is directly related to the accuracy with which the amplitude of this three-dimensional Gaussian curve can be fit, and to how adequately the Gaussian curve represents the true star–antenna convolution output. The fitting procedure is complicated by the time-varying radiation coming from the sky. This variation is caused by changes in the atmospheric conditions along the path of the antenna beam.

We made a careful study of the accuracy and adequacy of this curve-fitting procedure. The problem is complicated by the need to use only a single curve-fitting procedure and by different signal-to-noise situations. Thus the same curve-fitting routine is used when the radio "star" is small compared with the HPBW and when the "star" is nearly equal to the HPBW. Hence, the estimate of fitting accuracy must accommodate a range of possible basic shapes. In addition, the fitting routines must accommodate low signal-to-noise conditions. A complete measurement cut requires about 5 min. It is not unusual for the sky background temperature to change a few tenths of a kelvin during this time. This sky background correction for each of the five drift curves requires an additional five degrees of freedom in the curve-fitting routine. Although this improves the statistical fitting accuracy significantly, it also makes it more difficult to interpret the relationship between the statistical measure of the curve-fitting accuracy and the associated error in determining NEF or G/T.

To get a feel for the relationship between curve-fitting accuracy and measurement accuracy, actual data were fitted to different curves based on the sinc function, two different higher order Bessel functions, and the Gaussian function. The am-

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[1] Except for the constant, S_0, eq. (2), of [40, p. L12] was used to transfer Cas A flux density in time and frequency. The value used in this paper for S_0 was 3154 f.u. in order for the flux value to agree with [40].

plitude differences between the four models ranged from 0.19 to 0.24 dB over 15 sets of data taken at different elevation angles on a single earth terminal, while the typical fitting uncertainty was about 0.1 dB. By examining the plot of residuals, we determined that the sinc function was not a satisfactory model. But the Gaussian and Bessel function curves were equally valid and neither one could be selected on any statistical basis. Frankly, this was not expected. The crux of the difference was that the best fit results for the sky background differed from model to model. Although cold sky data were available for each data set and the fitted cold sky results could, in principle, be compared with actual data taken 5 to 15 min earlier or later, the natural drift in sky temperature was great enough to obscure which model gave the best cold sky fit! On the basis that all the models which had a well-behaved residual plot gave consistent results within the statistical fitting errors plus the uncertainty of the sky background, the error quoted for fitting accuracy is calculated using the statistical fitting error plus the uncertainty of the cold sky background temperature.

The ETMS measurement system affects the measurement accuracy in three areas. First is the accuracy with which the noise power from the earth terminal is measured; second is the accuracy with which the measurement system can respond to the change in power as the radio star drifts through the antenna pattern; and last is the degree of immunity of the measurement to the gain instability of the earth terminal. In the ETMS, the power is measured with an NBS type-IV power meter [46] which measures the ratio of stable noise powers to an accuracy of better than 0.1 percent. The ETMS responds to changes in power level as the star drifts through to an accuracy of better than 0.2 percent. The effects of gain variations in the earth terminal under test are suppressed by utilizing a noise-adding technique [47]. The stability of the noise source over the 30 min required to make a complete measurement set is better than 0.6 percent [48].

IV. CONCLUSIONS

The uncertainty of measuring NEF or G/T in the 1-10-GHz range for systems with antenna gains between 51 and 65 dB is typically between 5 and 15 percent. Currently, the accuracy of the measurement is limited by the uncertainty in the flux from Cassiopeia A and the moon, by the errors in calculating the atmospheric effects, and by the inaccuracy of fitting the measured results to a three-dimensional Gaussian curve.

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