Output Noise Temperature of a Waveguide Cryogenic Noise Source in W-band

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Abstract— **A waveguide cryogenic noise source (CNS) is discussed for noise temperature standards in W-band. The CNS consists of a noise pickup horn, a cavity, an electromagnetic absorber, and a liquid nitrogen container. The output noise temperature (NT) of the waveguide CNS is obtained from electromagnetic radiation of the absorber and the dissipative loss of horn. The waveguide CNS and an ambient temperature noise source serve as reference noise sources. To calibrate an unknown noise source thermal noises emanated from the CNS, the ambient temperature noise source, and the unknown noise source are measured by a dedicated radiometer. Measurement results of a commercial diode noise source are presented.**

I. INTRODUCTION

MILLIMETER WAVES are extending its applications such as automotive anti-collision radar systems and versatile imaging systems for defense, astronomy, and security. For the calibration of noise temperature (NT) transfer standards used to evaluate the noise performance of aforementioned systems, two reference noise sources operating at different temperatures are required; one is at ambient temperature and the other is at below or above ambient temperature. Among the two reference noise sources a W-band waveguide cryogenic noise source (CNS) is discussed in this paper. Specifically, the output NT of the CNS is obtained for a given atmospheric pressure and temperature. Associated uncertainty in determining the output NT is then briefly described. As a metrological application, measurement results of a commercial diode noise source are presented.

II. THE OUTPUT NT OF THE WAVEGUIDE CNS

In the early 1980s, several national metrology institutes have developed a reference waveguide CNS [1]. In this paper, we have developed a waveguide CNS for NT standards in W-band to meet some industrial applications including an automobile anti-collision radar system at 77 GHz.

The CNS consists of a noise pickup horn, a cavity, an electromagnetic (EM) absorber, and a liquid nitrogen container. The EM absorber is installed at the bottom of a metal cavity and it is maintained at liquid nitrogen boil-off temperature T_m. The wedge absorber made of silicon carbide radiates EM wave energy corresponding to liquid nitrogen boil-off temperature. The horn installed at the top of the cavity picks up the EM wave energy while the neck of the horn is kept at ambient temperature T_h by circulating temperature-controlled water. The radiated energy is then measured by a dedicated waveguide radiometer. The output NT of the CNS in use is calculated as follows and the calculated data are used as the reference NT.

The output NT of the waveguide CNS T_n is given by [2]

$$T_n = q_m T_m + \Delta T_h , \tag{1}$$

$$\Delta T_h = (1-\alpha)(T_h - T_m) , \tag{2}$$

$$q_m = \frac{x}{e^x - 1}, \quad x = \frac{hf}{kT_m} \tag{3}$$

where h is Planck constant (6.626×10^{-34} J/Hz), k is Boltzmann constant (1.38062×10^{-23} J/K), f is the frequency in Hz, and q_m is the quantum correction factor varying with frequency. In (2), α is the attenuation of the horn at an operating temperature given by

$$\boldsymbol{\alpha} = 10^{-\frac{A}{10}} . \tag{4}$$

The attenuation of the horn is then given by

$$A = \sqrt{\frac{\boldsymbol{\rho}}{\boldsymbol{\rho}_0}} K A_0 \tag{5}$$

where $\boldsymbol{\rho}$ and $\boldsymbol{\rho}_0$ (=1.7422 μΩ•cm) are the resistivity of highly pure electroformed copper, which the horn is made of, at the operating temperature and the reference temperature 300 K, respectively. The attenuation coefficient of the horn varies along the horn axis and a numerical integration is used to obtain A_0, the attenuation of the horn at 300 K [3]. Ambient temperature T_a is measured using a calibrated thermometer during measurements. In (5), K is the excess loss factor for accounting the surface roughness of the horn and the skin effect.

III. CALCULATING THE OUTPUT NT OF THE WAVEGUIDE CNS

The output NT of the waveguide CNS is calculated as follows [4]:

A) For the measured atmospheric pressure P in mmHg, the liquid nitrogen boil-off temperature is determined by a fitting formula

$$T_m = 37.6922 \cdot P^{0.1084} - 0.016 \cdot \tag{6}$$

The equation (6) has been obtained from the tabulated data [5].

B) The quantum corrector factor q_m is calculated using (3). The q_m becomes lower than 1 at a higher frequency and for lower temperature.

C) The excess NT, ΔT_h is calculated.

(a) We get the reading of the horn temperature T_h by a thermometer installed into a hole of a metal block which is fixed onto the base plate of the radiometer. The temperature of the radiometer is stabilized by circulating temperature-regulated water.

(b) Then, we obtain $\boldsymbol{\rho} (= b_0 + b_1 T_h)$, the resistivity of the electroformed copper where $b_0 = -3.290 \times 10^{-1}$, b_1=–6.904

$\times 10^{-3}$, and T_h is the horn temperature.

(c) The horn attenuation A_0 does not take into account the effect of surface roughness on the losses, estimating a loss which is lower than the actual value. Therefore, A_0 increases by a factor K as given in (5). The value K has been determined by comparing the measured and calculated (assuming no surface roughness) attenuation for a waveguide section with the same surface roughness as the horn [1].

(d) The horn attenuation at an operating temperature A is obtained by (5).

(e) The horn efficiency α is obtained by (4).

(f) The excess NT, ΔT_h is subsequently calculated by (2).

D) The output NT of the CNS T_n is obtained and the results are shown in Fig. 1 for 762.28 mmHg and 296 K.

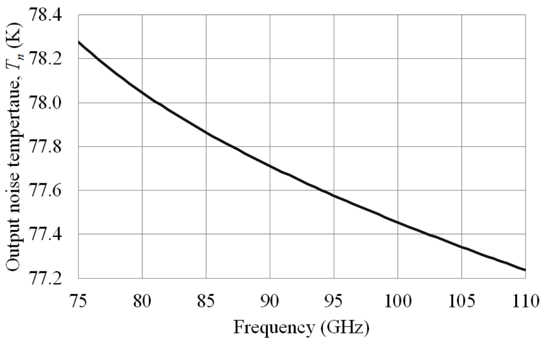

Fig. 1. The output noise temperature of the CNS.

The uncertainty of the output NT of the CNS has been evaluated according to the "Guide to the expression of uncertainty in measurement" [6] and its expanded uncertainty is (+0.37/-0.52) % at 92.5 GHz. Details on uncertainty evaluation of the output NT can be found in [4]. Note that the uncertainty in [4] has been evaluated in a classical way; i.e., the total uncertainty was obtained by just adding each uncertainty contribution. The three major sources of the uncertainty are as follows: The first is the uncertainty in resistivity used in (5) to calculate the attenuation of the horn. The horn is made of highly pure electroformed copper and its surface was not finished with gold to ensure a good estimation of resistivity [4]. The second is the uncertainty in the temperature of the microwave absorber T_m. This partially stems from the instrumentation uncertainty of a barometer. When the CNS is in use, the absorber temperature is determined by reading the atmospheric pressure by a barometer and converting to the liquid nitrogen boil-off temperature by (6). The last one is the uncertainty in the excess loss factor K used in (5).

IV. CALIBRATION OF A DUT

In order to determine the NT of a DUT, we should measure the output power of the waveguide CNS, the ambient temperature noise source, and the DUT. For this, we constructed and evaluated a W-band waveguide radiometer as briefly describe in [7]. The measured output noise powers, the calculated NT of the CNS and the ambient noise temperature are substituted into a radiometer equation [8] to obtain the NT of the DUT and the results are presented in Fig. 2 in terms of excess noise ratio(ENR) defined by

$$ENR = 10 \cdot \log \frac{T_x - T_0}{T_0},\ T_0 = 290\ \mathrm{K} \tag{7}$$

where T_x is the noise temperature of the DUT at a measurement frequency. Fig 2 shows that our results are in good agreement with those of NPL (National Physical Laboratory), United Kingdom.

V. SUMMARY

A reference waveguide cryogenic noise source (CNS) and its output NT was considered. The NTs of the CNS along with an ambient temperature noise source are used for measuring an unknown noise source. By measuring the noise powers of the CNS, the ambient temperature noise source, and an unknown noise source by a radiometer and by using the corresponding radiometer equation, we determined the NT of the unknown noise source. Measurement results of a commercial diode noise source were presented.

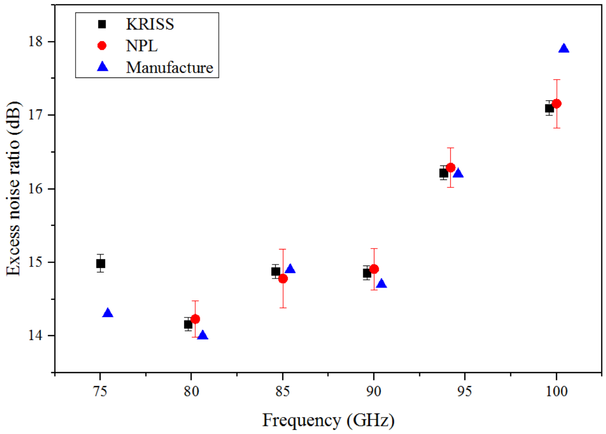

Fig. 2. An example of the calibration of a DUT using the output noise temperature of the CNS.

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