

Development of a NIST WR10 Radiometer

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Abstract — This paper describes the development of a waveguide radiometer to measure noise from millimeter wave electronic components from 75 GHz to 110 GHz. The radiometer will estimate the noise temperature of a device under test (DUT) based on comparison with room temperature and 77K noise standards. This is a standard physical approach in other NIST microwave radiometers. The radiometer is particularly amenable to performing noise temperature as well as noise parameter measurements for amplifier and transistor characterization. As wireless communications progresses towards millimeter wave systems, noise characterization of related components and subsystems becomes essential. We report our progress in radiometer design, construction and verification for millimeter wave noise metrology at NIST.

Index Terms — Noise metrology, radiometry, millimeter waves, WR10 band, waveguide radiometer

I. INTRODUCTION

The thermal noise metrology project at NIST in Boulder has a long history of applying radiometry to noise temperature measurement. These endeavors have ranged from lab-based metrology stations for the characterization of electronic noise emitted from active and passive components to blackbody reference targets for satellite-based microwave remote sensing. The present WR10 radiometer development reflects a renewed emphasis in electronic component and circuit noise characterization. This is in part due to a recent mandate to support advanced wireless communications.

A radiometer estimates object temperature by comparing the radiation it receives from this object with one or more standards. For our lab-based WR10 radiometer, the object is a one-port electronic DUT. As in other NIST microwave radiometers [1], DUT noise is compared to noise from a room temperature and a liquid-nitrogen-boiling-point standard using the same calibrated receiver. Each noise source is switched into the receiver input as shown in Fig. 1.

Usually the DUT is a diode that is designed for enhanced noise output. Once the noise spectrum from this diode is characterized with the radiometer, two-port electronic components such as waveguide amplifiers and filters can be inserted between this DUT and the radiometer receiver. In this configuration, the diode's noise can provide a unique source of broadband simultaneous frequency excitation.

When measuring noise power, the assumption of linearity is maintained by nibbling a broad noise spectrum in short

enough spectral segments to accurately estimate temperature across any peaks. With short enough spectral segments the ratio of the power to the bandwidth of these segments defines their local temperature [2]. Broadband noise from each source is downconverted in spectral segments that range from 10 MHz to 1 GHz wide. Noise power measurement per segment is slow enough to assume that equilibrium has been reached.

Peaks in the noise spectrum of an electronic device represent non-thermal variations in temperature. A focus on these peaks may provide useful information about the interplay between materials, structure and circuit topology. These effects are often attributed to circuit nonlinearity and intermodulation distortion. Injected noise may provide a much more thorough way to explore these energy dependencies. We proceed with the WR10 radiometer development by assuming that its characterization as a linear network, described above, remains a valid basis for observing non-thermal variations.

Kang et al recently reported a WR10 radiometer relying on the same physical approach of estimating DUT temperature based on room temperature and 77K noise standards [3]. Our design uses the same tuned RF receiver architecture and its characterization relies on the same theory outlined over the last 50 years. We do allow for two paths to contrast balanced versus sub-harmonic mixing, but the basic differences in sensitivity and accuracy between our radiometer and other modern designs will likely be small. The specific difference for our work comes from applying this hardware to two-port component testing and from a focus on noise spectral features for what they reveal about component performance. As a specific example, a well-characterized noise diode would provide a signal source to the input of a broadband signal amplifier DUT. The tuned receiver parses emissions from this DUT into short IF spectral segments. In this way DUT sensitivity to the simultaneous excitation of one to many simultaneous instantaneous frequencies (wavelets) in the WR10 band would be revealed in comparison with DUT noise at the same bias without noise diode excitation. The average noise level between these would be normalized, accentuating peaks and valleys. Radiometer characterization for standard operation remains fundamental to making such measurements and we plan to fully report on this at the conference. Beyond this, we hope to report on one such two-port DUT experiment performed at narrow IF bandwidth.

II. WR10 RADIOMETER

A. Design

The WR10 radiometer relies on swapping in temperature standards, T_{RT} and T_{CT} , as well as the DUT, T_{DUT} , with a 4-port rotary waveguide switch in order to piece out representative noise spectra about a given frequency in the WR10 band by mixing and IF filtering through a shared signal path. Our radiometer allows for downconversion through a balanced mixer or a 1/3 sub-harmonic mixer with a second 4-port rotary waveguide switch in order to compare these. Receiver operating temperature of $23.0^\circ\text{C} \pm 0.5^\circ\text{C}$ will be maintained with water cooling. However, during this initial checkout phase, components operate from 22.0°C to 24°C .

B. Components and Characterization

Noise temperature standards in Fig.1 are: a WR10 matched load T_{RT} , a NIST custom cryogenic standard T_{CT} that operates at the boiling point of liquid nitrogen, $77\text{K} \pm 1\text{K}$ [4] and a device under test T_{DUT} , often a noise diode.

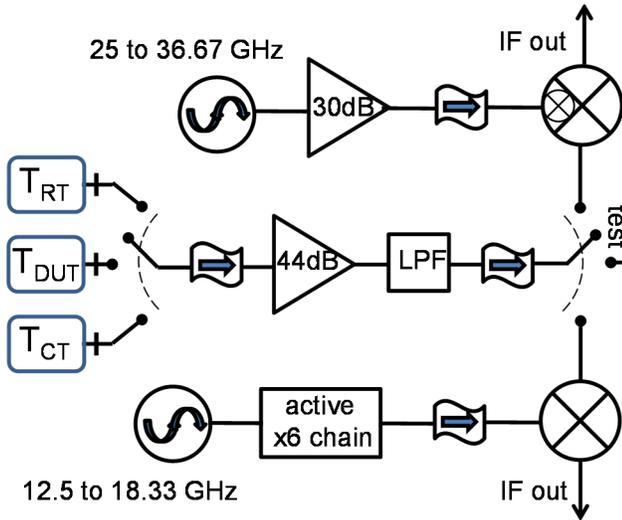


Fig. 1 Architecture of WR10 switching radiometer.

We have two diode noise sources to verify the performance of the WR10 radiometer over its operational life. The vendor specifies these to have an excess noise ratio (ENR) of 12 dB with ± 3 dB flatness across the band. As part of initial testing, the input was switched between these two noise diodes and the matched termination, directly measuring power for these connections at the point “test” in Fig. 1 with a WR10 power sensor and no added filtering. The direct ratios of measured power between each diode and the matched termination provide ENR estimates of 8.0 dB and 8.5 dB, respectively. Two amplifiers, each with an average noise figure of 5.5 dB (per the vendor’s specification) are concatenated to make up the 44 dB gain stage in Fig.1. Considering this noise figure

and overall amplification, preliminary ENR measurements are reasonable. These results confirm operation of each diode and the amplifier chain. Next steps will be to characterize the gain and noise of the amplifiers in the 44 dB chain in order to de-embedded accurate ENR values for these noise diodes, and to measure with short spectral segments using each mixer path, in order to see ENR variations.

Balanced mixer conversion loss was measured with LO consistently offset by 100 MHz from the RF. RF and LO power were monitored with couplers in these paths with these couplings accounted for. Measured IF power is shown offset by +15 dBm in Fig.3. Note that the LO signal is between -2 dBm and +2 dBm while the RF signal is between -10 dBm and -13 dBm in Fig.3. The vendor specifies an LO drive power of between 2 dBm and 4 dBm and an RF signal level of around -10 dBm to limit conversion loss to no more than 12 dB. Fig. 2 shows conversion loss of 12 dB or less up to ~ 108 GHz even at the low LO and RF powers of our initial tests.

III. CONCLUSIONS

We will report on further progress towards the full WR10 radiometer system characterization and implementation at the conference.

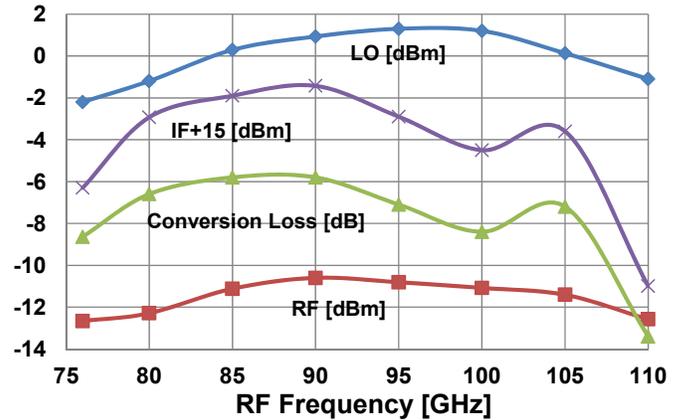


Fig. 2. Balanced mixer conversion loss for the above input powers and with sinusoidal LO less than sinusoidal RF by 100 MHz.

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