This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TTHZ.2020.3036179, IEEE Transactions on Terahertz Science and Technology

A Novel 1/f Noise Mitigation Technique Applied to a 670 GHz Receiver

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***Abstract*—In this letter, a novel 1/f noise mitigation technique is presented to improve the receiver 1/f noise performance of a 670 GHz receiver. Time domain 1/f noise corrected samples are compared with samples obtained without the correction. Spectral domain analysis shows that the 1/f noise mitigation method improves the receiver noise performance by 19 dB in the receiver under test. The presented 1/f noise mitigation technique can be applied to any direct-detection receiver in the THz frequency range.**

***Index Terms*— 1/f Noise, Calibration, Low-Noise Amplifier, Millimeter-wave Radiometer, Passive Imaging, THz Receivers**

I. INTRODUCTION

ICE clouds, covering more than half of the Earth's surface at any given time, regulate the weather and climate through radiative feedback and precipitation. The interaction of ice particles with radiation at THz frequencies strongly depends on the ratio of the ice particle size to observation wavelength. The amount of radiation received by a THz range radiometer instrument viewing the Earth is expected to decrease as a result of scattering by the ice particles in the upper atmosphere. This property can be exploited using measured brightness temperatures in the THz range to retrieve information on the size distribution of ice particles in the upper troposphere and lower stratosphere [1], [2].

Recent developments in transistor technologies have extended the operating frequency of amplifiers into the THz range [3]. This, in turn, has provided the capability of developing uncooled (non-cryogenic) THz integrated receivers for atmospheric remote sensing instruments [3], [4]. The stability, accuracy and sensitivity of these receivers are critical for the reliability and quality of radiometric data [5].

Flicker noise, often called 1/f noise, can degrade the stability of receivers by generating stationary random gain fluctuations with a spectral power density function inversely proportional to frequency [6]. Heterodyne receivers, which perform amplification at a lower intermediate frequency (IF) that is substantially lower than the RF frequency, are less susceptible to 1/f noise, but at a cost of higher power consumption and volume compared to a direct-detection receiver. Direct-detection receivers, which perform all of the amplification in the THz range, suffer from significantly higher 1/f noise [7]. As a result, high 1/f noise can be a challenge in direct-detection THz receivers, causing degradation of the radiometric performance.

The addition of a Dicke switch is useful for reducing 1/f noise in radiometers [5], [8]. However, only limited work on switches has been done at THz frequencies [9]. This, in turn, makes Dicke-switching architecture impractical for radiometry in the THz range. Therefore, a significant need exists to address 1/f noise in THz direct detection receivers.

The proposed mitigation technique relies on tracking the rapid gain variations in the radiometer due to 1/f noise and correcting them by generating a baseline state in the first amplification stage of the low noise amplifier (LNA). The proposed 1/f noise mitigation method can be applied to any receiver, but it is especially valuable for THz receivers since any switch inserted between the antenna and the low-noise amplifiers will add high insertion loss at these high frequencies, making them impractical for use in radiometric applications.

This study demonstrates a novel 1/f mitigation technique on the 670 GHz receiver of the Tropospheric Water Vapor and Cloud Ice (TWICE) 6U-Class small satellite instrument. The technology developed for TWICE is expected to enable global observations of upper tropospheric and lower stratospheric water vapor, as well as information on the cloud ice particle size distribution using submillimeter wave-to-THz channels at 240 GHz, 310 GHz, 670 GHz and 850 GHz, in addition to water vapor sounding channels near 183 GHz and 380 GHz [10].

II. THE 1/F NOISE MITIGATION TECHNIQUE

The block-diagram of the TWICE 670 GHz direct-detection receiver with the proposed technique is shown in Fig. 1. The packaged integrated receiver used in this study was designed and manufactured at Northrop Grumman Corporation [4], [11]. The command and data handling (C&DH) system shown in Fig.

Manuscript received Month, Day, 2020. This work was supported in part by the U.S. National Aeronautics and Space Administration, Science Mission Directorate, as part of the Instrument Incubator Program under Grant NNX14AK70G.

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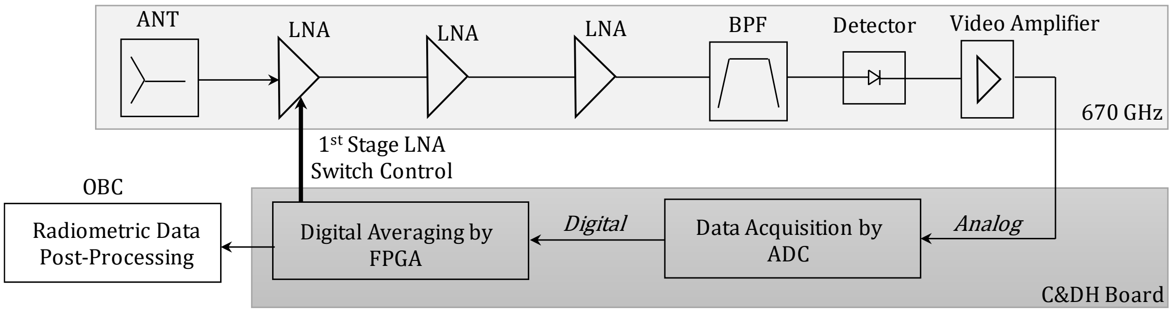

Fig. 1. Block diagram of the RF receiver showing the strategy of the 1/f noise mitigation technique.

1, designed, tested and demonstrated at Colorado State University, is used to test the receiver performance for atmospheric remote sensing applications [10]. This study focuses on the 1/f noise performance of the integrated receiver and presents a new mitigation technique.

In the diagram shown in Fig.1, the feed horn antenna receives THz radiation from the scene, which is amplified by the LNAs and bandlimited by the bandpass filter. The amplified THz radiation, which can be characterized as a scene brightness temperature, is then detected by a GaAs Schottky Zero Bias Detector manufactured by Virginia Diodes Incorporated (VDI). The analog output voltage of the 670 GHz integrated receiver is then sampled by the analog-to-digital converters (ADCs) of the data acquisition circuitry on the C&DH board of the TWICE receiver [10]. Digital averaging is performed on the digitized samples output by the ADCs before the data are sent to the on-board computer (OBC) for further processing.

All semiconductor devices have 1/f noise. In the direct-detection receiver shown in Fig. 1, 1/f noise contributors include the three MMICs (each with eight transistor stages) and the GaAs Schottky detectors. Each of these contributes to the cumulative 1/f noise of the direct detection receiver. Note that direct-detection receivers output a DC voltage proportional to the received power, and are therefore are particularly susceptible to 1/f noise. In Fig. 1, we adjust the gate bias of the first transistor stage between the on and off states of the transistor. Therefore, as graphically illustrated in Fig. 1, a switching mechanism is implemented in the receiver to switch the first transistor stage of the first LNA periodically on and off with a digital switching signal from the FPGA on the C&DH board.

In this design, gain tracking is performed by changing the state of the LNA faster than the 1/f noise gain variations to reduce the effects of 1/f noise on the resulting radiometric brightness temperatures. Therefore, two different receiver output levels, referred as LNA_{ON} and LNA_{OFF}, are generated based on the LNA switch control position as the signal switch control denoted Fig. 1. It should be noted that the radiometer does not have any reference matched load or any similar calibration source that can be measured, as used in a Dicke-switching radiometer [5], [8]. In the proposed technique, the receiver always measures only the antenna signal in both the LNA_{ON} and LNA_{OFF} states. The 1/f noise variations modulate both states of the acquisition independent of the scene currently viewed by the antenna. If the switching frequency of the first transistor state is faster than the 1/f noise frequency, receiver gain variations can be tracked by comparing the acquired samples of the two states, LNA_{ON} and LNA_{OFF} [12].

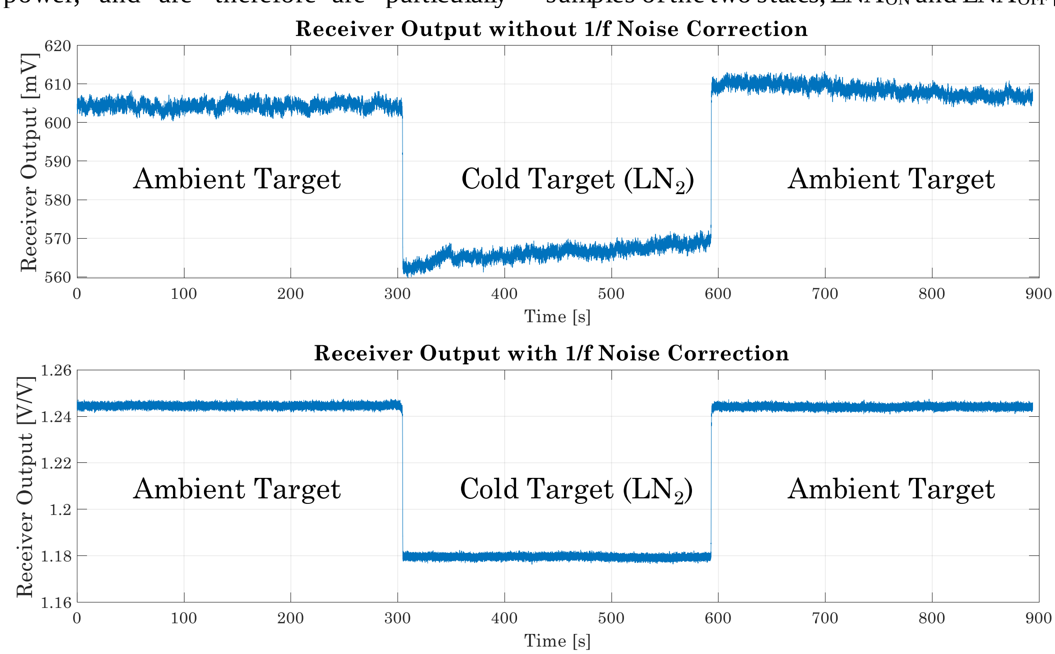

Fig. 2. The 670 GHz receiver Y-factor measurements: The receiver output without 1/f noise mitigation technique (top) and with 1/f noise mitigation technique (bottom).

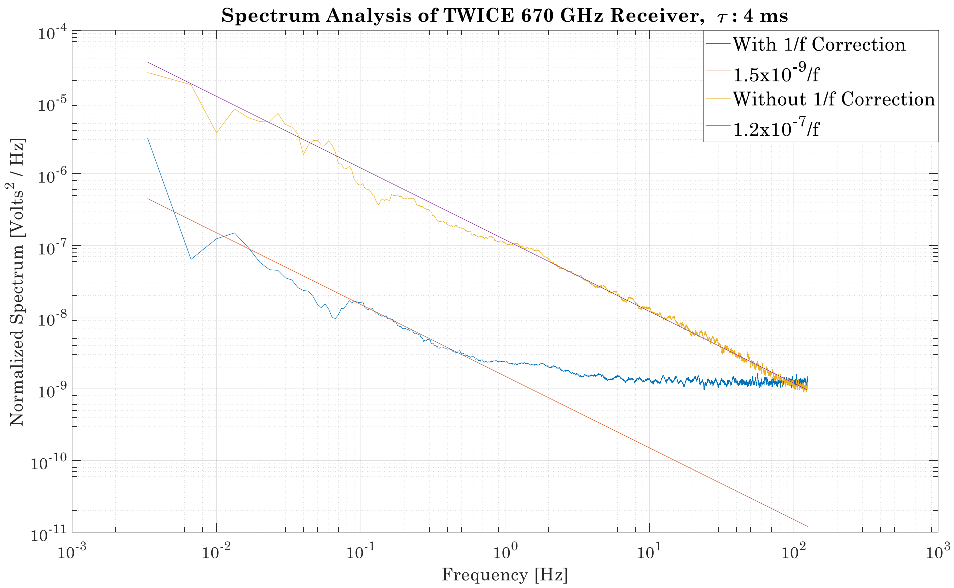

Fig. 3. The normalized PSD analysis of radiometric acquisition with and without 1/f noise correction of the 670 GHz receiver.

III. 1/F Noise Mitigation Technique Results

The described 1/f noise mitigation technique has been applied to the TWICE 670 GHz receiver. During the test, Y-factor measurements have been performed using the 670 GHz integrated receiver, while the C&DH board performs digital acquisition of the analog receiver output at 16-bit resolution and 50 kSPS sampling rate. The first stage LNA control signal is a square wave at a frequency of 5 kHz. In addition, the C&DH system synchronizes data acquisition with the receiver LNA gain stage control signal used for 1/f noise mitigation.

The upper panel in Fig. 2 shows the sampled output voltage acquired from the integrated 670 GHz receiver while the LNA switch is set to the ON state during Y-factor measurements. The antenna is viewing an ambient blackbody target at room temperature, followed by another blackbody target submerged in liquid nitrogen (LN_2) at 77 K and then the ambient blackbody target again. To apply the 1/f noise mitigation technique to the collected samples, the output voltage temperature is calculated by comparing the LNA ON and OFF state samples, as shown in (1),where Q_{ON} and Q_{OFF} are the samples acquired during the LNA first stage ON and OFF states, respectively, and M is the number of samples averaged. The corrected digitized receiver output is shown in the lower panel in Fig. 2. Based on these time series measurements, the power spectral density (PSD) curves are calculated for the receiver outputs, both with and without the 1/f noise mitigation applied. Results are shown in Fig. 3. For the uncorrected case, the 1/f noise dominates the PSD curve, in which the broadband spectrum is not visible for the half-side spectrum domain plot shown up to 125 Hz, corresponding to a sampling time of 4 ms. With the correction applied, a 19 dB improvement in the stability is shown by applying the 1/f noise mitigation technique.

$$V_{out,final} = \frac{\Sigma_1^M Q_{ON}}{\Sigma_1^M Q_{OFF}} \ [\text{V/V}] \tag{1}$$

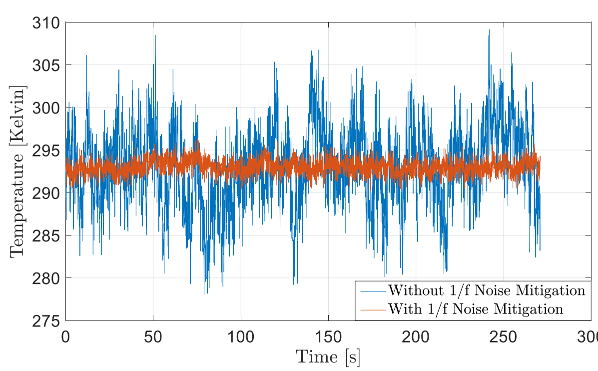

Fig. 4. The calibrated antenna temperature measurements over an ambient target of the 670 GHz.

The calibrated antenna temperature plot obtained from ambient blackbody target measurements by the 670 GHz receiver is provided in Fig. 4 for the 1/f noise uncorrected and the corrected cases. The radiometric resolution is improved to 0.88 K from 4.75 K for the case studied at 50 ms integration time. After 1/f noise mitigation, the radiometric resolution can be further reduced using longer integration times [8].

IV. Conclusions

A novel 1/f noise mitigation strategy for THz range receivers has been presented. The application of the proposed approach relies on controlling the receiver gain variation by tracking the 1/f noise in the system.

This new technique has been demonstrated using the 670 GHz TWICE integrated receiver. The 670 GHz time series measurements have shown that the technique significantly corrects for gain variations. The PSD curves show that the 1/f noise mitigation technique provides 19 dB of improvement in the radiometer receiver output. The new 1/f noise mitigation technique can provide high accuracy imaging for THz range receivers.

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