Millimeter Wave Synthetic Thinned Aperture Radiometer

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***Abstract*—Imaging of temperature and humidity profiles of the atmosphere on a global scale with high temporal and spatial resolution requires a large aperture millimeter wave radiometer on geostationary orbit. We developed a prototype 50 GHz millimeter wave synthetic aperture radiometer and Low Noise Amplifier (LNA) MMICs and receiver technology for a 180 GHz synthetic aperture system. The 50 GHz system was tested in laboratory and in field with a 4-meter target disk by refocusing the array to near-field by digital phase corrections. The 180 GHz system development included novel 180 GHz MMIC LNAs that provide more than 100 GHz of bandwidth with more than 15 dB of gain and a noise figure of 3.7 dB.**

I. Introduction And Background

ATMOSPHERIC science and weather forecasting require measurements of the temperature and humidity vs. altitude. These sounding measurements are obtained at frequencies close to the resonance frequencies of oxygen (60 and 118 GHz) and water (183 GHz) molecules. A geostationary microwave sounder is recommended in the NRC decadal survey of Earth science missions. This Precipitation and All-weather Temperature and Humidity (PATH) sensor will have a primary mission of observing hurricanes and severe storms. The Geostationary Synthetic Thinned Aperture Radiometer (GeoSTAR) concept developed under the Instrument Incubator Program of ESTO is the only sensor that can meet the PATH mission objectives. The sensor will operate in two spectral bands: near 50 GHz, with 4-6 channels, for temperature sounding and near 183 GHz, with 4-5 channels, for water vapor sounding. That will give the same functionality and capabilities as provided with current and future LEO sounders, such as the AMSU instruments. GeoSTAR uses an Y-array of correlation interferometers, and aperture synthesis to achieve high resolution, continuous, hemispheric coverage without any mechanical scanning.

II. Results

We developed a 24-receiver 50-55GHz demonstration instrument that provided technical proof that a practical system can meet calibration and performance requirements [1]. The receivers include 50-56 GHz InP MMIC LNAs and second harmonic in-phase and quadrature (I-Q) mixers that downconvert the target radiation signal to baseband. The baseband signal is amplified and digitized in 8-bit digitizers at 100 MHz clock rate. A FPGA correlator performs 2-bit cross-correlations of the digitized signals to obtain the uv-plane visibility signals. The final image is obtained by performing a Fourier transform of the visibility image. A photo of the instrument is shown in Fig 1 [2].

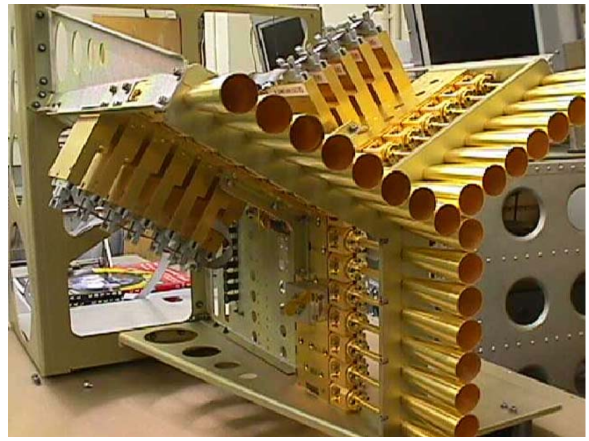

Fig. 1. Prototype instrument with 24 receivers [2].

The far-field of this demonstrator instrument is over 200 meters, which would require a target of 50 meter diameter to represent the earth view from GEO. However, simple phase corrections enabled us to operate the instrument in the near field [3]. As a lab demonstration of this capability Fig. 2. shows a photograph of a person and the corresponding received and synthesized temperature image.

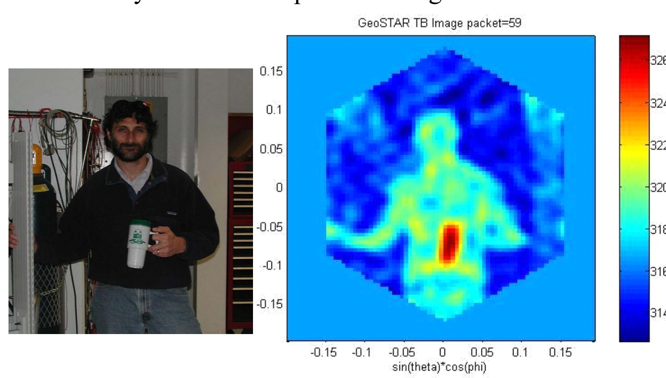

Fig. 2. Photograph of a person holding a coffee cup and the corresponding near field image synthesized at 50 GHz using the 24 receiver prototype instrument

The 30 minute image refresh rate requirement for observations at 180 GHz is challenging. We have improved the 180 GHz receiver sensitivity by developing LNA MMICs for this frequency range. The measured InP monolithic millimeter-wave integrated circuit (MMIC) amplifier had more than 18 dB of gain from 100 to 180 GHz and 15 dB of gain up to 220 GHz (Fig. 3) [4].

The measured noise temperature results are shown in Fig. 4 [5]. These results are mission enabling with measured noise temperature of 370 K at 160 GHz, which is half of the previous state-of-the-art. The graph shows noise temperature and noise figure results from 155 to 190 GHz in addition to

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the calculated gain. The circuit was fabricated in Northrop Grumman Corporation 35 nm InP high electron mobility transistor (HEMT) process

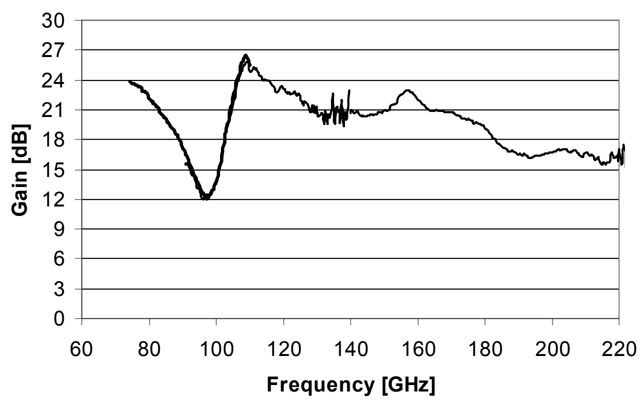

Fig. 3. The measured gain of the broadband MMIC LNA at 75 to 220 GHz frequency range [4].

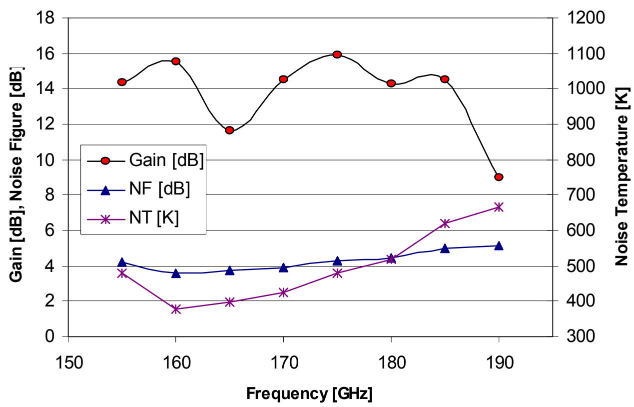

Fig. 4. Measured results for the waveguide packaged MMIC LNA. The noise temperature (NT) of this LNA is < 400 K, less than half of the previous state-of-the-art. The noise figure of the LNA is NF = 3.7 dB [5].

In space application this LNA would be operated at lower physical temperature than ambient, so we tested the noise temperature of the LNA at different operating temperatures. Fig. 5. shows the noise temperature of the LNA vs. physical temperature [5]. It is noteworthy that the expected operating temperature of the GeoSTAR receivers will be T_{phys}=240 K. At this temperature the the noise temperature of the LNA is less than the system requirement T_n=400 K within the 165 to 183 GHz frequency range. Furthermore, the LNA has less than 100 K noise temperature at cryogenic temperatures (T_{phys} = 30K) [5].

Finally, we cascaded two waveguide MMIC LNAs with a low LO power VDI diode mixer. Fig. 6 shows the measured results for this double sideband second harmonic receiver. The receiver has 15 dB of conversion gain from 165 to 183 GHz and noise temperature of 430 to 470 K over the same frequency band [5]. This receiver operated with low DC bias power (55 mW) and required only .1 mW of LO power at W-band. These low DC and LO power results are promising for the implementation of large arrays, where power consumption of the receivers and LO distribution network are critical.

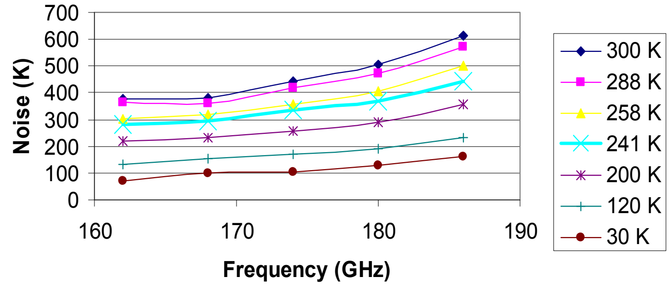

Fig. 5. Measured results for the waveguide MMIC LNA. At 241 K (expected operating temperature of the GeoSTAR instrument) the noise is less than 400K from 165-183 GHz, meeting the GeoSTAR requirement [5].

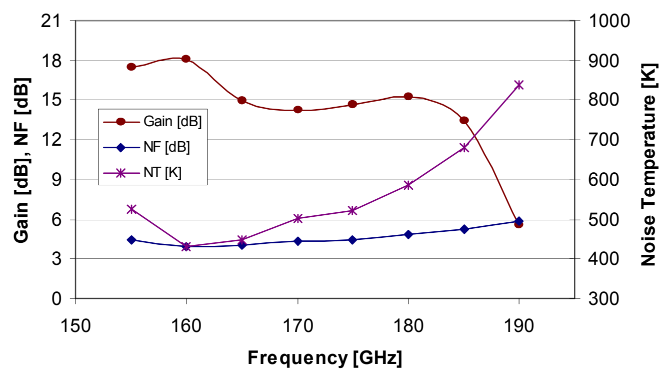

Fig. 6. Measured gain and noise of the double sideband receiver. A single sideband receiver will have same noise temperature [5].

ACKNOWLEDGEMENT

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