MIMRAM — Miniature MMIC low mass/power Radiometers for Geostationary Thinned Aperture Radiometer

P. Kangaslahti, A. Tanner, B. Lambrigtsen and D. Pukala
Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA, 91109, USA
W. Deal, X.B. Mei and R. Lai
Northrop Grumman Corporation, Redondo Beach, CA 90278 USA.

***Abstract*— We developed millimeter wave receiver technology for the measurement of hurricanes and severe storms in the weather focus area and convection and clouds in the hydrologic-cycle focus area. A 183 GHz microwave sounder is particularly well suited to address those topics – much better than IR sounders, for example, which cannot penetrate substantial cloud and storm systems. We designed 183 GHz MMIC low mass/power radiometers that enable continuous observation of the hemisphere from Geostationary orbit at 25 km resolution. Such a high resolution in combination with a short integration time is achieved with radiometer modules that have noise temperature (NT) of less than 500 K. Furthermore, these miniature modules can be integrated in arrays with 6 mm spacing that is required for Geostationary Synthetic Thinned Aperture Radiometer system (GeoSTAR).**

***Index Terms* — millimeter wave, low noise amplifier, MMIC, noise measurement.**

I. INTRODUCTION

Our instrument development answers the ESSD question "How are global precipitation, evaporation, and the cycling of water changing?" by providing 180 GHz radiometer technology needed for studies of the Global Water and Energy Cycle. GeoSTAR is the only technology that can provide a single instrument to supply all these measurement capabilities relevant to the hydrologic cycle from GEO [1]. The 180-GHz sounding band is used to obtain vertical profiles of water vapor (and to some extent liquid water). This requires a strong water absorption line, such as the one at 183.3 GHz. The sounding spectral channels are positioned in the flanks of this line (e.g. AMSU uses bands 2, 3, 7 and 17 GHz from the line), to provide a range of opacities and thus penetration depths into the atmosphere. By combining the measurements from different depths it is possible to reconstruct the vertical distribution of the absorbing/emitting water vapor. Specifically, the synthetic apertures of the instrument can be installed on the satellite without obstructing the field of view from each other or the other instruments on-board. Although the physical size of the synthetic aperture is equal to the size of a filled aperture, it is thinned and thus leaves most of the area of the aperture empty. Furthermore, the reduction of the receiving area due to aperture thinning is compensated by the simultaneous reception of all the digitally synthesized beams. This digital signal processing approach to the scanning of the aperture has the added benefit that it eliminates all vibrations and torque effects related to mechanical scanning. The lack of vibrations and torque effects provides a stable mechanical environment for other instruments sharing the same platform.

The increase in integration time per pixel in the thinned array is compensated by parallel integration of all pixels at once in the digital signal processing system. The mechanical scanning system must divide observation time among N pixels within the image, whereas the synthesis array must add N Fourier Series terms to synthesize an image with N independent pixels. The net effect is that the synthesized ΔT grows at the same rate as the scanner (by $\sqrt{N}$) in both cases.

The low noise radiometers for GeoSTAR perform low noise amplification and downconversion of the received signal to in-phase and quadrature baseband signals. This direct conversion approach minimizes radiometer complexity and enables narrowband measurements of upper and lower sideband signals. Recent technology advancement in Indium Phosphide MMIC technology [2] enabled us to design Low Noise Amplifiers (LNA) that have lower than 450 K NT at 165 to 183 GHz frequency range [3]. These LNAs also provide 7 dB of gain per HEMT amplifier stage, thus significantly reducing the DC power consumption. Furthermore, we reduced the local oscillator (LO) power consumption by implementing the latest diode technology in the second harmonic I-Q mixer. These mixers operate with less than +3 dBm of local oscillator power. The radiometer modules house two LNAs and a second harmonic I-Q mixer in a single leadframe package that weighs less than 30 g.

II. LOW NOISE AMPLIFIER DEVELOPMENT

We have demonstrated InP LNAs from 1GHz to 200 GHz examples of which are shown in Figure 1. Amplifiers have been reported even at higher frequencies [2],[4]-[6]. For this study we improved the performance of the LNA for the 166 to 183GHz frequency band in terms of noise figure, gain and DC power consumption by utilizing the latest 35 nm InP MMIC technology [2]. Fundamental to the design of low noise MMIC amplifier is the development of devices with sufficiently good gain characteristics at the targeted operating frequency. The 35 nm InP device technology epi wafers were grown by MBE and employed a pseudomorphic In0.75Ga0.25As channel, a silicon delta-doping layer as the electron supply, an In0.52Al0.48As buffer layer and an InP substrate. Room temperature electron mobility over 12000 cm2/V.s was achieved with a sheet charge of 3.5x1012 cm-2. Excellent DC characteristic of the HEMTs included a peak G_m of 2000-mS/mm (Fig. 2) and a breakdown voltage over 2.5V. The output conductance is also well controlled by a carefully optimized gate recess etch and epitaxial structure design. The gate was formed with over 80% yield and excellent uniformity [2].

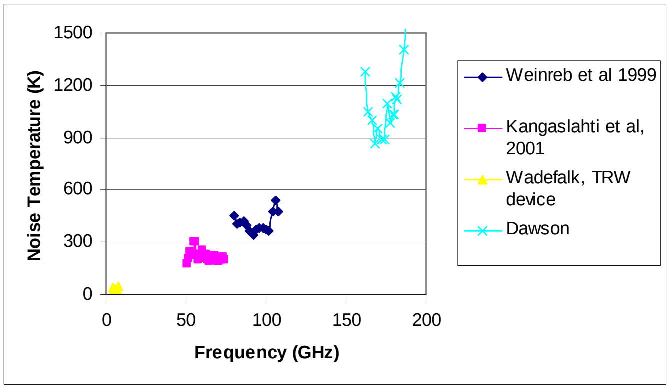

Figure 1 Demonstrated low noise amplifiers in InP technology

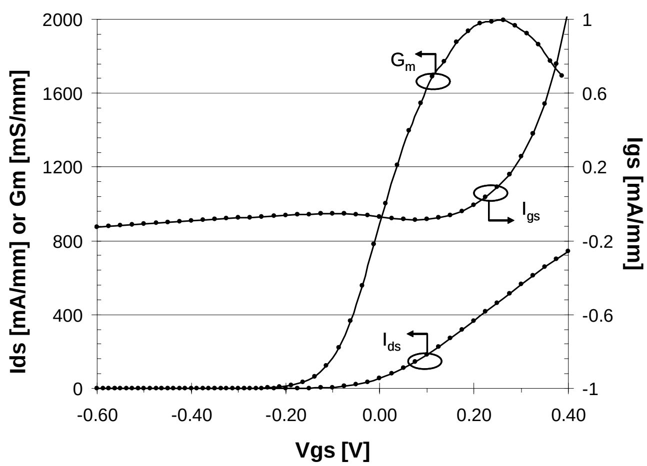

Figure 2 The measured DC G_m, I_{ds} and I_{gs} for a 40-um device.

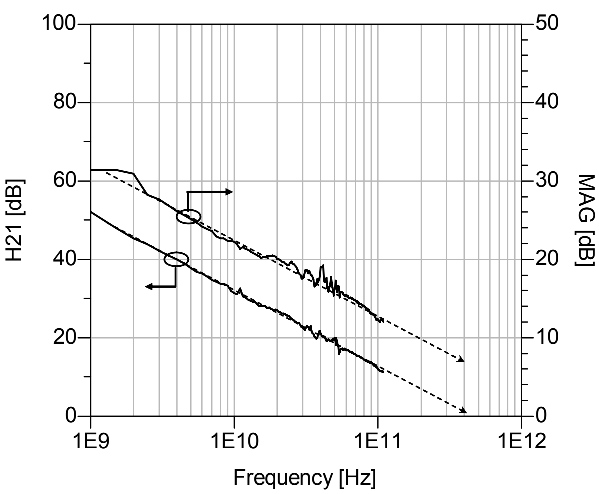

Figure 3. The measured 1-110-GHz S-Parameters of a 30-µm device at a drain bias of 1-V and 150-mA/mm de-embedded to reference plane of the device.

The result of combining the high performance epi profile and aggressive gate is a device with excellent RF characteristics. Shown in Fig. 3 are the measured H21 and MAG for a two finger device with periphery of 30-µm. The measurements were taken on an unthinned substrate with the devices in a coplanar configuration. Measurements were taken with an on-wafer extended reference plane calibration with the reference planes of the measurement placed at the device feeds. Extrapolated f_T from the H21 trace is ~450-GHz using 20-dB slope/decade and the extrapolated MAG of the device at 180-GHz is ~10-dB.

Low noise amplifiers were designed using microstrip and coplanar waveguide technologies [3]. The measured circuits had lower than 400 K noise temperature, which is more than sufficient to obtain the required receiver sensitivity (Figure 4.).

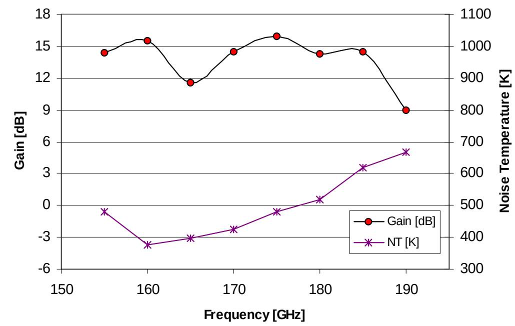

Figure 4. Measured noise temperature and gain of a waveguide MMIC LNA [3].

III. DOWNCONVERTER DESIGN

We used the same high performance NGC InP 35 nm MMIC technology that we use for LNA design to implement the second harmonic I-Q mixer. Additionally, we designed thin film mixers using low power flip chip diodes from VDI. The MMIC mixers were designed based on the principles that were demonstrated at lower frequencies [7]. Resistive HEMT mixers as the unit mixers provide low conversion loss and operate with low LO power. The resistive HEMT mixers need to be biased close to the channel pinch off condition; however, this gate bias does not draw current, so DC power consumption is minimized. On the RF side we designed a 166 to 183 GHz 90 degree hybrid using a Lange coupler. On the LO side of the MMIC (83 to 91.5 GHz) we divided the power to both mixers and designed a balun to convert from single ended mode to a balanced mode to drive the single balanced unit mixers. We achieved this by using the previously demonstrated double spiral inductor structure that has been measured to work resonance free up to 95 GHz [8]. Low power diode mixer was also designed based on VDI low power mixer diodes. Besides the diodes, VDI integrated the same diodes in a second harmonic waveguide mixer that operates with .1 to .5 mW of LO power.

IV. MINIATURE RADIOMETER MODULE DESIGN

We have extensive experience of the split block packaging technology and have recently developed platform package MCMs suitable for automated assembly. In this study we extended the frequency range of the automated assembly type of packaging to 180 GHz to be able to produce low mass and low cost modules for large arrays. A leadframe type of package, as shown in Figure 5 was better suited for this application. A baseplate with the machined cavities for the MMICs, waveguide feedthrus and bias connections will be attached to the leadframe. The MMICs will be assembled and wirebonded using ribbon for the millimeter wave connections. A lid will close the MMIC cavities and furthermore provide a backshort for the waveguide transitions. This single leadframe package will contain all the millimeter wave functionality of the downconverter as is shown in the block diagram of Figure 6. The RF input is WR-05 waveguide and it is followed by two low noise amplifier MMICs. The IQ mixer MMIC will downconvert the signal to a DC to 10GHz IF frequency that will be output through the leads of the leadframe. On the LO side we will use commercially available buffer amplifier MMICs to provide the required LO drive signal to the mixer. The LO signal will be provided through a WR-10 waveguide input.

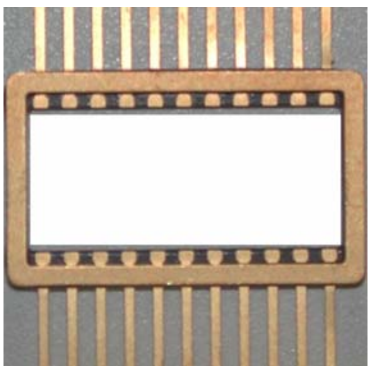

Figure 5. Leadframe package for integrating the 180 GHz receiver shown in Figure 6.

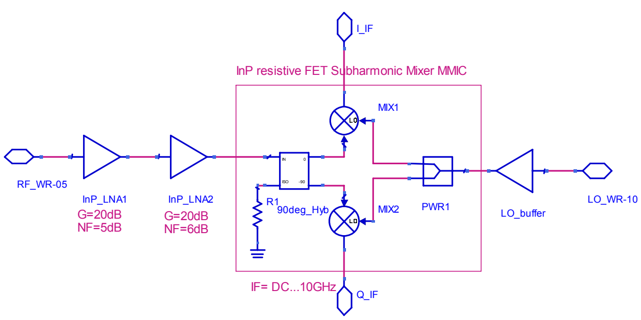

Figure 6. The block diagram of the 180GHz receiver.

V. Array Integration

The development of the MMICs and leadframe package technology will be followed by design of the IF and baseband circuitry using PCB surface mount technology. We will base the design on commercially available Silicon Germanium (SiGe) MMICs that are surface mountable devices (SMD). The functionality will include a direct to baseband conversion at 165 to 183 GHz frequency range. The LO can be tuned to the required channels within that range to sample the 200MHz total bandwidth (upper and lower sidebands). However, to shorten the measurement time, it is highly desirable to add additional channels that can be sampled in parallel. For this end we will take advantage of the wide IF frequency range of the developed miniature 180 GHz downconverter and use the image frequency separating capabilities of the I-Q mixer to perform second downconversion of the upper sideband (USB) and lower sideband (LSB) signals separately. With commercially available SiGe amplifier and Gilbert cell downconverter MMICs we can currently implement parallel reception of channels up to +/- 3 GHz of the center frequency. In this configuration we can receive five 200 MHz channels in parallel, e.g. 182, 180, 179, 178 and 176 GHz. If we switch the main LO frequency from 89.5 GHz to 84.5 GHz, we can receive the channels 166, 168, 169, 170 and 172 GHz. The reception frequencies are not limited by filtering, so the instrument can be programmed to receive different combinations of frequencies. A further advantage of this architecture is that the number of implemented parallel receive channels can be increased or decreased in the instrument development phase depending on the available DC power or alternatively a number of parallel channels could be implemented but only a few of them would be turned on at a time based on observation needs. The low IF frequency range, elimination of filtering and programmable receive configuration are the main benefits of this receiver configuration in comparison to a filtered single sideband receiver.

The compact design of our radiometer modules enables us to integrate receivers in the array with the 6 mm spacing required for GeoSTAR (Figure 7). The high receiver density requires population of both sides of the waveguide plate and staggering the receivers. We will compensate for the difference in the RF path lengths in the IF circuits.

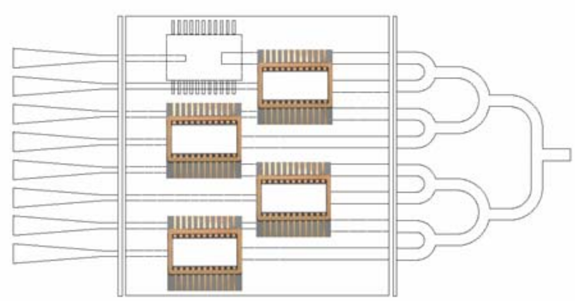

Figure 7. Integration of the MIMRAM miniature modules in an array with 6mm spacing

VI. Conclusion

Miniature 166 to 183 GHz MMIC radiometer modules were designed in this study. We have measured less than 400 K noise temperature for the LNA in this frequency band. This module technology enables 180 GHz receiver arrays for future synthetic thinned array radiometers (GeoSTAR).

VII. Acknowledgements

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