National Aeronautics and Space Administration

Cold Capable Low Noise Amplifier for Deep Space Radar and Communication Application

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Program: SURP

Project Objective:

The objective of the proposal was to evaluate and deliver the latest SiGe (Silicon Germanium) technology based hetero-junction bipolar transistor (HBT) and low noise amplifier (LNA) for designing radio frequency subsystems of radar and communication systems capable of operation and performance in harsh radiation environment and cryogenic temperature.

Samples:

To understand the interaction of simultaneous cryogenic temperature and gamma radiation on SiGe transistors and low noise amplifier, three test boards were developed. The test boards each with HBT and LNA were used in three in-situ tests. To accomplish the goals of this task, we had to meet the following milestones: 1- Selecting HBT and LNA from SiGe fabrication processes. 2- Development of three PCB's (printed circuit boards). 3- Room environment testing. 4- In-situ testing and measurements of HBT and LNA in presence of radiation while in cryogenic temperature. 5- Repeating the in-situ test for three sample boards. 1st figure illustrates the PCB development. 2nd figure illustrates one PCB viewed through test chamber window. 3rd figure is block diagram of sample board.

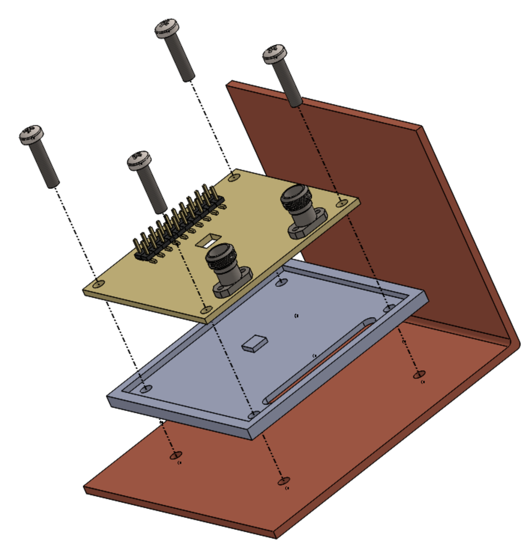

Figure 1: PCB (top), aluminum interposer (middle), cold plate (bottom)

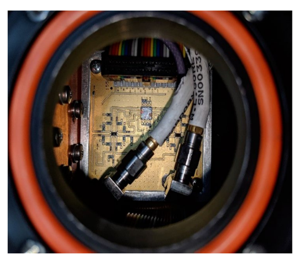

Figure 2:PCB viewed through test chamber window.

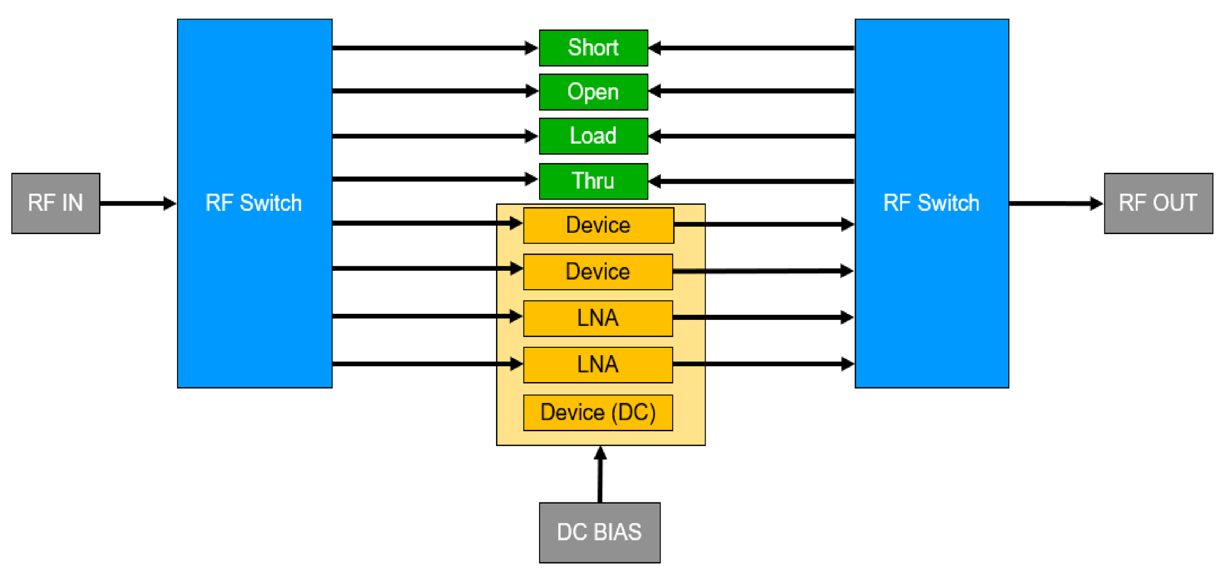

Figure 3: Sample board

Results:

- The forward and inverse Gummel characteristics of HBTs for pre- and post-radiation are shown in Figure 4. As the temperature decreases, the slope of the IV (current vs voltage) characteristics increases because there is an exponential relationship between temperature and the amount of current owing through the device at a given voltage. It is more pronounced in the inverse Gummel, but it seems that the same amount of damage (density of traps) has less effect in leakage current at lower temperatures.

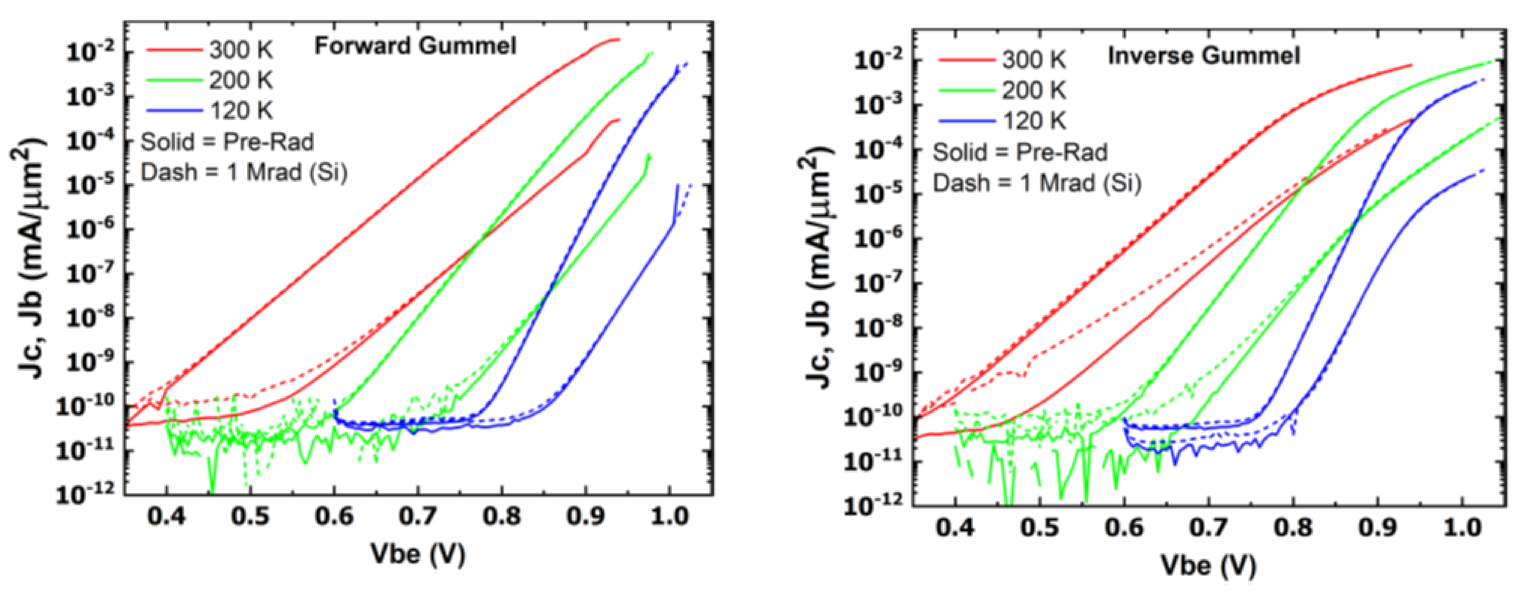

Figure 4: Comparison of (a) forward and (b) inverse Gummel characteristics over temperature. The inverse Gummel shows more when damage measured at 300 K, but at 120 K almost all of the damage is hidden.

Results:

- Shown below (Figure 5) are the results of pre- and post-radiated measurements of the S21 parameter (i.e., gain) of two LNAs. One thing that is very evident is that the gain of the LNA actually increases as the temperature is decreased. This is known and can be explained by the increased performance of SiGe HBTs at low temperatures (i.e., gain, fT , fmax). The damage created by 1 Mrad (Si) of TID in the LNAs, however, shows that there is negligible degradation in the LNA performance.
- One of the most important parameters of LNA performance is how much noise the LNA itself produces on top of a signal, namely, its noise figure (NF). Less NF is obviously better. Shown in Figure 6, is the NF. Measurements. Similar to the gain explanation, the NF reduces as the LNA is cooled; again, this is mainly due to the improvement of device noise performance with decrease in temperature. It is also tempting to say that the NF changes with TID. However, a closer look will show that there is no statistically significant deviation from pre-radiation NF to post-radiation NF.
- Other important LNA parameters are third order intercept (IIP_3) and 1dB compression point (P_{1dB}). Figure 6 illustrates that IIP_3 degradation is negligible at 120K temperature but improves a little after radiation, compared to when it is irradiated at 300K. The P_{1dB} compression point improves a bit at 120K temperature but degrades due to radiation. Overall the change is negligible..

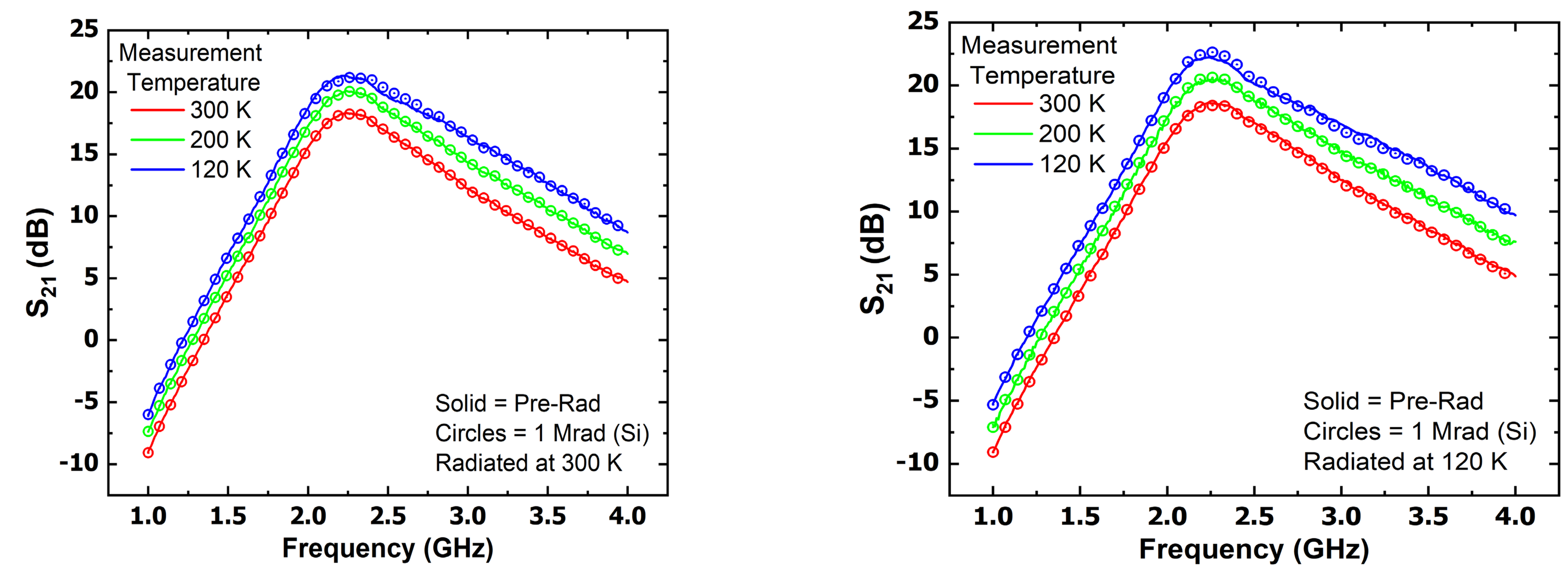

Figure 5: Comparison of LNA gain when irradiated at (a) 300 K vs (b) 120 K.

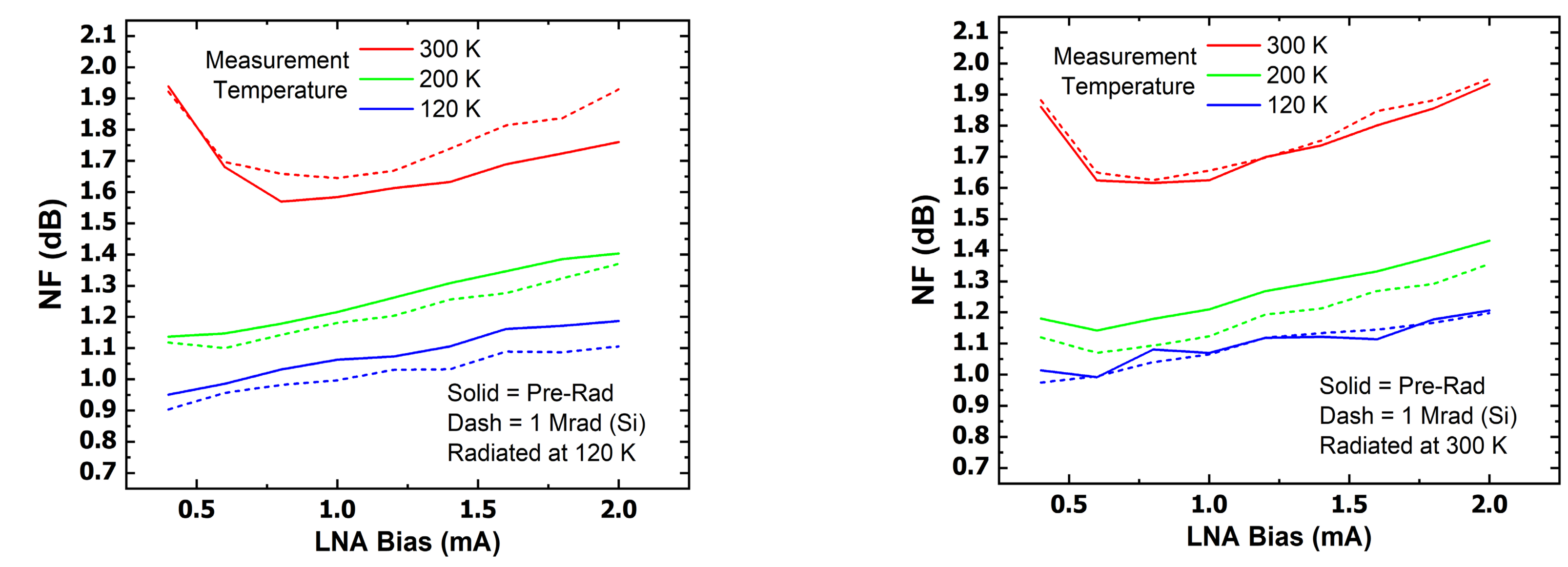

Figure 6: Comparison of LNA noise figure when irradiated at (a) 300 K vs (b) 120 K.

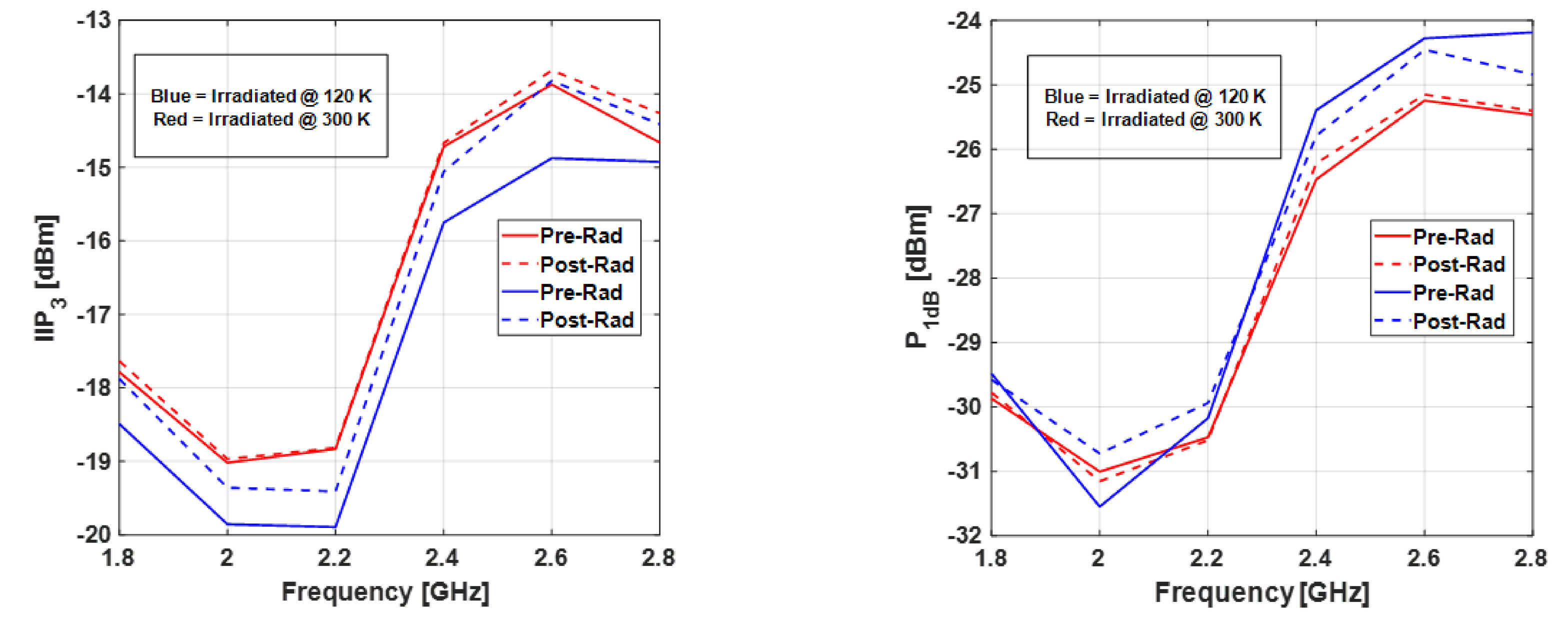

Figure 7: Comparison of LNA linearity when irradiated (1Mrad) at (a) 300 K vs (b) 120 K.

Benefits to NASA and JPL:

- This result signifies that current Global Foundry HP9 SiGe technology has the potential to be used to develop RF circuits that operate in 120K temperature and 1Mrad radiation without a need for legacy warm box that is generally used in space crafts. This is a significant accomplishment and encouragement for extending the development to a cold capable transceiver for infusion into JPL and NASA missions.
- Due to low power consumption of SiGe, its high integration capacity, and absence of thermal management system (e.g. heaters), SWaP of RF signal chains can be improved significantly. This SWaP improvement enables miniaturization of a number of subsystems and enables missions that were not possible before with added scientific capability:
  - It supports the NASA and JPL strategic vision for building highly miniaturized and revolutionary technology for exploration of NASA desired targets. The desired space targets may be Earth orbit or deep space.
  - This task demonstrates potential for new avenues in implementing small robots and satellites or a constellation of them, formation flying space crafts and instruments, instruments for EELS (Exobiology Extant Life Surveyor) that will be accessing under ice habitable oceans of the solar system, radars (sounder, doppler, passive, W-band landing radar, etc..), communication systems, and radiometers.
- Today's space electronics commercial off-the-shelf market offers parts immune to radiation levels only up to 10s to 100s of krad levels, and have limited RF capability, and no data sheets for temperatures beyond -55 ˚C to +125 ˚C. => Serious constraint for minimizing SWaP. This task extends state-of-the-art by opening up the potential for cold-capable qualified space electronics market using SiGe's process potential to offer multiple orders of magnitude better total dose radiation immunity, and a temperature range that can be from 1K to 400K.

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