

Low Power Silicon Germanium Electronics for Microwave Radiometers

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Abstract—Space-based radiometric observations of key hydrological parameters (e.g., soil moisture) at the spatial and temporal scales required in the post-2002 era face significant technological challenges. These measurements are based on relatively low frequency thermal microwave emission (at 1.4 GHz for soil moisture and salinity, 10 GHz and up for precipitation, and 19 and 37 GHz for snow). The long wavelengths at these frequencies coupled with the high spatial and radiometric resolutions required by the various global hydrology communities necessitate the use of very large apertures (e.g., >20 m at 1.4 GHz) and highly integrated stable RF electronics on orbit.

Radio-interferometric techniques such as Synthetic Thinned Array Radiometry (STAR), using silicon germanium (SiGe) low power radio frequency integrated circuits (RFIC), is one of the most promising technologies to enable very large non-rotating apertures in space. STAR instruments are composed of arrays of small antenna/receiving elements that are arranged so that the collecting area is smaller than an equivalent real aperture system, allowing very high packing densities for launch. A 20-meter aperture at L-band, for example, will require >1000 of these receiving elements. SiGe RFIC's reduce power consumption enough to make an array like this possible in the power-limited environment of space flight.

An overview of the state-of-the art will be given, and current work in the area of SiGe radiometer development for soil moisture remote sensing will be discussed.

I. INTRODUCTION

The global hydrological cycle ties the Earth's lands, oceans, and atmosphere together into an integrated physical system. Global soil moisture is critical to understanding and predicting potential changes in climate and in terrestrial ecosystems, to the mitigation of natural hazards associated with floods and drought, and to the environmental applications that are dependent upon water-related land-surface processes. Observation of soil moisture is based on relatively low frequency thermal microwave emission at L-band (1.4 GHz). The long wavelengths at these frequencies

coupled with the high spatial (i.e. 10km) and radiometric resolutions required by the various global hydrology missions necessitate the use of very large apertures (e.g., >20 m) [1]. Synthetic Thinned Array Radiometry (STAR) is the most promising technology to enable very large non-rotating apertures in space.

The L-band soil moisture measurement spatial resolution requirement and the constraints of a space flight mission result in the instrument requirements shown in Table 1. A STAR instrument will require as many as 1000 receivers, which leads to a receiver power consumption of < 0.25 W. At L-band and above, the only receiver options are Gallium Arsenide (GaAs), Indium Phosphide (InP), and a new technology, Silicon-Germanium (SiGe).

II. SIGE ELECTRONICS

Silicon-Germanium (SiGe) Hetero-Junction Bipolar Transistor (HBT) technology is a new process that has extended the performance of silicon BiCMOS technology. The developments in SiGe have been driven by the desires of commercial communications manufacturers for wide bandwidths and high integration capability. SiGe competes directly with GaAs for the bulk of the consumer communications electronics market for frequencies up to 5 GHz. In this range of frequencies SiGe has the advantages of a single power-supply, lower turn-on voltage, lower power consumption, lower 1/f noise, better process control, and the economies of scale from being able to run in a silicon fabrication line [3]. In addition to the above advantages, SiGe adds the capability to be integrated directly with low power high speed CMOS devices for high speed RF mixed signal application such as Analog to Digital (A/D) converters, Phase Locked Oscillators (PLO) on a single chip, and integration of many of the components of a complete receiver on a single chip, for system-on-a-chip circuits. These advantages make SiGe an important technology for space flight remote sensing instruments.

III. L-BAND RADIOMETER

For the reasons listed above, SiGe was selected as the basis for the L-band radiometer for this work. In addition to the

TABLE 1

INSTRUMENT REQUIREMENTS FOR SOIL MOISTURE MEASUREMENT

Frequency	Polarization	Power consump.	Noise temp.	Antenna Size
L-band, C-band	H,V	< 400 W	< 250 K	>25 m

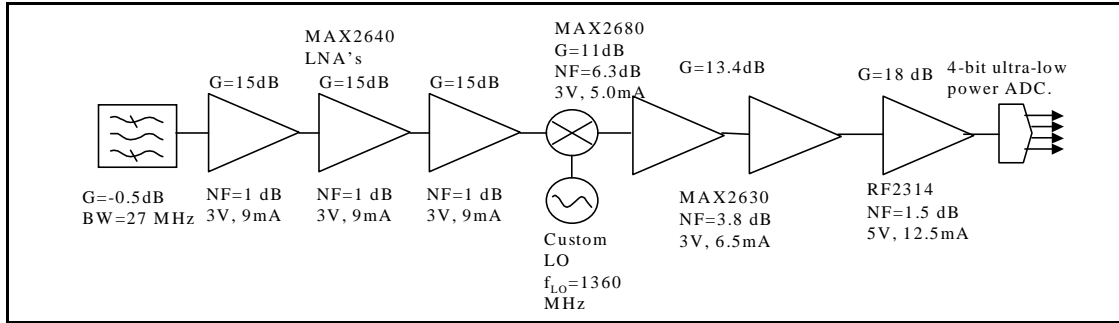


Fig. 1. L-band radiometer block diagram

TABLE 2
RADIOMETER COMPONENT PERFORMANCE

Element	Number	Gain (ea. dB)	Noise Figure (dB)	Power Consumption (ea. mW)
LNA's	3	15	1	27
Mixer	1	11	6.3	15
IF amps	3	13.4	3.8	19.5
Local Osc	1	NA	NA	27

power consumption and center frequency requirements listed above the L-band receiver should have a bandwidth of 25 MHz and a system noise temperature of less than 250 K. Figure 1 shows a block diagram of the SiGe L-band radiometer. It is largely based on a series of parts from Maxim Integrated Products, Inc. of Sunnyvale, CA. These products provide all of the building blocks for low noise receivers that cover DC to 6 GHz. These building blocks have built in biasing and some internal matching to 50 Ohms. Since this family of parts was designed to be attractive to the portable consumer electronics markets they were designed to be very low power consumption. Table 2 shows the performance of the various parts of the block diagram. The total power consumption is estimated to be 265 mW.

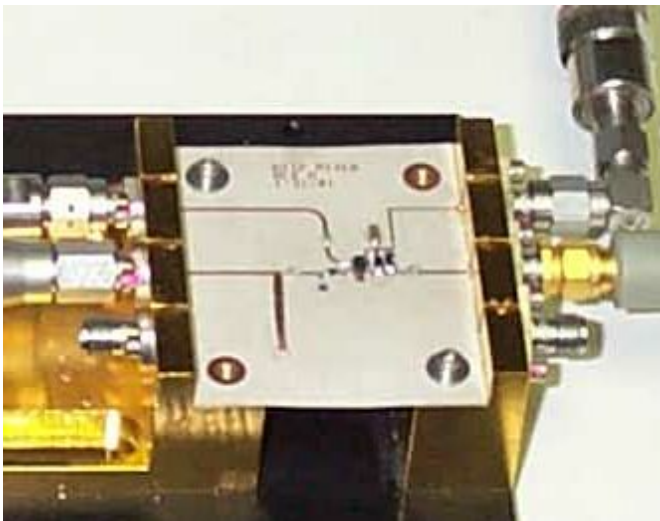


Fig. 2. L-Band mixer mounted in microwave test fixture

Layouts have been designed for the mixer, the LNA's and the IF amplifiers. Figure 2 is a photograph of the L-band mixer in the standard microwave test fixture. These layouts are done on Rogers Duroid 6002 0.01-inch thick substrate using microstrip circuit techniques.

IV. TEST RESULTS

Figures 3 shows the results of testing that was performed on the LNA vs. the simulation data. The mixer has also been designed and tested. It has a conversion gain of 6 dB, RF return loss of 7 dB and IF return loss of better than 10 dB over 32 MHz bandwidth. These numbers and the measured power consumption all match well with the published data from the manufacturer. The gain and conversion loss difference are most likely due to some losses in the substrate material and mismatches in the circuit design. A second iteration and a smaller layout should improve these results. The designs of the IF amplifier and the local oscillator are not complete and the noise figure of the LNA has not yet been tested.

V. CONCLUTIONS

The preliminary results of this work indicate that SiGe is a good technology for use in microwave remote sensing instruments below 6 GHz. The power consumption and low noise figure make them attractive as an alternative to the

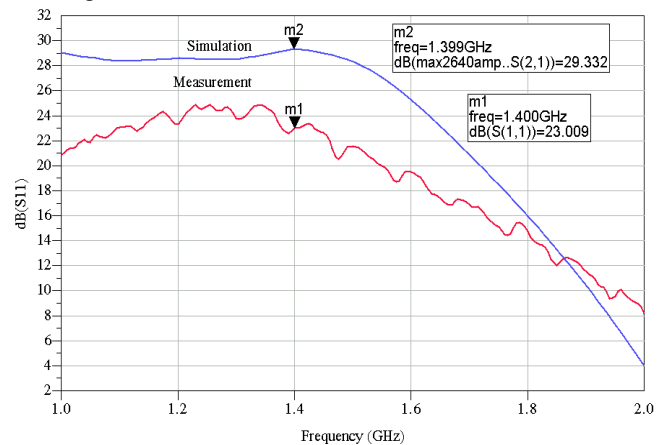


Fig. 3. LNA Measurements vs. Simulation Results

more expensive GaAs. The ability to integrate CMOS circuits onto the same wafer as the SiGe HBT and produce SiGe BiCMOS circuits opens the real possibility of the radiometer on a chip. Future efforts will investigate the short and long term stability of SiGe receiver components, the possibility of using SiGe for low power wideband A/D converters, and the integration of Micro-Electro-Mechanical (MEMS) devices onto the same wafer as receiver components to allow components like switches and filters to be on chip with the receivers.

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