Power and Performance Analysis for a Small L-Band Total Power Radiometer

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Abstract

This paper presents the design and development of a portable, ultra-low power and compact total power L-band radiometer based on an ARM A8 embedded microprocessor, with focus on the digital receiver and signal processor. This study shows a significant tradeoff between power consumption and algorithm performance limiting the processing capability and the system flight time. The processing algorithm, based in C, was tested for different clock frequencies, and high-level software optimizations were applied to reduce the power down to 2 W. The system was tested with different integration times, and clock frequencies, and it was found that the power consumption varies inversely proportional with the integration time and the processing speed, but the measurement resolution was not significantly affected (ΔT< 2 K). Moreover, this approach allows finding the optimal point of work between power consumption and algorithm performance for portable radiometers. Fig. 1 summarizes the values of power consumption at 10 MS/s for each high-level optimization at different clock frequencies and Fig. 2 shows significant reduction in power while the algorithm execution time increases, which unfavorably affect the scan velocity and processing speed of the system. The total size of the radiometer, including the antenna array is 30cm x 30cm x 10cm allowing these systems to become portable, low cost, and be carried by small drones to scan a large area. The physical system, including the L-band antenna array is shown in Fig. 4 and Fig. 5. For a radiometer flying at 8 m/s for 30 min, with a footprint of 60 m x 60 m, the power consumption is calculated for a sampling speed of 10 MS/s, and τ=4 ms. For a clock speed of 300 MHz, the calculated energy consumption is 1.5 Wh, while scanning 200 footprints. If the clock speed is 1 GHz, the energy consumption is 2.2 Wh, while scanning 410 footprints.

Introduction

Microwave radiometers are very important in applications such as agriculture, drought monitoring, water resource management, and assessing vegetation health [1]. In weather forecasting, satellite radiometric data helps in the prediction of hurricanes and climate changes, such as "La Niña" phenomenon. The radiometers systems are sizeable; they weigh tens of kilograms, consume large amounts of power, and have limitations of mobility and portability, like the ones shown in [1] and [2], powered by 220 VAC, that affect the data acquisition in the field, and the resolution and quality of the data [2]. Few works have focused on reducing the size, weight, and power consumption of microwave radiometer systems. The end goal of our project is the design of a low size, weight and power (SWaP) dual-band microwave radiometer (L/Ka-bands) for ocean salinity and soil moisture measurement applications, that can be mounted on a compact UAV. In [3] we presented the concept for the shared-aperture, dual-band antenna to be used in the final system. Since the 1.4-1.427 GHz and the 31.3-31.5 GHz bands have all emissions prohibited worldwide, and the 31.5-31.8 GHz band has all emissions prohibited in the Americas, we selected them for our system. This paper presents an approach to design a low (SWaP) digital receiver for a compact L-band total-power radiometer. The processing module is based on embedded systems with C programming on Linux OS. This prototype serves as the first stage of our system development, as a proof of concept for the dual-band system.

Information charts

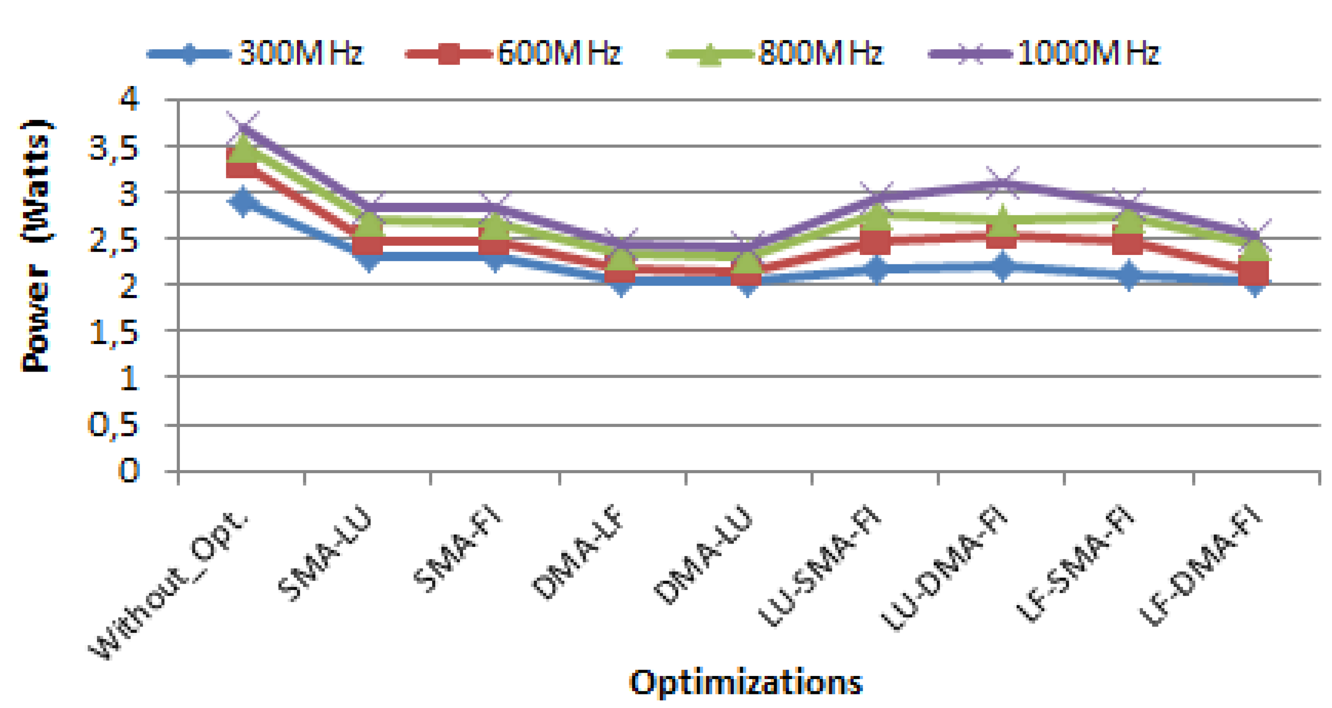

Fig. 1 Power consumption vs high level optimizations at different clock frequencies

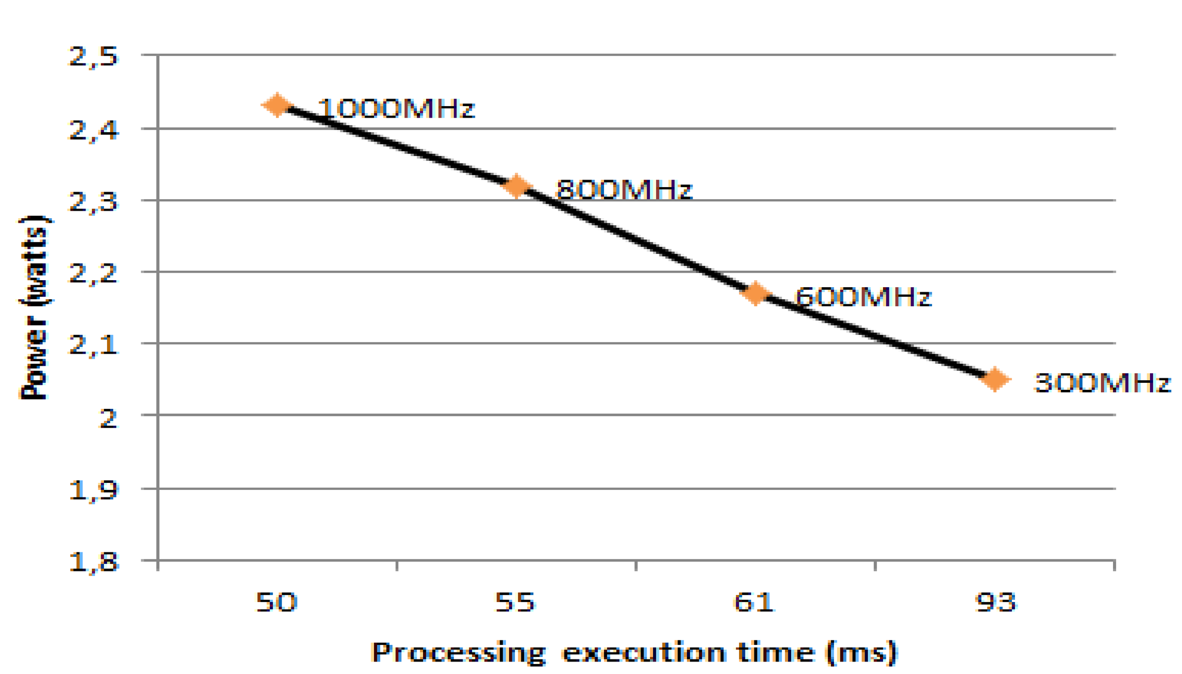

Fig. 2 Power consumption vs. algorithm execution time at different clock frequencies with DMA-LF optimization

The proposed L-Band Total Power Radiometer

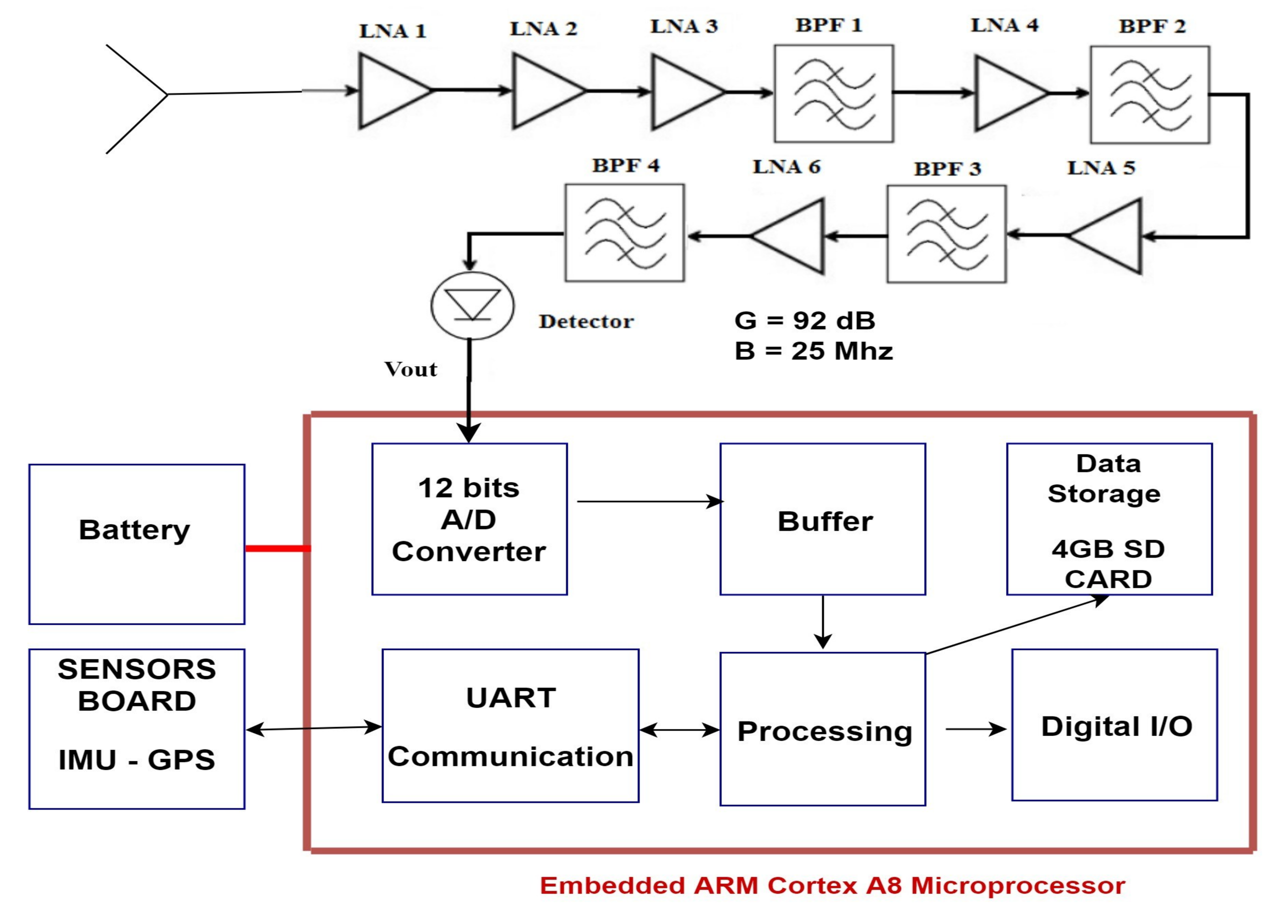

Figure 3, Block diagram of the proposed radiometer system

The block diagram of the L-band total power radiometer system is shown in Figure 3, where the core is an ARM A8 microprocessor running at 1.0 GHz. The ARM A8 performs the data acquisition, buffering, processing and storage. It runs embedded Debian Linux V.8, and its internal analog-to-digital converter has 7 channels at 12 bits, with a maximum sampling rate of 10 MS/s. The data is buffered into a dynamic array with capacity for 400 integer values. After processing, the data is stored in an expandable 4 GB SD-card. The system has a sensor board to correct the errors in the data acquisition of signals due the UAV movement and vibration, it includes an Arduino Atmega328 microcontroller, a GPS receiver, a high precision atmospheric pressure sensor module (GY-BME280), and the MPU 6050 (6-axis IMU sensor). This architecture is designed to supplement the information provided by the UAV.

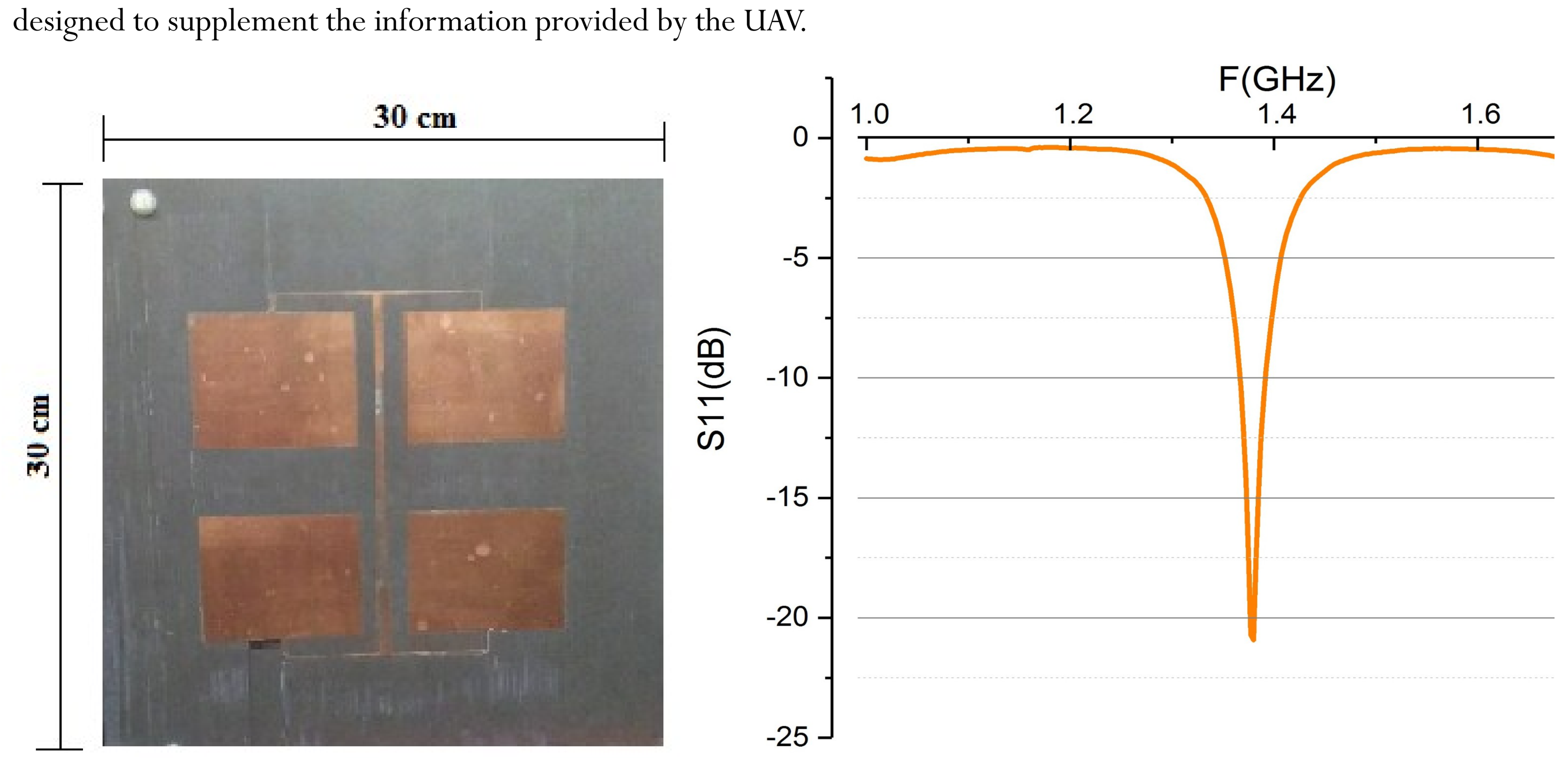

Figure 4. L-band antenna array (left) and input reflection coefficient (right)

The microwave emissions from the surface are received by the antenna, and filtered and amplified by the microwave receiver. An envelope detector is used to bring the received signal frequency to an intermediate frequency. The power at the input to the detector is

$$P = K(TA + T'REC)BG \qquad (1)$$

where K is the Boltzman's constant, TA is the antenna temperature we wish to determine, $T'REC$ is the receiver noise temperature with transmission line losses, B is the bandwidth, and G is the gain along the signal path. The antenna is a 2x2 array of microstrip patches with a gain of 12.06 dB, efficiency η_b= 97.34%, 3dB beamwidth of 46 degrees, bandwidth B = 25 MHz. The array size is 30 cm x 30 cm, including the ground-plane, and the material used was Rogers RT Duroid 5880 with ε_r=2.20. For a UAV flying at 60 m, the antenna footprint will be about 60 m in diameter. Fig. 4 shows a photo pf the array and the input reflection coefficient. The L-band front end is composed by high gain chain of low noise amplifiers (G = 92 dB) and band pass filters to attenuate out-of-band frequencies.

Results

Fig. 5 shows the physical proof-of-concept system, where the sensor board, battery, DC to DC converters and ARM A8 microprocessor are on the bottom, and the RF front-end with the antenna are on the top. The size of the system, including the antenna, is 30 cm x 30 cm x 10cm, the cost including all components was $400, and the weight is 982 g, including a LIPO battery of 3600 mAh at 14 V. Fig. 1 summarizes the values of power consumption at 10 MS/s for each high-level optimization, with different integration times. It is clear that the lowest power values were for DMA + LF with 1.52 W. DMA manages memory more efficiently, releasing the memory allocations once they have been used, and LF reduces the number of long jumps, replacing them with shorts jumps, which are less power expensive at low-level.

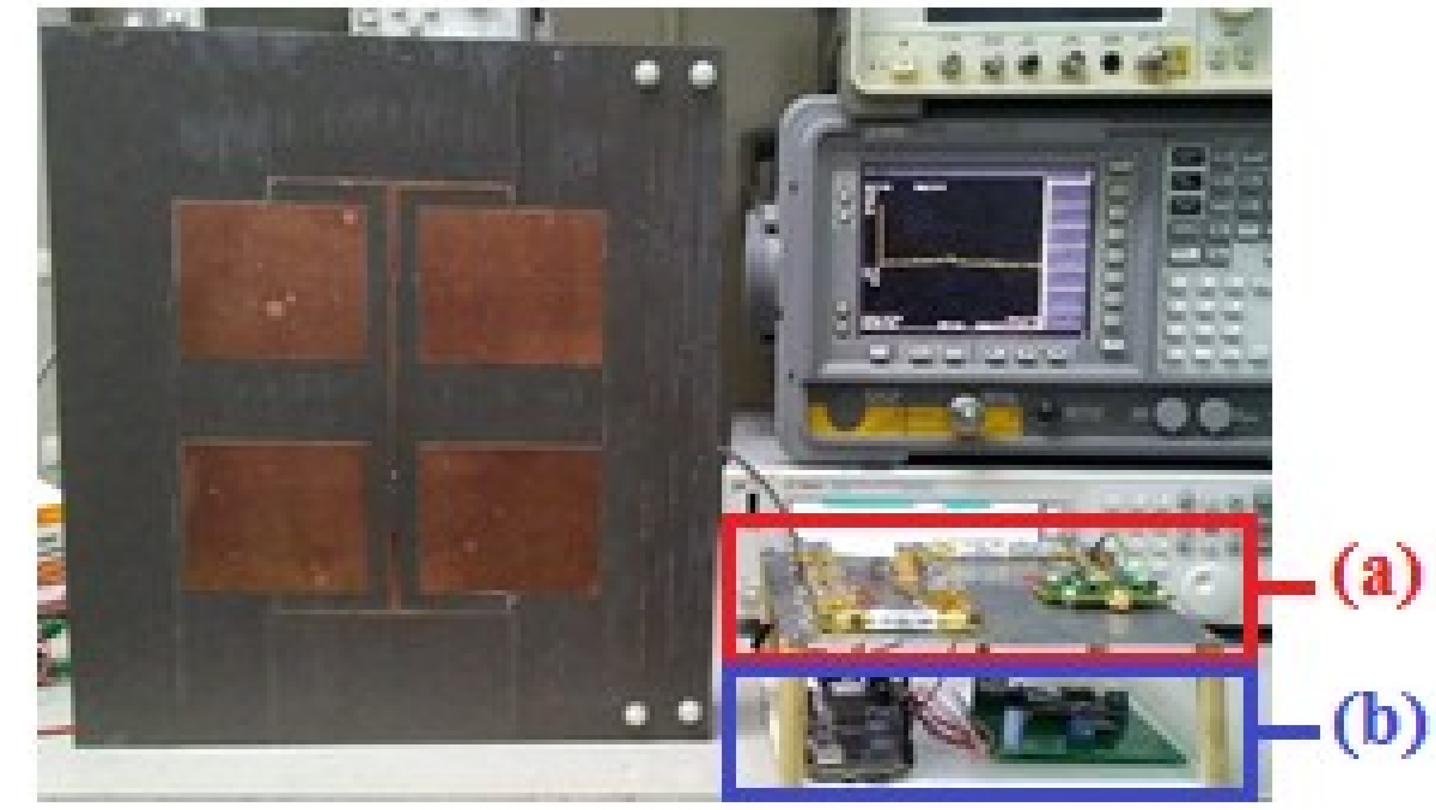

Figure 5. System prototype and measurement setup. (a) is the front end, (b) is the processing back end, battery, and sensor board.

Conclusion

This article presents the design and construction of a low SWaP receiver for a small-UAV mounted, compact radiometer; power consumption reductions were obtained through high-level optimization methods. This work demonstrates that it is possible to miniaturize radiometer systems by processing real time large amounts of data using the ARM embedded microprocessor. The system was tested with different integration times, and the power consumption varies inversely proportional with the integration time, but the performance of the complete system was not significantly affected (ΔT < 2 K). Another contribution of this work is integrating all components of a radiometer such as sensors, data acquisition, communication, data storage and processing into a single and portable compact system and designing a printed circuit board for the front end amplifying characterization as shown on figure 6. Finally, due the small SWaP, this system can be used in UAVs to scan land and sea areas, for different applications.

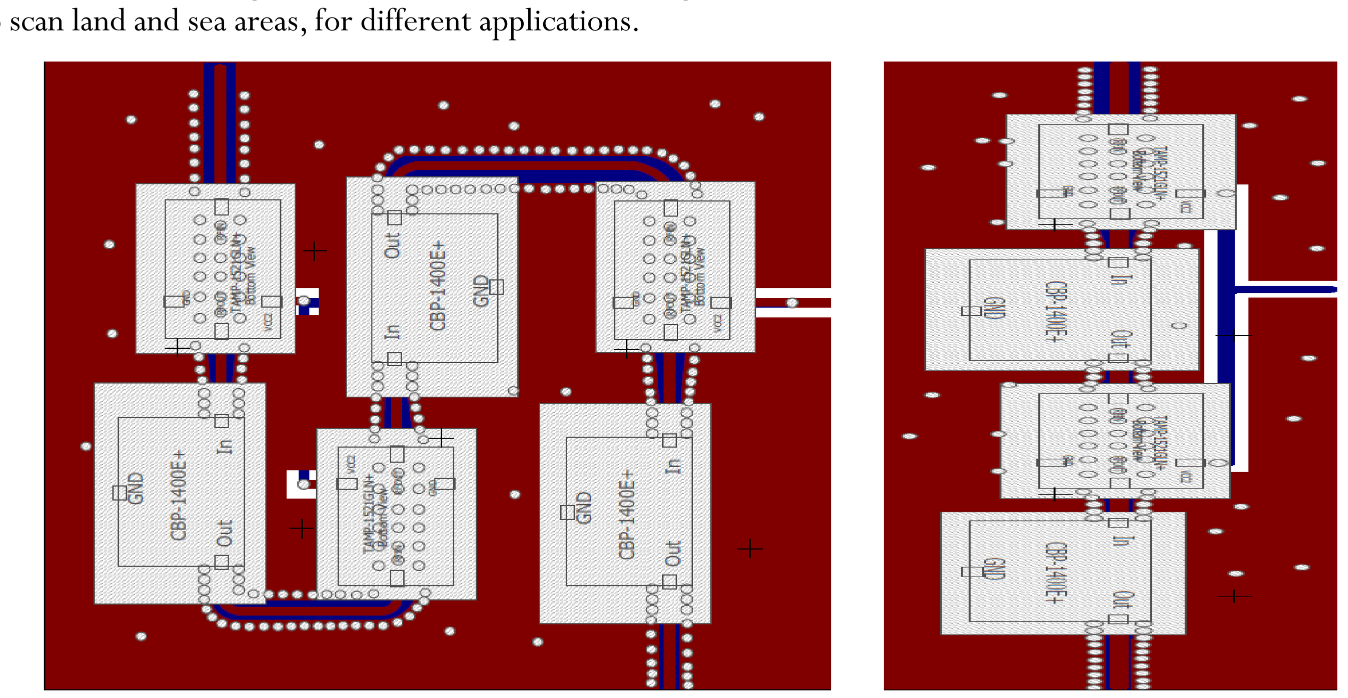

Figure 6. Front end printed circuit board with (a) 100 dB gain and (b) 70 dB gain

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Acknowledgement

This work is supported in part and monitored by NOAA-CESSRST under the Cooperative Agreement Grant NA16SEC4810008