Design and Implementation of a Software Defined Radio-Based Radiometer Operating from a Small Unmanned Aircraft Systems

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***Abstract*—Passive remote sensing services are indispensable in modern society as they provide crucial information for Earth science and climate studies. In parallel, modern society also depends heavily on active wireless communication technologies for daily routines, with emerging technologies such as 5G further increasing this dependence. Unfortunately, the growth of active wireless systems often increases radio frequency interference (RFI) experienced by passive systems. This necessitates development of coexistence techniques and creation of new technology that enhances the existing and future wireless infrastructure. To study this problem, we are developing a unique testbed for collecting remote sensing datasets with ground truth in real-world settings, which will enable training, optimization, and benchmarking the coexistence solutions. The testbed includes (1) a software defined radio (SDR) based radiometer, incorporated with a dual-polarized microwave antenna operating in the L-band (1400 MHz-1427 MHz) and (2) prototyping SDR-based communication systems. This paper presents design and implementation of such radiometer from an unmanned aircraft system (UAS) for supporting different scenarios and geometries.**

***Index Terms*—SDR, Radiometer, RFI, UAS, microwave, L-band, b210, dual-polarized, passive, soil moisture.**

I. INTRODUCTION

L-band (1400 MHz-1427 MHz) microwave radiometer uses the received brightness temperature to retrieve the earth surface geophysical parameters [1], [2]. This protected band can be used for soil moisture and vegetation optical depth estimation on the agricultural field [3]–[5]. The European Space Agency (ESA) developed first L-band spaceborne radiometer Soil Moisture and Ocean Salinity Satellite (SMOS) followed by National Aeronautics and Space Administration (NASA's) Soil moisture active passive (SMAP) radar radiometer deployment for the remote sensing of earth surface soil moisture retrieval [6], [7]. Recent measurements by the L-band radiometers onboard both NASA's SMAP and ESA's SMOS are impacted by RFI from different active services such as communications systems and radars [8]. RFI contamination can result in a huge amount of data loss and measurement gaps in space and time and hampering the effectiveness of the collected data for science. We have recently initiated development of a unique testbed for data collection, verification and optimization of active/passive co-existence in real-world settings. This paper will summarize design and implementation of a Software Defined Radio (SDR)-based radiometer operating from Unmanned Aircraft Systems (UAS).

Portable radiometer has been demonstrated its compact design with onboard two port calibration and its capability of integrating on a small copter UAS in [9] and fixed wing UAS in [10]. A Universal Software Radio Peripheral (USRP) ETTUS N-200 based radiometer has been also designed and implemented in [11] but it has been for a tower-based platform. Here, we present design and development of highly compacted SDR-based low power radiometer that can sample entire bandwidth for RFI data generation and be also incorporated into a small UAS system. The present radiometer has been built around a USRP B210 board and all the components have been carefully designed considering the size and weight, without compromising the performance. The following sections will provide a brief description of design considerations and data collection process along with summary and future work.

II. DESIGN SCHEMATIC

The entire radiometer operates based on the direct detection architecture and is divided into two sections. The RF front end comprises a four-port microwave switch, an isolator followed by a band-pass filter, and a low noise amplifier (LNA), and the second part of the system is based on SDR. The front end of the radiometer is independent of the temperature stabilization, as the system performs internal calibration with a matched resistive load at ambient temperature and an active cold source (ACS) at each measurement cycle performed with an integration time of one second, considering that the noise temperature remains constant during that time-frame. The physical temperature of each component of the radiometer system is recorded in each measurement cycle and can be used to correct the effect of instrument-generated noise temperature. The radiometer records the raw data while utilizing the full bandwidth (27 MHz). In post-processing, the raw data can be analyzed to map the surface's brightness temperature and identify any potential source of interference and can be mitigated by designing digital filters in SDR. The four port microwave switch is controlled by a Raspberry Pi 4. One Intel Mini-PC (NUC8i7HVK) is used to control and sync Raspberry Pi with SDR.

Prototyping a bench-top radiometer system is shown in Figure 1. The same radiometer is being enclosed inside a compact box in a multi-layer manner having thin layer of metal tape to isolate the inter instrument electromagnetic interference. A custom built dual polarized antennas is also being integrated outside of the box with a 45 degree angle and facing downward. The whole radiometer will be attached underneath a small (hexa-copter) UAS shown in the picture.

III. Data Collection Process

The four-port microwave switch is connected with horizontal and vertical polarization antennas, 50 ohm match resistive load as ambient source, and one resistive load followed by a LNA as cold source. The antennas were custom-designed to achieve higher gain and low side lobes to fit into small UAS payload. A two by two array of copper patch is considered for both antennas to achieve the required higher gain for radiometer application. This dual-polarized microstrip patch antenna was designed with FR4 substrate and incorporated an airgap between the top and bottom layers. A coaxial port as feed line is connected on both antennas to receive signals. The linear correlation of the ambient source and cold source is used for onboard two port calibration. Each of the four ports are switched to collect data for 250 ms and controlled by a raspberry pi4. The data is then pass through the 20 dB isolator, a bandpass filter, a LNA and a SDR. The SDR converts the signals to base-band before sampling and converting to a digital signal for storage. The data is stored into the onboard storage unit for post processing. The software used for this project is Python and C++ for the system development including controlling USRP, front-end relays, and connecting to Pi from NUC. For USRP programming GNU-Radio is used to develop scripts that achieve desired recording characteristics and data formats. The instrument has one channel which receive a signal directly from antenna. The signals are then filtered, amplified, and connected to the USRP B210. This radio converts the signals to base-band before sampling and converts to a digital signal for storage. Currently, the raw signal is directly used for identification and labeling RFI sources. In future, before storing the raw signal data, some processing will be directly carried out into the SDR to reduce noise and unwanted frequency components.

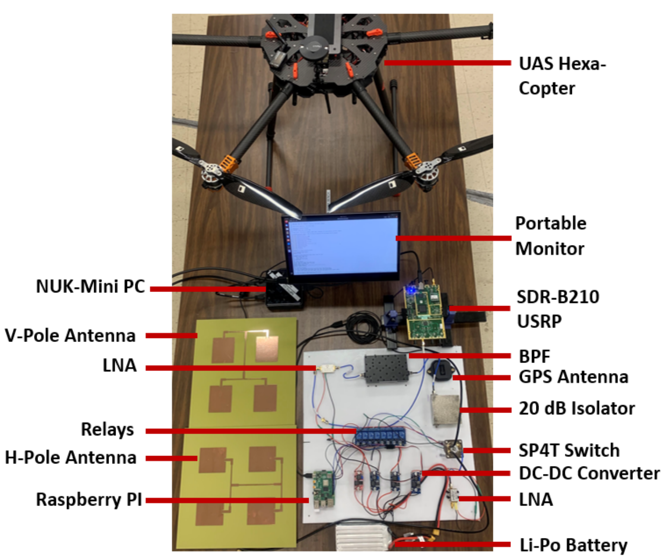

Fig. 1. A picture of the bench-top Radiometer setup and hexa-copter UAS.

IV. Summary and Future Work

We have designed and implemented a SDR-based radiometer. Physical components after the bandpass filter and first LNA are easily replaced by SDR as these components can be internally build inside the GNU-Radio block for processing the collected raw data signal. Therefore, the designed radiometer is compact and lightweight which can be operated from a small UAS where the speed and altitude can be precisely controlled. The radiometer facilitates to test varying coexisting communication waveforms and geometries and to generate data-sets on which we can quantify the impact of RFI on the radiometer's brightness temperature. The trade-off consideration from a UAS-based radiometer design and integration will be demonstrated. The preliminary results from data collection in conjunction with various active sources in anechoic chamber will be presented.

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