Airborne Radio Frequency Interference Studies at C-band using a Digital Receiver

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***Abstract*— An airborne system for observing radio frequency interference at C-band is described. The digital receiver included has the capability of providing high temporal and spectral resolution of interference, as well as implementing simple mitigation strategies. Plans for observations with the system are discussed.**

I. Introduction

The absence of a protected portion of the spectrum at C-band [1] makes radio frequency interference (RFI) a major concern for C-band microwave radiometry. The C-band channel of the AMSR-E radiometer on the AQUA satellite has already shown a major corruption of data over a large percentage of global land mass [2]. Recent data from the WindSAT satellite [3] also shows significant corruption of the C-band channel. C-band channels remain highly desirable over land however due to their improved sensitivity to soil moisture and other environmental parameters compared to higher frequency channels. The CMIS instrument of the NPOESS generation of satellites includes a C-band channel [4], but clearly some form of RFI mitigation will be required in order to produce a successful instrument [5]. Possible strategies include the use of multiple frequency channels as opposed to a single channel [6], more rapid time sampling of the incoming data, or the use of digital receiver technologies to achieve improved RFI resolution both in time and frequency. Predicting the performance of these approaches is difficult without a detailed understanding of the existing RFI environment.

To address this issue, a combined analog/digital radiometer for airborne experiments was designed and developed through a collaboration of NOAA/ETL and The Ohio State University. The radiometer is based on the PSR/C of NOAA/ETL, with the addition of a new downconversion section so that small bandwidth analog radiometric observations throughout C-band are possible. A portion of the IF signal after downconversion is coupled to a digital receiver developed at Ohio State; this digital receiver is capable of providing highly detailed information on RFI properties as well as implementing some simple RFI mitigation strategies.

The next section of the paper provides a brief discussion of RFI issues for traditional microwave radiometers, while Section III describes a basic block diagram of the system developed. Section IV then provides more information on the digital receiver, and Section V describes preliminary plans for flights and experiments.

II. RFI Issues for Microwave Radiometers

The design of a traditional microwave radiometer is based on the assumption that the observed signal consists only of thermal noise. Because the goal of radiometry is to estimate accurately the mean power of the incoming thermal noise, long integration periods (on the order of milliseconds or longer) are desirable in order to reduce uncertainty. Only the mean power estimate after this integration period is of interest, so a traditional radiometer will not record information within an integration period. In addition, the use of large bandwidth channels is desired in order to further reduce uncertainty in the estimate of mean power. Because naturally emitted thermal noise varies very slowly with frequency in most cases, measurements from channels with similar center frequencies are deemed identical, and single channel observations are sufficient to represent a large portion of the spectrum.

The addition of RFI to the observed channel violates the noise-only assumption, and causes serious problems for a traditional radiometer. Although interference can take a variety of forms, in many cases RFI may be expected to be localized either in time (i.e. pulsed type interference) or frequency (narrowband interference), or in both domains. If only a small number of such "localized" interfering sources are present, a large portion of either the observation time or bandwidth may contain no interference. However, the traditional radiometer is unable to separate the corrupted and uncorrupted portions of the observation, and therefore may produce corrupted data even with only limited RFI. Because RFI will always increase the mean power when compared to that of the geophysical background, post-processing of the data can be applied to eliminate abnormally high observations. However, lower level RFI can be difficult to separate from geophysical information, making parameter retrievals problematic. Note that an interferer with a large amplitude but small temporal duty cycle and/or small bandwidth may appear as low level RFI when averaged over time and frequency.

A simple way to extend the RFI mitigation capabilities of the traditional radiometer is to increase either the temporal sample rate or the number of frequency channels in the system. These approaches can be implemented in an analog fashion by simple extensions of the traditional radiometer, and the complete data set recorded for post-processing to eliminate RFI at finer temporal and spectral resolution. However, the number of channels that can be implemented using an analog approach is limited, given that additional hardware must be added for each new channel. The temporal sampling rate that can be achieved is also limited by both the RF hardware and the data acquisition subsystem, since the amount of data to be stored eventually becomes unmanageable. Use of digital receiver technologies can address some of these issues: the implicit high temporal sampling rate of a digital receiver allows temporally localized sources to be resolved. In addition, an FFT operation can be performed in real time to obtain a much larger number of frequency channels than is possible using analog sub-channels. However, the data rate of such a system is also much larger than that of the analog approaches. To reduce the data rate, an RFI mitigation processor can be added to the digital receiver to implement simple time and/or frequency domain mitigation algorithms in real time. The resulting "RFI-free" data is then integrated over time and/or frequency to produce a manageable final output data rate. The digital receiver developed at Ohio State implements is based on such an architecture.

III. System Block Diagram

Figure 1 is a simplified block diagram of the RF and downconverter sections of the combined analog/digital radiometer. The antenna, LNA, and gain stages are those of PSR/C, located in a sophisticated positioner in the aircraft to allow a high degree of control over the antenna look direction. The front end filter has upper and lower 3 dB cutoff frequencies of 5.75 and 7.55 GHz, respectively; the filter has only 3 poles so the rolloff beyond these frequencies is relatively slow. This wide filter enables measurements to be performed over a wide range of C-band frequencies. Although only a single antenna input is illustrated for simplicity, the entire analog/digital radiometer is capable of observing both vertically and horizontally polarized brightnesses. Internal calibration loads are also omitted in Figure 1 for simplicity.

Following the initial filtering and gain components, a portion of the input is coupled off to a new downconversion stage of the PSR/C. The remainder of the input is passed on to the existing PSR/C direct detection receiver [6], which operates with four analog sub-channels and provides fully polarimetric observations. These sub-channels provide some measure of RFI mitigation, but remain large analog channels (∼400 MHz bandwidth) compared to the bandwidth of likely RFI sources.

To reduce the possbility of out-of-band interference, the downconversion stage first passes the incoming signal through a filter with a 3 dB bandwidth identical to that of the front-end filter, but with a much more rapid out-of-band cutoff (eight poles as opposed to three in the front end filter). The downconversion step utilizes an image reject mixer that passes the upper sideband only. The IF center frequency is 125 MHz, and the local oscillator is capable of tuning from 4.6 to 8.9 GHz. The IF output is amplified and then filtered by both 10 MHz and 100 MHz wide filters. Filter outputs are amplified and detected by a logarithmic amplifier, then sampled by the PSR computer. Due to the limitations imposed by the downconverter filter, the tuning range of the oscillator was set to 5.4 to 7.5 GHz, so that final observations with the 100 MHz channel cover the range 5.5 to 7.7 GHz. A total of 22 100 MHz channels result; these channels provide tuned observations at C-band using an analog filter approach without requiring a dramatic increase in hardware. The 10 MHz channel allows the performance of a smaller bandwidth analog channel to be investigated, and provides information on observed RFI properties when compared to coincident measurements with the 100 MHz channel.

IV. Digital Receiver

A portion of the 100 MHz IF channel is also provided to the digital receiver subsystem, illustrated in Figure 2. The digital receiver is based on two 10-bit, 200 mega-sample-per-second (MSPS) analog-to-digital converters (ADCs), resulting in a 10 nsec temporal resolution. The choice of 10 bits in the ADC components is designed to retain high dynamic range so that large RFI sources will not produce saturation. Each ADC is used to sample 80 MHz of the incoming bandwidth from 110-190 MHz. Processing of the sampled data is implemented in field-programmable-gate-array (FPGA) hardware, allowing flexibility in the RFI algorithms to be applied. The current procedure digitally filters each of the ADC outputs to 50 MHz, then combines to the channels into a 100 MHz bandwidth signal sampled into 16-bit I/Q data at 100 MSPS. This first processor stage is referred to as the "digital IF" (DIF) processor. The first RFI mitigation strategy, referred to as "asynchronous pulse blanking" (APB), is implemented with the DIF in a single FPGA. The APB algorithm attempts to remove high amplitude temporal data in real time through a simple detection and blanking procedure; see [7]-[8] for detailed information. Outputs of the DIF/APB component are then passed through a 1024 point FFT operation, so that 1024 100 kHz channels are obtained approximately every 10 microseconds. FFT outputs are passed through a detection operation and integrated for a user-controllable time period in an FPGA component referred to as the "spectral domain processor" (SDP). The SDP processor also has the capability of performing a "max-hold" operation of the incoming data instead of integration. Finally, a "capture card" is included for facilitating data transfer through a high-speed digital I/O card (National Instruments PCI-DIO-32HS) to a data recording and control computer.

To increase flexibility in the digital receiver, an ethernet interface was implemented to each FPGA component for setting parameters of the suppression algorithms. This interface allows the APB, FFT, power detection, and/or max-hold/integration operations to be begun or suspended by the control computer as the receiver is in operation. Although a variety of observational modes are possible, the basic configurations of interest are

- Integration, APB on
- Integration, APB off
- Max-Hold, APB on
- Max-Hold, APB off
- Capture

Varying the APB status enables the effectiveness of the APB algorithm to be investigated. The max-hold configurations are of interest because these operations are typically much more sensitive to time localized RFI than integration. The final "capture" mode refers to passing through raw DIF data without implementing APB, FFT, or SDP algorithms. Because no integration occurs in the capture mode, the data rate is extremely large, and the resulting duty cycle of observations low. However this configuration (temporal sampling of the incoming field at 10 nsec resolution) can be extremely useful for identifying temporal properties of RFI sources.

Because it is the PSR data acquisition computer that controls oscillator tuning in the downconverter, the digital receiver and PSR computers must be interfaced. To make this interface as simple as possible, a simple 1-bit "trigger" signal was used. This TTL-level pulse is sent from the PSR control computer to the digital receiver computer whenever a tuning operation has been completed and measurements should begin. In addition, both computers include highly accurate on-board clocks, synchronized through the IRIG-B standard, so that knowledge of the oscillator frequency for a particular measurement is obtainable by recording trigger pulse times.

The IF signal provided by PSR occupies the bandwidth 75-175 MHz, while the digital receiver requires two input channels both centered at 150 MHz. A channel selection interface is thus also required, as illustrated in Figure 2. For flexibility in setting incoming power levels, an amplifier followed by a computer-controlled step attenuator is included. The IF signal is then separated and filtered into a 75-125 MHz portion and a 125-175 MHz portion. Then 125-175 MHz portion is directly passed to the digital receiver, while the lower band is mixed and filtered again to occupy the bandwidth 125-175 MHz before reaching the digital receiver. The DIF processor corrects for the spectral reversal of the lower band due to this mixing process.

V. Preliminary Experiment Plans

Preliminary flight plans include deployment in the Soil Moisture Experiment 2004 [9], scheduled for July-August 2004 in the Southwestern US and Northern Mexico. Observations on the transit flight from the US East Coast are also planned. A procedure has been developed in which each 100 MHz channel is observed for approximately 20 msec; including internal calibration source observations and the time required to tune the oscillator results in a trigger pulse every 36 msec. The complete set of 22 channels is then observed every 792 msec. For these flights, the PSR antenna will complete an azimuthal scan approximately every 3 seconds, and a complete 22 channel sweep occupies 71 degrees of azimuthal rotation. All observational modes of the digital receiver will be used; modes will be cycled every four frequency sweeps (3.2 seconds.) Estimates of data acquisition efficiency for the digital receiver suggest a hardware integration time of approximately 1.3 msec as near optimal, while capture lengths are limited to 64K samples ($\sim$ 655 μsec). A total duty cycle of approximately 65% is estimated for the digital receiver, due to data storage and timing requirements.

Inclusion of both analog and digital subsystems will allow the relative advantages and disadvantages of these two approaches to be examined more quantitatively. Information on the performance of the APB algorithm against C-band RFI sources will also be obtained. The high temporal and spectral resolution of the digital receiver will allow detailed properties of RFI sources to be recorded for the development of future mitigation strategies. If successful, the data from these measurements should provide important information for the design of future C-band satellite radiometers.

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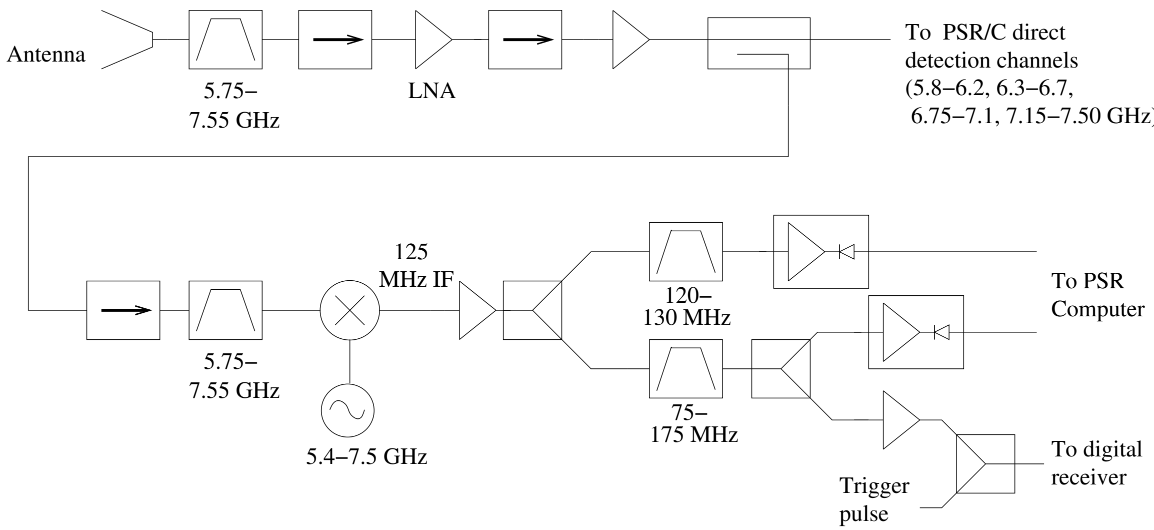

Fig. 1. Simplified block diagram of gain and downconverter stages

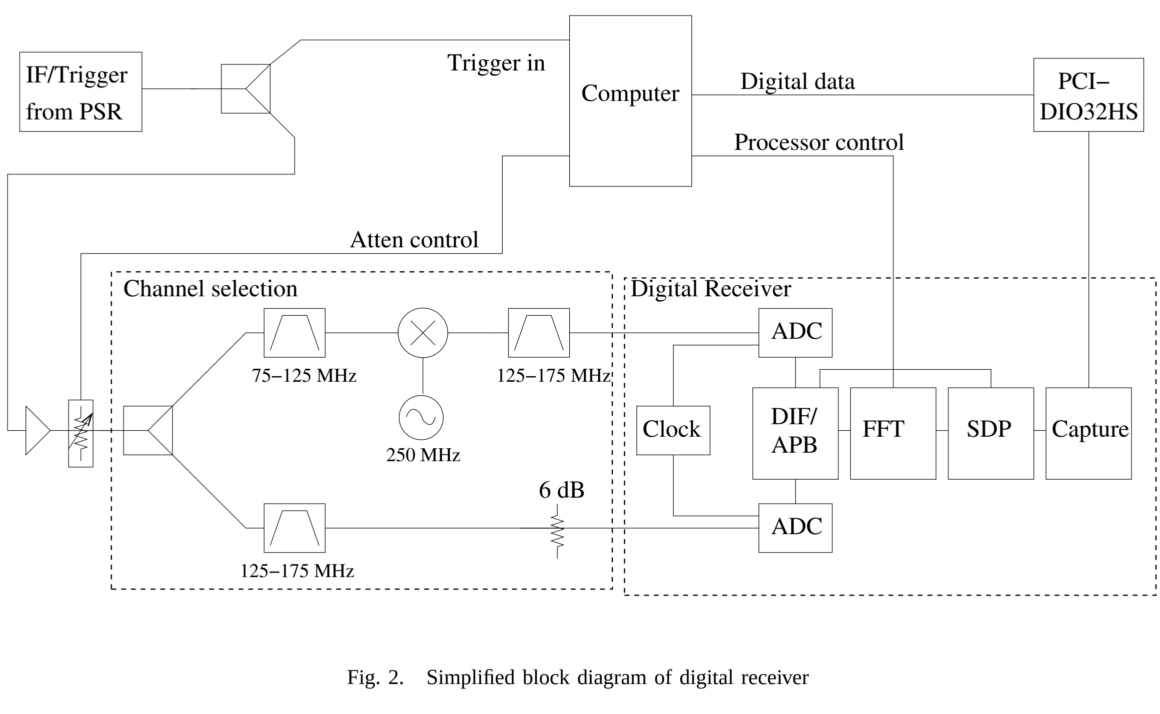

Fig. 2. Simplified block diagram of digital receiver