RFI MITIGATION USING TIME AND FREQUENCY RESOLUTION

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ABSTRACT

Methods for detecting and mitigating radio frequency interference (RFI) in microwave radiometry using high resolution both in time and frequency are described. Time domain detection and mitigating algorithms (i.e. "pulse blanking") based on simple thresholding of observed powers have been implemented in real time at 10 nsec resolution in a digital receiver, and results are presented to show the performance of this approach against pulsed interference sources. The performance of "cross-frequency" techniques using a 100 kHz spectral resolution for detecting and removing narrowband RFI sources is also described.

1 INTRODUCTION

Radio frequency interference (RFI) is a major concern for passive microwave remote sensing of the Earth's surface. Traditional radiometer receiver architectures are very susceptible to RFI corruption of observed brightnesses; recent studies [1]-[9] are developing new radiometer technologies to address this issue. Combating the impact of RFI requires methods both for detecting the presence of RFI (detection algorithms) and for removing RFI when detected (mitigation algorithms.)

While a variety of detection algorithms have been applied in radio astronomy applications (e.g. [10]), Earth remote sensing studies to date have primarily emphasized three particular approaches. The first two methods essentially involve a search for "outliers" in measured powers, based on either measurements as a function of time (i.e. a "pulse" detection method [2]-[3]) or frequency (i.e. a "narrowband" detection method [3]-[5].) Pulse detection strategies are designed to detect RFI with large amplitudes but short time durations (i.e. low duty cycle pulses), and are improved by matching the time resolution of the detector to the time duration of expected RFI pulses. Given the possible impact of long range air search radar systems on L-band radiometry, desirable time resolutions are often in the range of a few microseconds so that individual radar pulses can be resolved. Narrowband detection strategies are designed to detect frequency localized RFI that may be more continuous in time, and again are improved by matching the frequency resolution of the detection algorithm to the bandwidth of RFI sources. Other strategies based on tests for normality of the received data, for example using a kurtosis detector [6]-[9], have also been used, but are not discussed further here.

This paper reviews recent experiments performed by The Ohio State University ElectroScience Laboratory to demonstrate the performance of time and frequency-based RFI detection and mitigation algorithms. The next section presents a brief overview of the digital receiver developed for this purpose, and Section 3 describes the experimental results obtained.

2 L/C-BAND INTERFERENCE SUPPRESSING RADIOMETER

The L/C-Band Interference Suppressing Radiometer (LISR or CISR) is a digital backend system that can sample a 100 MHz IF channel (or 2 50 MHz channels in distinct polarizations) through the use of 2 200 MSPS A/D converters. Data sampled by the receiver is processed into an I/Q form at 100 MSPS (10 nsec time resolution.) A time domain detection algorithm called "asynchronous pulse blanking" (APB) is then implemented in real time through the use of FPGA hardware. The algorithm first computes the power in the incoming sampled fields, and simultaneously computes a running estimate of the mean power and its standard deviation. Pulse detection is declared if observed powers exceed the estimated mean by a specified number of standard deviations. The processor is also capable of "blanking" (i.e. setting to zero) samples within a time window surrounding the detected sample; the width of this window is a parameter of the algorithm. More information on the APB process is available in [2]-[3].

Following the APB, measured data is passed through a 1K FFT, again computed in real-time in FPGA hardware, so that a spectral resolution of $\sim$ 100 kHz is achieved. FFT outputs are then square law detected by the processor, and the results integrated over a user specified time period before being passed to a data recording computer. Narrowband detection algorithms (i.e. using powers as a function of frequency at a given time) currently are implemented only in post processing, but could also be implemented in digital hardware in future work.

A control interface to the LISR/CISR FPGA processor allows APB and FFT output integration parameters to be varied, as well as the APB blanking operation to be turned on or off, without reprogramming the FPGA. The system is therefore a very useful tool for examining the performance of real time pulse blanking algorithms as well as the performance of cross frequency detection and mitigation. The current absence of real time cross frequency mitigation requires that all 1K FFT channel outputs be recorded, so that the system data rate is relatively high if short integration periods are utilized. While near 100% duty cycle observations can be achieved in ground and aircraft based observations, limitations on the datarate of a spacebased system would likely require that the number of FFT channels be reduced. Nevertheless, LISR/CISR information provides a useful testbed for assessing the impact of spectral resolution on RFI detection performance. Further information on the LISR/CISR systems is available in [1]-[4], and a detailed performance study of the APB algorithm is described in [11].

3 RESULTS

LISR/CISR observations from two experiment campaigns are summarized in the following sections. The first involved ground-based L-band observations conducted near an Air Route Surveillance Radar (ARSR) system in Canton, MI, while the second involves airborne C-band measurements over Texas cities and the Gulf of Mexico.

3.1 L-band: Pulse Blanking

A joint L-band campaign with researchers from the University of Michigan and NASA Goddard Space Flight Center was conducted in June 2005. In this campaign, the LISR digital backend measured 50 MHz bandwidth IF signals provided by a truck-mounted L-band radiometer of the University of Michigan. The ARSR radar system in close proximity to the radiometer operated at 1315 MHz, well out of the protected 1400-1427 MHz spectrum where the radiometer observed. Nevertheless, radar emissions produced measurable RFI due to the high radar power level and finite stop band attenuation of the radiometer's filters. The observed ARSR signals are excellent candidates for time domain mitigation, given their pulsed nature (approximately 2 usec pulses produced every few msec.)

Figure 1 compares spectrograms of LISR calibrated antenna temperatures in vertical polarization with the APB algorithm turned off (left) or on (right). The radiometer antenna was directed toward the horizon, and observed a partial forest/partial sky scene. The horizontal axis in the plots is the RF frequency (resolved into 512 frequency channels of 0.1 MHz each) while the vertical axis is time. In this case, the radiometer antenna was directed away from the ARSR, so that the observed RFI is relatively weak (around 2-3 K when averaged over the entire radiometer passband, comparable to the approximately 1 K radiometer measurement uncertainty.) However, when resolved in frequency, apparent RFI near 1414 MHz is obvious, as well as weaker narrowband RFI at 1400 MHz. A review of the measurement process showed that the 1315 MHz radar emissions map to an apparent frequency of 1414 MHz when aliased by the digital receiver. The right hand plot shows the APB algorithm to be successful in mitigating the radar's contributions while maintaining calibration of the observed brightnesses. Note the weaker source near 1400 MHz is not affected, and apparently is continuous, not pulsed, interference. More information on the results of this campaign is available in [3].

3.2 C-band: Narrowband detection

An airborne C-band campaign was conducted in August of 2005 jointly with researchers from the University of Colorado and the University of Michigan. In this campaign, the Polarimetric Scanning Radiometer (PSR) of the University of Colorado [5] provided a vertically polarized 100 MHz bandwidth IF signal for observation by CISR. This 100 MHz channel was tuned from 5.5-7.7 GHz throughout the measurements, and the radiometer operated in a conically scanned observation pattern from the high altitude NASA WB-57 aircraft. The 90 minute flight plan included observations over Texas cities and more rural regions, as well as the Gulf of Mexico.

Due to the absence of pulsed interferers in most of C-band, the focus for CISR observations was the performance of cross frequency detection methods. An algorithm was developed for detecting RFI in a CISR 1024 point frequency spectrum at a fixed time, based on an approach similar to that used for time domain pulse blanking. A detailed description of the algorithm is available in [3].

Figure 2 illustrates CISR 7.1-7.2 GHz geolocated and calibrated brightnesses from a portion of the flight over a rural portion of Texas. The left image illustrates brightnesses averaged over the entire 100 MHz channel before any detection or mitigation has been performed, while the middle image provides the same plot after application of the cross-frequency algorithm. The difference between the two images (right) shows that both high and low power level RFI was detected and removed. Note the strong but narrowband RFI sources easily detected in the CISR spectra appear as weak-RFI (i.e. between 1 and 10 Kelvin) when averaged over the entire channel bandwidth. Additional analysis of these results is provided in [3].

4 CONCLUSIONS

Several campaigns have demonstrated that simple time and frequency domain strategies can be successful at detecting and mitigating RFI for microwave radiometry. Time domain algorithms are most successful against short pulsed interference, while frequency domain strategies are intended for narrowband sources. In both cases, the algorithms perform best when their resolution is matched to that of the interfering sources. Performance is expected to be reduced for other types of interference. The simplicity of these algorithms allows them to be implemented easily in digital hardware, and both real-time detection and mitigation (e.g. pulse blanking) is possible. For space based operations, the use of real time detection should allow these approaches to have a minimal impact (a simple one bit detection flag) on the system datarate.

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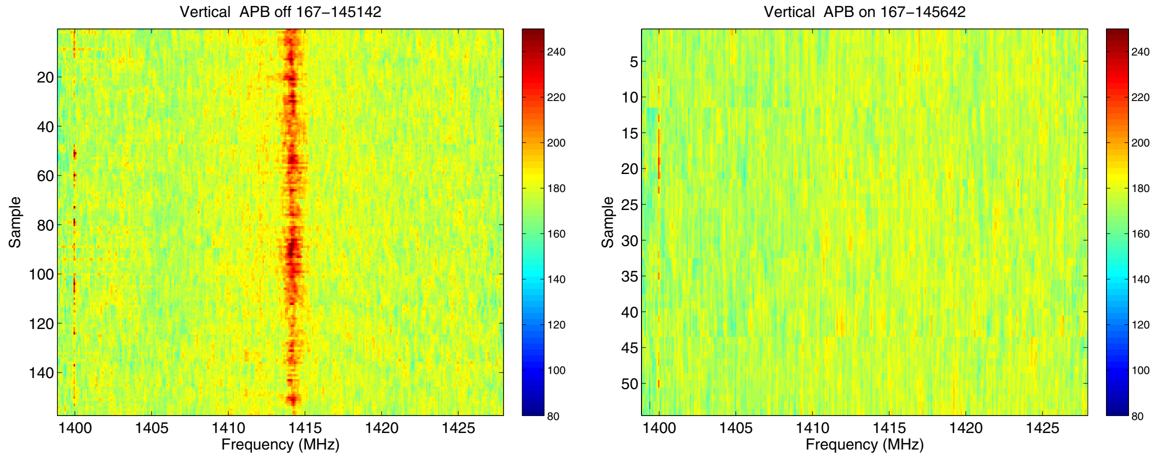

Figure 1: Spectrograms of vertically polarized antenna temperatures measured by LISR in the L-band campaign, with the APB algorithm off (left) or on (right.) Results demonstrate the success of a simple pulse detection strategy against the radar interference source in the campaign (which appears near 1414 MHz in the left plot.)

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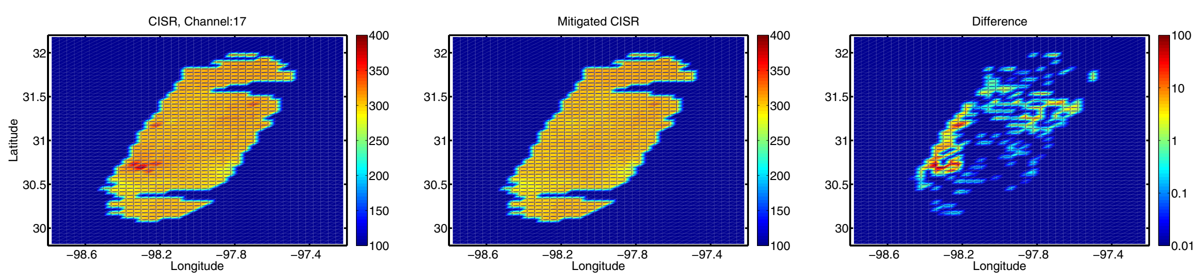

Figure 2: Geolocated and calibrated 7.1-7.2 GHz brightness temperatures observed by CISR during a portion of the WB-57 test flight over Texas. Left image plots initial brightnesses averaged over the 1024 CISR channels within the 100 MHz bandwidth, while middle image illustrates brightnesses following application of a cross-frequency RFI detection/mitigation algorithm. Difference plot on the right shows that both strong and weak RFI contributions have been mitigated.