Development of an Agile Digital Detector for RFI Detection and Mitigation on Spaceborne Radiometers

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***Abstract* — A new type of microwave radiometer detector has been developed that is capable of identifying high and low levels of Radio Frequency Interference (RFI) and of reducing or eliminating its effect on the measured brightness temperatures. The Agile Digital Detector (ADD) digitizes its pre-detection radiometer signal, performs digital sub band filtering, and then measures the first four moments of the signal's probability density function for each sub band. The second central moment reproduces the square law output of a conventional analog detector. Algorithms that utilize higher order moments are used to detect the presence of RFI. ADD can discriminate between RFI and natural thermal emission signals using higher order moments of the signal. After detection, ADD then uses spectral filtering methods to selectively remove the RFI. ADD performance has been experimentally verified in controlled laboratory tests and in a series of ground based and airborne field campaigns. High level RFI is easily identified and removed. The detectability of low level RFI contamination is found to vary, depending on the probability distribution of its electric field amplitude. Analysis and experimental confirmation of ADD detection statistics are presented for several common sources of RFI. A brassboard version of ADD is also in development. Its purpose is to demonstrate that critical functions of the ADD can be performed by flight qualified devices and fault tolerant firmaware. An overview of the brassboard design is also presented.**

I. INTRODUCTION

Passive microwave observations for Earth science are becoming increasingly contaminated by Radio Frequency Interference (RFI) from man made sources of emission such as telecommunication transmissions and civilian and military radars. If the RFI has a very high power level, it can usually be identified and flagged. If the RFI has a relatively low power level, it will often be mistaken for the variability in the observations that is expected of natural geophysical signals. This can have a very significant detrimental effect on the value of archival data records, such as are used for climate studies, and on operational uses of the measurements, *e.g.* for use as observational constraints on numerical weather forecast.

An Agile Digital Detector (ADD) has been developed that is capable of performing the standard functions of a conventional analog detector, the more advanced functions of an analog bank of sub-band filters and detectors, as well as an entirely new class of radiometer detection and mitigation algorithms that are optimized for the removal of low level RFI contamination of microwave radiometer T_B. The essential elements of the ADD hardware consist of a high speed, high resolution analog-to-digital converter (ADC), followed by a field programmable gate array (FPGA) to perform digital signal processing (DSP) functions. Analog radiometer signals enter the ADD in place of what would ordinarily be the detection stage of the hardware. The DSP stage of the ADD provides direct measurements of the probability density function (PDF) of the pre-detection signal. The PDF can be used, in ways described in the following sections, to detect the presence of RFI. The ADD should be considered as a potential replacement for the simple analog detector scheme that has historically been used by nearly all previous airborne and spaceborne microwave radiometers [1-3].

II. SPREAD SPECTRUM RFI DETECTION

ADD directly measures the first four moments of the amplitude probability distribution of the pre-detected radiometer signal. The n^{th} such moment is given by

$$m_n = \left\langle x^n \right\rangle \tag{1}$$

where x is the amplitude of the pre-detected signal. A conventional analog square-law detector measures the second central moment of the pre-detected signal, as given by

$$c_2 = \left\langle (x - \langle x \rangle)^2 \right\rangle \tag{2}$$

which can be derived in post processing from the first two moments, m_1 and m_2. In general, the second central moment of a signal is proportional to its power and, in the case of a radiometer, to the system noise temperature from which the brightness temperature is derived. The fourth central moment is given by

$$c_4 = \left\langle (x - \langle x \rangle)^4 \right\rangle \tag{3}$$

and can likewise be derived in post processing from the all four of the measured moments, $m_1 - m_4$. Detection of the presence of RFI can be significantly simplified and also

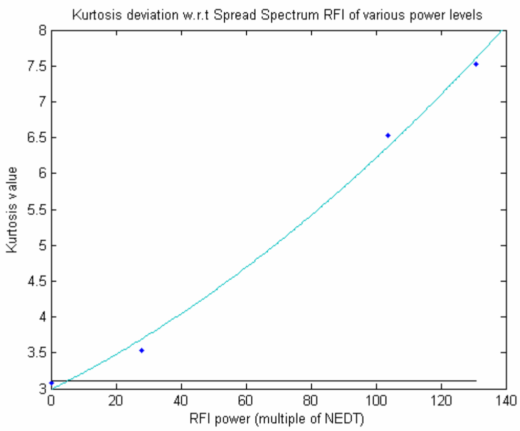

Figure 1. Agile Digital Detector measurement of kurtosis for a broadband spread spectrum Radio Frequency Interference (RFI) signal coupled onto a background ambient blackbody source. The horizontal line near the x-axis indicates a kurtosis value that is 3 times the NEΔK above a constant value of 3.0, which is always measured when no RFI is present. NEΔK is the standard deviation of the kurtosis measurement. Values of the kurtosis that are above the horizontal line indicate the presence of RFI with high probability of detection and low probability of false alarm.

enhanced by examining the kurtosis of the pre-detection signal. The kurtosis is the ratio o the fourth central moment to the square of the second central moment, or

$$k = c_4/(c_2)^2 \tag{4}$$

The kurtosis is always equal to 3 for a gaussian distributed signal, regardless of its variance. Pre-detected radiometric signals are gaussian distributed when completely free of RFI. Thus, so long as a radiometer is observing natural thermal emission, the kurtosis will be 3, independent of variations in the brightness temperature or in the gain of the radiometer electronics. This fact makes the kurtosis a particularly robust means of detection of RFI. In case the signal is corrupted by RFI, the amplitude probability may deviate from a gaussian distribution and the value of the kurtosis may deviate from 3.

The capabilities of the kurtosis for detecting continuous and pulsed sinusoidal sources of RFI have been studied and reported in detail [4]. The continuous sinusoid model can be used to represent telecommunication satellite uplinks for which their modulation envelope is a small fraction of the radiometer bandwidth. The pulsed sinusoid model represents typical air traffic control and early warning radar signals that can interfere with spaceborne radiometers operating in neighboring portions of the spectrum. Another potential source of RFI, and one which has the potential to grow appreciably with the expected growth in the use of commercial wireless products, is telecom using spread spectrum protocols.

Commercial spread spectrum wireless modems have noise like power spectra but the probability distribution of their radiated amplitude is not the same as true thermal noise and so it is possible for their kurtosis to detect them. A first look at the detectability of spread spectrum signals by ADD has been investigated experimentally. The spread spectrum signal was generated using a commercial Xbee RFI ID Tag. The Zigbee device uses the IEEE 802.15.4 spread spectrum protocol. Wireless transmission is generated on a 2410 MHz center frequency and the information is contained in a 5 MHz spread spectrum signal bandwidth. An ADD kurtosis channel bandwidth of 3 MHz was used, so that the spread spectrum signal completely covers the complete measurement bandwidth and looks, as much as possible, like a “noise like” signal and not a localized modulated sinusoid.

The experiment was conducted by coupling a highly attenuated, very low power version of the spread spectrum signal into a bench top S-Band radiometer to which the ADD kurtosis detector was attached. The background brightness temperature observed by the radiometer during the experiment is from an ambient temperature blackbody target. The power level of the spread spectrum signal was varied while the kurtosis was measured. The results are shown in Figure 1. The equivalent brightness temperature of the spread spectrum signal (in units of the *NEΔT* of the radiometer, which was ~0.5 K) is plotted versus the kurtosis of the composite signal, which contains both the ~290 K background blackbody brightness and the spread spectrum signal. Measurements of the kurtosis are accompanied by an additive noise component that is gaussian distributed with zero mean and a standard deviation, *NEΔK*, given by

$$NE\Delta K = \sqrt{\frac{24}{B\tau}} \tag{5}$$

where B is the pre-detection bandwidth of the signal and τ is the integration time over which the kurtosis is estimated. The *NEΔK* uncertainty is the standard error associated with estimating the kurtosis from a finite number of samples of the signal, in a similar manner as the *NEΔT* uncertainty associated with estimates of the brightness temperature itself. In Figure 1, the measured kurtosis can be seen to increase above its nominal, RFI-free, value of 3.0 as the equivalent brightness temperature of the spread spectrum RFI increases. The kurtosis deviates from 3.0 by more than three times the *NEΔK* uncertainty for RFI levels greater than 3 times the NEDT uncertainty in measurements of the brightness temperature. This represents the minimum power level above which the spread spectrum RFI can be detected with high probability while simultaneously maintaining a low false alarm rate when RFI is not present.

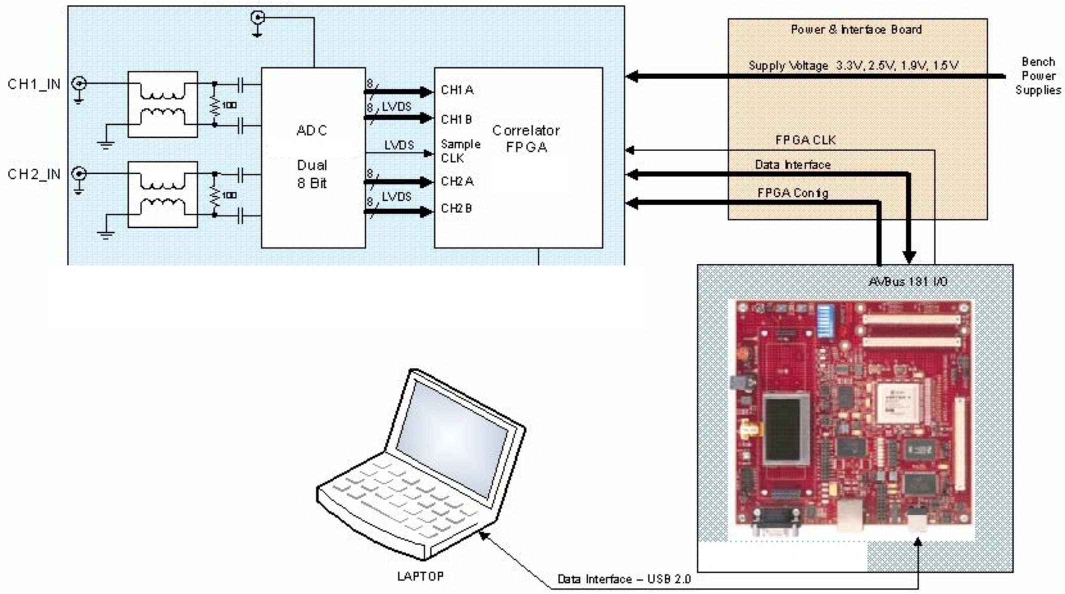

Figure 2. Agile Digital Detector brassboard (upper left) and support interface boards used to characterize the performance of a flight-like ADD design.

III. Brassboard Agile Digital Detector

A flight brassboard quality version of the Agile Digital Detector (ADD) is in development. The brassboard is intended to verify that the performance of the ADD in relevant scientific environments, as demonstrated earlier in the project through a series of field campaigns with a non-flight qualifiable prototype, could be carried over to a flight qualifiable version. Particular attention was paid during the design of the brassboard to using flight qualified components for all critical elements and to following mechanical and thermal layout and assembly procedures approved for flight subsystems.

Testing of the ADD brassboard is intended to address: 1) fault tolerance of the design to single event upsets (SEUs) and accommodations in the design for SEU refresh and recovery; 2) digital master oscillator stability requirements and the impact of clock jitter on system level performance; and 3) manufacturability issues, in particular quality assurance inspection and verification of proper fabrication of high density very large scale integrated circuits. In each of these cases, the brassboard that is currently under development can be used to help address the issue

A functional block diagram of the ADD brassboard and supporting interface boards and command and data handling computer are shown in Figure 2. The brassboard is currently in development.

IV. Summary

The Agile Digital Detector (ADD) has been developed to serve as a new type of microwave radiometer detector. It fulfills all the conventional requirements of an analog square-law detector and also provides the capability to detect and mitigate Radio Frequency Interference (RFI) at both high and low, otherwise undetectable, levels. ADD directly measures the kurtosis of a radiometer's pre-detection signal. The kurtosis is insensitive to variations in the brightness temperature of a radiometer signal, provided the origin of the signal is purely thermal. RFI tends to be non-thermal in origin and can be readily detected by the kurtosis. The detectability of commercial wireless spread spectrum signals is evaluated experimentally. Spread spectrum RFI can be reliably detected provided its equivalent brightness temperature is greater than or equal to three times the NEΔT uncertainty in the radiometer measurements. A flight-like version of the ADD is currently in development.

References

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