

Detection and Mitigation of Radio Frequency Interference Using a Digital Kurtosis Spectrometer/Detector

Christopher Ruf¹, Sidharth Misra², Rachael Kroodsm³, Steve Gross⁴, Roger DeRoo⁵

¹Space Physics Research Laboratory, Dept. of Atmospheric, Oceanic and Space Science, University of Michigan, 2455 Hayward St., Ann Arbor, MI 48109-2143 USA, 734-764-6561 (V), 734-936-0503 (F), cruf@umich.edu

²⁻⁵University of Michigan: samisra@umich.edu², rakro@umich.edu³, smgross@umich.edu⁴, deroo@umich.edu⁵

Abstract

A new microwave radiometer detector has been developed that is capable of detecting low levels of Radio Frequency Interference (RFI) and of reducing its effect on the measured brightness temperatures. The Agile Digital Detector (ADD) digitizes the pre-detection radiometer signal, performs digital sub band filtering, and then measures the first four moments of the signal's probability density function. The second moment reproduces the square law output of a conventional analog detector. The ADD can discriminate between RFI and natural thermal emission signals using higher order moments of the signal. The ADD uses spectral filtering methods to remove the RFI.

1. 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 [1-3]. 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 [4]. 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 higher order moments of the signal amplitude than the second moment that is measured by conventional "square law" detector diode. 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.

2. Principle of Kurtosis-based RFI Detector

The signal detected by a microwave radiometer is primarily from natural thermal emission as well as thermal noise generated by the hardware. The PDF of the amplitude of this signal is gaussian distributed. This property can be utilized when detecting the presence of RFI. The RFI detection algorithm makes use of the generating function for higher order moments of a gaussian distribution, given by

$$m_n = \langle (x - \langle x \rangle)^n \rangle = 1 \cdot 3 \cdot \dots \cdot (n-1) \sigma^n \quad (1)$$

where σ is the standard deviation of x . In case of a gaussian distributed signal, higher order moments are uniquely determined by the standard deviation. The kurtosis of x is defined as

$$R = \frac{m_4}{m_2^2} \quad (2)$$

For a gaussian distributed signal, the kurtosis is always equal to 3, independent of σ . 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.

3. Model for Kurtosis in the Presence of a Pulsed Sinusoid

The kurtosis may change in the presence of RFI. Here we characterize the behavior of the kurtosis in the presence of a radar-like source of RFI. Assume that the RFI can be modeled as a pulsed sinusoid with a duty cycle n and amplitude A . We require the probability distribution of both the thermal emission and the RFI signals. In our case, even though the RFI is deterministic in nature, we consider its amplitude histogram as an equivalent probability distribution. The probability distribution functions for the thermal emission and RFI signals are respectively represented by $g(x)$ and $f(x)$

$$g(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}} \quad (3)$$

$$f(x) = (1-n)\delta(x) + \frac{n}{\pi\sqrt{A^2 - x^2}} \quad (4)$$

Because the two signals can be considered statistically independent, the probability distribution of the composite signal is given by a normalized version of the convolution of the above two equations, or

$$r(x) = f(x) * g(x) \quad (5)$$

In order to calculate the kurtosis, we require the first four central moments of the resultant signal, given by

$$m_1^{g+f} = 0 \quad (6)$$

$$m_2^{g+f} = \sigma^2 + \frac{nA^2}{2} \quad (7)$$

$$m_3^{g+f} = 0 \quad (8)$$

$$m_4^{g+f} = 3\sigma^4 + 2nA^2\sigma^2 + \frac{3nA^4}{8} \quad (9)$$

The kurtosis for a gaussian distributed signal is given by

$$R = \frac{m_4}{m_2^2} = \frac{3\sigma^4}{(\sigma^2)^2} = 3 \quad (10)$$

In the presence of pulsed-sinusoidal RFI, the moment ratio becomes

$$R = \frac{m_4^{g+f}}{(m_2^{g+f})^2} = \frac{3\sigma^4 + 2nA^2\sigma^2 + \frac{3nA^4}{8}}{\left(\sigma^2 + \frac{nA^2}{2}\right)^2} \quad (11)$$

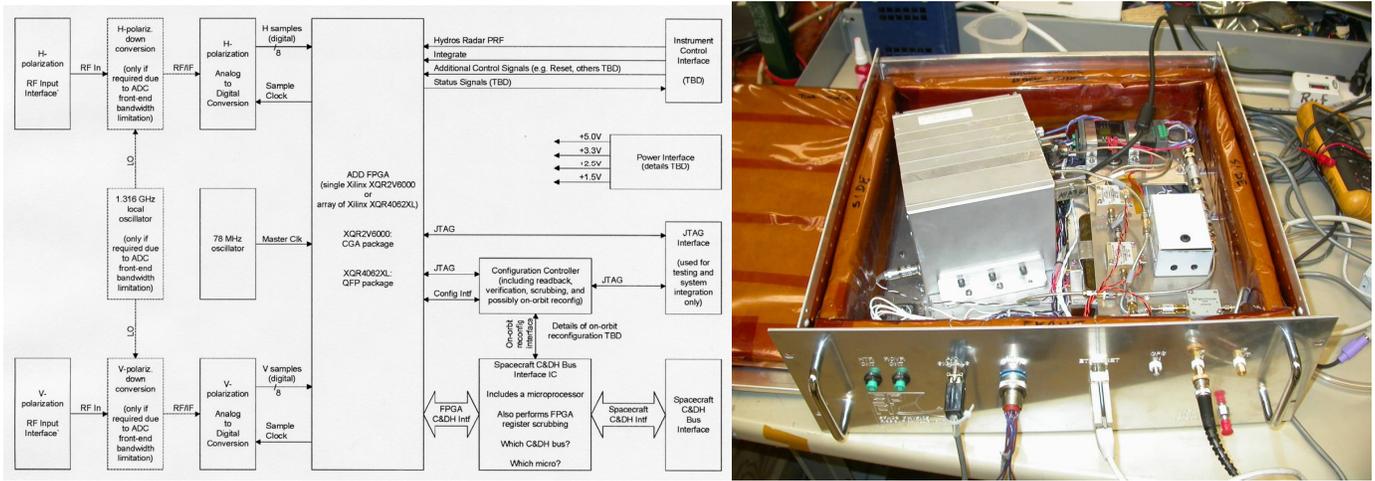


Figure 1. Functional block diagram (left) and photograph of hardware (right) for the Agile Digital Detector.

4. Airborne Field Trial

Results of the ADD performance during ground-based field trials have been reported in [4]. A subsequent airborne field trial was performed during August 2005 with the ADD installed in parallel with the standard back-end detector subsystem of the stepped-LO C-Band channel of the NOAA/ETL Polarimetric Scanning Radiometer (PSR). A functional block diagram of the ADD, together with a photograph of the ADD subsystem as it was deployed during the airborne campaign, is shown in Figure 1. The ADD was operated during one ~2 hour flight that began and ended near Houston, TX and included overflights of the Dallas-Fort Worth and San Antonio urban areas, more rural portions of east-central Texas, and a brief period out over the Gulf of Mexico. A 60 second sample of the raw measurements while over Dallas is included here, to illustrate ADD performance in the presence of relatively severe levels of RFI. Time/frequency plots of the kurtosis and of the 2nd moment of the measurements are shown in Figure 2. In Figure 2, benign, RFI-free, regions are distinguishable by normalized kurtosis values (kurtosis/3) of one. There are two broad regions of the time/frequency space that are free of RFI. They cover frequency channels 171-176 (roughly 7.45-7.50 GHz) during elapsed times 0-25 and 40-50 seconds. Elsewhere, strong excursions from unity of the kurtosis are clearly evident.

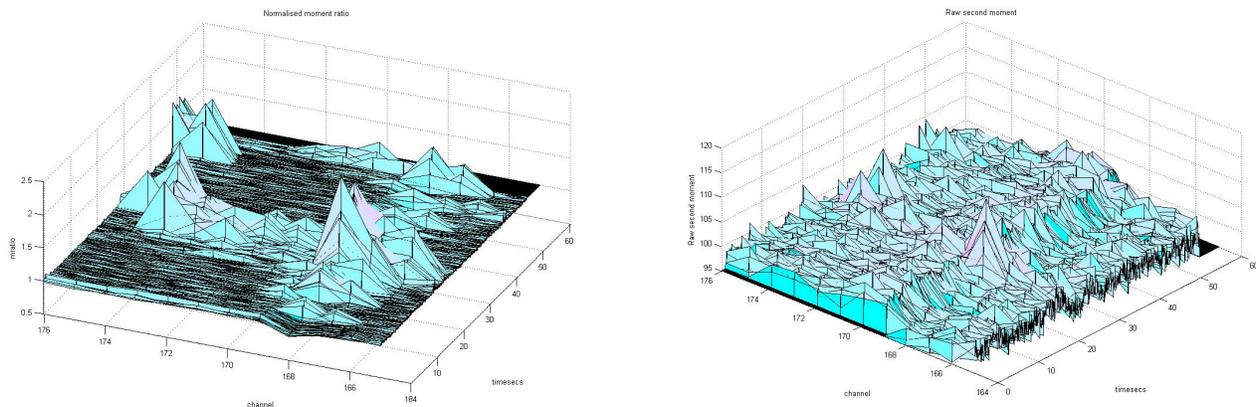


Figure 2. Normalized kurtosis (left) and second moment (right) while flying over Dallas. Channel numbers 176-184 roughly correspond to frequencies between 7.4 and 7.5 GHz. The time axis is elapsed time over one minute of data taking. Significant deviations from unity of the normalized kurtosis indicate the presence of RFI. The 2nd moment is linearly proportional to the detected system noise temperature. Spikes in the 2nd moment tend to be associated with the presence of RFI. However, there are time/frequency regions in which the kurtosis clearly indicates that RFI is present but variations in the 2nd moment are not noticeably different from that in regions with variability governed by natural geophysical variability in the observed brightness temperature.

In Figure 2, some of the time/frequency regions with RFI also clearly show spikes of high 2nd moment. RFI in these instances could likely be identified by conventional RFI detection algorithms based solely on the 2nd moment. However, as one counterexample, consider the variations in the 2nd moment at frequency channel 170. The RFI-free elapsed times 0-25 seconds

are not noticeably distinguishable from the variations during times 25-40 seconds, when the kurtosis clearly indicates the presence of RFI. A conventional RFI detection algorithm would have considerably more difficulty with this sequence of measurements.

5. Laboratory Spread Spectrum Evaluation

Laboratory measurements were also conducted to assess the ability of the ADD kurtosis detector to detect the presence of very low level spread spectrum wireless communication signals. A commercial Xbee wireless modem was used, operating with the IEEE 802.15.4 spread spectrum protocol. A small portion of the modem signal was tapped off of the Comm channel and fed into a microwave radiometer operating at 2410 MHz. The analog front end of the radiometer used a standard total power design and the back end consisted of the ADD subsystem. The power level of the spread spectrum signal was varied while the deviation of the kurtosis from its value while observing a gaussian distributed signal was computed. The results are shown on Figure 3. ADD is able to detect the presence of spread spectrum RFI when it is above 3 times the NEDT of the radiometer,

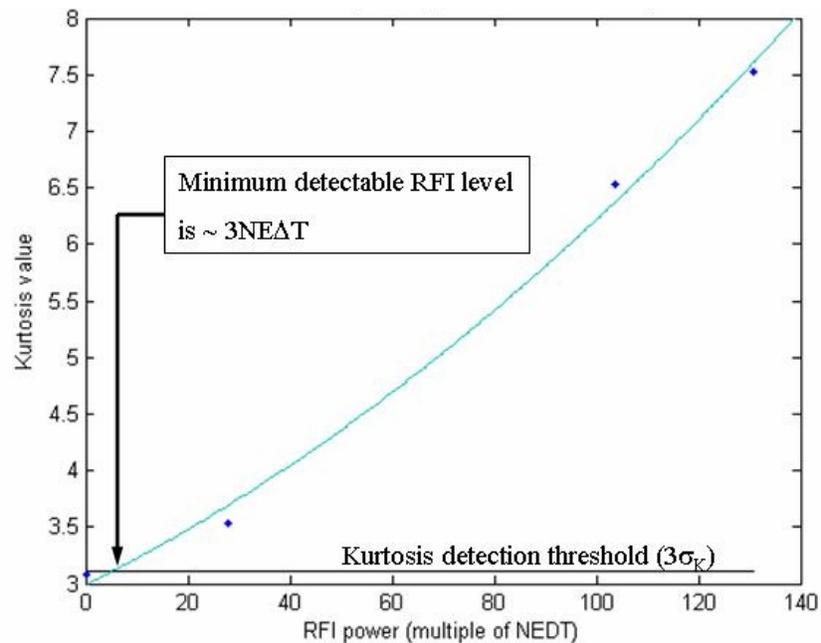


Figure 3. Results of spread spectrum signal detection using ADD. The ADD kurtosis detector is able to reliably detect the presence of spread spectrum RFI imbedded in a much large natural thermal emission signal when it has a signal strength equivalent to 3 times the sensitivity level of the radiometer.

6. Conclusion

A new type of microwave radiometer detector has been developed that can detect the presence of RFI and, in particular, low level RFI. The Agile Digital Detector directly measures the first four moments of the pre-detected signal, from which the kurtosis of the signal can be computed. In the absence of RFI, the kurtosis is found to be invariant to changes in brightness temperature. In the presence of even very low level pulsed sinusoidal RFI, it changes and, so, can be used to detect its presence. Small variations in the apparent brightness temperature observed – due to low level RFI – that might otherwise be indistinguishable from natural geophysical variability are reliably identified.

7. References

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