Design Concept for the IIP Radiometer RFI Processor

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Contents

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1 Introduction

This note describes a design concept for the IIP RFI processor. This design assumes a 100 MSPS input signal consisting of complex-valued samples, as would be provided by the front end proposed in [1]. A high-level block diagram is shown in Figure 1. The processor consists of four functional blocks, defined below and described in more detail later:

- *Asynchronous Pulse Blanking (APB).* This block removes strong and/or wideband pulses that are difficult to mitigate by any other method. Ground-based radars are an expected source of such signals.

- *Parametric Estimation/Subtraction (PE/S).* This block uses the PE/S strategy of Ellingson, Bunton, and Bell [2] to mitigate signals that can be described in terms of a few slowly-varying parameters. It is not yet clear which, if any, signals experienced by remote sensing systems will fall into this category.

- *FFT Excision (FFTE).* This block applies the Fast Fourier Transform (FFT) and attempts to identify bins which are corrupted by narrowband, low-level RFI. These bins are then blanked. FFTE is also useful for "clean up" of undesired signals making it past the front end, APB, and PE/S. The output is then either (1) processed to determine total power in the passband (for total power radiometry) or routed to the XPP (for interferometry).

- *Correlator Pre-Packaging (XPP).* If the RFI processor is just one of N comprising a interferometer, then it is necessary to transport the complex-valued output of the FFTE block to a correlator which combines the output of N processors. Since the processor output has already been channelized by the FFT, this correlator is envisioned to be of an "FX" architecture. To make the data transport problem tractible, the XPP truncates the FFTE's output to a minimum number of bits per sample (nominally, 2+2) and serializes the FFT block output so that a technology such as LVDS can be used to connect XPPs to the correlator.

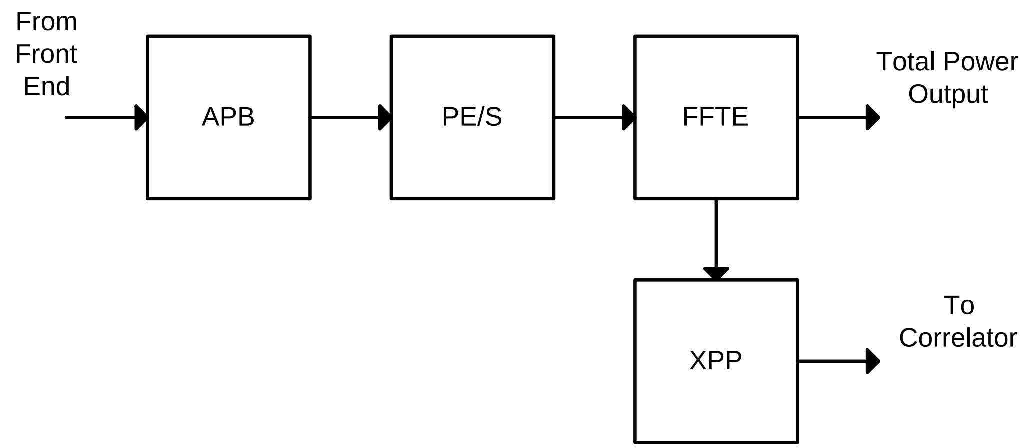

Figure 1: Block Diagram of the RFI Processor.

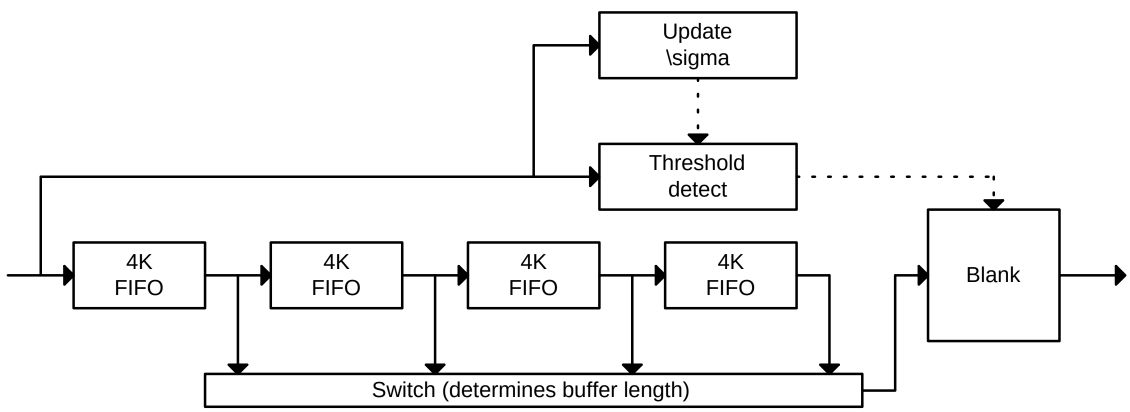

Figure 2: Block Diagram of the APB.

2 Asynchronous Pulse Blanking (APB)

A block diagram of the APB is shown in Figure 2. The APB consists of a variable-length sample buffer followed by a pulse detection and blanking circuit. The sample buffer consists of four 4K FIFOs that can be used to acheive a total buffer length L of 4K, 8K, 12K, or 16K samples; this is 40.96 μs, 81.92 μs, 122.88 μs, or 163.4 μs respectively. The magnitude of the sample currently entering the buffer is compared to a threshold δ. If exceeded, then the next $2L$ samples out of sample buffer are zeroed.

The buffer length is set by the user to accomodate the expected pulse width of the radar, plus margin to accomodate multipath, receiver recovery, and so on. The idea is to make the buffer long enough to remove corrupted time samples, but no longer so as not to give away any more integration time than necessary.

δ is set to be some multiple β of the RMS noise level, σ. σ is computed from samples taken during non-blanked periods; alternatively, all samples can be used and median statistics can be used to eliminate pulse-induced outliers. β sets the "aggressiveness" of the blanker: a low value (e.g., 3σ) will tend to trigger on spurious noise peaks, whereas a high value (e.g., 100σ) may allow weak pulses through. Good performance was demonstrated with $\beta = 10$ for pulse radar field data in [3].

3 Parametric Estimation / Subtraction (PE/S)

The strategy for implementing the PE/S block will be the same in principle as discussed in [2], adapted to the specific modulations of concern in this application. A new consideration emerges in this architecture, however: The estimation algorithm must be informed when the APB is blanking. A "flywheel" mode of operation is envisioned, in which the parameter estimation either freezes at it's current value when blanking is initiated, or tracks at a rate of change determined from parameter estimates made before blanking begins. In either case, the intent is not to continue generating the canceling signal during blanking, but rather to be ready with reasonable parameter estimates when a blanking period ends.

4 FFT Excision (FFTE)

A block diagram of the FFTE is shown in Figure 3. The length M of the FFT is proposed to be 1K (10.24 μs), yielding a bin width of $\approx$ 97.7 kHz. First, the data is windowed using a Bartlett (triangular) window. The output of the FFT is routed either to the XPP (for interferometry), or continues within the FFTE, for total power radiometry.

For total power radiometry, the next step is to compute magnitude-squared for each FFT output bin. The value of each bin is compared to a threshold δ_{FFT}, and is zeroed if it exceeds the threshold. δ_{FFT} is computed dynamically from the RMS noise

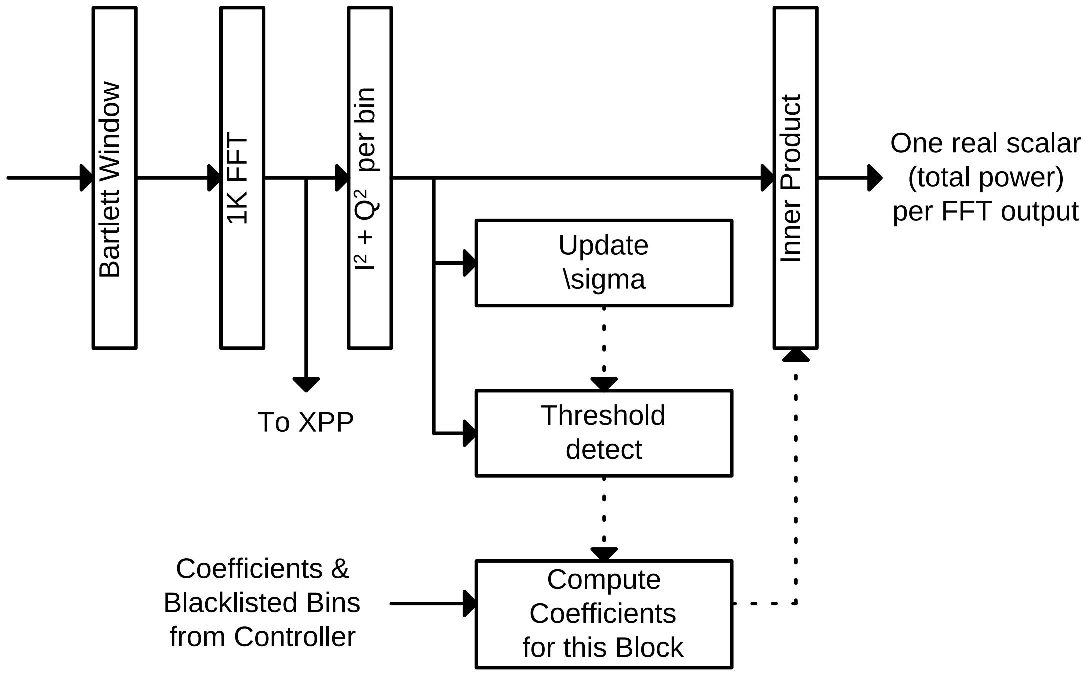

Figure 3: Block Diagram of the FFTE.

power measured across the bins, times a constant, γ. The guidelines for selecting γ are analogous to those for selecting β in APB: it must be set small enough to exclude objectionable RFI, but not so small so as to trigger excessively on spurious noise peaks. Information on which bins are blanked for each block is sent from the FFTE to a higher-level controller for record-keeping, coordination accross the elements of an array, and for scale corrections in the correlator, if necessary.

An FFT bin may also be “blacklisted” by the higher-level controller; that is, always blanked. This feature can be used to suppress RFI which is known to be present at a certain frequency, but which is too weak to reliably detect. Another way for the controller to designate blacklisted bins could be from a statistical analysis of the per-block bin-blanking data provided by the FFTE.

For total-power radiometry, the unblanked bins are summed, and scaled to account for the power loss due to missing bins. This measurement of total power per block can also be averaged to generate a single power measurement for a longer integration time. For additional flexibility, the blanking and summing operations are combined into a single “inner product” operation. One vector input to the inner product is the set of bin powers. The other vector input is nominally all 1's, in which case no bins are blanked. Bins are blanked by setting the appropriate coefficients equal to zero. A third possibility is to set bins to some intermediate value, which may be useful in equalizing the frequency response of the bandpass.

5 Correlator Pre-Processing (XPP)

Interferometry requires that that the element outputs be correlated. In this case, the blanking of bins should be coordinated accross all array elements. Thus, one function of the XPP is to receive bin-blanking guidance from the higher-level controller, and then blank as directed. An simpler alternative to this "decentralized" blanking approach is to do all blanking at the correlator. An advantage of the approach shown here is that blanking can be used to reduce the data rate to the correlator. Some additional study is required to know which approach is best.

It is desirable to reduce the data volume as much as possible before transport to the correlator. Since the RFI has nominally been removed at this point, the noise should be almost indistinguishable from Gaussian noise, and therefore each sample should be able to be represented with as few as 2 bits. It is known that there is a marginal improvement in sensitivity associated with reduced quantization noise for 3 or 4 bits, so this should be considered as well. In the worst case, each sample should be encodable in 8 bits: 4 for "I" plus 4 for "Q".

An attractive method for transporting data under these conditions is LVDS, a serial protocol. Assuming 8 bits per sample and no blanking, the data rate is 800 Mb/s, which is within reach of the latest LVDS chips. We can achieve 640 Mb/s with our current LVDS chips, so we could also simply send half of the bins on one such link and the other bins on a second link.

6 Development Strategy

In this architecture, the FFT is applied regardless of which other combination of RFI mitigation techniques are applied. Therefore, it is recommended to design and develop the FFTE first, followed by total power detection.

Due to it's simplicity, it is recommended that APB be implemented next. Because the various blocks in this architecture are "modular", the should be no difficulty in developing a piece at a time (e.g., on seperate demonstration boards) and then plugging them together.

We should not start work on PE/S until we have a better idea of what RFI sources we might apply it to. So, we should wait until we have results from our own RFI survey before beginning work on this part. Again, we should think ahead on how to build the APB and FFTE prototype boards so that it is simple to insert the PE/S at a later time.

Finally, development of the XPP block is a low priority until other blocks of the RFI processor and the front end are well along. This is because the XPP should be relatively simple to develop, and is not really needed unless we have a correlator.

References

[1] S.W. Ellingson, "Design Concept for the IIP Radiometer", informal memo, January 11, 2002.

[2] S.W. Ellingson, J. Bunton, and J.F. Bell, "Removal of the GLONASS C/A Signal from OH Spectral Line Observations Using a Parametric Modeling Technique," *Astrophysical Journal Supplement*, Vol. 135, pp. 87-93, July 2001.

[3] S.W. Ellingson, "Analysis and Mitigation of Radar at the RPA", informal report, January 20, 2002. Download available: http://www.esl.eng.ohio-state.edu/rfse/downloads/rparadar.pdf.