High-Speed Spectroradiometry using a Statistical Method of RFI Suppression for Radio Observations with RATAN-600

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Abstract. We report the design and construction of the new spectrometer intended for solar observations on the RATAN-600 radio telescope, capable of the RFI excision using the statistical algorithm based on the spectral kurtosis estimator. The design of the analog front end is described, as well as the operation of the FPGA-based DSP system. The achieved maximum spectral resolution is 122 kHz in frequency band 1.0–2.0 GHz or 2.0–3.0 GHz. The output spectrum can have from 64 to 8192 frequency bins, depending on the observer's requirements, the output rate is 120 spectra per second. The results of laboratory testing and the first solar observations show that the employed algorithm can successfully detect and suppress the interference from most local RFI sources.

Keywords: telescopes; techniques: radar astronomy

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1 Introduction

The radio telescope RATAN-600 was designed for operation in the range of frequencies from 0.6 GHz to 30 GHz (wavelengths from 0.5 m to 1 cm). However, in the last decade, the frequencies below 3 GHz have been virtually inaccessible for the observations because of strong radio frequency interference from various wireless communication facilities, ground radars, etc. As a consequence, the spectral range of the multiwavelength spectropolarimetric complex that is currently in use for solar observations has the low boundary at 3 GHz by design. The expansion of the wavelength range to 30 cm, especially if supplemented with a high time and frequency resolution, would allow studying the fast changes in radio emission of solar active regions while tracking the source of emission, which is a new observation method for the RATAN-600 currently under development (cf. Storozhenko et al. (2020)), as well as performing the detection and analysis of pulsed and quasi-periodic signals, investigating the details of solar emission bursts, etc. One possible way to distinguish the radio astronomical signal from the artificial interference is in the difference in their statistics. It is supposed that the signal of interest has the Gaussian distribution of the intensity or the power spectral density, while artificial signals from ground sources possess some regularity, thus their statistics differ from Gaussian. In our work, we employed a method of spectral kurtosis estimator, which has been adopted successfully at several large radio telescopes (cf. Dou et al. (2009), for example).

2 Spectral Kurtosis Estimator

The general architecture of a digital spectrometer using the spectral kurtosis estimator for RFI excision and the underlying theory are given in Nita et al. (2007) and Nita & Gary (2010). Consider a real-valued time-domain signal sampled at a constant rate. The spectrometer performs digital Fourier transform (DFT) on incoming data frames, each N samples long. Then, given M power spectra obtained, in each spectral channel k the following estimator is calculated:

$$SK = \frac{M-1}{M+1}\left(\frac{MS_2}{S_1^2} - 1\right), \text{ where } S_1 = \sum_{m=1}^{M} P_k,\ S_2 = \sum_{m=1}^{M} P_k^2,$$

i. e. S_1 and S_2 are the summed power and power squared in k-th channel. For a pure Gaussian signal $SK \to 1$ as M increases. Setting a certain threshold on difference between SK value and unity, we can weed out channels which statistics differ from Gaussian, thus leaving in consideration only channels with signal of presumably natural origin.

3 Hardware Implementation

Currently there are no receivers capable of operating in 1-3 GHz band in the RATAN-600 Solar complex, so we were forced to develop the entire analog front end. Its block diagram is shown in Fig. 1. The front end is comprised of two channels, one for the band 1.0–2.0 GHz, and another for the band 2.0–3.0 GHz. The pre-amplifier stage is designed to avoid the LNA saturation with RFI caused by closely located sources. High-pass filters just before the first LNAs cut off frequencies below 1 GHz, where the heaviest RFI occurs. The notch filters at 1.85 GHz and 2.15 GHz with suppression of -30 dB in a 80 MHz passband excise the bands of GSM base stations. Multi-function amplifier (MFA) performs further amplification and commutation of the signals, switching between two

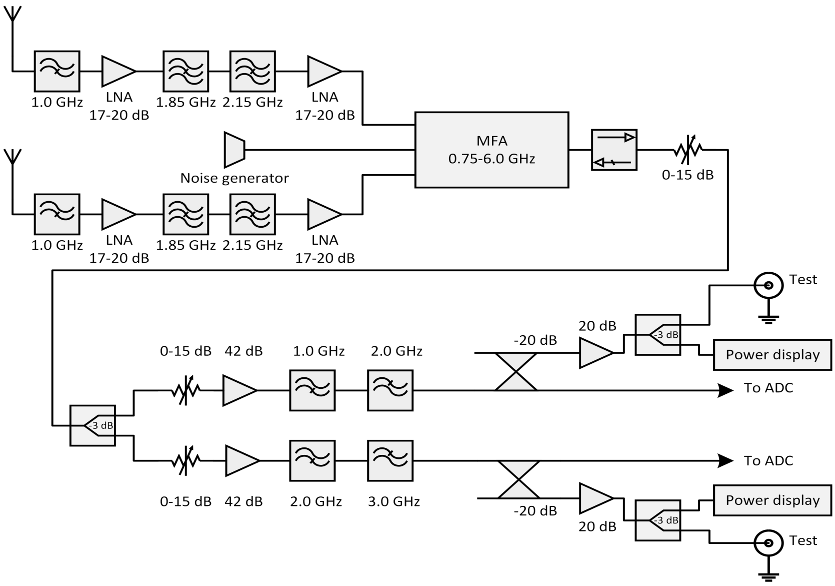

Fig. 1. Analog front end

frequency channels and noise generator used for calibration. It is followed by the signal conditioning circuitry that matches the dynamic range and frequency band of the signal with the ADC input. The high-speed 10-bit e2v ADC ev10aq190 is clocked by a 2 GHz stabilized low jitter quartz generator, providing the sample rate of 2 GSPS. The spectrometer works in undersampling mode, using 2nd and 3rd Nyquist zones for 1.0–2.0 GHz and 2.0-3.0 GHz bands respectively. The ADC output is demultiplexed to two channels. All the following signal processing is realized in Xilinx 7 Series FPGA evaluation board (currently KC705 with Kintex FPGA). The block diagram of the main processing pipeline is shown in Fig. 2. The FPGA hardware performs a massive parallel processing in order to meet the bandwidth requirements. The 16 384-pt Fourier transform is done in parallel on 8 standard Xilinx FFT cores 2048-pt each, then the results are phase shifted, and final stage of the FFT is performed on custom designed 8-pt 8-way FFT core. The next block in the pipeline accumulates the power and power-squared values in frequency channels, providing output values averaged over every 1024 power spectra, and supplementing them with spectral kurtosis estimated values. In order to reduce the data volume, the output stream shaper can average power values over 2, 4, 8, 16, 23, 64, or 128 frequency channels, providing the information on the fraction of samples considered “bad” based on the assumed spectral

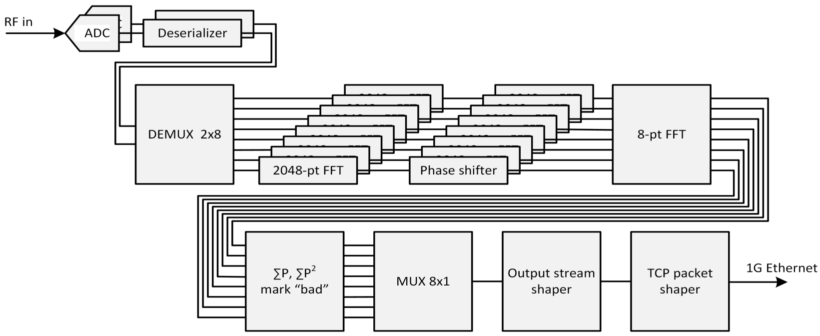

Fig. 2. Main processing pipeline

kurtosis criterion. Finally, the TCP packet shaper forms the payload for output TCP packets. All the auxiliary control functions are done by the Microblaze CPU implemented in the FPGA fabric. The output data stream is transmitted over Gigabit Ethernet to the universal PC for storage and further processing.

4 Conclusion

We developed a prototype spectrometer with maximum frequency resolution 122 kHz and time resolution 1/120 s using a statistical algorithm for RFI mitigation. The results of laboratory testing and first field observations show that the algorithm can successfully excise the interference from most of local RFI sources. In the same time, the interference from some permanently acting powerful sources was revealed, which requires an additional filtering in order to keep the amplifiers in linear mode. Recently, we got a new Xilinx board with Virtex 7 FPGA, which will allow the simultaneous processing of two frequency bands.

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