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FPGA based digital backend system for the Gauribidanur Radioheliograph

Indrajit V. Barve*, Mayuresh Sarpotadar, M. S. Sundara Rajan, R. Ramesh and C. Kathiravan
Indian Institute of Astrophysics, Koramangala, Bangalore 560034, India

Abstract. The Indian Institute of Astrophysics operates a low frequency (< 150 MHz) radioheliograph for dedicated observations of the solar corona at the Gauribidanur radio observatory (≈ 77°E 14°N) located about 100 km north of Bangalore[1] (Ramesh et al. 1998; Ramesh 2011). The basic receiving element in the radioheliograph (called the Gauribidanur RAdioheliograPH, GRAPH) is a log-periodic dipole (LPD). The array has 384 of them arranged in a 'T' configuration. The arms of the 'T' are in the east-west and north-south directions. The LPDs in the each of the above two arms are subdivided into 32 groups. RF signal from the 64 antenna groups in the array are presently correlated using a 4096-channel correlator system comprising of discrete digital circuit elements (Ramesh et al. 2006). Taking advantage of the developments in the field of signal processing, a FPGA based digital backend system is being developed for the GRAPH. To this date, a prototype 8-channel system has been designed and fabricated. All possible correlations between signals from 8 different antenna groups can be performed with this system either online or offline.

1. Experimental set-up

A 8-channel online time-domain complex correlator has been designed to obtain correlation between the signals from 8 antenna groups in the GRAPH. The intermediate frequency (IF) signal ($f_c \approx 10.7$ MHz, $\Delta f \approx 4$ MHz) from the analog receiver chain is quantized to two levels (+1 or 0) using a high speed comparator (AD 790). The TTL output from the comparator is converted to 3.3 V logic and transmitted to the FPGA. Figure 1 shows the block diagram of the FPGA correlator. The signals are quadrature

*email: indrajit@iiap.res.in
[1] http://www.iiap.res.in/centers/radio

sampled in a D-flipflop at the rate of ≈ 16 MHz. This is about a factor of two higher than the required Nyquist sampling rate (≈ 8 MHz) for the IF signal bandwidth (≈ 4 MHz) mentioned above. But with the sampling clock frequency located beyond the high frequency edge of the IF band (i.e. ≈ 12.7 MHz), we are able to utilize the entire 4 MHz IF band centered at 10.7 MHz without any aliasing. The sampled signals are delayed using shift registers to compensate for the propagation delay. A custom double side band (DSB) IP Core was made using Verilog. Each IP comprises of a complex correlator unit contains several X-OR, X-NOR, latch, integration, and multiplexer circuits[2]. The cosine (inphase) and the sine (quadrature) correlations are given by $\overline{(C1 \oplus C2)} + \overline{(S1 \oplus S2)}$ and $\overline{(C1 \oplus S2)} - \overline{(C2 \oplus S1)}$, respectively. Here the notations C1, C2 and S1, S2 signify the cosine and sine IF signals corresponding to the antenna groups 1 and 2. The final output obtained as correlation counts are transmitted to the computer via a Gigabit ethernet cable. Ethernet Media Access Controller (MAC) takes care of the ethernet framing protocols and error detection of the frames. The FPGA chip used is Virtex-5 which has an on-chip Embedded Tri-mode Ethernet MAC (TEMAC). It interfaces with a PHYsical Layer (PHY) chip (Marvell 88E1111) which is a line-driver for driving and sensing the ethernet cable for data transmission.

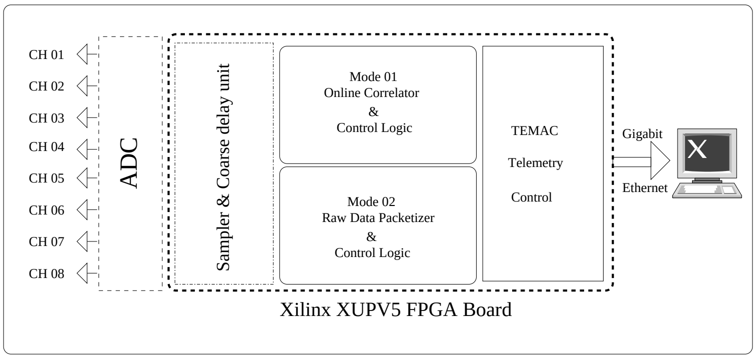

Figure 1. Block Diagram of FPGA Based Digital Backend system .

2. Raw data packetizer

In order to handle more number of inputs and frequency channels the packet correlator is used. With this setup, the raw voltages are sampled and filled into a First-In-First-Out (FIFO) unit. From the FIFO, the data are read and transmitted via Gigabit ethernet port using the TEMAC. A customized network frame structure is used to carry out the above set of tasks. Each frame has 28 Bytes of header containing the network protocol information, data frame count followed by 1024 data and 16 bytes trailer. Each data frame contains 1024 bytes of data. The LSB and MSB bits correspond to channel

[2]http://www.xilinx.com/univ/xupv5-lx110t.htm

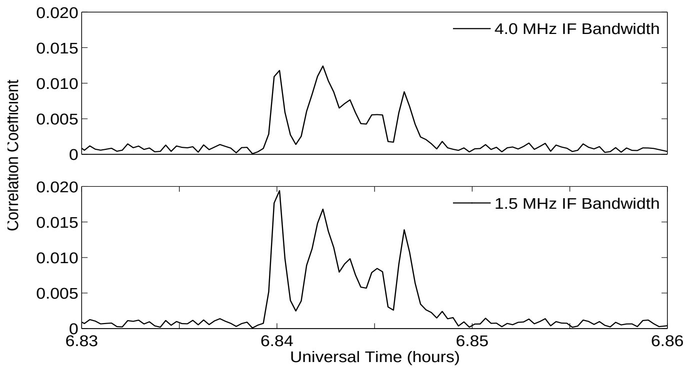

Figure 2. Time profile of a solar radio burst at 80 MHz observed in the online correlation mode for two different IF bandwidths. The reduced amplitude in the 4 MHz case (upper panel) compared to the 1.5 MHz case (lower panel) is due to bandwidth decorrelation (Thompson et al. 2004). This highlights the importance of identifying and correlating frequency channels of narrow width within the IF band rather than correlating the entire IF band.

1 and 8, respectively. On the computer side, the Wireshark is used to debug the frames. Using TCPDUMP, the raw voltages are dumped to the harddisk for offline analysis. Using LabVIEW, the individual channel data are extracted and the cross power spectra are obtained. Presently we are working on handling the data slips using Lossless Gigabit Remote Packet Capture (GULP) With Linux.

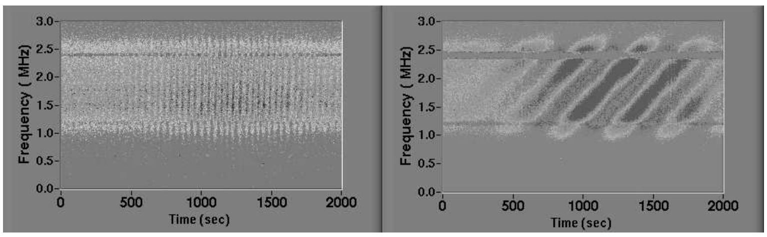

Figure 3. Interference fringes obtained during the meridian transit observations of Cassiopeia-A on a long baseline (left) and short baseline (right) in the GRAPH in the offline correlation mode.

3. Acknowledgements

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