Argus: An L-Band Array for Detection of Astronomical Transients

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I. Introduction

Traditional radio astronomy uses large, filled-aperture antennas, both singly and in arrays, to achieve high sensitivity and spatial resolution [1]. However, such instruments have the disadvantage that they have very narrow field of view (FOV), and thus limit the potential for discovery of new transient astronomical sources. Observations of the radio component of gamma ray bursts (e.g., [2], [3]) and the intermittent "giant pulses" generated by some pulsars (e.g., [4]) are examples that suggest that the radio sky might be rich with transient sources – some of them being very strong by astronomical standards – but which remain undetected simply because no existing instrument is pointing in the right direction. An especially tantalizing possibility is that one might detect an intermittent ultra-narrowband beacon transmitted by an extraterrestrial civilization, if only it were possible to continuously monitor a sufficiently large portion of the sky simultaneously [5].

"Argus" is a concept for an L-band radio telescope that is designed primarily for the detection of wideband pulses associated with naturally occurring transients, as well narrowband signals that might indicate technological sources. Argus achieves an instantaneous FOV covering most of the visible sky using an array consisting of large numbers of low-gain antennas, as originally proposed by Dixon [6]. In the Argus architecture, the output of each antenna is individually digitized, and all subsequent processing occurs in the digital domain so as not to prematurely limit the FOV.

This paper reports on a development project underway at the Ohio State University ElectroScience Laboratory (ESL), with the goal of implementing a small prototype Argus system. Our system uses a novel array signal processing architecture which facilitates flexible scaling in terms of number of antennas and processed bandwidth, and also supports the addition of special, user-defined features on-the-fly, as changes to software or firmware. Although the system is not yet complete, we have constructed and validated much of the design. We have experimentally confirmed effective aperture, antenna temperature, and system cost, each on a per-antenna basis, to be $\sim$60 cm^2 (1420 MHz), $\sim 215^\circ$K, and less than \$1000 respectively. A system with 64 elements will have a sensitivity $\sim(10^{-20}\ \mathrm{W\ m^{-2}\ Hz^{-1}})(\cos\theta)(B\tau)^{-1/2}$ where θ is the angle from zenith, B is bandwidth, and τ is integration time. Using the design described here, such a system will cost less than US\$64K for $B = 34$ kHz processed bandwidth, and the cost will scale linearly with B. With such a system, the strongest ($\sim 10^{-23}\ \mathrm{W\ m^{-2}\ Hz^{-1}}$) astrophysical sources are detectable within $\tau \sim 30$ s.

II. System Description

A block diagram is shown in Figure 1(a). A brief description is given below; for additional details see [7].

Antennas: An Argus antenna (see Figure 1(b)) is a singly-polarized planar spiral on a printed circuit board, suspended above a multi-tiered ground plane of three concentric rings. This results in a very broad pattern with low gain at and below the horizon. VSWR is better than 2.5:1 from about 900 MHz to 1700 MHz.

Receivers: Embedded in each antenna is a custom uncooled low-noise amplifier (LNA) using the Agilent ATF-34143 PHEMT. This LNA achieves about 15 dB gain, 170°K noise temperature, and an input 1-dB compression point of -5 dBm over the bandwidth of the antenna. The output of the antenna unit is routed to a nearby line amplifier of custom

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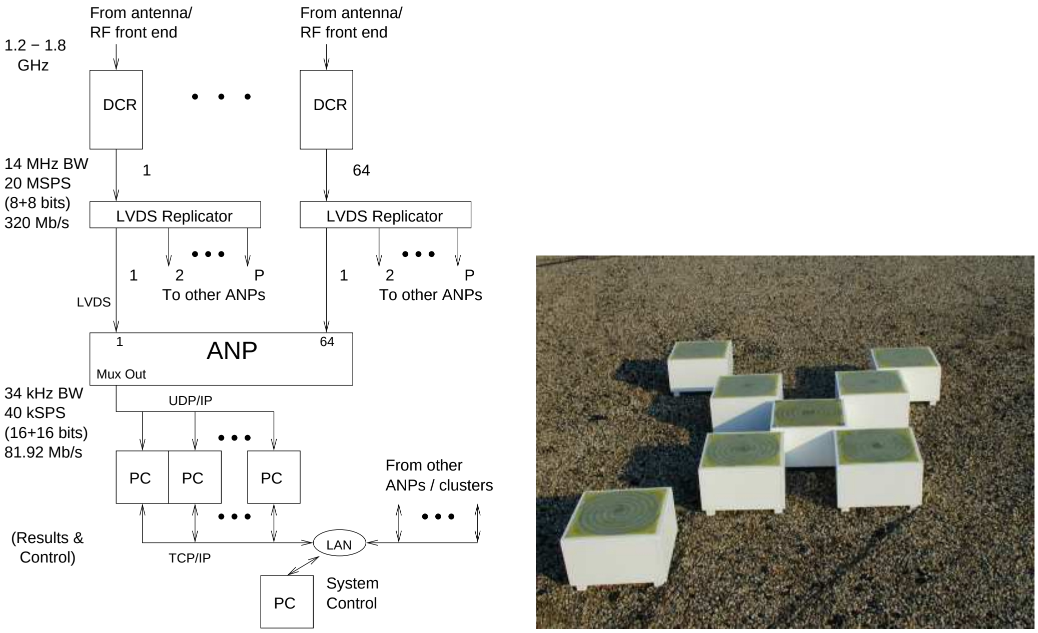
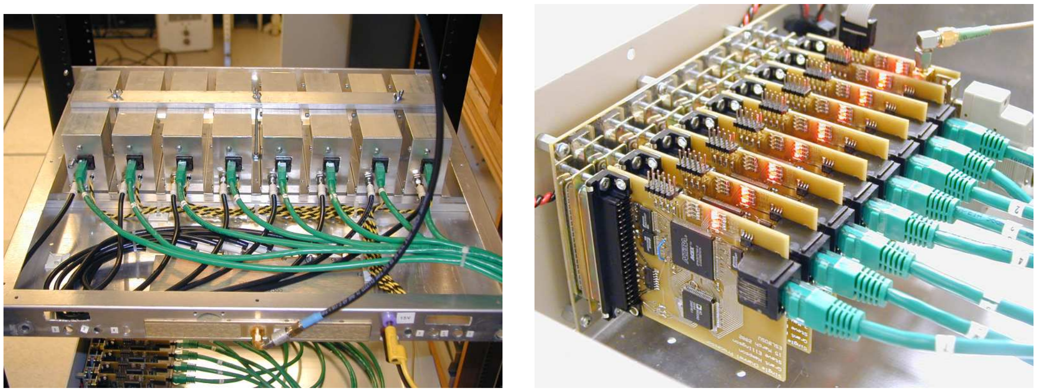


(a) (b)

Fig. 1. (a) System architecture. (b) Some antenna units. Each antenna is about 13-in square × 8-in high, and is enclosed in a box.



(a) (b)

Fig. 2. (a) A tray of 8 DCRs. (b) An ANP consisting of 8 (of a possible 64) DRP cards + 1 output (to PC) card.

design, which provides an additional 20 dB of gain for the long cable to the receiver, as well as being the source of power for the LNA via a bias-tee arrangement. Indoors, a custom-designed direct conversion receiver (DCR; see Figure 2(a)) is used to convert a 14-MHz swath of spectrum from within the L-band tuning range into a complex-valued digital signal consisting of 8-bit + 8-bit samples at 20 MSPS. This in turn is converted into a 320 Mb/s serial data stream for transmission using Low-Voltage Differential Signaling (LVDS). The LVDS output signal from each DCR is carried using off-the-shelf CAT-5 ethernet cable.

Argus Narrowband Processor (ANP): An ANP accepts the output from up to 64 DCRs. A functional block diagram is shown in Figure 3 and a picture is shown in Figure 2(b). An ANP selects a swath of about 34 kHz from the 14 MHz passband for further processing, organizes the array output into snapshots (sets of samples consisting of one sample from each element of the array taken at the same instant), and broadcasts the snapshots across

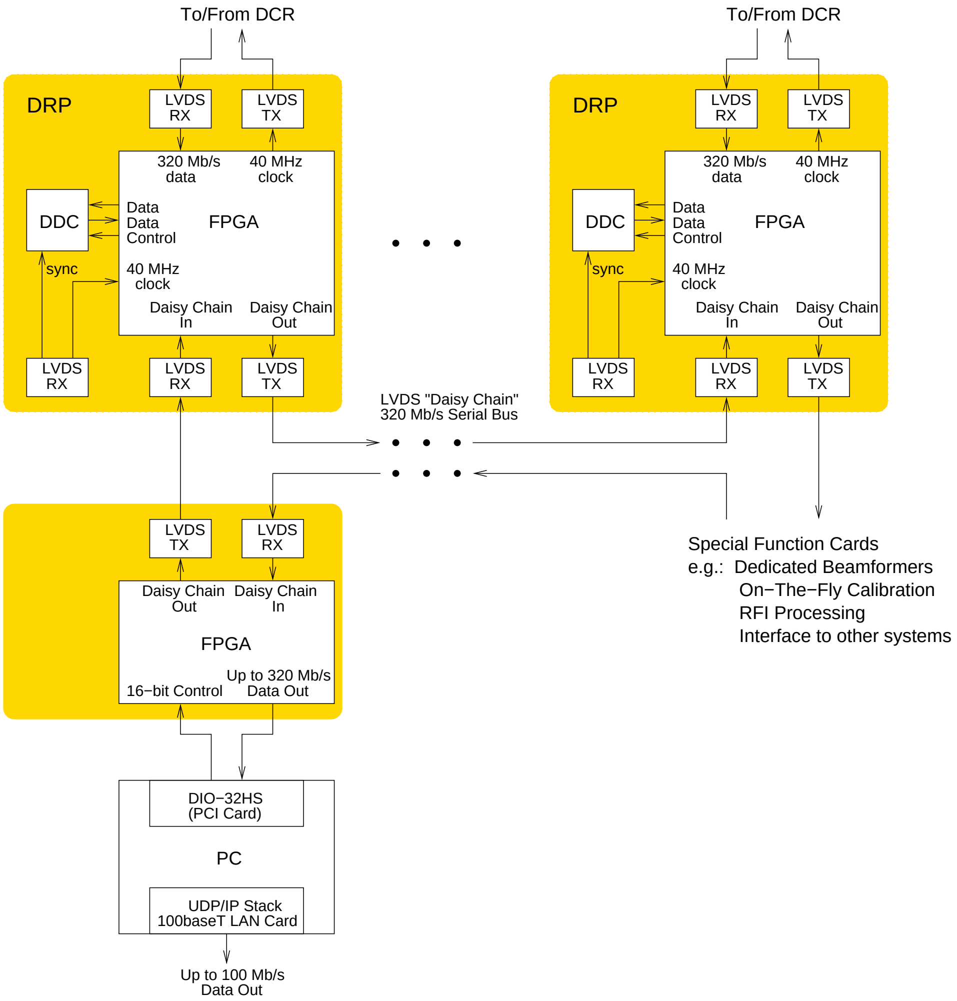


Fig. 3. The Argus Narrowband Processor (ANP). DRP = Digital Receiver/Processor. DDC = Digital Downconverter (the Analog Devices AD6620).

a 100baseT ethernet network using UDP/IP. The daisy chain architecture of the ANP is actually capable of greater decimated sample rates internally, but 40 kSPS × 32 bits/sample × 64 elements = 81.92 Mb/s, which is close to the 100-Mb/s limit of the 100baseT output path. Although the bandwidth processed by the ANP is only about 0.2% of the DCR bandwidth, it is simple and inexpensive to "fan out" the LVDS output of the DCR as many times as necessary, as shown in Figure 1(a). The entire 14 MHz can in principle be processed simultaneously by replicating DCR outputs and implementing 412 additional ANPs and computing clusters. In addition, the daisy chain architecture of the ANP makes it straightforward to implement new functions using additional cards with the same size and electromechanical interfaces as the DRPs. Examples of possible in-line processing include on-the-fly calibration and algorithms for mitigation of interference. Such cards could also be used to provide a path out of the system which is transparent and non-disruptive to routine operations, for example to facilitate special, dedicated "back ends" for other applications.

Cluster Computing: The snapshots broadcast from the ANP are received by a cluster of PCs running Linux. The PCs are organized by the System Control PC (a single PC which has overall control of the Argus system) to acquire sets of contiguous snapshots and process them. Normally, the computational burden associated with processing a single ANP output will be more than one PC can handle. In this case, the System Control PC organizes the PC nodes such that they take turns accepting data from the UDP/IP broadcast. This concept was developed and demonstrated in [8]. The output from each PC in the cluster is limited to (nominally) infrequent detection alarms and periodic status/control traffic. This is handled using a separate TCP/IP LAN; i.e., each PC is dual-homed.

Signal Detection and Analysis: Since the bulk of the computational effort is implemented in PCs, there is great flexibility in implementing signal detection algorithms. Initially, we intent to concentrate on detection of ultra-narrowband tones and astrophysical pulses, as discussed in Section I. One approach for this is to form a set of beams covering the entire sky, and then to apply tone and pulse detection algorithms to the beam outputs independently [5]. We have developed several methods for achieving this in a computationally-efficient manner, including simultaneous nulling of radio frequency interference (RFI) [9], [10]. However, the "beamforming first" strategy requires accurate calibration, which is quite difficult to achieve in a large, distributed array. Therefore, we are also considering an alternative approach which does not require calibration to achieve detection, yet achieves almost the same sensitivity [7]. Using this strategy, calibration is still required to determine direction of arrival (DOA); however, the calibration procedure does not need to be initiated until a detection occurs, and a less-comprehensive calibration that simply localizes the DOA to a patch of sky is sufficient.

III. Current Status

This project has been underway since 1998 and the system described above is in fact the third generation of design and implementation. As of January 2003, we have built for the project 24 antenna units, 18 LNAs with line amplifiers, 10 DCRs, and a single 8-channel ANP with an attached cluster of 5 PCs. The antenna units, LNAs, line amplifiers, and DCRs have been extensively tested and have in fact been successfully employed in a number of other radio astronomy and remote sensing projects at ESL. An 8-input ANP and computer cluster has been constructed and successfully tested in a lab environment. Current design information, construction progress, and interim results are publicly available at `http://esl.eng.ohio-state.edu/∼swe/argus/docserv.html`.

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