FIRST CELESTIAL MEASUREMENT RESULTS OF THE THOUSAND ELEMENT ARRAY

J. G. Bij de Vaate[(1)], G.W. Kant[(2)], W.A. van Cappellen[(3)], S. van der Tol[(4)]

ASTRON, Oude Hoogeveensedijk 4, 7991 PD, Dwingeloo, The Netherlands

E-mail: vaate@astron[(1)], kant@astron.nl[(2)], cappellen@astron.nl[(3)], tol@astron.nl[(4)]

ABSTRACT

A phased-array demonstrator known as the Thousand Element Array (THEA) is currently under construction of which the first celestial results with a single tile are presented in this paper. THEA is an out-door phased array system that is able to detect signals from different strong astronomical sources simultaneously (multi-beaming). It consists of sixteen one square meter tiles (arrays) operating in the frequency band of 600-1700MHz. The beamforming for THEA is done at two levels; Radio Frequency (RF) beamforming on every tile (64 elements) and digital beamforming with the sixteen tiles [1]. A sky image shows satellite detection in the RF signal. The sun is detected with the auto correlator back-end

INTRODUCTION

The international radio-astronomy community is currently making detailed plans for the development of a new radio telescope: the Square Kilometer Array (SKA). This instrument will be two orders of magnitude more sensitive than telescopes currently in use. ASTRON is in the process of establishing phased array technology, which is particular attractive for the 200-2000MHz frequency range of SKA. For this a number of prototype systems have been build, an 8-element Adaptive Array Demonstrator (AAD) and a 64-element One Square Meter Array (OSMA)[2]. Phased arrays have the advantage of multi-beaming and interference rejection - both of major interest in current radio astronomy. Multiple beams not only allow more users on the system at the same time, but also create possible observations which cannot be done with traditional instruments. Each THEA tile can form two independent RF-beams from which 32 finer dependent digital beams can be formed when the signals of the 16 tiles are combined in the digital beamformer. Adaptive digital beamforming has been implemented.

IMPLEMENTATION

Front-end

The antenna element designed for THEA is a taper slot Vivaldy element with a close to two octaves wide bandwidth[3]. The antenna is followed by a Low Noise Amplifier (LNA) with a 40 Kelvin Noise Temperature at room temperature. After the LNA the signal is splitted to create the two beams. A Vector Modulator subsequently takes care of the Phase and Amplitude modulation. RF combining networks create the RF signal, which is down converted and digitized with 40MHz 12 bits Analogue to Digital Convertors. The digital output of each beam is transmitted to the THEA back-end with a 1.2Gb/sec fiber link.

The tile, realized for THEA, is a low cost casted epoxy structure. Fig.1 gives a photograph of 4 tiles, covered with a radome. Besides the tile also compact low cost has been pursued with the design of units as the column board, containing the antenna, LNA and Vectormodulators, and the IF receiver unit. For all these parts, multiplayer boards have been designed that combine the RF electronics, the digital control electronics and the power supply distribution. The column board e.g. is a 8 layer board with 2 microstrip layers on the outsides (two times signal and ground) and 4 layers inside for power supply and control. For the connection to the row board a single multipurpose connector has been used. Fig. 2 give a picture of the board. With these board designs a significant step has been made in direction of low cost front-ends that

Fig. 1. Four THEA tiles in a compact setting, covered with the protecting radome

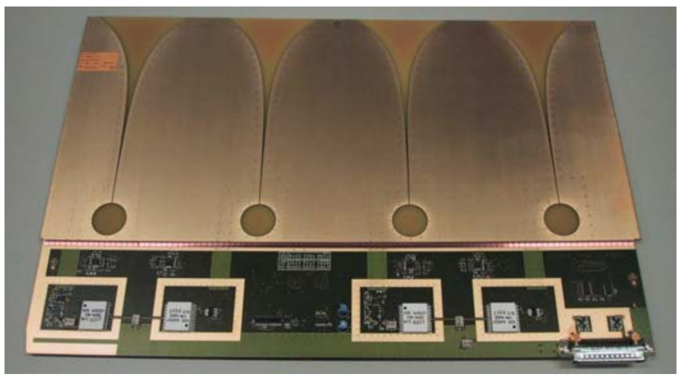

Fig. 2. A picture of a column board, with 4 antennas, amplifying and beamforming network

are affordable on the SKA scale. The parameters of the dual receiver chain are controlled with a Front-End Controller (FEC). The FEC sets the vectormodulators on the columnboards and the parameters for the receiver unit. It is capable of the storage of 1200 pre-calculated beams, which allows fast beam switching, of interest for the deterministic nulling of moving interferes e.g. satellites. For the power supply of all the units, a DC-DC convertor has been used. It creates the required voltages out of a 48 DC supply.

Back-end

In the (digital) data processing of the THEA, two major parts can be distinguished, see also the blockdiagram in fig. 3: the Adaptive Digital Beamformer (ADBF) and the Reduction and Acquisition unit (RAP). The ADBF consists of the Adaptive Weight Estimator (AWE) and the actual digital beamformer. The RAP consist of a memory / beam selection board and a digital signal processing board.

The incoming 1.25Gbit/s serial data stream on the fibers is converted to parallel on the High Speed Link (HSL) receiver. In order to handle the resulting parallel lines, up to 400, a high density connector is used in combination with a dense ‘sandwich’ structure: the HSL fiber receiver board is plugged directly on the DBF while the DBF is placed on top of the RAP unit, fig.4 gives a picture of the three boards. The complete assembly is mounted in an industrial PC in a standard PCI slot. The final output of the system is then stored on a hard-disk or on storage CD’s.

The Digital Beamformer is controlled by the AWE. The AWE determines from snapshots of the raw data the optimal, in terms of RFI suppression, complex weights of the DBF. For RFI studies and multi-beam experiments, memory has been placed on the selection board. With this memory 16 channels (beams) can be stored for 0.8 seconds or one channel for 12 seconds.

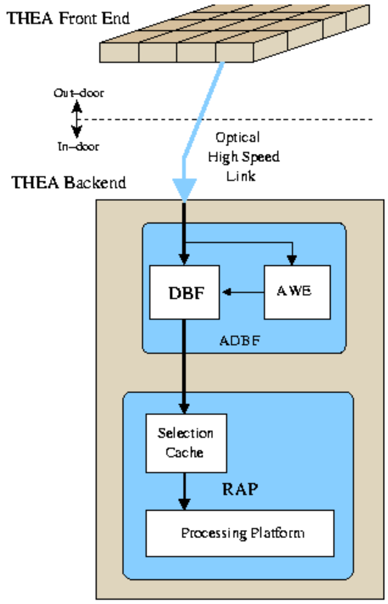

Fig. 3. Block diagram of the THEA system

Fig. 4. Photograph of the High Speed Link Receiver, the Digital Beamformer and the Selection board

The processing unit performs a 1024 points FFT. The number of integrations can be set with a minimum of 32 spectra (100µs) and a maximum of 4000 spectra (100ms). With post processing the integration time can be enlarged up to 1hour. The processing unit is capable of performing autocorrelations of two channels simultaneously or complex cross correlations of two independent channels, with a bandwidth of 20MHz.

SYSTEM TEST

A first quarter of THEA (4 tiles) has been produced. Calibration of a phased array system is a crucial step. For this a Phase Toggling Technique has been developed [4]. The verification of such processes was traditionally only possible by measuring beam patterns. However, the calibration accuracy of each individual element could be verified using a Planar Near Field Scanner. With the scanner, data are taken and transferred into a holographic view of the aperture of the array. Additionally the scanner data are transferred to provide far field beam patterns [5].

Since the indoor measurements are on a single tile level in an artificial environment, a re-calibration is required when tiles are combined and placed outside. In particular, truncation effects change the antenna behavior [6]. A reference source, placed in a nearby mast, has been used to perform a re-calibration at the antenna platform, again using the phase toggling technique.

RESULTS

A strong far field source in the THEA band is the recently launched digital radio satellite. Afristar transmits a carrier with modulation at 1480MHz. The satellite is geo stationary and could in principle be used for the calibration of the system as well. Fig. 5 shows the signal levels at 1480MHz of one tile, where the satellite shows up at 26^o elevation and 165^o azimuth. Some basic array aspects are demonstrated with this measurement. Due to the spacing of the array, $\lambda/2$ for 1200MHz, on a rectangular North-South grid, we expect afristar also to be observed in a grating lobe when the array is pointed at 15^o azimuth. The beamwidth for the 1 meter tile can be calculated width $\theta_{HP}=\theta_0/\cos(\theta)$, where θ_{HP} is the half power beamwidth and θ_0 is equal to 17^o at 1480MHz for this aperture. The resulting beamwidth of 23^o can be seen in the measurement. A demonstration of the capabilities of detecting an astronomical source is given with the detection of the power spectrum of the sun, plotted in fig. 6. With an on off measurement, a clear detection of the (very) strong signal of the sun is measured with the digital auto correlator back-end.

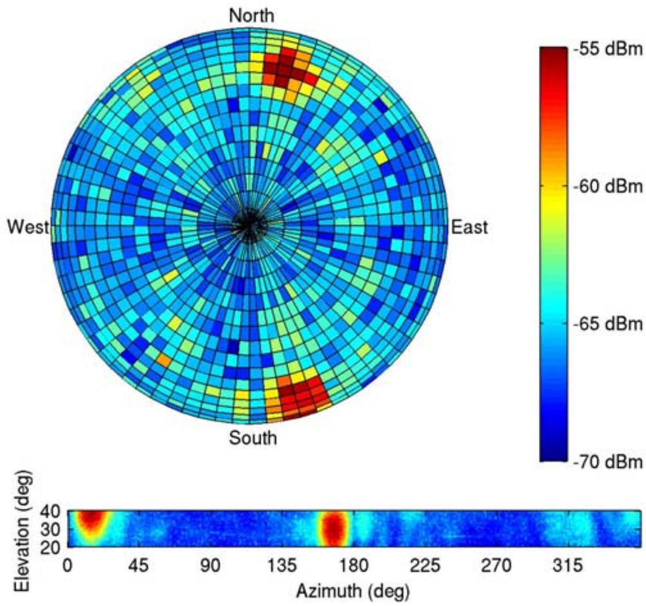

Fig. 5. Power levels of the afristar satellite in a full sky u-v plot and in an azimuth-elevation subsection

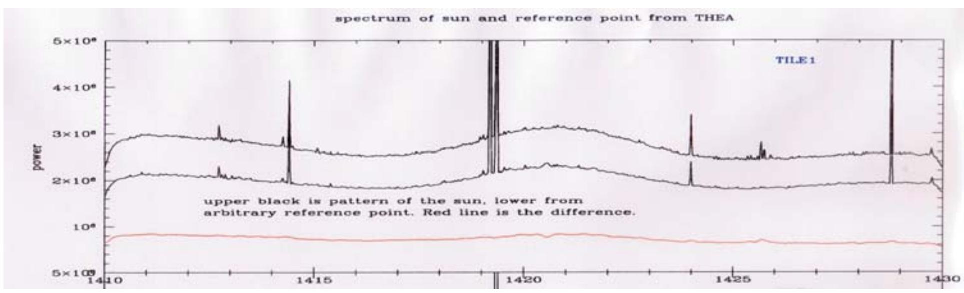

Fig. 6. On-Off power spectrum measurement of the sun

CONCLUSION

The first celestial observations including the sun are presented of a proto-type phased array system intended to demonstrate the potential of this concept for application in the Square Kilometer Array. These are the first results of a full scale phased array designed for radio astronomy.

REFERENCES

[1] A. B. Smolders and G.W. Kant , “Thousant Element Array (THEA)”, *IEEE Int. Conf. on Antennas and Propagation*, Toronto, Canada, July 2000

[2] A. van Ardenne, A. B. Smolders, and G. A. Hampson, “Active adaptive antennas for Radio Astronomy; results for the R&D program towards the Square Kilometre Array”, *SPIE conference*, Munich, Germany, March 2000

[3] A. B. Smolders, J G Bij de Vaate, G. W. Kant, A. van Ardenne, D. Schaubert and T. H. Chio, “Dual-beam Wide-band Beamformer with Integrated Antenna Array*”, IEEE Millennium Conference on Antenna & Propagation*, Davos, Switzerland, April 2000

[4] G.A. Hampson and A. B. Smolders, “A Fast and Accurate Scheme for Calibration of Active Phased-Array Antennas”, *IEEE Int. Conf. on Antennas and Propagation*, Orlando, USA, pp 1040-1043, July 1999

[5] G. A. Hampson and J. G. Bij de Vaate, “Verification of THEA Tile Calibration and Beamforming Results using a Near Field Scanner”, *IEEE European Microwave Conference*, London, UK, Vol. 3 pp 141-144, Sept. 2001

[6] C. Craeye, M. J. Arts and J. D. Bregman, “Truncation Effects in Tapered-slot Antenna Arrays for Radio Astronomy Applications”, *URSI 2002*, Maastricht, The Netherlands, Aug. 2002