

## Digital Beamforming for Parabolic Reflector Focal Plane Phased Arrays

### Introduction

Wide field imaging in radioastronomy is becoming an important driver for next generation radio telescopes. An emerging concept to achieve wide fields of view is an antenna system with a phased array at the focus of a parabolic reflector to extend the field of view. The signals from the phased array elements are beamformed to generate multiple independent beams. A digital beamformer for the concept is currently being designed. The beamformer processes one Terabit/sec of data requiring a computation capacity of ~10 Tera operations/sec.



### Digital Beamforming

A large array of reflectors, each with a phased array at its focus, as shown above, can be used to form a synthesis telescope. With the phased array at its focus each antenna can generate multiple independent beams on the sky and for each corresponding beam a correlation is formed between every possible pair of antennas. The Fourier transform of this data generates a high resolution image of the sky. With multiple beams large areas of sky can be mapped rapidly.

In such a system, there will need to be a digital beamformer for each of these reflectors. The optimum beamformer or combiner to form the multiple optimised beams for each reflector will need to perform accurately weighted summations of order 10-40 elements depending on the frequency of operation. Errors in this crucial beamforming operation will directly impact on the overall imaging fidelity and dynamic range of the complete telescope.

Various measures of optimality including maximum gain and minimum noise are shown to directly impact on the beamformer size and achievable field of view. The maximum gain optimum, or conjugate match to the focal fields, forms one solution. In practice this is modified so as to minimise the noise pick up due to spillover and other noise contributions. The beamformer weights needed to satisfy the optimum solution vary both with frequency and element location.

Existing arrays of receptors are also subject to variations with frequency due to the reflector imaging, intra-element coupling and matching of the receptors to free space and to electronic low noise amplifiers. They are also subject to gain and phase variations in time resulting from a number of causes.

An important requirement is the ability to calibrate and correct any variations to ensure the resulting beams are known and constant to a high degree of accuracy. For this reason digital processing is chosen to minimise the number of potentially variable elements and provide maximum flexibility in the application of corrections.

### Digital Beamforming for the xNTD

The Australian xNTD project proposes the use of focal plane phased arrays with 100 dual polarised elements and a bandwidth of 300 MHz. The resulting data rate input to each beamformer is 1 Terabit/sec and the beamformer requires approximately 60 multiplies per input sample to produce up to 40 output beams. This is now cost-effectively achievable using latest generation FPGA technology, as described in more detail in a companion paper at this conference (Bunton et al, "NTD/KAT Beamformer — A Terabit/s DSP Engine").

A beam is formed by taking a weighted sum of the digitised signals from the focal plane array antenna elements. These weights are complex and vary with frequency. Digital Polyphase Filter Banks are used to divide the 300 MHz band into 20 MHz bands. This is sufficiently narrow to allow simple multiply and add beamformer topology to be used. The components of a digital polyphase filter bank (FIR filter and FFT) can easily be implemented in an FPGA, and the simple weight and sum process for the beamforming can also be readily implemented in FPGAs. The filterbank scheme is also used to further divide the signals into the 5 to 10 kHz frequency resolution required for the xNTD specifications. All of this processing can occur in the xNTD digital beamformer.

### Conclusion

By digitising the signals as early as possible, maximum advantage can be obtained from the use of digital processing architectures. We have seen that a digital beamformer allows the correction of a number of frequency dependant errors and allows flexibility in calibration procedures. Additionally, the use of FPGAs allows a single hardware module to be developed that can be used for a number of different FPGA-based processing tasks. A companion paper at this conference shows how this is done in the xNTD project to provide the processing tasks mentioned in this paper as well as those required for the station correlator.

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