Introduction to FPGAs & DSP in Radio Astronomy

Jack Hickish

Cavendish Laboratory, University of Cambridge
Outline

Radio Astronomy
  Why Radio Astronomy?
  Technology in Radio Astronomy
  Signal Processing in Radio Telescopes

Building DSP systems for Radio Telescopes
  System characteristics
  Design Examples
  FPGA Hardware
Outline

Radio Astronomy

Why Radio Astronomy?
Technology in Radio Astronomy
Signal Processing in Radio Telescopes

Building DSP systems for Radio Telescopes
System characteristics
Design Examples
FPGA Hardware
Why Radio Astronomy?

Because Radio emissions show things other frequencies don’t.
Radio Astronomy

Why Radio Astronomy?

Technology in Radio Astronomy

Signal Processing in Radio Telescopes

Building DSP systems for Radio Telescopes

System characteristics

Design Examples

FPGA Hardware
Technology in Radio Astronomy

Large Dishes

Arrays of small telescopes

Phased Arrays

EXPENSIVE ELEMENTS

EXPENSIVE COMPUTATION
Outline

Radio Astronomy
  Why Radio Astronomy?
  Technology in Radio Astronomy
  Signal Processing in Radio Telescopes

Building DSP systems for Radio Telescopes
  System characteristics
  Design Examples
  FPGA Hardware
Beamforming

Take the power: \[ |v_1 + \phi_2 v_2 + \phi_3 v_3|^2 = \]
\[ v_1^2 + v_2^2 + v_3^2 + \phi_2^* v_1 v_2^* + \phi_3^* v_1 v_3^* + \phi_2 \phi_3^* v_2 v_3^* + \phi_2 v_2 v_1^* + \phi_3 v_3 v_1^* + \phi_3 \phi_2^* v_3 v_2^* \]
Beamforming

- Increase collecting area
- Reduce output data rate
- Reduce Field of View
- Steerable
- Can form multiple beams
Correlation

Beam power:

$$\sum_{\{i,j\}} \phi_i \phi_j^* v_i v_j^*$$
Correlation

- Calculate the product of all antenna pairs
- $O(N)$ antennas means $O(N^2)$ correlations
- Increase data output rate
- Maintain field of view
- Create images after averaging data
- Can form multiple beams
Channelisation

Signals also need channelizing to remove interference and observe the frequency-dependence of astronomical signal.
Outline

Radio Astronomy
Why Radio Astronomy?
Technology in Radio Astronomy
Signal Processing in Radio Telescopes

Building DSP systems for Radio Telescopes
System characteristics
Design Examples
FPGA Hardware
Building DSP systems for Radio Telescopes

- Large data input rates
- Large computation rates
- Simple operations
- Many common components between different telescopes
- Highly parallel
Building DSP systems for Radio Telescopes

- Large data input rates
- Large computation rates
- Simple operations
- Many common components between different telescopes
- Highly parallel
Building DSP systems for Radio Telescopes

- Large data input rates
- Large computation rates
- Simple operations
  - Many common components between different telescopes
  - Highly parallel
Building DSP systems for Radio Telescopes

- Large data input rates
- Large computation rates
- Simple operations
- Many common components between different telescopes
- Highly parallel
Building DSP systems for Radio Telescopes

- Large data input rates
- Large computation rates
- Simple operations
- Many common components between different telescopes
- Highly parallel
Outline

Radio Astronomy
  Why Radio Astronomy?
  Technology in Radio Astronomy
  Signal Processing in Radio Telescopes

Building DSP systems for Radio Telescopes
  System characteristics
  Design Examples
  FPGA Hardware
A Simple Spectrometer
A Multi-Antenna System
A Multi-Antenna System
A Multi-Antenna System
Outline

Radio Astronomy
Why Radio Astronomy?
Technology in Radio Astronomy
Signal Processing in Radio Telescopes

Building DSP systems for Radio Telescopes
System characteristics
Design Examples
FPGA Hardware
Digital Hardware
Field Programmable Gate Arrays

- Programmable arrays of logic elements, with configurable interconnect
- High Performance
- Low Power
- High Input/Output Bandwidth
Field Programmable Gate Arrays

MATLAB Simulink

XILINX ISE Design Suite
- Radio telescopes use multiple receivers to improve their ability to detect and measure astronomical signals
- In modern telescopes, this demands powerful DSP
- Many telescopes share common processing needs
- CASPER advocates the use of generic DSP architectures using commodity components (like ethernet switches)
- The collaboration provides all the libraries required to rapidly deploy large, scalable radio astronomy DSP systems