6º CONGRESSO
COMITÉ PORTUGUÊS DA URSI
16 de novembro de 2012, Lisboa
Aplicações das ondas eletromagnéticas: da eficiência energética à bioengenharia

Design of a novel X band digital receiver

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Summary

- Objectives
- Methodology
- Radio Astronomy as a top driver instrument
- Test Station Facilities
- Measurements
- Specifications
- Architecture
- Concluding Remarks

Objectives

- Development of a full digital polarimeter with high bandwidth and high resolution using COTS for:
  - Space Science
  - Radio Astronomy
  - Wide band Remote Sensing
  - Other Scientific Applications
- Using high performance SDR techniques
- Specifications:
  - Central Frequency: 10GHz
  - Bandwidth: 1GHz
  - 4 channels entering FPGA at 1Gsps
  - 32Gbps processing inside FPGA

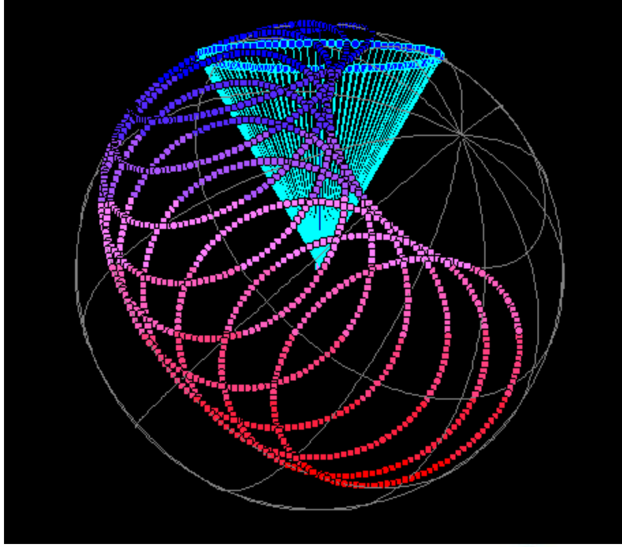
Methodology

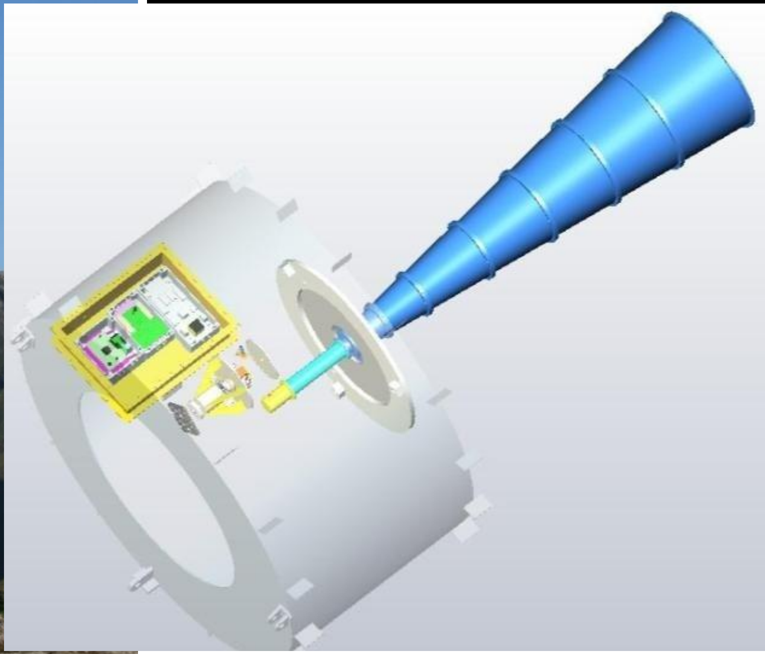
- Calculation of the Stokes-Parameters (circular polarization)
- Measure the change (ΔT) in the antenna equivalent noise temperature (T_A) which is extremely low .
  - Targets:
    - Sensitivity (ΔT) is 0.2 mK
    - Equivalent Temperature of the Receiver is 17 K
  - Center Frequency = 10GHz with 1GHz Bandwidth

Radio Astronomy top driver technology

- Evolution of pseudomorphic or metamorphic high electron mobility transistors (pHEMT and mHEMT) or by the heterojunction Field Effect Transistors (HBT FET) with both GaAs and InP technologies;
- Development of very high sampling rate ADC now pushing acquisition rate beyond 1 GS/s at reduced costs;
- FPGA developments with very high clock rates that can perform digitization, integration and correlation of the incoming signals.

Test Station Facilities





Measurements

Stoke Parameters

- Two waves:
  - Left hand polarization (LHCP)
  - Right hand polarization (RHCP)
- Each wave is represented by its complex Electrical Field (E_L and E_R).
- Polarization state of the incoming noise signal characterized by the Stokes Parameters

$$I = \langle E_R^2 \rangle + \langle E_L^2 \rangle$$
$$Q = 2\Re\langle E_R E_L^* \rangle$$
$$U = 2\Im\langle E_R E_L^* \rangle$$
$$V = \langle E_R^2 \rangle - \langle E_L^2 \rangle$$

The equipment that allows the measurement of these variables is called Polarimetric RADIOMETER

Measurements

- Each incident wave can be described by its equivalent complex electrical field.
- $E_L = a_L + jb_L$ $E_R = a_R + jb_R$
- Since each E_R/E_L is considered a random variable it is possible to expand the Stokes Parameters formula.

$$I = \langle E_R^2 \rangle + \langle E_L^2 \rangle$$

$$Q = 2\text{Â}\langle E_R E_L^* \rangle$$

$$U = 2\text{Á}\langle E_R E_L^* \rangle$$

$$V = \langle E_R^2 \rangle - \langle E_L^2 \rangle$$

$$I = a_R^2 + b_R^2 + a_L^2 + b_L^2$$

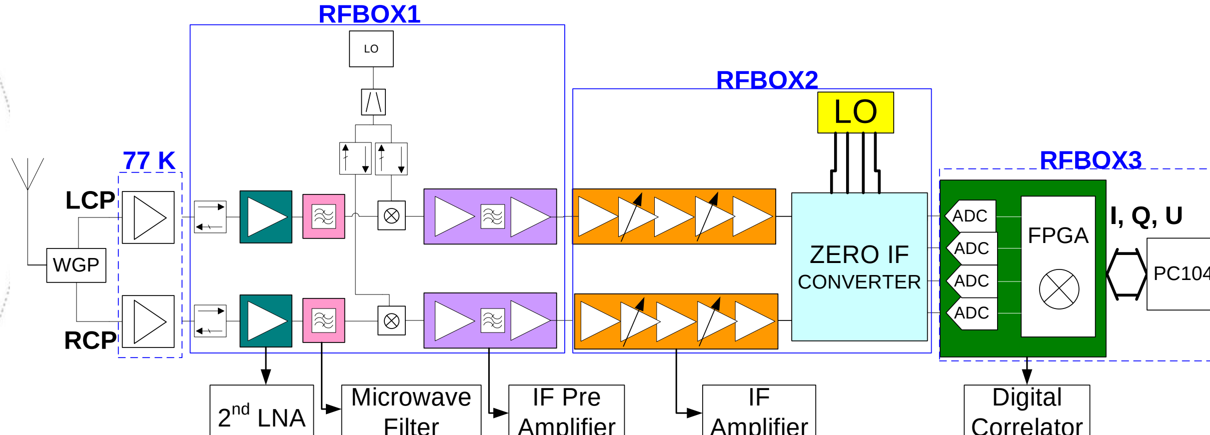
$$Q = 2\left(a_R a_L + b_R b_L\right)$$

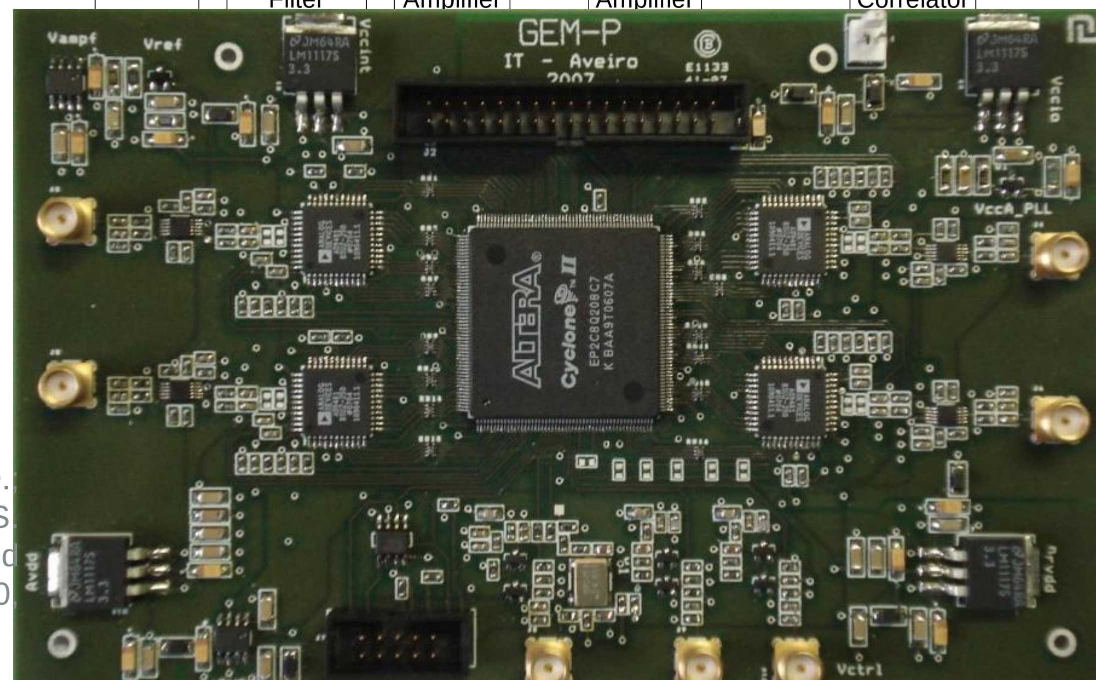
$$U = 2\left(a_R b_L + a_L b_R\right)$$

$$V = a_R^2 + b_R^2 - a_L^2 + b_L^2$$

A simpler alternative: previous developments

Full Digital Receiver Polarimeter at 5 GHz with 200 MHz bandwidth

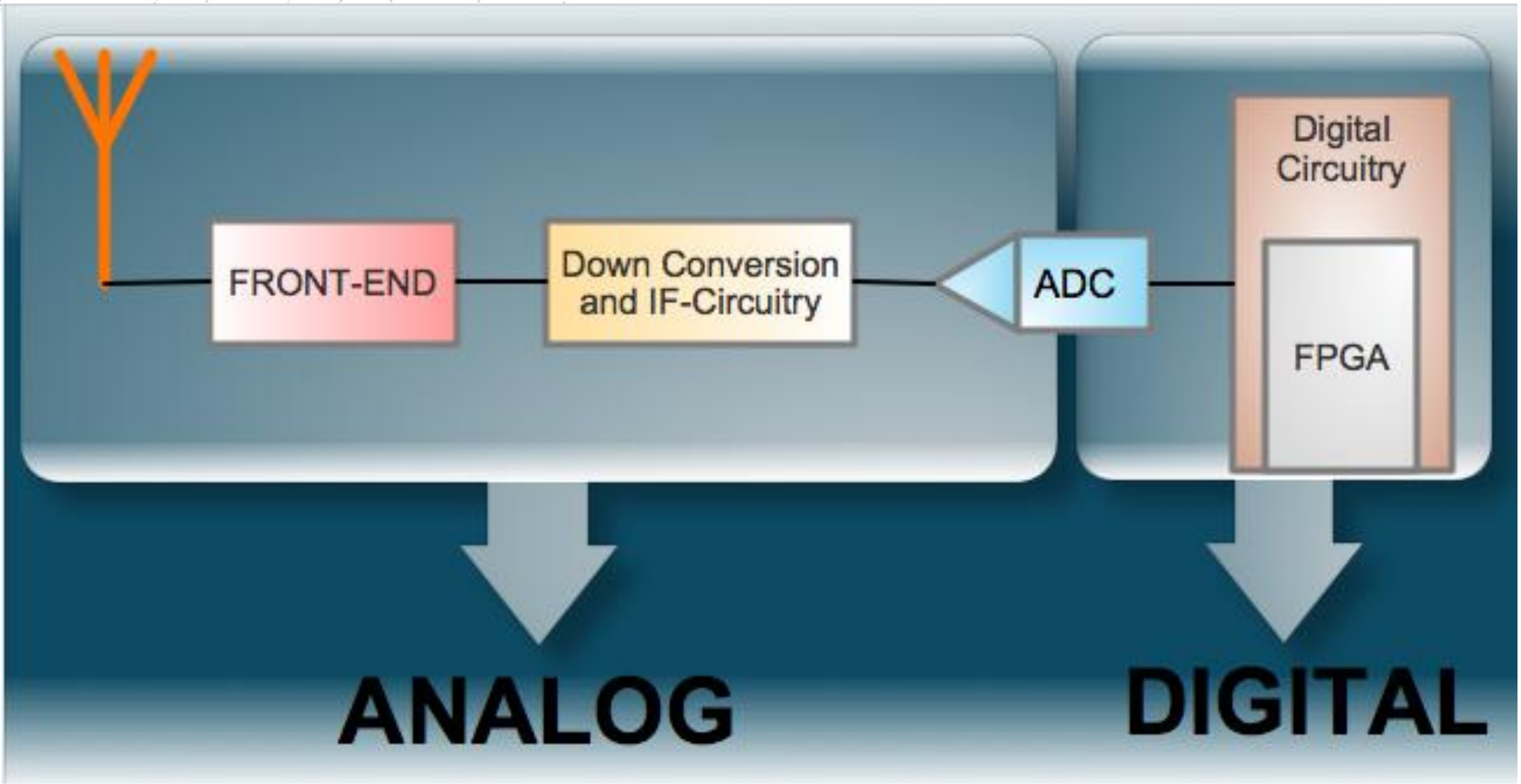




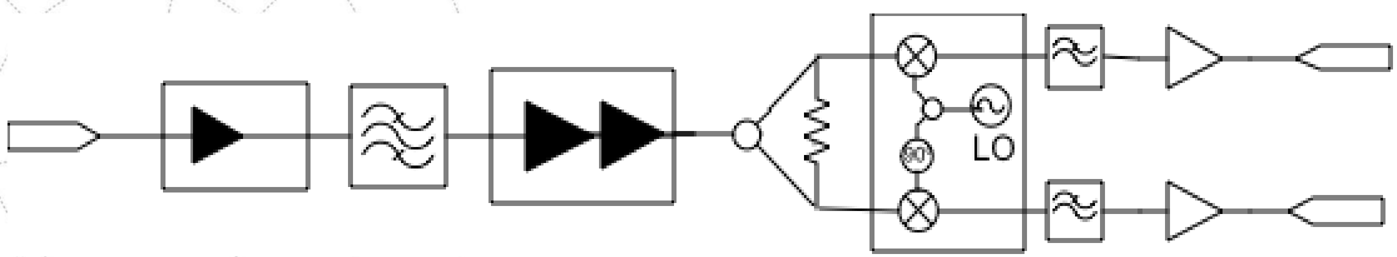
- Narrow band digital correlator using a low-cost Field Programmable Gate Array. This new digital backend comprises a base-band complex cross-correlator outputting the four Stokes parameters of the incoming polarized radiation.
- New Design under development: 10 times the bandwidth of this one

Bergano , JB; F. F. Fernandes; L. Cupido; Barbosa , D. R. Fonseca ; I. S. V. Ferreira; B. Grossan; G. F. S Smoot; "Digital Complex Correlator for a C-band Polarimetry survey", *Experimental Astronomy*, Vol. 30 No. 1, pp. 23 - 37, February, 2011.

Block Diagram - Proposal



Link/Power Budget

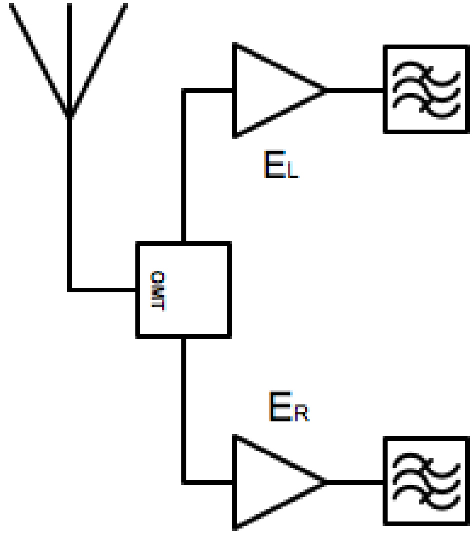


	Antenna	LNA	Filter	Mixer	Amplifier	LPF	ADC
Temperature (K)	30.00	3.00	55.38	1539.78	359.23	350.00	
NF (dB)		0.04	0.50	8.00	3.50	4.00	
Gain		35.00	-0.50	-8.00	65.00	-4.00	
Linear Gain		3162.28			3.16E+06		
Output Equiv. Temp (dBm)	-93.83	-58.83	-59.33	-67.33	-2.33	-6.83	-11.00

Resolution	25 arcmin
Target Instantaneous Sensitivity	1.3 mK $s^{-1/2}$

Front-end

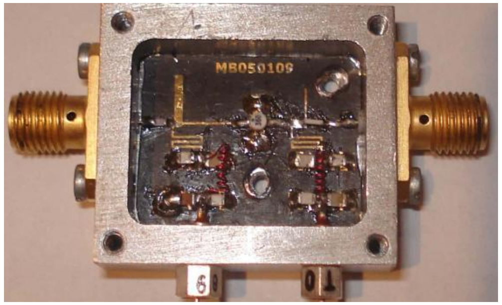
Front-end to obtain the four cartesian components (a_R, b_R, a_L, b_L)



LNA	RF Filter
LNF-LNC6_20A	Waveguide Resonator

- The LNA involves an evaluation stage:
  - New technologies (GaAs and InGaAs) transistors (mHEMT and pHEMT) from the main providers (Fujitsu, Avago… and Mitsubishi)
  - HJT FET will also be considered

PREVIOUS DEVELOPMENTS

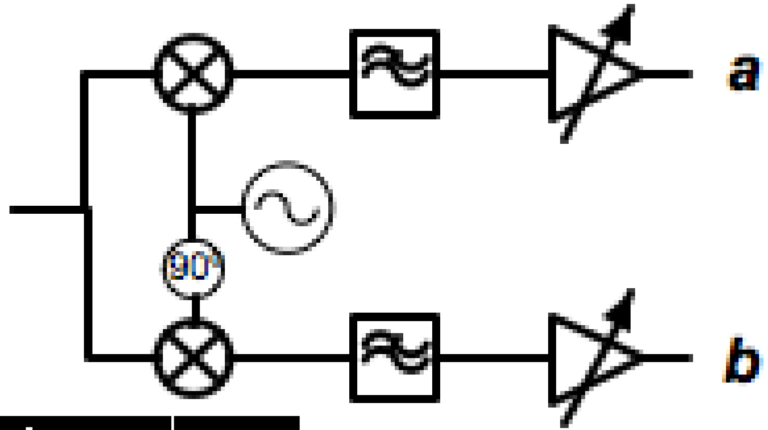


A C-band (5 GHz) Low Noise Amplifier (LNA) using new low noise Pseudomorphic High Electron Mobility Transistors (pHEMTS) from Avago. The amplifier was a cost effective solution in a receiver chain for Galactic Emission Mapping (GEM-P) project in Portugal and a solution to improve TSys

Bergano, M.; Rocha, A.; Cupido, L.; Barbosa, D.; , "A 5 GHz LNA for a radio-astronomy experiment," *EUROCON - International Conference on Computer as a Tool (EUROCON), 2011 IEEE* , vol., no., pp.1-4, 27-29 April 2011

Down-Conversion, IF Circuitry and Digitalization

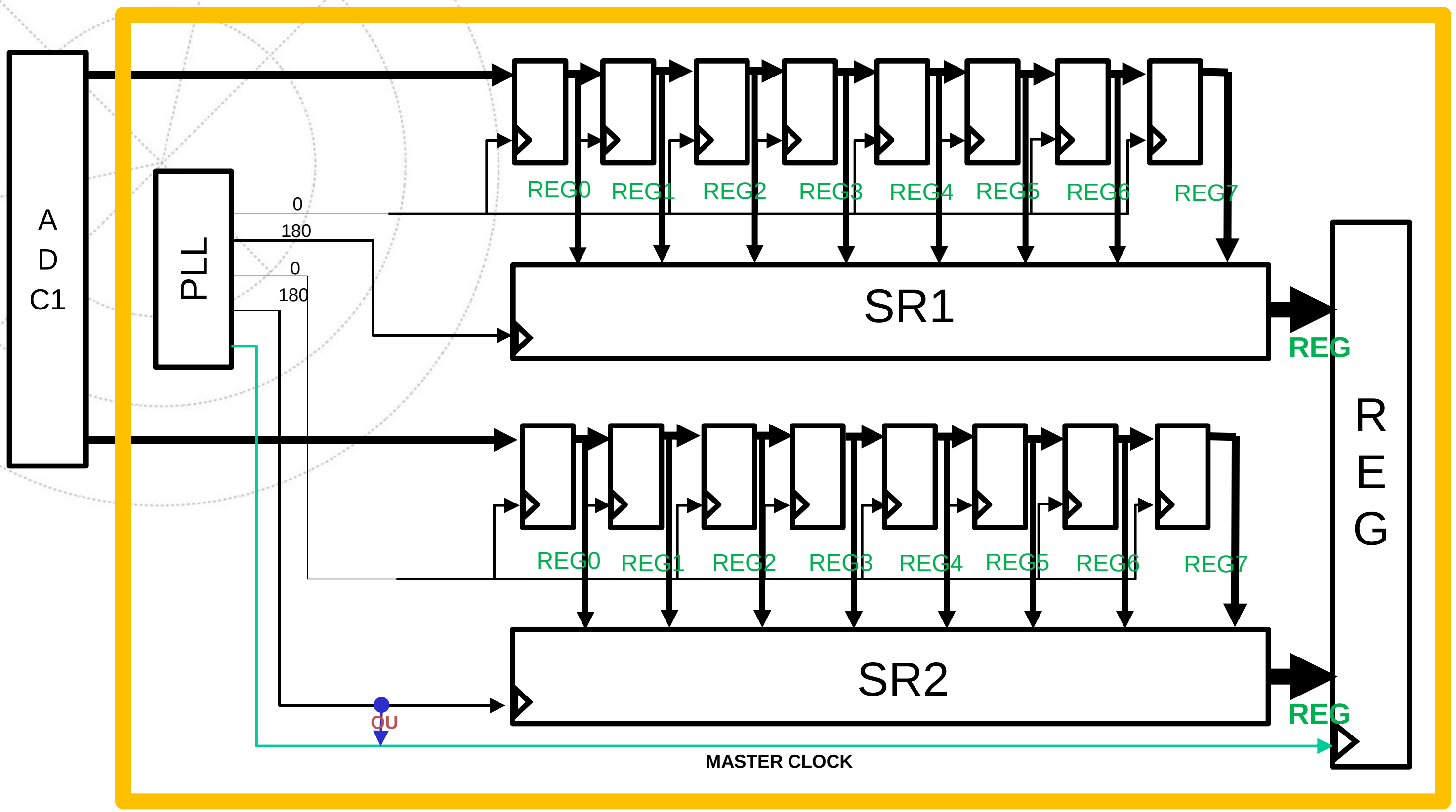
Mixer	LPF	Amplifier
SIM-24MH+ Minicircuits	Coupled Resonators	ERA Minicircuits



Reference	Res.	Max. Conv. Rate	Power Consumption		Dual
			Operating	PDM	
ADC081000	8 bits	1 GSPS	1.6W	3.5 mW	no
ADC08D1500	8 bits	1,5 (3) Gsps	1.8 W	3.5 mW	both
ADC10D1000	10 bits	1 (2) GSPS	1.6 (2.8) W	6 mW	both
ADC10D1500	10 bits	2 (3) GSPS	1.9 (3.6) W	6 mW	both
ADS5400	12 bits	1 GSPS	2.2 W	-	no
MAX104	8 bits	1 GSPS	4.9 W	-	no
MAX108	8 bits	1,5 Gsps	4.9 W	-	no
MAX109	8 bits	2.2 GSPS	5.9 W	-	no

For each polarization chain

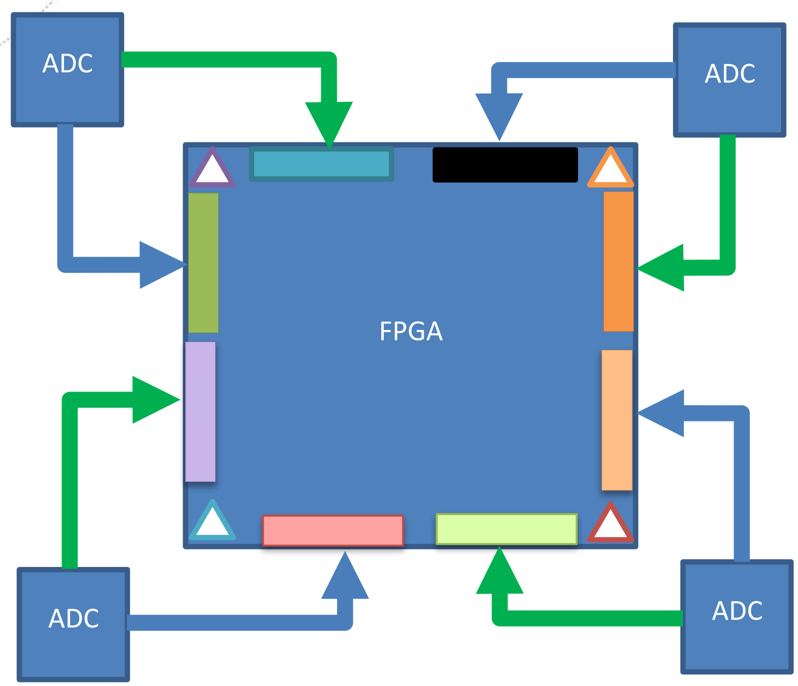
Digital Circuitry: Implementation of a Correlator



- Techniques to reduce FPGA signal processing rate
  - Serializer – converting a serial to several outputs
  - Clock sequential phasing
- Analyze merits of each solution

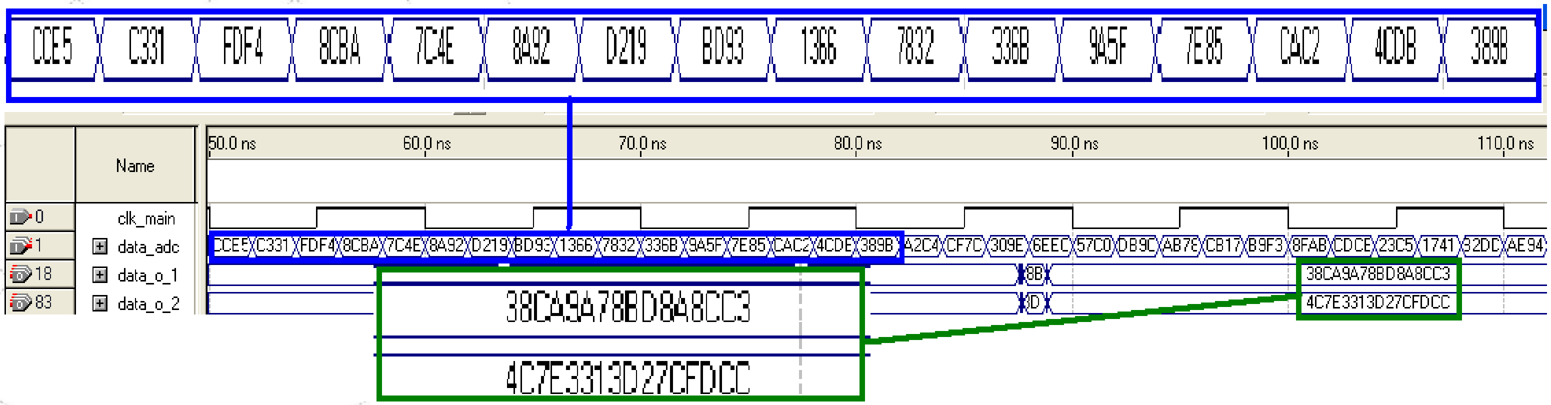
FPGA: Processing

- A 2 ns window of available data encompasses the use of serializers/deserializers.
- FPGAs ready to use this are extremely expensive.
- Constraints on the programming of VHDL
- Very low level hardware programming

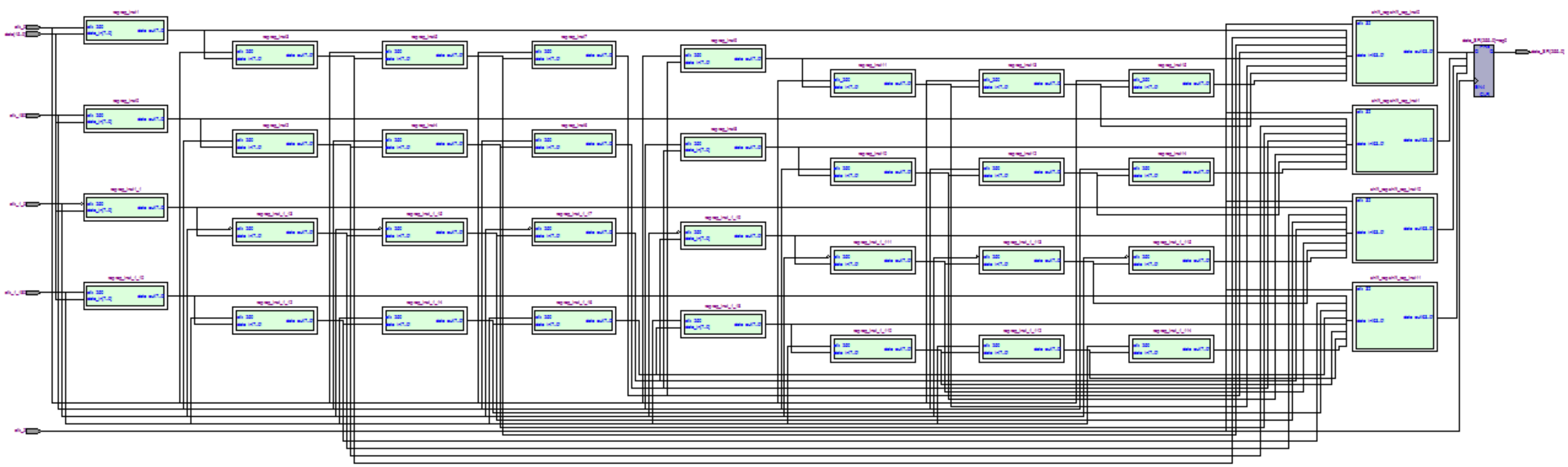


Simulations

FPGA: Cyclone III from Altera - EP3C55F484C6



RTL viewer



Conclusions

- A high performance correlator using COTS & adaptable to several scenarios (Measuring Cosmic Noise Signal Signatures, Remote Sensing, Space Science)
- Equipment complex and expensive – Several Architectures reviewed and compared
- Design of a novel very wide bandwidth X band digital receiver
  - Implementation of an innovative digital detector based on high data rate sampling and FPGA processing (using SDR techniques)
    - Approach relevant to other niches: Telecommunications and Earth-Sensing
  - Central Frequency: 10GHz
  - Bandwidth: 1GHz
  - 4 channels entering FPGA at 1Gsps
  - 32Gbps processing inside FPGA
- **Implementation – mid 2013**