

GEM Project, C-Band Polarimetry using a full digital correlator

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FCT Grants

- POCTI/CTE-AST/57209/2004
- PTDC/CTE-AST/65925/2006



Authors

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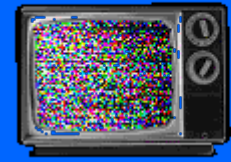
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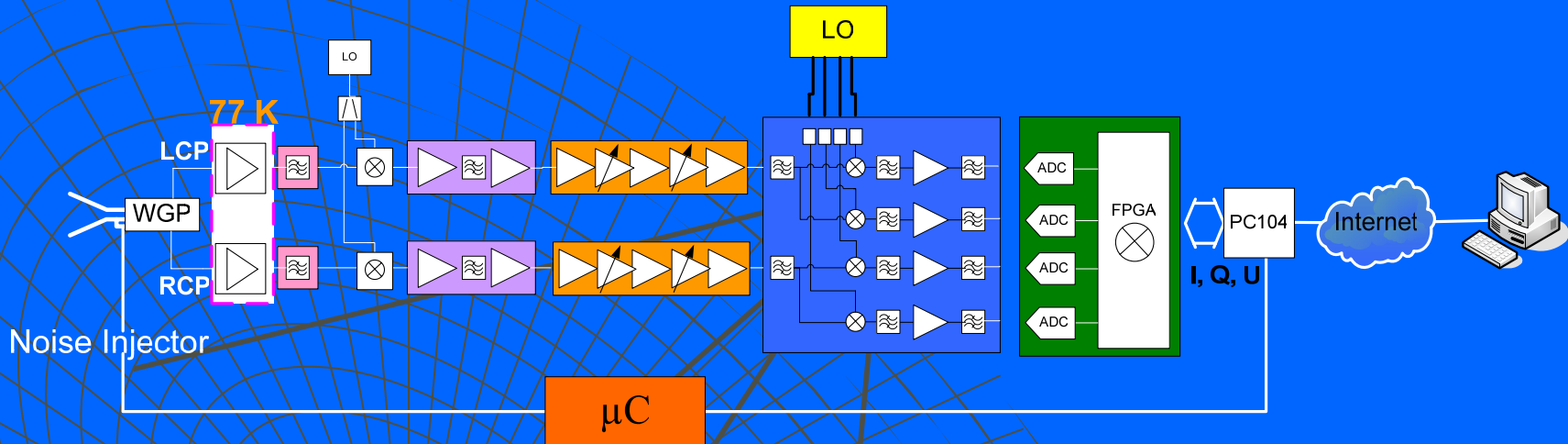
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Overview



- ◆ Unveil the Sky to CMBR;
- ◆ Applicable to a Galactic Experiment;
- ◆ High sensitivity radiometer;
- ◆ Superheterodyne Receiver with Double Down Conversion – Zero IF;
- ◆ IF chain developed and tested;
- ◆ Full Digital Back-end;
- ◆ Stokes Parameters Calculation.

Superheterodyne Receiver (Base-band Complex Correlator)



Novel approach to digital correlators!

The radiometer/polarimeter gain budget:

Antenna	LNA	Passive Filter	Mixer	IF Pre Amplifier	IF Amplifier	Converter	ADC
Input (dBm)	26	-4	-7	31	56	2	Output (dBm)
-105,6	-79,6	-83,6	-90,6	-59,6	-3,6	-1,6	-2

Receiver characteristics

- **Bandwidth of 200MHz around 4.9GHz; ADS designed**
- Tant ~10K - total power of -105.6dBm–TOTAL GAIN~104 dB;
- RF Cryogenic PHEMT InP LNAs (@ 77K);
- Image rejection filter;

- **Latest RF technology and microstrip lines**
- **SMD components; central freq. 600MHz**
- **Slope Compensation Network application;**
- Diode Mixers; IF Preamplifier – filter 31dB gain;
- IF Amplifier 71dB gain with digital control attenuator;
- Zero IF converter; **I/Q modulation per polarization**
- **Full Digital correlator:**
 - **ADC at 200 MSPS with 8 bits of resolution;**
 - **Altera Cyclone II FPGA working at 100MHz with Interleaving;**

IF part designed and tested

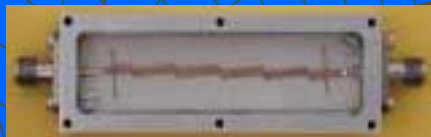
B=200MHz; 31dB; Butterworth
MMIC (best response flatness)



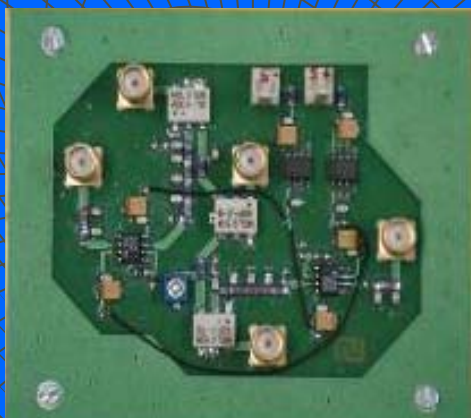
Flat gain; 71dB;
Digital attenuation



4.9GHZ; B=600MHz
Coupled Line filter



IF Chain+RF Filter



120dB isolation between ports



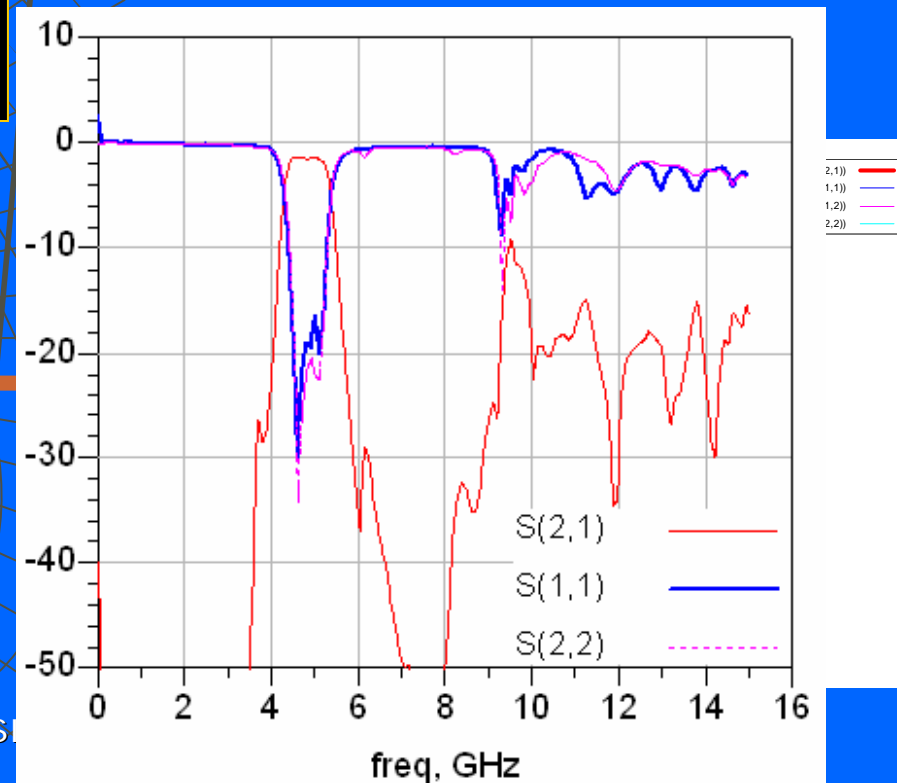
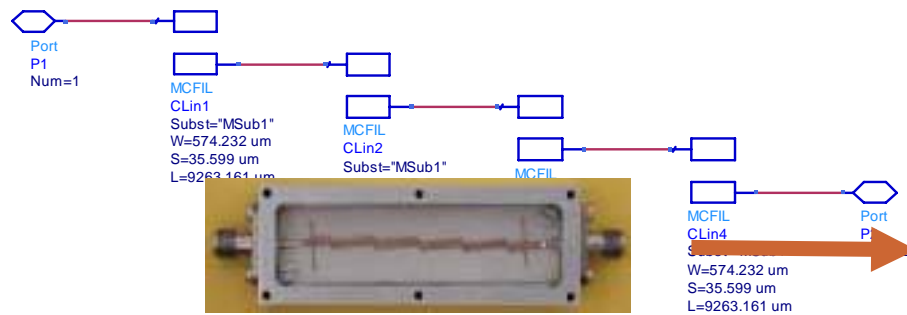
Frequency 600MHz; VCO; MMIC Amp.;
PLL synthesizer; 7dBm

Microwave Passive Filter

- ◆ Central Frequency = 4,9 GHz;
- ◆ Bandwidth = 800 MHz;
- ◆ Coupled Lines;
- ◆ ADS Design aided;
- ◆ Electromagnetic Simulation.

Substrate – RO4003C

Substrate Thickness	H	20 mil
Relative Dielectric Constant	ϵ_r	3,38
Conductor Thickness	T	0,35 μ m
Dielectric Loss Tangent	$\tan \delta$	0,0021



IF Pre - Amplifier

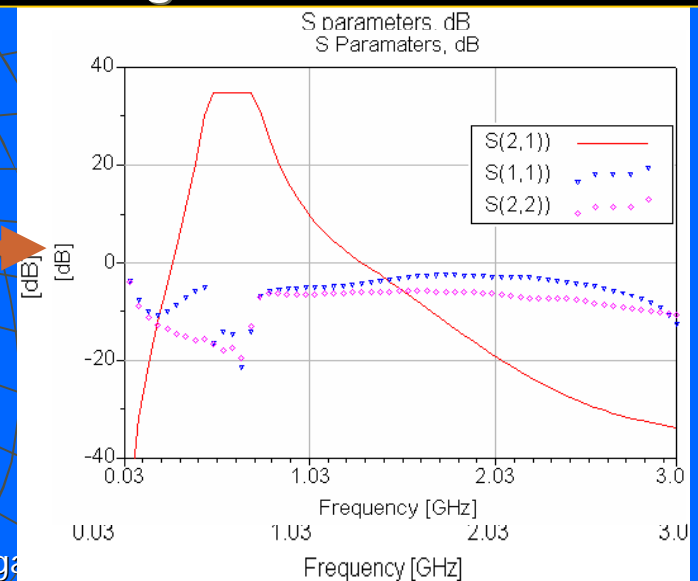
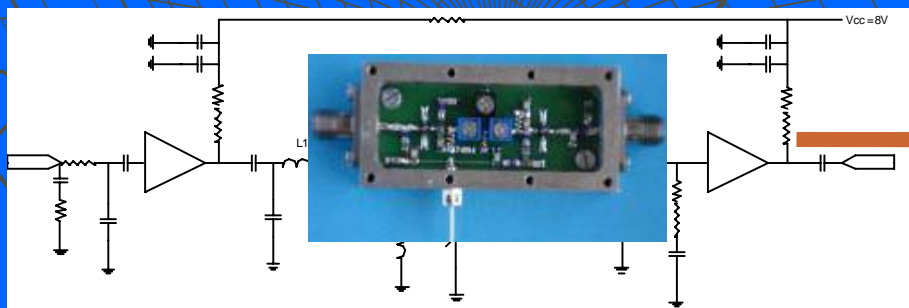
Amplifier

- ◆ Gain = 31 dB
- ◆ Slope Compensation Network;
- ◆ Gain variation with frequency;
- ◆ Gain variation with Temperature;
- ◆ S-Parameters Simulation.

Filter

- ◆ High Q filter;
- ◆ Central Frequency = 600 MHz;
- ◆ Bandwidth = 200 MHz;
- ◆ T configuration
- ◆ Butterworth Prototype;
- ◆ Hand made Inductances
- ◆ ADS Design aided;

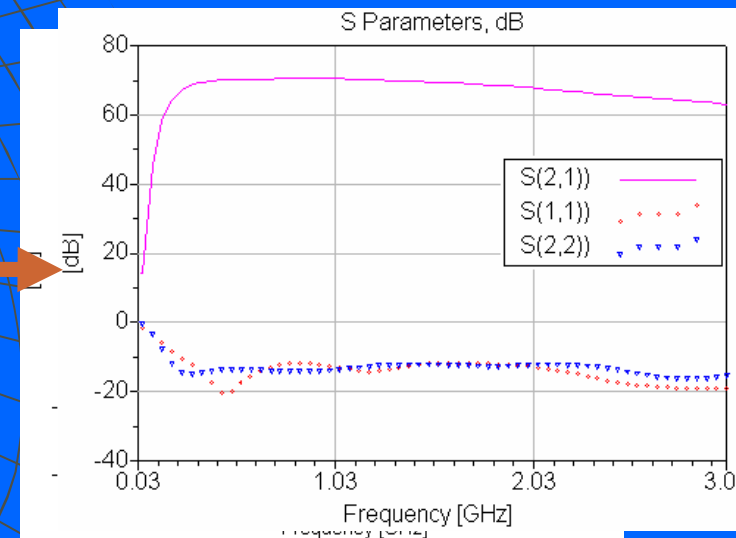
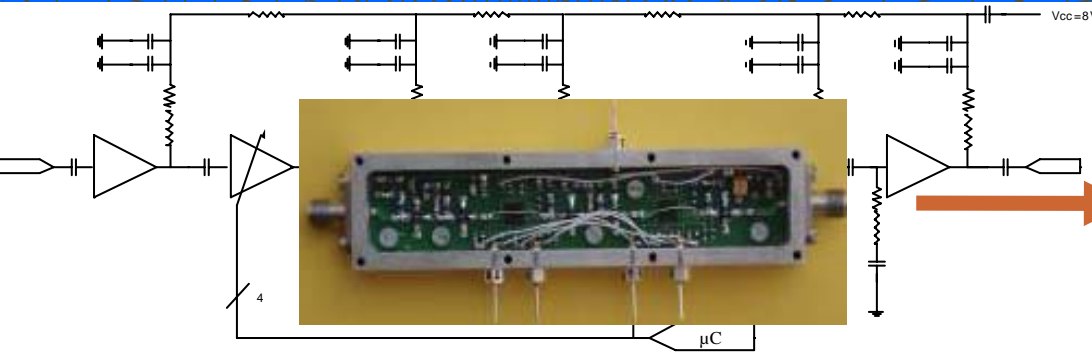
P1dB = -24 dBm



IF Amplifier

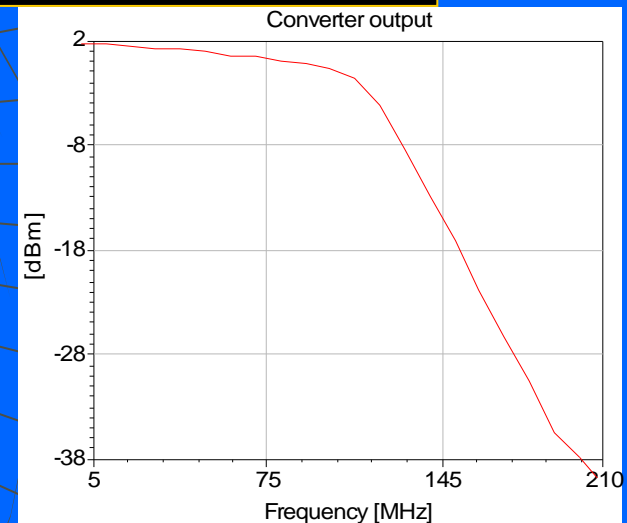
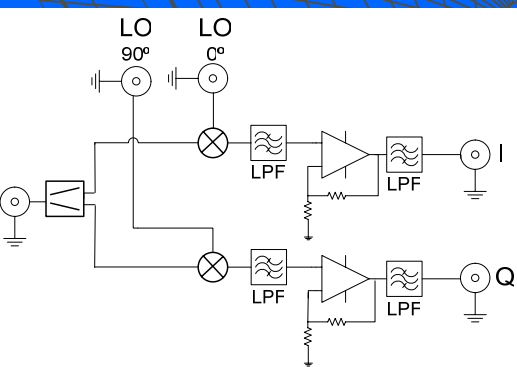
- ◆ Gain = 71 dB;
- ◆ Flat gain;
- ◆ Digital attenuation control;
- ◆ Slope Compensation Network;
- ◆ Gain variation with frequency;
- ◆ Gain variation with Temperature;
- ◆ S-Parameters Simulation.

P1dB = -61 dBm
IP3 = -41 dBm



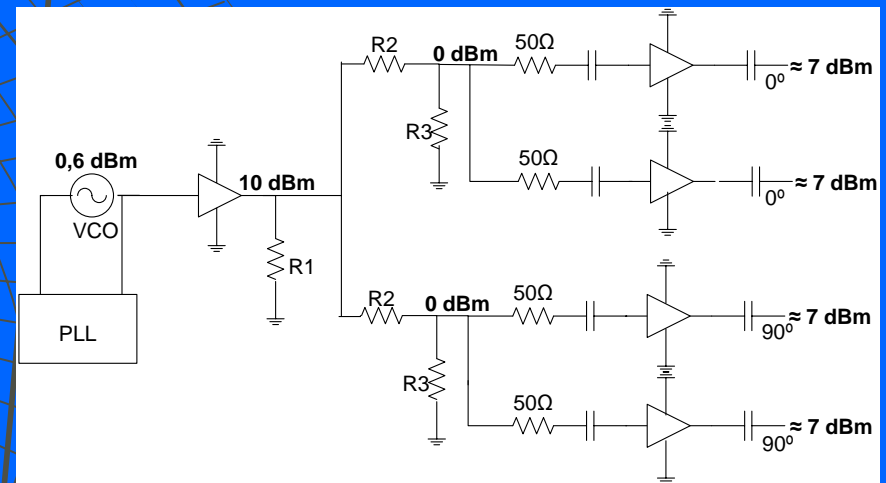
Converter

- ◆ Zero – IF Conversion ($LB = 100\text{MHz}$);
- ◆ Phase (I) and Quadrature (Q) Modulation;
- ◆ Signal Amplification ($G_{\text{SIGNAL}} = 16 \Rightarrow 25\text{ dB}$);
- ◆ Port Isolation = 120 dB;
- ◆ Suitable for Stokes Parameters Calculation;
- ◆ Microstrip Lines with equal lengths;
- ◆ Protection (outside interference & parasitics).



Local Oscillator

- ◆ Frequency = 600 MHz with 7 dBm;
- ◆ Provides the converter with 4 signals
- ◆ PLL Synthesized;
- ◆ Microstrip Lines with equal lengths;
- ◆ Protection (outside interference & parasitics).



Full 4-channel Digital Correlator

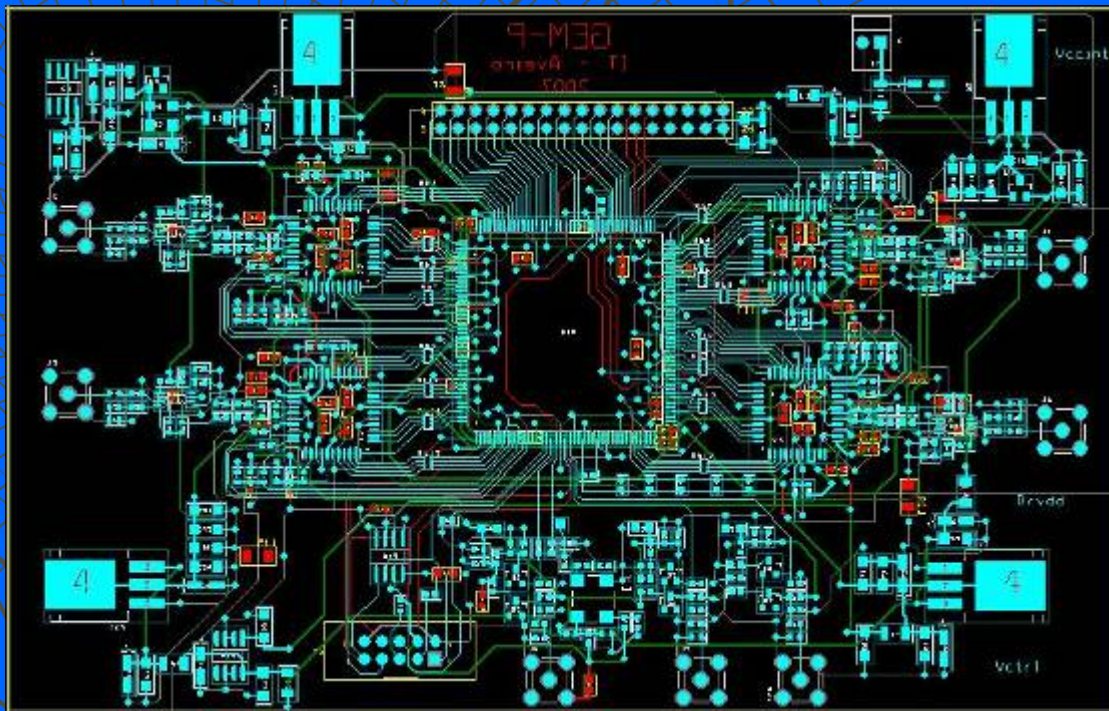
Correlations computed in a FPGA after signal digitalization (ADC interleaving) and outputs I,Q,U Stokes signals:

$$RL = \Re\{E_{rcp} E_{lcp}^*\} \rightarrow \text{Stokes } U$$

$$LR = \Re\{E_{rcp, -\frac{\pi}{2}} E_{lcp}^*\} \rightarrow \text{Stokes } Q$$

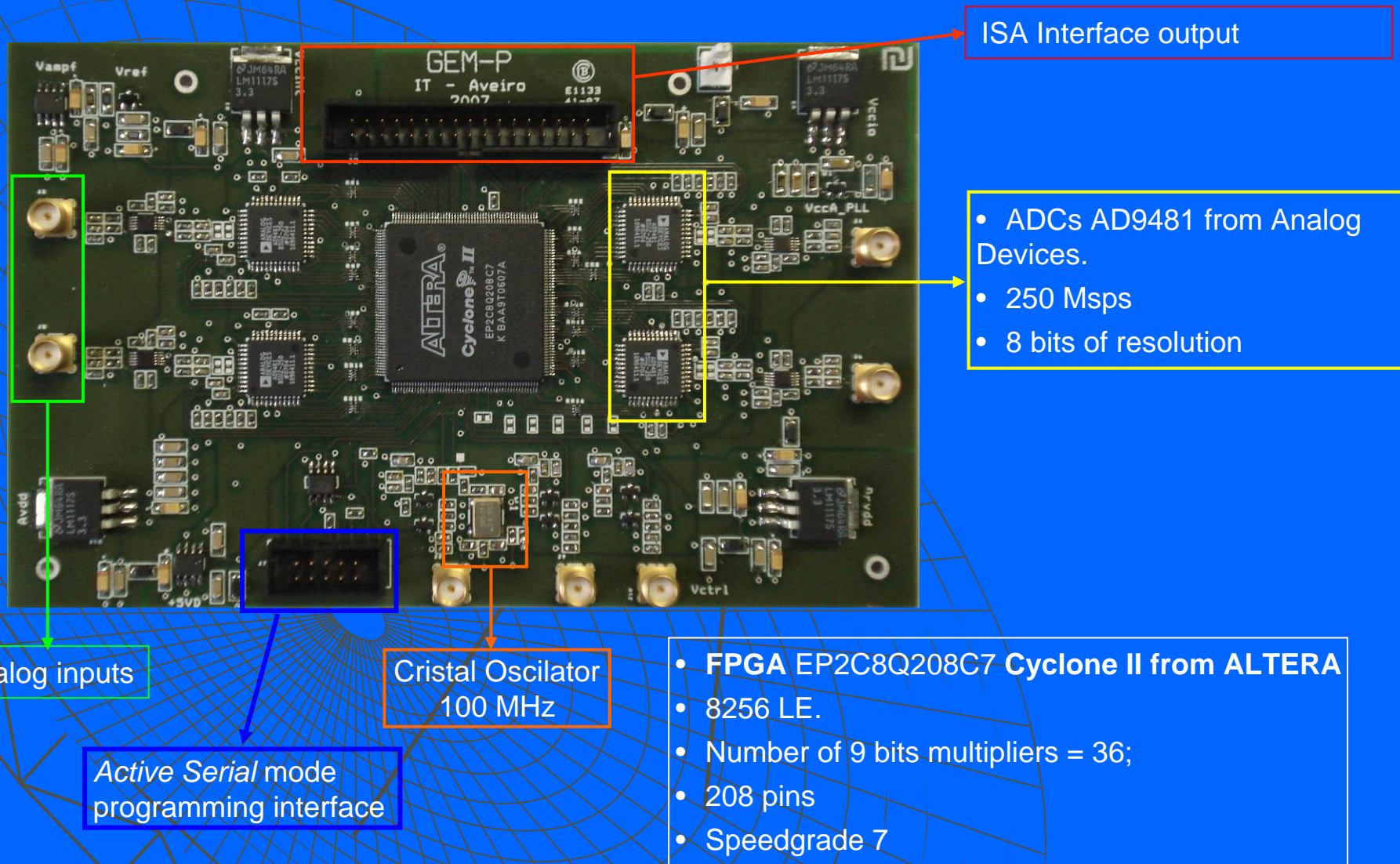
$$RR + LL = \langle E_{rcp} E_{rcp}^* \rangle + \langle E_{lcp} E_{lcp}^* \rangle \rightarrow \text{Stokes } I$$

Why an FPGA Cyclone II from ALTERA?



- Embedded Multipliers;
- Number of pins;
- Frequency.

Digital Correlator

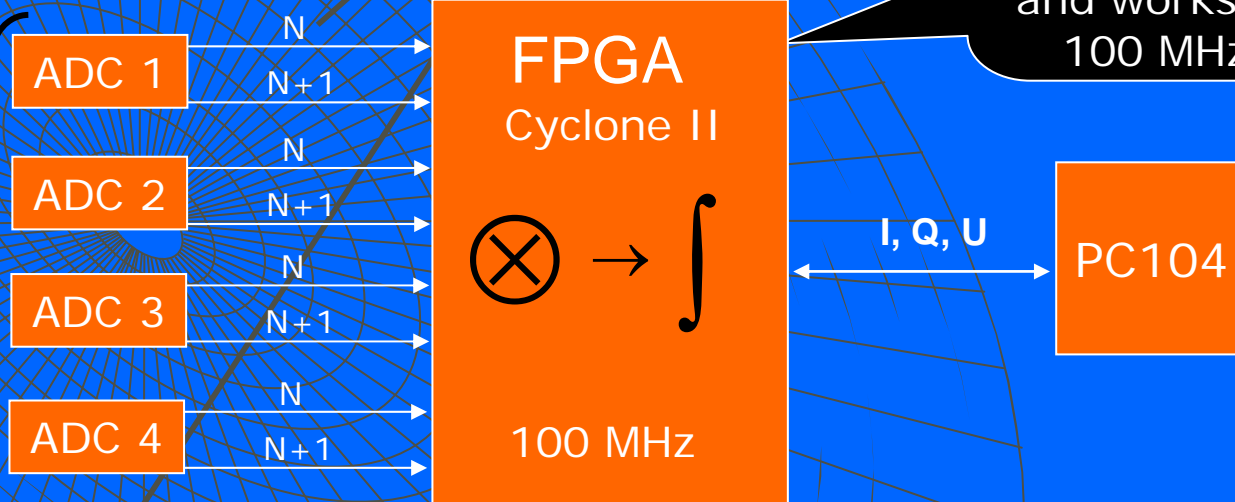


Full Digital Correlator

*FPGA calculates the Stokes parameters (I, Q, U).
(VHDL code implementation by Francisco Fernandes)*

1. Signals correlation from the 4 ADCs, (8 bits sum and multiplications every)
2. Integration of correlated signals.
3. Output Stokes parameters to PC104

8 bits of resolution
200 MSPS
0,5Vpp



FPGA is an
ALTERA
Cyclone II
and works at
100 MHz

$$I, Q, U, V = F(\text{ADC1}, \text{ADC2}, \text{ADC3}, \text{ADC4})$$

Main Features of PC104 (MOPSIcdLX*)



◆ Hardware

- 500 MHz AMD LX800™ Processor
- 256 MByte DDR-RAM
- ChipDisk IDE 1 GByte
- Support: ISA, Ethernet
- Power supply: 5V

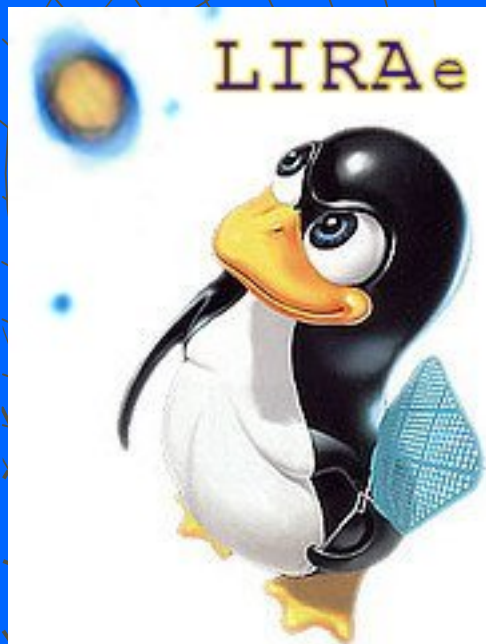
◆ Software

- Linux, kernel 2.4
- **Dedicated, custom-made software for FPGA communication via ISA bus (C lang. – implemented by Francisco Fernandes).**
- SSH File transfer.

* www.kontron.com/MOPS

LIRAE

Linux for Radio Astronomy embedded



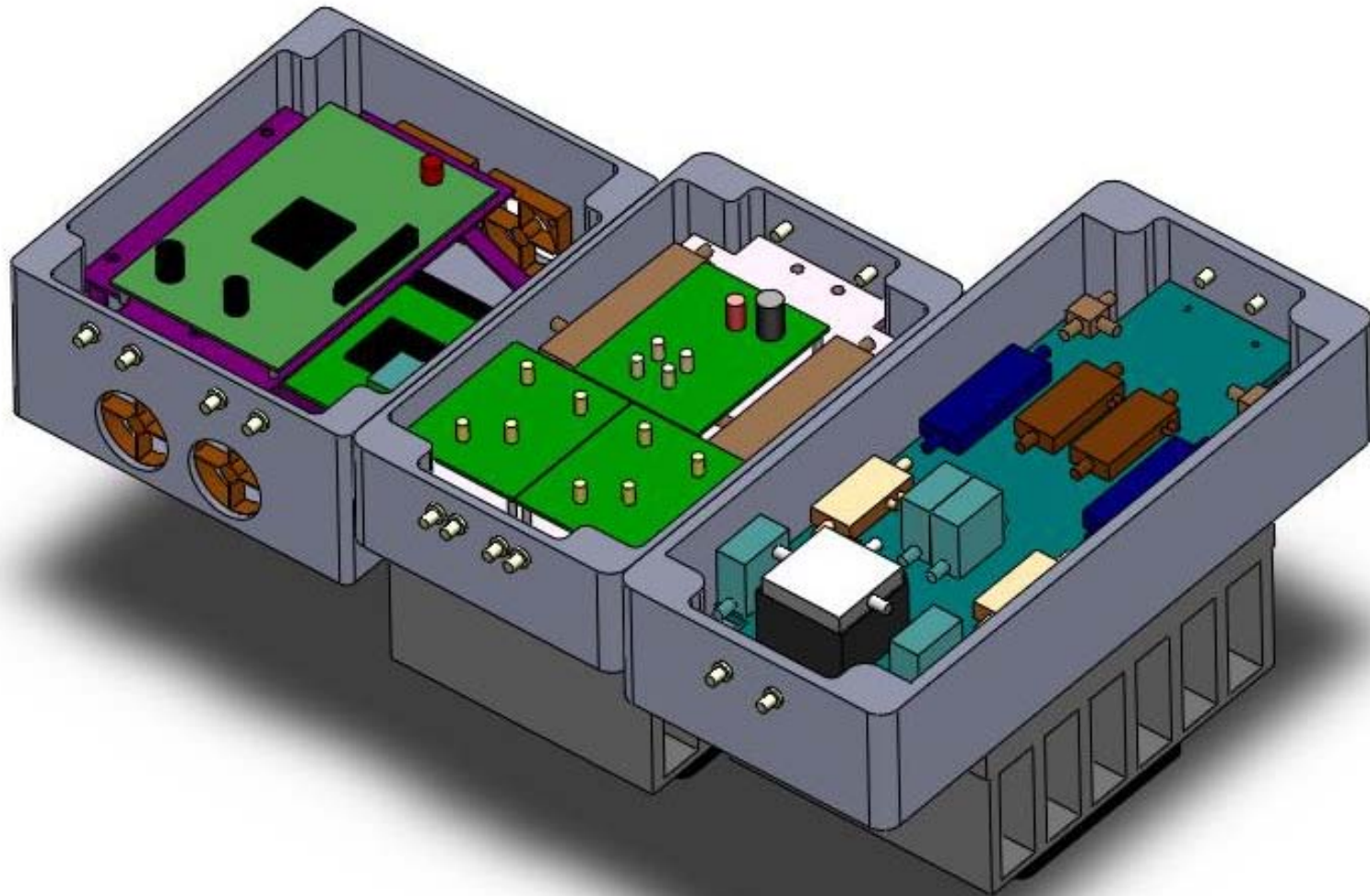
LIRAE is a microlinux distribution, to run on CPU embedded systems and control radioastronomy digital correlators based on FPGA chips.

The system was tested and runs on a PC104 from Kontron, model MOPSIcdLX.

Download available soon.

LIRAE main developer: Francisco Fernandes
email : ff@av.it.pt

Mechanical Layout



Conclusion : Radiometer facts

- ◆ $T_{\text{sys}} < 20 \text{ K}$; $B = 200 \text{ MHz}$; 104 dB gain
- ◆ High-performance IF strip
- ◆ Latest RF tech+ microstrip design + MMIC

New Radioastronomy Design:

- ◆ Zero-IF Converter + I,Q modulation
- ◆ Digital Correlator : 4-channel, FPGA implemented!
- ◆ Dynamic Range: Total=20dB, Instantaneous=80dB
- ◆ Suitable for state of the art radioastronomy applications.