Instrumentation Development for a 5 GHz Receiver for a Radioastronomy Experiment

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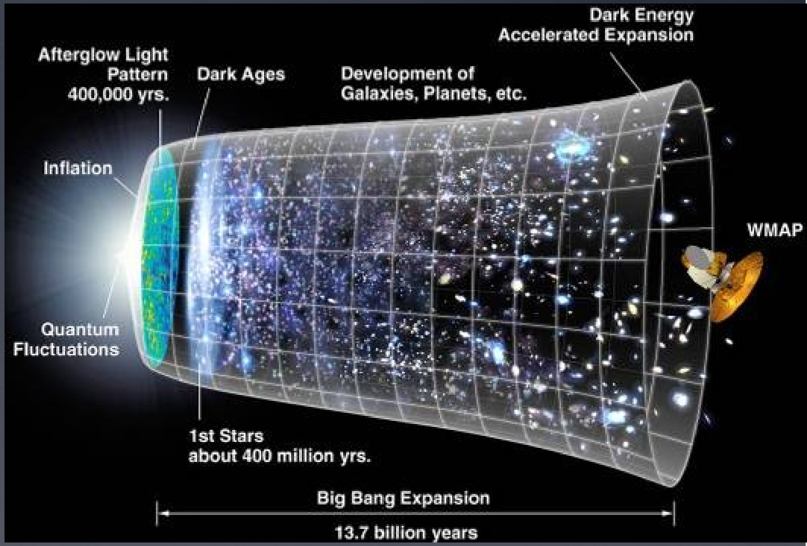
Overview

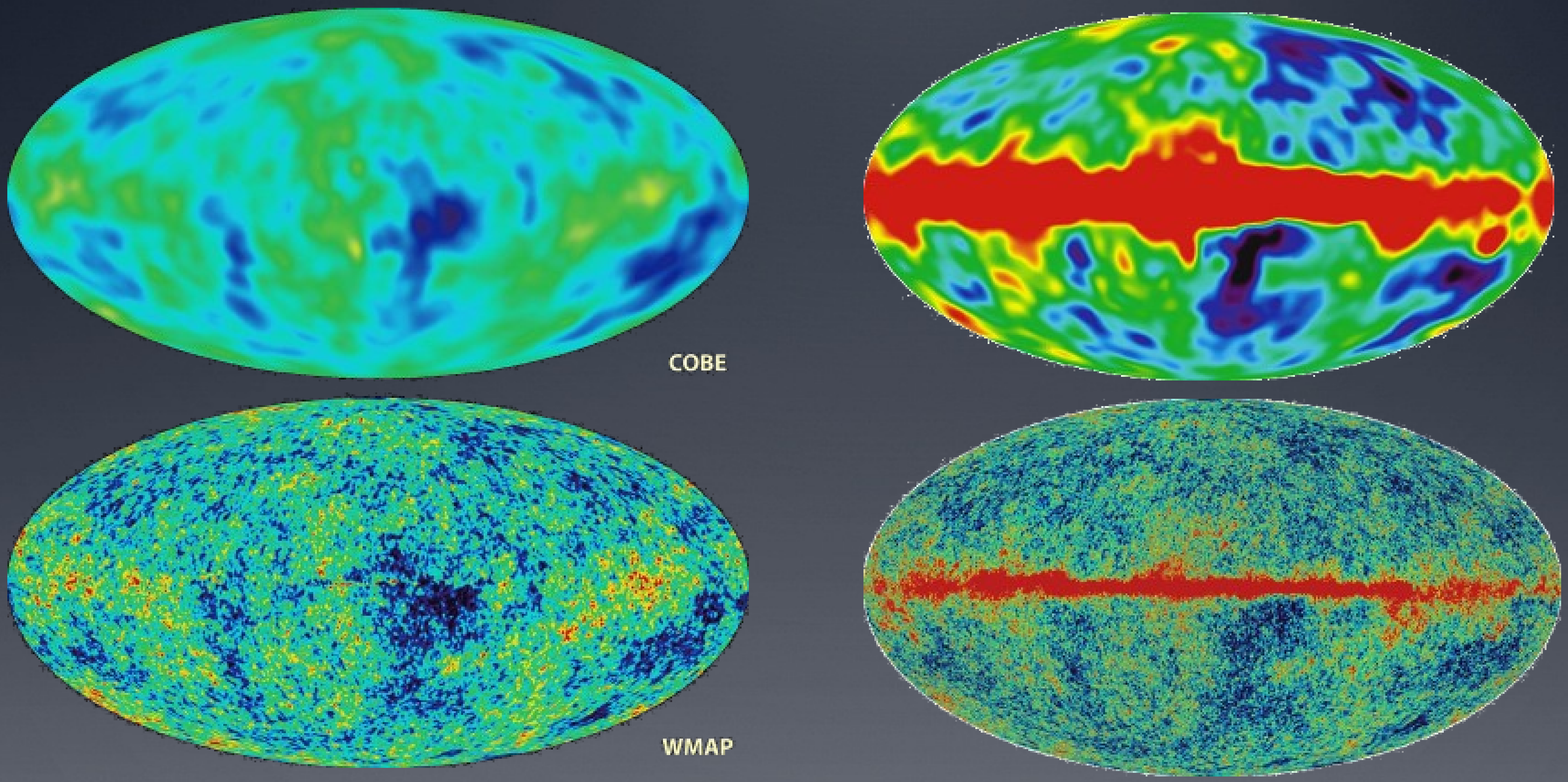
- The meaning of CMBR;
- Description of a Galactic Experiment Project;
- Types of radiometer
- Description of the Superheterodyne Receiver of GEM;
- Development of a Very Low Noise Amplifier for this Project (applicable to other RA projects)
- Full Digital Back-end;

What is CMBR?

- Cosmic Microwave Background Radiation
- Best “Big-Bang” relic (Fossil);
- First Sky map: 1992 by COBE satellite COBE (PI G. Smoot, was awarded the Physics Nobel Prize in 2006 for this discovery)
- CMBR fluctuations (anisotropies) allow to determine the geometry, age of the Universe.



CMBR



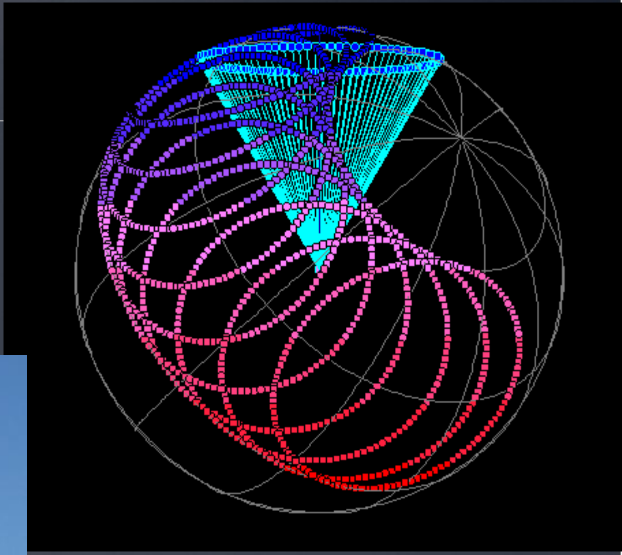
Maps provided by NASA/WMAP

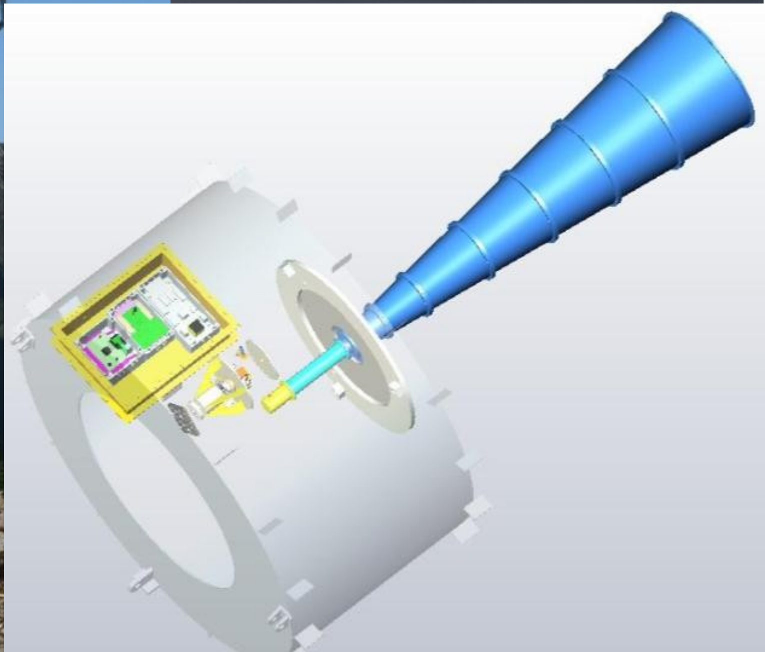
GEM : auxiliar experience to

Planck Surveyour (ESA 2009)

GEM – Galactic Emission Mapping

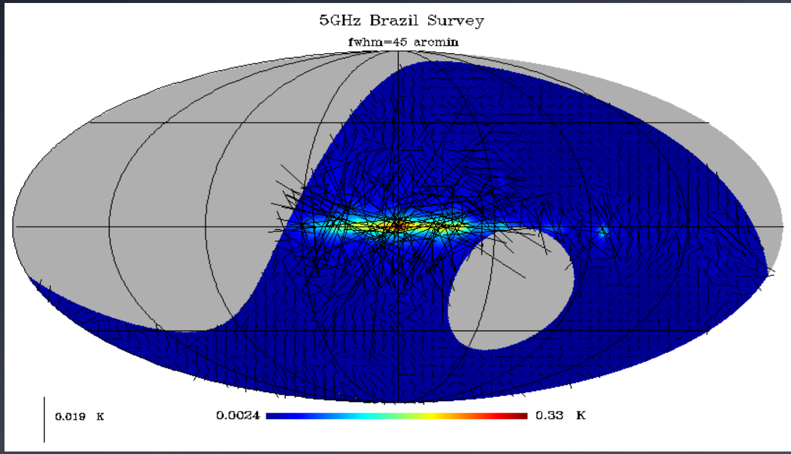
- North/South Hemisphere (Portugal and Brasil)
- 80% sky coverage

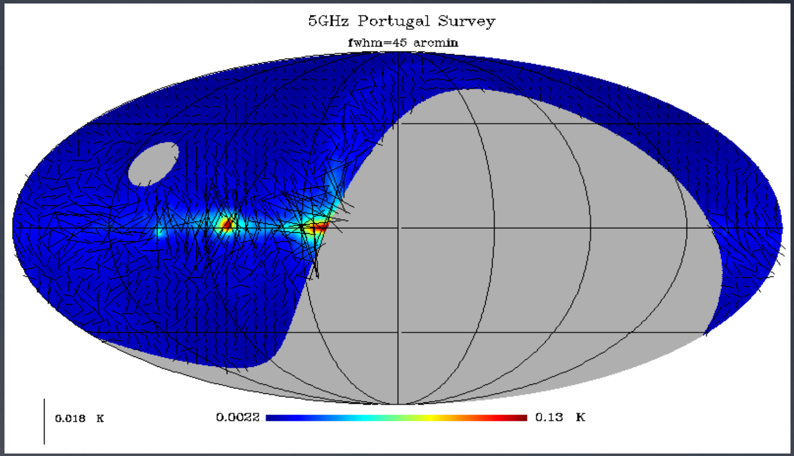


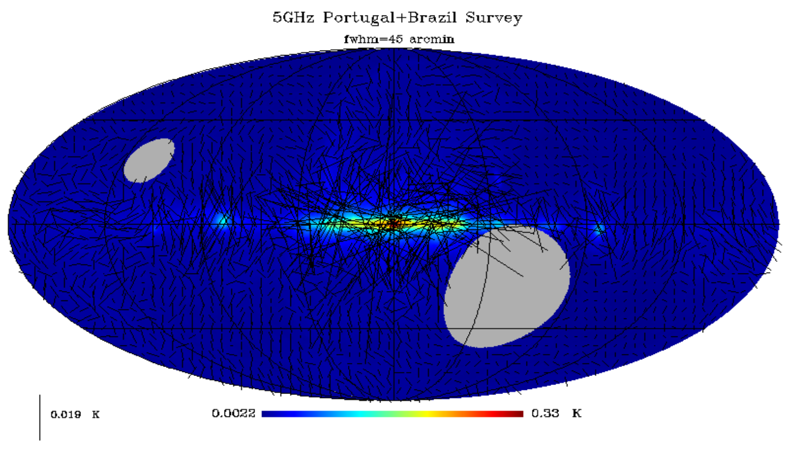


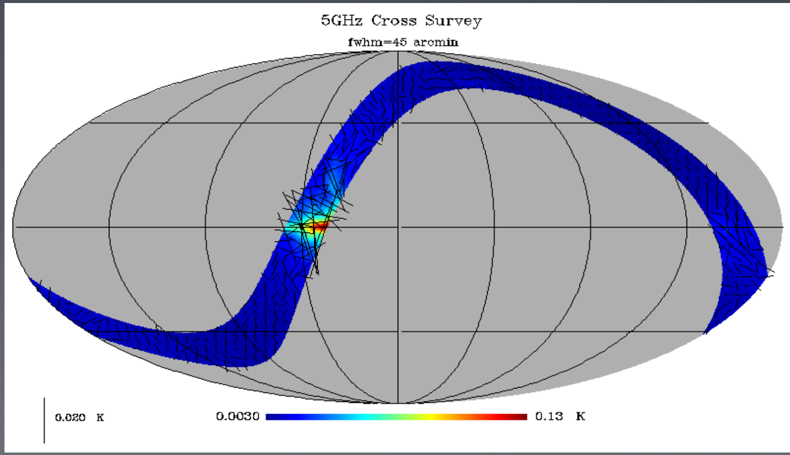
5 GHz Portugal and Brazil Surveys

Coverage simulations



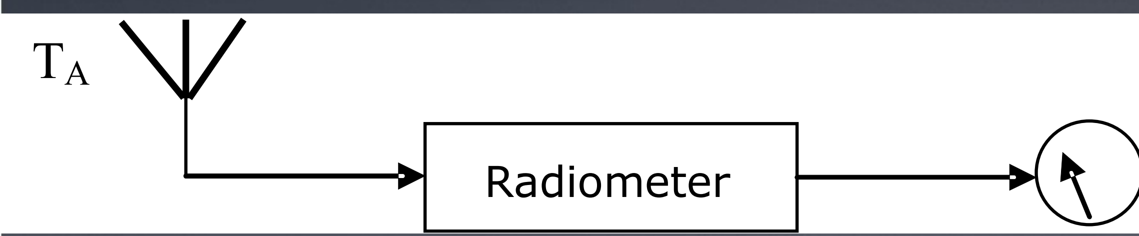






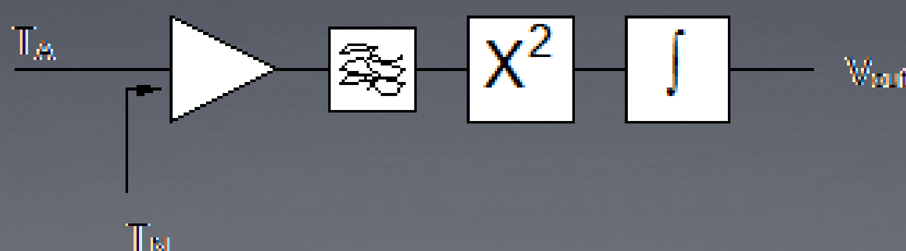
Radiometer?

- High sensitivity, well calibrated microwave receiver;
- Detect and measure celestial sources;



$P = KBGT_A \; Watts,$

K – Boltzmann Constant $= 1{,}38 \times 10^{-23} \; J/K$



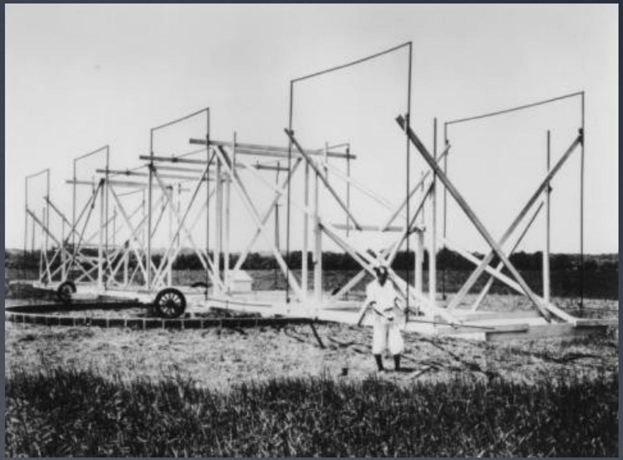
Radiometer Types

Amplification:

- Direct;
- Superheterodyne

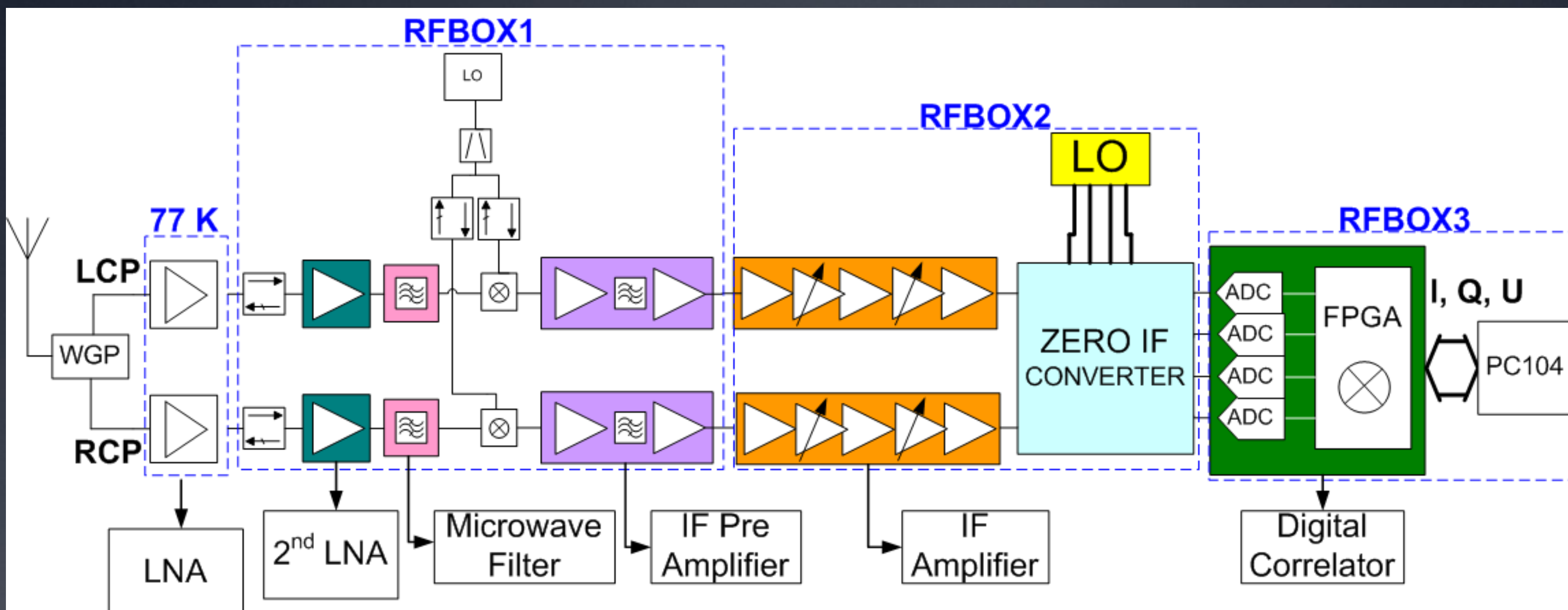
Accuracy:

- Dicke Radiometer
- Noise Injection Radiometer
- Total Power Radiometer



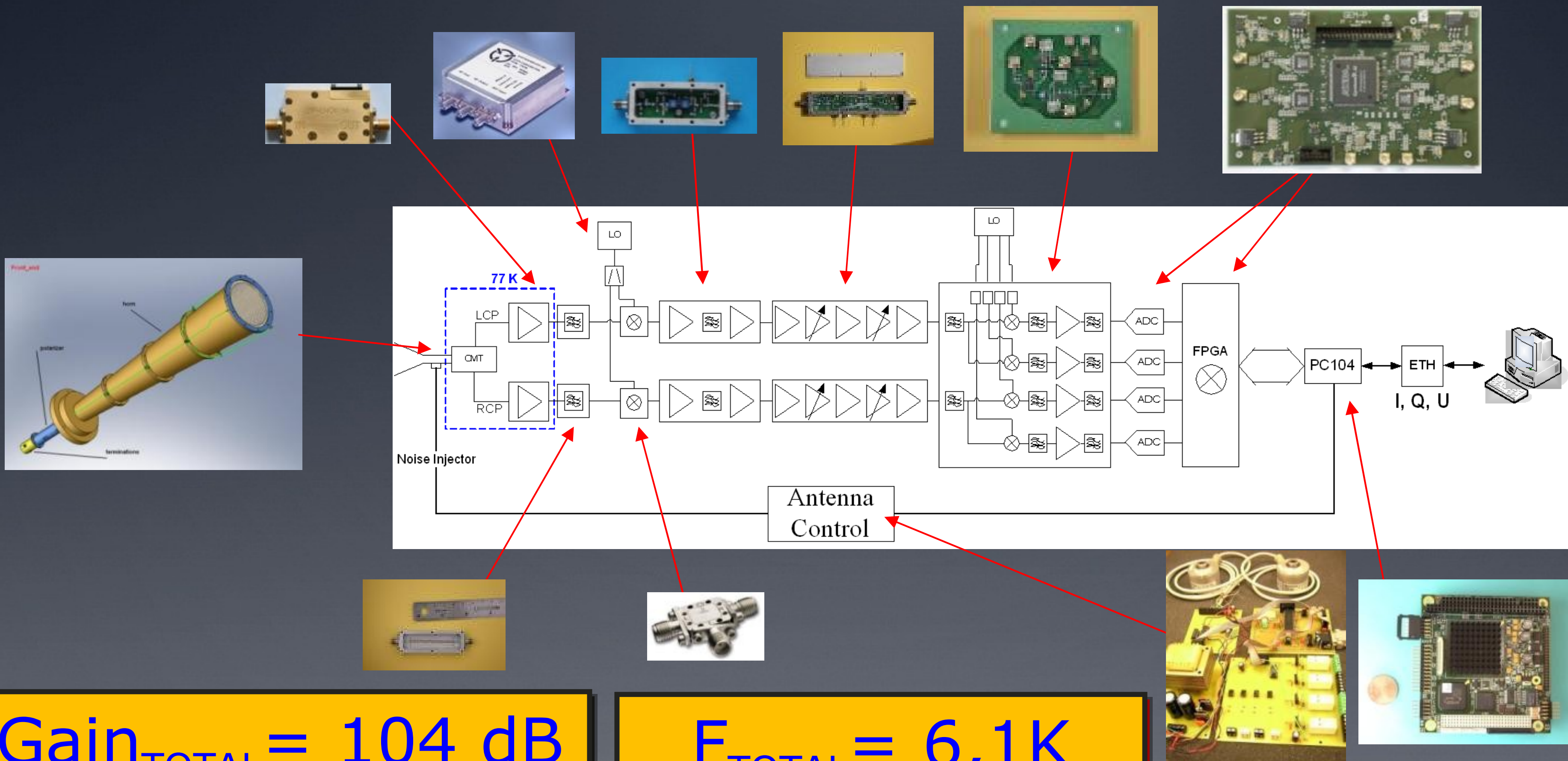
$$\Delta T = 2 \cdot \frac{T_A + T_N}{\sqrt{B \cdot \tau}}$$

Superheterodyne Receiver (Base-band Complex Correlator)



Novel approach to digital correlators

Receiver



$Gain_{TOTAL} = 104$ dB

$F_{TOTAL} = 6{,}1K$

Receiver Characteristics

- **System Temperature about ~ 20K**
- **Sensitivity ~ 2mKs$^{-1/2}$**
- **Frequency 5GHz with 200MHz Bandwidth**
- **Gain ~ 100dB**
- **Suitable for Stokes Parameters Calculation**
- **LNA Cryocooled pHEMT Amplifiers**

2º LNA Requirements

- **Working at environment Temperature.**
- **Frequency 5GHz**
- **Gain ~ 13dB**
- **GaAs pHEMT or HJFET Amplifiers**
- **Noise Figure below 0,65 dB**
- **Main function is to reduce the noise contribution of the RF passive Filter and Mixer.**

NF contribution

- Introducing a LNA between the cryogenic one and the set filter, mixer and pre-amplifier reduces the contribution of the later devices

	LNA	2^{nd} LNA	Filter + Mixer + IF Pre Amplifier
T_{eq}	6K	36K	6202K
NF	0,3dB	0,5 dB	13,5 dB
Gain	36 dB	13 dB	20 dB
Linear Gain	3891	20	100

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}$$

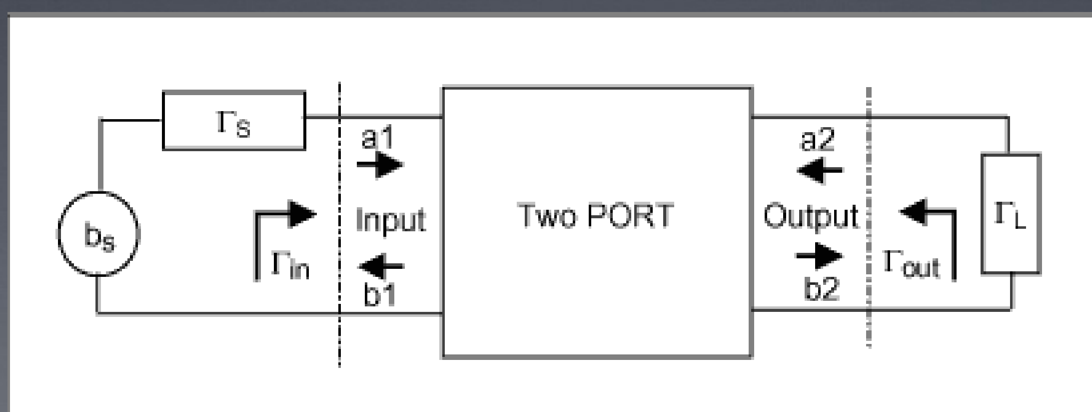
$$F_{2¼LNA} = 6{,}08$$

$$F_{without\,2¼LNA} = 7{,}59$$

First Approach

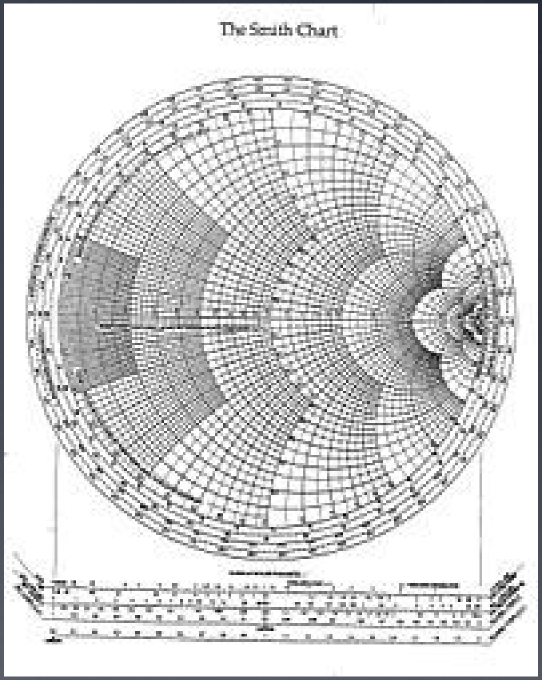
- The development of an amplifier starts by defining two main characteristics:
  - Maximum Gain – more current
  - Minimum Noise – less current

$$G = \frac{1 - |\Gamma_s|^2}{|1 - S_{11}\Gamma_s|^2} |S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$



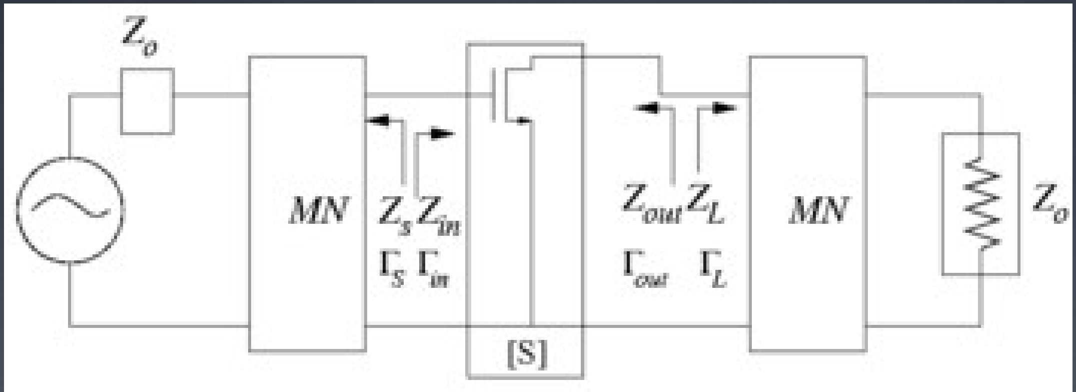
Statements

- Γ_{OPT}, r_n and NF_{min} are the provided
- Noise Circles and Gain Circles are designed
- Selecting the best suitable impedances for G_L and G_S
- But it is an Unilateral device $S12 \neq 0$, so:
  - G_L or G_S must consider the influence on each one



Noise and Gain Compromise

- In order to obtain the best performance for noise G_S must be matched for Γ_{OPT}



- The bilateral case implies the output to be matched considering the input matching network

Commercial Availability

- GaAs pHEMT and HJFET Low Noise Transistors
- Noise Figure between 0,3 and 0,6 dB
- Total Gain approximately 12/13 dB
- Noise and S-parameters Provided by manufacturer
- Substrate to be used: RT5880 (low ε_r=2,2)

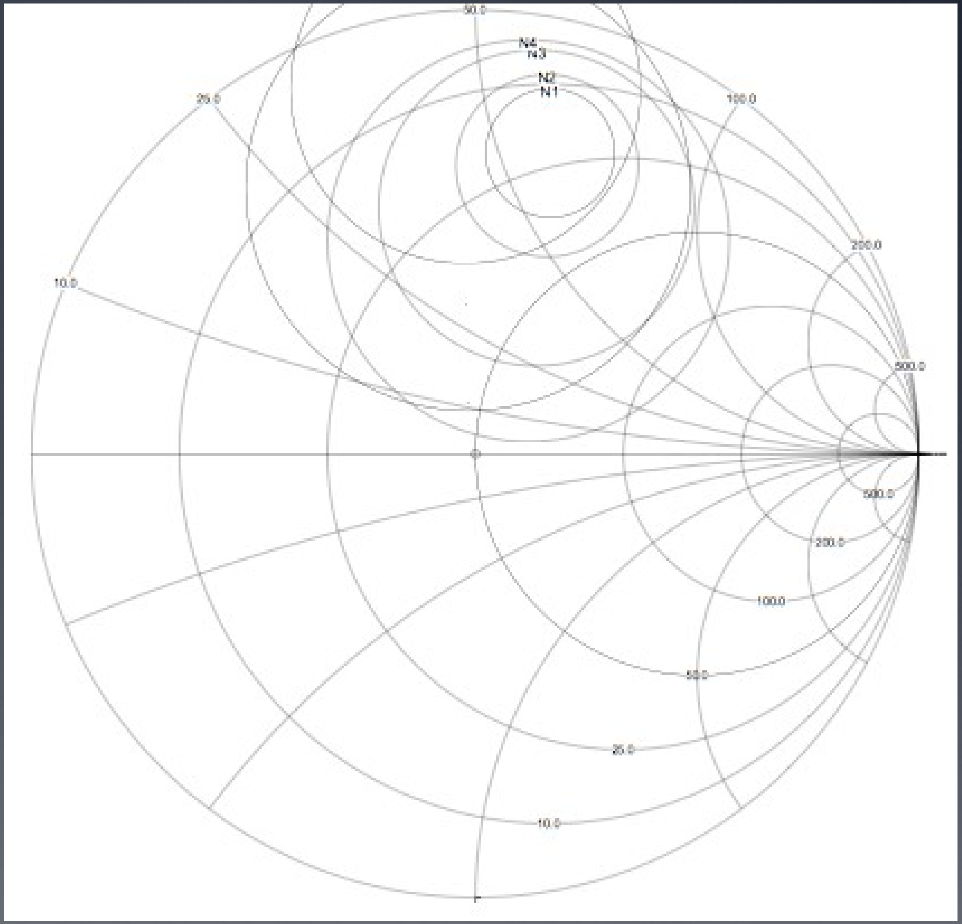
	Company	NF (dB)	GAIN (dB)	@Freq. (GHz)
MGF4953	Mitsubishi	0,40	13,5	12
MGF4941	Mitsubishi	0,35	13,5	12
MGF4419	Mitsubishi	0,50	12	12
ATF-36077	Agilent	0,5	12	12
MGF4931	Mitsubishi	0,60	11,5	12
NE3511S02	NEC	0,30	13,5	12
FHX13X	Fujitsu	0,45	13	12

ATF-36077 Typical Noise Parameters,
Common Source, Z_O = 50 Ω, V_{DS} = 1.5 V, I_D = 10 mA

Freq. GHz	F_{min}[1] dB	Γ_{opt} Mag.	Γ_{opt} Ang.	R_n/Z_o -
1	0.30	0.95	12	0.40
2	0.30	0.90	25	0.20
4	0.30	0.81	51	0.17
6	0.30	0.73	76	0.13
8	0.37	0.66	102	0.09
10	0.44	0.60	129	0.05
12	0.50	0.54	156	0.03
14	0.56	0.48	-174	0.02
16	0.61	0.43	-139	0.05
18	0.65	0.39	-100	0.09

Circles

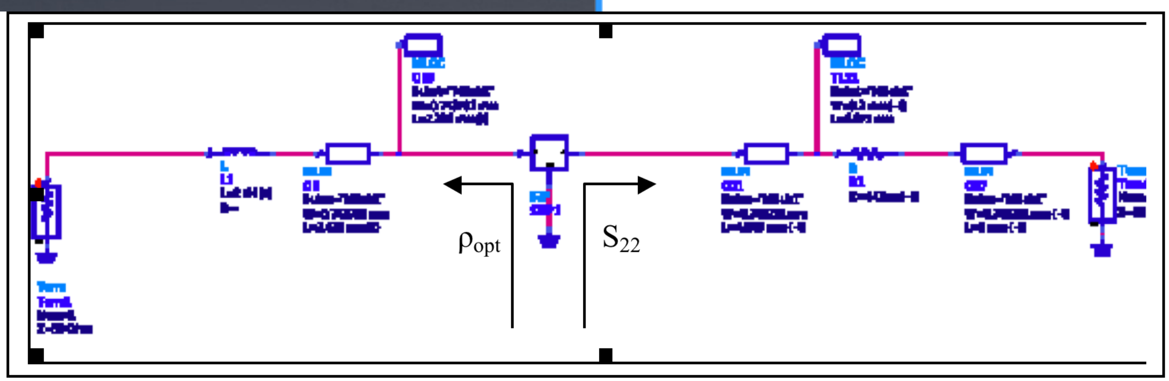
- Noise circles for ATF-36077
- Nfmin=0,3dB
  - N1=0,35dB
  - N2=0,4dB
  - N3=0,6dB
  - N4=0,8dB
- Maximum gain = 18,4dB
  - G1=15dB



Matching Networks

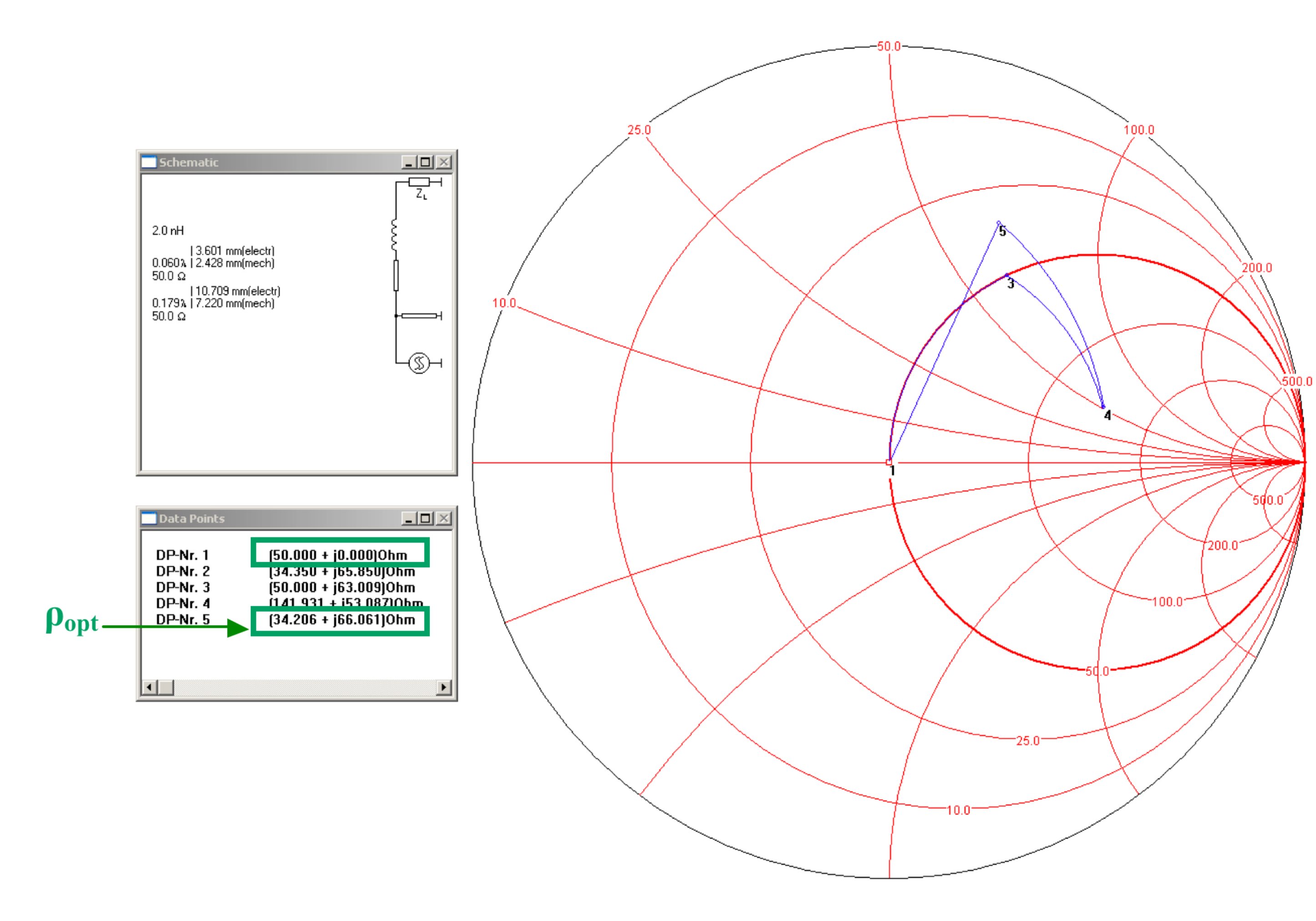
- Since the transistors are packaged (MMIC) the network should match 50 ohm to Γ_{OPT}
- Considering the previous network determine the new Zout
- Match Zout for 50 ohm

$$\Gamma_{OUT} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S}$$

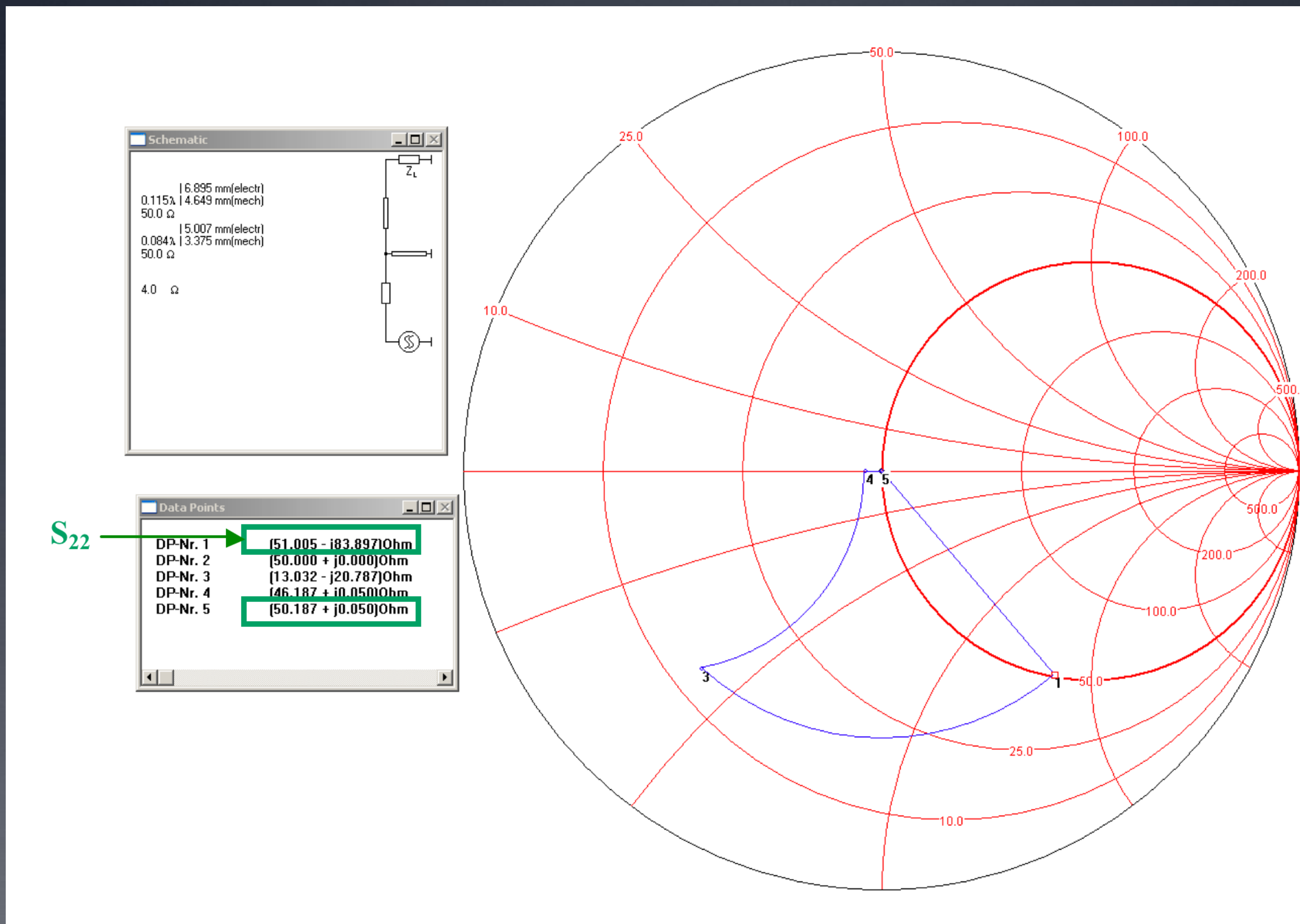


Malha de entrada

Input Matching Network

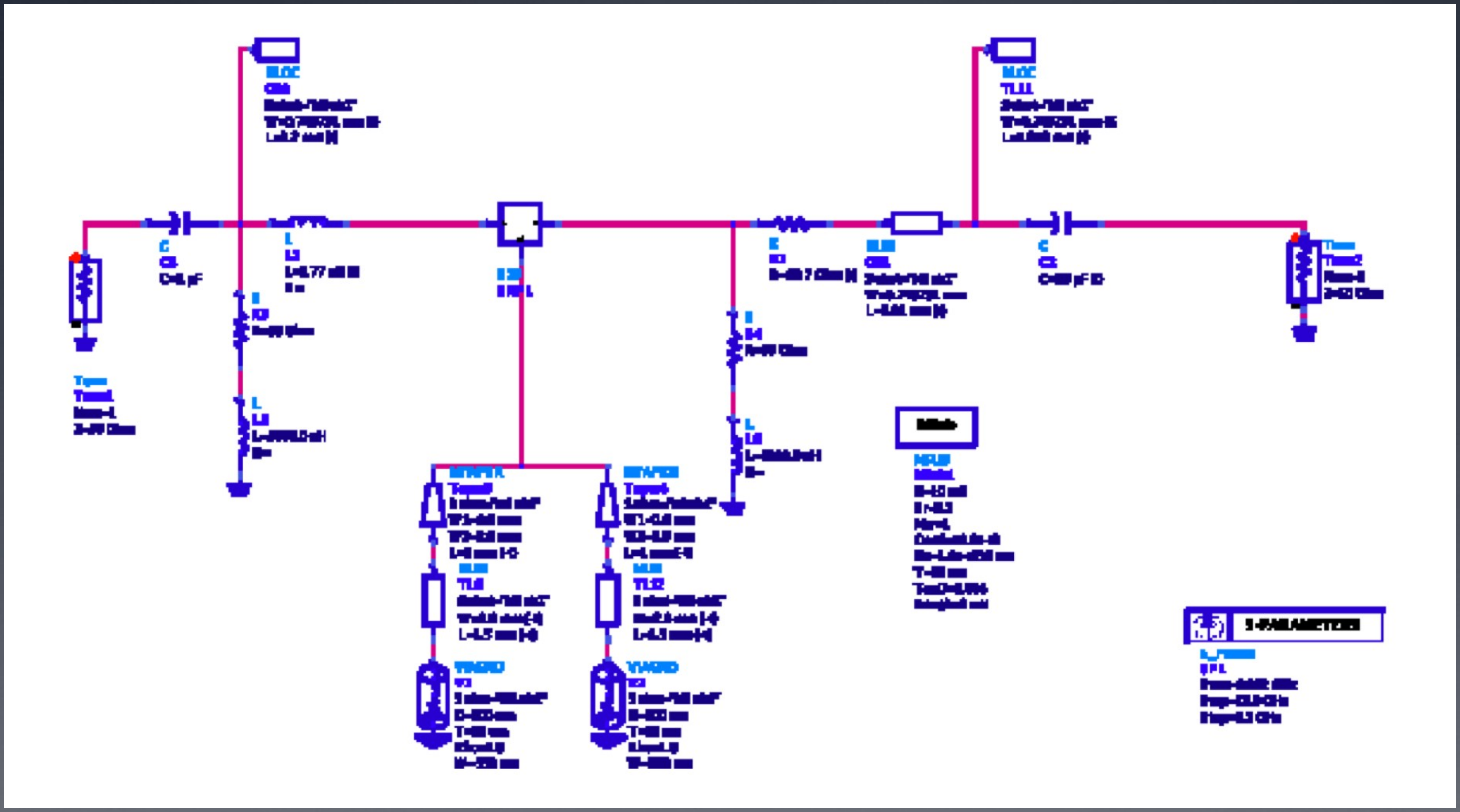


Output Matching Network



Schematic

- Includes the bias networks



SIMULATIONS

- **S and Noise Parameters provided by the manufacturer**
- **Challenge is to create good matching networks, that will provide the lowest NF;**
- **Obtain low NF for a wide frequency band.**

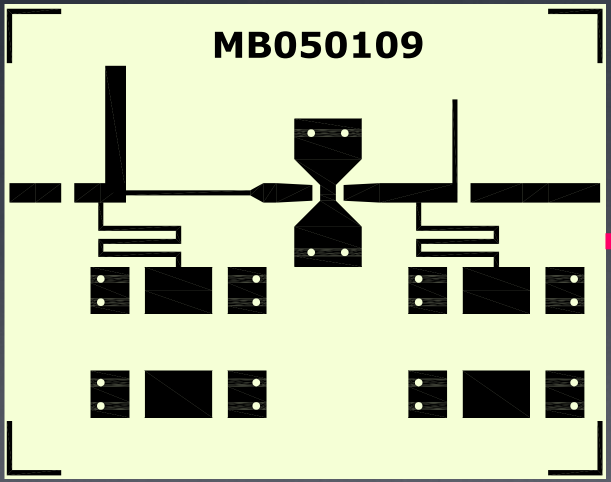
Device	NF(dB @ 5GHz)	GAIN(dB @ 5GHz)
MGF4941 from Mitsubishi	0,25	13,8
MGFC4419 from Mitsubishi	0,28	12,3
MGF4931 from Mitsubishi	0,48	11
ATF-36077 from Agilent	0.38	13
NE3511S02 from NEC	0,25	13
FHX13X from Fujitsu	------	14

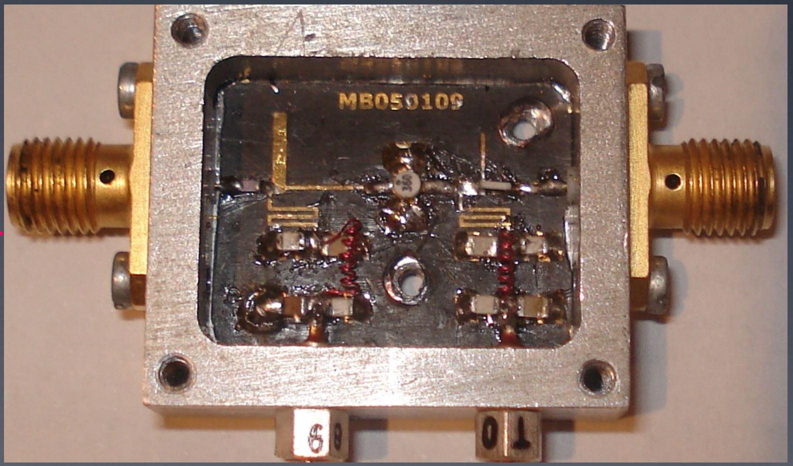
- **The described procedure was applied for each device**

Design Constraints

Using the Noise Parameters provided, and following the usual procedure to design an input and output matching networks, a LNA with NF=0,38 dB and 13,4dB of gain was implemented

Designed with the help of a vectorial tool, AUTOCAD

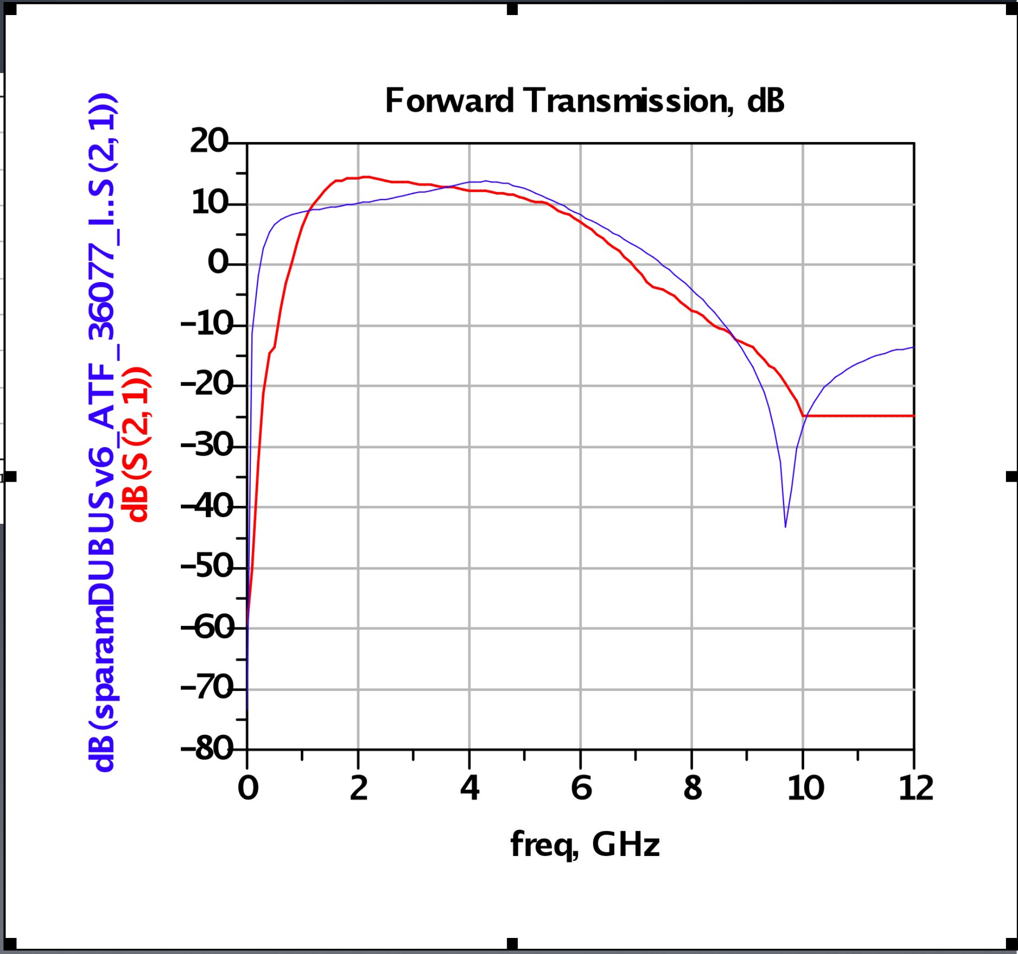




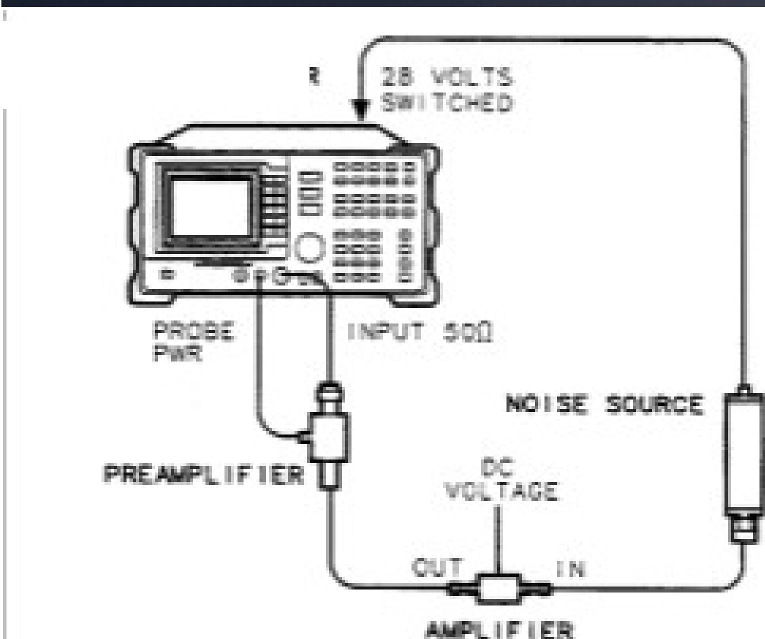
Avago ATF-36077 Results

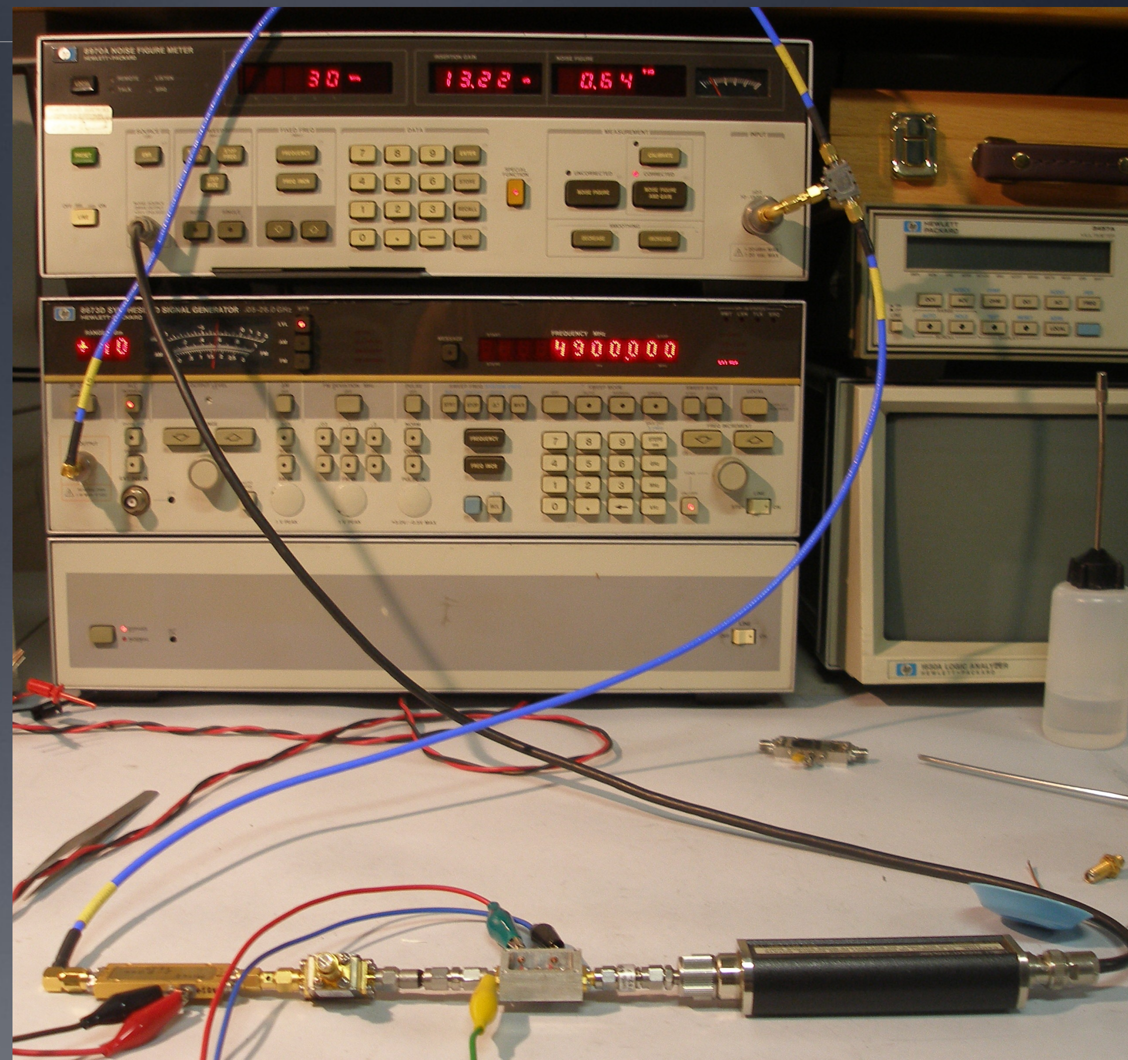
Noise Figure

Gain



Noise Figure Measurements

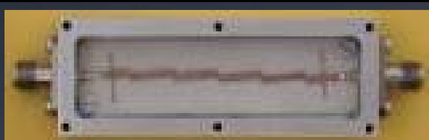




IF part designed and tested

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

4.9GHZ; B=600MHz
Coupled Line filter
RO4003



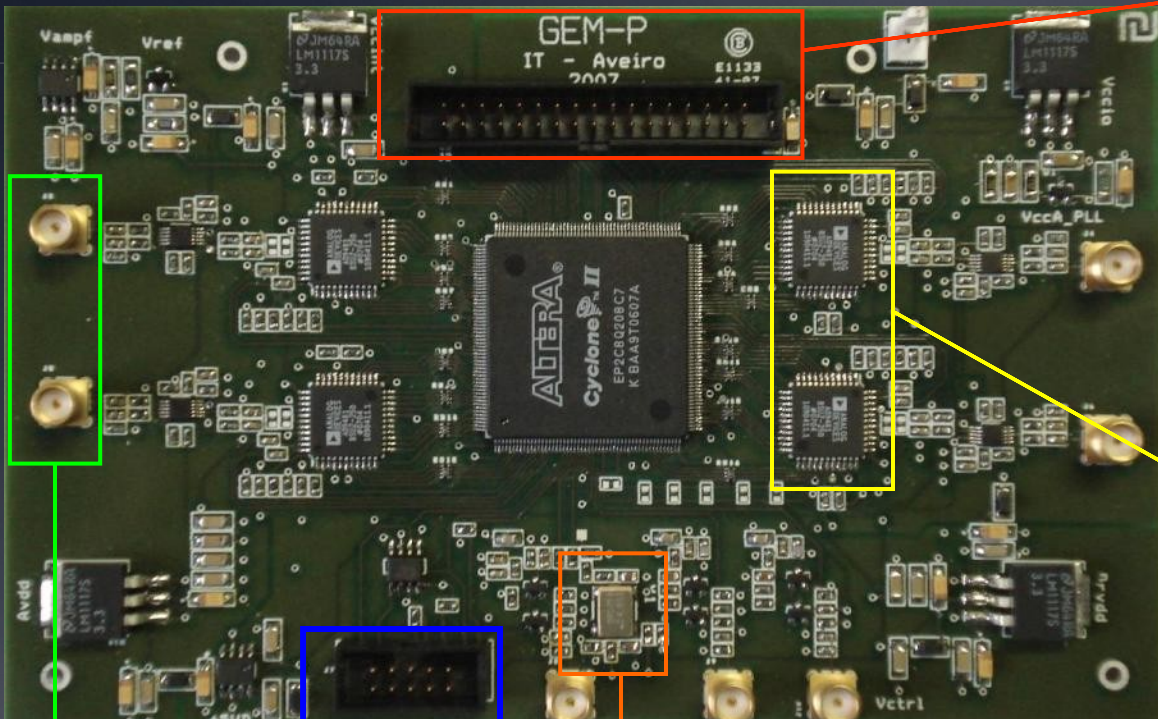
IF Chain+RF Filter

Flat gain; 71dB;
Digital attenuation

120dB isolation between ports

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

Digital Correlator



ISA Interface output

$$RL = \Re e\left(E_{rcp}\,E_{lcp}^{*}\right) \rightarrow Stokes\ U$$

$$LR = \Re e\left(E_{rcp,-\frac{\pi}{2}}\,E_{lcp}^{*}\right) \rightarrow Stokes\ Q$$

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

- ADCs AD9481 from Analog Devices.
- 250 Msps
- 8 bits of resolution

Analog inputs

Active Serial mode programming interface

Cristal Oscilator 100 MHz

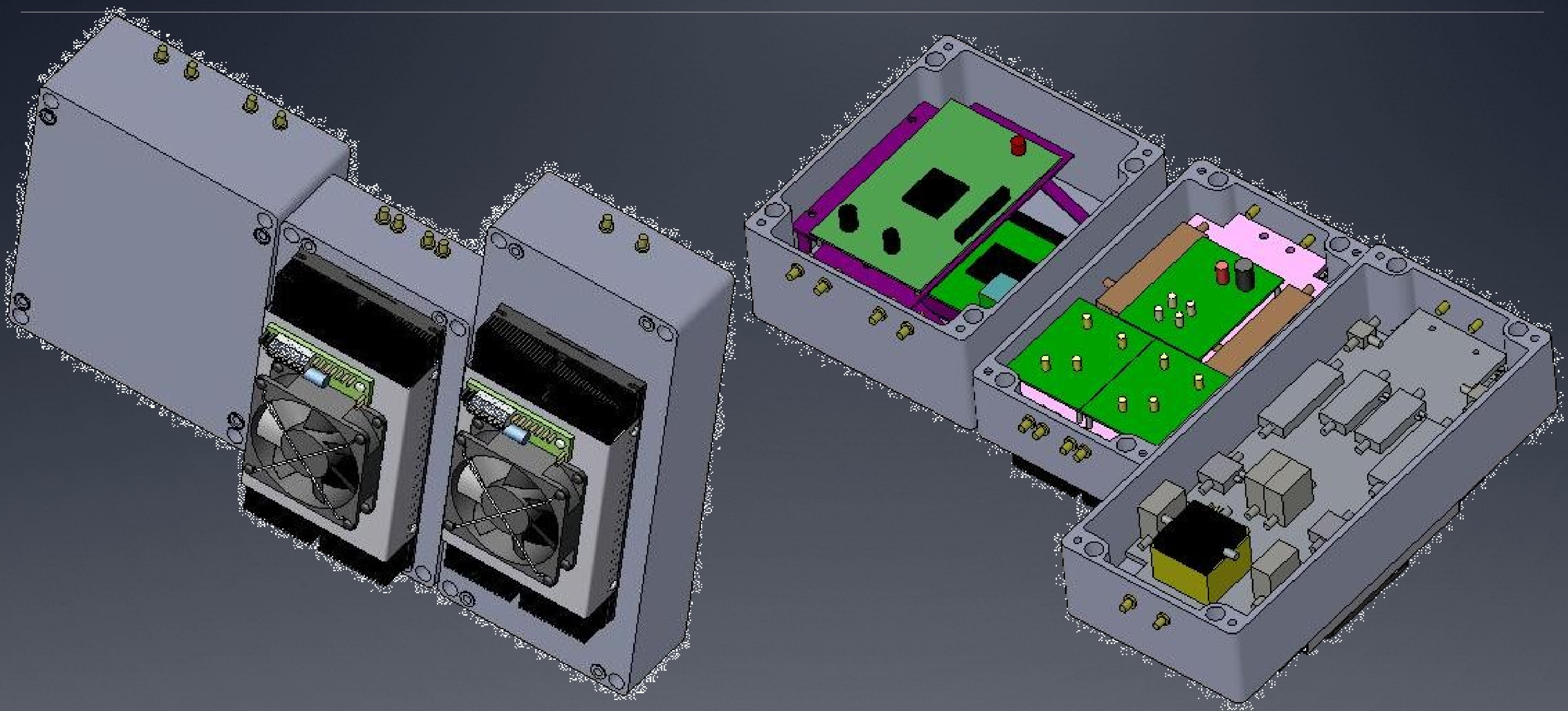
- **FPGA** EP2C8Q208C7 **Cyclone II from ALTERA**
- 8256 LE.
- Number of 9 bits multipliers = 36;
- 208 pins
- Speedgrade 7

Main Features of PC104 (MOPSlcdLX*)

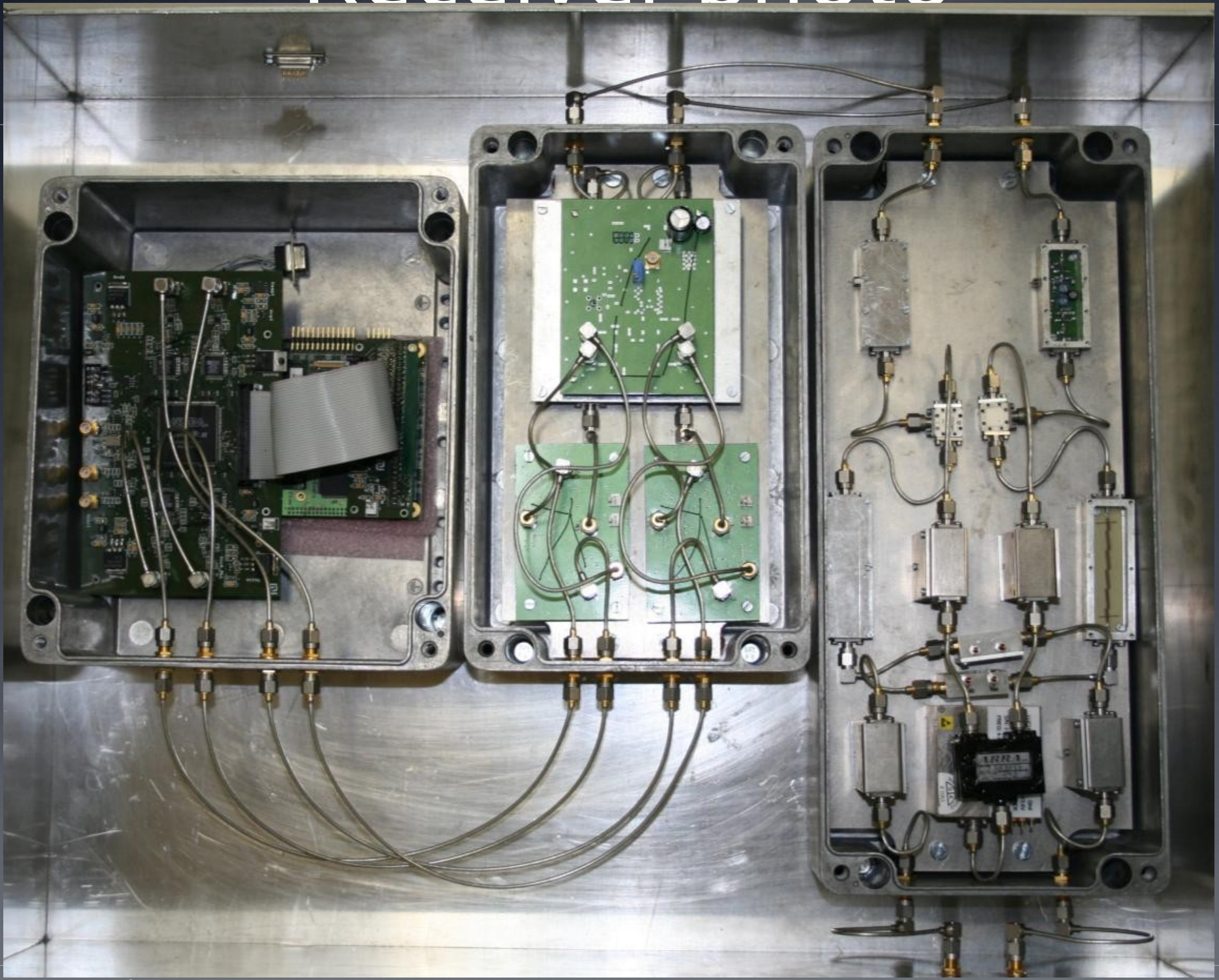
* www.kontron.com/MOPS

- **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.

Mechanical Layout



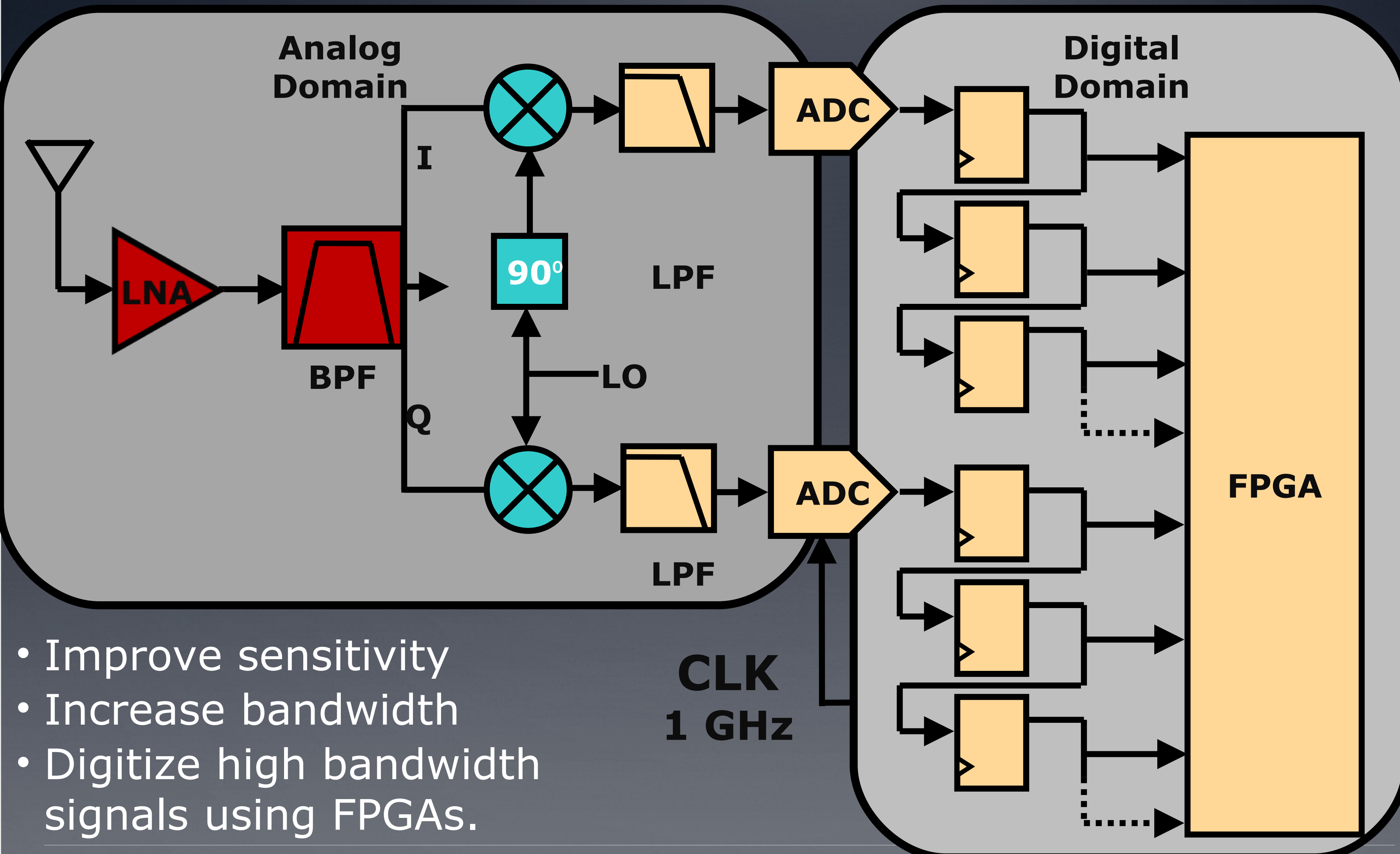
Receiver photo



Conclusion : Radiometer facts

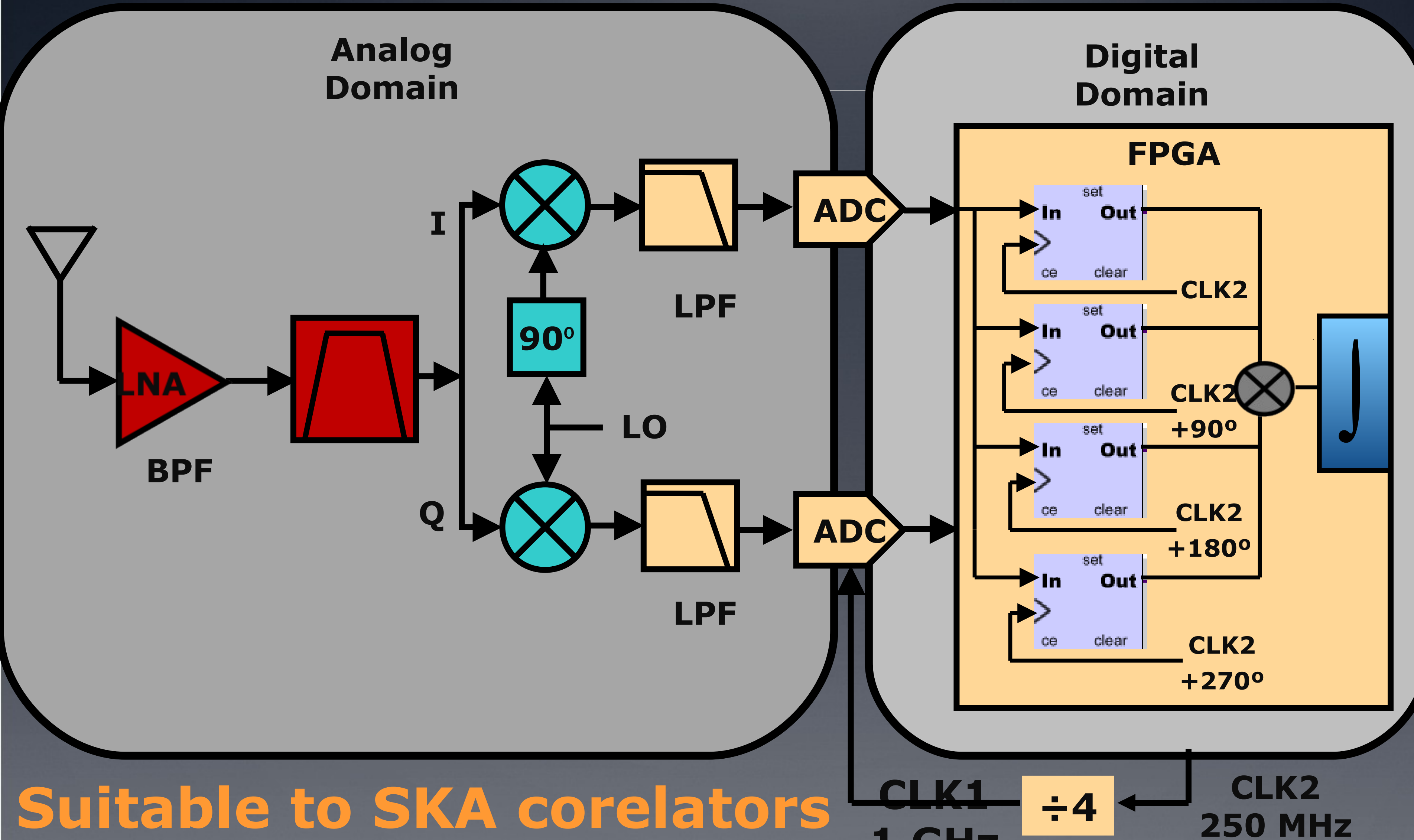
- Tsys < 20 K; B = 200 MHz; 104 dB gain
- High-performance IF strip
- Latest RF tech+ microstrip design + MMIC
- Zero-IF Converter + I,Q modulation
- Digital Correlator : 4-channel, FPGA implemented processing 16Gbps!
- An SKA (Potential!) Digital Demodulator
- Dynamic Range: Total=20dB, Instantaneous=80dB
- Suitable for state of the art RA applications.
- MoU with ESA Planck Science Team.

Future



- Improve sensitivity
- Increase bandwidth
- Digitize high bandwidth signals using FPGAs.

Future



Suitable to SKA corelators

FIM

Muchas Gracias