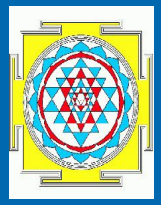


A Multifrequency Interferometry Telescope for Radio Astronomy: MITRA

Girish Kumar Beeharry

Mauritius Radio Telescope

Department of Physics

Faculty of Science

University of Mauritius

Stuart MacPherson & Gary van Vuuren

Department of Electronic Engineering

Faculty of Engineering &

the Built environment

Durban University of Technology

Africon IEE URSI Conference 10th September 2013

Outline

-Motivation

-Overall description

-Station outline

- Sensitivity & Resolution
- Science & Technology
- Preliminary work
- People
- Ministerial visits

Motivation 1

- It has a relatively low cost of capital investment. It is important that this project's progress be marred by the current financial atmosphere. The countries must be able to support the capital and the running costs.

- The modularity of the project enables it to expand progressively. This is crucial for the project to take off.

- The learning curve for local academics, engineers and technicians is rather non steep. Before considering the enlisting and training of students, it is important to train the trainers.

Motivation 2

·There is the possibility of developing an base of students in astronomy, engineering and technology.

· Most of the countries have fledgling undergraduate programmes in astronomy.

·There is an involvement in international scientific collaboration. This can be a major boost to research in radio astronomy in Africa.

· There will be original output in science and technology from Africa.

MITRA: Overall description

- A sensitive high resolution multi-frequency dual polarity

- Frequency range 200 to 800 MHz

- Multiple independent stations of low-cost dipoles

- Baselines: ~metres, 250-500-1000-3000-5000 km-

- Instrument & station: modular & subsets

- Technical specifications function of number of stations

MITRA: Station outline

- Each station is planned for observations on its own.

- Sufficient sensitivity and resolution built in.

- The front-end & the back-end should be integrated with the data acquisition locally.

- The data pipeline should also cater for intra-station as well as inter-station correlation.

-Local hub managing system which will be synchronised, centrally, with other stations.

Sensitivity 1

- Sky noise ~300 K at 150 MHz; up to 1000 K in the Galaxy (Golap 1998, Issur 2003)

- No cooling of field electronics: science & cost factor

- ~250 mJy point source sensitivity per station for 1024 antennas. (Golap 1998, Pandey 2006, Daiboo 2012). 1 MHz BW, 16 s integration, area ~4000 m^2

- Aim to improve

Sensitivity 2

-The w term

-Convolution & Gridding

-Primary beam

-Phasing

-Bandwidth decorrelation

-Ionospheric effects

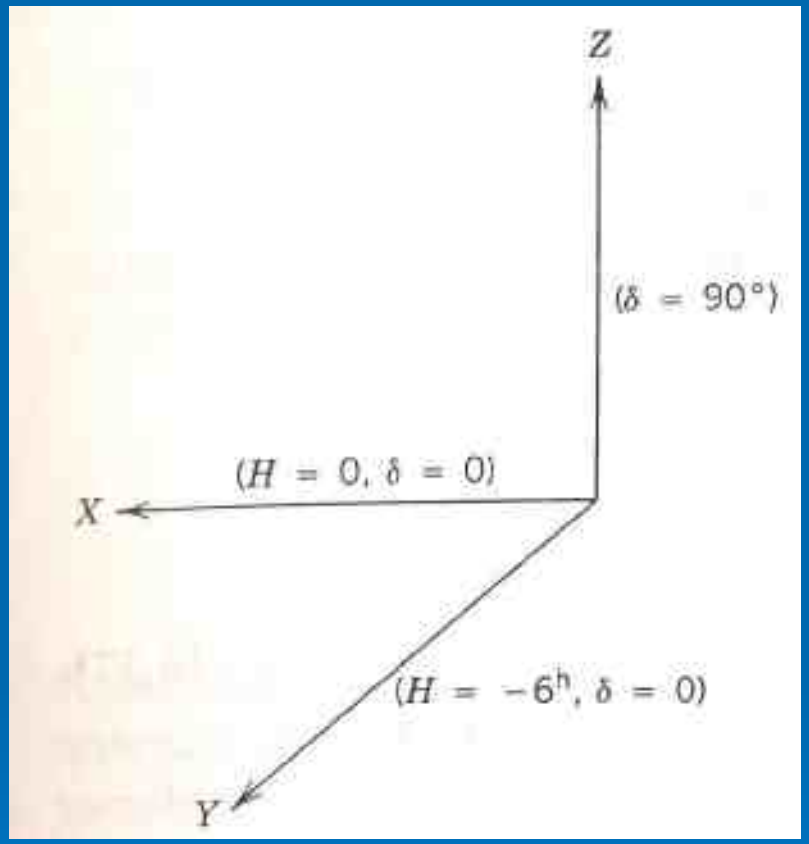
Resolution

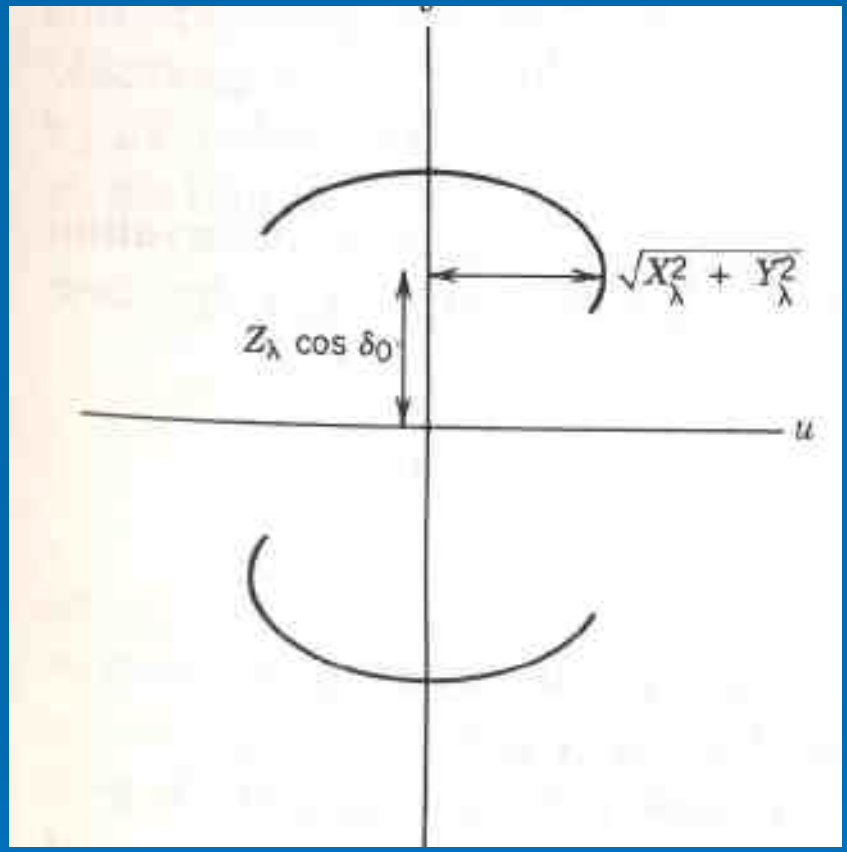
ν	λ	Resolution							
MHz		10m	100m	1km	500 km	2500km	5000km		
		<---------- arcseconds---------->							
50	6.0	123758.9	12375.9	1237.6	5.0	2.5	1.24	0.495	0.248
100	3.0	61879.4	6187.9	618.8	2.5	1.2	0.62	0.248	0.124
200	1.5	30939.7	3094.0	309.4	1.2	0.6	0.31	0.124	0.062
300	1.0	20626.5	2062.6	206.3	0.8	0.4	0.21	0.083	0.041
400	0.8	15469.9	1547.0	154.7	0.6	0.3	0.15	0.062	0.031
500	0.6	12375.9	1237.6	123.8	0.5	0.2	0.12	0.050	0.025
600	0.5	10313.2	1031.3	103.1	0.4	0.2	0.10	0.041	0.021
700	0.4	8839.9	884.0	88.4	0.4	0.2	0.09	0.035	0.018
800	0.4	7734.9	773.5	77.3	0.3	0.2	0.08	0.031	0.015
900	0.3	6875.5	687.5	68.8	0.3	0.1	0.07	0.028	0.014

uv coverage 2 stations

uv coverage 14 stations

uv coverage

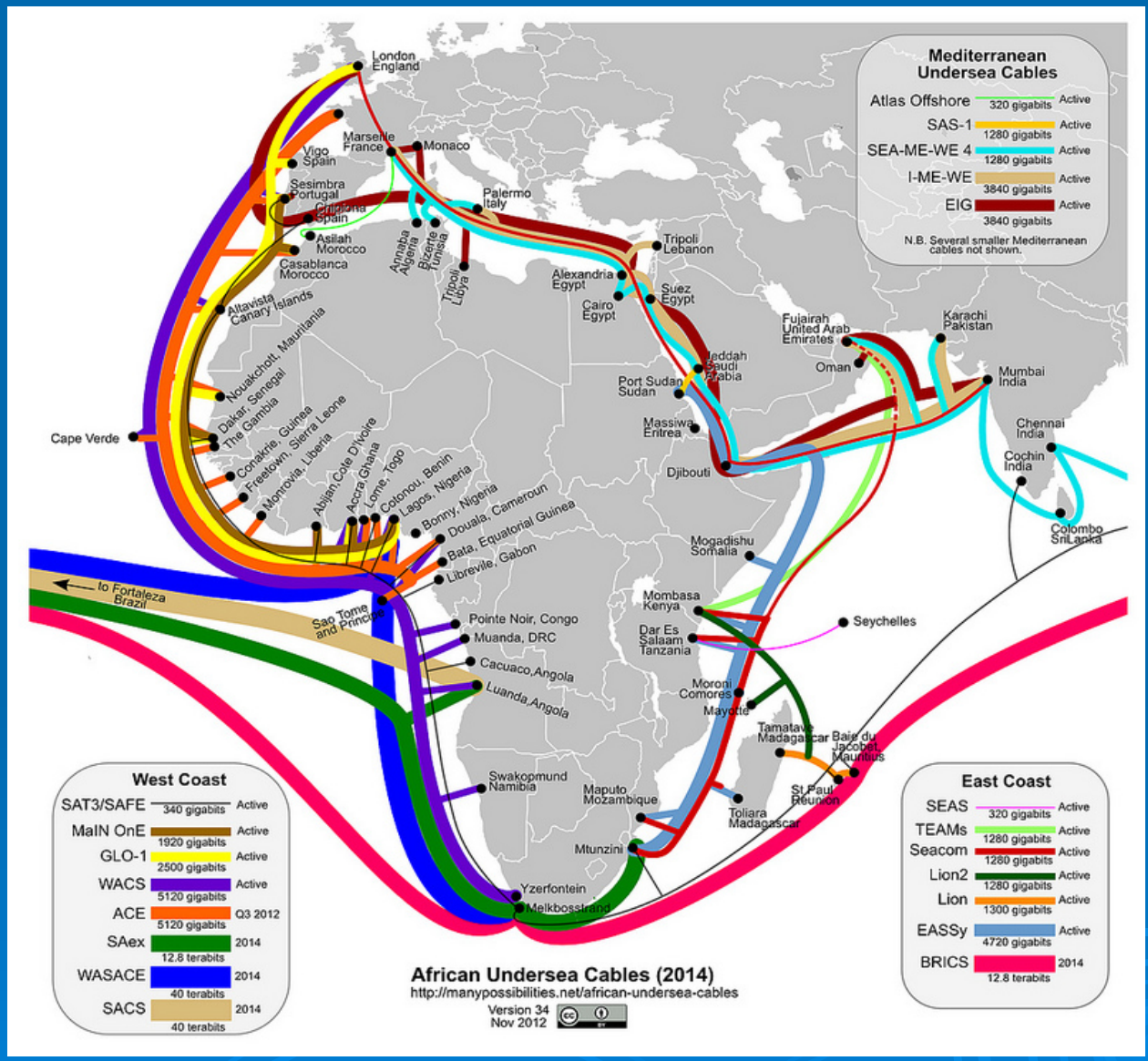




$$u^2 + \left(\frac{v - Z_\lambda \cos \delta_0}{\sin \delta_0} \right)^2 = X_\lambda^2 + Y_\lambda^2$$

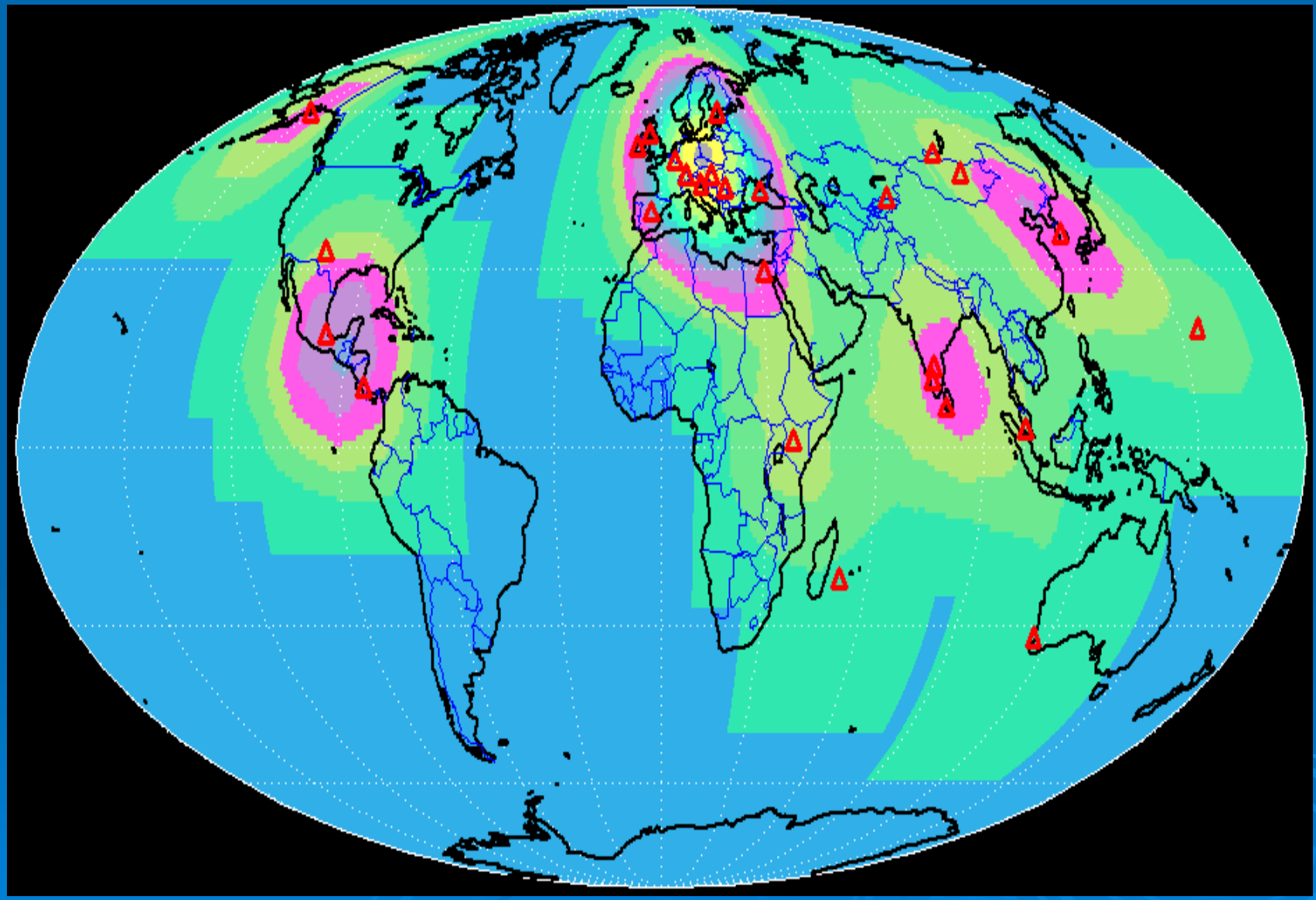
Interferometry & Synthesis in Radioastronomy
Thompson,Moran &Svenson
1998

Connectivity



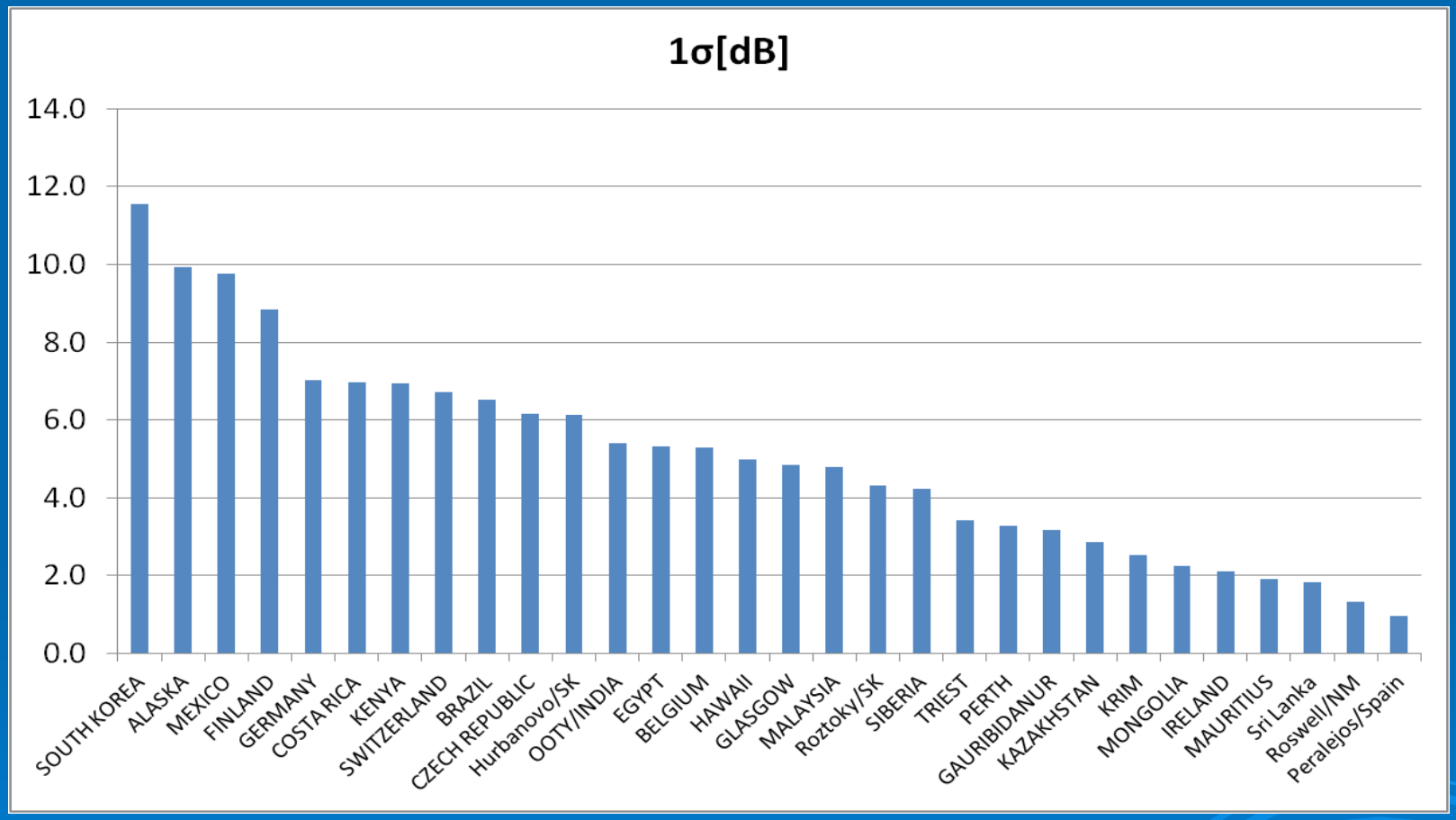
http://manypossibilities.net/africa-undersea-cables

RFI levels 45-870 MHz



Christian Monstein 2013

RFI levels 45-870 MHz



Extremely wide field imaging with heterogeneous non coplanar arrays

- Short spacing

- w/n term, sampling & visibility

- Primary beams: size and dependence on position

- Bandwidth decorrelation

- Imaging & CLEANing etc

- Future problem for the SKA

MITRA: Science I

- Solar: flares, coronal mass ejections (de Pontieu et al 2011, Zaarashvili et al 2013)

- The Milky Way, Galactic centre star forming regions(Yusef-Zadeh et al 2013)

- Galaxies and clusters of galaxies (van Weeren et al 2011)

- Pulsars & Supernova remnants (Stappers et al 2011, Han et al 2013)

MITRA: Science II

- Low brightness wide sources (Dodson 1997)

- Transient sources (Nithyanasdan et al 2011, Bannister et al 2011, Schmidt et al 2013)

- Spectral and recombination line observations (De Pree et al 1997)

- Spectral indices of sources(Miley et al 2008)

- Interstellar scintillation, Jupiter (Rickett et al 2002, Zarka et al 2005, de Pater et al 2003)

- Ionospheric and Space Weather (Judd et al 1987)

MITRA: Technology I

- Receiver system design (Ginourie 2009, Lutchumon 2011, Mahadu 2011, Bhoyrub 2012, Chataroo 2012, Armoogum 2013)

- Data acquisition system design (N. Pirthee 2013)

- Radio Frequency(RF) Electronics
(UOM & DUT projects with collaboration)

- Networking (Conhyea 2007, Armoogum 2013)

MITRA: Technology II

- Data Management (Brunner et al 2001, Morgan et al 2013, Grange et al 2012)

- High Capacity Multi-Parallel-Correlation (Begeman et al 2011, Jheengut 2008, Platel 2010, Mondon 2011, N. Pirthee 2013)

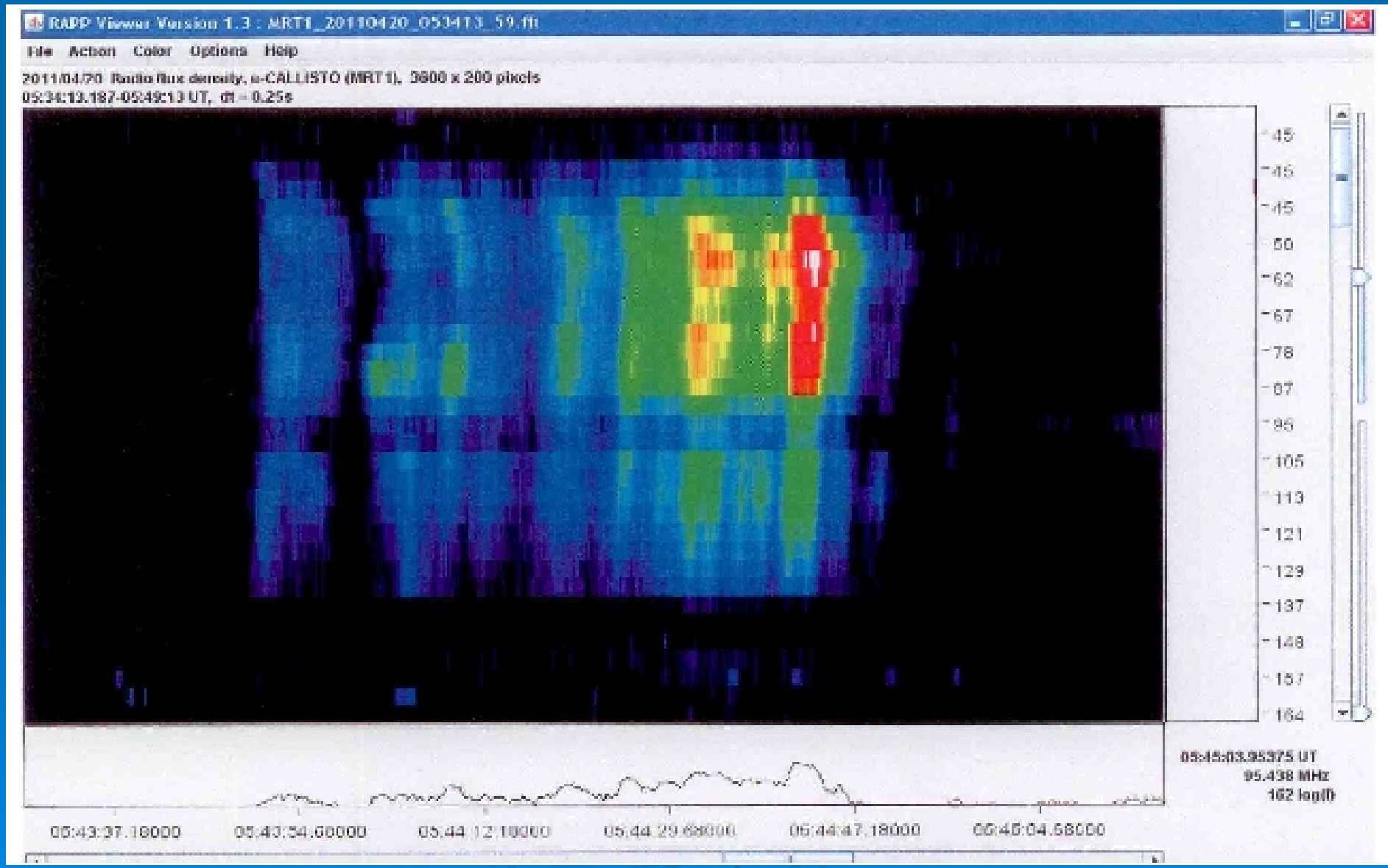
- Antenna design (Muthoor 2005, Ramdohee 2007, Mohur 2007, Boyjpnauth 2008, Nursimhulu 2009, Nunkoo 2009, Prayag 2011, Shibchurn 2013)

- VLBI and e-VLBI (e.g EVN)

MITRA Preliminary work: Antenna design Version 1

Prayag, Lallbarry &
Beeharry @ Bras d'Eau,
Mauritius

MITRA Preliminary work: Solar flare with antenna 20.4.2011



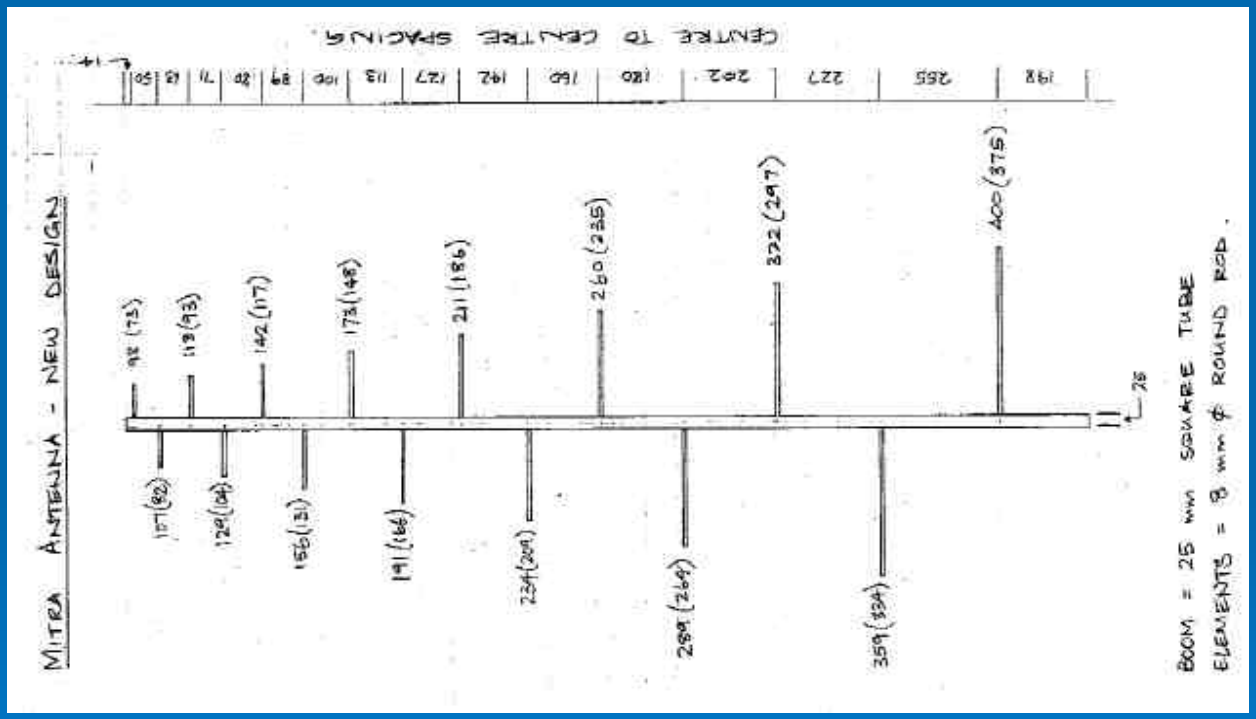
MITRA Preliminary work: 1st antenna 100-850 MHz

MRT
Bras d'Eau
Mauritius

DUT
Durban
RSA

G Van Vuuren & Students
from Kenya & Zambia

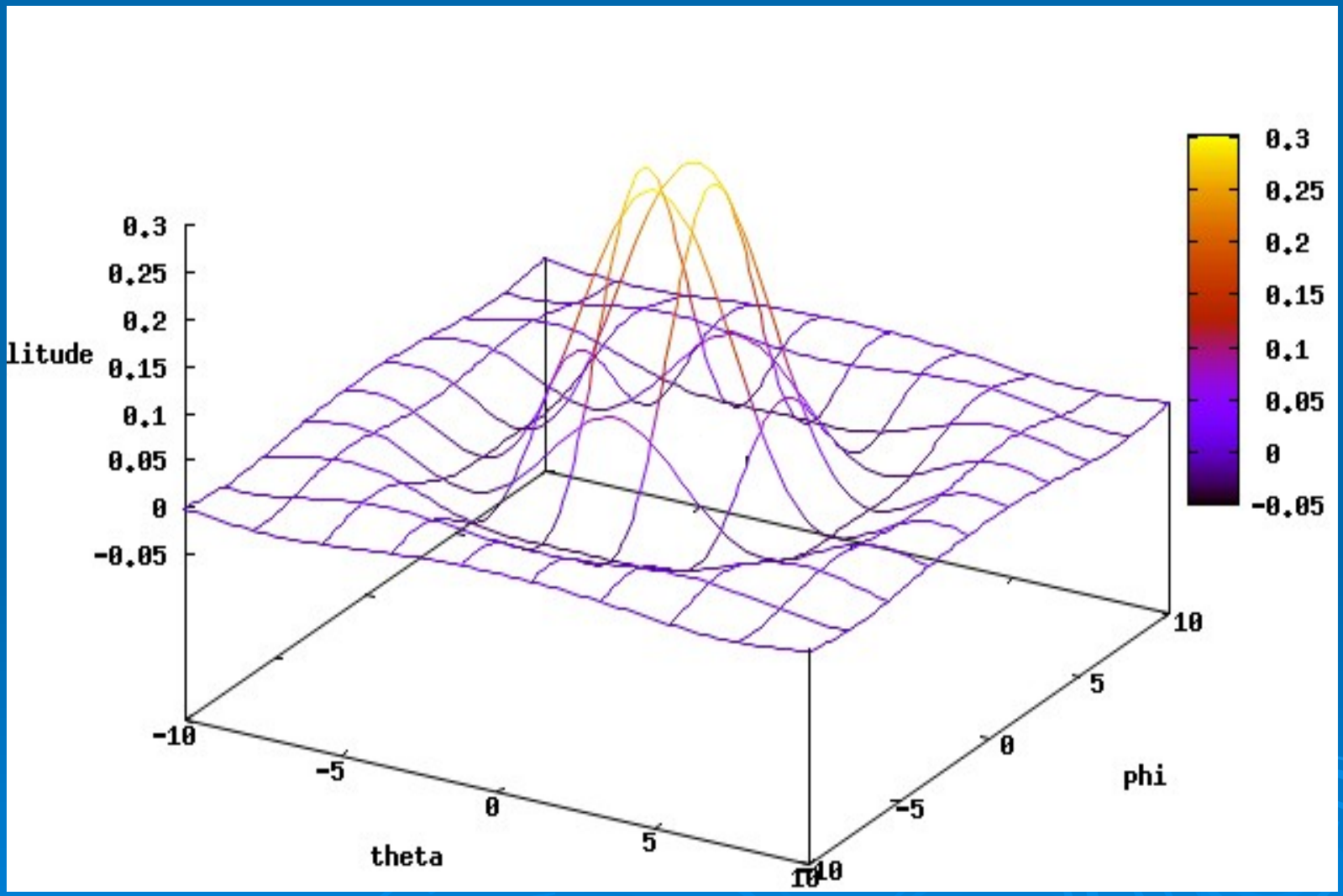
MITRA Preliminary work: new antenna design 200-800 MHz



New Antenna design@DUT, Durban, RSA

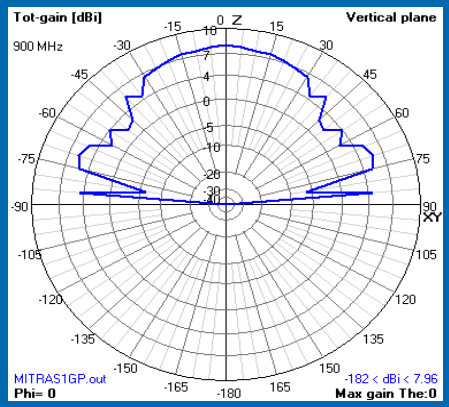
Antenna@MRT Bras d'Eau, Mauritius

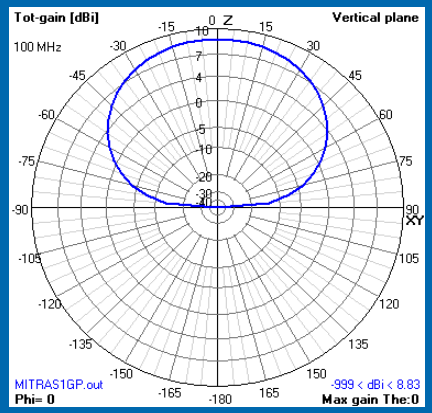
MITRA Preliminary work: simple model new antenna design 200-800 MHz

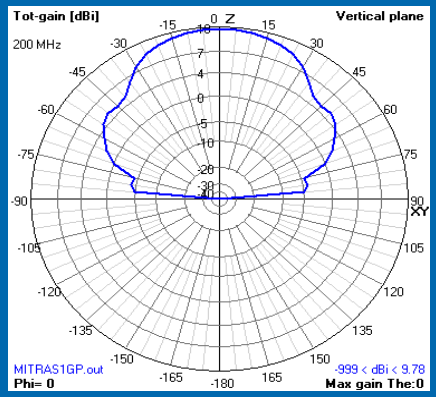


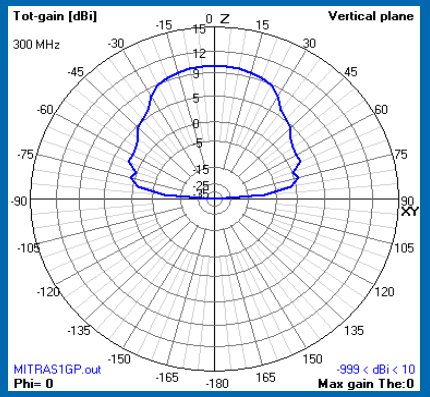
K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

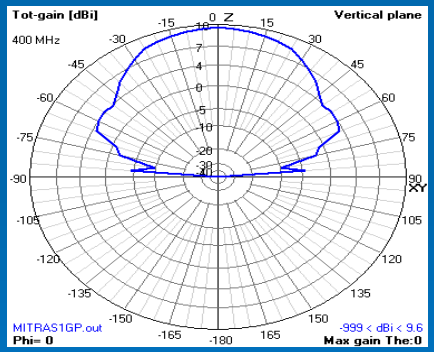
MITRA Preliminary work:
New Antenna design 200-800MHz

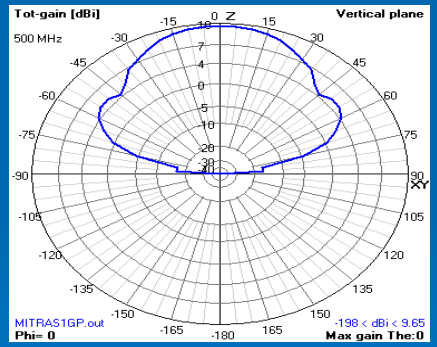


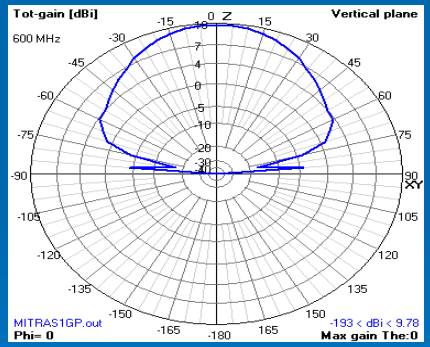


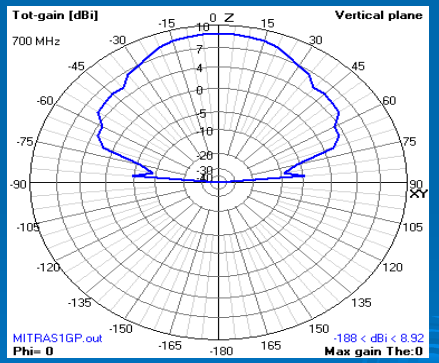


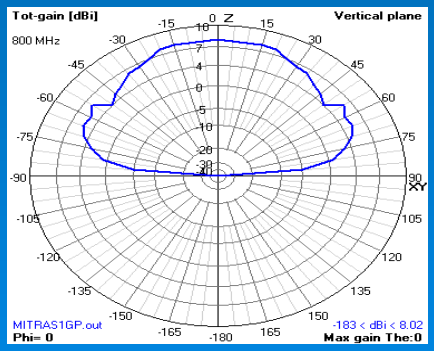


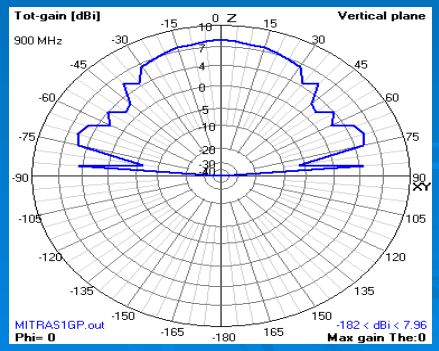












Ground plane 14: from last element with shorting bar.

SMacPherson@DUT

Model fit needed

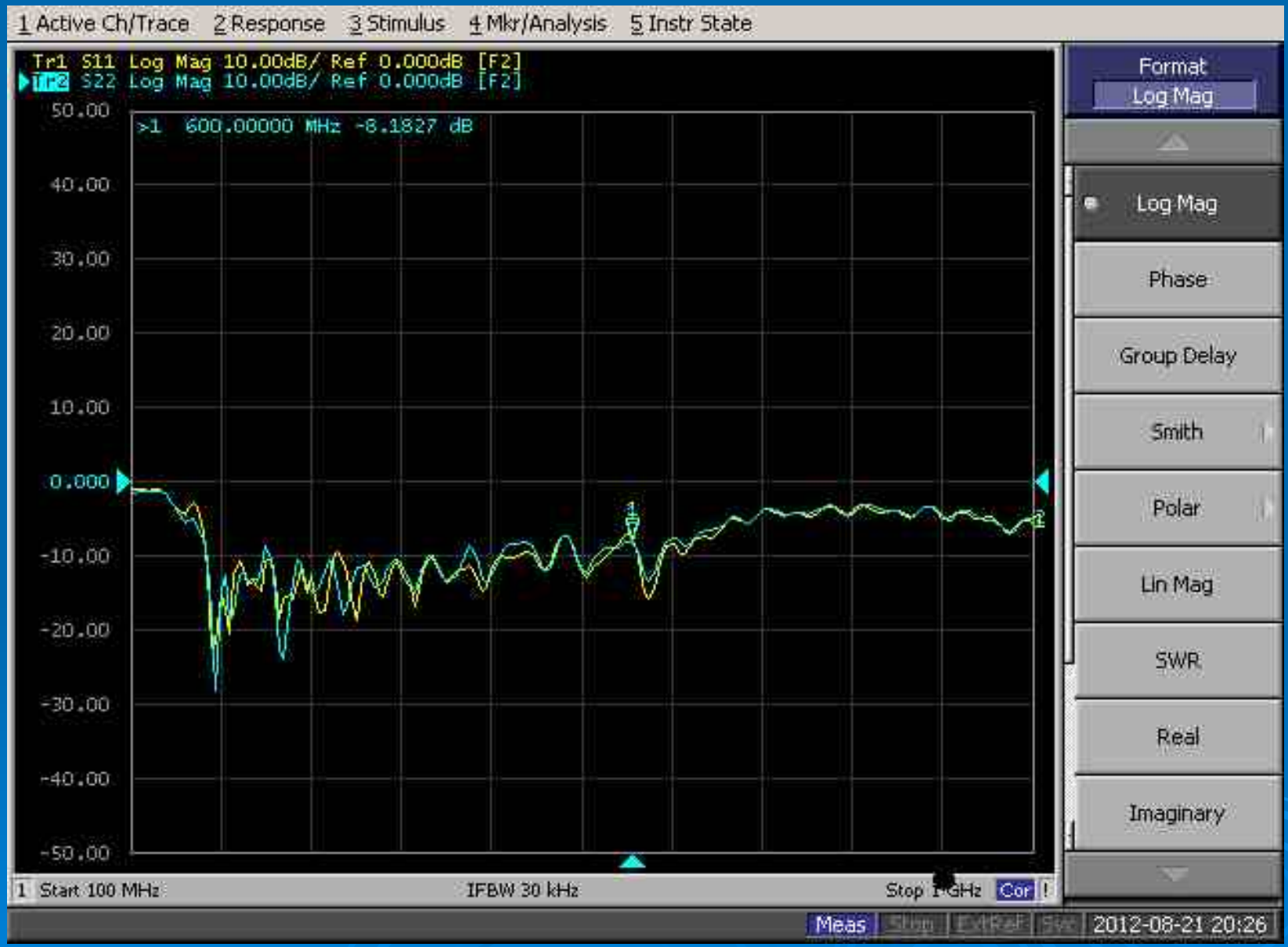
MITRA Preliminary work: Antenna design Version 2

Shibchurn, Lallbaree, Beeharry @ Bras d'Eau, Mauritius 2012-13

MITRA Preliminary work: new antenna VSWR

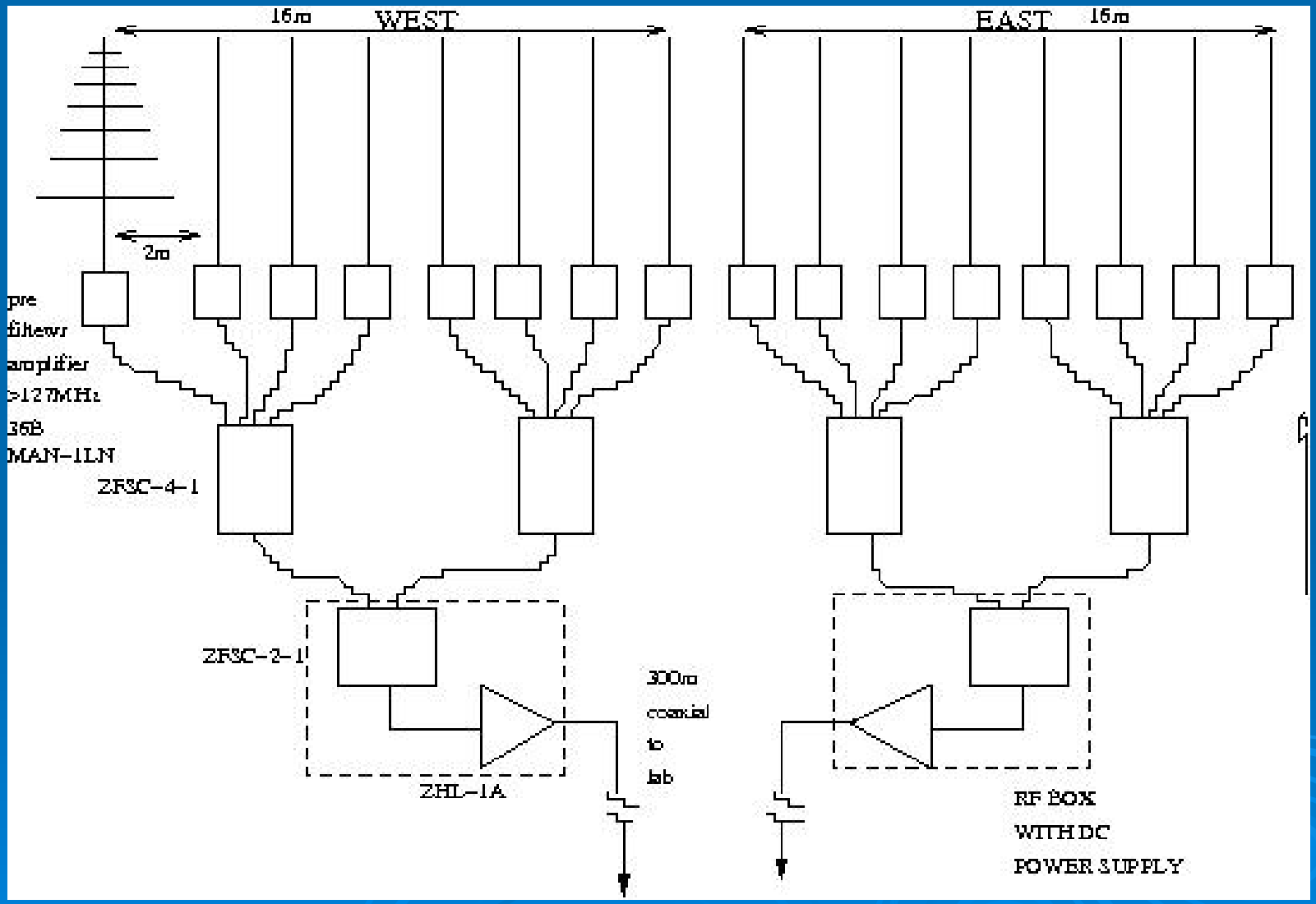
D. Ingala,S MacPherson & G. Van Vuuren, Durban

MITRA Preliminary work: new antenna Return loss



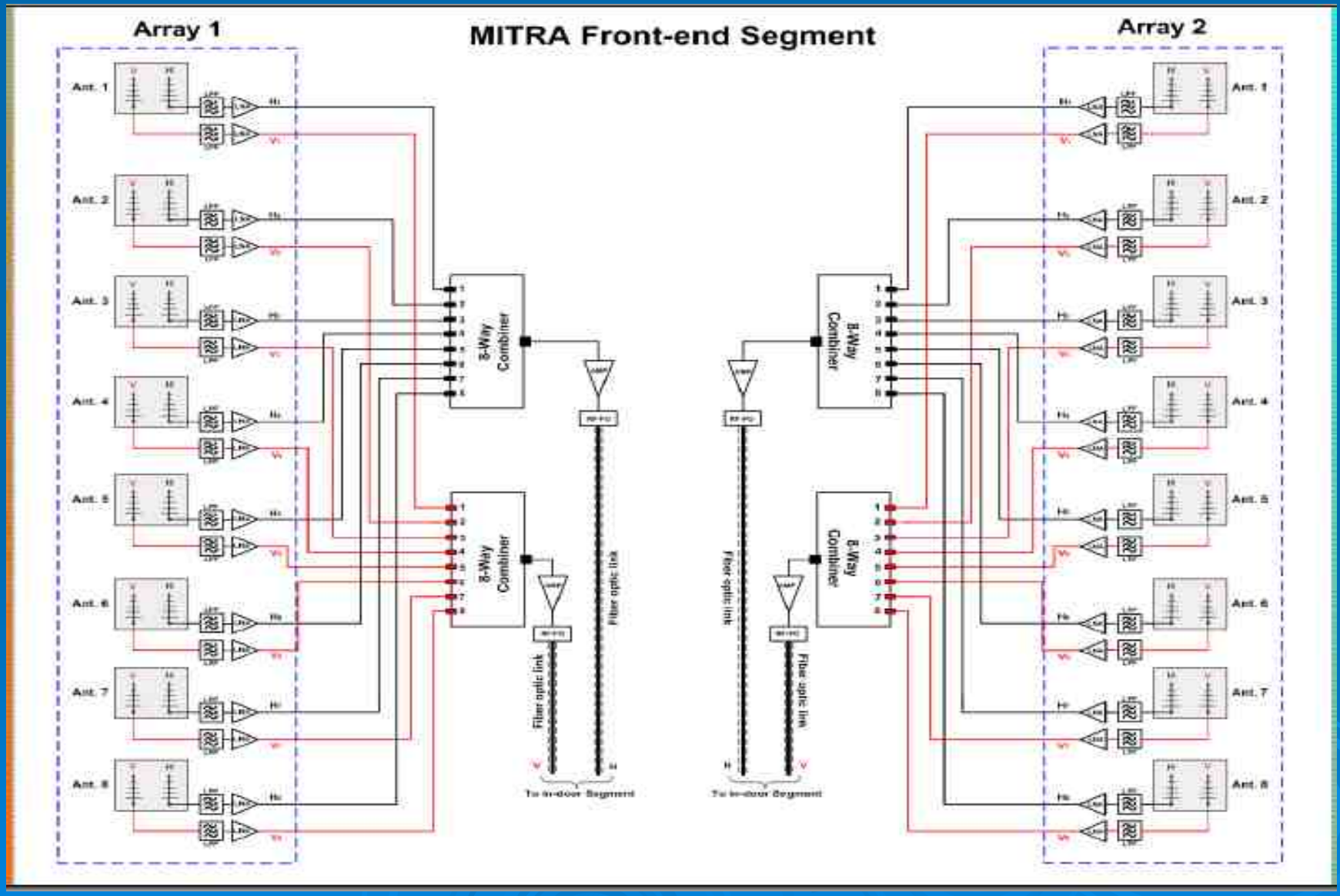
D. Ingala,S MacPherson & G. Van Vuuren, Durban

MITRA Preliminary work: Front end: Mauritius



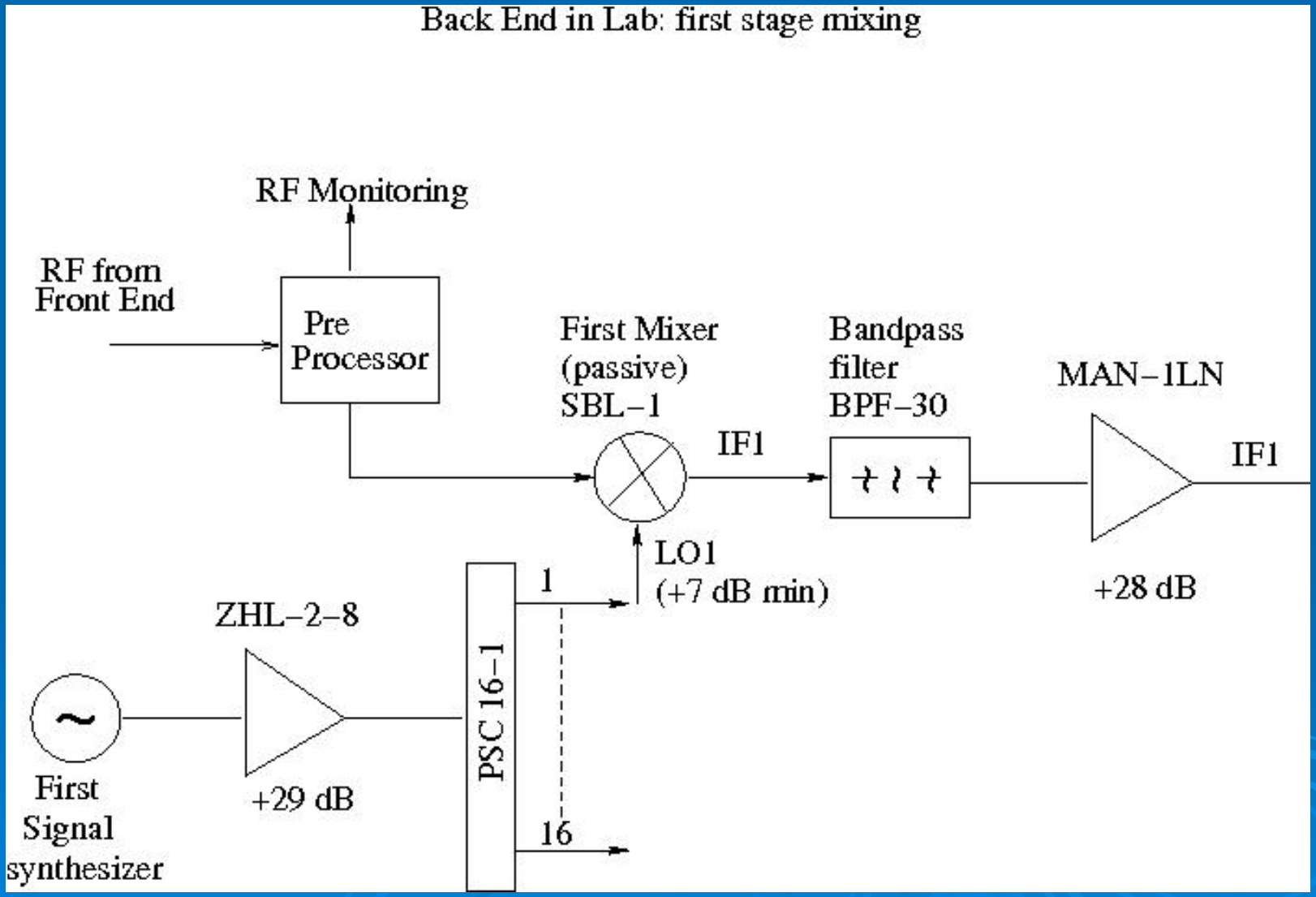
N Vydelingum & GK Beeharry Mauritius

MITRA Preliminary work: Front end: Durban



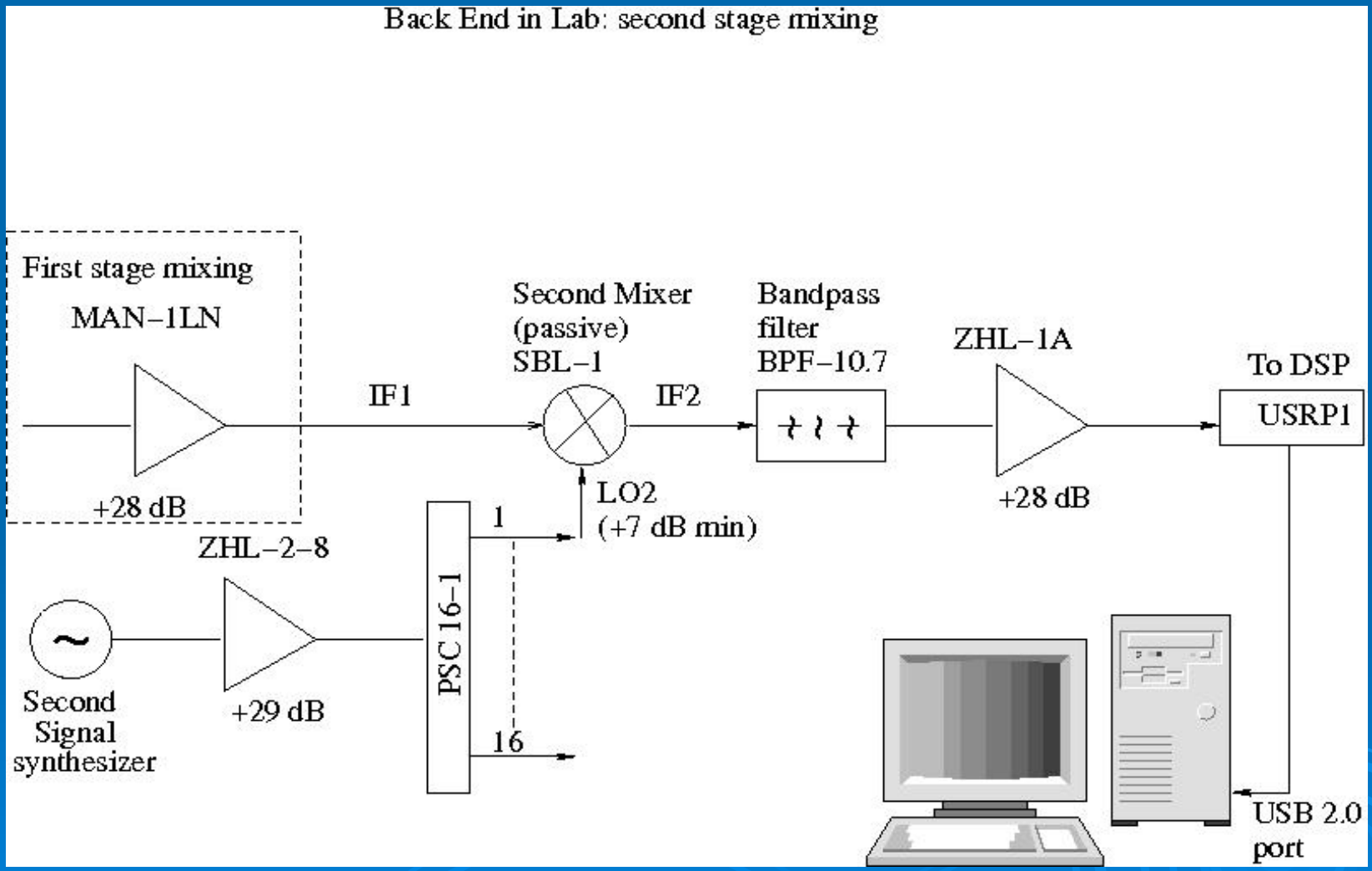
Dominique Ingala @DUT

MITRA Preliminary work: back end I: Mauritius



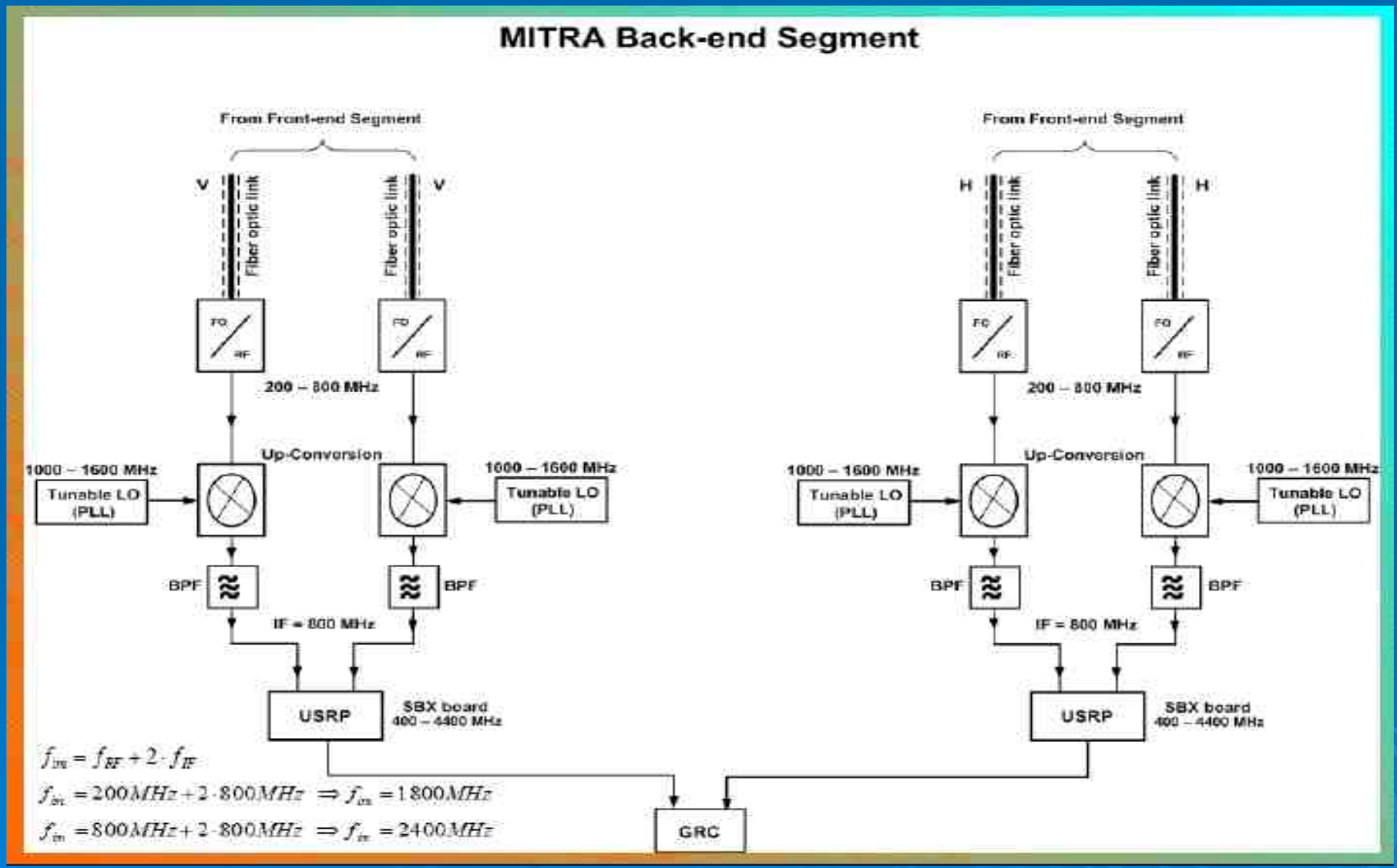
K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

MITRA Preliminary work: back end II:Mauritius



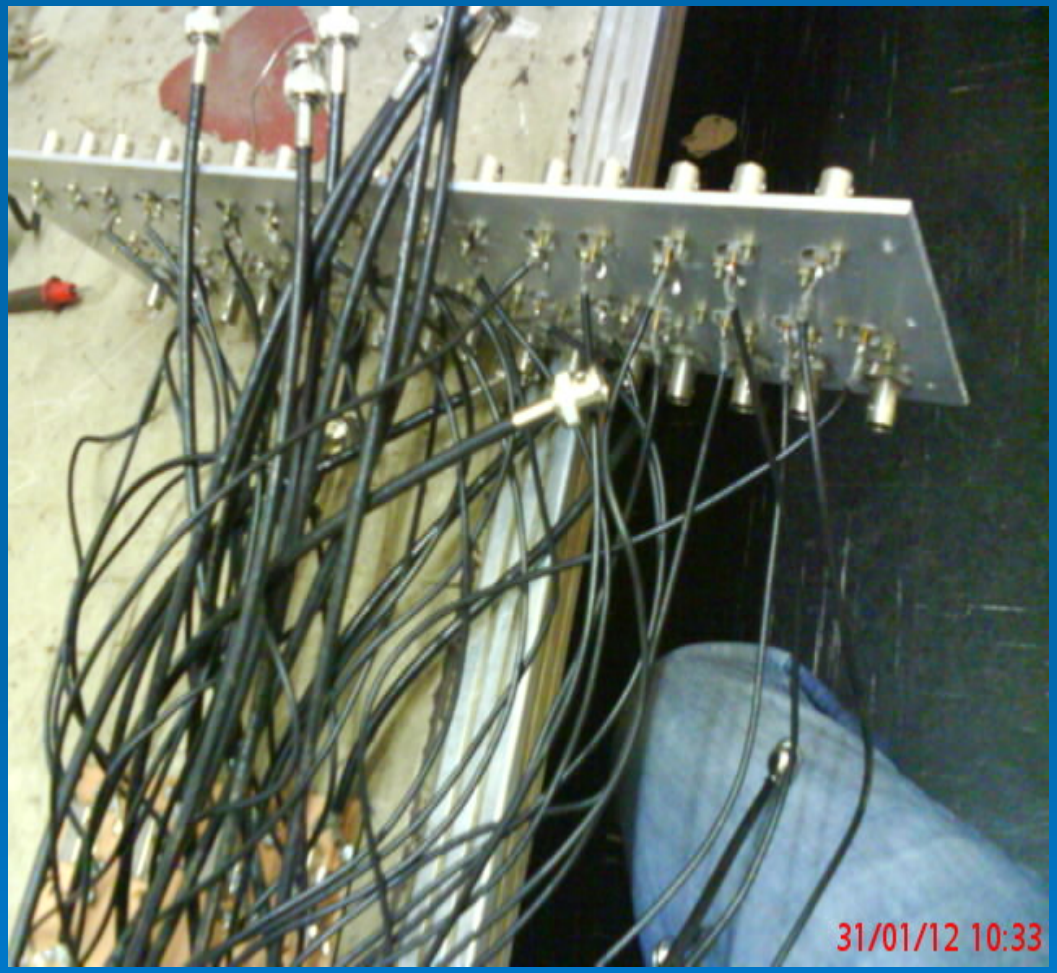
K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

MITRA Preliminary work: back end:Durban



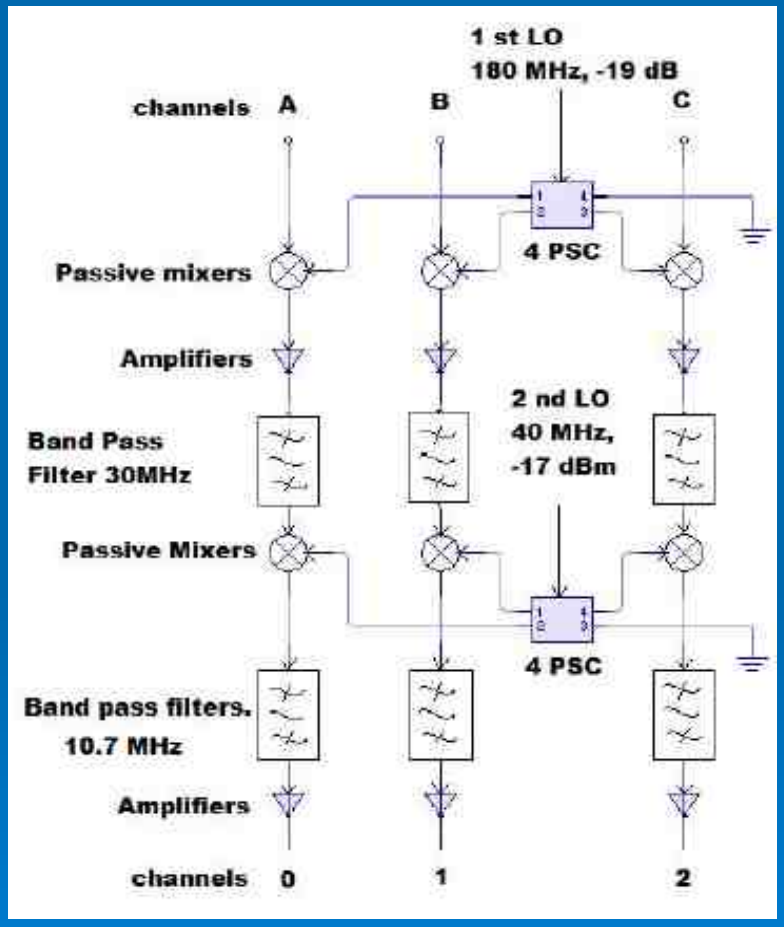
Dominique Ingala @DUT

MITRA Preliminary work: students at work



K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

MITRA Preliminary work:
4- channel receiver(4->16)



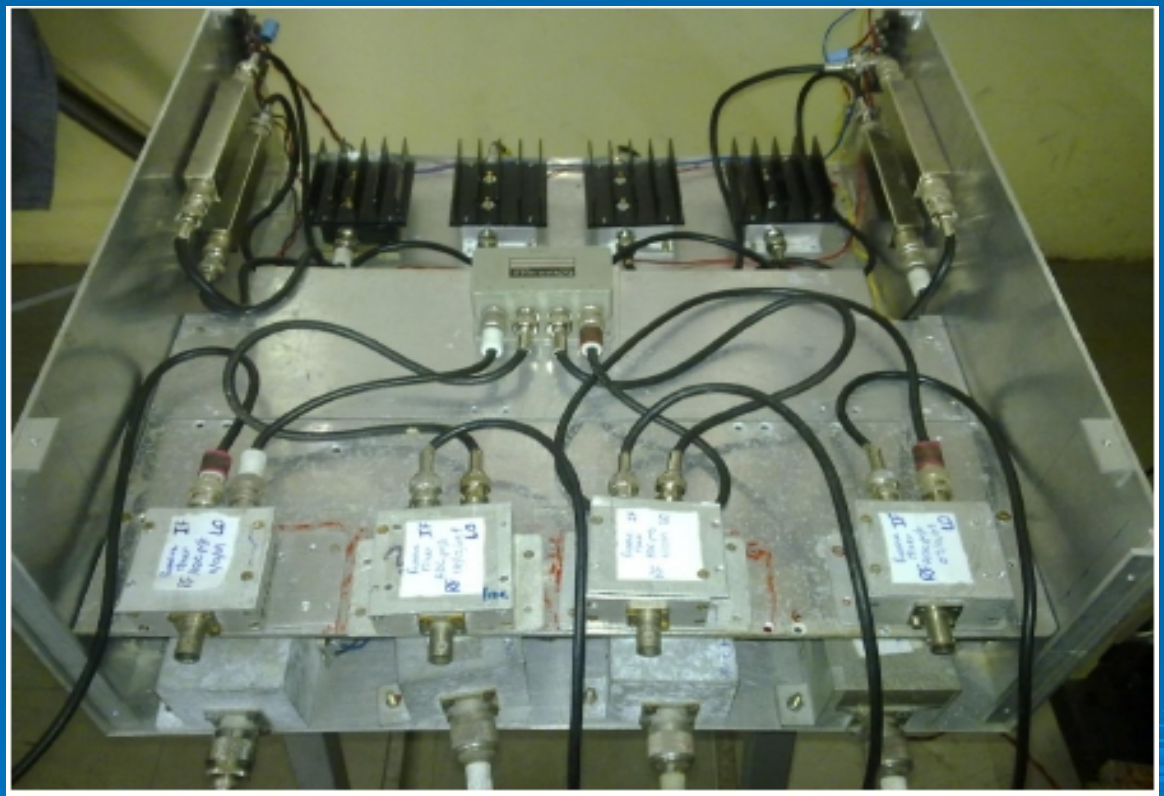


Figure 6.5: New back-end receiver system

Muthoor, Ramdohee, Nursihmhulu, Nunkoo,
Ginourie, Lutchumon, Mahadu, Chataroo, Bhoyrub

MITRA Preliminary work: 4 channel receiver (4->16)

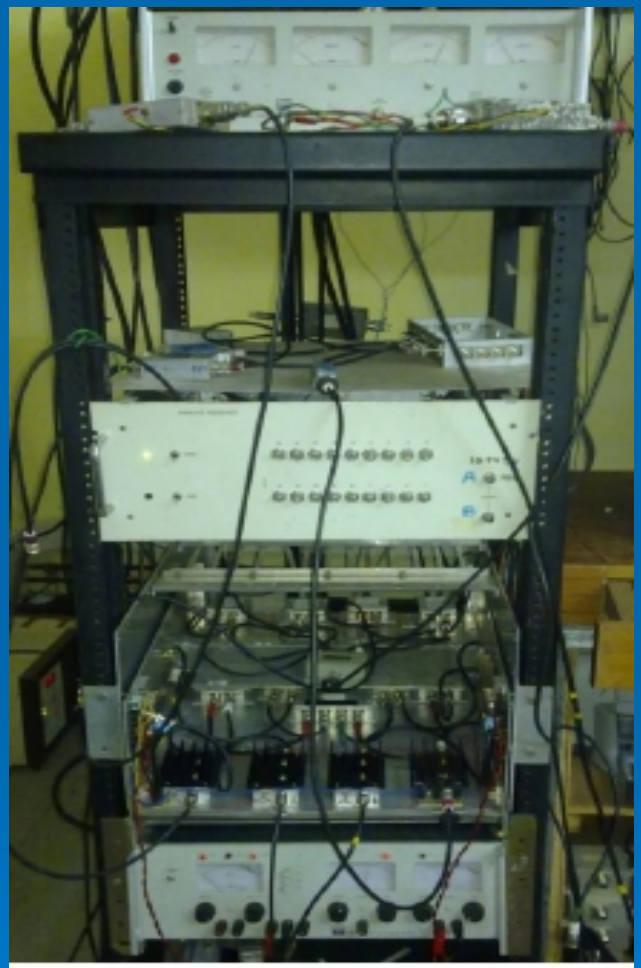


Figure F.34: Receiver system

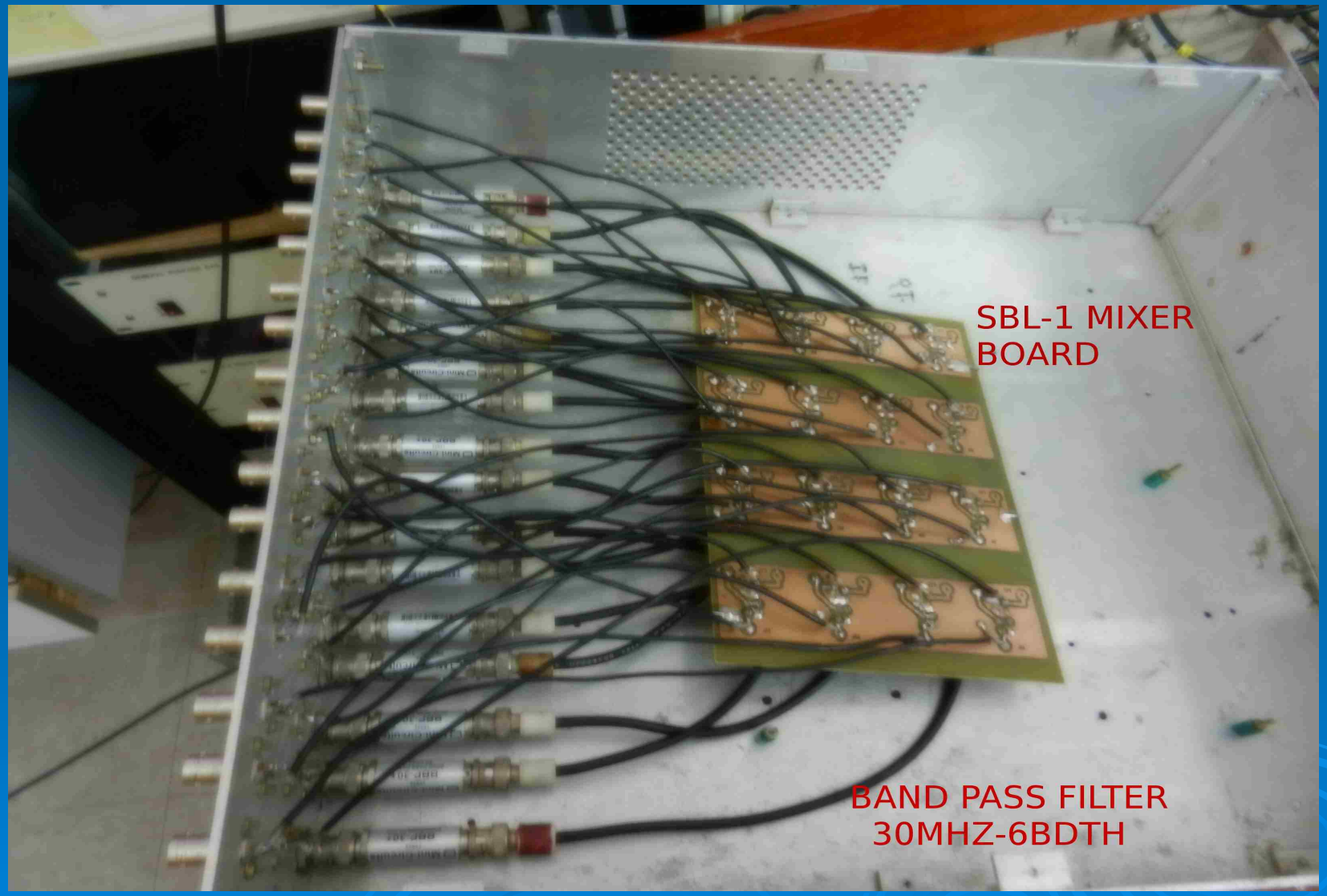
Figure F.29: PCI-ADC card

Muthoor, Ramdohee, Nursihmhulu Nunkoo, Ginourie, Lutchumon, Mahadu, Bhoyrub, Chataroo

MITRA Preliminary work: 16 channel receiver pre-processor

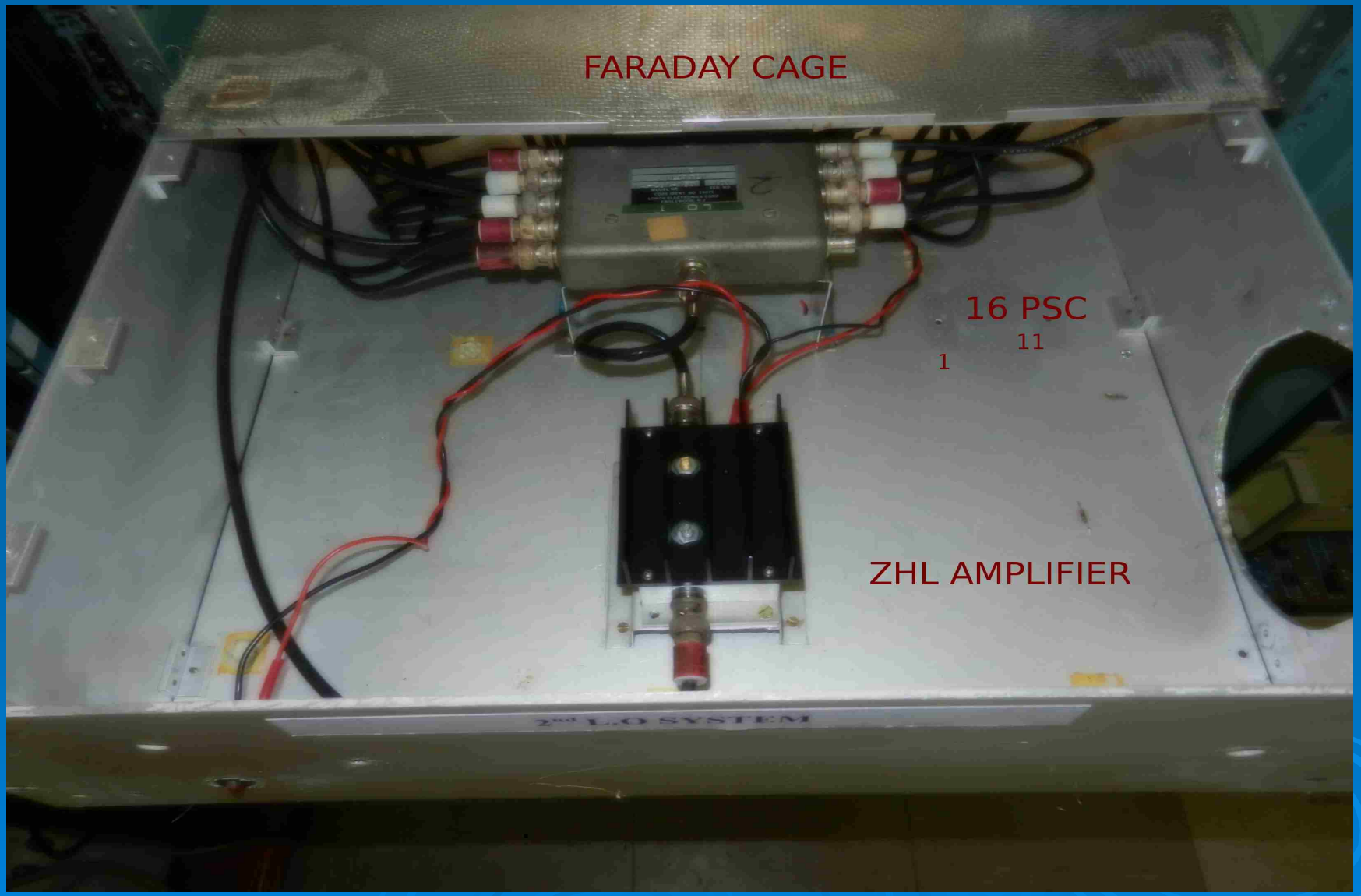
K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

MITRA Preliminary work: 16 channel receiver first mixer



K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

MITRA Preliminary work: 16 channel receiver LO distribution

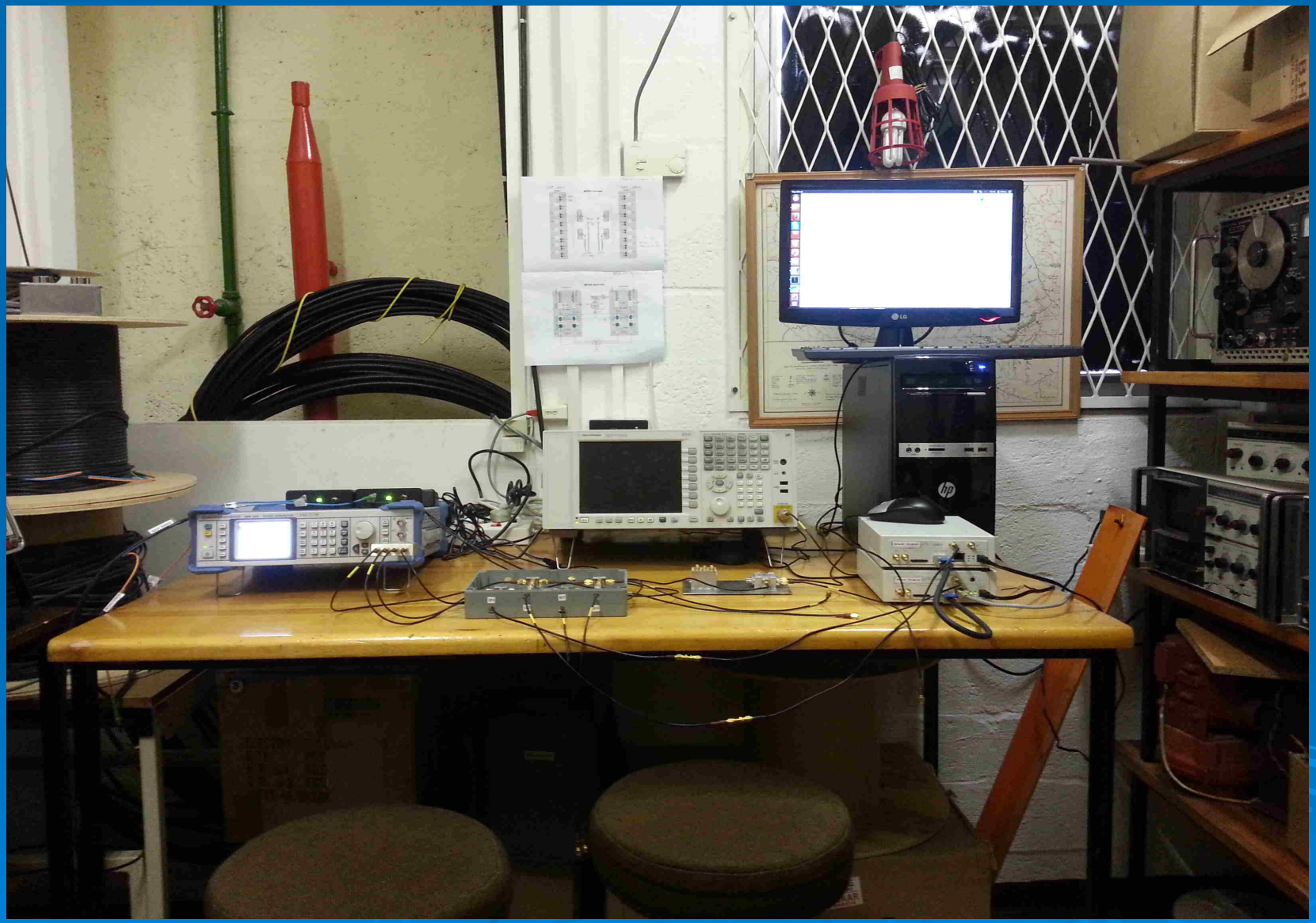


K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

MITRA Preliminary work:
16 channel complete receiver

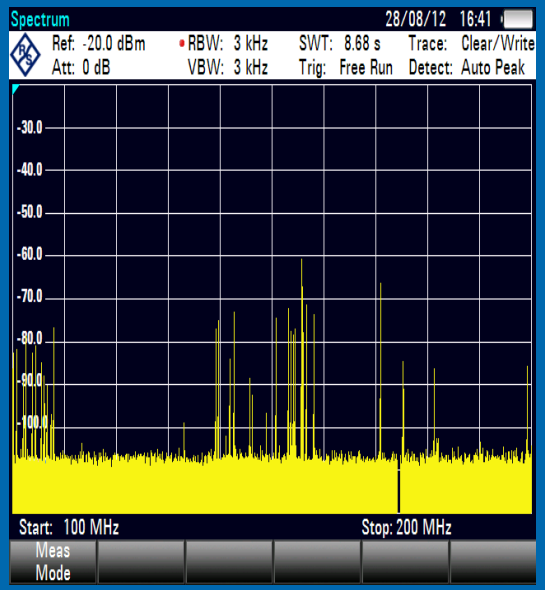
K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

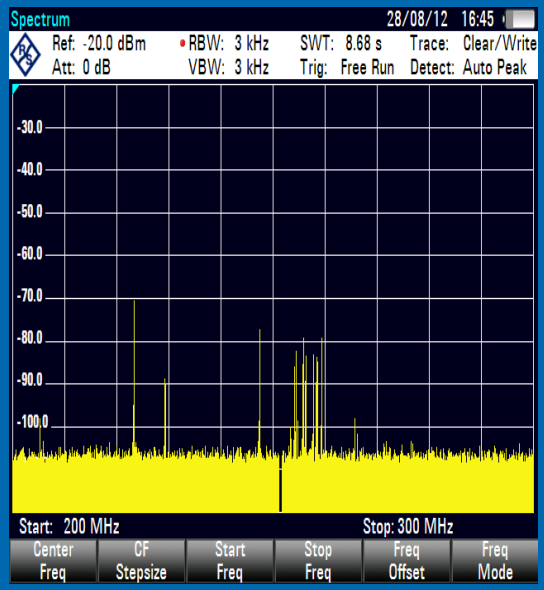
MITRA Preliminary work:
DUT receiver room

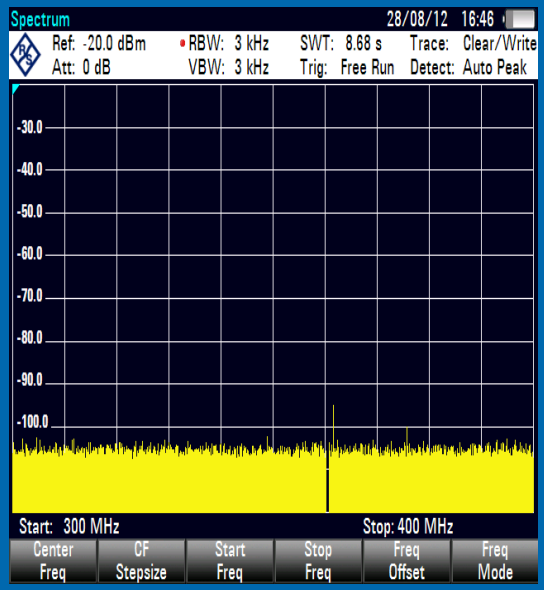


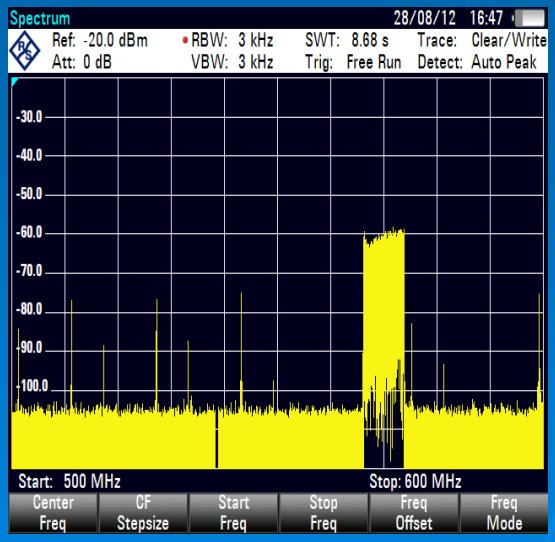
S.MacPherson, G. van Vuuren, D Ingala DUT 2013

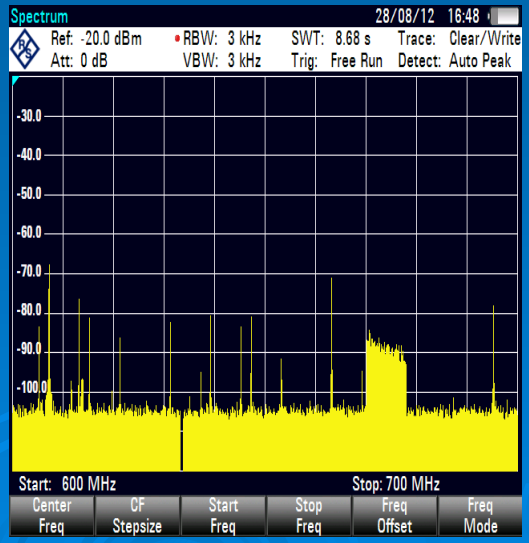
MITRA Preliminary work: back end:Durban

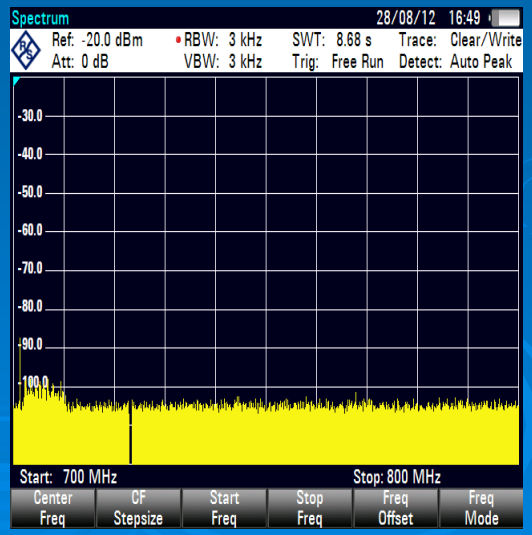






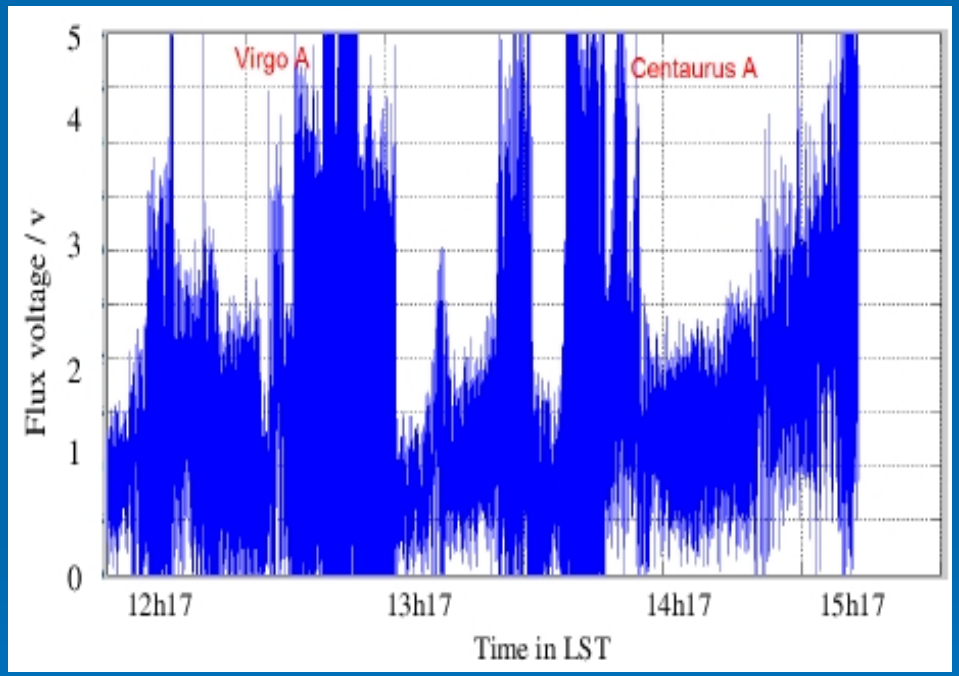


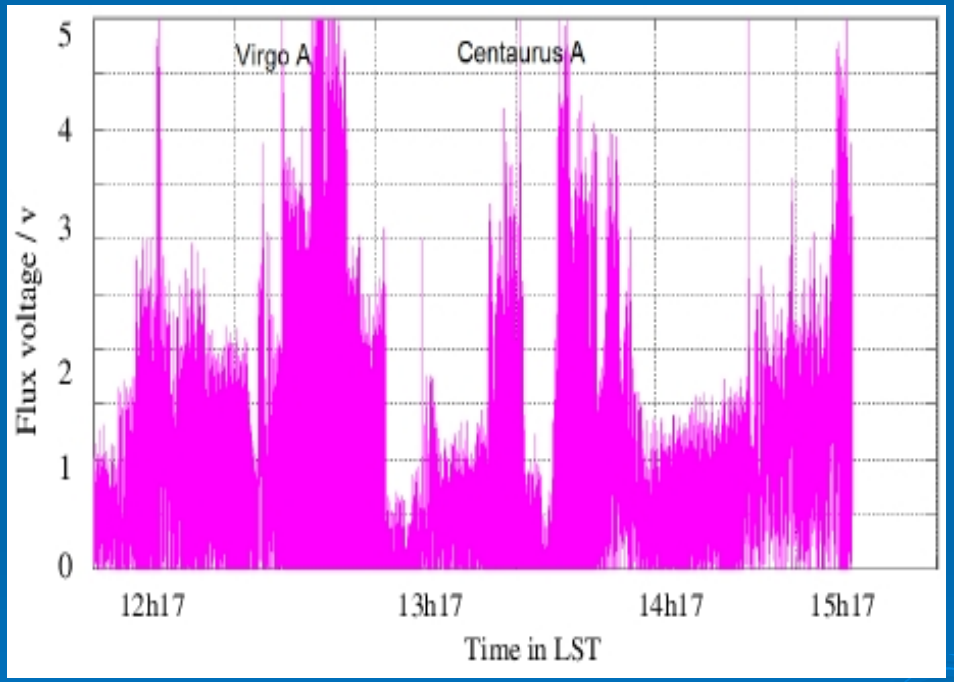




Dominique Ingala @DUT

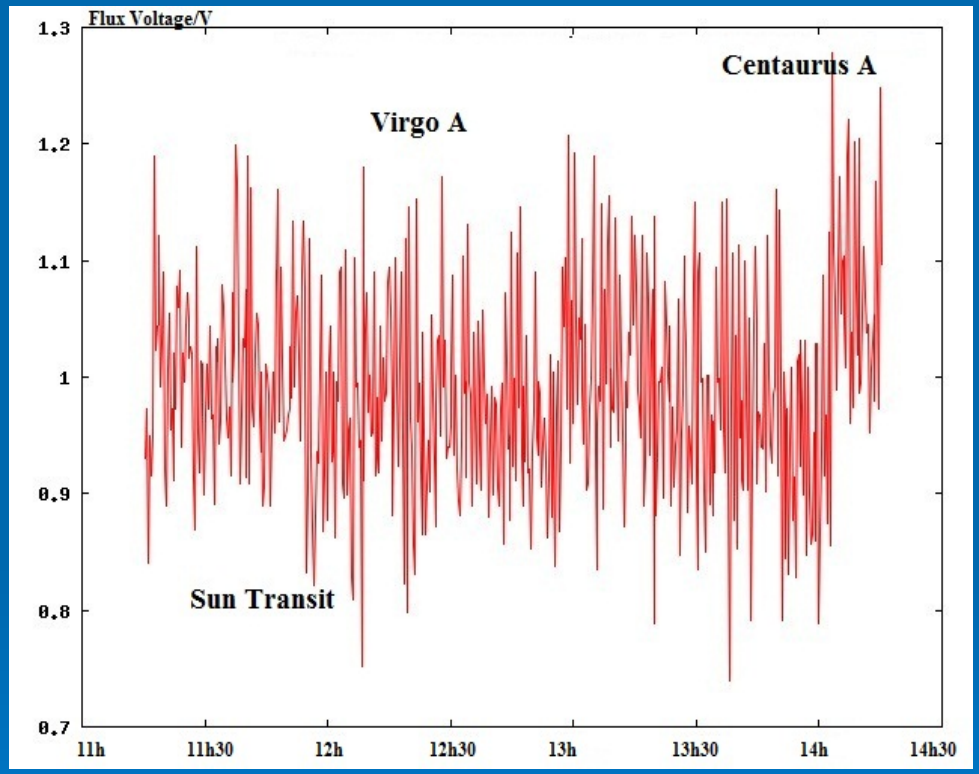
MITRA Preliminary work
4 channel receiver

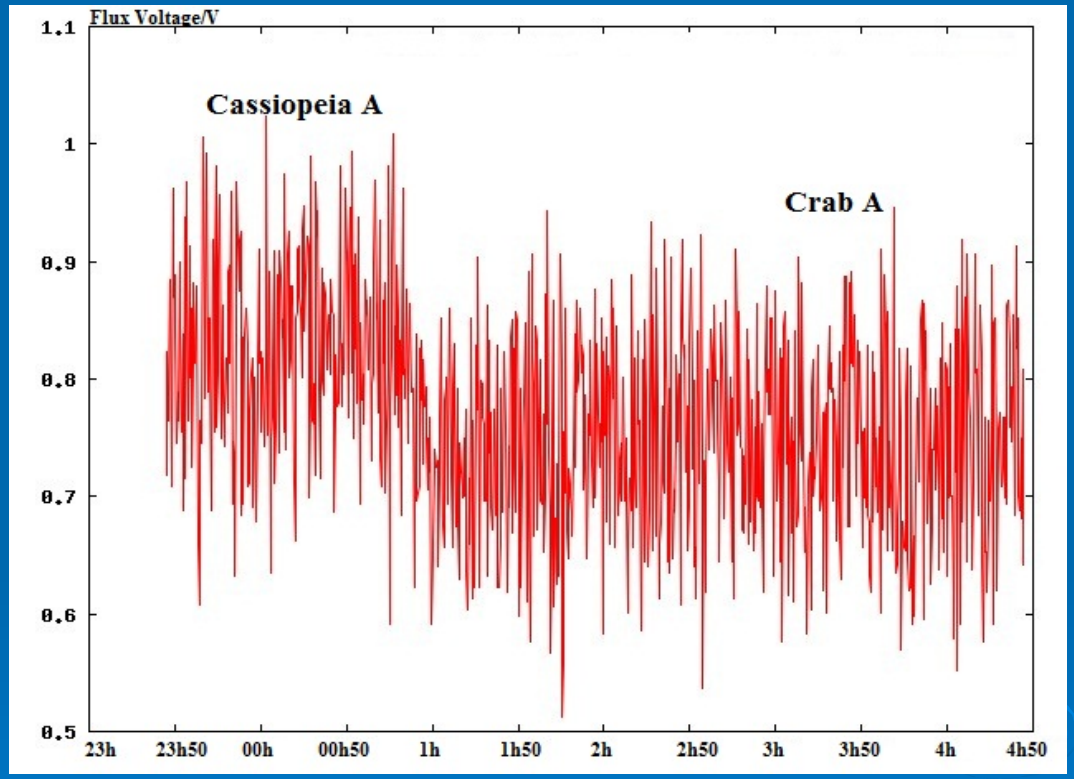




1 D dirty scan (8 antennas) Cos(left) and Sin(right)
150 MHz RF 2-channel correlator ADC card Mahadu & Lutchmon

MITRA Preliminary work
16 channel receiver





1 D dirty smoothed scan (8 antennas) 150 MHz RF 2-channel correlator ADC card Bhoyrum & Chataroo April 2012

MITRA Preliminary work
16 antenna array Durban

S.MacPherson, G. van Vuuren, D Ingala DUT 2013

MITRA Preliminary work
16 antenna array Mauritius

MITRA Preliminary work: Universal Software Radio Peripheral Hardware

- Ettus Research

- Open source design

- Programmable FPGA

- PC-USRP USB link

- Daughter boards available: WBX transceiver

- PC initial data processing

MITRA Preliminary work: Universal Software Radio Peripheral Software

- Software Defined radio

- Open source GNU Radio

- Processing defined by flow graphs in Python

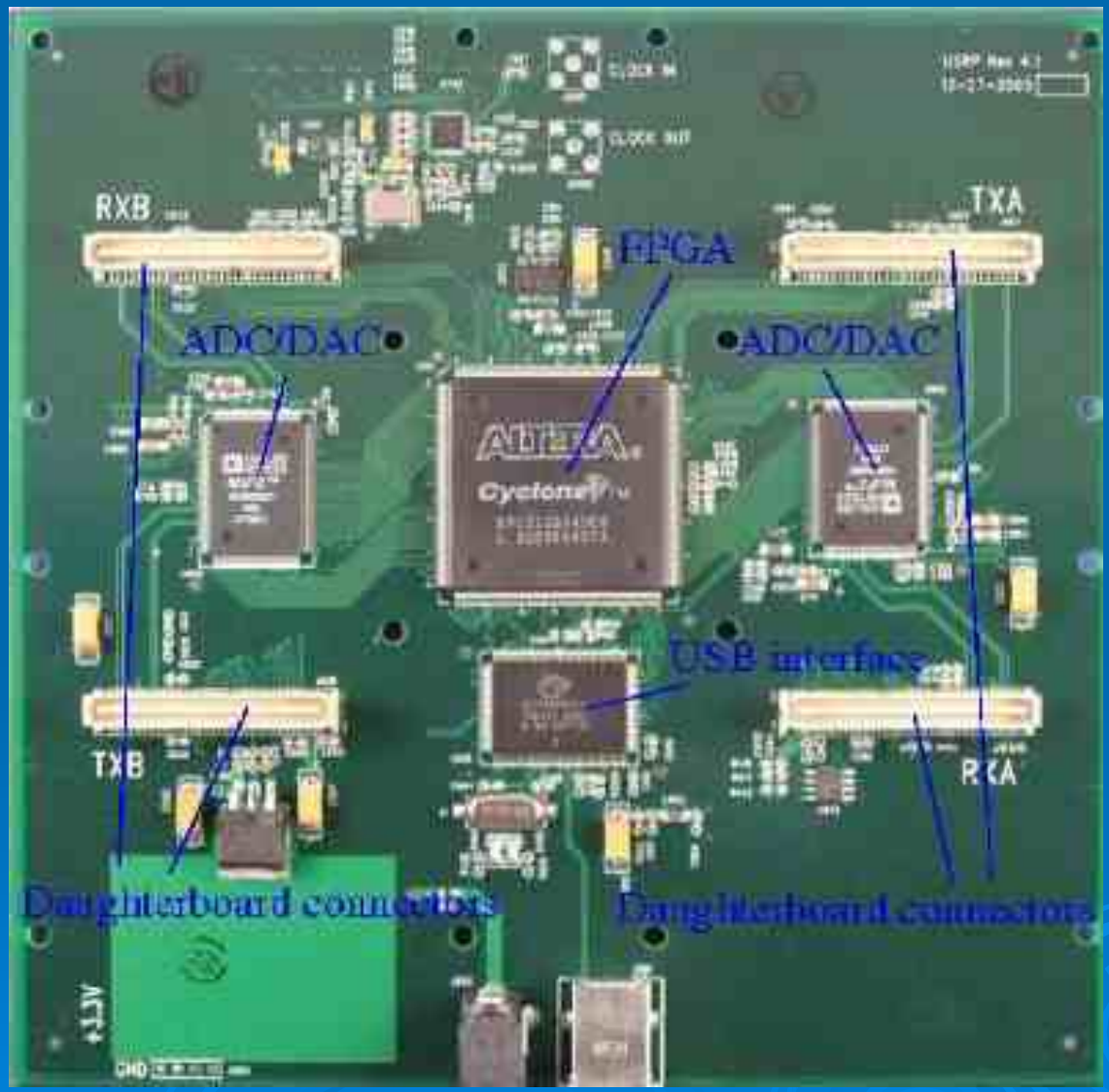
- Primitives in C++

- Programmes for the FPGA

MITRA Preliminary work: USRP1 Front panel

Website

MITRA Preliminary work: USRP1Mainboard



Website

MITRA Preliminary work: USRP1Mainboard

- GNU Radio free open software

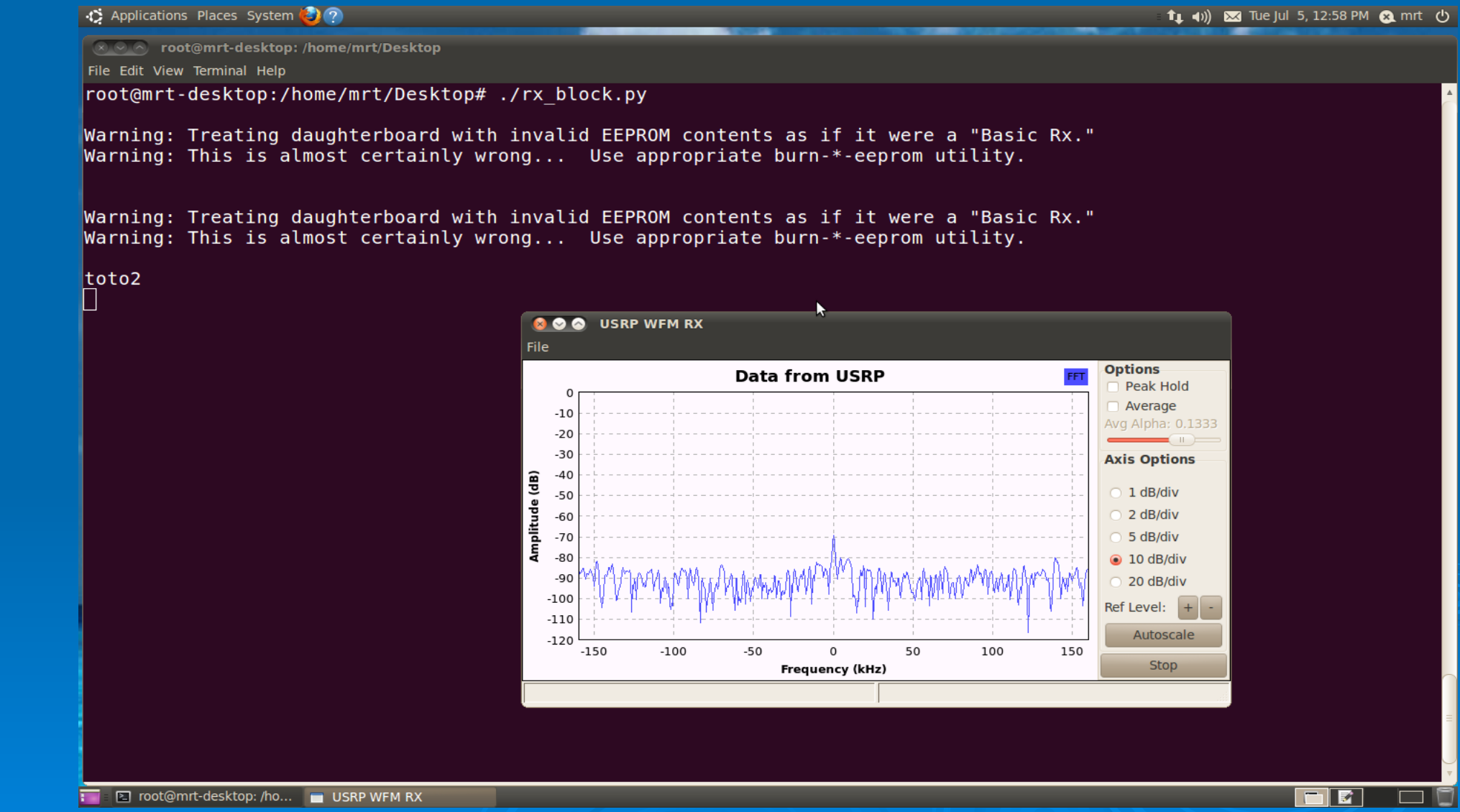
- ~1.5-2 months to install in GNU/Linux

- Tried on Slackware, Debian and Ubuntu

- Modified source code “rx_block.py”

C Mondon, N Vydelingum & GK Beeharry Mauritius

MITRA Preliminary work: USRP1Mainboard



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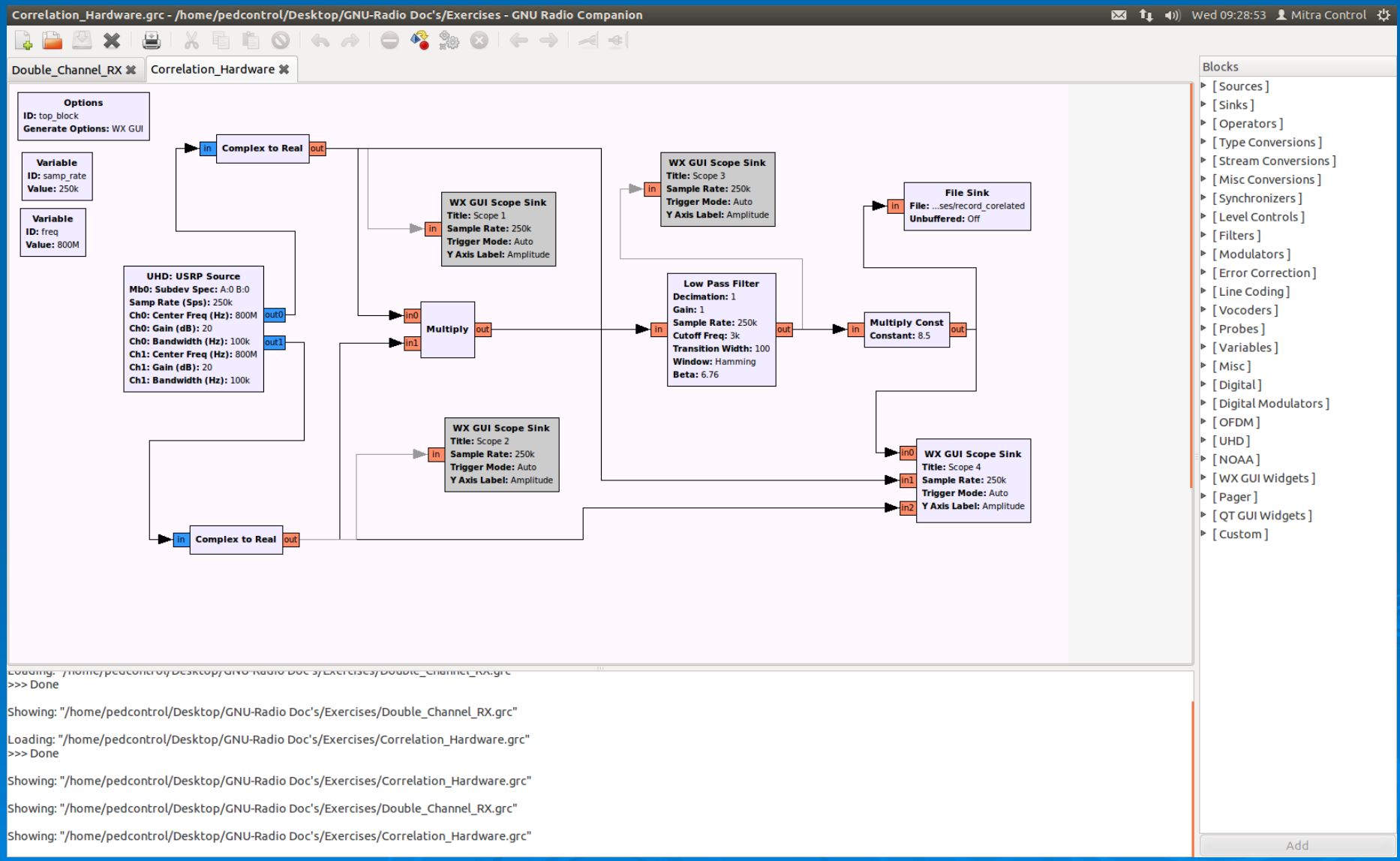
MITRA Preliminary work:

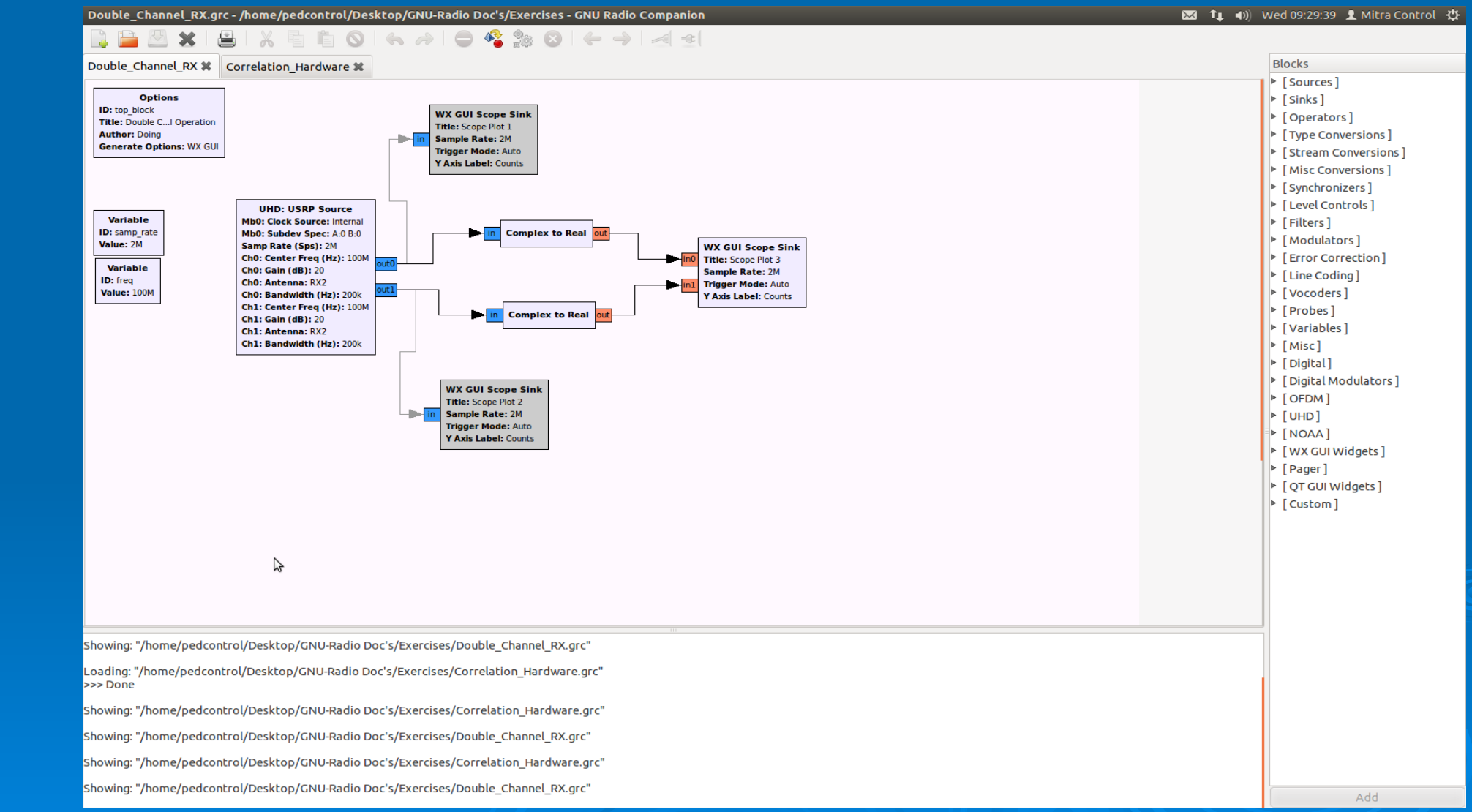
USRP control using GNU Radio Companion



D Ingala Durban

MITRA Preliminary work:

2 USRP detection using GNU Radio Companion



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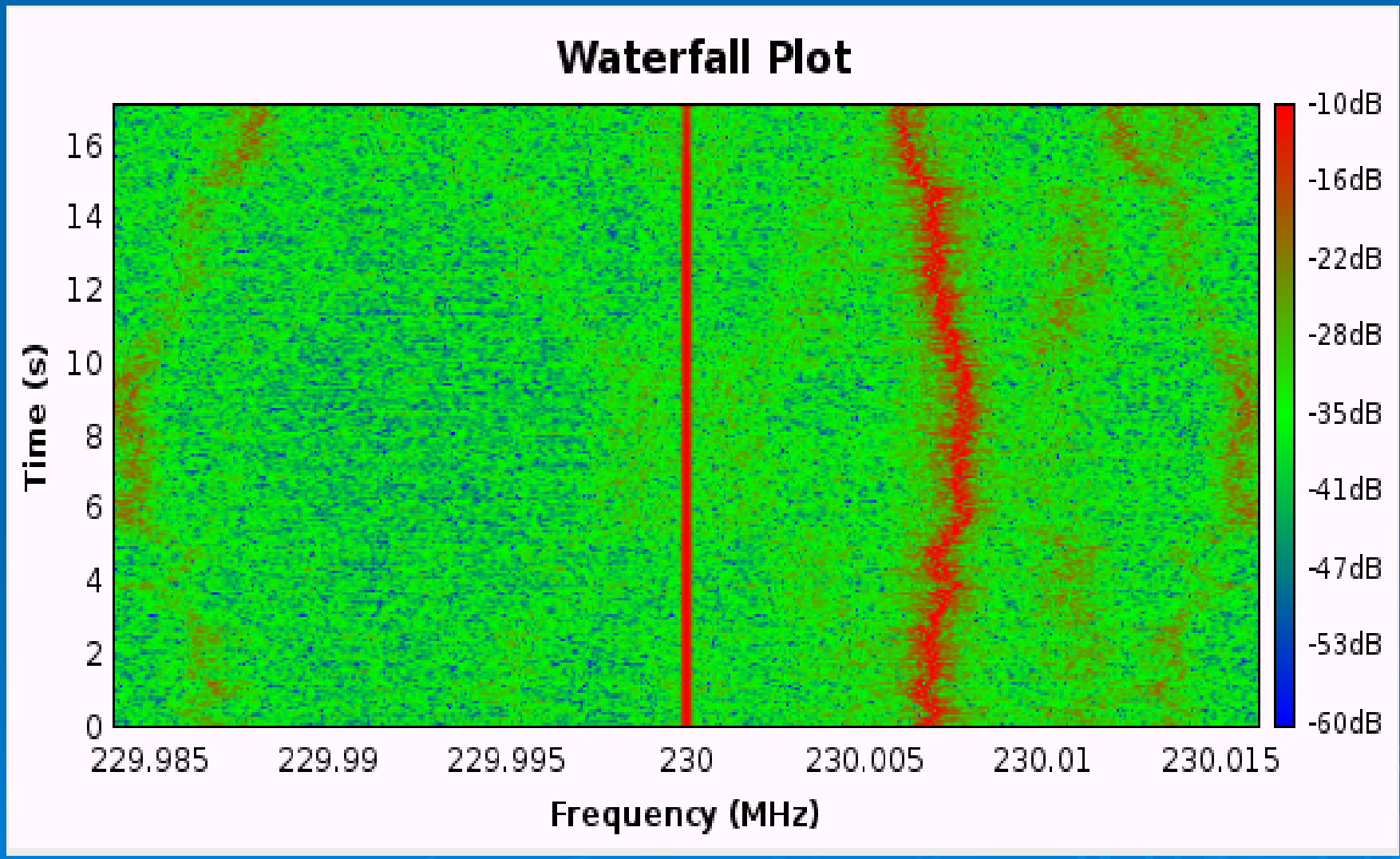
MITRA Preliminary work: Waterfall



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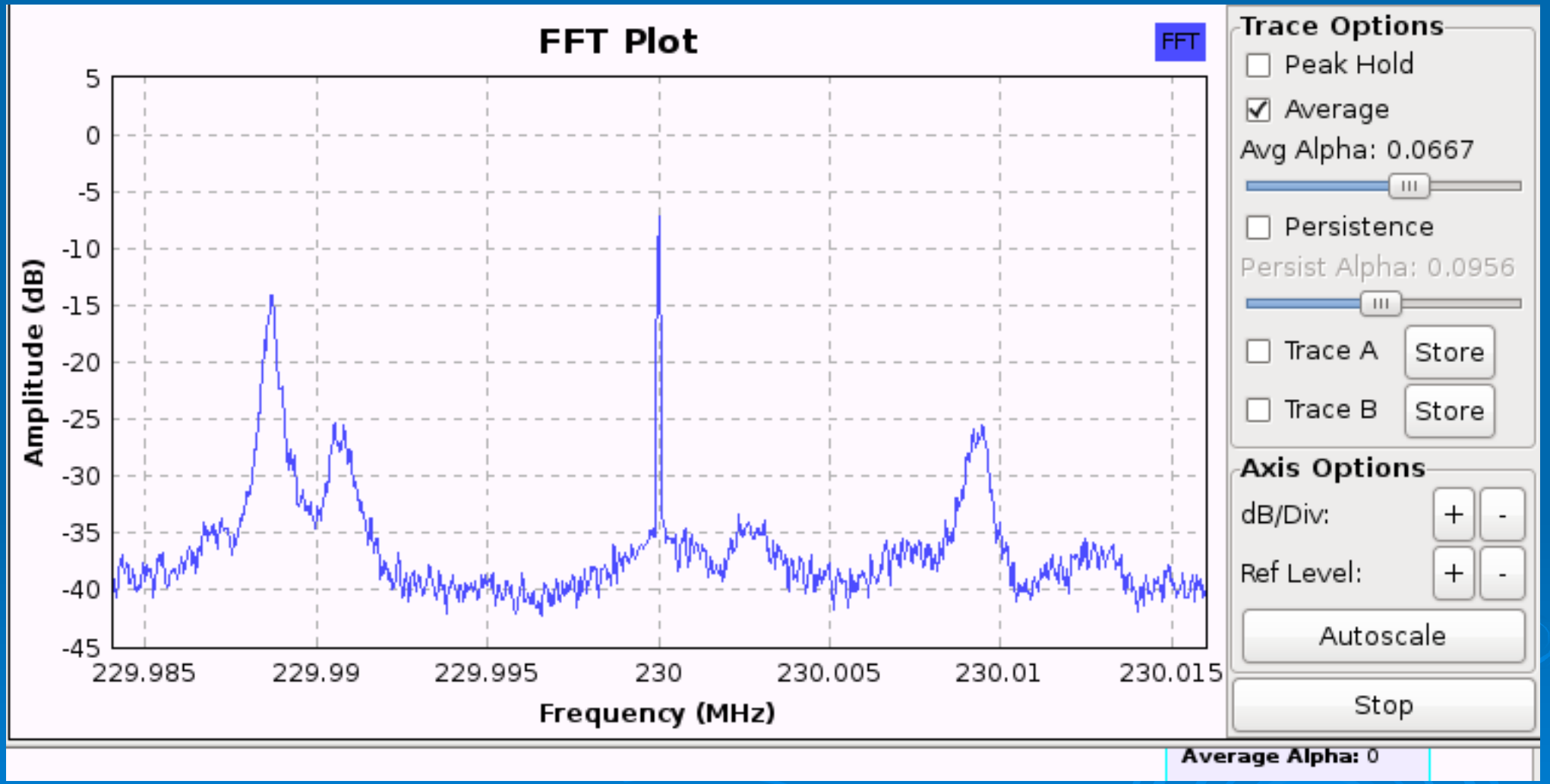
MITRA Preliminary work: FFT



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MITRA Preliminary work: Recent relevant software

Software correlation on CPU (Jheengut)

ADC card acquisition software CPU (Ginourie)

ADC card acquisition software GPU (Platel)

CALLISTO flare detector (Benfifi)

USRP1 programming (Mondon)

MITRA Preliminary work: Recent & future

Design & construction of a 16 channel receiver (Bhoyrub & Chataroo 2011-12}

Front end
Construction of 2 groups, with 8 antennas per group (Shibchurn 2012-13) May be extended to 8 x 8.
Set up of optical fibre network (Armoogum 2012-13)

Back end
Integration of receiver & USRP programming using GNU Radio companion (Pirtee 2012-13, Prayag)

Receiver system, USRP1 & 2 programming D. G.Ingala (DUT Mtech 2012)

MITRA Preliminary work: RF over optical fibre

Modulator RF optical & Demodulator Optical to RF
Optical fibre 100 MHz to 2.4 GHz
Gain +5 dB
Gain flatness +/- 2 dBover band width
RF input level range -50 to 0 dB
VSWR 2.1
Noise figure < 25 dB
Laser diode 1310 nm
Receiver photodiode operating wavelength 1200-1650 nm
Input & output impedance 50 Ω
RF input and output connectors SMA
Optical connectors (Trans./ Rec.) FC/APC

MITRA Preliminary work: Correlator

FX FPGA Correlator

ROACH board excellent but very expensive

Preliminary work on low cost FPGA on the USRP board

Virtex 6 board

Cost: Front end

Item	Quantity	Cost (MUR)	Cost (ZAR)	Notes
DPLPDA	8	16,928	4,445	local made
PFAmp	8	11,520	3,032	Minicircuits
8way C	1	4,446	1,170	ZFSC-8-43+
RFOmod	1	57,440	15,116	High cost 57.5%
Opt Fib	50 m	4,800	1,253	Cost down/coax
DC pow.	1	4,800	1,263	
8 A1pol		99,934	26,299	
8A 2 pol		182,940	48,143	
64 G 512 A		11,708,160	3,081,152	

Cost: Back end

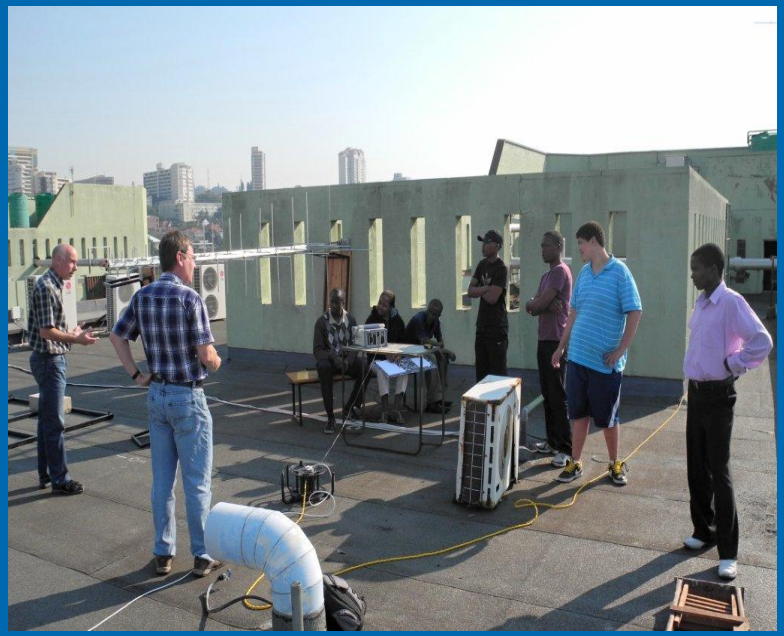
Item	Quantity	Cost (MUR)	Cost (ZAR)	Notes
RFO dem	1	38,400	10,105	68% cost 2.4 GHz
Hyb junct	1	640	168	Monitorings
LNA	3	4,480	337	3 stage amp
SBL-1 mixer	2	640	168	High cost 57.5%
BP Filter	2	960	253	Manuf local
16pow.com.	1	11,488	3,023	ZC16 PD-252
8 A1pol		56,608	14,896	
8A 2 pol		113,216	48,29,792	

Cost: Scenaios

	Station 512 antennas	Station 1024 antennas	Relayive ensitivity
Version 1 (MUR)	18,953,984	37,907968	1
Version 1 (ZAR)	4,987,740	9.975,480	1
Version 2 (MUR)	12,820,224	24,640,448	0.7
Version 2 (ZAR)	3,473,596	6,747,152	0.7
Relative sensitivity	0.7	1.0	

People in Mauritius

People in Durban South Africa



Minister Pandor visit 19.9.2011

Minister Jeetah visit 09.08.2012

Thanks

DST RSA