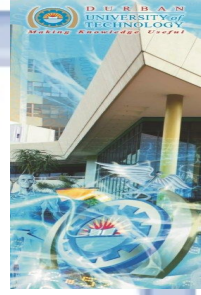
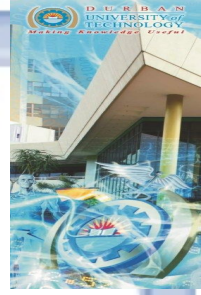


A Multifrequency Interferometry Telescope for Radio Astronomy: MITRA

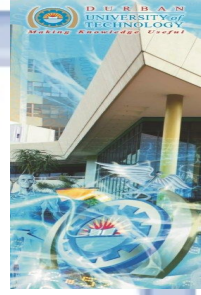
Girish Kumar Beeharry
Mauritius Radio Telescope
Department of Physics
Faculty of Science
University of Mauritius

Stuart MacPherson & Gary van Vuuren
Department of Electronic Engineering
Faculty of Engineering &
the Built environment
Durban University of Technology

Outline



- Motivation-
- Overall description
- Station outline
- Recent developments
- Preliminary tests
- People
- Ministerial visits
- Future & funding



Motivation 1

An African Low Frequency E-vlbi: ALFE

(GKB'talk SKA bursary conf Stellenbosch 5th 12 2009)

- African countries thrived/thrive/(will thrive?) on their natural resources.
- It is now time to gear up to new science and technology based avenues which can, without being exceedingly vatic, induce bootstrapped development.
- However, the prevalent attitude has been/is to purchase first world technology which is customarily understood at end-user level but, sadly, not at that of research and development

Motivation 2

- Another important issue is that of regional integration. There is a paucity of areas of cooperation in science and technology.
- Additionally, there is ample scope for bolstering higher education ventures.
- Promising science and technology fields are can be made to be at par with the other ones, provided there is sufficient federative and cohesive ground.

Motivation 3

-There is the possibility of developing an base ofstudents in astronomy, engineering and technology.

· Most of the countries have undergraduate programmes in astronomy. Masters needed.

·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.

SWOT 1

Strengths:

- Regions with relatively low noise

- Most of radio telescopes are concentrated in the Northern hemisphere, there have been very few (<1GHz) radio sky surveys in the South

- No multi-frequency simultaneous survey

Weaknesses:

- Infrastructure

- Science & Technology

- Education

SWOT 2

Opportunitiess:

- Region use S&T to address the weaknesses
- Greater regional integration in S&T : SA has shown the way to co-operation
- S&T Industry initiation in other African countries

Threats:

- Immobility
- Lack of human resources
- Lack of funding
- Engineering & Technology Industry deficit

MITRA: Overall description

- A sensitive high resol 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 can observe on its own.

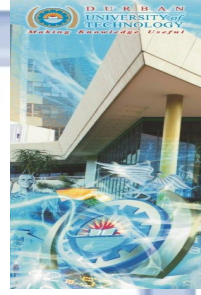
- Sufficient sensitivity and resolution built in.

- 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). 32 EW 16 NS: BL 1 MHz BW, 16 s integration, area ~4000 m^2

- Aim to improve: $\Delta S \sim (\Delta \nu . n . \Delta t)^{-1/2,}$

Sensitivity 2

-The w term

-Convolution & Gridding

-Primary beam

-Phasing

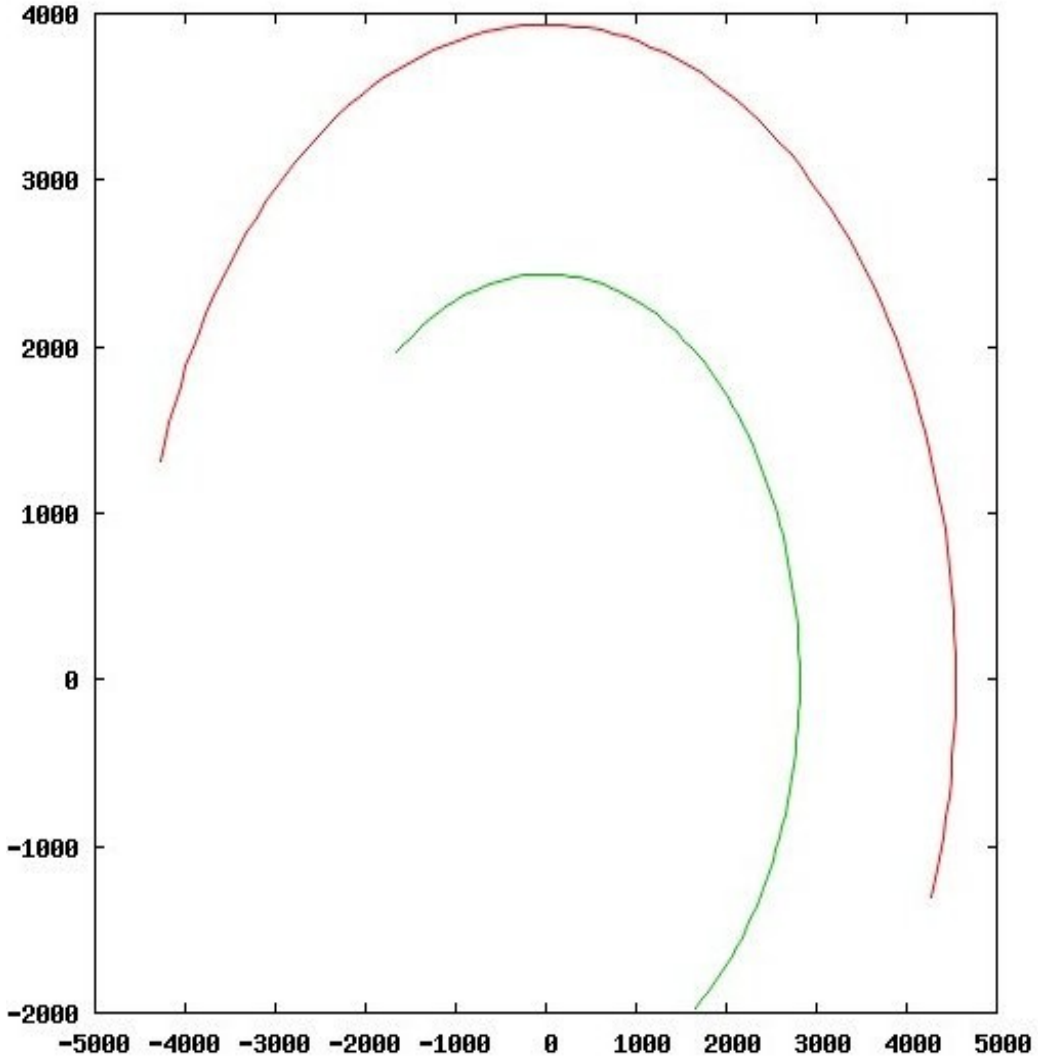
-Bandwidth decorrelation

-[Ionospheric effects]

Resolution

ν MHz	λ	Resolution 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	0.01

uv coverage 2 stations



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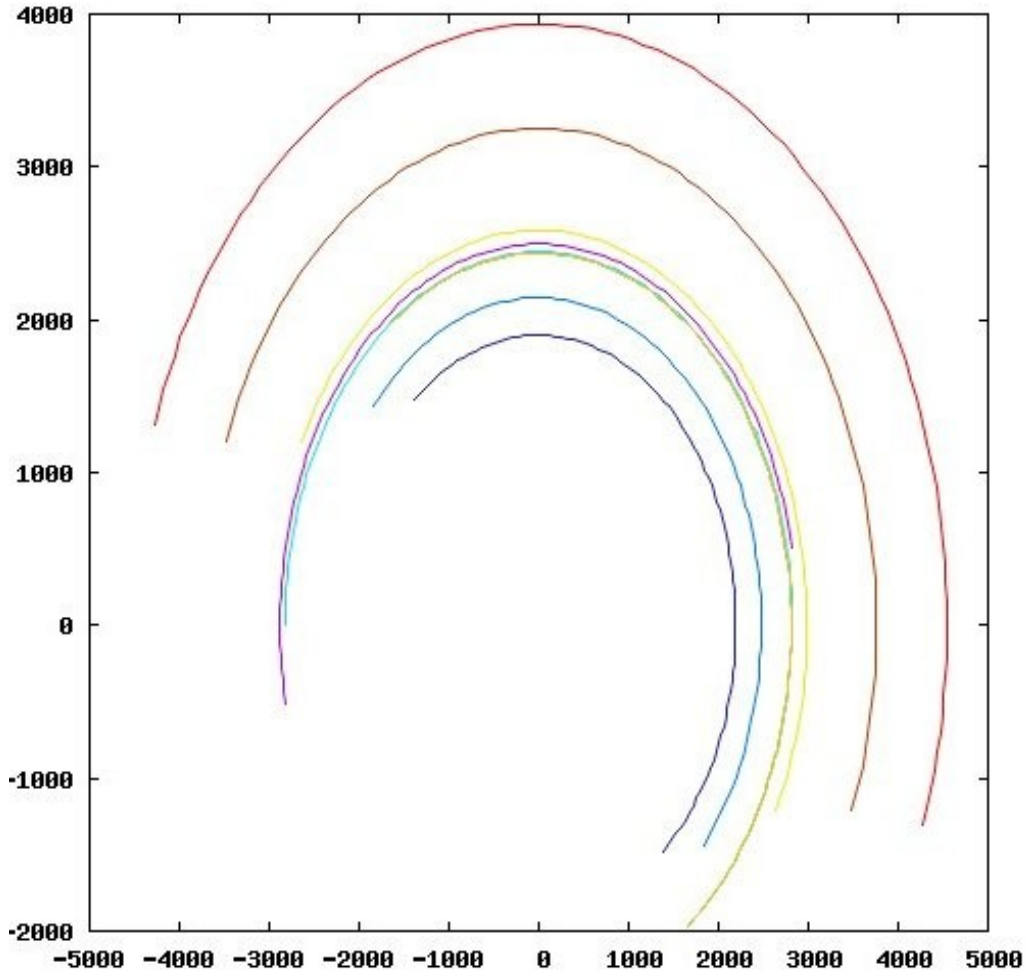
uv coverage 9 stations



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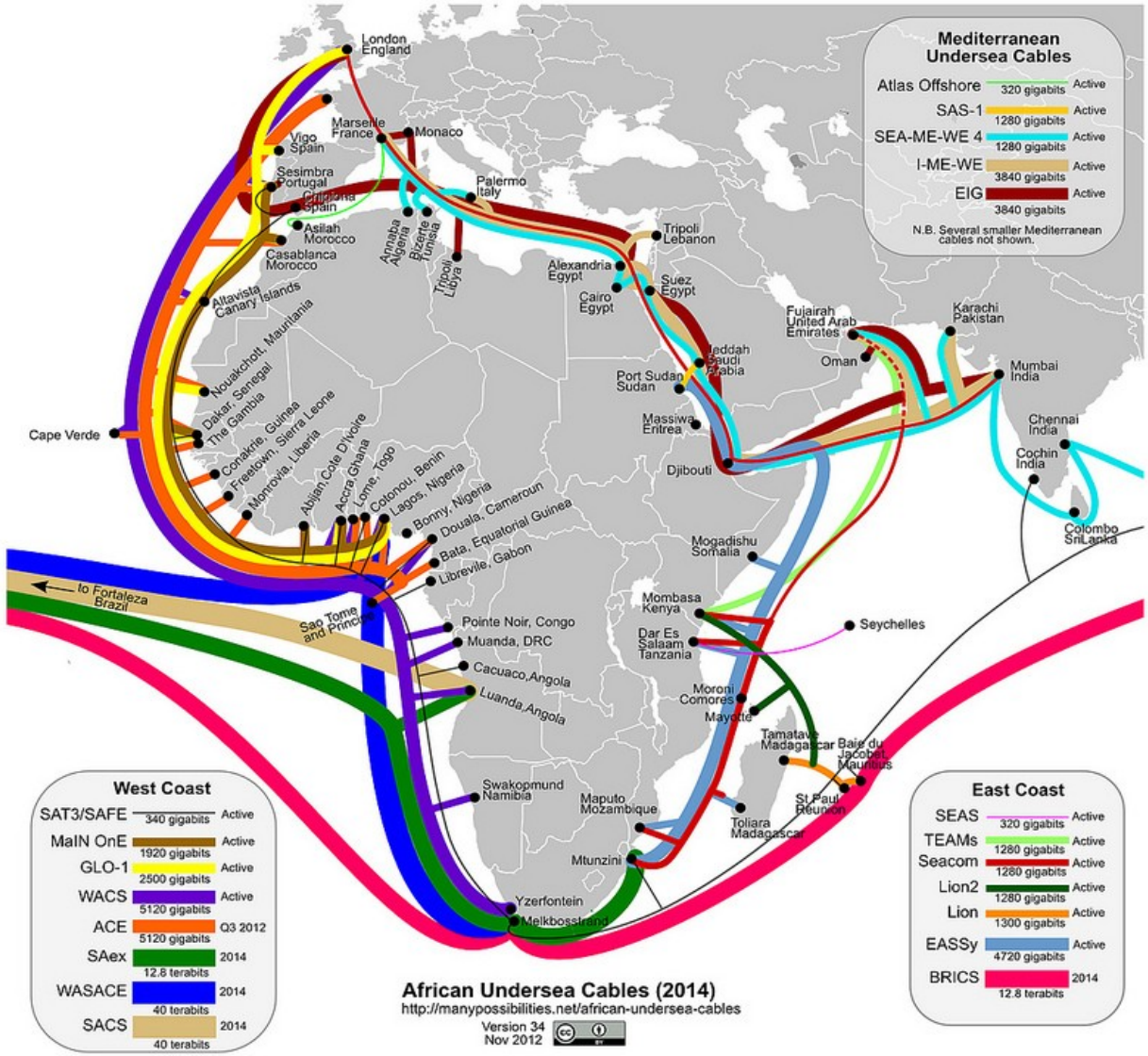
Connectivity



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

Extremely wide field imaging with heterogeneous non coplanar arrays

- Short spacing
- w/n term, sampling & visibility

- Primary beams: size and dep, 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

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MITRA Preliminary work: 1st antenna 100-850 MHz

MRT
Bras
d'Eau
Mauritius

DUT
Durban
RSA

G Van Vuuren & Students
from Kenya & Zambia

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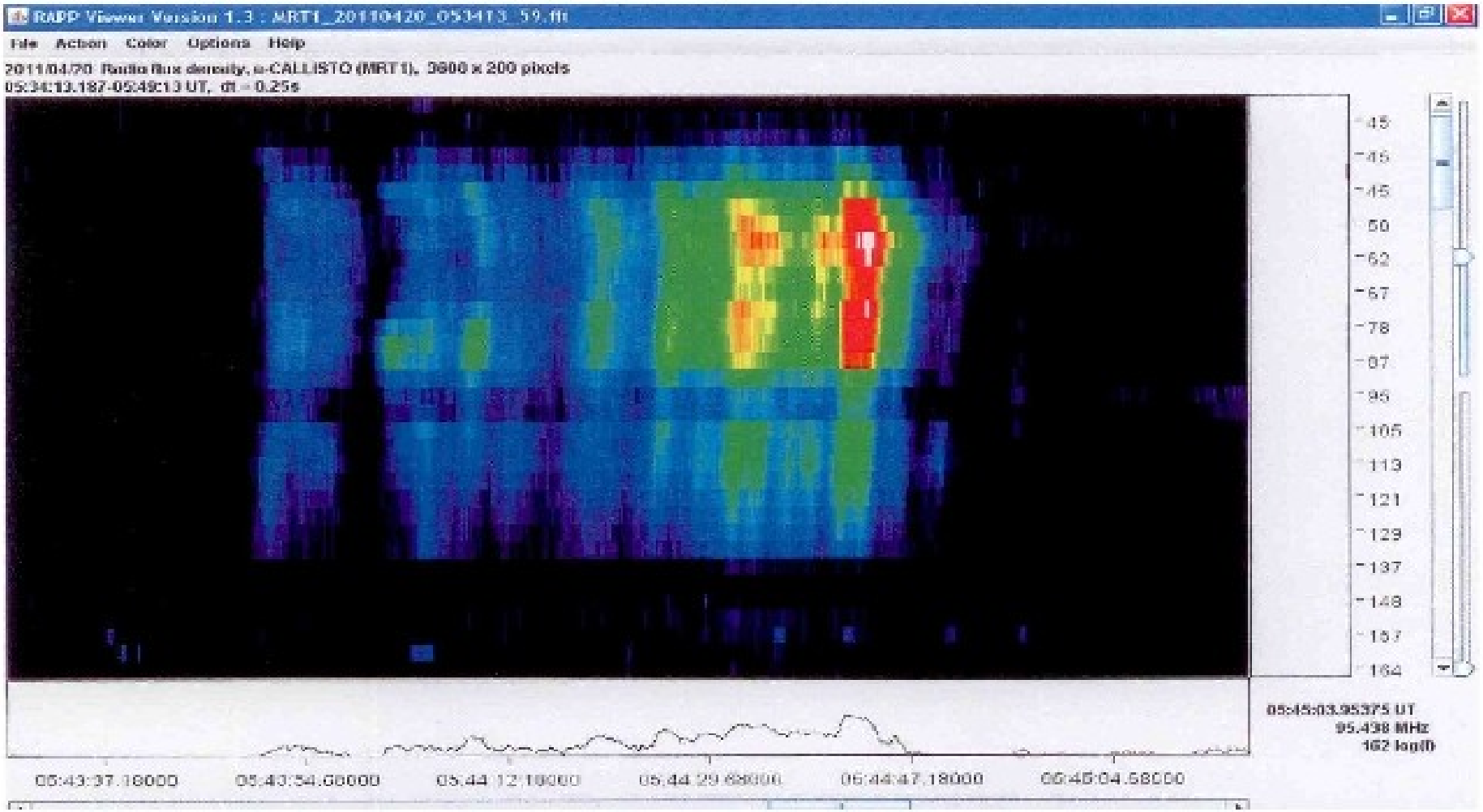
MITRA Preliminary work: Solar flare with antenna 20.4.2011



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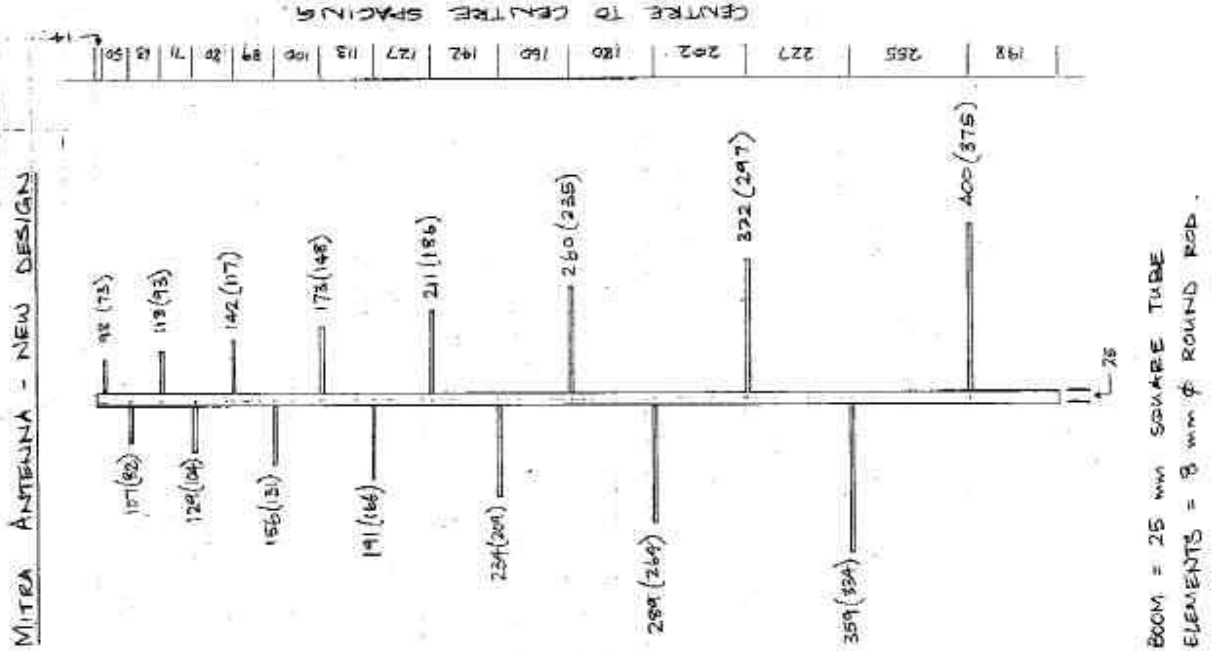
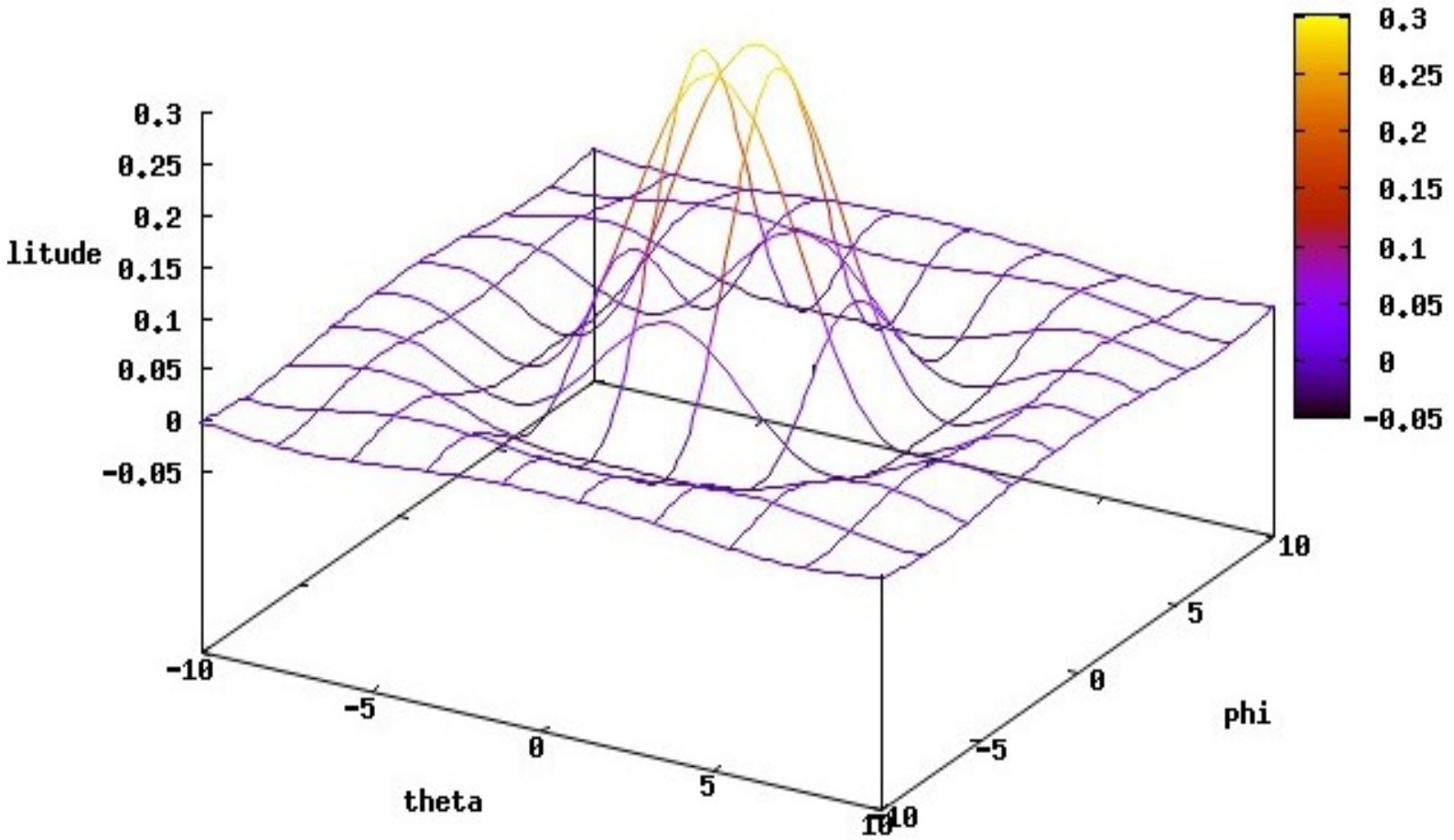
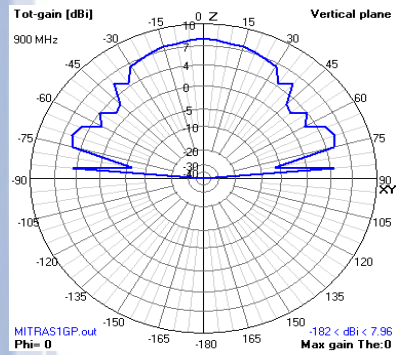
MITRA Preliminary work: new antenna design 200-800 MHz

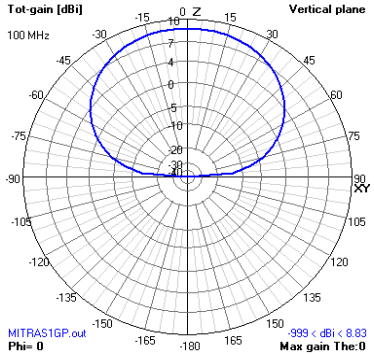


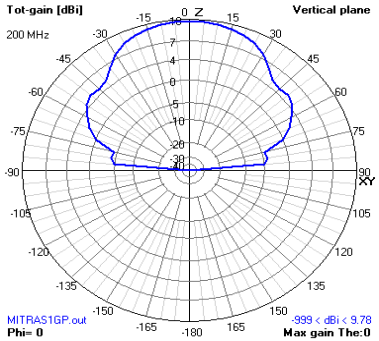
MITRA Preliminary work: simple model new antenna design 200-800 MHz

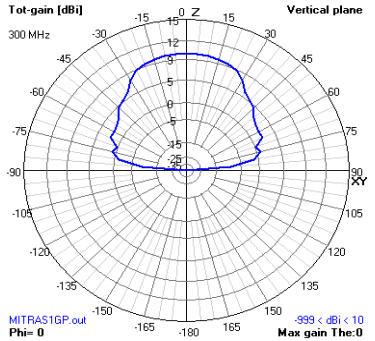


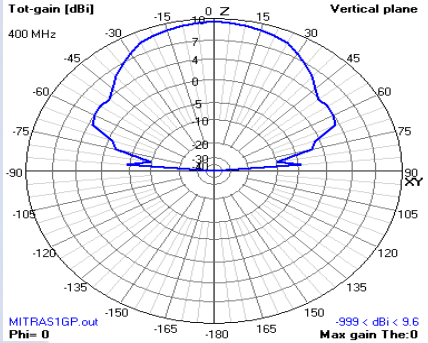
MITRA Preliminary work: New Antenna design 200-800MHz

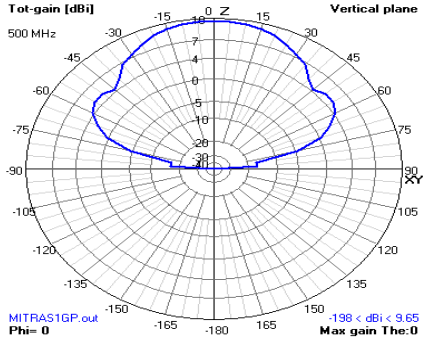


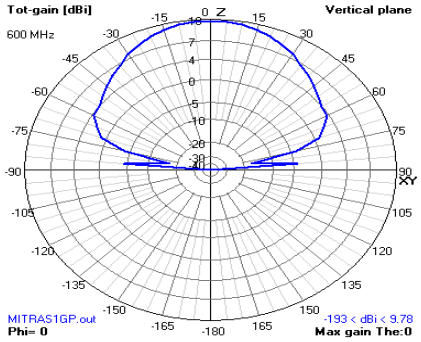


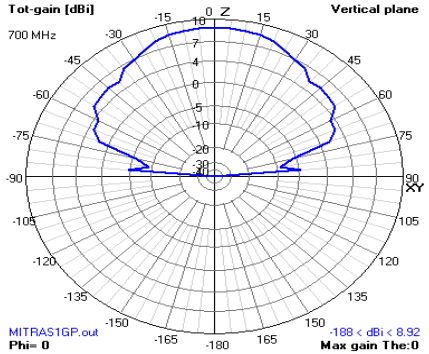


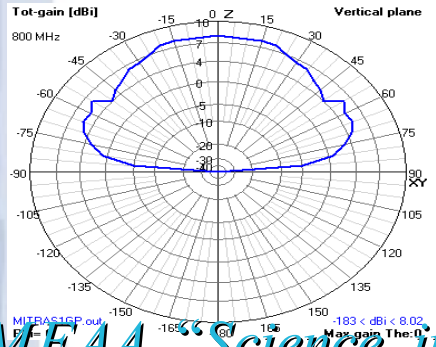


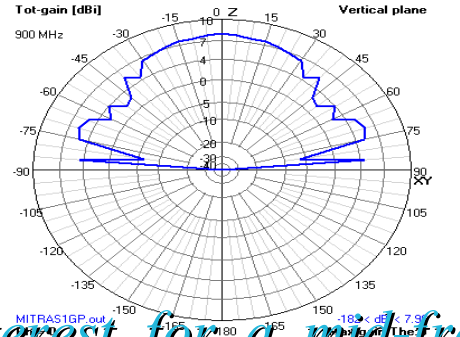












Grou Model fit needed

MITRA Preliminary work: Antenna design Version 2

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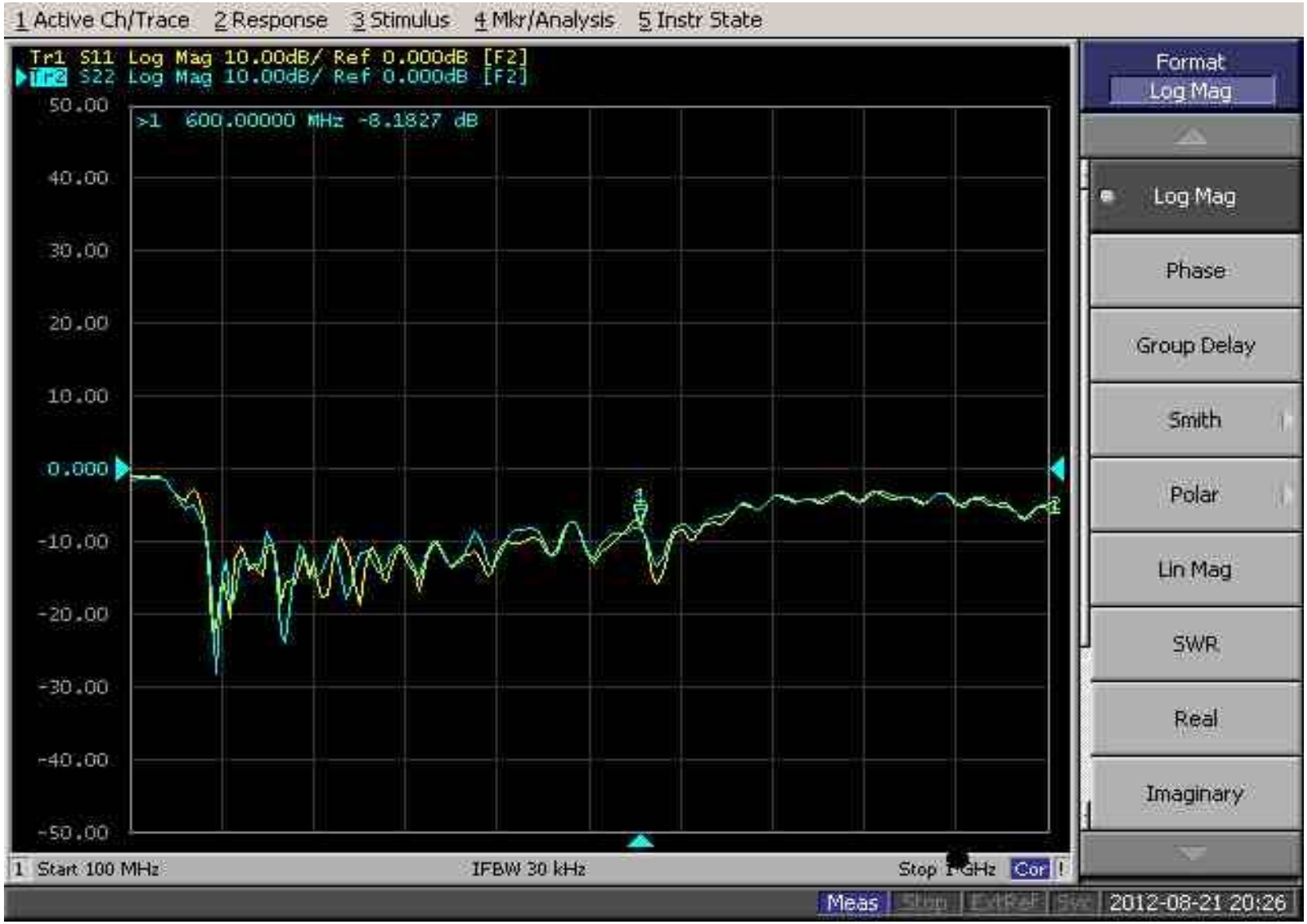
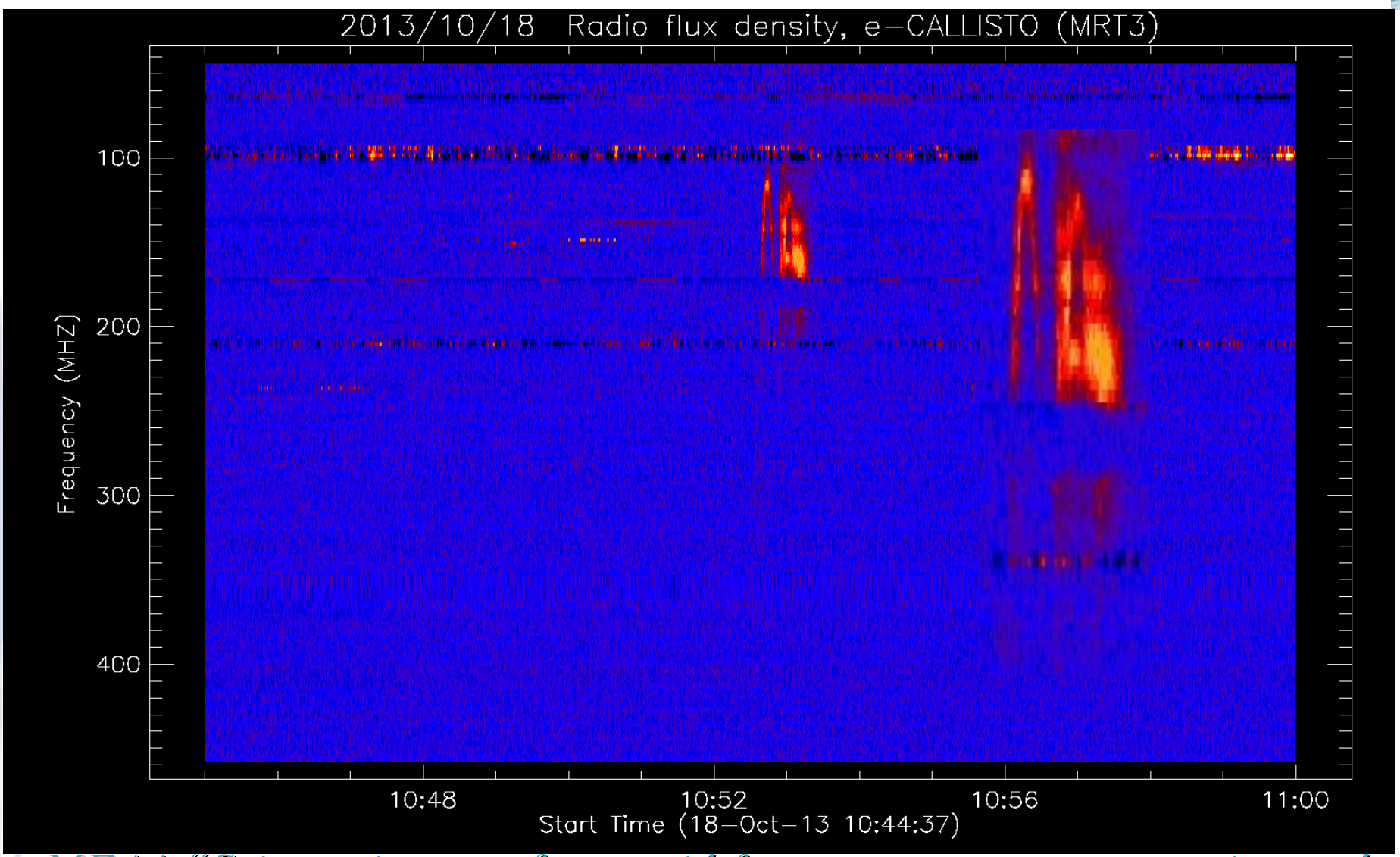
Shibchurn, Lambaree, Beeharry @ Bras d'Eau,

MITRA Preliminary work: new antenna VSWR

MITRA Preliminary work: new antenna Return loss

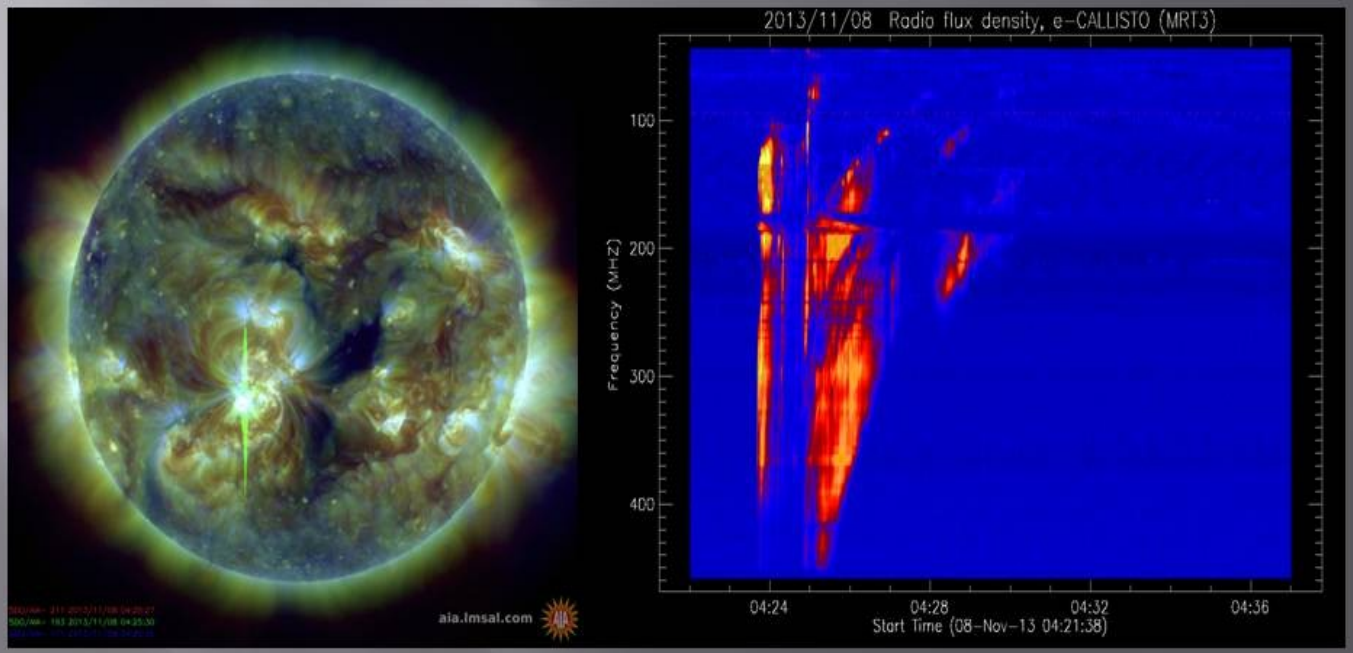


MITRA Preliminary work: rare U flare with antenna 18.10.2013

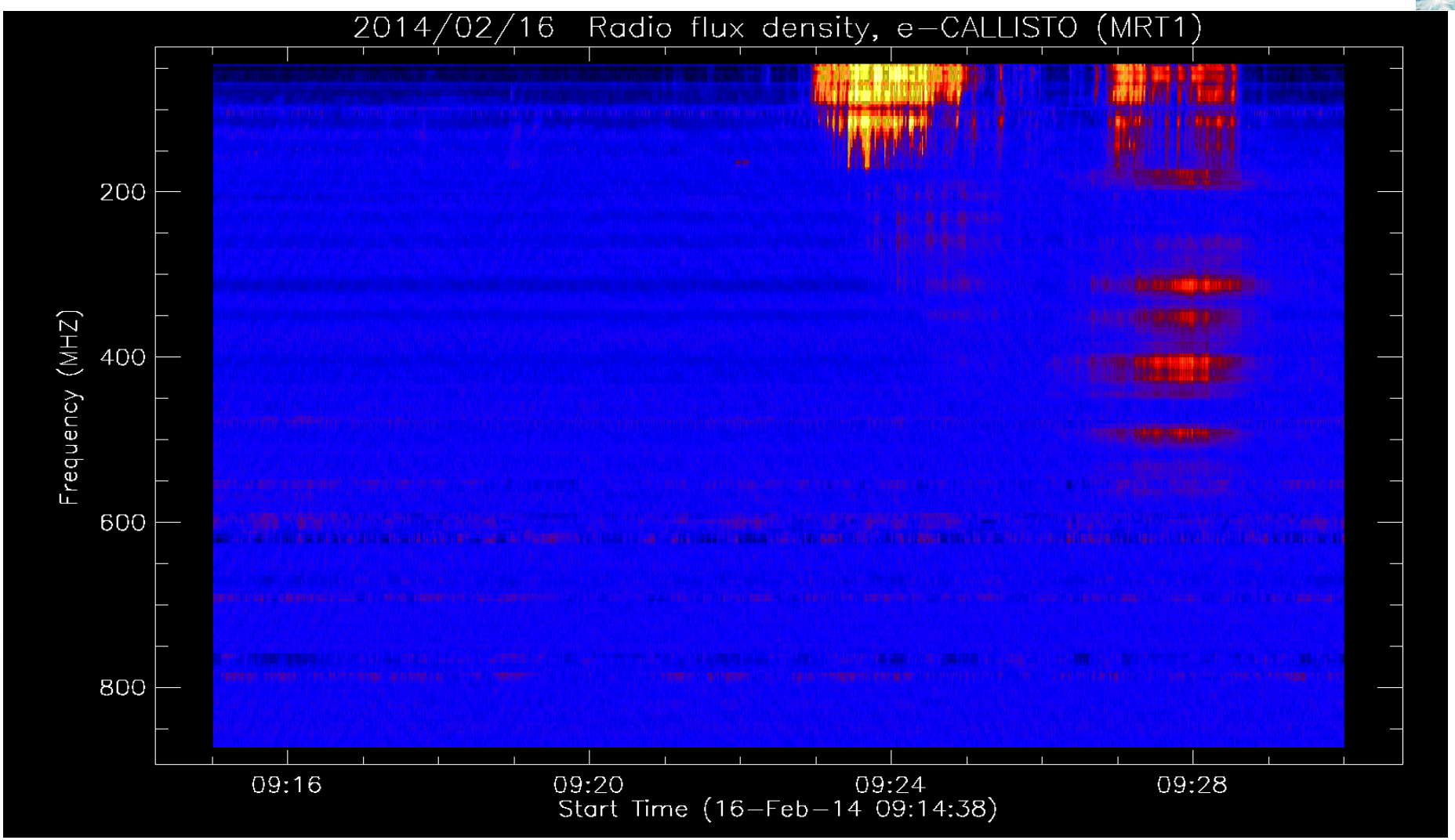


MITRA Preliminary work: Class X flare with antenna 13.11.2013

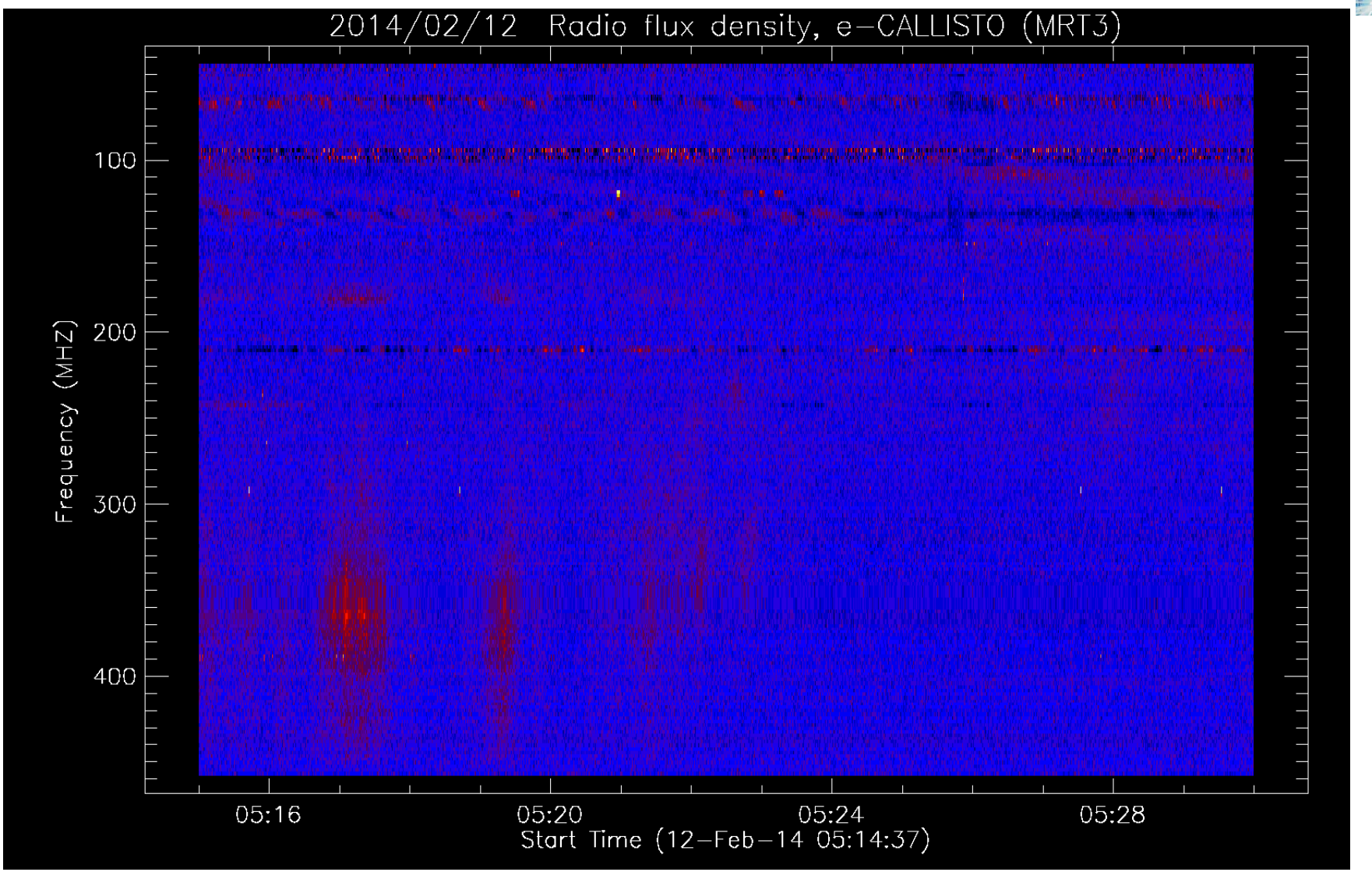
Big Sunspot AR1890 is crackling with strong flares. The latest, which peaked on Nov. 8th at 04:32 UT, registered M8 on the Richter Scale of Flares. NASA's Solar Dynamics Observatory recorded a flash of extreme UV radiation from the almost-X flare: And its Radio Flux density observed by Mauritius Callisto spectrometer.



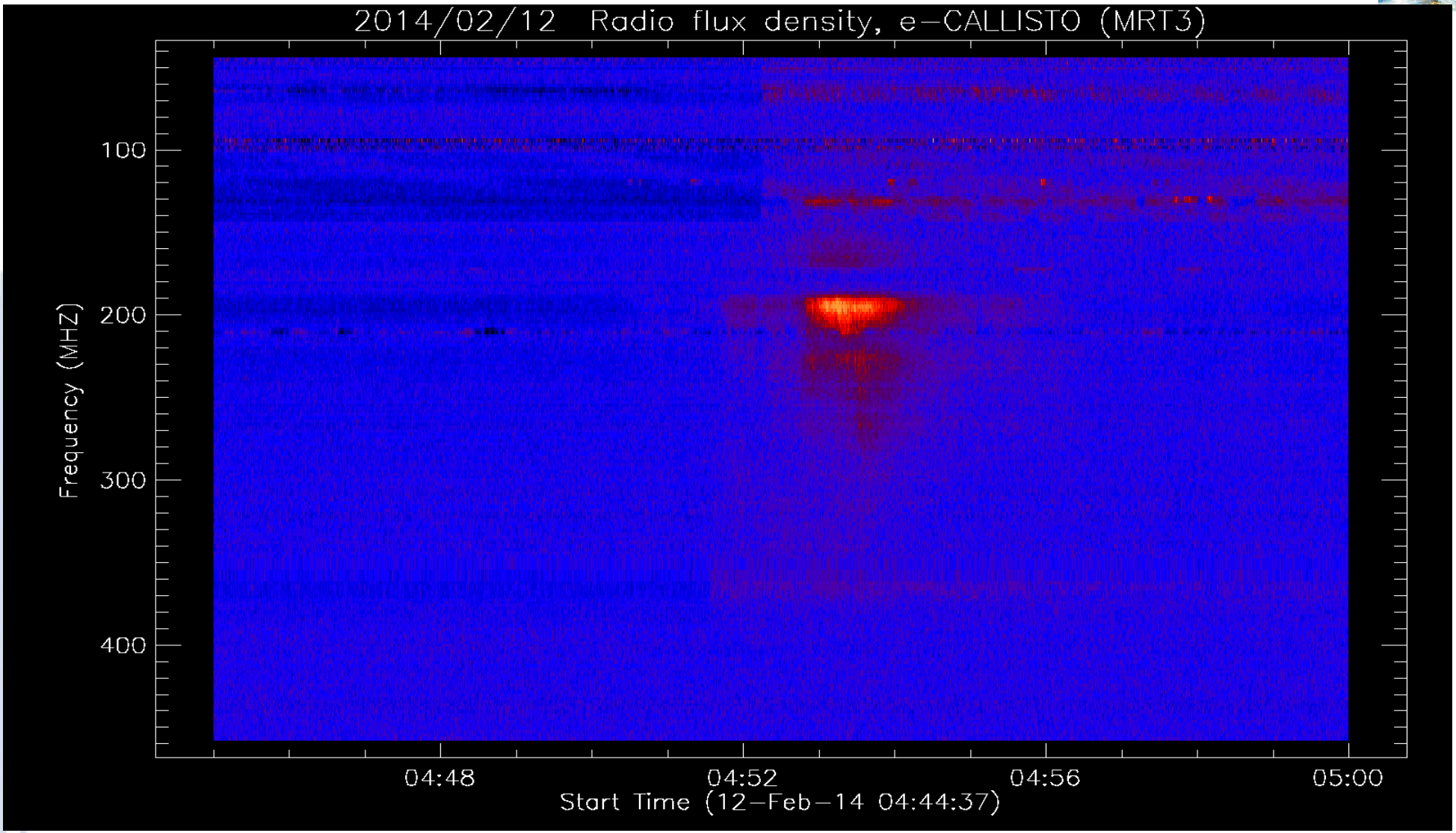
MITRA Preliminary work: Solar flare with new antenna 16.2.2014



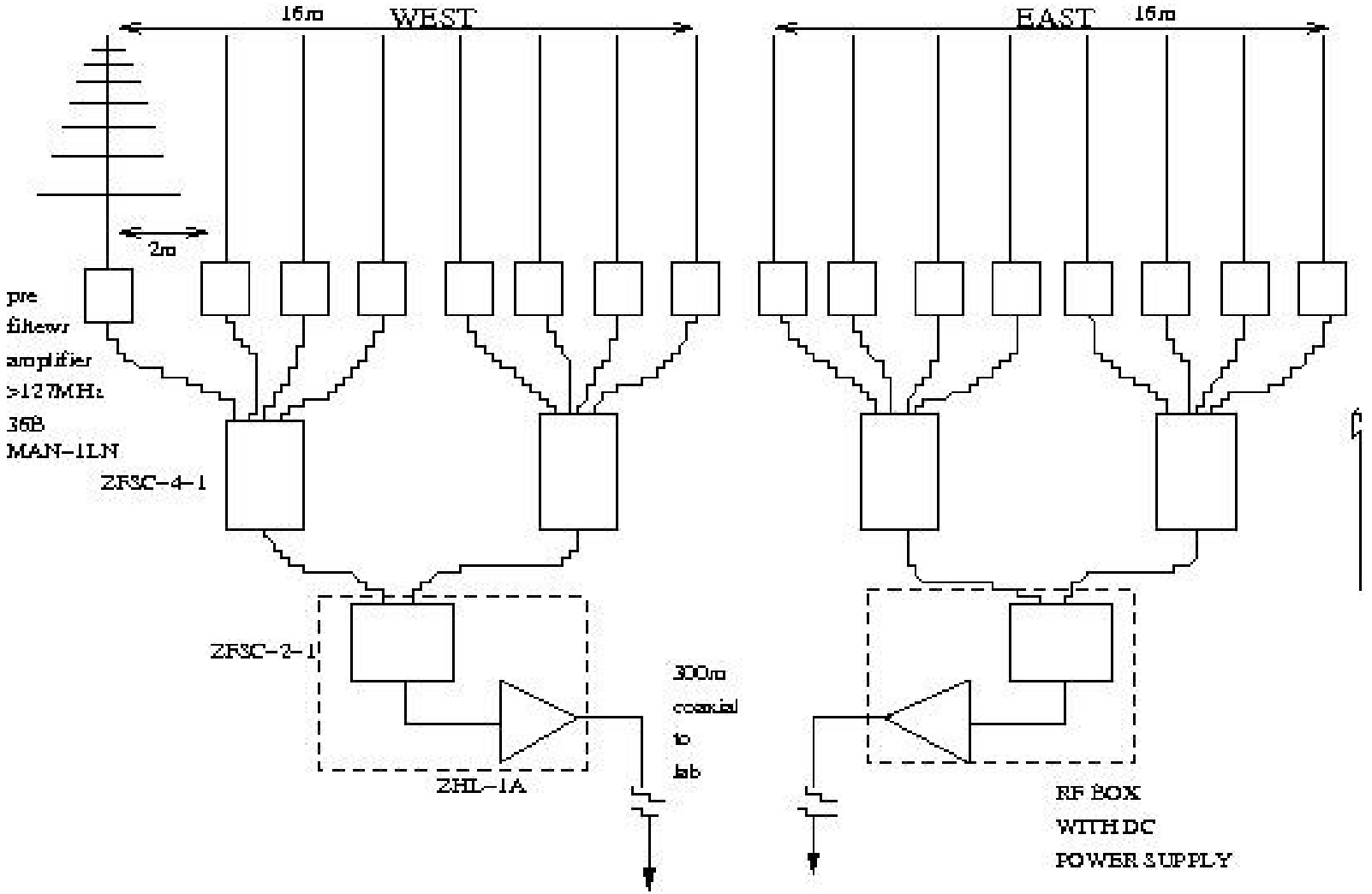
MITRA Preliminary work: faint flare with new antenna 12.2.2014



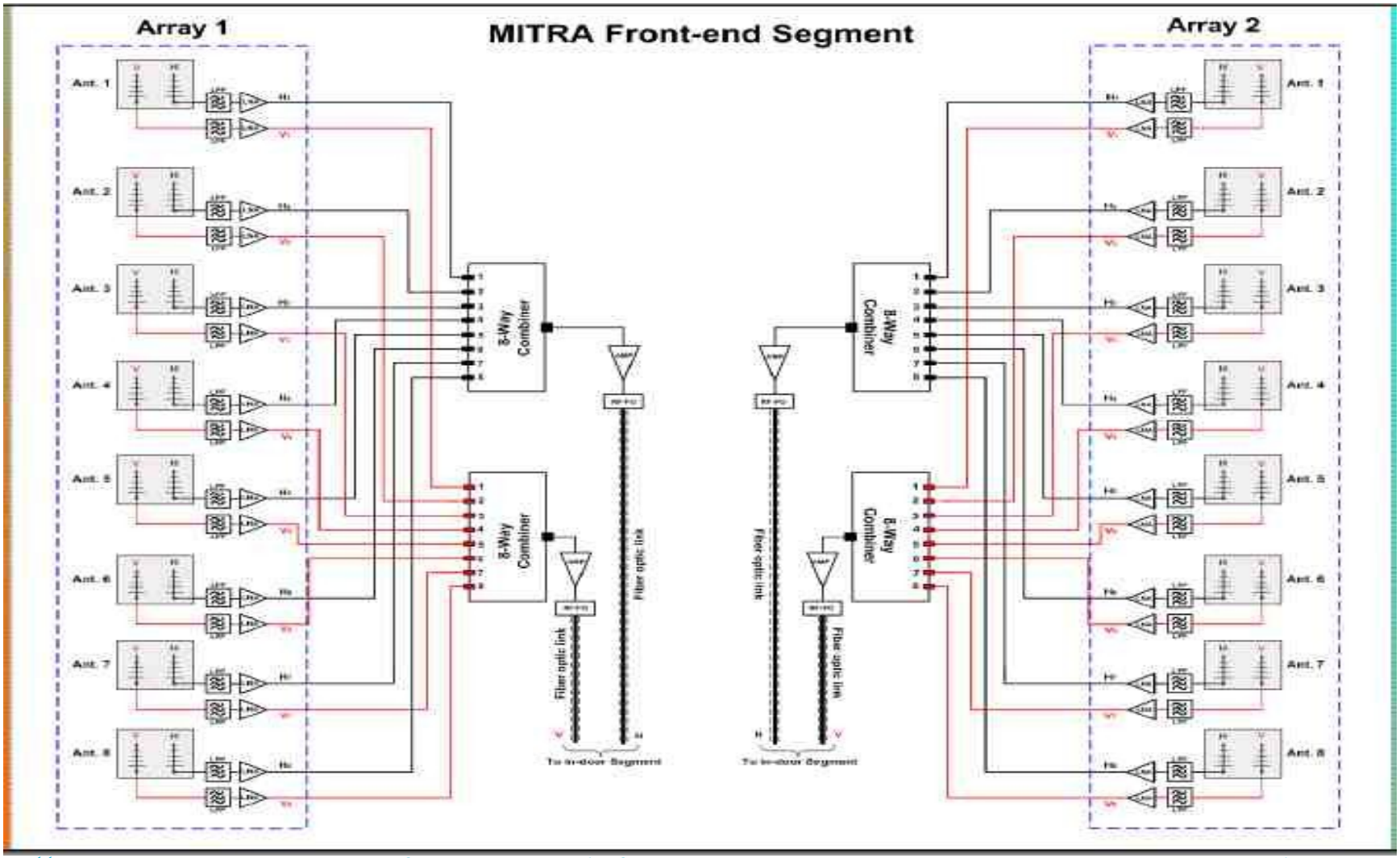
MITRA Preliminary work: faint flare with new antenna 12.2.2014



MITRA Preliminary work: Front end Mauritius



MITRA Preliminary work: Front end Durban



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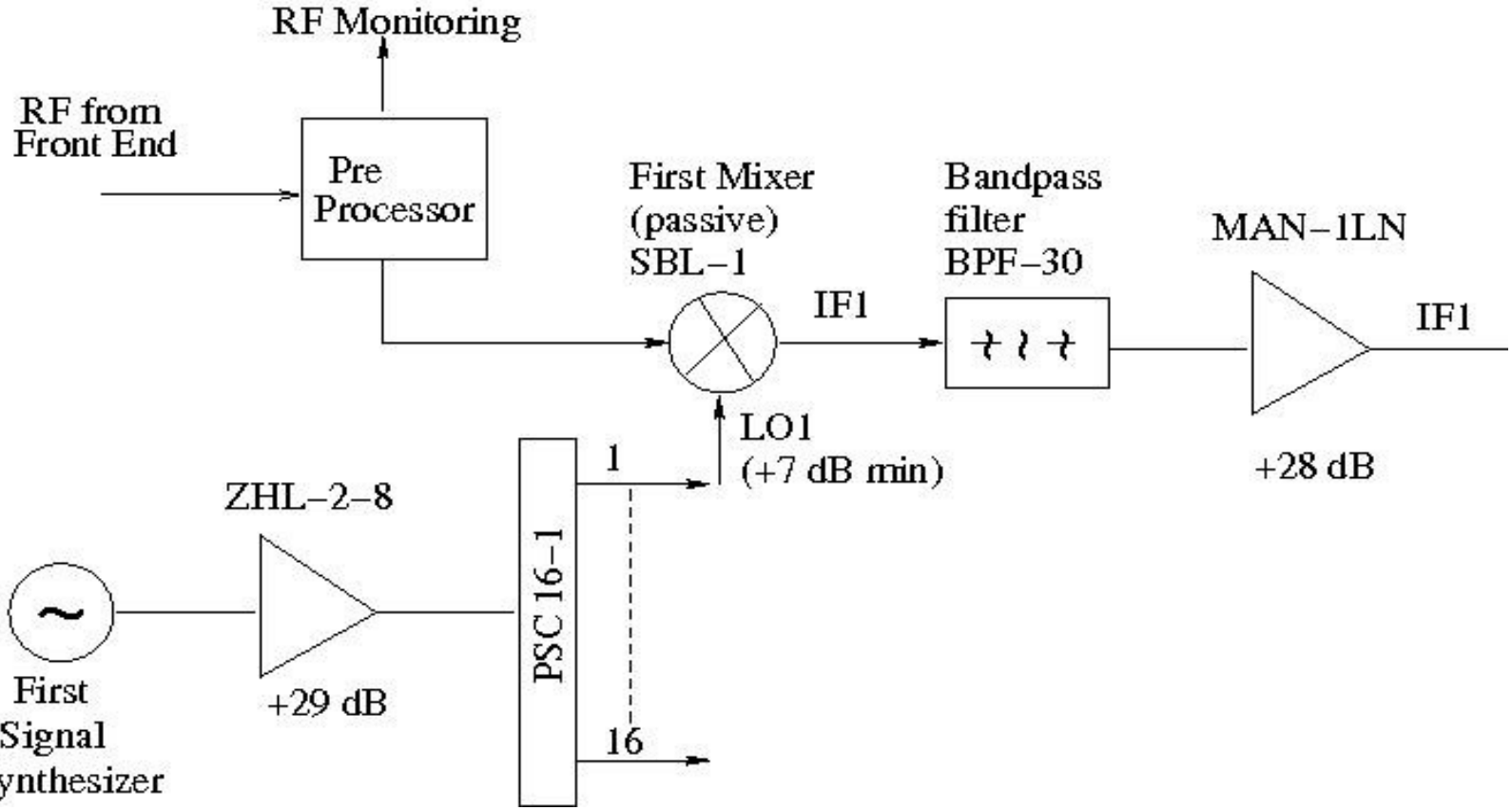
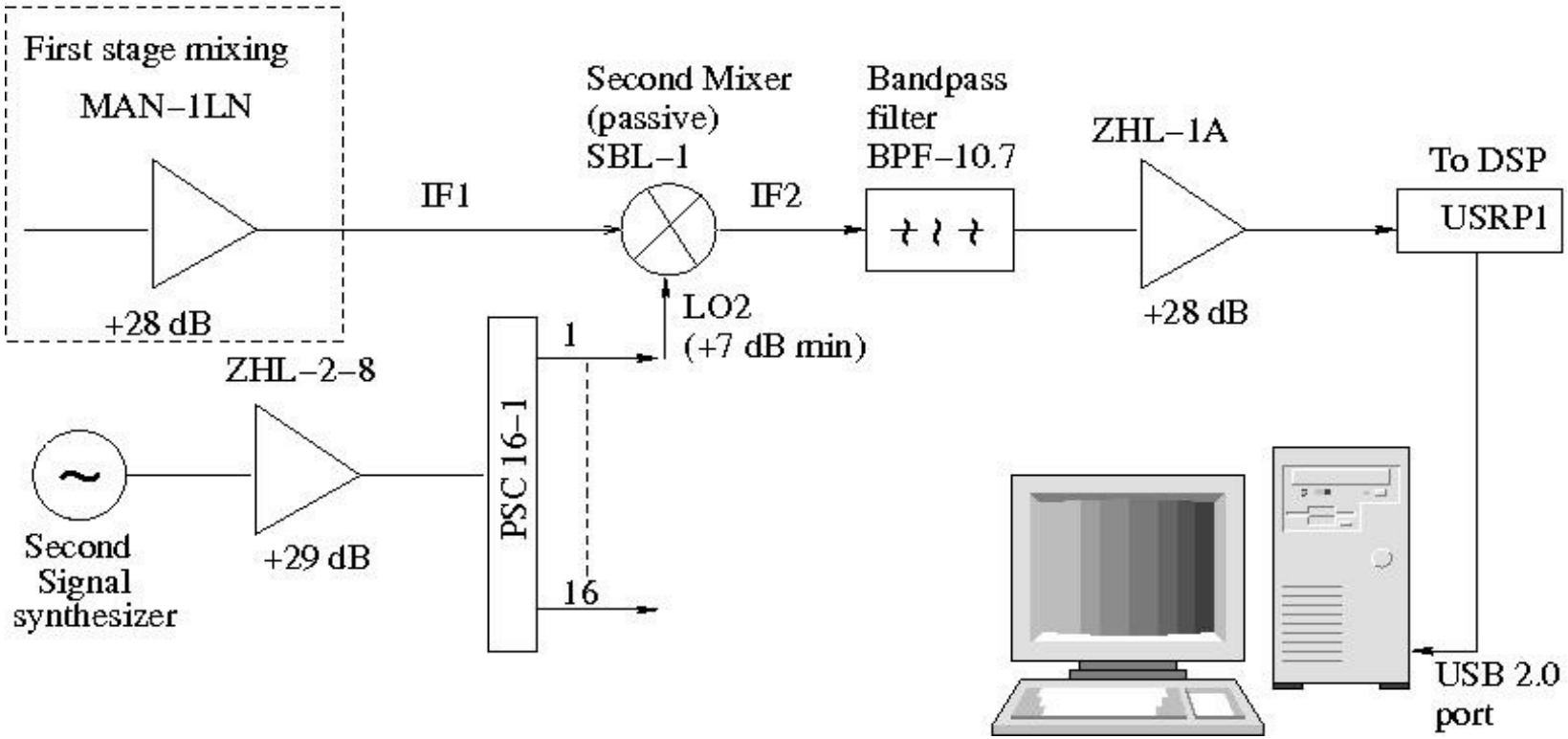
MITRA Preliminary work: Back end I Mauritius

Back End in Lab: first stage mixing

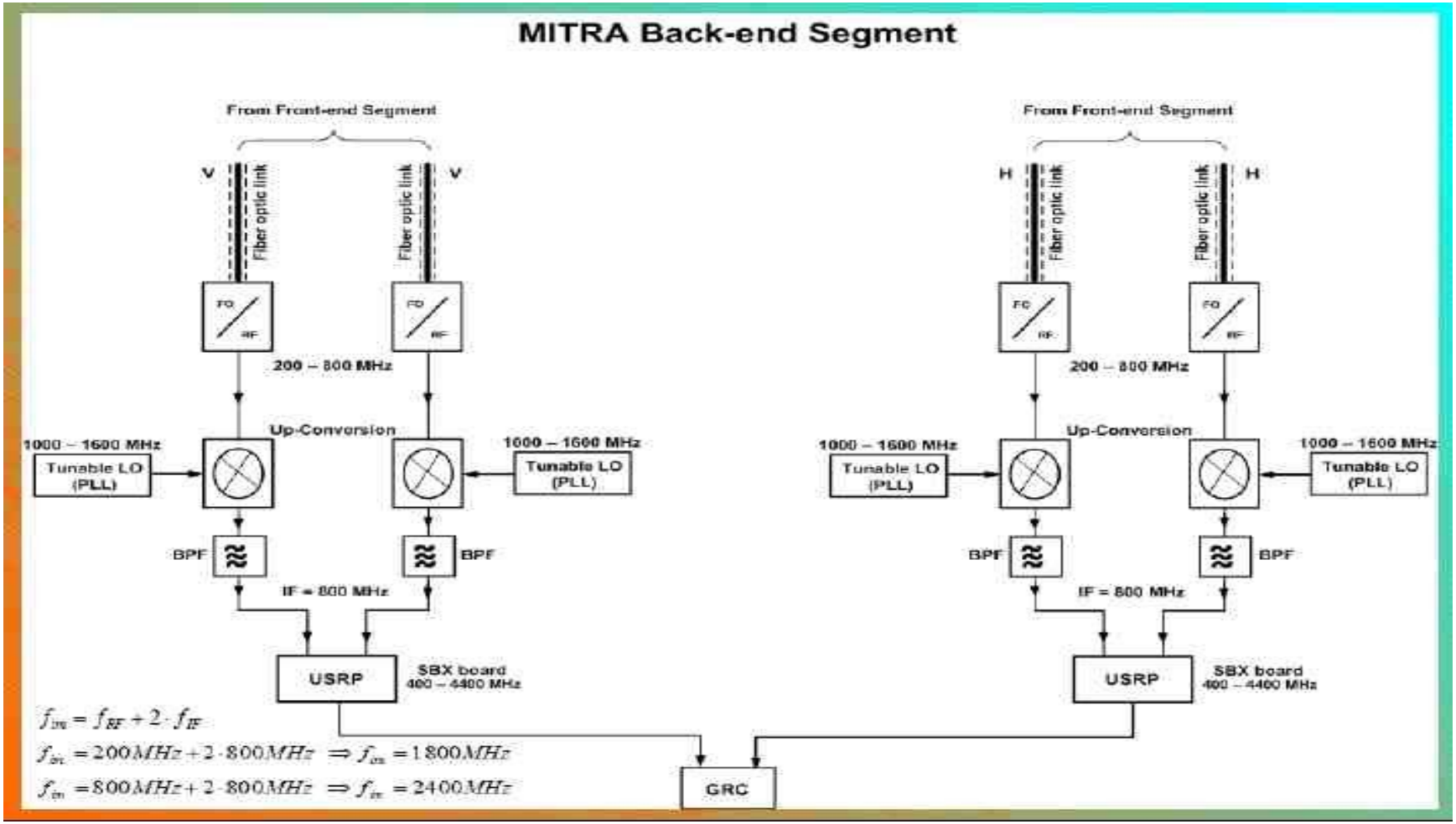


MITRA Preliminary work: Back end II Mauritius

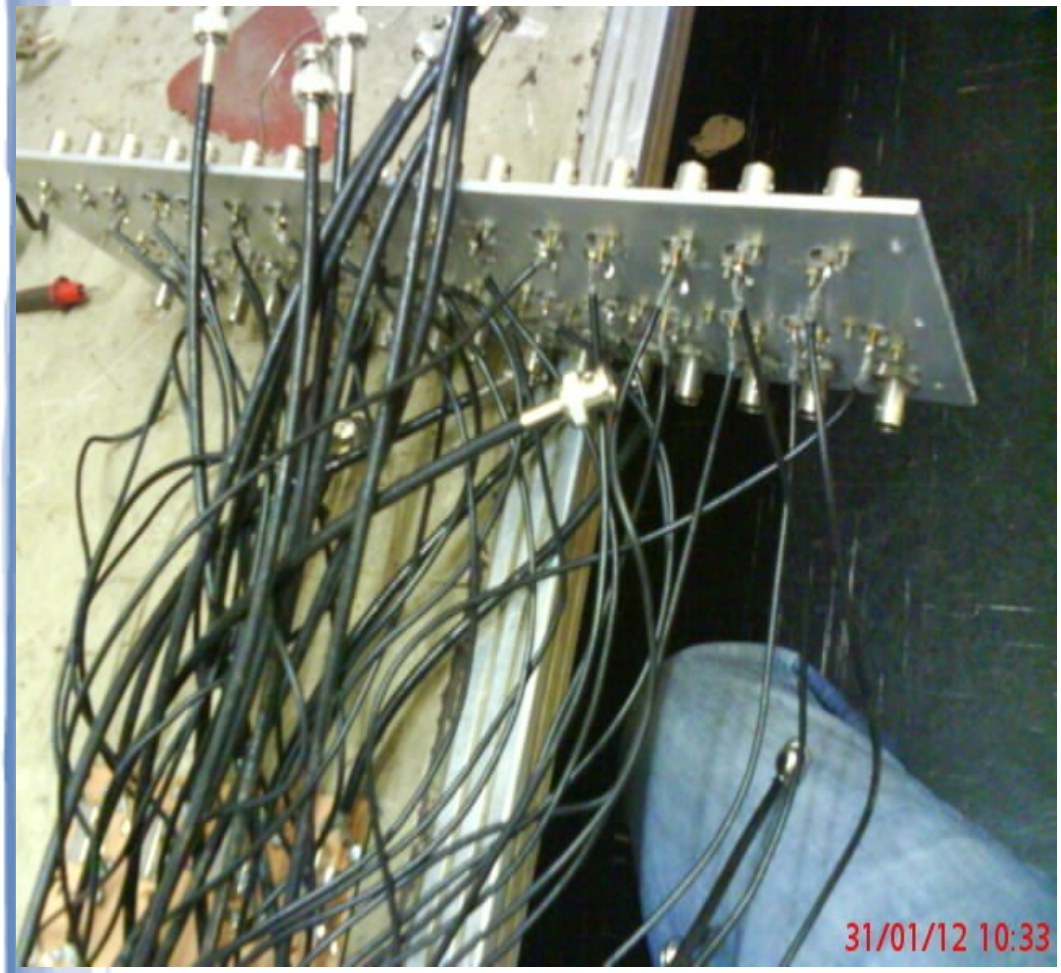
Back End in Lab: second stage mixing



MITRA Preliminary work: Back end Durban



MITRA Preliminary work: students at work



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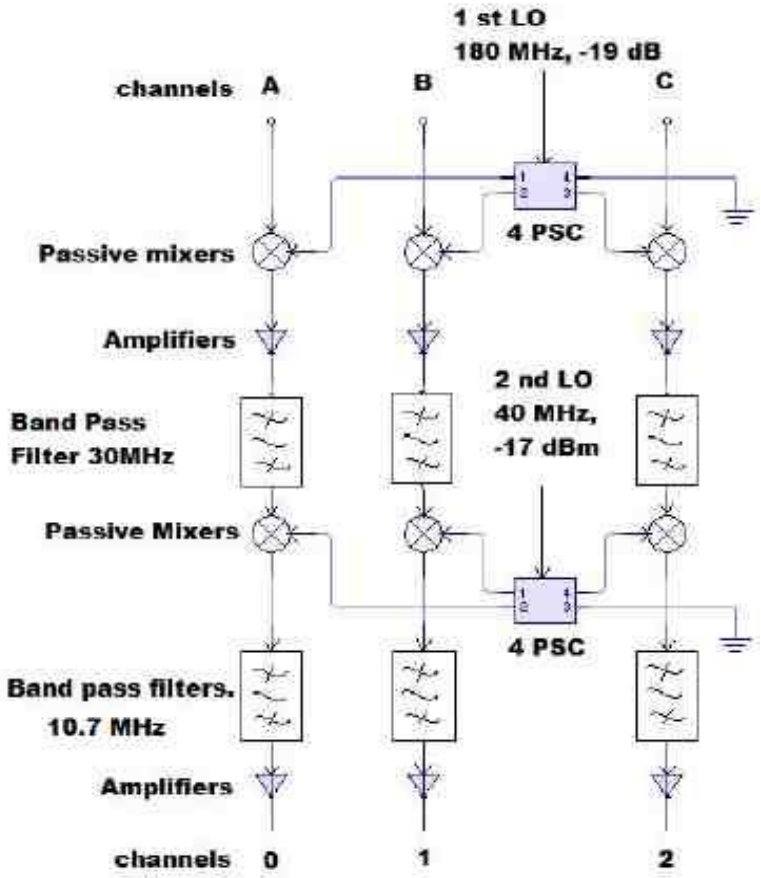
MITRA Preliminary work: 4- channel receiver(4->16)



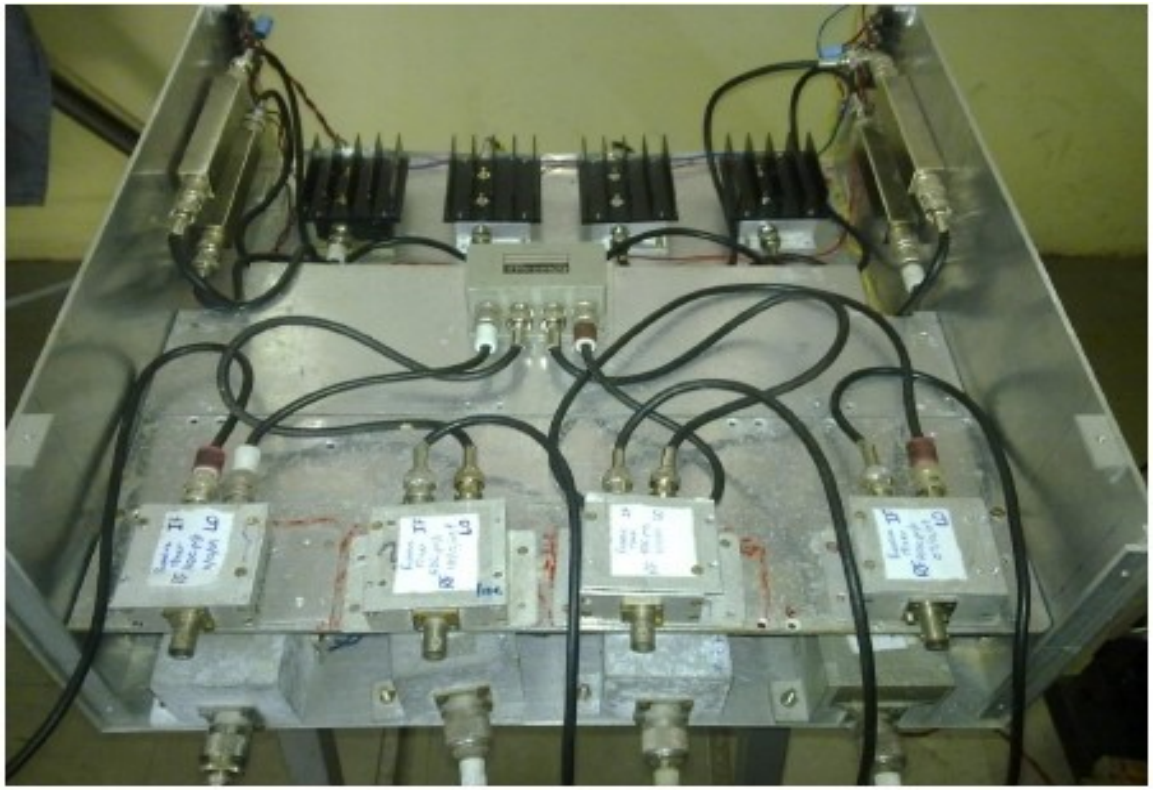


Figure 6.5: New back-end receiver system

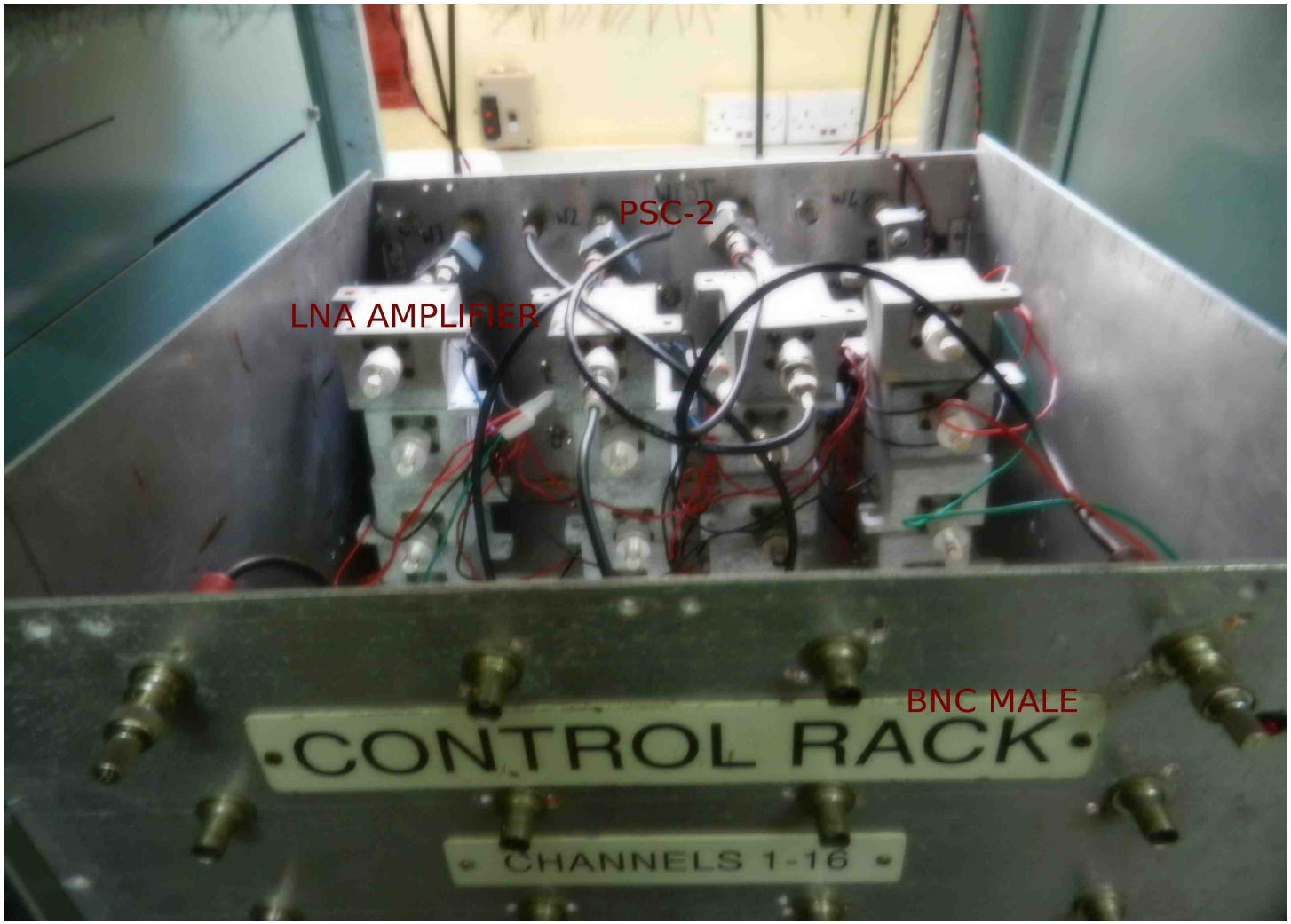
MITRA Preliminary work: 4 channel receiver (4->16)

Figure F.34: Receiver system

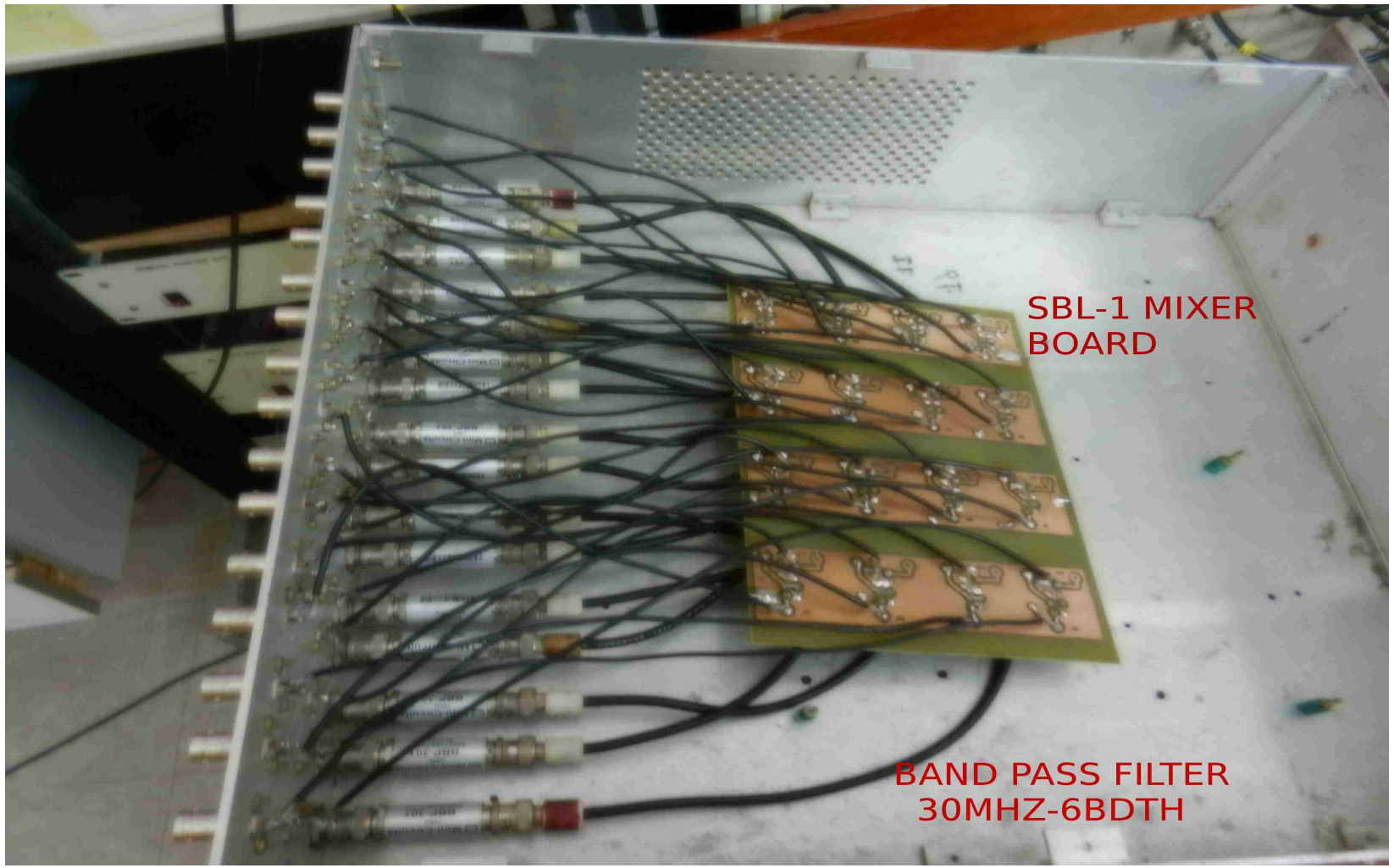
Figure F.29: PCI-ADC card

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

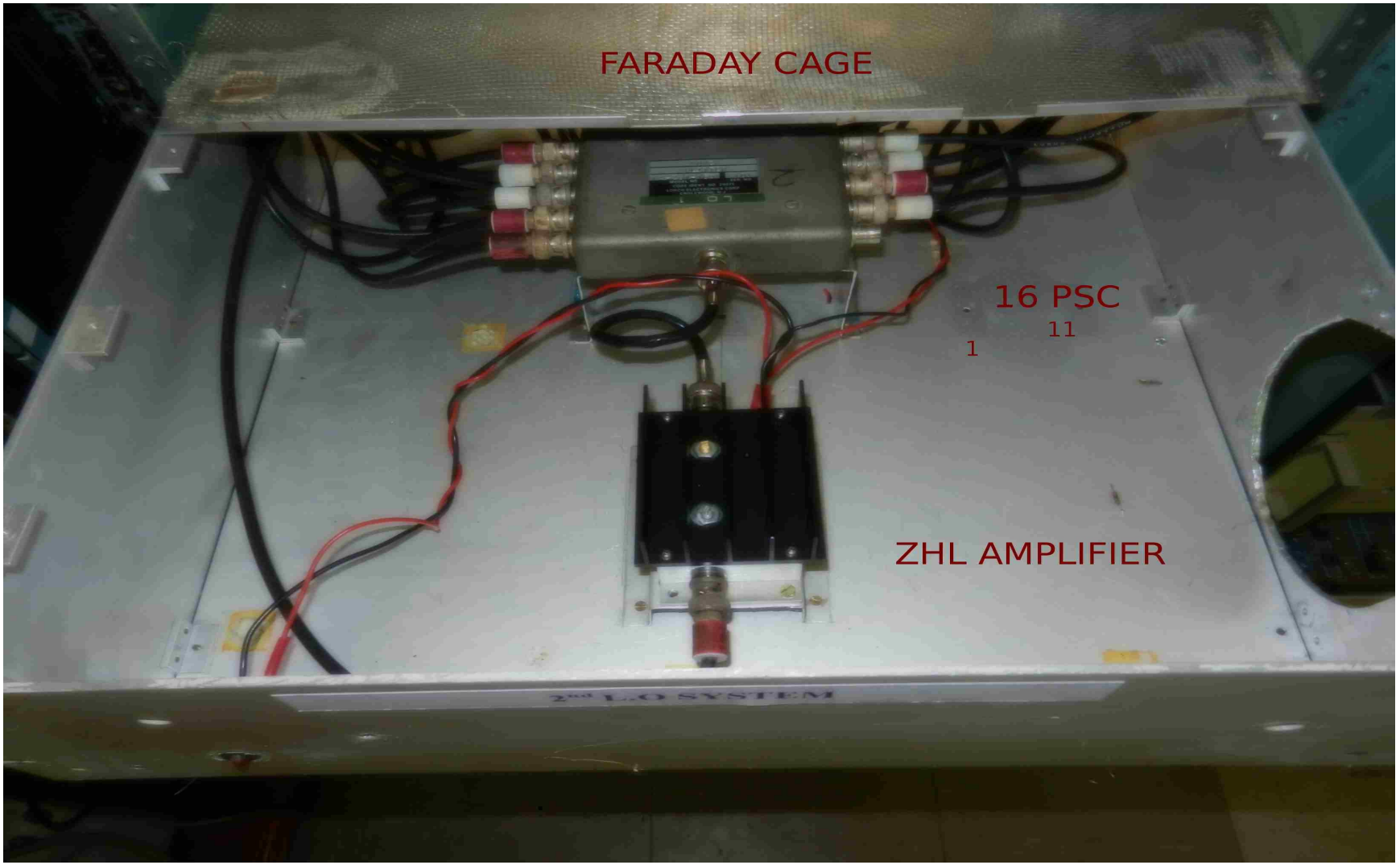
MITRA Preliminary work: 16 channel receiver pre-processor



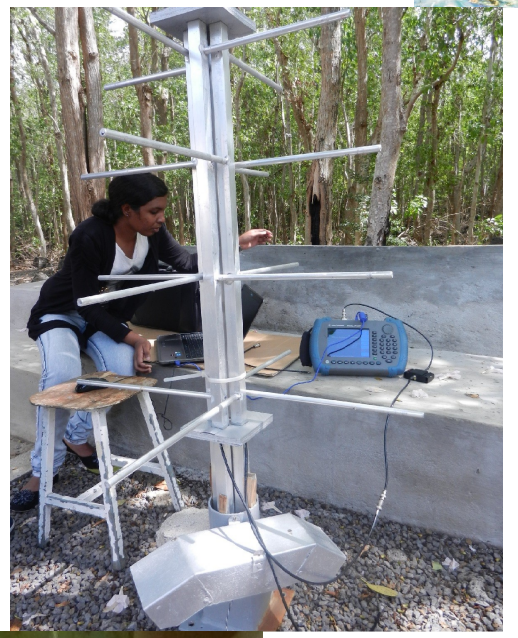
MITRA Preliminary work: 16 channel receiver first mixer



MITRA Preliminary work: 16 channel receiver LO distribution



MITRA Preliminary work: Front end 15.02.2014



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K Bhoyrub & A Chatarpoo Bras d'Eau, Mauritius

MITRA Preliminary work: Antenna testing 18.02.2014



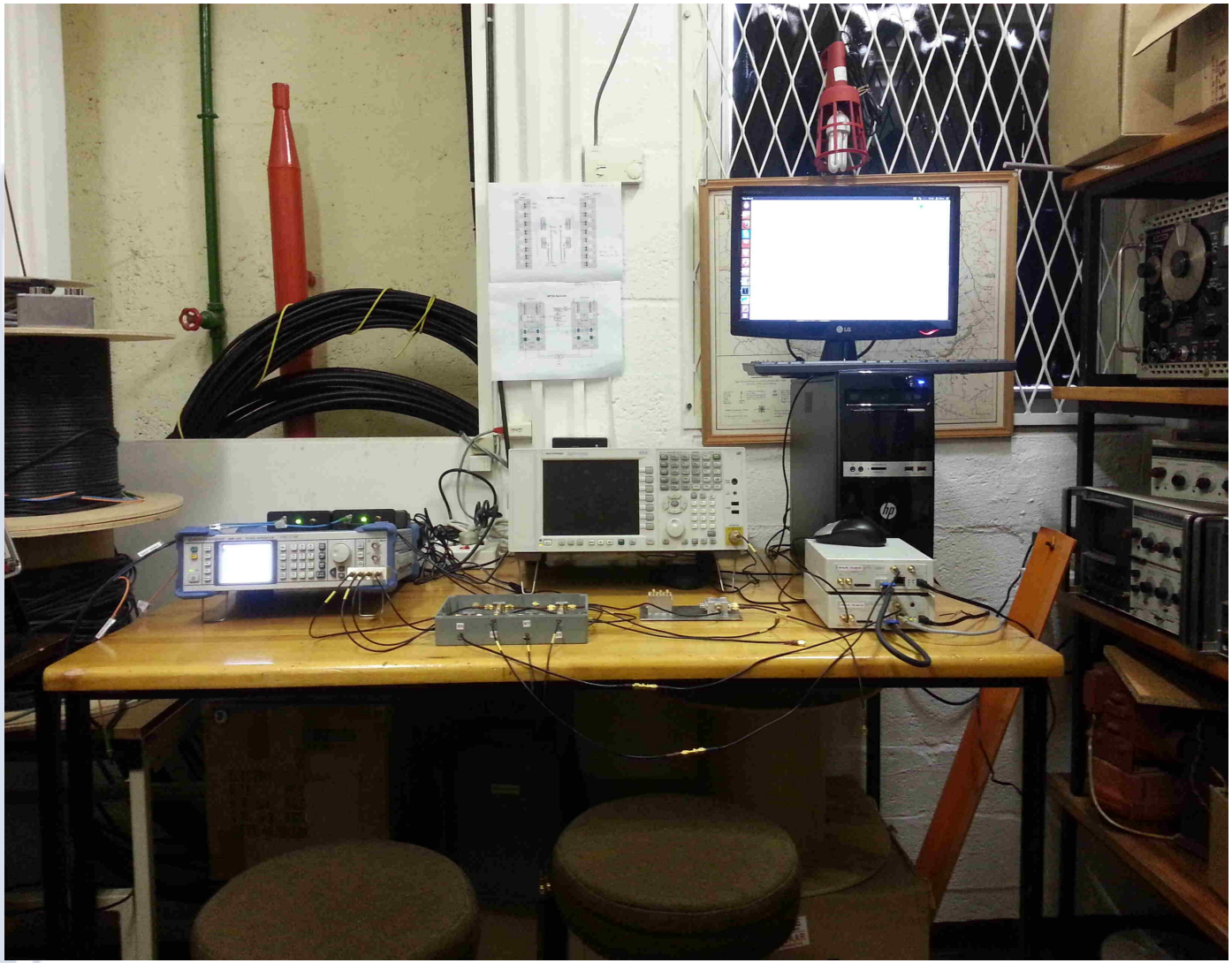




MITRA Preliminary work:
16 channel complete receiver

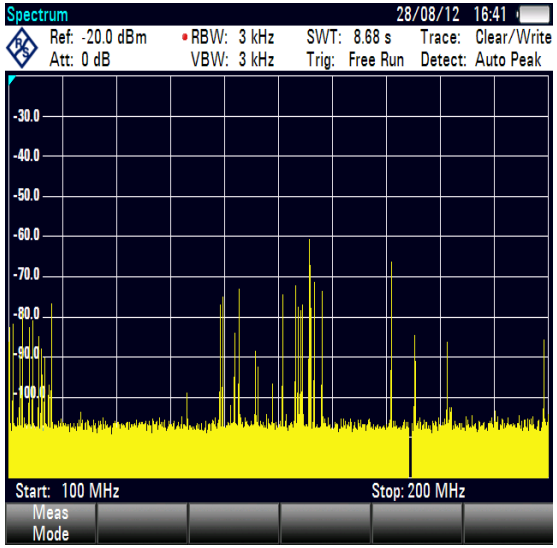
Second 16 channel complete receiver Being built

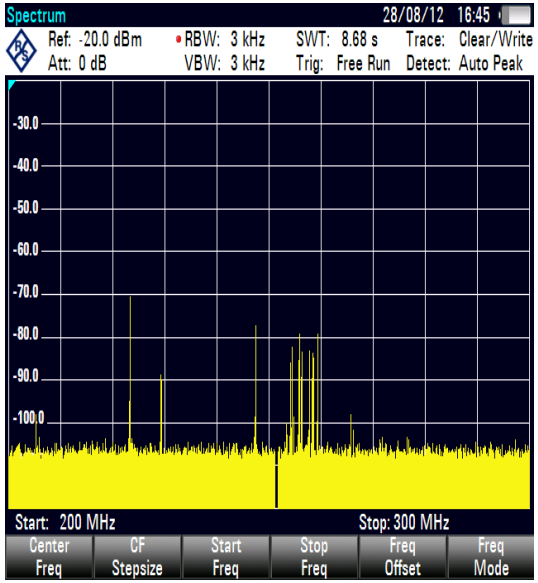
MITRA Preliminary work: DUT receiver room

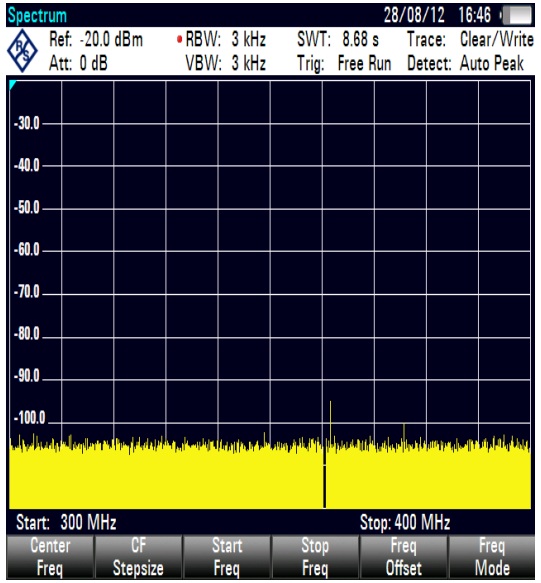


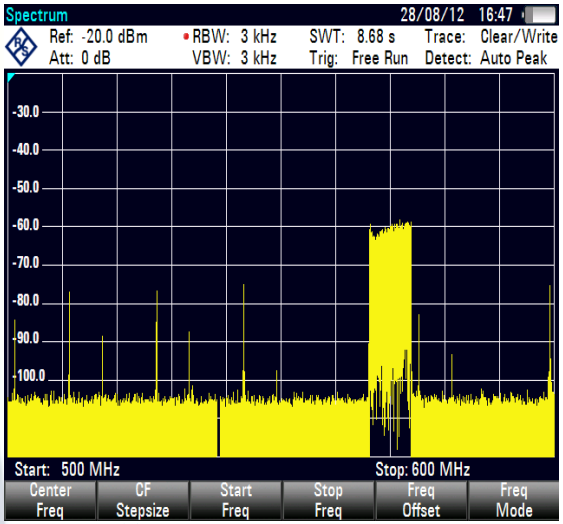
S.MacPherson,
G. van Vuuren,
D Ingala DUT
2013

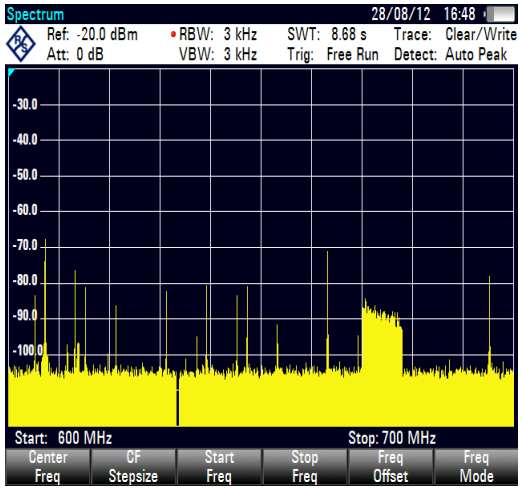
MITRA Preliminary work: back end:Durban

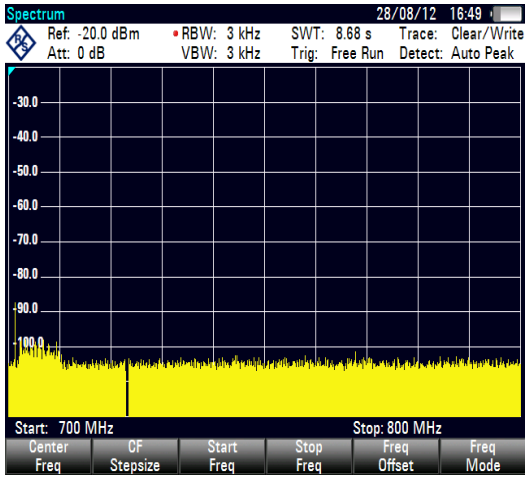




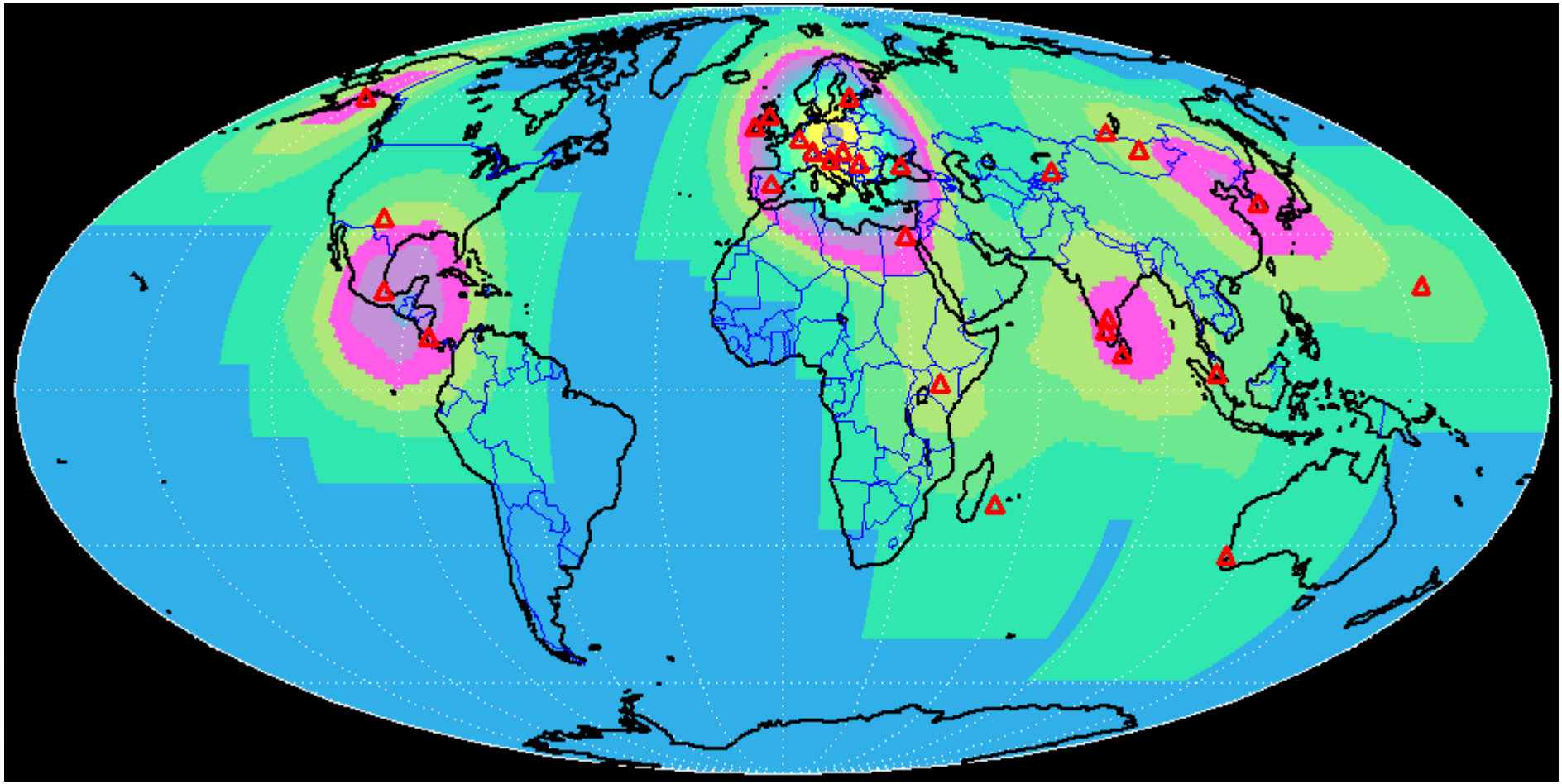








MITRA Preliminary work: Interference Mauritius



C.Monstein 2013

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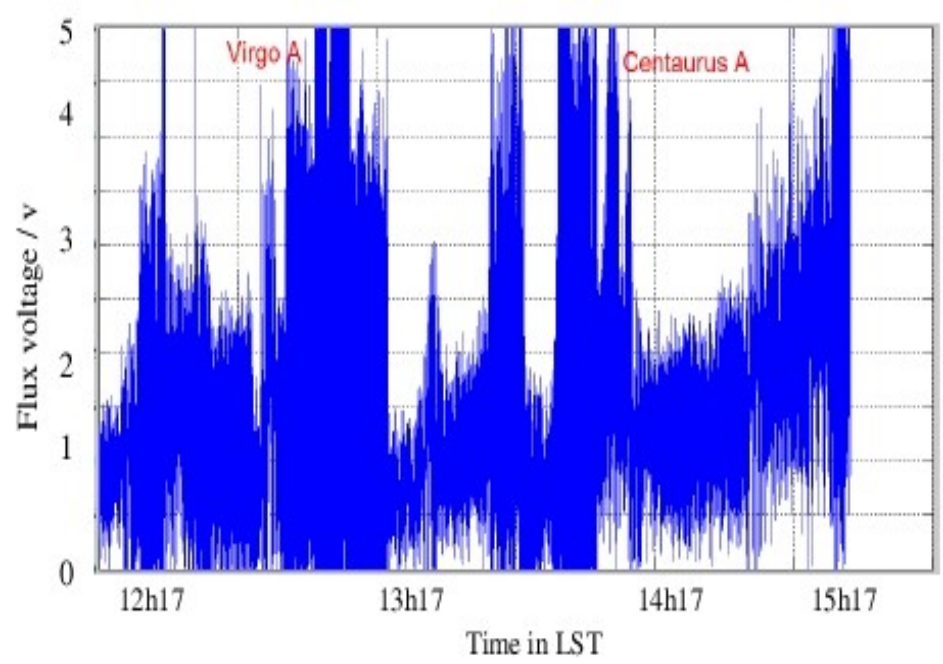
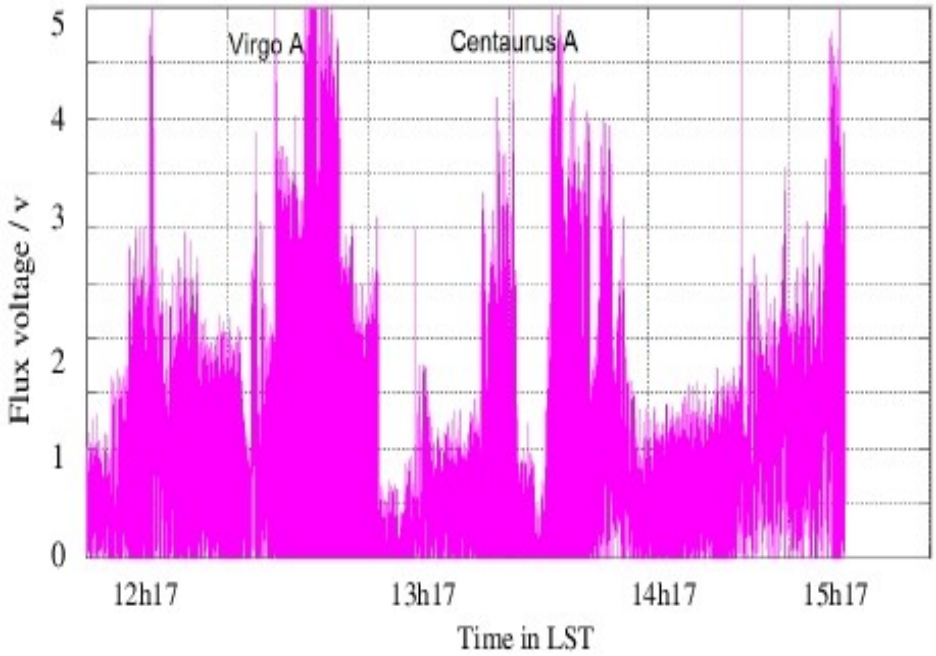
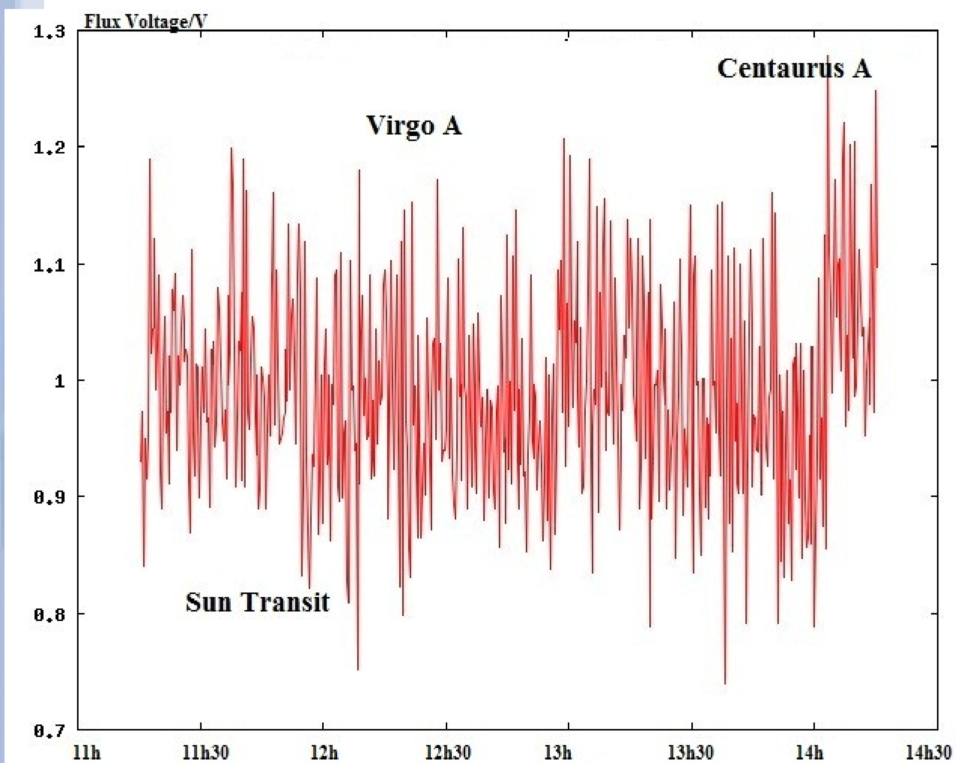
MITRA Preliminary work
4 channel receiver

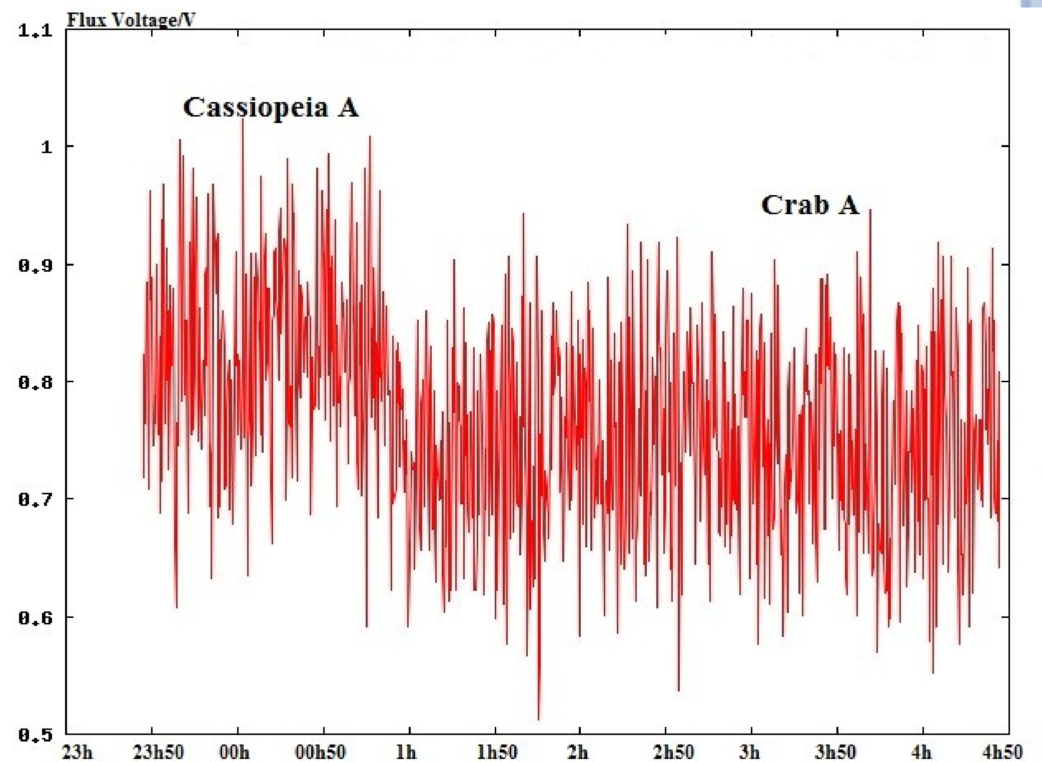




1 D dirty scan (8 antennas) Cos(left) and Sin(right)
150 MHz RF 2-channel correlator ADC card Matlab & Labview

MITRA Preliminary work
16 channel receiver





1 D dirty smoothed scan (8 antennas) 150 MHz RF 2-

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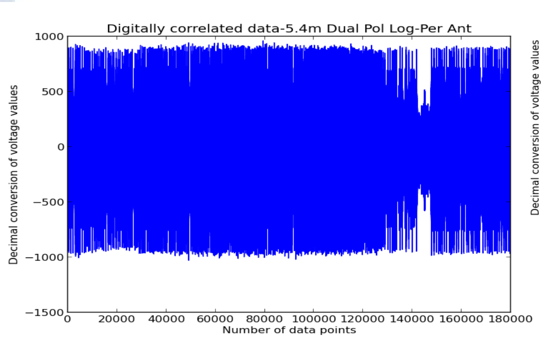
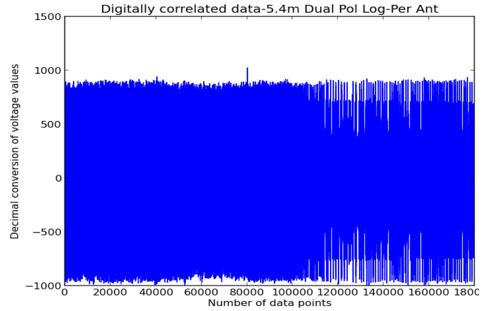
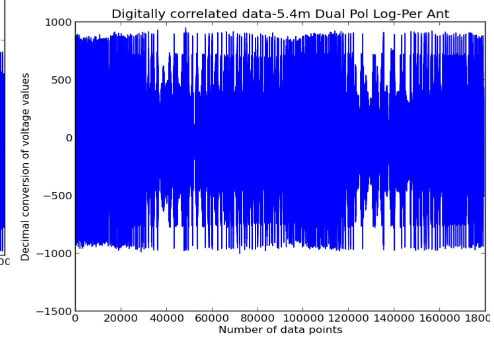
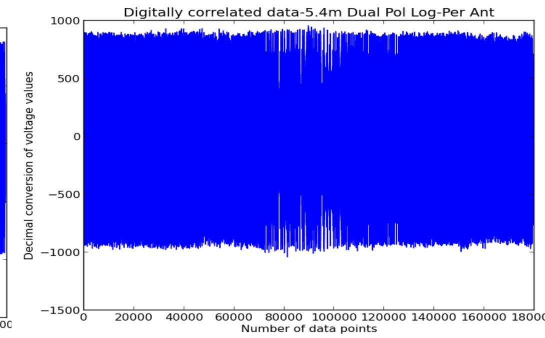
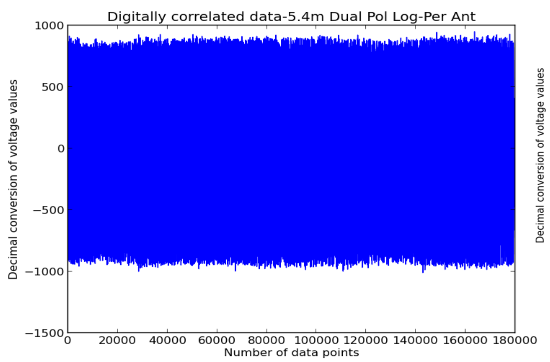
MITRA Preliminary work
15 min obs files 21.02.2014

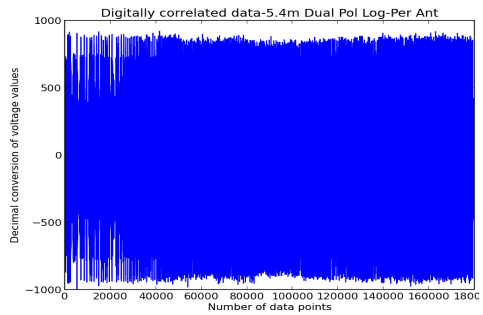


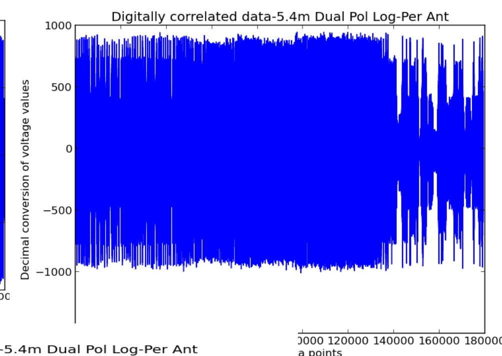


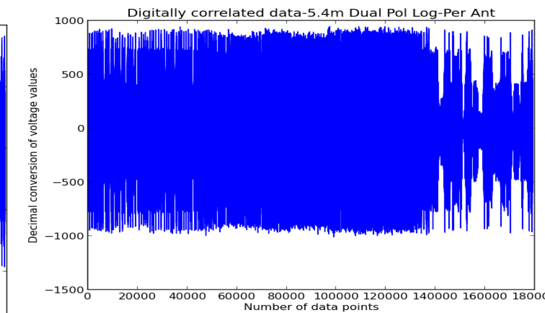


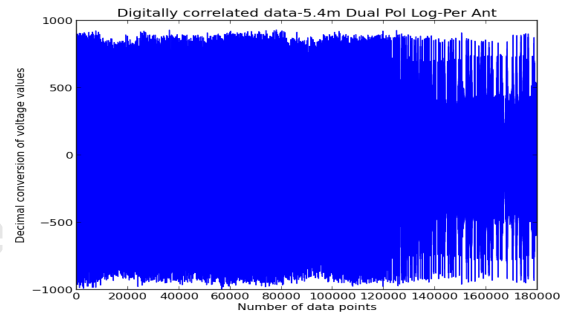












MITRA Preliminary work
16 antenna array Durban

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

MITRA Preliminary work
16 antenna array Mauritius

J.Shibchurn
G.K.Beeharry
& MRT team
2013

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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

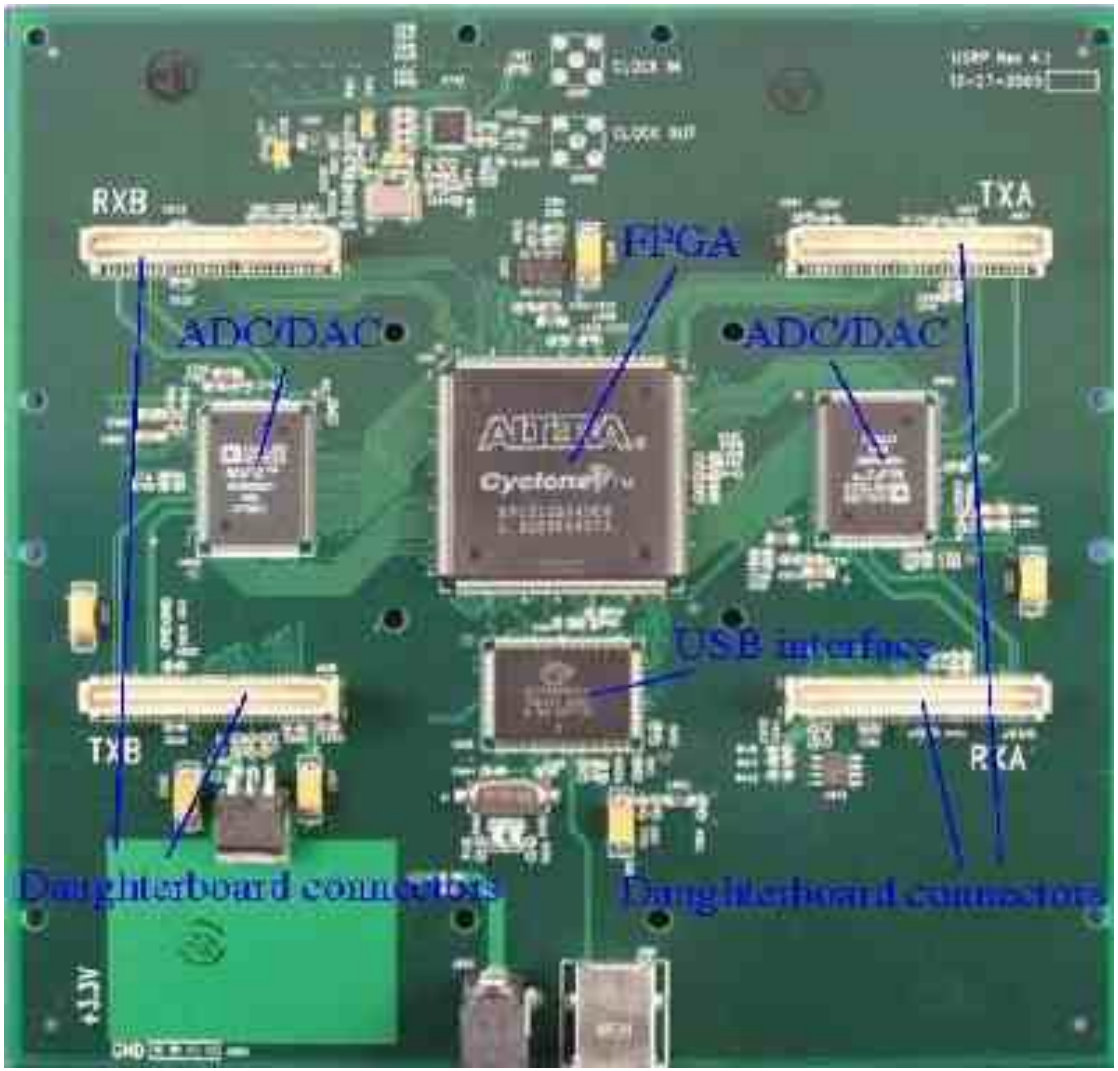
MITRA Preliminary work: Universal Software Radio Peripheral Software

- Software Defined radio
- Open source GNU Radio

- Processing defined by flow graphs in Python
- Primitives in C++

- Programmes for the FPGA

MITRA Preliminary work: USRP1Mainboard



Website

MITRA Preliminary work: USRP1Mainboard

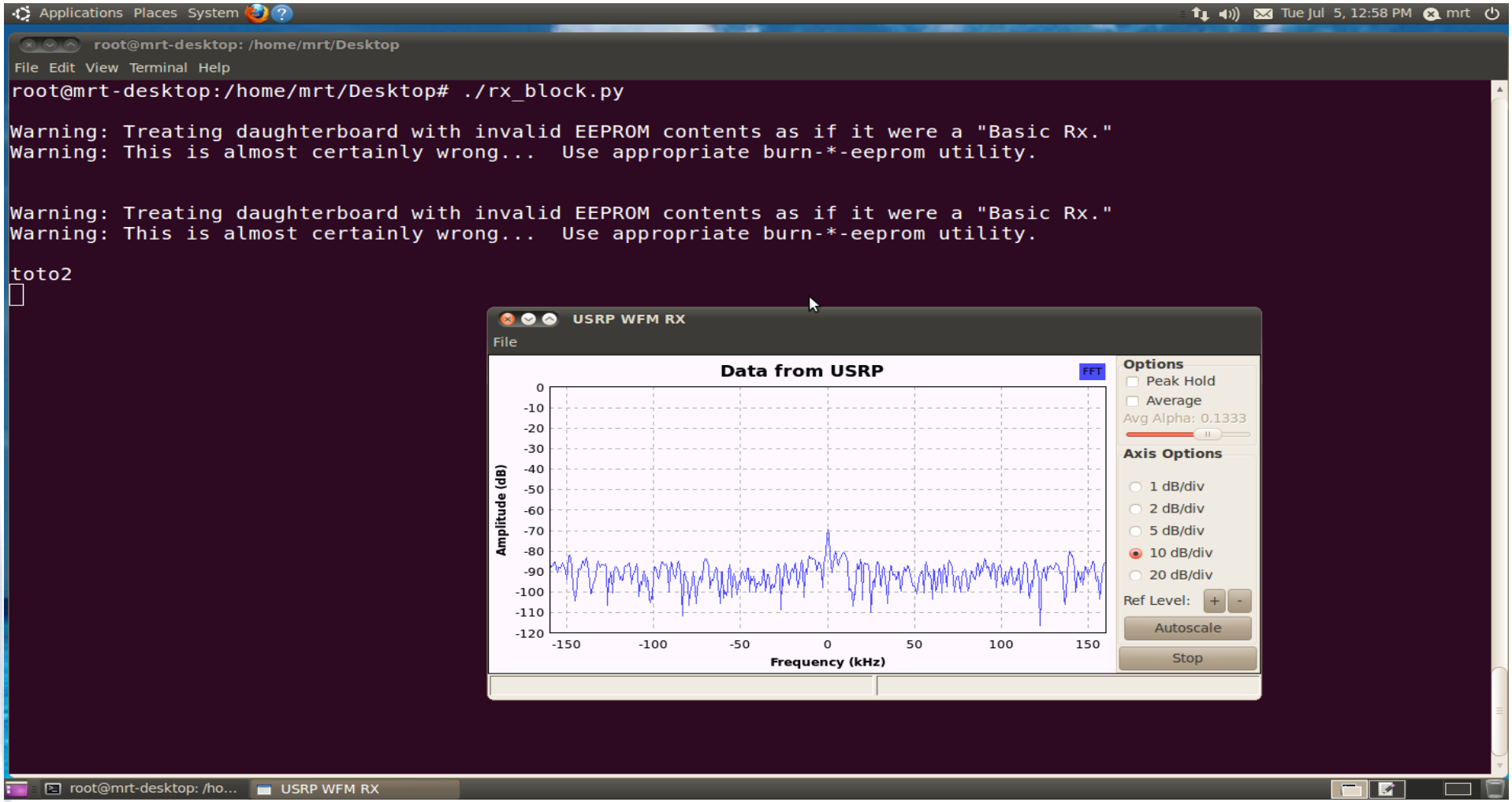
- GNU Radio free open software

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

- Tried on Slackware, Debian and Ubuntu

- Modified source code “rx_block.py”

MITRA Preliminary work: USRP1Mainboard



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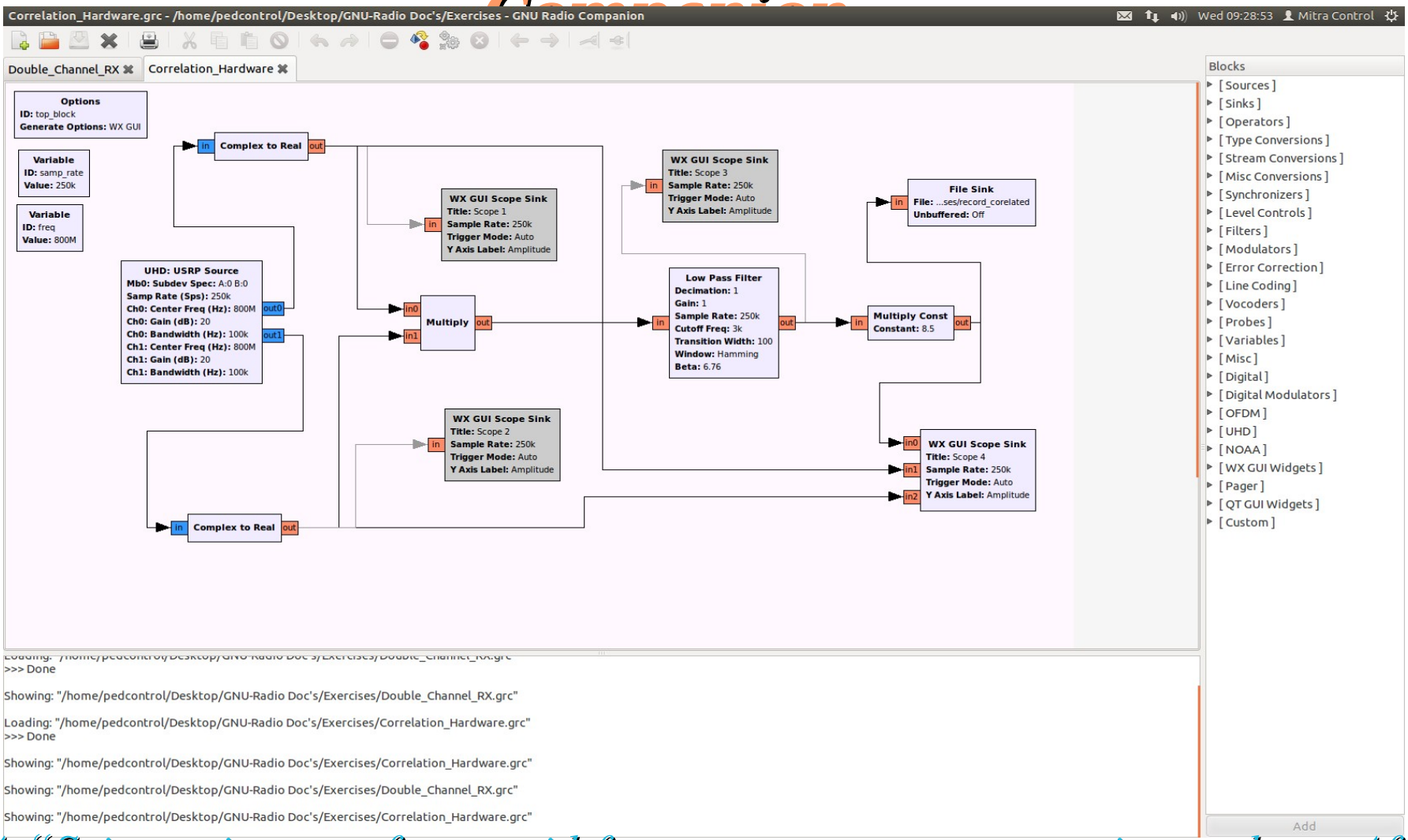
MITRA Preliminary work:
USRP control using GNU Radio Companion



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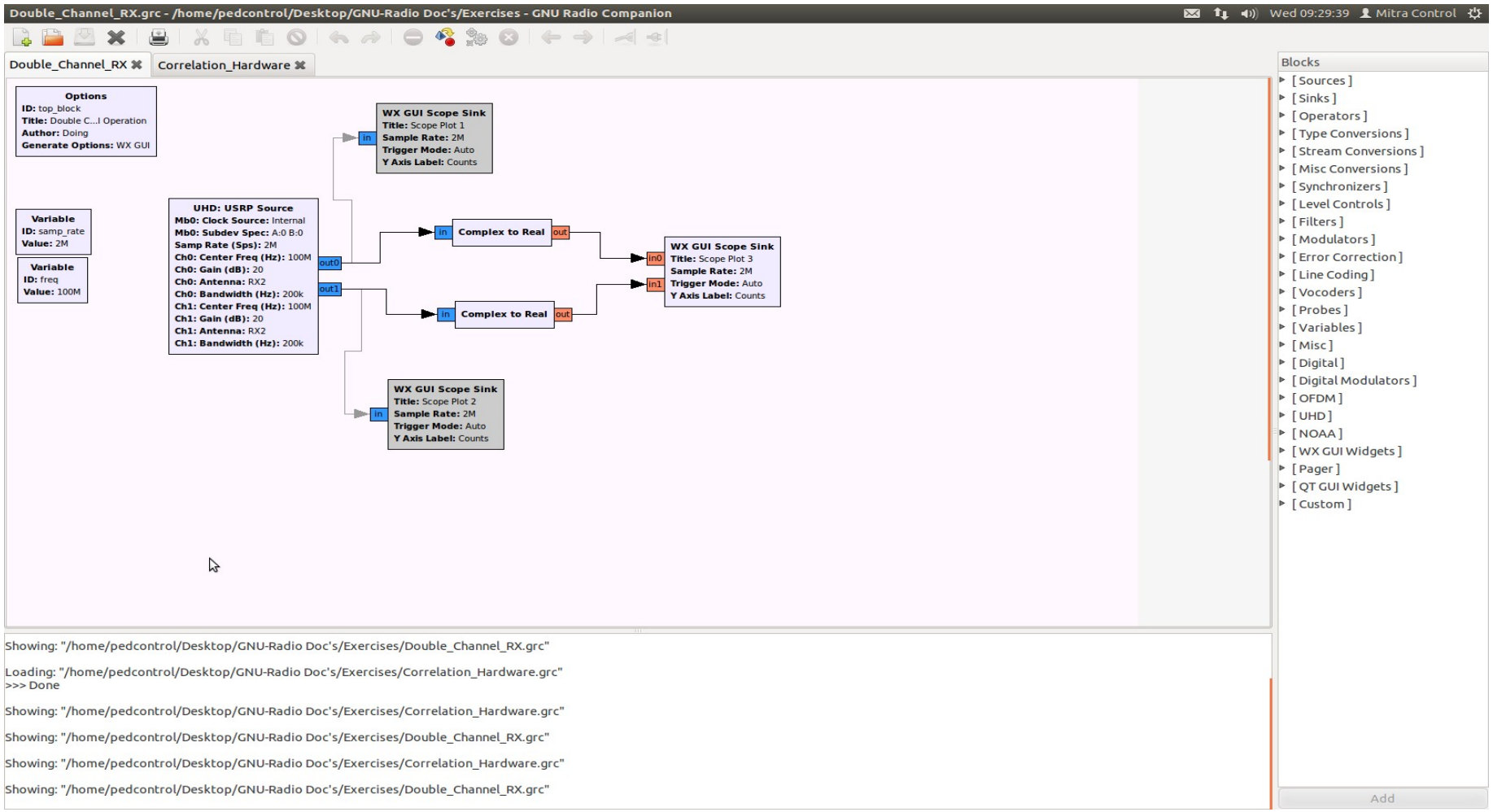
MITRA Preliminary work:
2 USRP detection using GNU Radio Companion



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MITRA Preliminary work: USRP1Mainboard

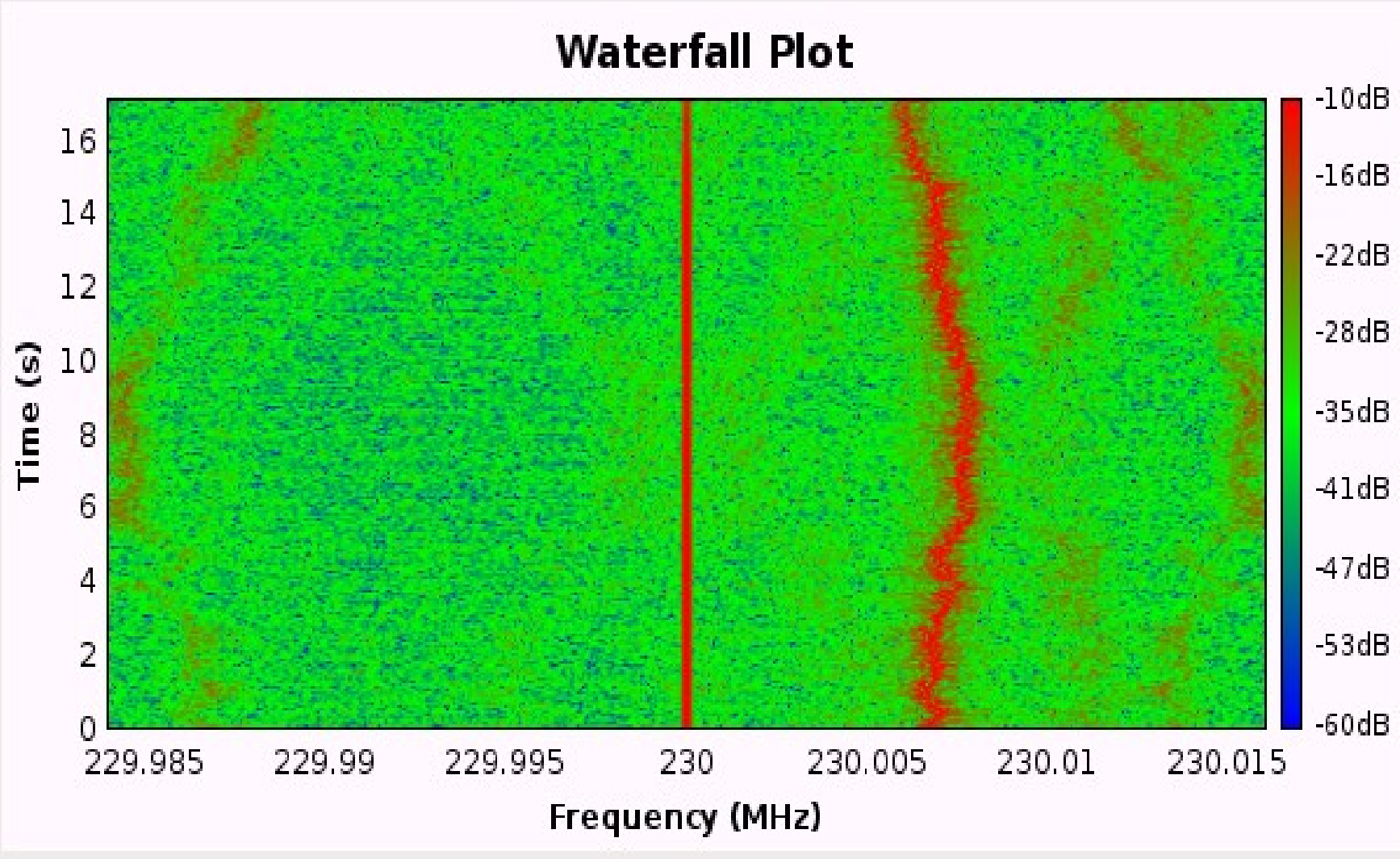
- GNU Radio free open software

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

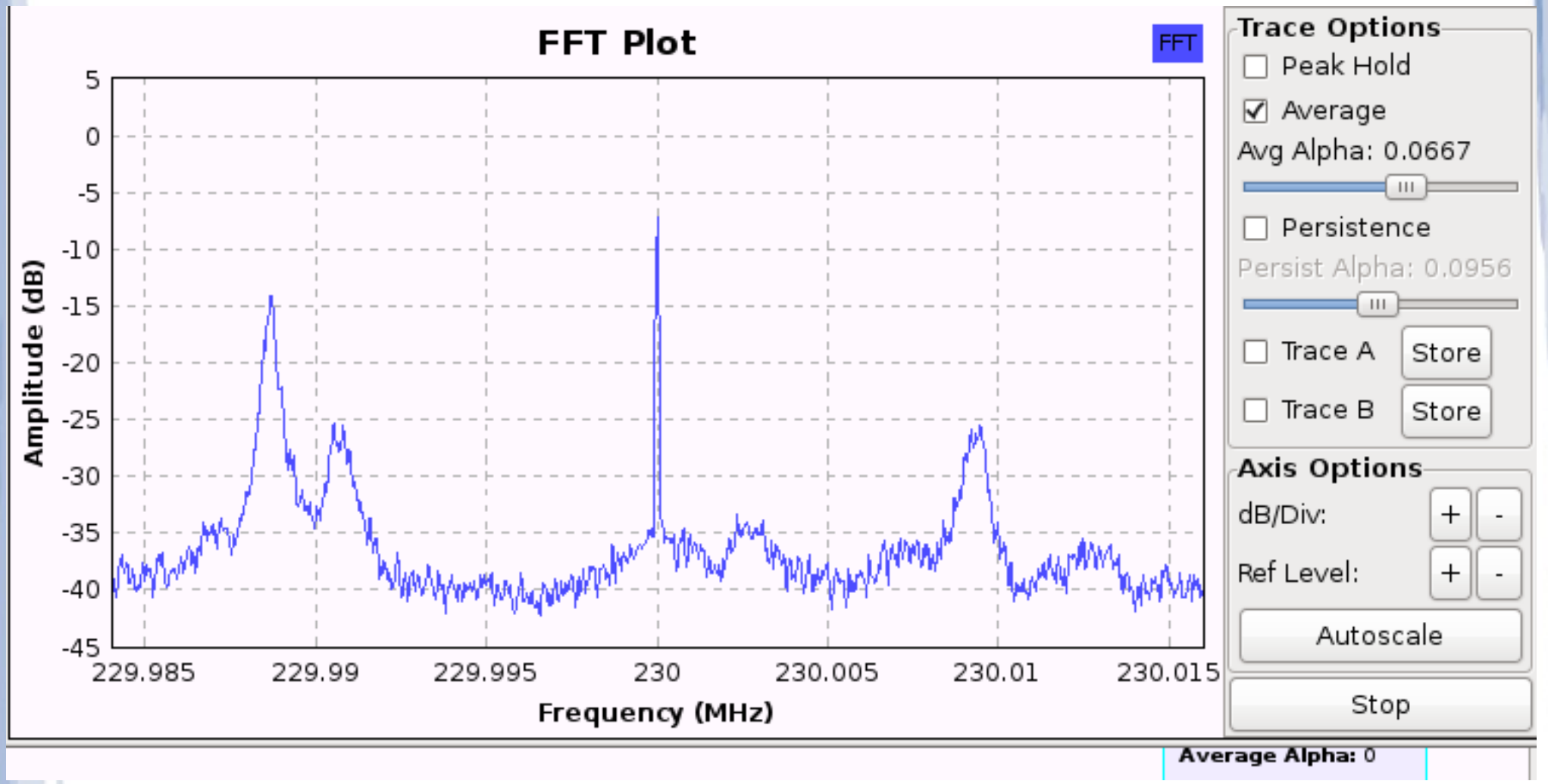
- Tried on Slackware, Debian and Ubuntu

- Modified source code “rx_block.py”

MITRA Preliminary work: Waterfall



MITRA Preliminary work: FFT



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)

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 λ 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

Preliminary work on low cost FPGA on the USRP board

Virtex 6 board

GPU array

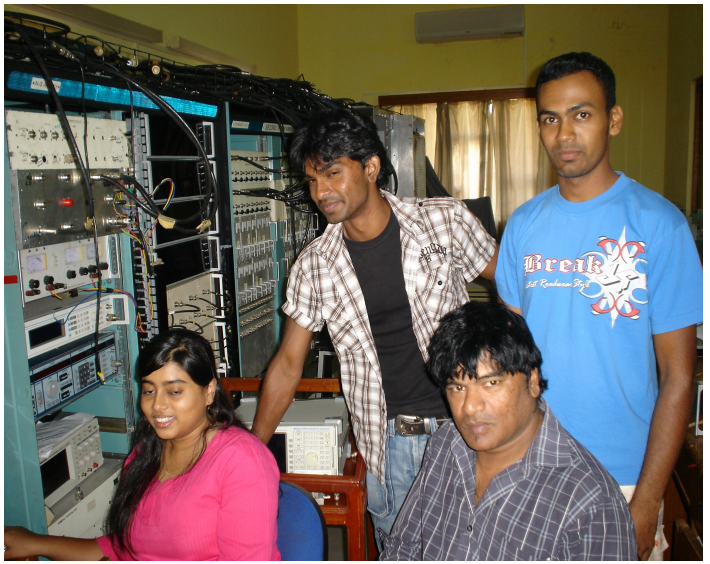
Item	Quantity	Cost (MUR)	Cost (ZAR)	Notes
DPLPDA	8	16,928	4,445	local made
PFAmp	8	11,520	3,032	Minicircuits
8way C	1	4,446	1,170	ZFSC-8-43+
RFOpto	1	57,440	15,116	High cost 57.5%
Opt Fib	50 m	4,800	1,253	Cost down/coax
DC pow.	1	4,800	1,263	
8 A1pol		99,934	26,299	
8A 2 pol		182,940	48,143	
64 G 512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

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	
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	
64 G 512 A		7,245,824	1,906,688	

Cost: Scenaios

	Station 512 antennas	Station 1024 antennas	Relayive Sensitivity
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



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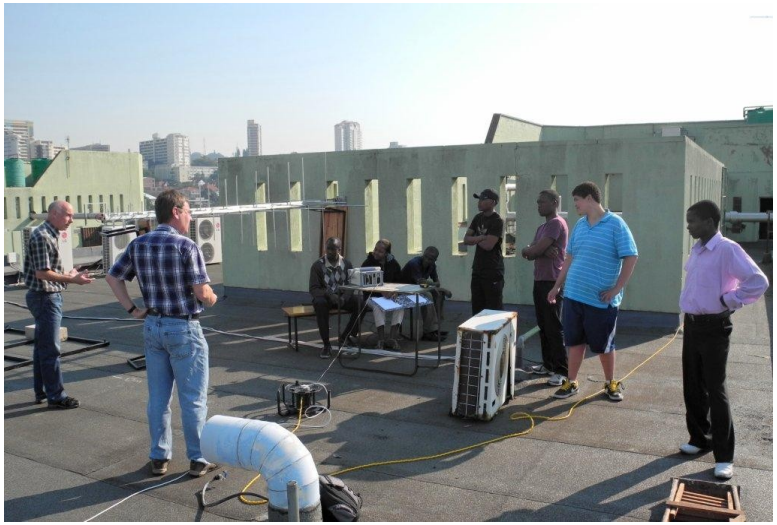
People in Durban South Africa



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Minister Pandor visit 19.9.2011

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Minister Jeetah visit 09.08.2012

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Pr Yves Rocard visit 09.2013

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Astron/SKA visit 16.09.2013

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Future: 8x8 array

Future: stations

Future: Plans

- Collaborations: Astron, SKA

- Training ground for African students, academics, engineers, technicians,

- Bursary programme

- Running our MSc

Thanks!