The upgraded GMRT : Current Status

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(on behalf of the large team working hard for the last few years on uGMRT)

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Pune India

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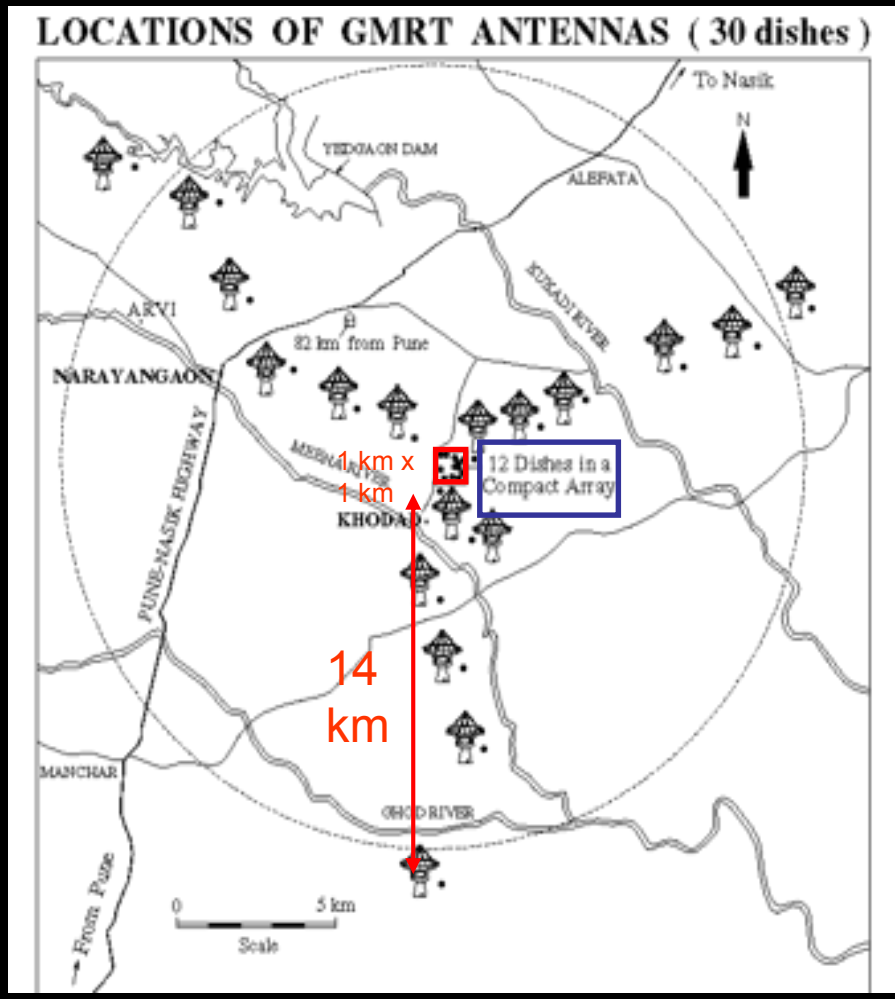
NCRA • TIFR

Plan of today's presentation

- Upgrading the GMRT – goals and plans
- Main features of the uGMRT
- Developments & current status of different aspects of the uGMRT
- Plans for (phased) release of the uGMRT to the user community

The *existing* GMRT : An Overview

- 30 dishes, 45 m diameter each
  - 12 dishes in a central 1 km x 1 km region (central square)
  - remaining along 3 arms of Y-shaped array
  - baselines : ~ 200 m (shortest);
    ~ 30 km (longest)
- Frequency range :
  - 130-170 MHz
  - 225-245 MHz
  - 300-360 MHz
  - 580-660 MHz
  - 1000-1450 MHz
  - max instantaneous BW = 32 MHz
- Effective collecting area (2-3% of SKA) :
  - 30,000 sq m at lower frequencies
  - 20,000 sq m at highest frequencies
- Supports 2 modes of operation :
  - Interferometry, aperture synthesis
  - Array mode (incoherent & coherent)



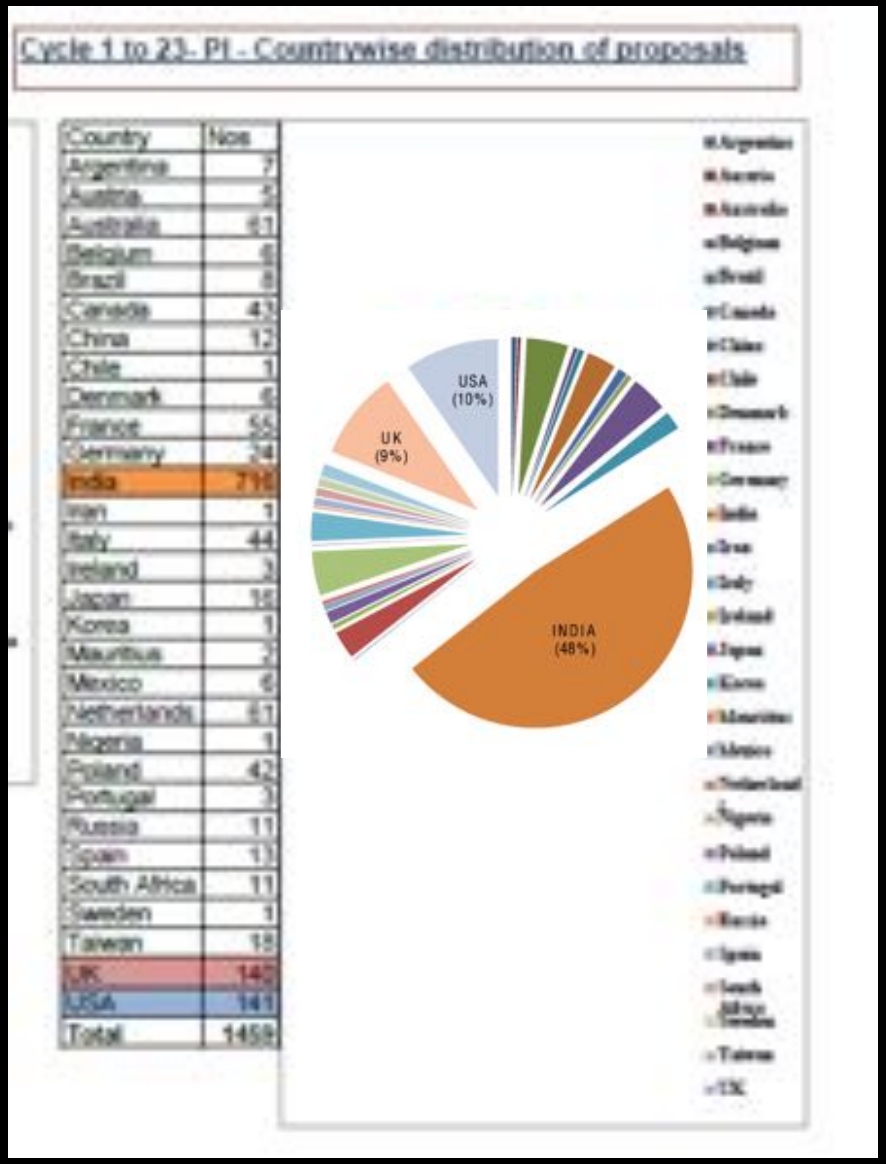
Dedication of the GMRT

The Giant Metrewave Radio Telescope was dedicated to the World Scientific Community by the Chairman of TIFR Council, Shri Ratan Tata.

October 4, 2001

GMRT : Usage Statistics

- The GMRT is open to international participation via a formal proposal system
- Proposals are invited twice a year and reviewed by the GMRT Time Allocation Committee
- Observations are scheduled for 2 cycles of 5 months each
- The GMRT is presently oversubscribed by a factor of 2.5
- Distribution of Indian vs Foreign users : close to 50:50



GMRT : Scientific Objectives

The GMRT is a powerful instrument to probe several astrophysical objects and phenomena :

- The Sun, extrasolar planets
- Pulsars : rapidly rotating neutron stars
- Other Galactice objects like : supernova remnants, microquasars etc
- Other explosive events like Gamma Ray Bursts
- Ionized and neutral Hydrogen gas clouds (in our Galaxy and in other galaxies)
- Radio properties of different kinds of galaxies; galaxy clusters
- Radio galaxies at large distances in the Universe
- Cosmology and the Epoch of Reionization
- All sky surveys such as the 150 MHz TGSS

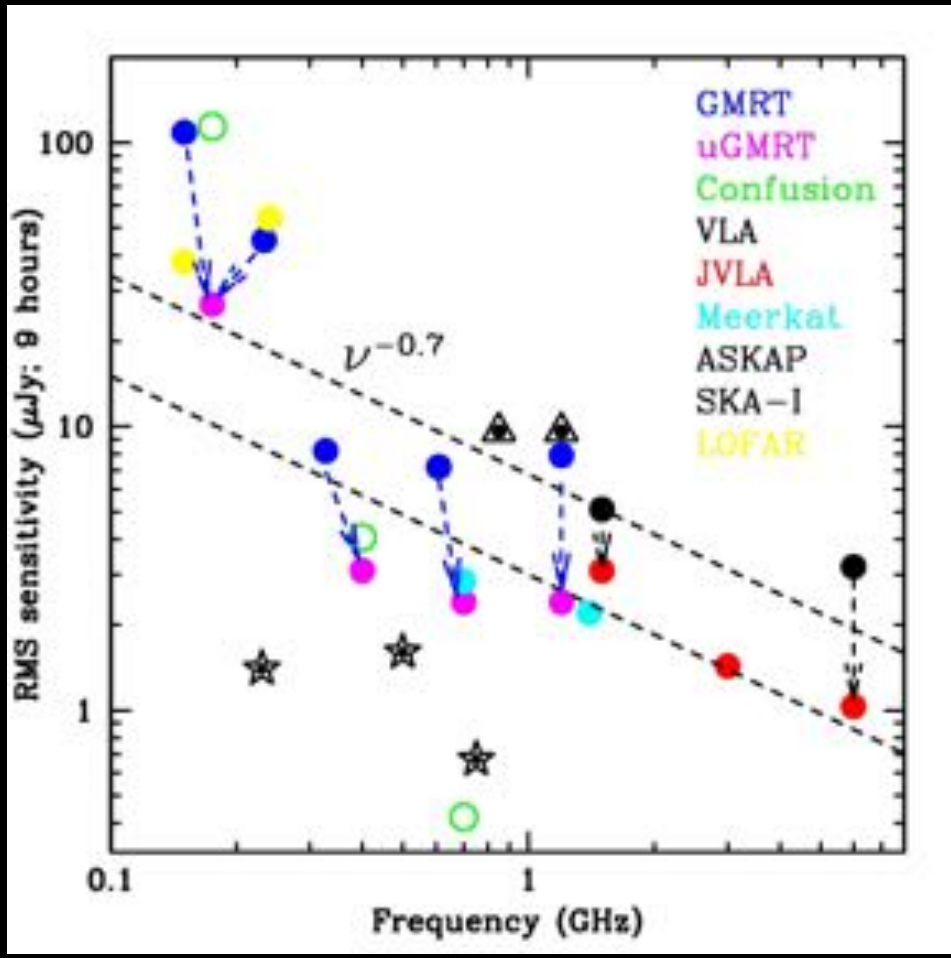
…and many interesting new results have been produced

Next Generation : The uGMRT

- For last several years the GMRT has been working well on the global stage; however, it was time to think of the future & upgrade the facility, keeping in mind technology development for global efforts such as the SKA.
- Main goals for the upgraded GMRT (uGMRT) were identified as :
  - Seamless frequency coverage from ~ 30 MHz to 1500 MHz, instead of the limited bands at present ➔ *design of completely new feeds and receiver systems with ~ octave bandwidths*
  - Improved dynamic range and G/Tsys ➔ *better technology receivers*
  - Increased instantaneous bandwidth of 400 MHz (from the present maximum of 32 MHz) ➔ *new digital back-end receiver*
  - Revamped servo system ➔ *brushless drives, new servo computer etc*
  - Modern, versatile control and monitor system ➔ *SKA contribution*
  - Matching improvements in offline computing facilities
  - Improvements in mechanical & electrical systems, infrastructure facilities
  - To be done without compromising availability of existing GMRT to users

uGMRT : Expected Performance

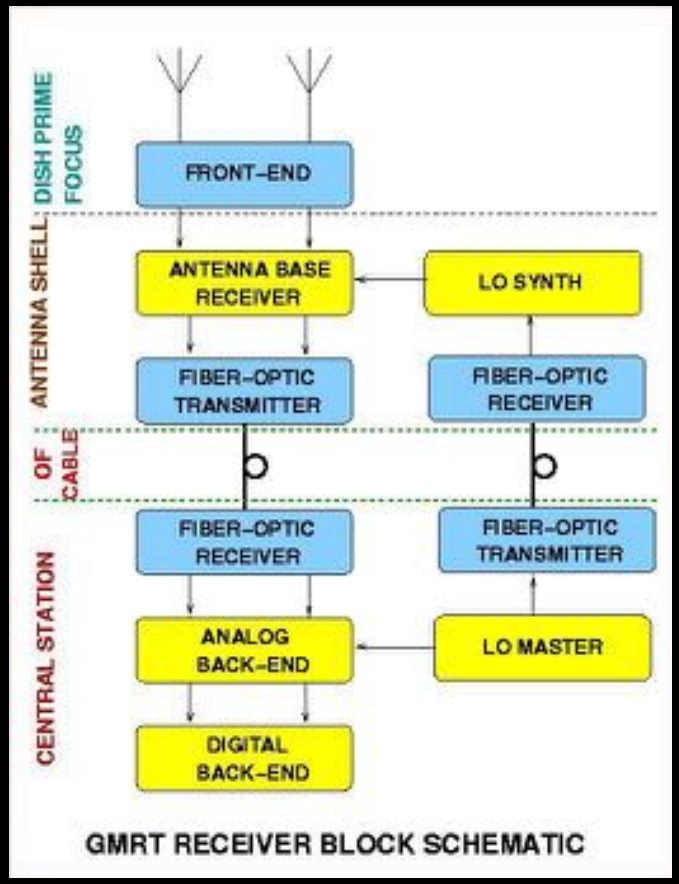
- Spectral lines : broadband coverage will give significant increase in the redshift space for HI lines + access to other lines
- Continuum imaging sensitivity will improve by factor of 3 or so.
- Sensitivity for pulsar observations will also improve by factor of 3.
- Only SKA-I will do better then uGMRT at centimeter wavelengths



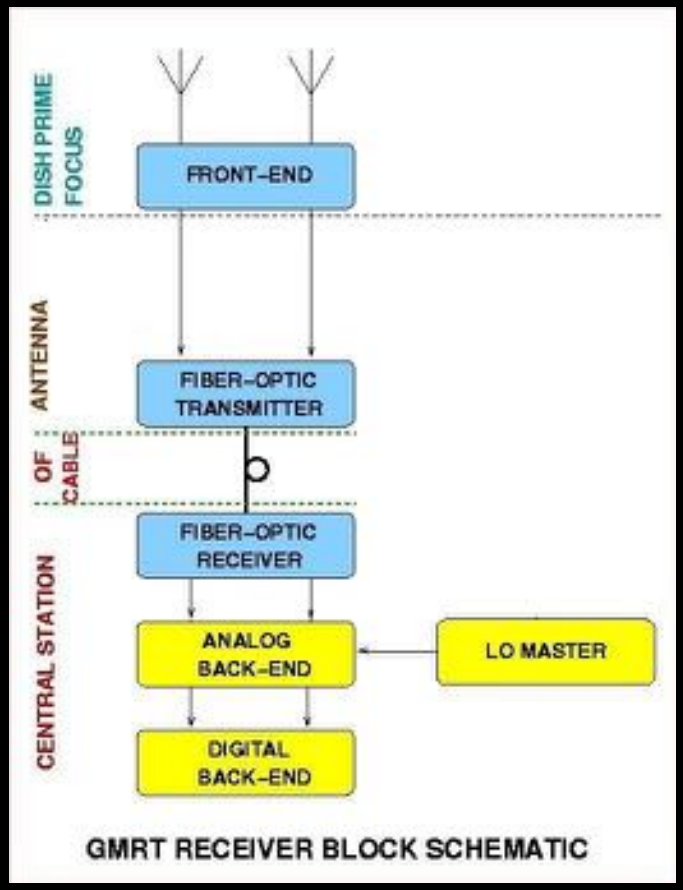
Expected sensitivity performance of the upgraded GMRT compared to other major facilities in the world, present and projected (courtesy : Nissim Kanekar, NCRA)

Overview of uGMRT Receiver System

- Relatively simplified electronics at antenna base
- Many improvements at the dish focus, optical fibre system & backends



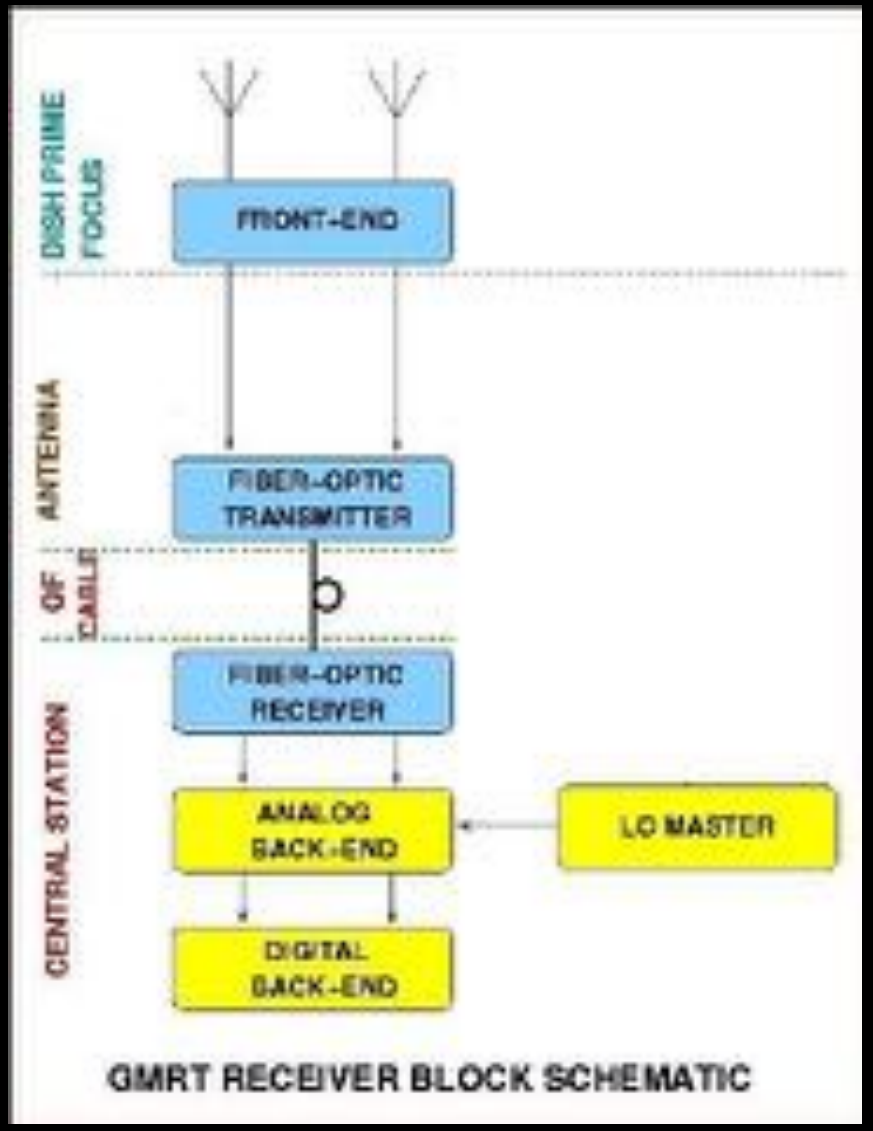
Existing GMRT system



Upgraded GMRT system

Overview of uGMRT Receiver System

- Broad-band feeds + FE (in octaves) :
  - 1000 – 1450 MHz (updating L-band)
  - 550 – 900 MHz (replacing 610)
  - 250 – 500 MHz (replacing 325)
  - 120 – 250 MHz (replacing 150)
- Modified optical fibre system to cater to wideband (50 to 2000 MHz) dual pol RF signals (while allowing existing IF signals)
- Analog back-end system to translate RF signals to 0 - 400 MHz baseband
- Digital back-end system process 400 MHz BW for interferometric and beam modes



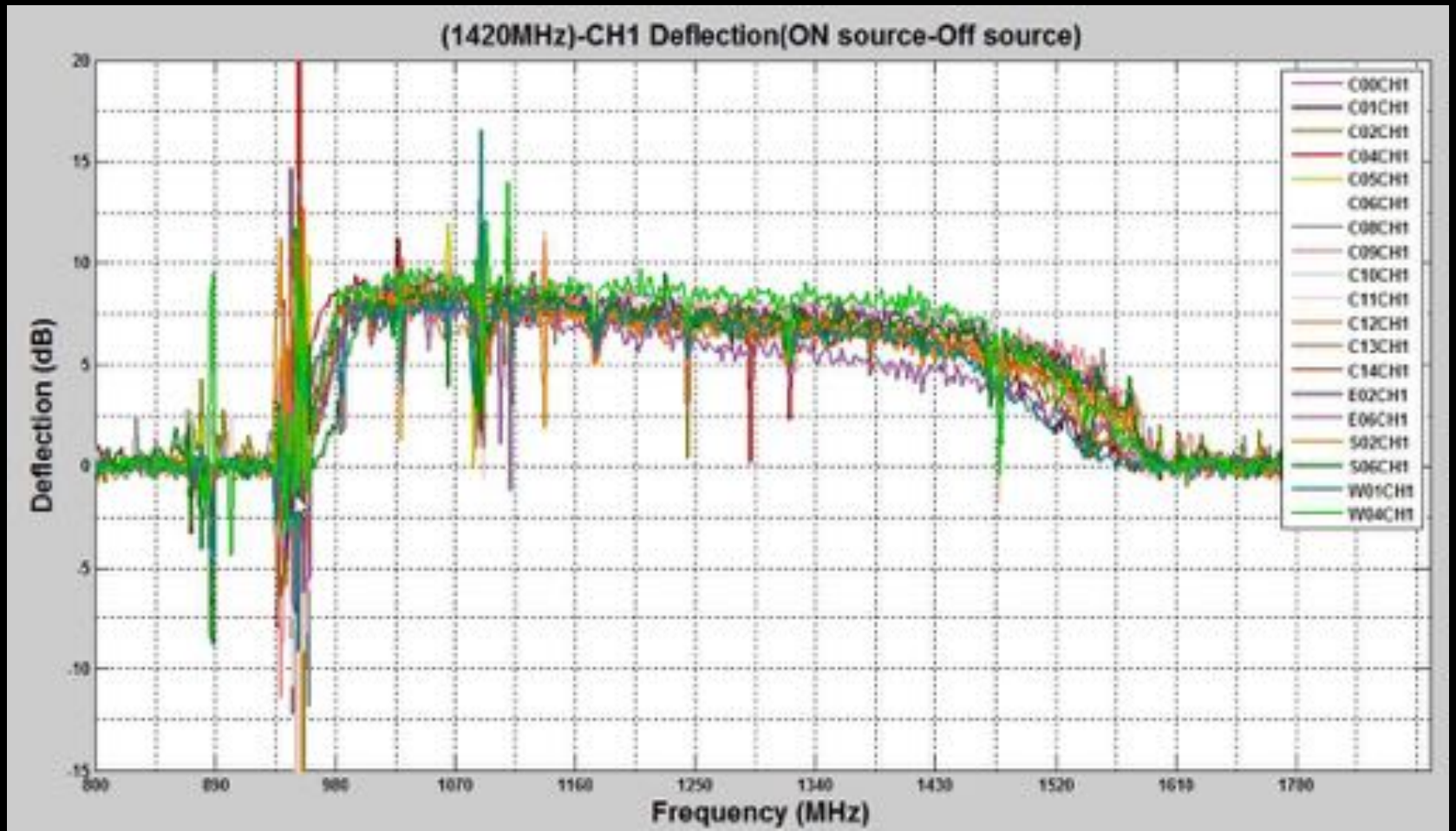
Wideband feeds + FE for uGMRT : L-band system – "Band 5"

- For this band, we are going with the existing broadband L-band feed : ~ 900 to 1450 MHz (usable from ~ 1000 MHz upwards due to mobile phone RFI)
- Improved LNA (higher dynamic range) + better filters for rejecting RFI
- 30 antenna system completed more than one year ago; some refinements of filters planned in 2nd phase of improvement
- Sufficient sets of spares in hand now.

- This system is FULLY READY !

Wideband feeds + FE for uGMRT : L-band system (Band-5)

- Performance of Lband system is monitored regularly by FE team to keep the system in good health – need to watch out for growing RFI also.



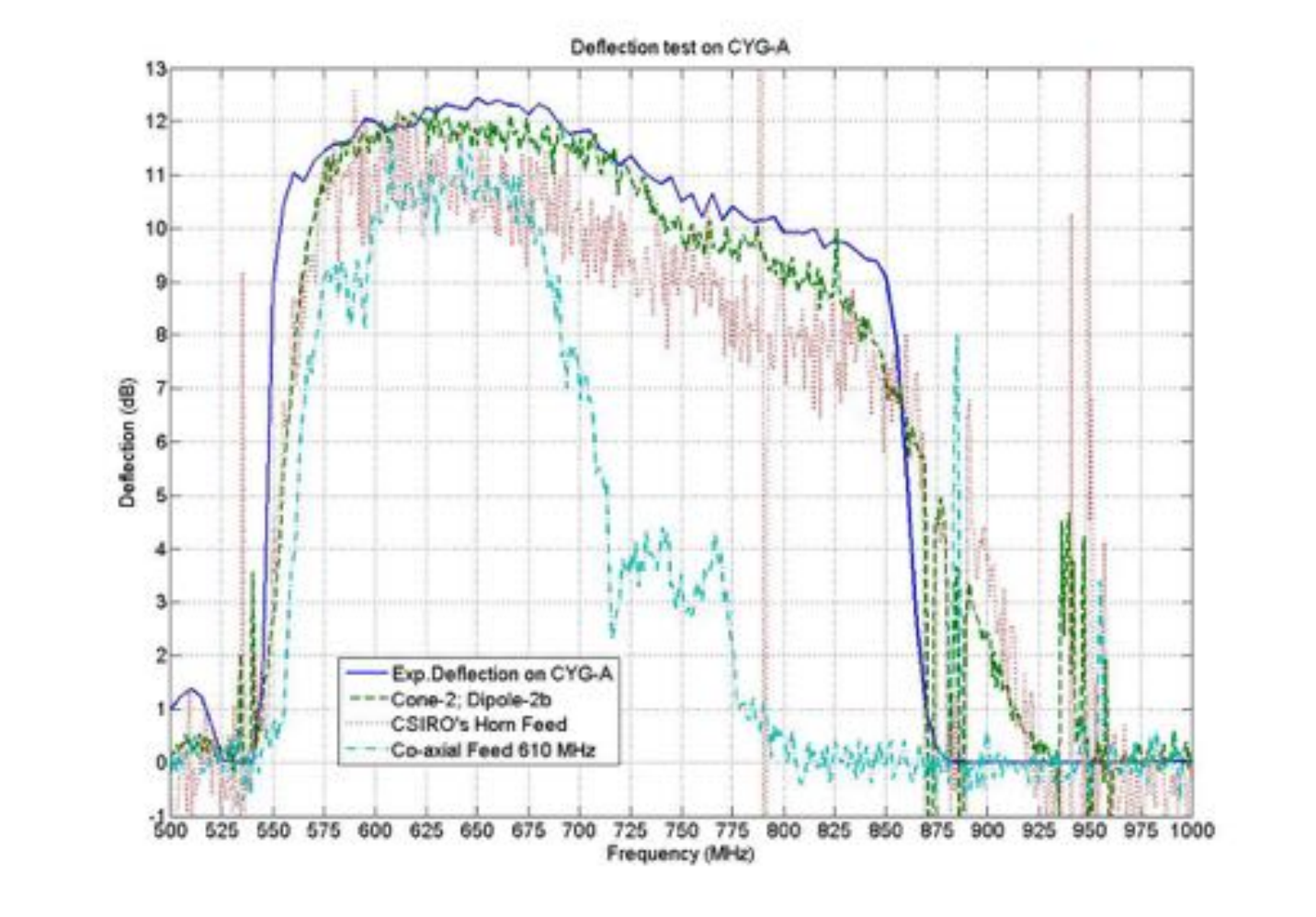
Wideband feeds + FE for uGMRT : 550-900 MHz system – "Band 4"

- Replaces existing 235/610 system
- Front-End system split into two parts :
- Polariser + LNA is right next to feed (to minimize the loss)
- Rest of the FE electronics is in the regular box
- Now installed on 10 antennas and growing…

Cone Dipole feed (for 550-900) alongwith polarizer and LNA

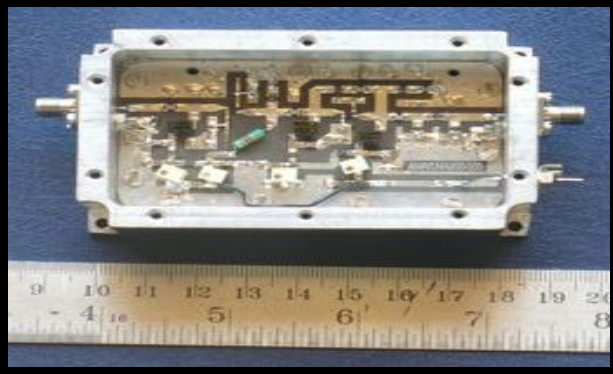
Wideband feeds + FE for uGMRT : 550-900 MHz system – "Band 4"

- Performs better than existing feed at 610 MHz and best of all options tried

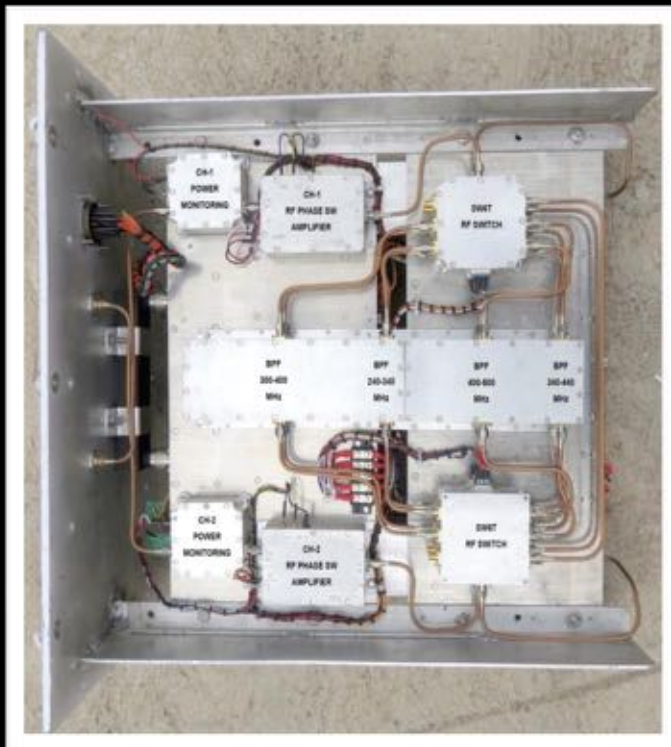


Wideband feeds + FE for uGMRT : 250-500 MHz system – "Band 3"

- Replaces existing 325 MHz system
- Broad-band (250-500 MHz) feed with good E-H pattern match
- Upgraded wideband FE system with new LNA : improved Tsys (22 vs 36 K) & dynamic range
- Up on 29 antennas – will complete all 30 next week !



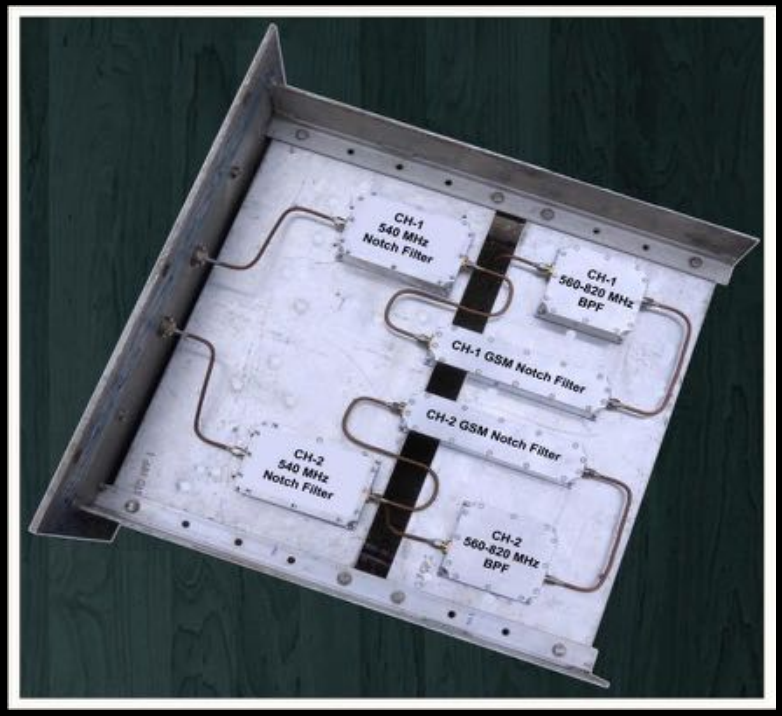
Cone Dipole feed (250-500) and FE box



Wideband feeds + FE for uGMRT : 120-250 MHz system -- "Band 2"

- Broad-band feed for 120-250 MHz in final acceptance phase, installed on 4 antennas
- Sensitivity : at 150 MHz -- better than existing system; at 235 MHz -- comparable to existing system

Dual Ring Feed : 130-260 MHz



uGMRT : New Wideband Systems Summary

- Proposed configuration of feeds and receivers and their current status :
  - Band 5 (1000 – 1450 MHz) : existing wideband feed + improved dynamic range rx with appropriate RFI filters -- completed on 30 antennas.
  - Band 4 (550 – 900 MHz) : cone-dipole feed with matching receiver system finalized and now in mas production phase -- 10 antennas completed.
  - Band 3 (250 – 500 MHz) : cone-dipole feed + receiver is well into mass production & installation -- 29 antennas completed.
  - Band 2 (120 – 250 MHz) : modified Kildal ring feed + modified electronics in last stages of validation.
  - Band 1 (30 – 80 MHz) : on hold at present.

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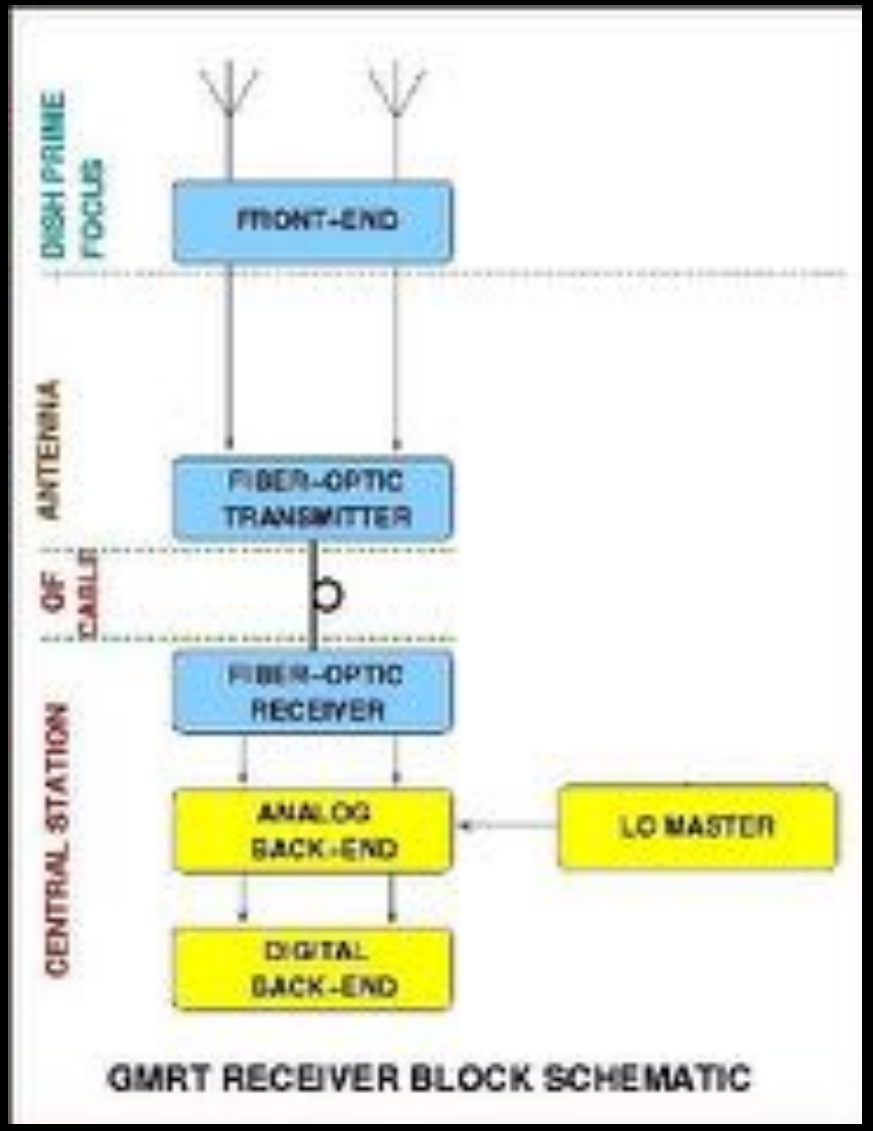
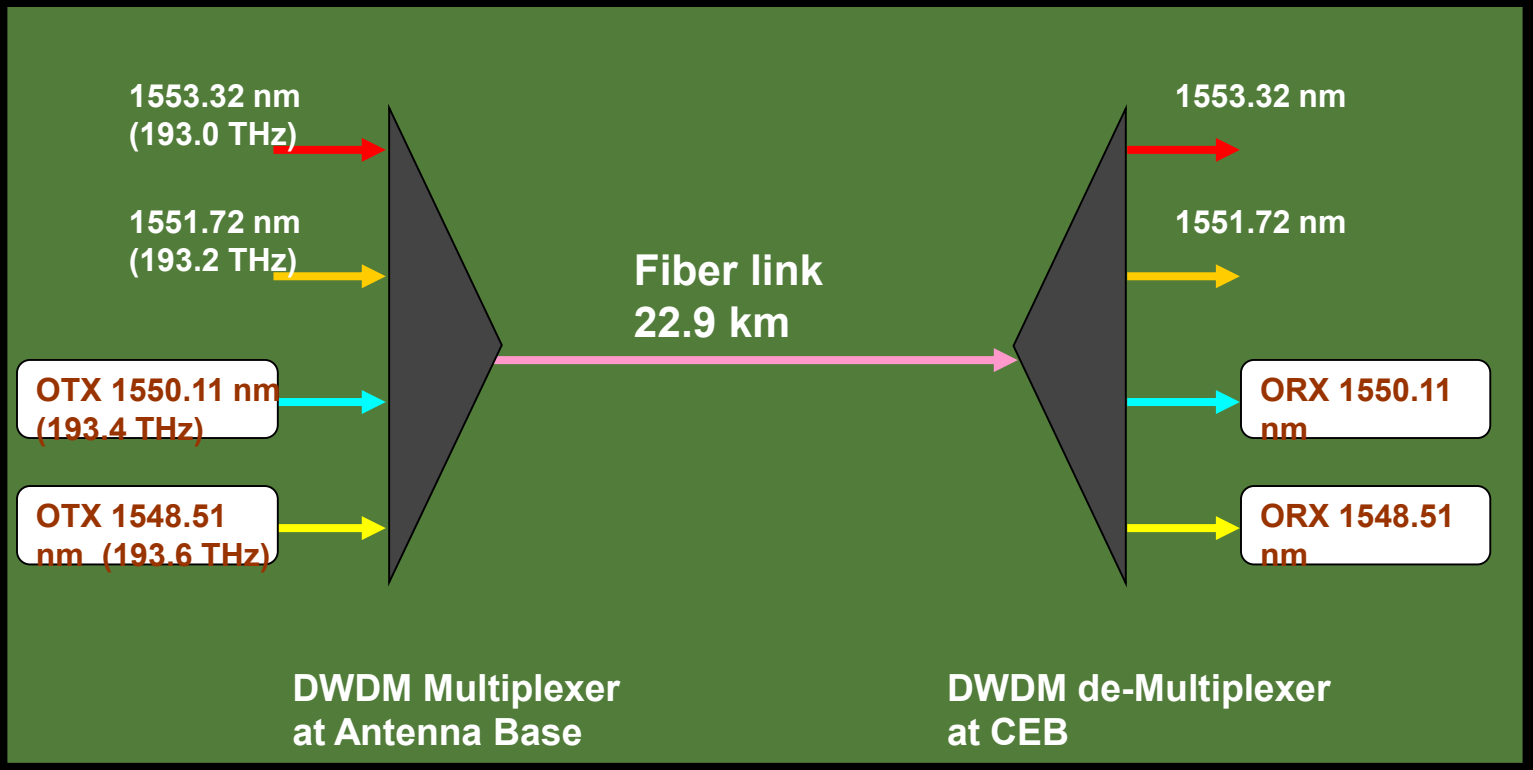


GMRT RECEIVER BLOCK SCHEMATIC

GMRT Upgrade : Optical Fibre Systems

- DWDM based, broad-band (2.5 GHz), analog optical fibre transmission scheme; features : 20 dB S/N; 40 dB dynamic range
- Will bring back 2 broad-band RF channels + existing IF channels ; will also support new and existing control and monitoring schemes



GMRT Upgrade : Optical Fibre Systems

Completed installation for all 30 antennas in September 2015 and working well

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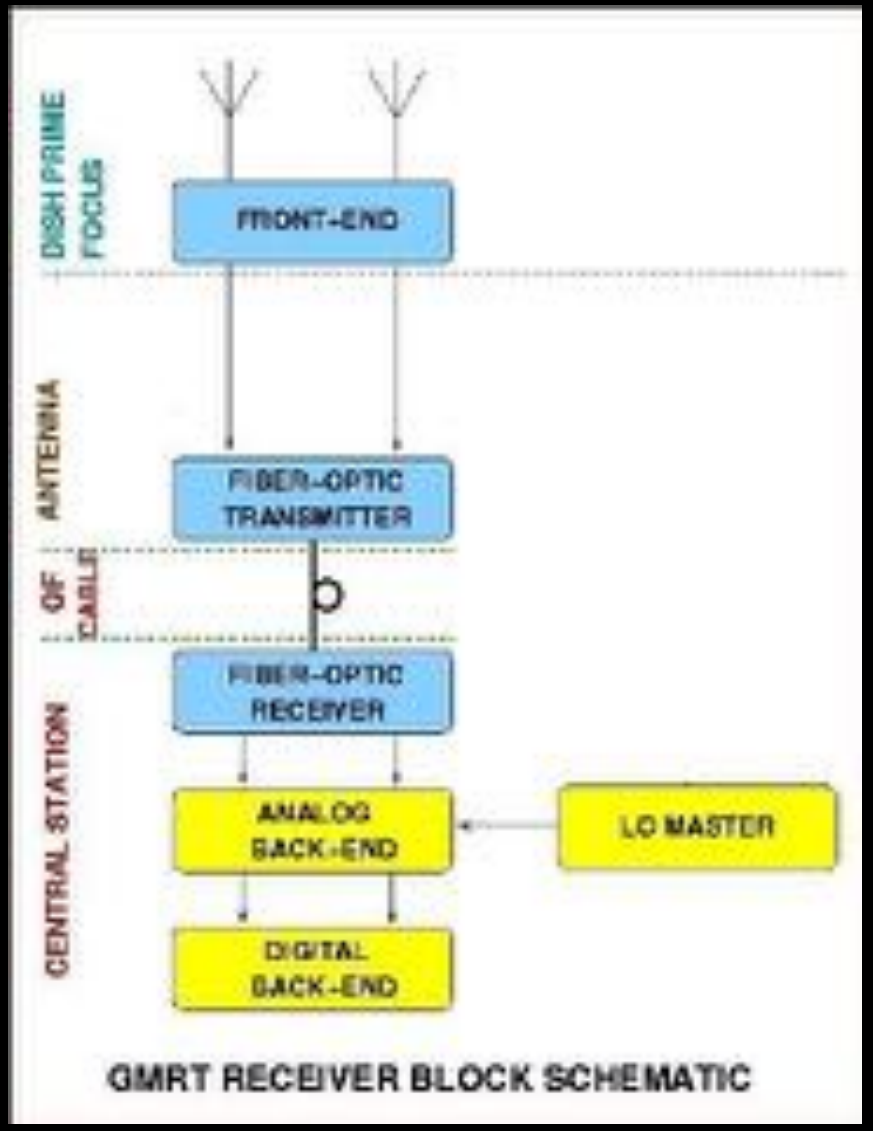
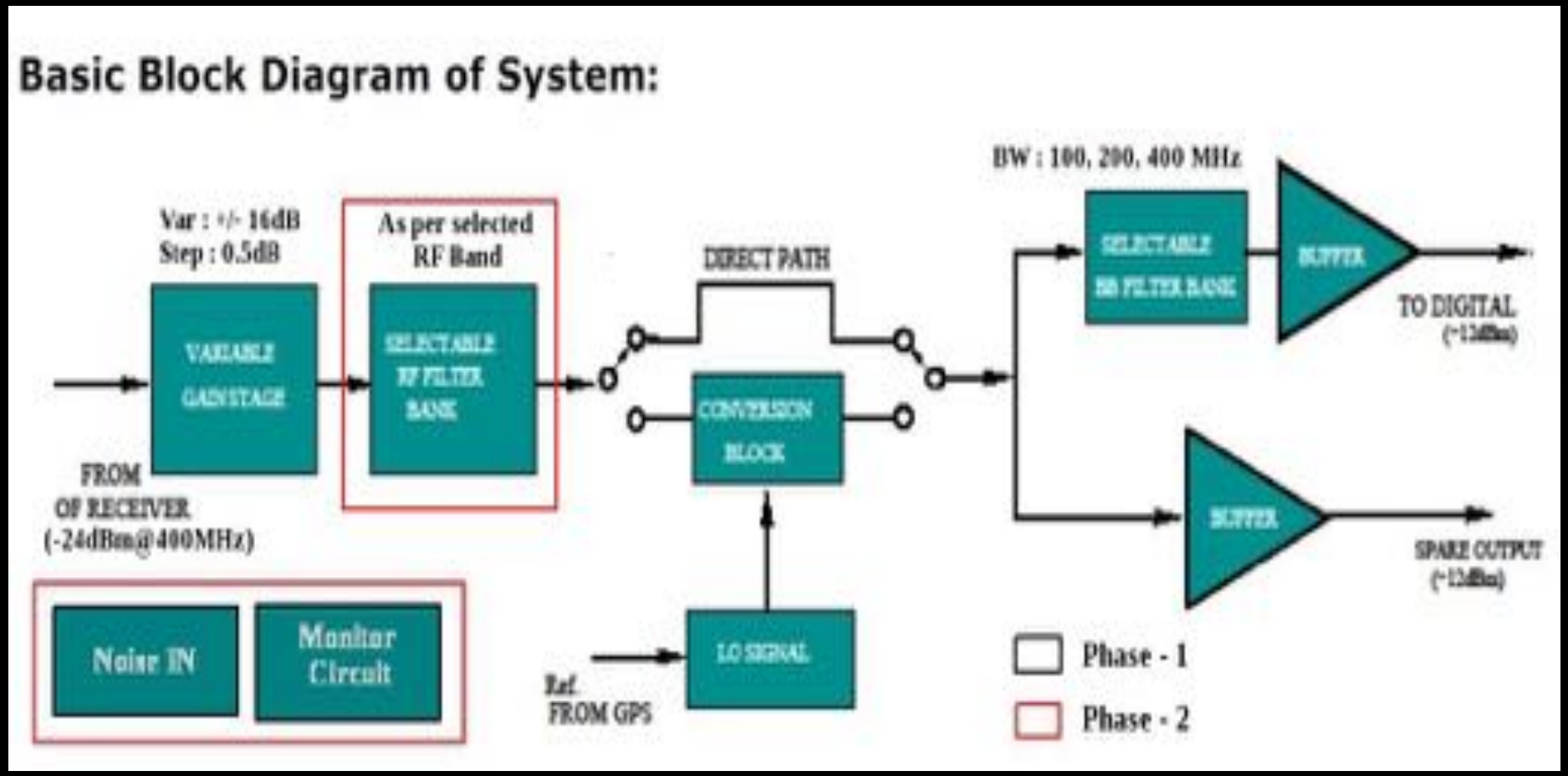


uGMRT : Analog Backend

- Receives wideband RF signals from OF system output
- Converts to baseband signals of 100, 200, 400 MHz BW after appropriate signal conditioning (amplification, filtering etc)



uGMRT : Analog Backend Status

- Phase-I 30-antenna system installation completed ; peripheral units under installation as part of phase-II

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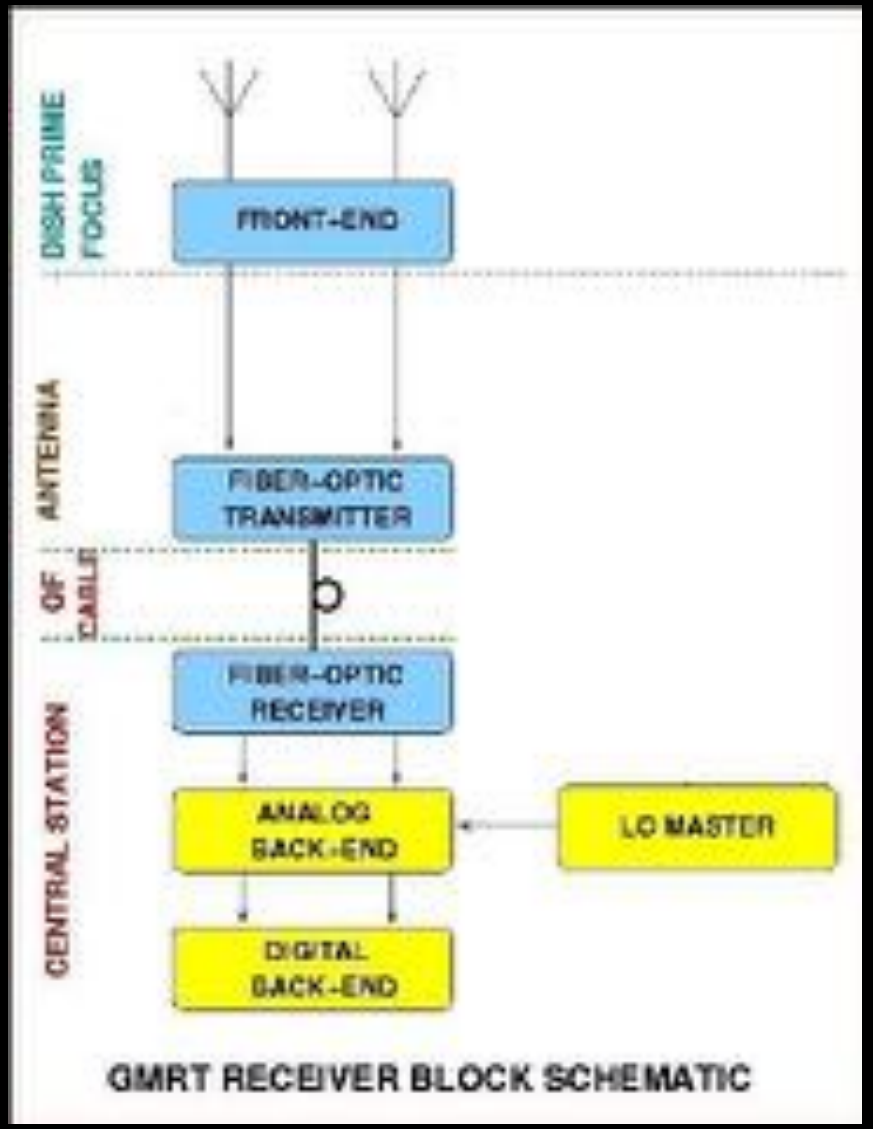
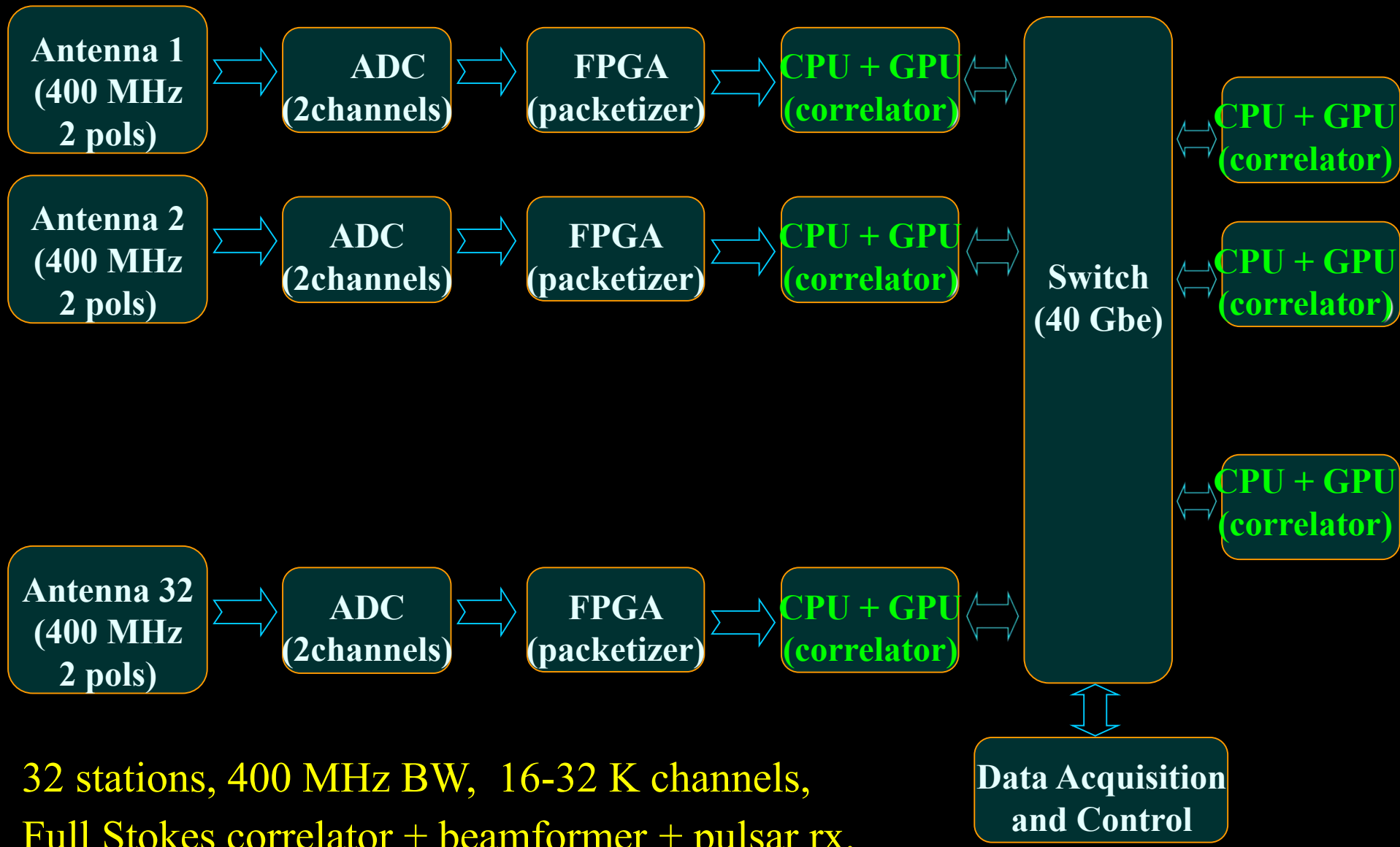


uGMRT Digital Backend : Hybrid Correlator Design



32 stations, 400 MHz BW, 16-32 K channels,

Full Stokes correlator + beamformer + pulsar rx.

GWB-III : 16 antenna (dual poln) 400 MHz software backend for the uGMRT

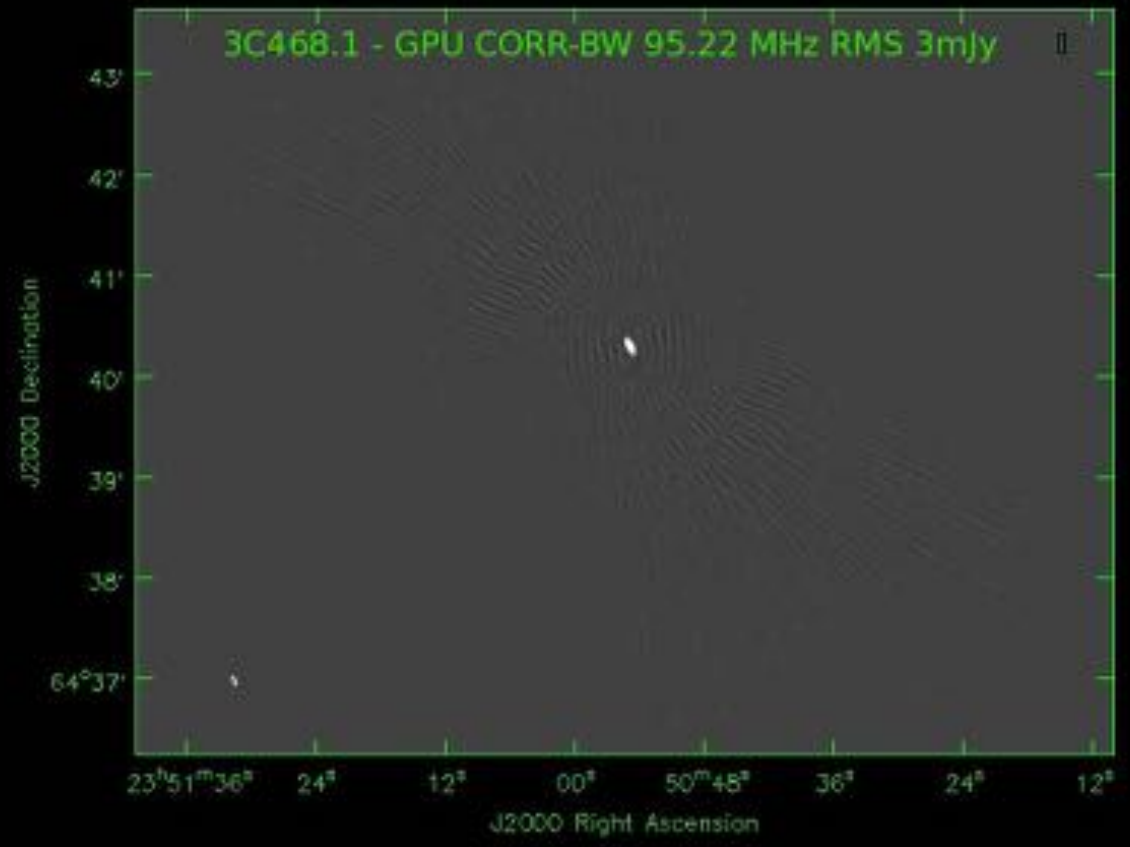
- 8-node GPU system
- 16 ADC cards + 8 FPGA boards
- Dual K20 GPUs on each T620 node
- Released in September 2015

- BW : 400 MHz, upto 16K channels
- Int Time : 0.67 sec
- IA/PA Beamformer
- **Upgrade to 32 stations by Nov 2016**

Towards a working uGMRT…

First result from new wideband signal path

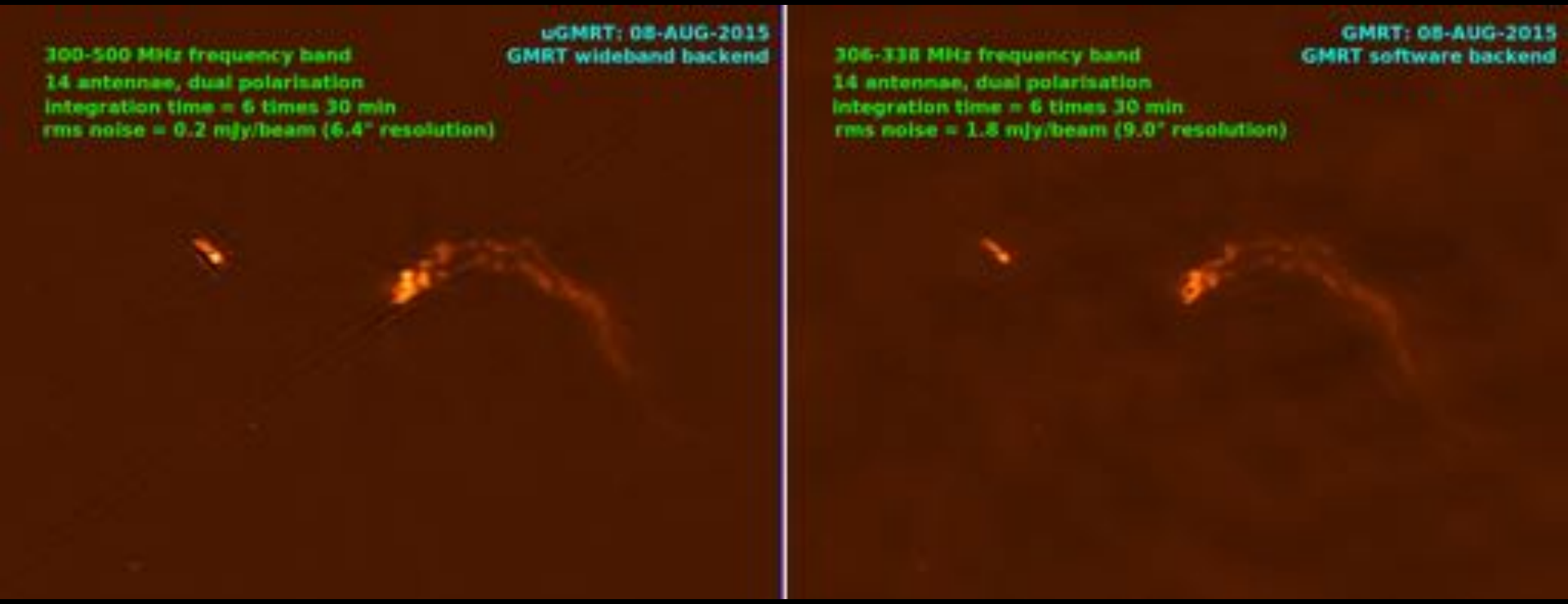
- First GMRT image using 100 MHz RF BW at L-band
- RMS noise : 3 mJy
- August 2012



First light results courtesy :
Dharam Vir Lal

Even More Recent Results with the Wideband uGMRT

3C129 imaged with the uGMRT system using 14 antennas, 200 MHz BW

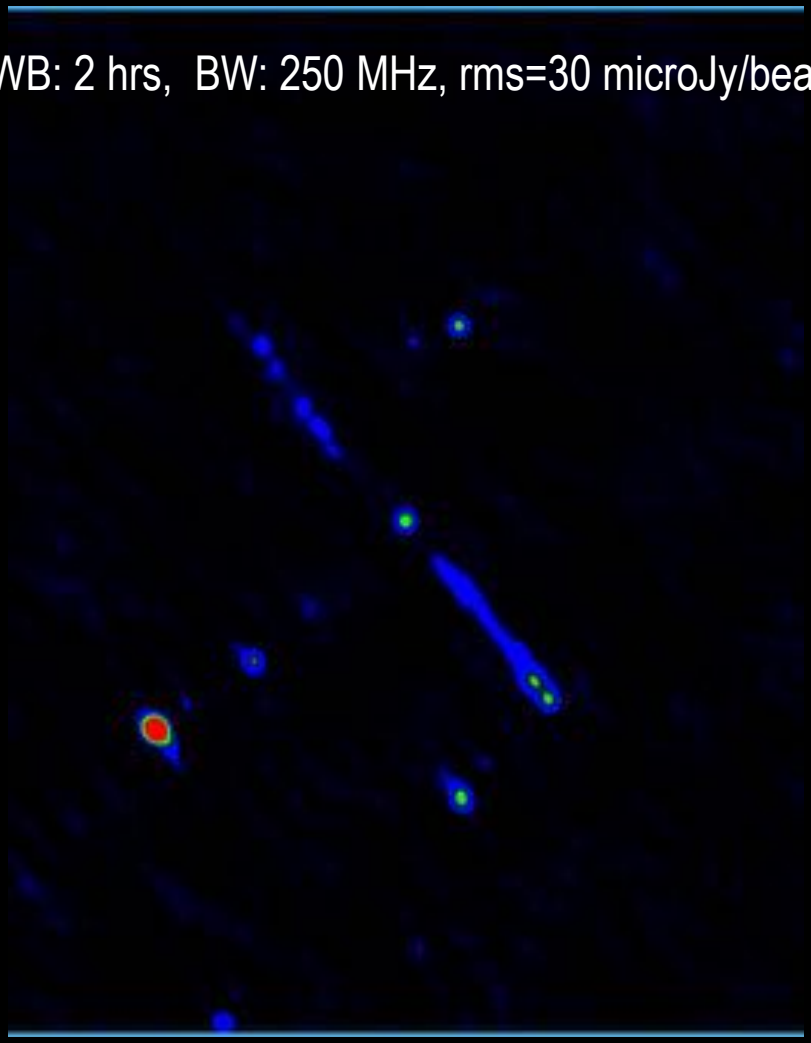


courtesy : Dharam Vir Lal + Binny Sebastian

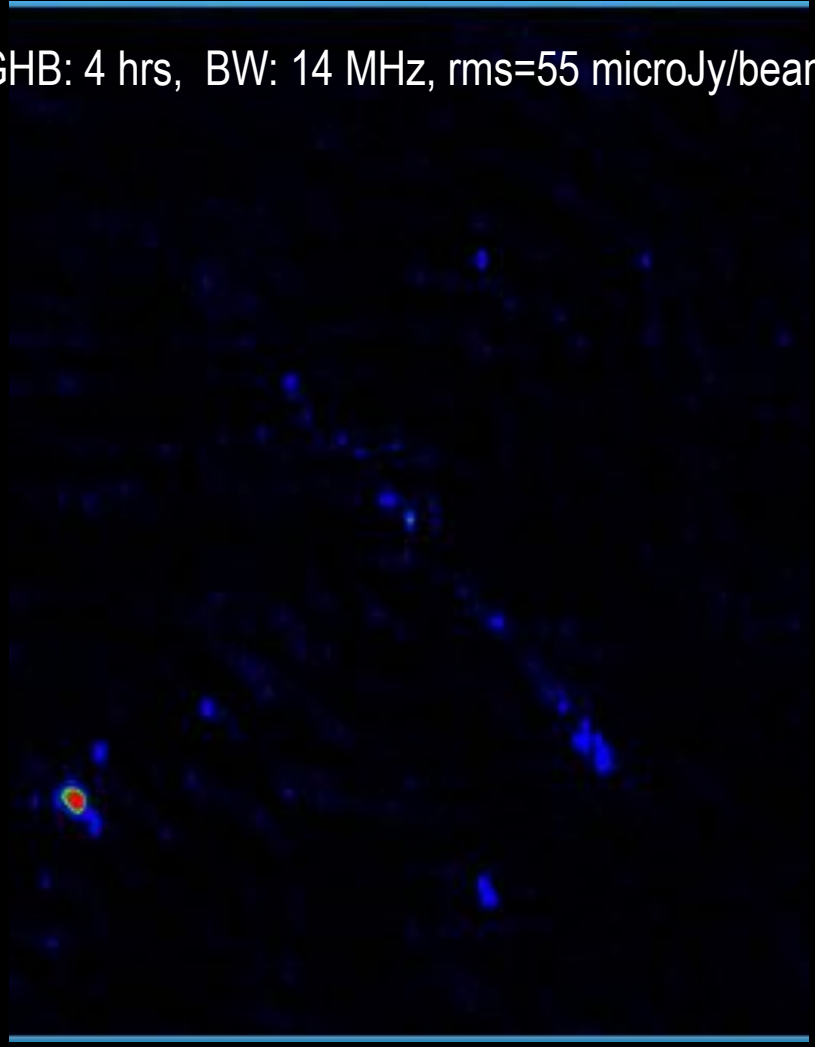
Even More Recent Results

Imaging with the 400 MHz bandwidth mode at Lband

GWB: 2 hrs, BW: 250 MHz, rms=30 microJy/beam



GHB: 4 hrs, BW: 14 MHz, rms=55 microJy/beam



courtesy : C.H. Ishwara-Chandra + Binny Sebastian

Wideband pulsar observations

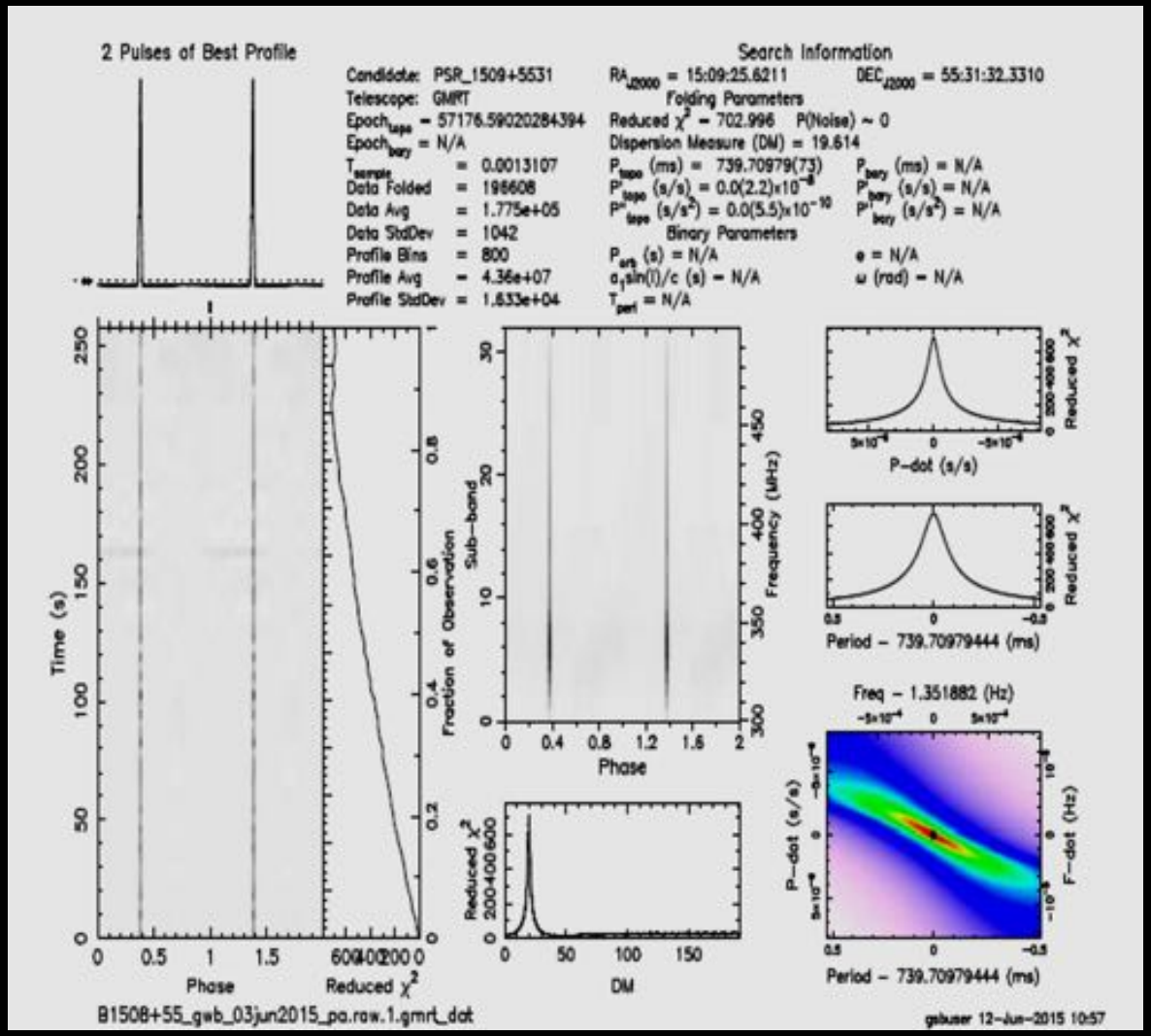
PSR B1508+55

300-500 MHz band

(200 MHz BW)

Using 8 antennas

Phased Array mode.



Wideband pulsar observations : improved sensitivity

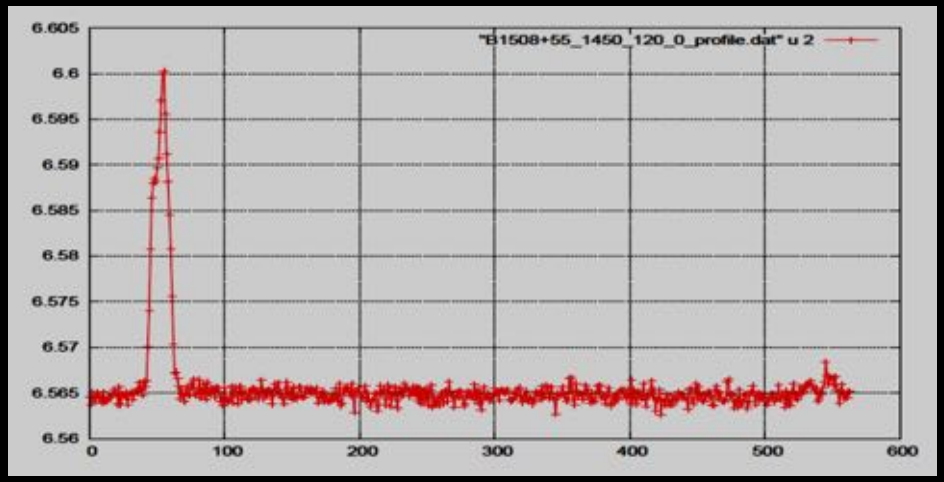
PSR B1508+55

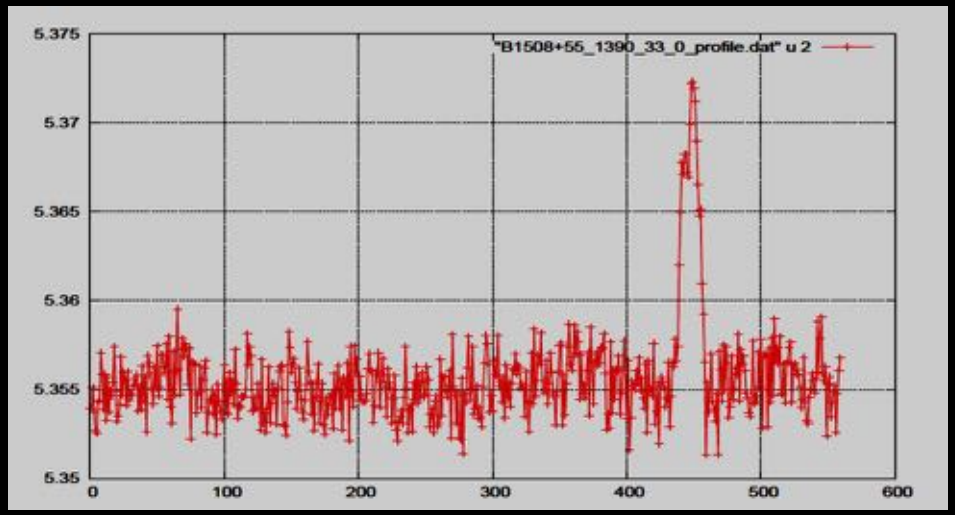
120 MHz at Lband (1330-1450)

vs

33 MHz at Lband (1390 sub-band)

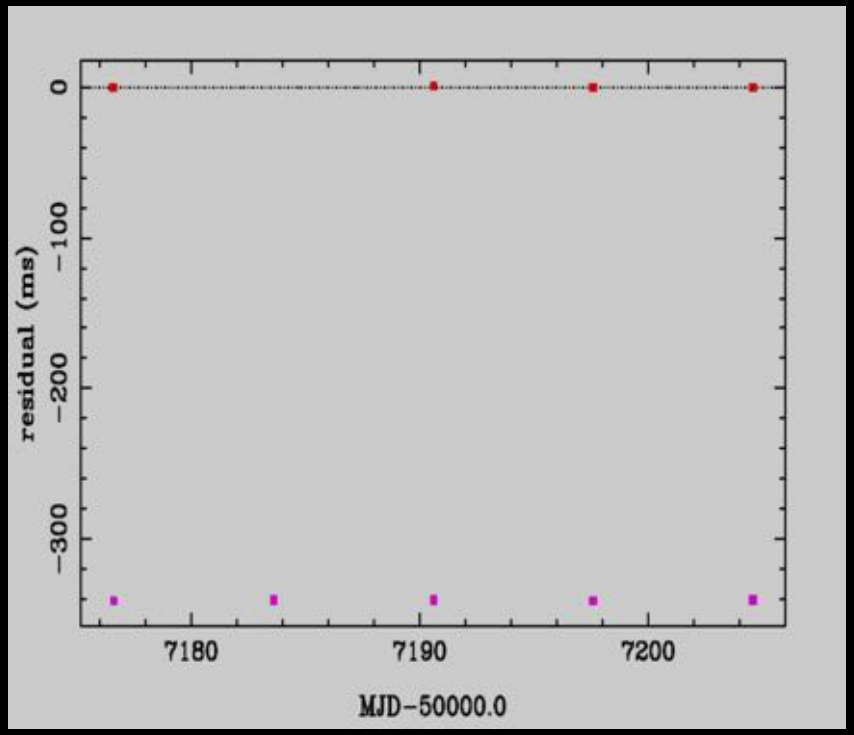
Simultaneous observations using same # of antennas in phased array mode.

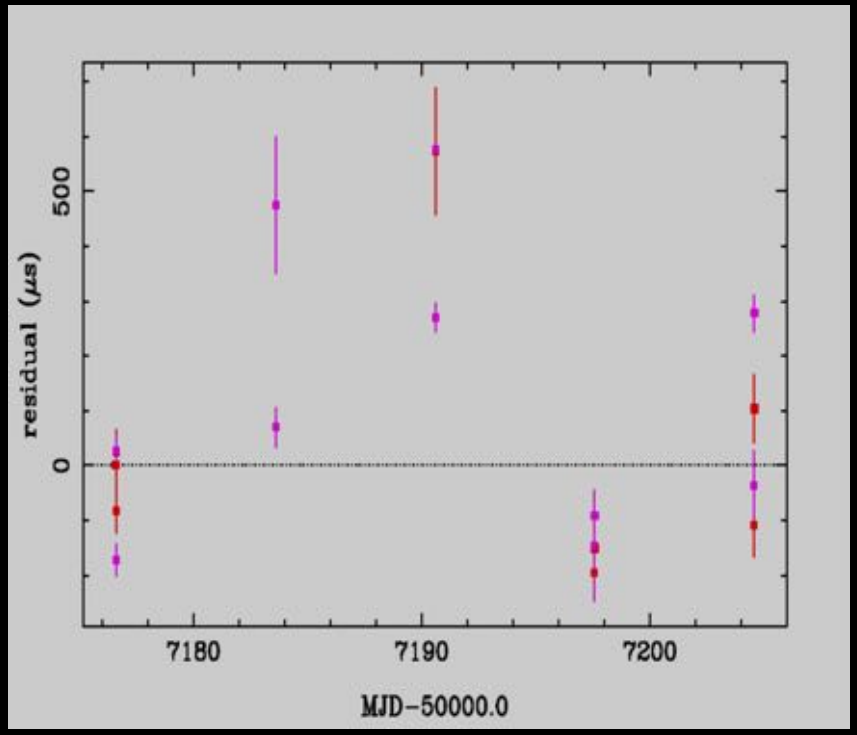




Pulsar timing results with uGMRT

Regular timing observations for a few well known pulsars
Simultaneous observations using GSB and GWB
Residuals align well for GSB & GWB, but have an offset between the two

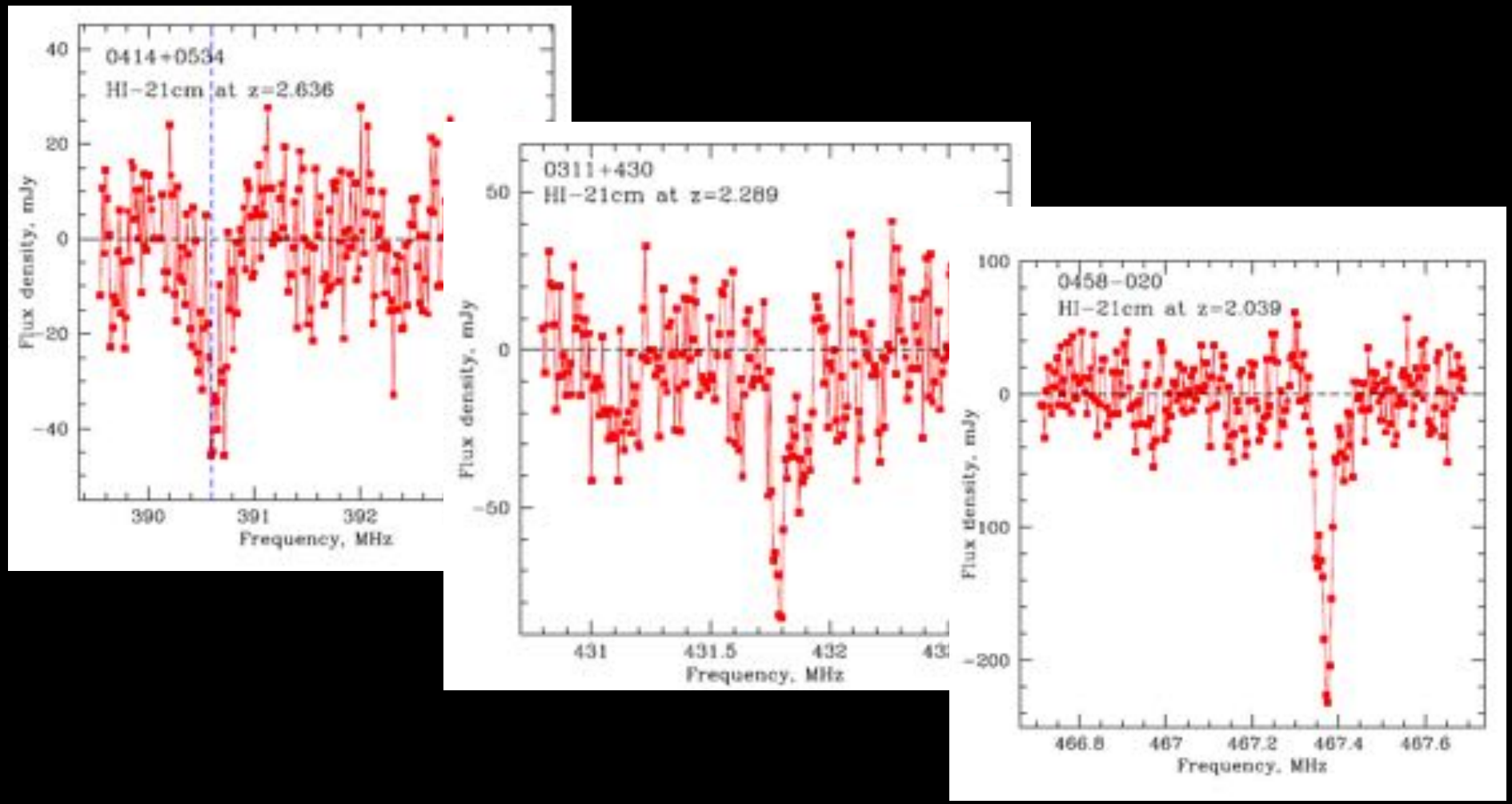




GSB (red) & GWB (purple) residuals for B1508+55, with & without offset

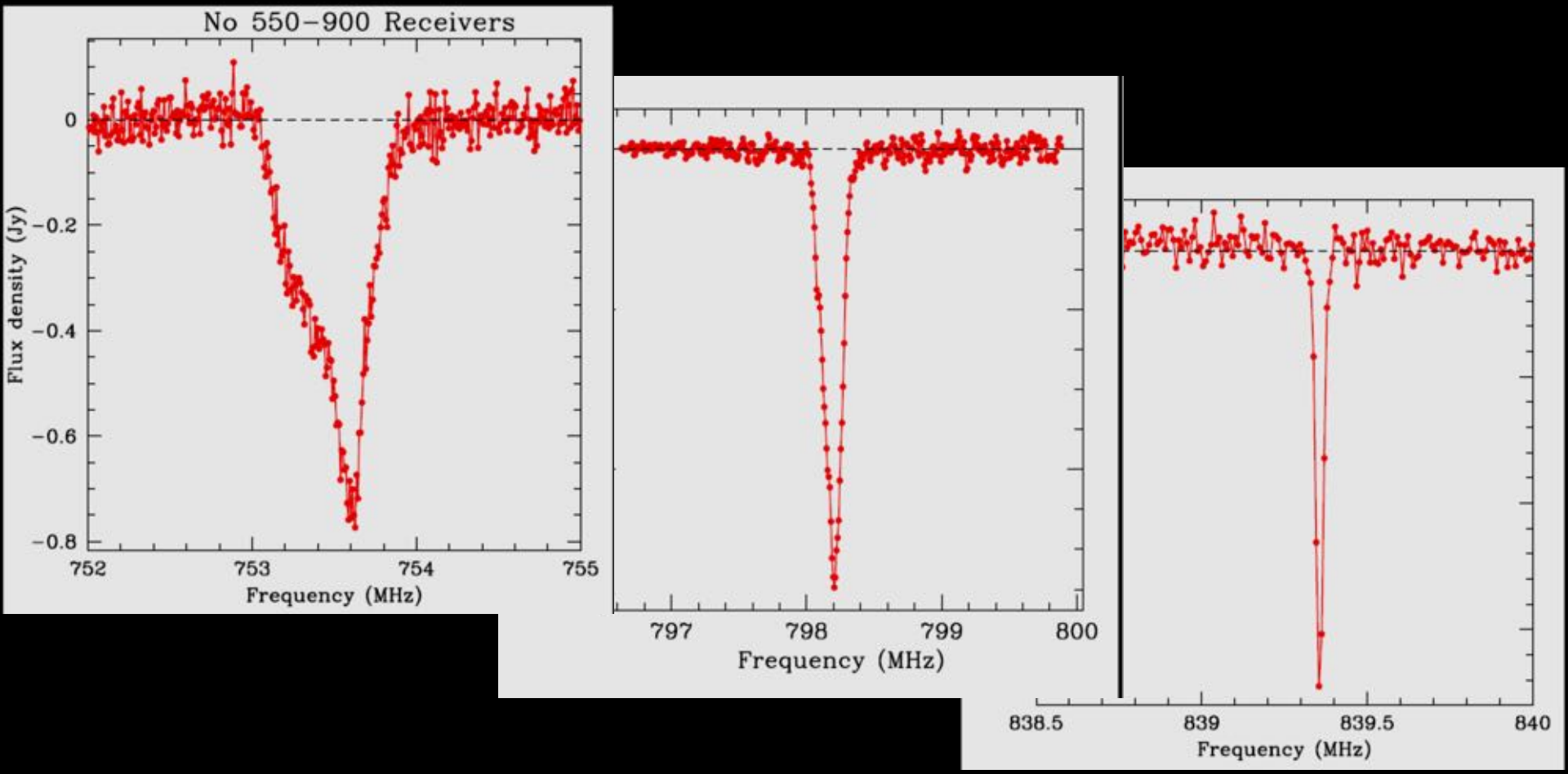
courtesy : Nikhil Naik & Y. Gupta

Upgraded GMRT : opening new windows – Band 3



First light results : spectral lines from different sources, at different parts of the 250-500 MHz band (Nissim Kanekar)

Upgraded GMRT : opening new windows – Band 4



First light results : spectral lines from different sources, at different parts of the 550-900 MHz band (Nissim Kanekar)

Challenges on the Road to uGMRT

The main challenges that we have encountered have been :

- Technological : design of the wideband receiver systems was a major challenge

- Operational : keeping the existing GMRT working for our regular users while upgrading simultaneously took some effort

- Taking care of man made Radio Frequency Interference (RFI) is and remains our biggest challenge !
  - Containing self generated RFI
  - Mitigating RFI from external sources :

    (i) broadband impulsive (ii) spectral line

RFI shielding of our electronics

- **RFI shielded monitor & control card unit**
- **Similar improvements for all new electronics at antenna base**

RFI friendly UPS at antenna base

- **New UPS having very low self-generated Radio Frequency Interference (RFI)**
- **Prototype unit tested successfully**
- **First lot of 10 nos have been delivered and under installation in antennas**

RFI mitigation efforts : ingredients

Ferrite Toroid

Finger clips for doors

Power line filter

Shielding fabric for connectors

Shielding fabric sheet

External Sources of RFI

Broadband RFI

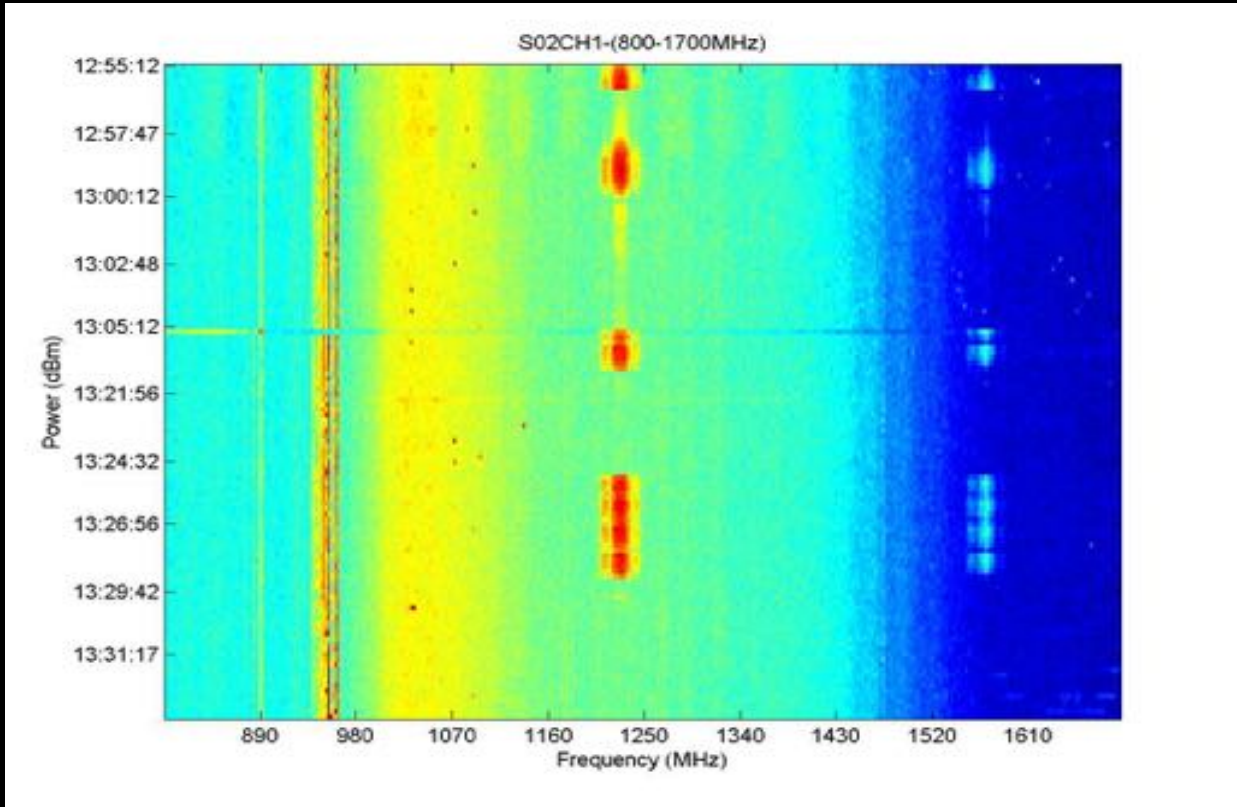
Sparking

Narrowband RFI

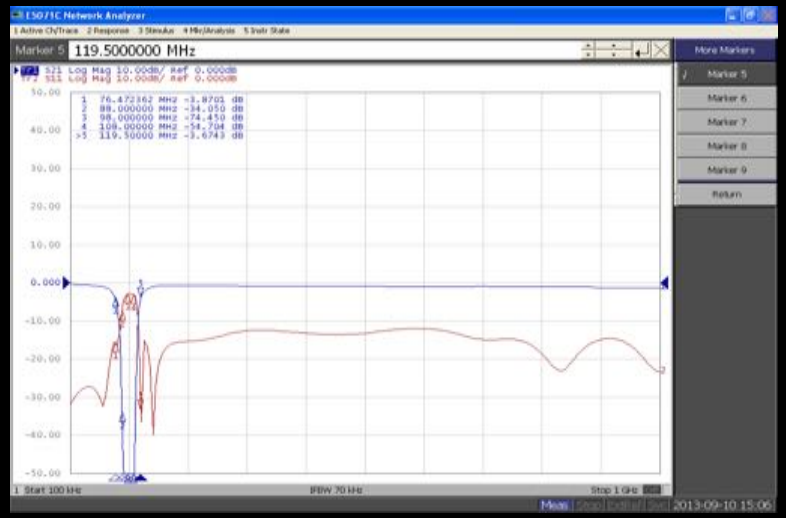
Image Courtesy: Wikipedia

Avoiding RFI from satellites

- Real-time prediction of positions of known satellites (stationary and moving) affecting GMRT
- Real-time warning when observing antenna beam comes within zone of avoidance (decided by beamwidth and strength of satellite)
- Predictive warning : can work on your submitted observing file
- Post-facto warning : can work on your lta file

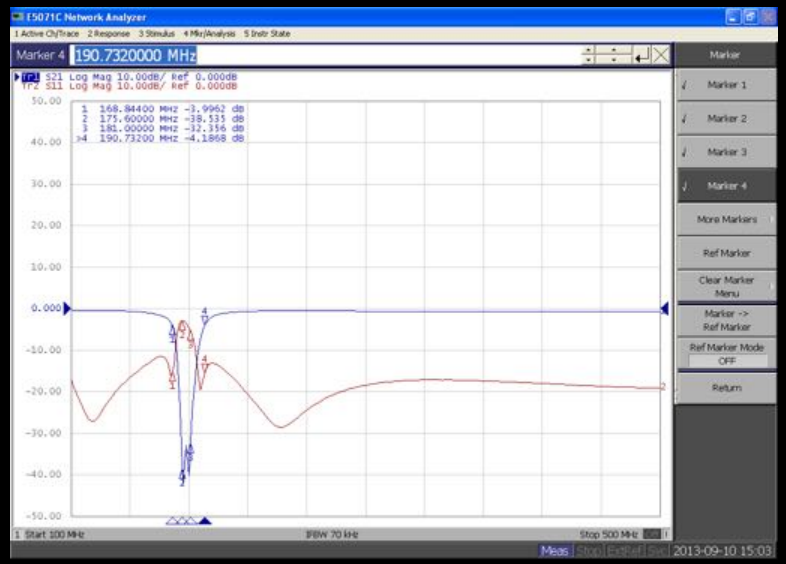


RFI mitigation : filters in analog chain



FM (88 – 108MHz) Notch Filter

Police Wireless Notch Filter (159 - 166MHz)

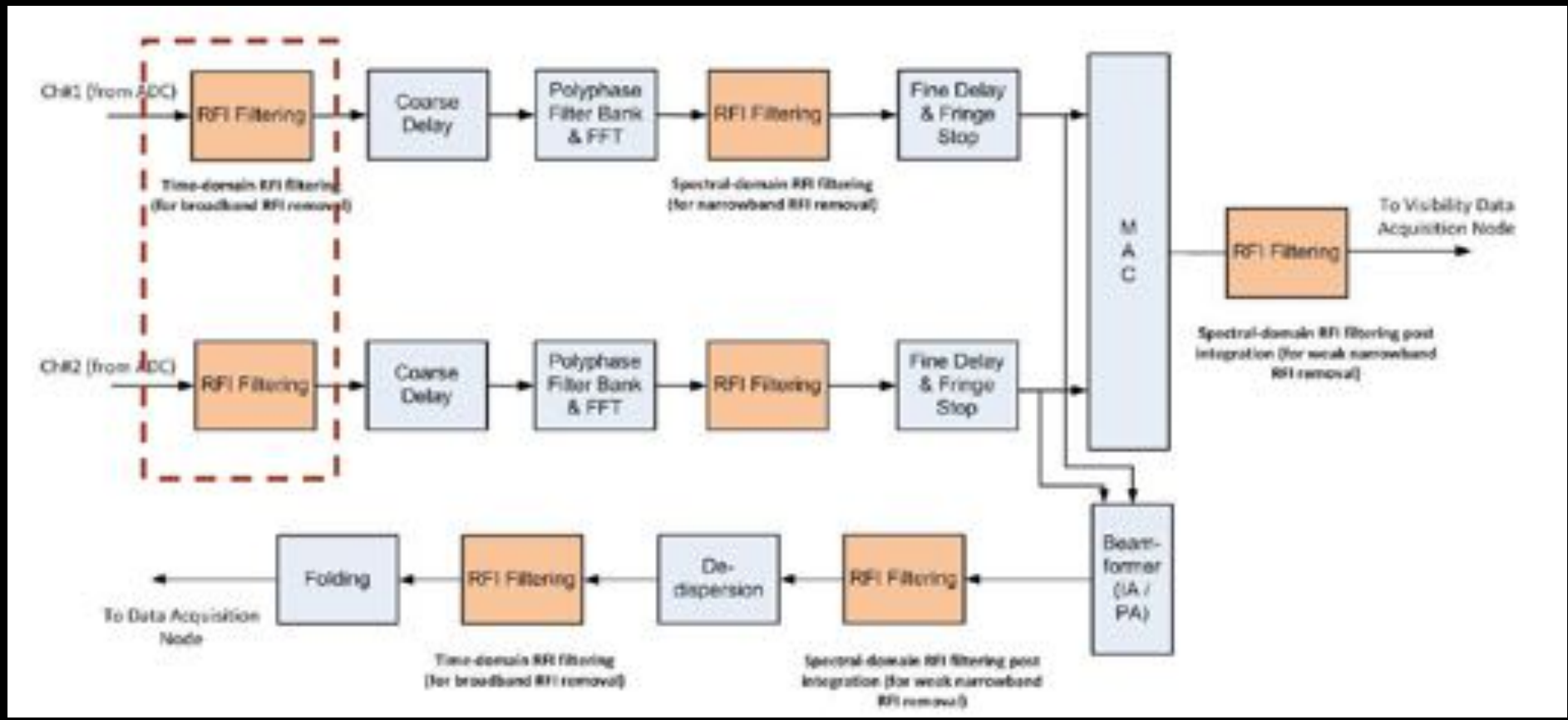


TV Notch Filter (175 -181MHz)

Satellite Notch Filter Filter (236-270MHz)

RFI Detection & Filtering in GWB

- Real-time filter running on broadband voltage data of each antenna
- Real-time spectral line filter running on spectra from each antenna
- Real-time filter running on time-frequency visibility data (planned)
- Real-time filter on time & frequency data of beamformer data stream.



RFI mitigation in digital domain

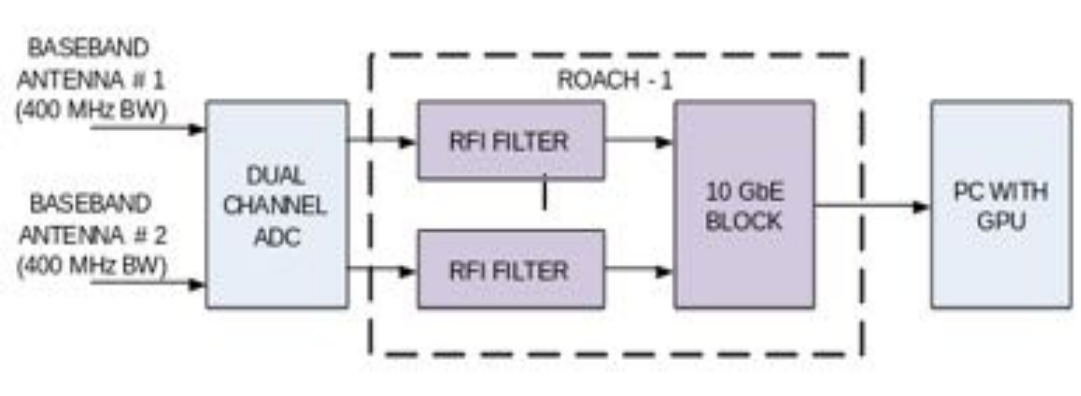
Median Absolute Deviation (MAD) based flagging of RFI

Detection followed by filtering and clipping the value at the threshold or replacement with random noise or median value

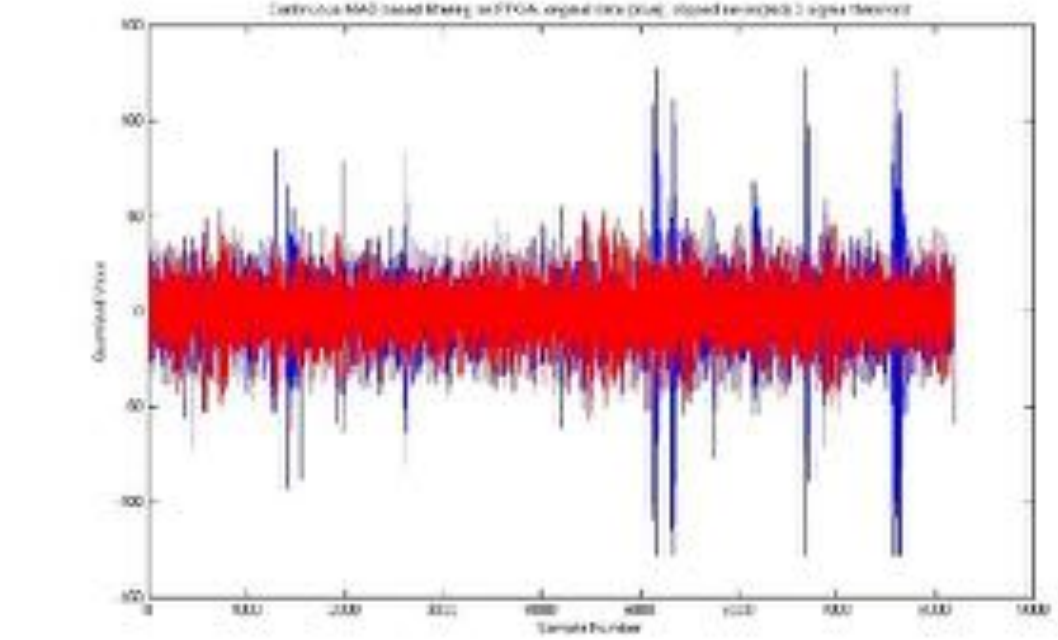
Can detect broadband random noise spikes (e.g. powerline RFI) in real-time on dedicated FPGA hardware

Is being integrated into the main correlator design; trial version will be released soon.

FPGA Implementation

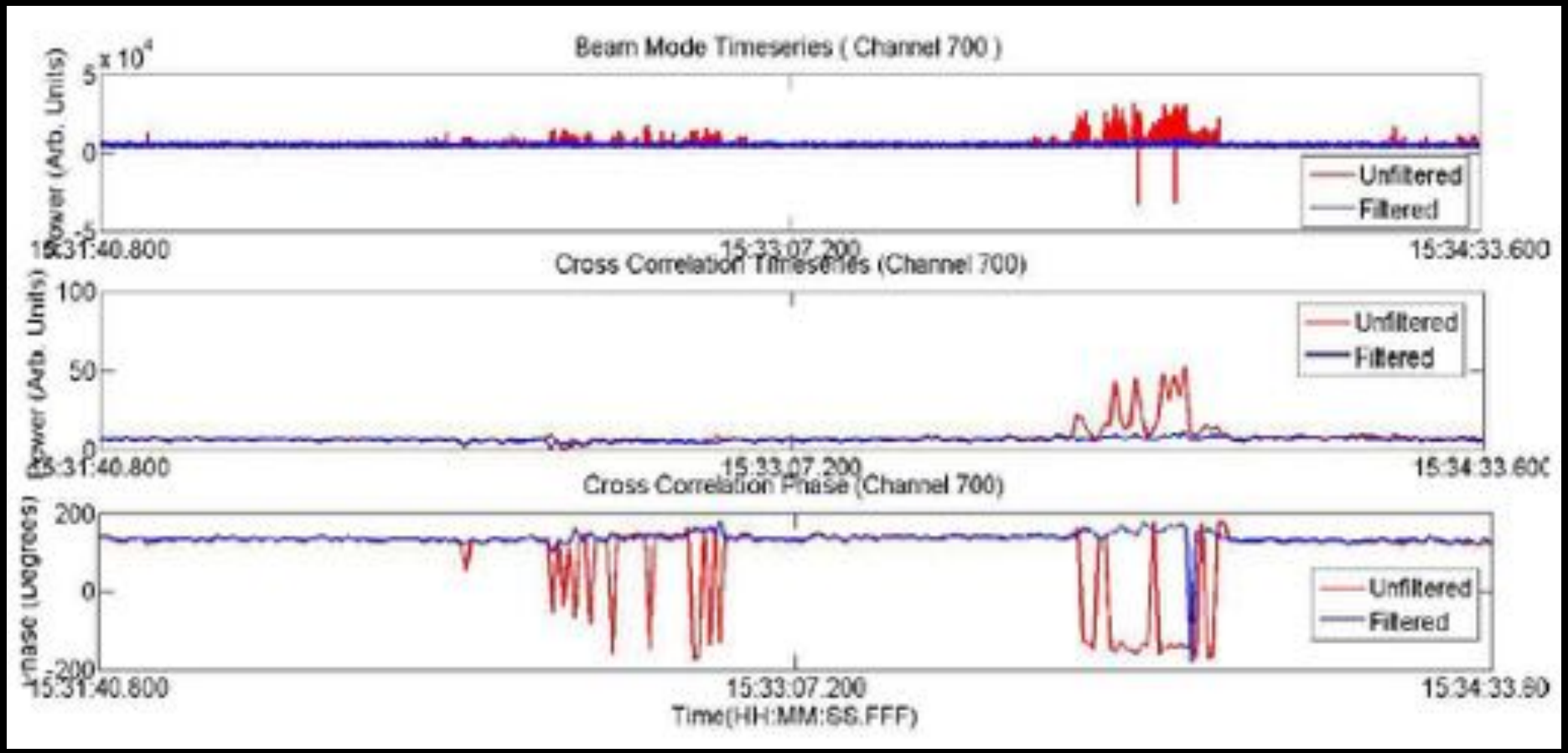


RF @ 150MHz (Blue) and 3σ clipped (Red)

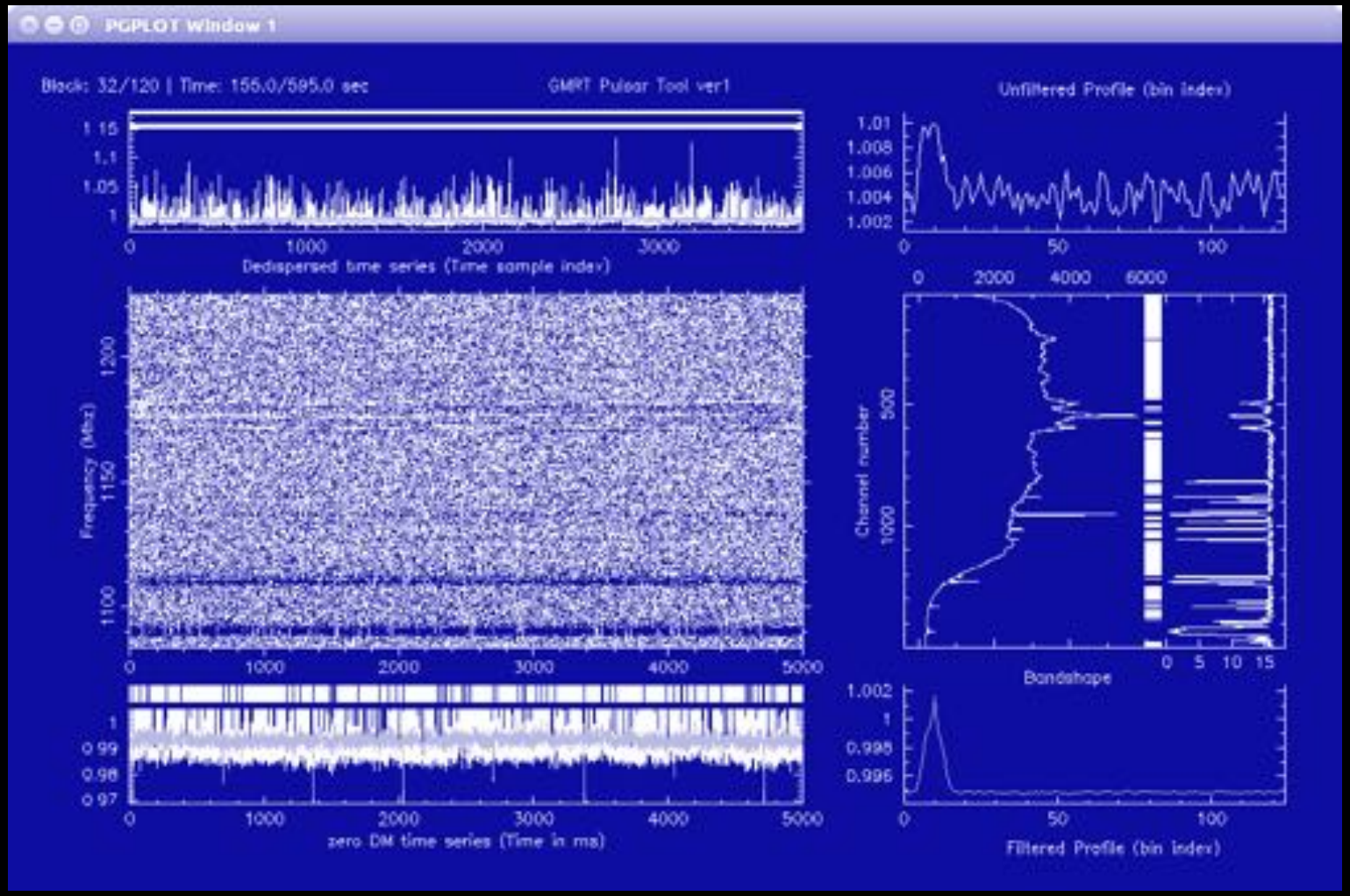


Real-time RFI Detection & Filtering

- Real-time filter running on broadband voltage data of each antenna
- Top panel shows effect of this filtering, in beamformer time series
- Bottom panels show effect of this filtering, in visibility domain data



Real-time RFI Detection & Filtering



Real-time filtering of time-frequency of beamformer data – now available

courtesy : A. Chowdhury

Release of uGMRT to Users

Releases in multiple phases :

1. First release of 8 antenna trial system – way back in September 2013 !

2. Release of 16 antenna system for internal users – September 2015.

3. Release of 16 antenna system for all users -- April 2016 .

4. Now happening : Release of a 30 antenna system with 2 bands fully functional : Band 5 (1000 to 1450 MHz) and Band 3 (250-500 MHz) -- October-November 2016 (GTAC Cycle 31)

5. In the future : Release of fully upgraded GMRT : 30 antenna configuration with all 4 bands fully functional -- September 2017.

That's all !

Thank You