RFI Mitigation Project at Italian Radio Telescopes

G. Serra and many other people from Italian National Institute for Astrophysics and other Institutes
Outline

- Introduction (Techno INAF-PRIN)
- RFI facilities at the Italian radio telescopes (IRTs)
- Project tasks for RFI monitoring: some examples of RFI at the IRTs
- Project tasks for RFI mitigation
  - WBLGB spectrometer
  - Off-line Dish Washer
- Tests of mitigation tools at the Sardinia Radio telescope
- Summary and ongoing developments
Intro: Techno INAF-PRIN

- Competitive tender notice for technological projects of relevant national interest (PRIN) published by INAF usually every two years
- Our project was financed in 2013 with 173 K€
- It was carried out in two years (2014-16)
Intro: Research units and people

IRA-Medicina staff

OA-Cagliari staff
S. Poppì (Local Coordinator)
G. Serra, F. Gaudiomonte
M. Buttu, C. Migoni

OA-Catania staff
C. Trigillio (Local Coordinator)
P. Leto, C. Buemi

IRA-Noto staff
G. Nicotra, R. Platania

Non-staff people
M. De Biaggi, F. Cantini, E. Favero (research grants with the project funds)

External collaborators
R. Prestage (NRAO), W. Baan (ASTRON), A. Jessner, A. Kraus, P. Muller and B. Winkel (MPIfR), G. Busonera (CRS4)
Intro: Research Units and tasks

- OA-Cagliari, IRA-Noto and – IRA-Medicina (RFI teams) → Characterization of the RFI situation at the three Italian radio-observatories
- IRA-Medicina, IRA-Bologna (backend team) → Development and implementation of the FPGA firmware for on-line mitigation (WBLGB spectrometer)
- IRA-Bologna, IRA-Medicina, OA-Cagliari (software team) → Development of an off-line mitigation tool (Dish Washer)
- OA-Cagliari, IRA-Medicina (RFI and backend teams) → Verification of the on-line mitigation algorithms
- INAF people and external collaborators → Verification of the mitigation tools and observational tests using telescopes
RFI facilities & ordinary activities at IRTS

64-m Sardinia Radio telescope
Mobile lab: 0.05 - 40 GHz

32-m Noto radio telescope
Fixed station: 0.1 - 3 GHz
Mobile lab: 0.05 - 40 GHz

32-m Medicina telescope & Northern Cross array
Fixed station: 0.3 - 12 GHz
Mobile lab: 0.3 - 40 GHz
Project tasks: RFI campaigns at IRTs

@ IRA- Medicina

Dedicated RFI meas. in the RA bands by fixed station and IRA mobile lab

@ IRA- Noto

2 RFI meas. campaigns in freq. range 0.05-40 GHz (in 2014 and 2016)
(by OA-Cagliari mobile lab)

@ SRT

1 RFI meas. campaign (in 2015)
freq range 0.05-40 GHz
(by OA-Cagliari mobile lab)
Example of RFI @ Medicina

Satellite signal in the Best2-Northern Cross band (400-416 MHz)

Primary RAS band
406.1-410 MHz

Freq @ 409 MHz
multiple transmissions every 5 KHz
BW = 50 KHz
Drift/doppler ~ +/- 9KHz
Tx duration 200 ms every 10-20 s
Example of RFI @ Medicina (@SRT as well)

Satellite signal in Best - NorthCross P-band (400 - 416 MHz)

Exclusive RAS band 406.1 - 410 MHz

Spurious Freq @ 409 MHz

Compatible with LEO Sat: OPTOS n.39420
CF = 402 MHz

G. Serra at al. RFI Mitigation Project at IRTs, Yebes Observatory (IGN, Spain), June 8-9
Example of RFI @ Noto

Low-C receiver band: two HiperLAN signals in a non-allocated band inside the RA band 4.95-5 GHz (Secondary Status)

- HiperLan @ 4970 MHz, BW = 16 MHz
- HiperLan @ 4980 MHz, BW = 16 MHz
Example of RFI @ Noto

Low-C receiver band: two HiperLAN signals in a non-allocated band inside the RA band 4.95-5 GHz (Secondary Status)

HiperLan @ 4970 MHz, BW = 16 MHz

HiperLan @ 4980 MHz, BW = 16 MHz
Example of RFI @ Noto

Low-C receiver band: two HiperLAN signals in a non-allocated band inside the RA band 4.95-5 GHz (Secondary Status)

Both transmissions were switched off after reporting them to local authorities!
Examples of RFI @ SRT

Low-C receiver (Under construction) band, no RFI in the SS RAS Bands but…
## RFI occupancy* at Italian RTs
(in current receiver bands)

<table>
<thead>
<tr>
<th>Receiver (focus)</th>
<th>Freq. Band [GHz]</th>
<th>Occupancy [%]</th>
<th>RFI notes</th>
<th>Frequency Band [GHz]</th>
<th>Occupancy [%]</th>
<th>RFI notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>P BEST – N. Cross (primary)</td>
<td>.400-.416</td>
<td>35</td>
<td>Radio Links, Radiosondes power lines</td>
<td>Coaxial P-L (primary)</td>
<td>.305-.410</td>
<td>52 Aeronautical digital links, self-RFI,</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>power lines</td>
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<tr>
<td>low-L (primary)</td>
<td>1.35-1.45</td>
<td>15</td>
<td>Radar</td>
<td>Coaxial P-L (primary)</td>
<td>1.3-1.8</td>
<td>57 Radar, satellite, cell phone, self-RFI</td>
</tr>
<tr>
<td>high-L (primary)</td>
<td>1.595-1.715</td>
<td>35</td>
<td>Satellite</td>
<td></td>
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<td></td>
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<tr>
<td>low-C (secondary)</td>
<td>4.3-5.8</td>
<td>45</td>
<td>HiperLAN Radio links</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>high-C (secondary)</td>
<td>5.9-7.1</td>
<td>25</td>
<td>Radio links</td>
<td></td>
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<td></td>
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<tr>
<td>Coaxial S/X (primary)</td>
<td>2.20-2.36</td>
<td>45</td>
<td>Radio links</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2-beam-K (secondary)</td>
<td>18.0-26.5</td>
<td>5</td>
<td>Radio links</td>
<td></td>
<td></td>
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<tr>
<td>Coaxial P-L (primary)</td>
<td>18 – 26.5</td>
<td>7</td>
<td>Cell phone network digital links</td>
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<td></td>
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<tr>
<td>Coaxial P-L (primary)</td>
<td>8.2-8.6</td>
<td>3</td>
<td>Digital links</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Coaxial P-L (primary)</td>
<td>31.85 - 32.35</td>
<td>2</td>
<td>Surveillance radar</td>
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<td></td>
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<tr>
<td>low-C (secondary)</td>
<td>2.189-2.371</td>
<td>11</td>
<td>Digital links</td>
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<td></td>
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<tr>
<td>Coaxial S/X (primary)</td>
<td>8.138-8.922</td>
<td>0</td>
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<td>high-C (secondary)</td>
<td>21.18-22.46</td>
<td>0</td>
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<td></td>
<td></td>
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<tr>
<td>Q (secondary)</td>
<td>39.0-43.5</td>
<td>0</td>
<td>Only up to 40 GHz</td>
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</tbody>
</table>

* with respect to the whole bandwidth of each receiver
Project tasks: spectrometer for RFI mitigation

Wide Band Lowpass Giga Bit spectrometer

Roach Board 1
http://casper.berkely.edu/wiki/ROACH/

implementation by Casper MSSGE

Spectrometer overview

Courtesy of A. Mattana
Project tasks: spectrometer for RFI mitigation

Wide Band Lowpass Giga Bit spectrometer

Roach Board 1
http://casper.berkely.edu/wiki/ROACH/

Hardware features:
- 8 bit, 1Gbps iADC
- External clock synchronization
- BW = 800 MHz
- integration time = 1ms (minimum for fast RFI detection)
- Data output rate = 1.25 Gbps

Firmware overview:
- Realtime data time stamping
- Freq channels = 4096 (maximum via PFB and DFT)
- Configurable digital gain and DFT shift (robust to RFI signals)
- overflow monitoring
- every stage inspectable via ram blocks
Project tasks: software for RFI mitigation

Off-line Dish Washer (DW)
**Project tasks: software for RFI mitigation**

**Off-line Dish Washer (DW)**

**Software features**

- Automatic RFI detection algorithm (basic version)
- Multi-feed, polarimetry data (R,L, Q, U) and spectral sections
- Support parallelization for multi-core/thread processors
- Input file format: metadata, FITS
- Output file: a FITS table added to the input FITS file
Mitigation tools: preliminary tests @ SRT

Set-up and adjustment

- WBLGB spectrometer firmware was installed on a SRT backend (ROACH 1) (DW not yet installed @ IRTs but tested off-line with Medicina and SRT dataset)
- Interfacing with the Antenna Control Software (Nuraghe) to get pointing coordinates, source name, UT and receiver setup
- the SRT IF baseband output was connected by a power splitter to:
  - the WBLGB spectrometer
  - spectrum analyzer with for the spectrometer digital gain adjustment (repeated for each SRT receiver band (L-P, C- and K-band)
Mitigation tools: preliminary tests @ SRT

Strong known RFI (digital link) in the C-receiver band (5.7-7.7 GHz)
Mitigation tools: preliminary tests @ SRT

Strong known RFI (radar) in the L-receiver band (1.3-1.8 GHz):

- Int time = 5 ms, temporal span = 10 s
- freq span = 1250-1370 MHz
Mitigation tools: preliminary tests @ SRT

Strong known RFI (radar) in the L-receiver band (1.3-1.8 GHz): 

\[
\text{Int time} = 5 \text{ ms}, \quad \text{temporal span} = 0.5 \text{ s} \quad \text{freq span} = 1260-1340 \text{ MHz}
\]
Mitigation tools: preliminary tests @ SRT

W3OH (astronomical calibrator) and strong RFI in the C-receiver band
In two years (2014-2016) the project has allowed to:

- create a network of people from different observatories/facilities of the INAF and external partners to face together the RFI issue affecting the RA observations
- support the local RFI groups in increasing the RFI monitoring at the national telescopes (RFI environment is constantly evolving)
- develop HW/SW tools in common at IRT for a national RFI mitigation
  - WBLGB spectrometer by using the local know/How in using ROACH-FPGA technologies and Casper development environment
  - Dish Washer based on a python free software providing:
    - an user-friendly GUI
    - Manual RFI flagging
    - Automatic RFI flagging (at moment a basic sigma-clipping has implemented)
    - In general, a software platform where sophisticated automatic methods for RFI mitigation can be implemented
Ongoing developments

Since the end of project (July 2016) the same network of people have been still working on:

- Finish DW debugging and test with various types of data (spectropolarimeters, telescopes, also involving the international collaborators) → almost completed
- Public release: it requires improving/testing some graphical functionalities and updating the documentation → almost completed
- Implement more sophisticated RFI detection algorithms → to be done (collaboration with other people involved in RA community would be very welcome)
- Implement support for different input data formats → Start/continue collaboration with other facilities (GBT tests encouraging!)
Thanks for your attention. Questions?

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