Interference Mitigation Strategies for Radio Astronomy: RFI research areas for SKA (1)

ASTRON, Foundation for Research in Astronomy, The Netherlands

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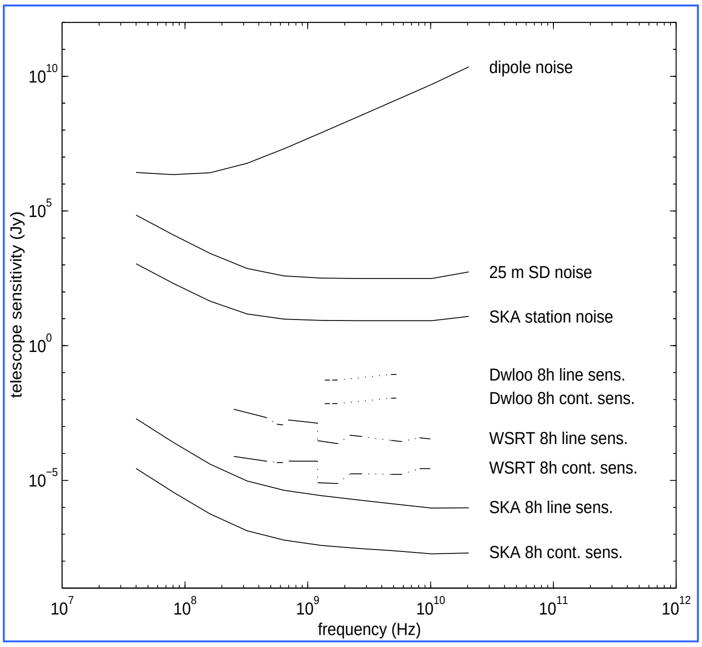
1. Introduction

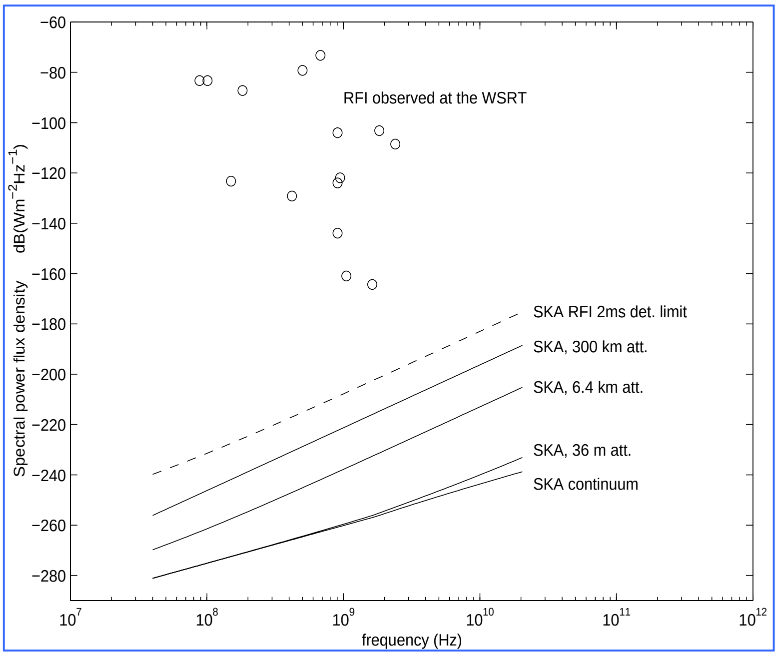
The next generation radio telescope, the Square Kilometer Array (SKA), is intended to be at least two orders of magnitude more sensitive than the current generation of telescopes. The increased sensitivity and the increase in required bandwidth make such a telescope more vulnerable to radio interference. Therefore, receiver systems need to be developed which remain linear in the presence of strong interference. Also, techniques have to be developed for mitigation of in-band radio interference.

2. Sensitivity of three generations of radio telescopes

The figure to the right shows the sensitivity of SKA for an 8 hour integration period of a single polarisation observation, both for continuum and spectral line observations (spectral resolution of 10^4) In the same figure, the sensitivity of the WSRT telescope array is also given. The WSRT consists of fourteen 25 m dishes, which together form an interferometer array. The sensitvity values for SKA are calculated using the “strawman” design specs. For comparison, also the "8 h " noise level of a SKA station, a 25 m sigle dish and of a single dipole are given.



3. RFI levels



The figure tot the left shows the maximum allowable RFI spectral power flux density for SKA for continuum observations (lower curve). The strongest interferers which were observed at the WSRT telescope site are plotted as little circles. The bandwidth used are the typical ‘channel bandwidth’ numbers. These interferers are a.o.: TV transmitters, FM transmitters, GSM downlinks, beacons, Iridium satellite signals, and air mobile communication. For interferometer telescopes, the maximum allowable interference levels are (apart from RFI mitigation techniques) a bit higher due to fringe frequency attenuation. This is caused by fringe frequency rotation which averages out the RFI signals. Estimations show that this averaging out may reduce the RFI by one or two orders of magnitude, depending on the telescope configuration and observing frequency (three curves with different baseline lengths ar plotted). Finally, the figure shows the 2ms RFI detection limit.

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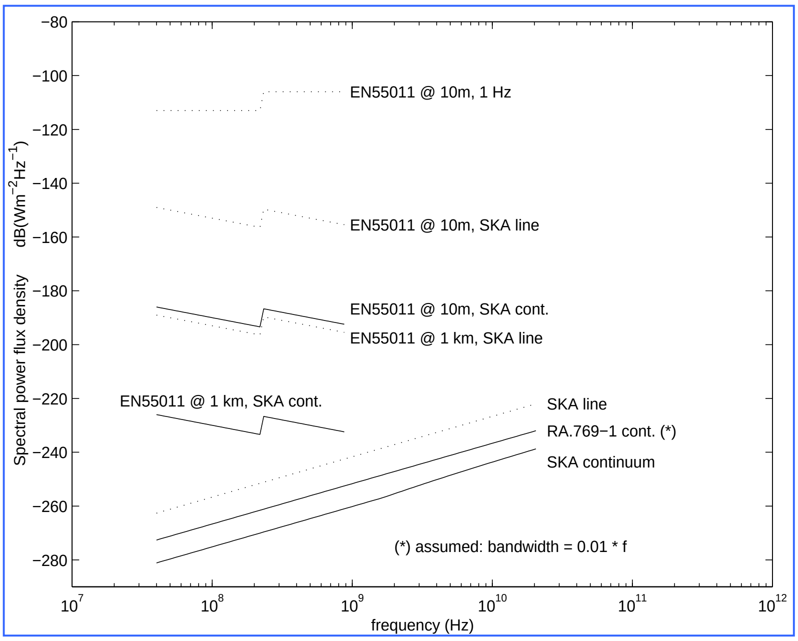
4. RFI threshold criteria

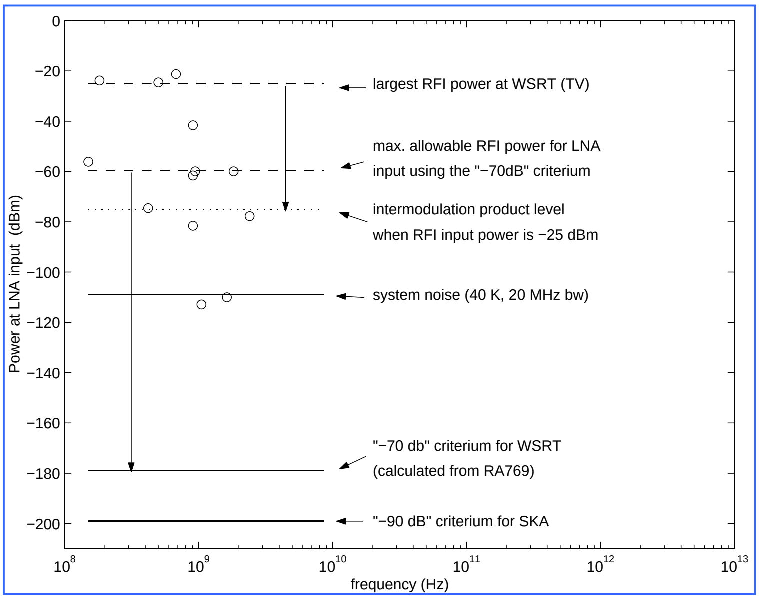
In the ITU document RA-769 the protection criteria for radio astronomy are described. The assumptiones are that in a 2000 s time interval, an interferer should not contibute more than 10% of the telescope system noise power level. It is further assumed that the sidelobe level is isotropic with an effective area of $c^2/(4\pi f^2)$ where c is the speed of light and f is the frequency. The bandwiths and system noise levels were taken from typical current radio telescope systems. The formula below is used to determine the harmful interference level S_H.

$$S_H = \frac{0.4\,\pi\,k\,T_{sys}\,f^2}{c^2\sqrt{\Delta t\,\Delta f}} \qquad (Wm^{-2}Hz^{-1})$$

In the figure to the right, the RA769 curve is plotted (a smothed version) assuming a bandwidth of 0.01 f. This criterium is a recommendation and it holds only for those bands in which radio astronomy has "allocations". Electronic equipment radiating isotropically with emission powers according to the maximum of the EN55011 norm, is plotted on the figure as well, for several distances to the SKA telescope (stations).



5. Influence of RFI power on LNA linearity



When RFI power reaches very high values it may drive the system in an alinear region Practical experience at the WSRT site with the new MFFE series receivers showed that the third order intermodulation products generated in the LNA's remain at an acceptably low level when these are attenuated to about -60 dBm input power (LNA input). The intermodulation products then are at a level comparable to the RA769 norm. When the RFI reaches -25 dBm, as is the case at the WSRT for a few TV transmitters then the intermodulation products lie about 100 dB above the norm, see the figure tot the left. This was solved by applying additional filtering between the antenna and the LNA (LNIR project). This was done at a cost however. Conventional filters attenuate the signals a few tenths of a dB, thus increasing the system noise with 10 to 30 K. For SKA this issue is an important one as SKA will have large bandwidths. Conventional filters may not be sufficient in all cases. HTSC filters may be an option. This is an area in which research is needed.

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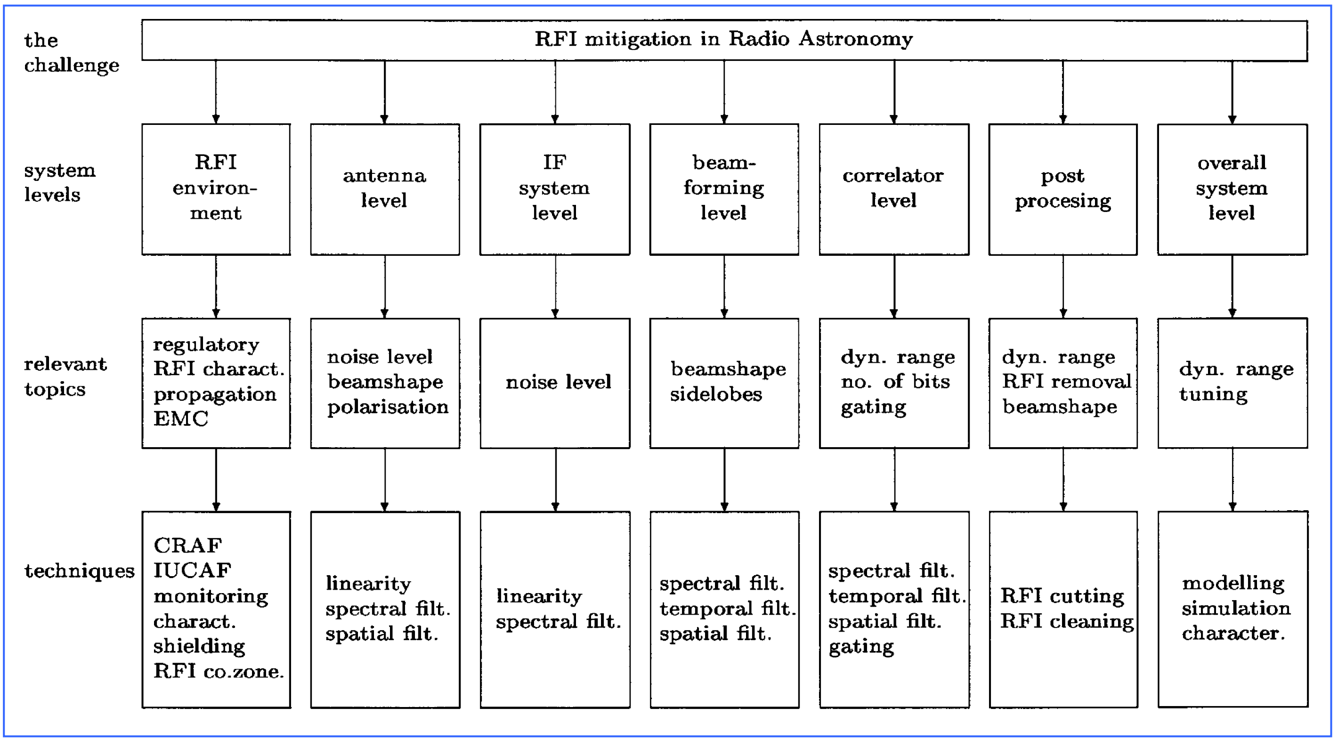
6. RFI mitigation: a generic approach



The RFI in many cases needs to be suppressed by many orders of magnitude. The RFI suppression mechanisms must be cascaded in order to reach te required values. At each level of the system the influence of RFI has to be taken into account. Therefore an overview is presented in figure above of levels which are relevant for RFI mitigation. The second row of the figure is the breakdown into levels in which the RFI issues and problems are more or les of the same type. In the third row the system properties which may be affected by RFI are listed. The fourth row contains some of the techniques which can be applied to tackle the RFI challenge.

7. Objectives of the ASTRON RFI mitigation programme

1. Investigate new RFI-robust receiver concepts
2. Investigate and apply digital (array) RFI mitigation techniques
3. Investigate post processing techniques for interference mitigation
4. Increase the ASTRON RFI monitoring capabilities
5. Characterize interference properties
6. Investigate and implement miniature HTSC filters for interference and intermoduluation suppression

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8. ASTRON projects and activities related to RFI mitigation

ASTRON initiated several projects for SKA (pre) studies. For instance the THEA project in which (a.o.) beam forming is studied. ASTRON projects which have a primary goal of RFI mitigation are listed below.

NOEMI project

TUDelft, ASTRON (STW project)

Goal:

- Interference rejection in multi-element receiving systems using array processing alogithms

Objectives:

- Characterization, throug recording and analysis, of sources of RFI, received by the WSRT
- Selection of appropriate signal detection and rejection algorithms, based on high-resolution subspace techniques
- Engineering of the slected algorithms into a system to be used for RFI mitigation at the WSRT

Robust receiver project

ASTRON, NRAL, MPIfR, JIVE, IRAM (EU project)

Goal:

- Investigation of RFI-robust receiver concepts

Objectives:

- Installation of monitoring equipment
- Monitoring an data storage
- Design a RFI robust receiver and or its components
- Investigation of rfi suppression techniques, applicable to the first stages of the receiver
- Demonstration of these techniques in a radio astronomical receiver at the WSRT

LNIR

ASTRON (finished project)

Goal:

- RFI-suppression of TV transmitters at the WSRT

Objectives:

- Design and construction of low loss lumped element filters for application in front of the LNA's in the WSRT-MFFE-UHF bands
- Suppression of strong TV signals at the WSRT in order to prevent the LNA's from generating intermodulation products
- Investigation of the limits in high dynamic range receivers using conventional filter techniques

WSRT RFI mitigator

ASTRON

Goal:

- Studying and testing new digital RFI mitigation techniques in order to increase the observational capability of the WSRT

Objectives:

- Investigate the effects of modern DSP based signal processor algorithms for RFI rejection
- Focus is on single and dual channel processing, like for example adaptive noise cancelling

Miniaturized, high Tc super-conducting, filtering techniques

(project proposal is being written)

Goal:

- Developing low-loss HTSC filters for the purpose of blocking of high power RFI.

Objectives:

- Development of low loss HTSC filters for 70-80 K operation
- Research on filter topologies, investigate tunability, miniaturisation and packaging
- Demonstrate operation of UHF and L-band filters in a radio astronomy receiver (WSRT MFFE).
- Investigate application of miniature cryocoolers.

9. Conclusions

- In order to obtain the desired sensitivity for SKA, wide RFI-free bands (before or after RFI mitigation) are necessary.
- Without RFI mitigation techniques, SKA cannot achieve the desired sensistivity.
- The challenge in the analog domain is: linearity.
- The challenge in the digital domain is: computational speed, scaling, optimal hierarchical design.
- There is not a single method to obtain the required RFI attenuation levels: methods must be stacked.
- Protection of RFI "free" bands and coordination zones remain necessary.

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