MWA Receiver Self Interference

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April 2010

1 Introduction

The following question by Bob has been considered by comparing possible RFI levels to that of a 1 mK far-field signal entering through the primary beam.

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Date:   22 Mar 2010
From:    Bob Goeke
Re:      The ASKAP spec for RFI

"My immediate question is: are these numbers (the RALI thresholds) sensible for MWA?
If so, we are going to need to do a heck of a lot better job shielding the receiver
electronics than currently contemplated. (We will meet the ASKAP specs with a little
extra shielding plus our relatively large separation from them.) Or is the sky
background such that, in our frequency range, these limits are not reasonable?"
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The following sections of bullet points were formulated under the assumption that the signals emitted by one receiver are uncorrelated with the signals emitted by another. Alan Rogers and Eric Kratzenberg have indicated that the main source of receiver RFI will be spectral lines from clocks, oscillators, and various intermodulation products. Narrowband signals from different receivers will be correlated, albeit with random phases, and we might expect the power levels at each MWA tile to be greater by a factor of about $\sqrt{64}$, or $\sim$10 dB.

It will be assumed in the following calculations that the receiver shielding is good enough so that signals, be they narrow tones or broadband noise, are below the RALI threshold at a given distance. However it should be kept in mind that the RFI will typically be narrow birdies that should in general be blanked. It should also be noted that effort has gone into eliminating narrowband RFI from digital equipment and keeping the system linear to avoid intermodulation products.

While this document does not consider the required level of shielding, and just assumes that it meets the MRO standard, it is important that this is understood. Alan Rogers has suggested that the receivers will need extremely well shielded boxes with more than 100 dB isolation, which means "double filtering of the AC lines to prevent signals leaking out and radiating from the AC lines", and "very tight covers with closely placed screws etc." The reader is referred to Deuterium Array memos 8, 35 and 36.

2 Receiver RFI is below the RALI Threshold at MWA

If RFI from the receivers reaches MWA tiles at the RALI MS 32 threshold, will this be good enough? The following considerations suggest that it will.

- At MWA frequencies the RALI threshold is -214 dBm.Hz^{-1} $= 4 \times 10^{-25}$ W.Hz^{-1}.
- Our noise floor of interest is $O(1)$ mK $\Rightarrow kT \approx 1.38 \times 10^{-26}$ W.Hz^{-1} $= -229$ dBm.Hz^{-1}.
- Assuming that receiver RFI will enter through sidelobes, at levels below -15 dB relative to the primary beams, the RALI threshold should be adequate for EoR observations. Models suggest that the gain for elevations below 5° will be below -30 dB relative to beam centre.
- We can expect further reduction due to the response of the interferometer (the synthesised beam) and smearing with the rotation of the Earth.

3 Receiver RFI is below the RALI Threshold at ASKAP

Suppose, however, that receiver shielding only reduces the RFI to the RALI threshold at the distance of the nearest neighbouring instrument, say 3 km. If we assume that path-loss is proportional to distance squared, then at a distance of 1 m the receiver RFI could be as much as -144 dBm.Hz^{-1} and still satisfy the MRO standard. So is there enough local protection to make up the lost 70 dB of attenuation?

There are a number of issues:

- There are 64 receivers emitting independent noise.
- There is still path-loss for distances of up to a few kilometres.
- Many baselines will have at least one antenna that is far from each receiver.
- Since the RFI is emitted from inside the array there is nowhere on the sky for which the RFI adds coherently.
- These random delays will change as the array tracks a field, which will reduce the average RFI level.
- The receivers will be at elevations of no more than a few degrees, in a deep antenna null.

A straightforward way to get a handle on the situation is to simulate it.

- It is assumed that the RFI is emitted isotropically, and in isolation a detector at 1 m in any direction would read -144 dBm.Hz^{-1}.
- Our goal is to reach -229 dBm.Hz^{-1}, or 85 dB of attenuation.
- The array configuration was taken from MAPS file `mwa_512_crossdipole_gp_20080714.txt`, which has maximum baselines approaching 3 km.
- The receiver locations were inspired by information at `mwa-lfd.haystack.mit.edu/twiki/bin/view/Main/ArrayConfiguration`.
- The median distance to the nearest receiver is ~ 40 m, or about 32 dB of attenuation (the $\log_{10}$ distribution is approximately Gaussian and centred at 1.6).
- The nearest receiver will be different for different tiles. The median distance to a given receiver ranges from about 180 m to 1120 m. The median is a couple of hundred metres, or 40 to 50 dB of attenuation.
- For a given pixel the RFI phases should be random in the visibilities, and the RFI signal should reduce by $\sim (512 \times 511/2)^{-1/2}$, or about 25 dB.

- So for a pixel in a snapshot image we might expect each receivers RFI to have been reduced by around 70 dB, and if we assume that the RFI enters the tiles at very low elevations, the relative gain should be below -30 dB. This suggests that in a sythesised beam the RFI will be at a level below the 1 mK signal of interest, even if we allow an extra 10 dB for the addition of 64 RFI signals.
- A simulation was carried out in which the amplitude and phase from each receiver was generated for each baseline, and then the average over all of the baselines was calculated for each receiver (for a pixel at zenith).
- Ignoring antenna gain (so just considering path-loss and phase differences), the minimum receiver RFI attenuation was 56 dB and the maximum was 98 dB. The mean was 67 dB, in agreement with the order-of-magnitude estimate.
- The simulation also suggests that the visibility gain at elevations below 5° should be better than -35 dB relative to beam centre.

4 RFI in uv Annuli

RFI in snapshot pixels should be below the 1 mK signal of interest, but the EoR spectrum will be searched for in the uv plane. To estimate RFI levels there, we can look at the mean value and variance of visibilities in annuli about the centre of the uv plane. Both of these quantities will be dependent on the size of the uv pixels into which the visibilities are gridded. Since the RFI phase will be random in these pixels, more visibilities per pixel results in more attenuation.

Figure 1 shows results from the simulation with uv pixel sides and annuli widths of 5 wavelengths (about 10 metres). The levels can be roughly compared to the attenuation of 85 dB that is required to reduce the RFI level to the RALI threshold. We can expect perhaps 30 to 40 dB more attenuation due to tile gains, and 10s of dB due to Earth rotation, since the RFI phases will be effectively random as we track a celestial phase centre. Changing to a bin size of 20 wavelengths drops the mean level (top plot) by 5 to 10 dB and the variance (bottom plot) by 10 to 20 dB.

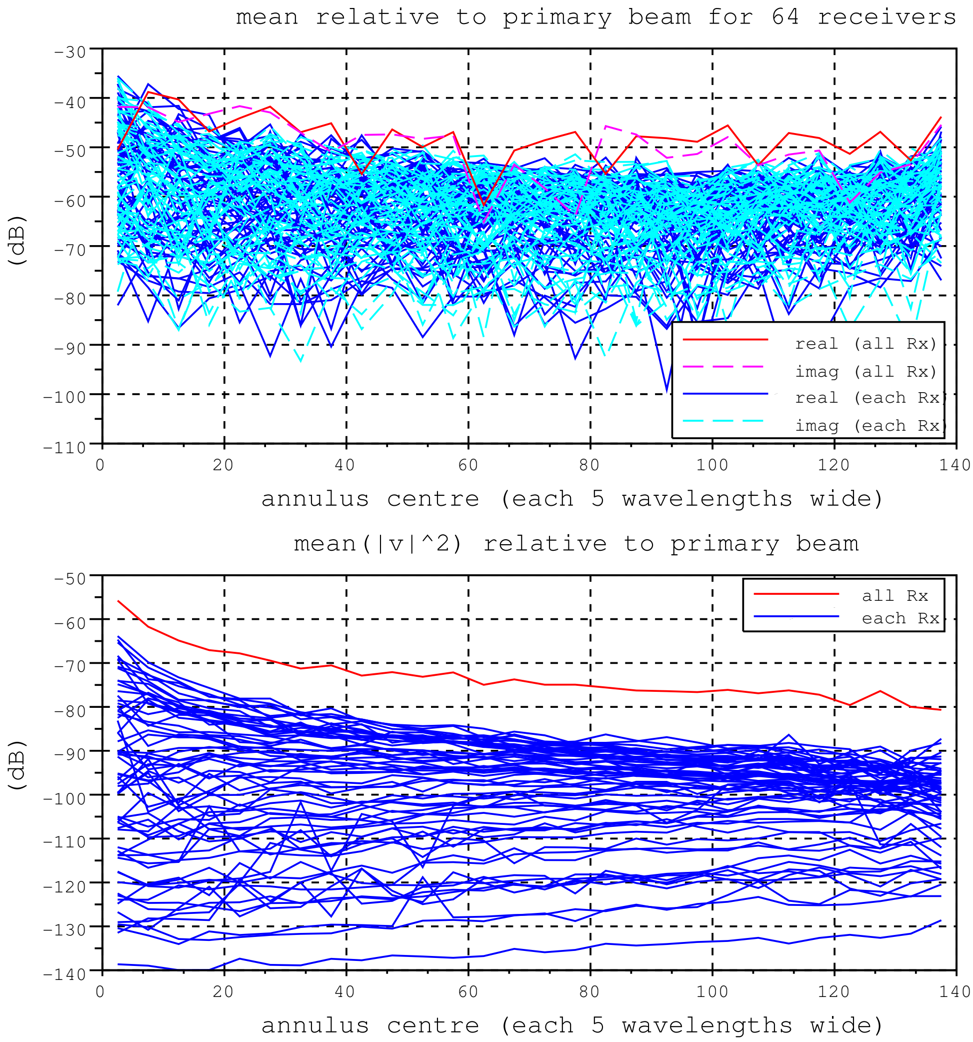

Figure 1: Receiver RFI relative to the incident RFI level. RFI phases and the attenuation due to path-loss were calculated for each visibility, but the sidelobe gain of the antennas has not been included. This is for a single snapshot.