32T Test Plan -- RFI Characterization (2b)

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1 Introduction

There are two areas of concern where observational data in the near term could clarify and possibly reduce risk in regard to Radio Frequency Interference (RFI):

a. Characterization of the ambient RFI environment and possible self-generated signals
b. Instrumental limitations (such as related to dynamic range) to observations in the presence of strong RFI signals (such as Orbcomm)

This plan is responsive to requirement #2b contained in the memo "MWA 32-T Objectives and Quality Assurance Evaluation Criteria", dated 4 September 2009 (46-03001.99).

a) The first step in the "mitigation" of RFI is to inventory and characterize the RFI environment at the MWA site across the radio spectrum. The fundamental parameters of interest for RFI signals are: frequency, signal strength, temporal variability, characteristic frequency bandwidth, nature of signal coding (if not a spurious, "pure tone"), origin of the signal (alt-az directional coordinates, if it's a stationary transmitter, and physical location, such as Geraldton, Perth, CSIRO Office, etc). Additionally, local emissions (self-generated RFI) needs to be identified, since the first step in mitigation of these signals will be for us to suppress/eliminate them at the source.

The 32T array itself is a sensitive detector of RFI, and its spectrometer capability, *especially* with the *software correlator*, which can provide any desired spectral and temporal resolution, will be an unsurpassed tool for characterizing the RFI signals detected in the MWA reception band.

Note that the MWA is sensitive is to the frequency range 70-325 MHz, so that out-of-band emissions that are either self-generated or part of the ambient MRO environment will have to be identified and characterized with other forms of instrumentation, such as the CSIRO RFI Trailer or portable RFI "sniffers."

The basic data sets that reach the relevant sensitivity level will consist of spectral scans made with the MWA instrument itself. If performed with the hardware correlator, the instrument can record 24x 1.28MHz bands at 10 kHz resolution (or 12x bands, if only half the nominal data rate can be achieved). The hardware correlator can cover the 70-325 MHz band up to 24x faster that the software correlator, which records only a 1.28 MHz band. However, the software correlator output spectroscopy can be generated at arbitrarily fine spectral resolution, which enhances the detectability of narrow tones and combs of harmonics of the sort that are typical of self-generated RFI from computers and other digital electronics (switched power supplies, etc). Furthermore, recording the baseband signals (which is a natural process in the software correlator data acquisition) will allow the data sets to be reprocessed at high-time resolution, if necessary, in order to understand the temporal variability and nature of signal encoding.

Total power spectra from the 32 antennas in the 32T array can be averaged together to enhance the integral Signal-to-Noise ratio, and the spectra can be compared among the antennas to infer possible local, self-generated origins. In addition, further gains in S/N can be obtained through the coherent addition that is inherent in techniques that decompose the covariance matrix formed from the cross-correlation of the 32 x (2 polarizations) = 64 signals from the array. As is the case for the spectral scans discussed in the previous paragraph, the measurements can be made with either the hardware correlator (which scans the spectrum more rapidly) or with the software correlator (which has more versatility for diagnostics and is more sensitive to narrow tones). The results of the covariance matrix decomposition can also be inverted to deduce the direction of arrival of the signals.

With self-generated RFI, it will be important to recognize whether it is received through the antenna tiles or picked up down stream internally to the instrumentation in the signal-chain.

b) There is some concern that the receiving system shows distortion in the presence of very strong RFI (such as the Orbcomm LEO communication satellite signals, which reach an order of magnitude higher power than the integral noise power in the 70-325 MHz band).

2 References

1 Leshem, A, van der Veen, A-J, Boonstra, A-J, 2000, ApJS, 131, 355, Multichannel Interference Mitigation Techniques in Radio Astronomy
2 Fridman, P.A., and Baan, W.A., 2001, A&A, 378, 327, RFI mitigation methods in radio astronomy
3 Baan, W.A., Fridman, P.A., and Millenaar, R.P., 2004, AJ, 128, 933, Radio Frequency Interference Mitigation at the Westerbork Synthesis Radio Telescope: Algorithms, Test Observations, and System Implementation
4 Boonstra, A-J, 2005, PhD Thesis, Radio frequency interference mitigation in radio astronomy
5 Kocz, J 2009, PhD Thesis, Applied Radio Frequency Interference Removal in Radio Astronomy, Chapter 5 (application to MWA data)
6 RRI Memos on the Laboratory Tests of the Coarse PFB firmware in the ADFB boards.

3 Measurement Description

The measurements will be made with as many functioning antenna tiles as are available at the time of the observations. The measurements will involve stepped the Coarse Channel selection through the full range of the MWA instrumental reception, including the acquisition of some sanity-check data in the 0 to 70 MHz range that is nominally suppressed by the low frequency cutoff of the ASC band-limiting filters. Any signals in the 0 to 70 MHz range must arise in the receiver, either through spurious pickup or through non-linear distortion.

In order to monitor the strength and frequency(ies) of the Orbcomm satellites, it will be useful to operate the USRP2 system with reference dipole throughout the RFI characterization period.

3.1 Acquisition of Appropriate Data Sets

Note that the following measurements will not use the RTS real-time calibration system, and in fact, these observations require that *either* raw baseband samples from the receivers *or* uncalibrated total power and cross power spectra from the hardware correlator be recorded for processing with very basic, application specific tools.

- Minimal Data Set – suitable for testing of basic analysis routines. Phase Tiles to point at Zenith; step coarse channel selection through 0-325 MHz spectrum (255 channels) three times. (Prefer to do this both with Software and Hardware Correlators)
- 24 hour Data Set – suitable to check for diurnal and other long-term temporal variation, including the effect of strong RFI, since the expectation is that multiple Orbcomm passes through the beam will occur during the course of 24hours. Phase Tiles to point at Zenith; scan through 70-325 MHz spectrum (200 channels) with repetition rate of ~6 scans per hour. (could be done with either Software or Hardware correlators, provided control of channel selection and data recorder is adequately fast)
- Tests at several Alt-Az pointings for the Tiles. Step through frequencies and a sampling of tile pointing coordinates as rapidly as the data acquisition will permit. This would permit construction of dynamic spectra for several tile phasings. This will probably require the Hardware Correlator so that 24 coarse channels can be observed simultaneously in order to cycle among the pointings sufficiently rapidly.
- For all three options above, it is desirable to obtain simultaneouls acquisition of USRP2 reference dipole data in the Orbcomm band (137-138 MHz) throughout the RFI monitoring campaign.

3.2 Analyses

3.2.1 Averaged and Dynamic Total Power Spectra

- Create a set of time-averaged spectra for each of the 64 signal paths from the tiles.
- Create dynamic spectra for each of the 64 signal paths.
- Inspect the above and edit as appropriate before averaging to form integral, "most sensitive" spectra to define the ambient RFI environment

3.2.2 Covariance Matrix Decomposition

Format cross power spectra into a cube of covariance matrices (one matrix per frequency channel). Decompose the matrix for each frequency channel to obtain eigen-value spectra.

3.2.3 Inversion of Eigen Decomposition Analysis to Infer Alt-Az Coordinates of Interference Source

Based on the decomposition (eigenvectors from 3.2.2) and using the known locations of the antenna tiles, use the array calibration (differential cable lengths, etc) to invert the solution for the eigenvalues that are statistical significant above the noise level to infer the Alt-Az coordinates of the interfering signal sources

3.2.4 Intercompare measured spectra with USRP2 reference spectra in time-frequency domains. Spurious signals or fluctuation in broadband power level that might occur in concert with episodes of strong Orbcomm power, will trigger further investigation in the nature of the distortion.

4 Resources Required

4.1 *Staffing*

- Astronomer, engineer or M&C wizard to implement a schedule for observation (prior to observation).
- Staffing on site to power the array and verify interferometric functionality during the time of the observations (during observation).
- Staffing on site to power the USRP2/dipole and verify functionality during the time of the observations (during observation).
- Astronomer/engineer to verify data quality during the observations (during observation).
- Astronomer/engineer to analyze datasets (post-observation).

4.2 *Hardware*

Functioning Array:

- As many antenna tiles as possible…
- GPS timing to determine local time.
- M&C system to control data-acquisition, reset sky frequency, and possibly steer tile beams through a series of topocentric alt-az coordinates
- Phase lock of receivers, with verified fringe coherence, with celestial sources (preferred) and/or noise source
- Correlator: either software or hardware correlator

4.3 *Software*

- M&C control of pointing, frequency setting, scan start/stop. Prefer 1 second integrations with 1 second reset time, thus obtaining a 200*2=400 second = 7 minute cycle time for spectral scans made by recording baseband samples for subsequent offline software correlation or 8*2=16 second cycle time for a complete spectral scan made with the Hardware Correlator backend.
- Correlator control in Channel Mode. (software or hardware correlator)
- Offline Processing:
    - Production of total power and cross power spectra
    - Averaging spectra to increase signal to noise ratio for weak, prolonged RFI signals
    - Inspection tools to obtain dynamic spectra for identification and characterization of time-variable RFI
    - Software to format the covariance matrix, perform the SVD decomposition, and display the results
    - Softtware to invert the decomposition in order to infer the direction of arrival of the RFI wavefronts

4.4 *Execution Time and Constraints*

Three Options:

1. *Minimum telescope time* would be the time to scan the spectrum by stepped through the coarse (1.28MHz) channels with ~1 second integrations per step and with the antenna tiles phased to point at Zenith. This should be repeated several times to provide some indication

of quality control and a zeroth-order assessment of variability. This data set could be acquired in less than **an hour of telescope time**.

2. A *more comprehensive test* would be to repeat the "minimum test" at several antenna tile pointings, taking **2-4 hours**, depending on the efficiency of the M&C control.

3. A *still more meaningful test* would be to take data throughout a **24 hour period** to observe possible diurnal behavior intrinsic to the sources of the RFI and variability in propagation effects for distant sources that appear to be intrinsically constant. This could be done using either a single pointing coordinate (probably Zenith) or by stepping through a small (half-dozen) sampling of Alt-Az coordinates.

5 Success Criteria

Characterization of the RFI environment at spectral resolution 10kHz or better. This includes cataloging the interfering signals, their strength, time-variability, and bandwidth. The distillation of this information with include plots of "spectral occupancy" and total RFI power in spectral bins across the MWA frequency range.

Revision History

Rev Ltr	Date	Author	Description
01	2009-09-30	FHB	Initial submission
02	2009-12-30	RFG	Formatting