EMC Certification of a Digital Radio Astronomy Receiver: A Case Study

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Abstract – **This paper outlines the challenge of practical EMC measurements on a large electronic system destined for a radio astronomy observatory. The digital receiver package of the Murchison Widefield Array (MWA) is used as a case study and progress towards meeting what is probably one of the world's most stringent EMC requirement is described.**

1 INTRODUCTION

Radio telescopes receive faint electromagnetic signals and must be operated in a radio quiet environment. Two SKA Precursors, the Murchison Widefield Array (MWA) and the Australian SKA Pathfinder (ASKAP) are currently being built at the Murchison Radioastronomy Observatory (MRO) in the mid-west of Western Australia. The MRO is an extremely radio quiet area and has also been selected as home for the Phase 1 and Phase 2 SKA low frequency arrays [1].

This paper describes the EMC certification process to date of the digital receiver used for the MWA. Results shown are illustrative and show a work in progress; data in this paper should not be taken as final.

2 EMC REQUIREMENTS

Radio astronomers and EMC engineers approach the issue of electromagnetic compatibility from different angles. The radio astronomer is concerned about the signal arriving at the receiver, typically expressed as power spectral density *PSD* in dBm/Hz, while the emission test in the EMC laboratory provides an electric field strength E_{noise} in dBµV/m for a given bandwidth *BW* in a given distance R_{test}. To convert E_{noise} to *PSD* values some assumptions are made:

- the antenna factor of the radio astronomy antenna in direction of the equipment is known (typically a value of 0 dBi is taken);
- the rate of decrease of the field strength with distance is known (a detailed analysis of the path loss may be necessary for large distances, but for short distances in the range of a few kilometers a $1/r$ decrease may be assumed);
- noise signals can be normalised to 1 Hz based on the bandwidth used during the test.

The maximum field strength E_{noise} and the distance *R* between the equipment and the antenna are known, from the EMC test and from the layout plan of the installation site. If an estimate is made for the antenna factor *PSD* values can be calculated.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) as the site manager of the MRO has developed RFI standards based on these principles. Considering the reduction in field strength with distance, target emissions are:

- MIL-STD461F - Navy Mobile and Army limits, if the equipment is more than 10 km from the radio astronomy antenna;
- 20 dB below MIL-STD461F limits, for a distance between 1 km and 10 km;
- 80 dB below MIL-STD461F limits, for a distance of less than 1 km.

Measuring against emission limits according to MIL-STD461F is the best most EMC laboratories can do. To bring the sensitivity of the lab instrumentation down to 20 dB below MIL-STD461F limits requires careful selection of low-loss cables and low-noise pre-amplifiers. Measuring emissions 80 dB below MIL-STD461F in an EMC laboratory is not usually possible.

3 MWA RECEIVER TEST CONFIGURATION

3.1 MWA receiver setup on the MRO

The MWA digital receiver is part of an extensive system which is described in a number of publications [1, 5]. Only details relevant to its RFI performance will be summarised here.

The receiver, including air-conditioning (A/C) system, has approximate dimensions of 2 × 1.5 × 0.8 m, and weighs about 100 kg. It will sit on a 2 × 2 m concrete pad, elevated by 150 mm of steel girder, and will be connected to eight analog beamformers. Each beamformer combines the signals from 16 dual-polarisation dipole antennas, one 'tile', into two wideband analog outputs [1]. Two coaxial cables run to each beamformer, carrying the analog signals, providing DC power to the beamformer, and handling the communication between receiver and beamformer.

Other connections to the receiver are the power cable running in a flexible shielding conduit, and an earth wire to each beamformer, parallel to the coaxial cables. The receiver is bolted to its metal supports which are likely to be electrically bonded to wire mesh inside the concrete pad.

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Data transfer from the receiver to the central processing station is via optical fiber.

The length of the power and signals cables can exceed 100 m. It is not possible to set up such a system in the EMC lab for emission tests, requiring a compromise test arrangement to be found, based on an appropriate interference model.

3.2 Interference model

Of the three elements of the MWA system (digital receiver, beamformer and dipole antenna) only the digital receiver is of concern as active noise source; previous tests on a beamformer connected to a dipole antenna showed no detectable emissions.

Notwithstanding, noise could propagate through the signal cables from the receiver to the beamformer, and either radiate from there, or be fed through to the dipole antennas and radiate from them. Therefore, at least one beamformer and one dipole antenna should be included in the setup.

While the site grounding arrangements for the receiver are not yet well defined they are unlikely to be very effective for EMC purpose. For the setup in the lab no ground connection is used apart the earth wire of the power cable. An earth wire was connected from the receiver to the beamformer.

Radiation from the signal cables, either between the receiver and the beamformers, or from the beamformers to the dipole antennas, cannot be ruled out. Such an emission would be generated from common mode currents along the cables and could be affected by the grounding situation at the receiver and the beamformer, and the connection of the cable shields at both ends. Furthermore the emission will depend on cable routing and cable length.

3.3 MWA receiver setup in the EMC lab

Based on this interference model the setup shown in Fig. 1 was chosen for the EMC test. The receiver is placed about 250 mm above the ground plane on a turntable, and powered through a Line Impedance Stabilization Network (LISN). The LISN is, for practical reasons, placed underneath the receiver, giving a bigger receiver-ground distance than on the MRO. The power cable runs in the same shielding conduit used later on the MRO; this conduit is not grounded at the LISN end.

The available space in the lab did not allow to place a beamformer and dipole antenna beside the receiver. Instead, a beamformer is connected to the receiver and placed on a 200 mm thick polystyrene block on top of the receiver. Signal cables and the earth wire from the receiver to the beamformer are ~2 m long. A dipole antenna is placed next to the beamformer, on a 100 mm thick polystyrene block. Coiled cables between the beamformer and dipole antenna are about 10 m long..

Table 1 summarises the differences between the MRO and EMC lab setups. While the lab setup differs from the installation on the MRO it is expected to produce comparable electromagnetic emissions.

MRO setup	EMC lab setup
Long power cable	Short power cable (~3 m)
Ground connection ill defined but unlikely to be effective for EMC	No ground connection
Power cable conduit grounded at both ends	Power cable conduit not grounded at LISN end
8×2 long signal cables to 8 beamformers	1×2 short signal cables to one beamformer (on top of A/C compartment)
8×16 cables to the 16 dipole antennas for each beamformer	1×2 cables (coiled up) from the beamformer to one dipole antenna (on top of receiver compartment)

Table 1: Comparison: installed vs. tested system

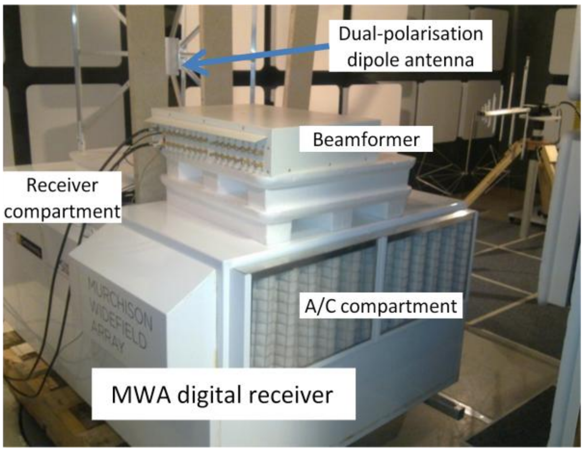

Figure 1: MWA receiver in the EMC laboratory

4 EMISSION TESTS

4.1 Prototype I

The tests were done in a semi-anechoic chamber with floor absorbers at ICRAR/Curtin, Perth, Western Australia, following MIL-STD461F in respect to bandwidth, test distance, and scan time. The target emission was 20 dB below MIL-STD461F limit values, and measurements were often made in four directions with horizontal and vertical antenna orientation.

Tests on Prototype I were made in June 2011 with a HP85642A EMC receiver. In a first step a comparison was made with the lid of the MWA receiver compartment removed and closed. The results are shown in Fig. 2.

The receiver generates broadband noise (100 MHz - 250 MHz) and some narrowband signals (300 MHz -

1 GHz). Without shielding from the enclosure the MIL-STD461F limit values are exceeded. After the enclosure was closed no signal above the noise floor was detected, but this noise floor was above the MRO limit. These results were obtained for horizontal antenna polarisation and for only one orientation of the receiver.

The sensitivity of the test instrumentation was improved by using a pre-amplifier (HP8447F). Results for vertical polarisation and four directions are shown in Fig. 3. They are significantly higher than for horizontal polarisation and show a significant directivity.

Broadband noise appears around 105 MHz, 160 MHz and 290 MHz; three narrowband signals at 164 MHz, 327 MHz and 655 MHz are related to clock frequencies of the receiver.

MIL-STD461F does not differentiate between narrowband and broadband emission. The conversion from an acceptable power spectral density to measured emission levels required a normalisation by the measurement resolution bandwidth. Narrowband and broadband signals respond differently to a change in resolution bandwidth. This is demonstrated in Fig. 4 where the broadband signal around 104 MHz decreases, when the resolution bandwidth is changed from 100 kHz to 1 kHz, while the narrowband signal at 164 MHz is not affected.

Further investigations were made of ways to reduce the emission from the receiver. One weak point was found to be the shielding performance of the A/C compartment. After the mechanical pressure between the cover and the main compartment was increased and made more uniform the emission level was reduced, but not sufficiently.

Common mode currents were measured on the power cable and the signal cables to the beamformer. Some noise signals were detected and reduced by applying ferrites. However, there was no correlation between the currents and the radiated emission.

4.2 Prototype II

Modifications were made to improve the shielding performance of the receiver enclosure, namely:

- better contact arrangements between the A/C compartment and its cover;
- better contact arrangements between the receiver compartment and the penetration plate with the connectors for the beamformer cables.

Tests on this new Prototype II were made in April 2012. There had also been an upgrade to the instrumentation in the ICRAR/Curtin EMC lab, including a more sensitive Rohde&Schwarz ESU26 EMC receiver. A broadband horn antenna was used instead of the earlier log-periodic antenna.

Initial measurements (see Fig. 5) revealed that some signals were still above the target emission, e.g. clock signals at 327 MHz (~10 dB) and 655 MHz (~7 dB), and a broadband signal around 170 MHz (~20 dB). A number of modifications were tried to bring the emission below the applicable limit line:

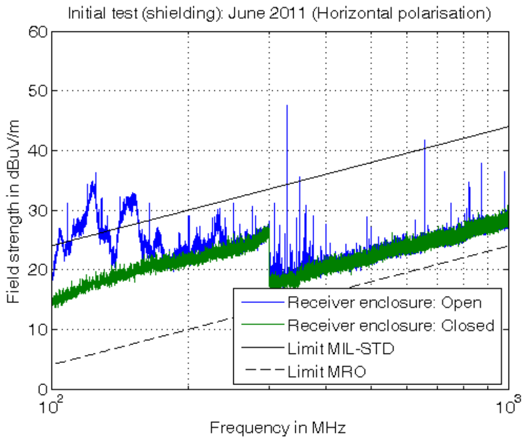

Figure 2: Emission with and without shielding

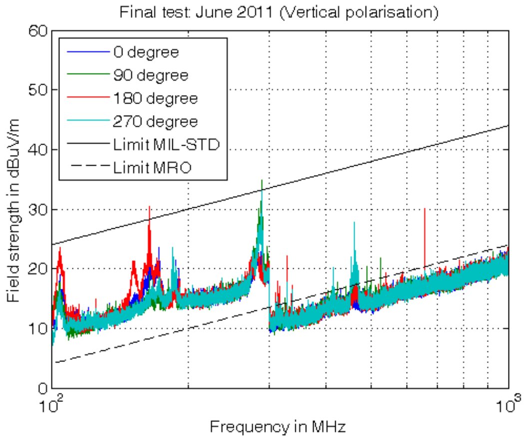

Figure 3: Emission for vertical polarisation

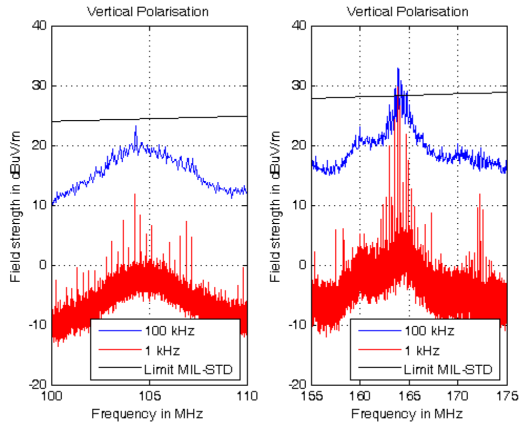

Figure 4: Influence of resolution bandwidth on broadband and narrowband signals

- disconnecting the beamformer/dipole antenna (*no improvement*);
- experimenting further with the A/C compartment cover (*emission reduced in some directions, but increased in others*);
- placing ferrites around the power cable inside the receiver enclosure between the mains filter and cable entry point (*marginal improvement*);
- placing ferrites around the power cable inside the receiver enclosure running from the mains filter to the A/C unit (*no improvement*);
- placing ferrites around some noisy signal cables inside the receiver enclosure connecting the various modules of the receiver with each other (*no improvement*).

The best result achieved with all the modifications listed above in place is shown in Fig. 6.

The sensitivity of the instrumentation is still not sufficient above 1 GHz when the standard resolution bandwidth is 1 MHz. However, when using a reduced resolution bandwidth of 100 kHz the noise floor is below the MRO limit, and still no emission from the MWA receiver is detected. This indicates that there is no narrowband signal above limit in the spectrum above 1 GHz.

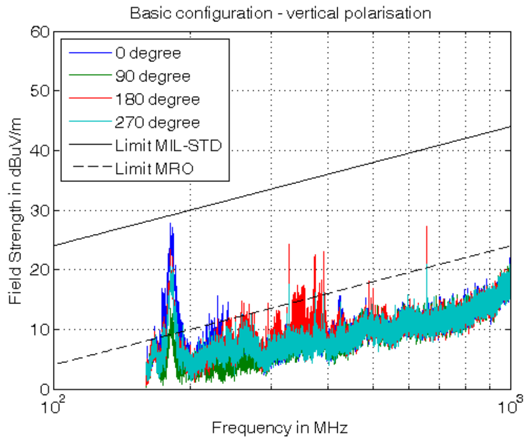

Figure 5: Prototype II - basic configuration

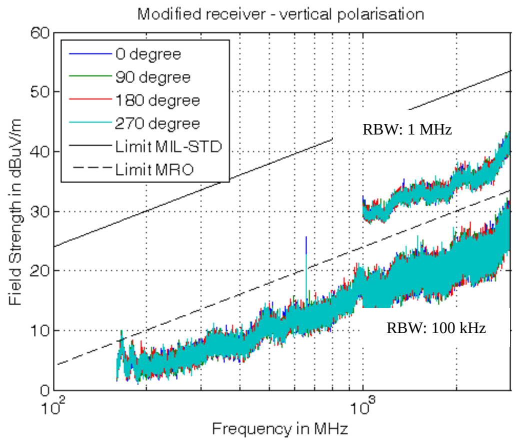

Figure 6: Prototype II after modifications

5 CONCLUSIONS

The setup of the receiver in the lab required some thought: a compromise test arrangement was found that was small enough, and complete enough, to serve as suitable representation of the deployed system.

Observing the effects of modifications on the emission was a challenge and a comprehensive measurement regime was necessary after each modification.

Work continues on further suppression of the weak residual emissions, with efforts focusing on source suppression in receiver internal modules.

References

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[2] Radiocommunications Assignment and Licensing Instruction: RALI MS32: “Coordination of Apparatus Licensed Services within the Mid West Radio Quiet Zone“, September 2007 http://www.acma.gov.au/webwr/radcomm/frequency_planning/frequency_assignment/docs/ms32.pdf

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