<u>Status of LWDA Electronics RF Emissions Measurements</u>

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This document summarizes recent efforts to characterize the emissions from LWDA electronics still in development. Near final versions of the ARL-developed variable gain stage (otherwise known as the second gain stage or SGS) and digital receiver (RX) have been completed, fabricated and tested recently; a near final version of the adder board is expected in the next few weeks. Individual enclosures for each the SGS, RX, and adder have been designed. To date, the enclosures for the SGS and RX have been fabricated and tested, while a prototype of the adder enclosure (which will accommodate both current and next revision of the adder) is expected within two weeks. It is expected that these individual board enclosures would provide some level of shielding of the emissions from the boards. Development of an intermediate chassis (known as the Level 1 chassis), which would house 8 RX and one adder, is in progress. This chassis is expected to provide an additional layer of shielding of emissions from the electronics boards and cabling between the boards. The completion and fabrication of this design is expected to be well over a month from now. A shielded rack has been purchased from Equipto, and is expected to arrive within two weeks, though the final modifications that must be made to the rack to accommodate LWDA system components will not be made for some time. For the initial LWDA deployment, two Level 1 chassis, a Level 2 chassis containing the final adder, the station computer, and other system equipment will be housed in this rack, which provides additional shielding. This rack will be housed at the LWDA site inside a shielded hut, which is expected to provide a final layer of shielding. Final modifications to the hut are currently in progress and should be completed in roughly 2 weeks.

In parallel to the development of the system components that will be deployed at the LWDA site, a shielded NEMA enclosure has been developed to enable near-term field testing of the full LWDA receive chain (antenna to PC). It houses three gain stages, an LWDA receiver and adder, and power conditioning circuitry. It provides two RF coaxial inputs and one USB interface to connect the adder to a PC for control/data download. The enclosure is large enough that a laptop can be placed inside and run off its batteries if there is a concern about its emissions interfering with measurements. This enclosure has been and will continue to be used for field testing in Central Texas. It is hoped that when combined with the shielded hut, sufficient shielding would be provided to meet EVLA emissions limits. This would allow receive chain testing to be performed at the VLA site as soon as the hut is installed there (likely within a month from now) rather than having to wait for the fabrication of the final rack-based system to be completed (likely two months or more from now.) Of course, close coordination with UNM and NRAO is required to meet these goals.

To date, emissions measurements have been performed individually on older versions of the RX and adder, on the newest version of the RX and its associated shielded enclosure, and on the NEMA enclosure described above populated with older versions of the RX and adder. The test setup used and results from these measurements will be described below. Upcoming measurements will include the emissions from the newest version of the adder with associated shielded enclosure, the emissions from CAT5 cabling between components, and the shielding provided by the completed electronics hut.

Test Setup / Data Processing Procedures for RF Emissions Measurements

The test setup used to conduct emissions measurements at ARL:UT is depicted in Figure 1. It consists of a reference antenna, which is connected through an LNA and low-loss cabling to a spectrum analyzer. The reference antenna is placed a specified distance from the device under test (DUT). Measurements were conducted inside a normal, non-shielded, non-anechoic laboratory. As such, there is concern that scattering from the walls and other objects in the room will negatively affect measurements. As such, three DUT positions equidistant from the reference antenna have been established. Ideally, the DUT is measured at multiple orientations relative to the reference antenna at each of these positions in order to mitigate errors due to scattering. Most of the initial measurements shown in this document were only measured at a worst-case (in terms of highest emissions) orientation at a single position, however, due to limited time; the determination of any final emissions / shielding estimate using this setup will involve the more rigorous method described above, though.

Using an unshielded laboratory, it is difficult to make reliable emissions measurements much below 1 GHz. This is due to the very high external RFI present in the city at lower frequencies. Therefore all results presented in this document focus on frequencies of 1 GHz and higher. In order to measure at lower frequencies, we will need to use the shielded room at a facility nearby ARL:UT; this facility can only be used sparingly due to the effort required to move all needed test equipment and having to coordinate schedules with the owners of the shielded room. The reference antenna used in measurements so far has been a wideband double-ridged waveguide horn, which is calibrated between roughly 800 MHz and 18 GHz. However, the wideband LNAs owned by ARL provide reasonable gain / noise temperature only out to 8 GHz. Therefore the frequency range for valid emission measurements is 800 MHz to 8 GHz. It should be reasonable to ignore frequencies higher than 8 GHz for now, however, since measurements conducted at the VLA facility in January 2006 indicated that the LWDA receiver emissions are very low above 6.5 GHz. Of course, final measurements at the VLA should eventually be used to confirm this. The spacing between the reference antenna and DUT was 1.5 m for all measurements, which is 5 free space wavelengths at 1 GHz.

Measurements at the VLA facility indicated that the LWDA RX emissions above 1 GHz are dominated by clock harmonics that occur every multiple of 50 MHz. We have set up a data collection procedure which utilizes this fact in order to maximize the available dynamic range while minimizing the time required to conduct measurements. The spectrum analyzer is controlled by laptop to measure in a very narrow span about each 50 MHz multiple between 0 and 8 GHz. Because the VCXO used on the LWDA electronics is so stable with time (better than 50 ppm), it is possible to use a measurement span as narrow as 10 kHz and guarantee that a harmonic will appear in each span over

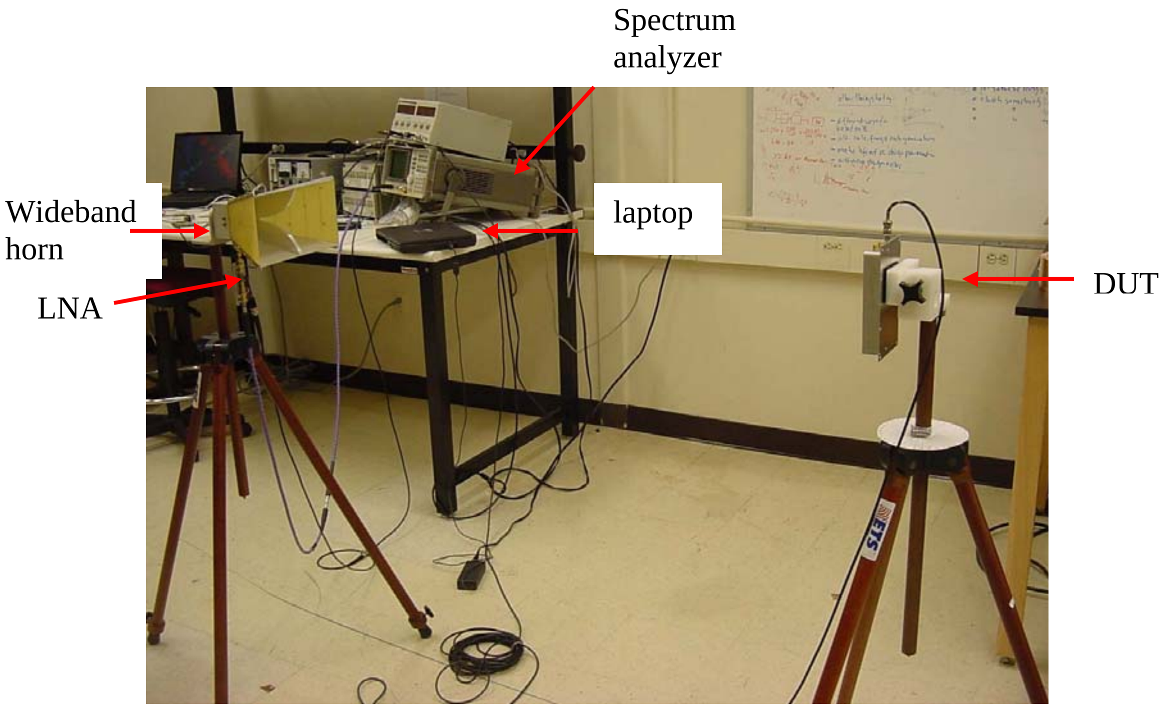

Fig. 1. Test setup used for LWDA emissions measurements.

the full length of the frequency sweep. With such a narrow span, very low resolution bandwidth (RBW) can be used to achieve high sensitivity but maintain a reasonable test length; using a RBW = 30 Hz, it takes roughly 12 minutes to take measurements every 50 MHz between 0-8 GHz. Using such a narrow span also excludes as much external RFI (i.e. not due to DUT) from the measurement as possible so emission estimates are not skewed by these interferers. Although most of the spectrum is relatively free of noise above 1 GHz, it is still is possible for external noise to be present in the narrow measurement span.

A calibration for this test setup was calculated so that an estimate of the DUT emissions in the form of an EIRP value could be determined. A calibration of the horn antenna in terms of gain, G_{ref}, versus frequency has been provided by the vendor. The total gain of the LNA and cabling between the reference horn and spectrum analyzer, G_{electr}, was measured using a network analyzer. Finally, the free space loss between the reference antenna and DUT, $L_{FS,}$ was calculated. An estimate of the EIRP of the DUT emissions referenced to the position of the DUT is given by

$$EIRP(f) = P_{meas}(f) - G_{ref}(f) – G_{electr}(f) + L_{FS}(f)$$

Where P_{meas} is the raw spectrum analyzer measurement, and the argument f indicates that these quantities are functions of frequency. The calibration data used for these measurements is plotted in Figure 2.

The reduction of the raw data involves simply finding the maximum power in each 10 kHz span (which in principle should be due to the emissions of the DUT), and applying the correction given above to calculate the corresponding EIRP. A more conservative estimate of the EIRP is attained by repeating the measurement at multiple locations and orientations and calculating the maximum over all of these measurements for each frequency. Again, the results presented here are only for the worst-case orientation for single position. A final factor to account for 300 m of free space loss between the LWDA site and the closest VLA position, CW7, is added to the final EIRP value at each frequency. This permits a direct comparison with the EVLA emission

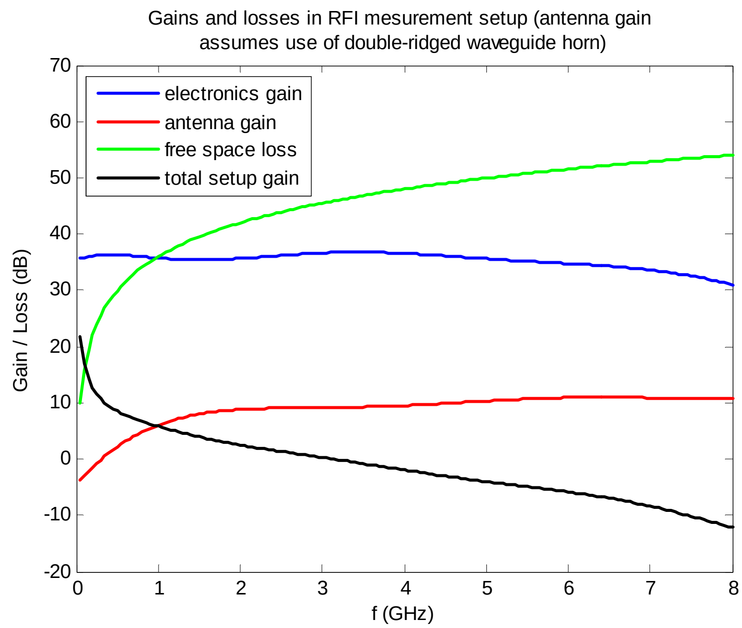

Fig.2. Calibration data for reference antenna gain, LNA/cabling gain, and free space loss used in emissions test setup. The antenna gain is extrapolated below 1 GHz from calibration data provided down to 1 GHz.

limits. The EVLA emission limits are presented here in terms of power by combining the emission limits in terms of power density with the effective area due to a 0 dBi sidelobe of a VLA antenna. Note that in the plots shown below, the sidelobe effective area was assumed constant in each band (e.g. L-band, S-band, etc.) with the value due to the center frequency in the band. In reality though, the effective area varies by up 6 dB in each band (that is for example, in L-band, the effective area and thus the emission limit in power is 3 dB higher at 1 GHz and 3 dB lower at 2 GHz than at the center frequency, 1.5 GHz.) This was not corrected in the plots below due to limited time.

Although emission estimates are provided in this report down to 50 MHz, it should be noted that only estimates above 800 MHz are reliable due to the limits of the reference antenna calibration. However, any difference between two different measurements (for instance to estimate shielding achieved by adding an enclosure to a board) should provide a reasonable result at all frequencies.

Results of Emissions Measurements

Measurements were first made to compare the emissions due to unshielded (bareboard) revision 2 and revision 3 LWDA RX designs. The rev. 2 RX was the version tested at the VLA in January 2006, while rev. 3 is newest, near final design, in which many changes were made to reduce emissions. Note that the rev. 3 design includes a board level "can" to shield all of the electronics. This can was removed for the bareboard comparison. The EIRP emissions estimates referenced to a VLA antenna corresponding to these measurements are given in Figure 3. As can be seen, the rev. 2 emissions are quite high, up to roughly 90 dB above EVLA emission limits in L-band. This agrees with measurements of the rev. 2 RX taken at the VLA. The rev.3 RX emission are lower than the rev.2 RX by 10 to 20 dB between 0 to 1 GHz, and 20-30 dB between 1-2 GHz. The rev.3 emissions appear to be a bit lower, possibly 5-10 dB, between 2-4.2 GHz, though it is difficult to tell since the two boards have somewhat frequency responses. Above 4.2 GHz, the rev.3 board appears to offers little improvement in emission levels. These improvements are likely due to changes in the board layout in the new revision, including shortening the length of and rounding active traces. These results imply that the peak emissions of the unshielded rev. 3 RX board near 1 GHz are roughly 70 dB above EVLA limits, which is a 20 dB improvement over the unshielded rev. 2 board.

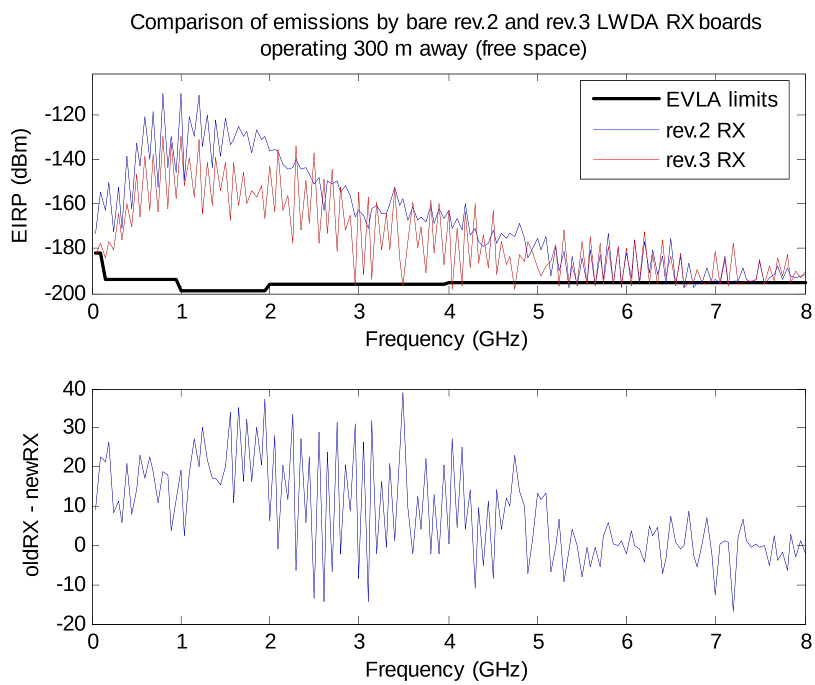

Fig. 3 Comparison of emissions by unshielded rev.2 and rev.3 LWDA RX boards (upper), and reduction in emissions in rev.3 design relative to rev.2 (lower).

Next, measurements were taken of the rev.3 RX placed inside a shielded enclosure with the board can installed. A Picture of the enclosed rev. 3 RX is shown in Figure 4. Measurement results comparing the rev.3 RX emissions with and without the shielded enclosure / board can are given in Figure 5. Below 600 MHz, it is surprising to see that little shielding is provided by the enclosure/can. This is likely due to the external RFI being captured in both measurements rather than the board emissions. Between 1 – 2.8 GHz, emissions are lowered by at least 20 dB, but 30 dB may be a better estimate for a typical value in this frequency range. Above 3 GHz, the shielded measurements begin to be limited by the noise floor of the test setup and the actual level of shielding provided cannot be ascertained. At most frequencies above 3 GHz, the emission levels are near or below EVLA limits. Ignoring for now the results below 600 MHz due to a lack of reliable calibration data and interference likely being present in the data, the highest emissions of the shielded rev. 3 design are roughly 30 dB above EVLA limits. This is an improvement of 40 dB over the unshielded rev. 3 design. Though not shown here, a separate measurement was made to determine the shielding provided by the board can alone. It appears that the can typically provides between 5-10 dB shielding between 1-3 GHz. This implies that the board enclosure provides roughly 20 dB of shielding over that frequency range.

The emissions of an unshielded rev.2 adder board were measured next and results are shown in Figure 6. The next revision (3) of the adder board is currently in development and the enclosure that fits either revision is awaiting fabrication and so they are not currently available for measurement. As can be seen, the peak emissions of the adder, at 1.0 GHz, are roughly 78 dB above EVLA limits. While this is 12 dB lower than the peak emissions of the bare rev. 2 RX board, it is 8 dB higher than those of the bare rev. 3 RX board. The enclosure designed for the adder is very similar to that designed for the rev.3 RX. Therefore, it is expected that similar shielding levels can be expected – roughly 20 dB over 1 to nearly 3 GHz. Due to physical constraints on the adder board, however, none of the active traces can be further reduced in length on the new revision and all traces that could have been rounded have already been in the current version. Therefore, improvements due to changes in layout as were achieved for the RX cannot be expected for the adder. This implies that the peak emissions of the rev. 3 adder with enclosure should be roughly 60 dB above EVLA limits.

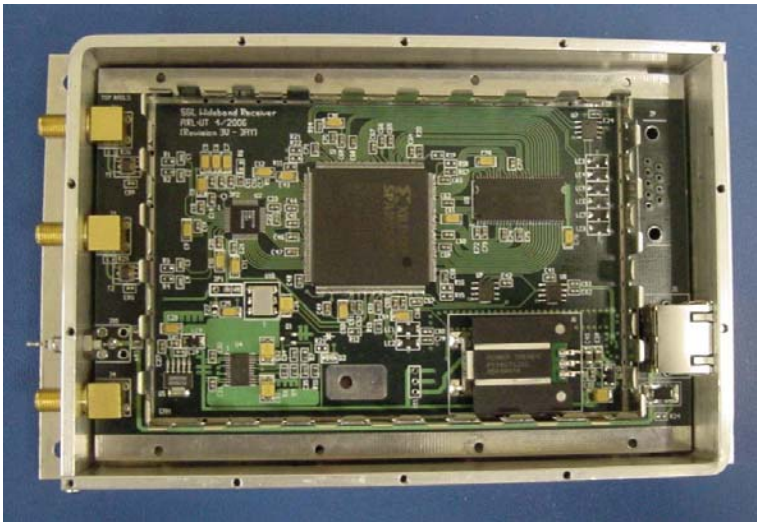

Fig. 4 Picture of enclosed rev. 3 LWDA receiver with top plate and board can removed

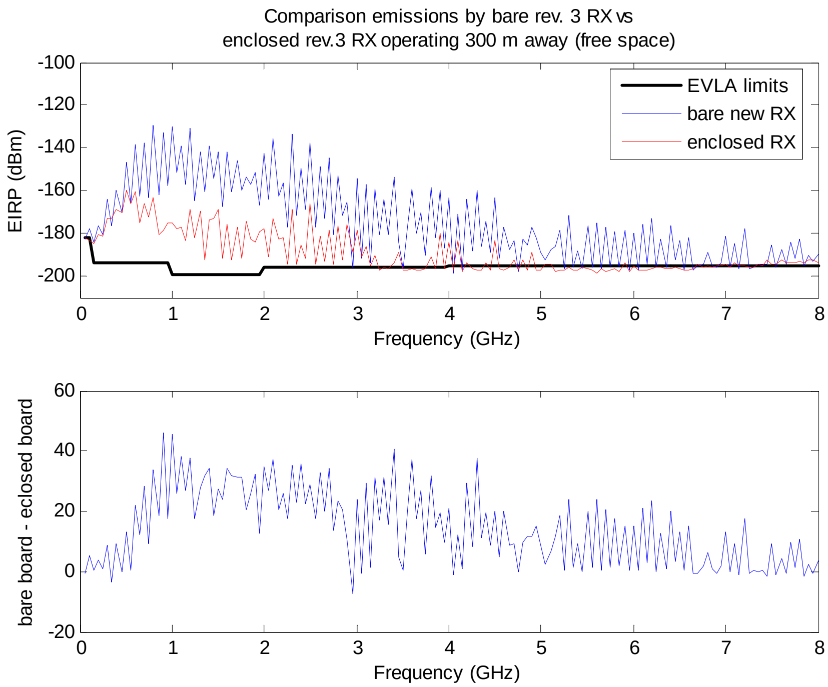

Fig. 5 Comparison of emissions by rev.3 LWDA RX board with and without shielded enclosure / board can (upper), shielding provided by shielded enclosure / board can (lower).

Finally, the emissions due to older revision electronics operating inside a NEMA enclosure were measured. Again, this is the setup used to conduct field measurements near Austin, and it is hoped it can be used to conduct measurements at the VLA in the near-term. Pictures of the enclosure populated with the electronics for one receive chain including an RX and adder are provided in Figure 7. Both the receiver and adder boards are placed inside temporary metal boxes, which provide some shielding for those boards. The box currently does not have an RF gasket installed around the inside of the top lid. Therefore steel wool has been used to line the top lid to serve as a temporary gasket until permanent gaskets can be installed. Measurements were taken with all of the electronics operating inside the enclosure both with the door open and closed. These results are compared in Figure 8. As can be seen, the peak emissions with the door open are very high and are nearly equal to those due to an unshielded rev. 2 RX. Since it is known that the temporary box used for the RX provides at least 20 dB (this box was measured at the VLA facility) this may imply that significant board radiation is coupling onto the data lines of the RJ-45 jack and being radiated by the unshielded CAT-5 cable running between the RX and adder. When the top lid of the NEMA enclosure is closed, however, the radiated emissions are reduced significantly. As shown in Figure 9, the NEMA box provides between 30-40 dB of shielding between roughly 0.7 – 2.4 GHz. At frequencies above 3 GHz, the door closed measurement is limited by the noise floor of the test setup, and the emissions are at or near the EVLA limit. With this setup, emissions at 1 GHz are roughly 34 dB above EVLA limits. It is expected that by replacing the RX and adder with enclosed new revisions and using shielded CAT 5 cable that L-band emissions

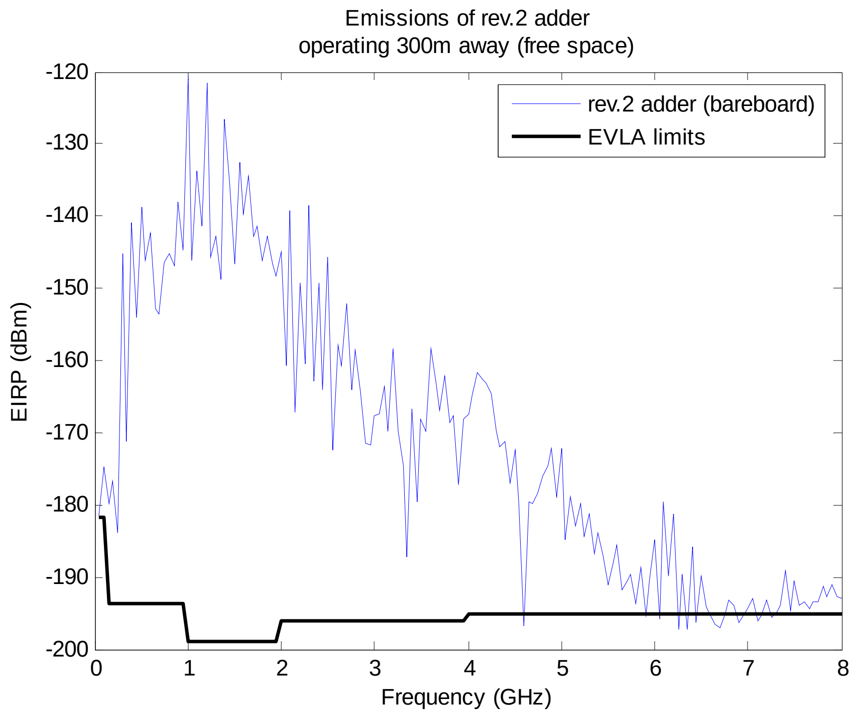

Fig. 6 Emissions measurement of rev.2 adder.

would improve by at least another 20-30 dB. This would put all of the emissions of the NEMA enclosure setup within 10-20 dB of the EVLA limits at frequencies of 1 GHz and higher. This combined with the shielded hut, which should provide significant shielding would likely meet EVLA emission limits. This may enable measurements to be made at the LWDA site within roughly one month - well before the fabrication and testing of the entire LWDA system will be complete.

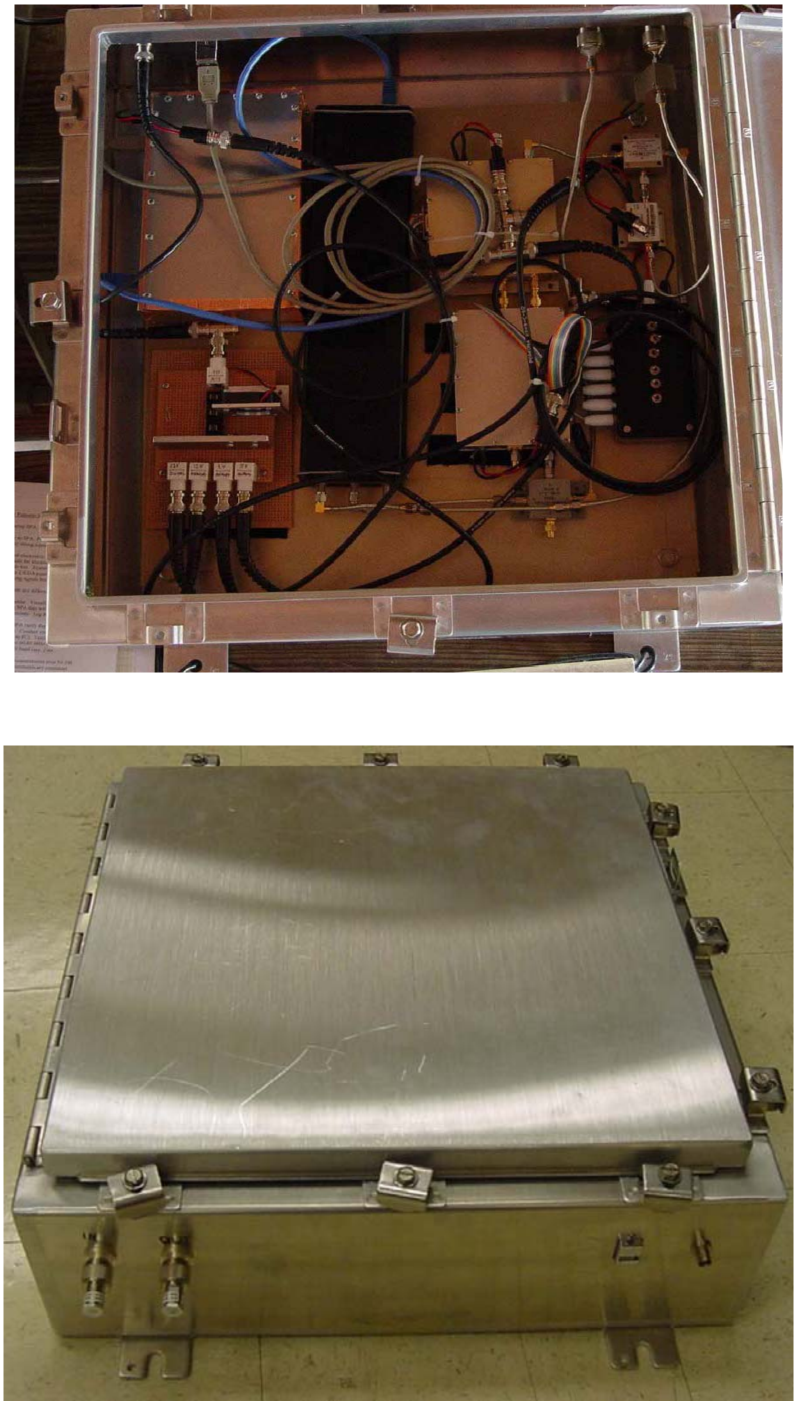

Fig. 7 Pictures of the NEMA enclosure used for field testing of the LWDA receive chain with top lid open (upper) and closed (lower). Note that the steel wool used for RF gasketing in preliminary emissions measurements is not shown.

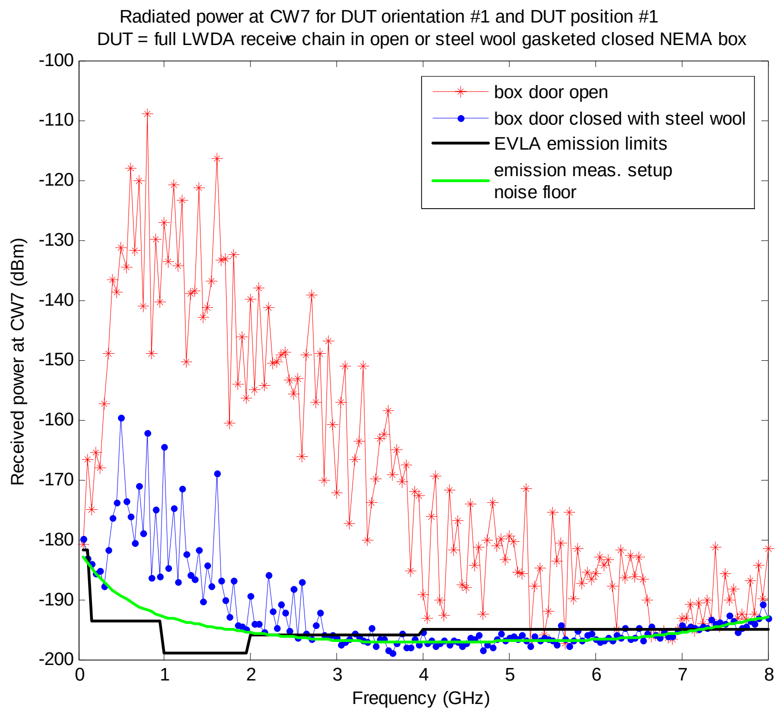

Fig. 8. Comparison of emissions by full LWDA receive chain inside NEMA enclosure with enclosure door open and closed.

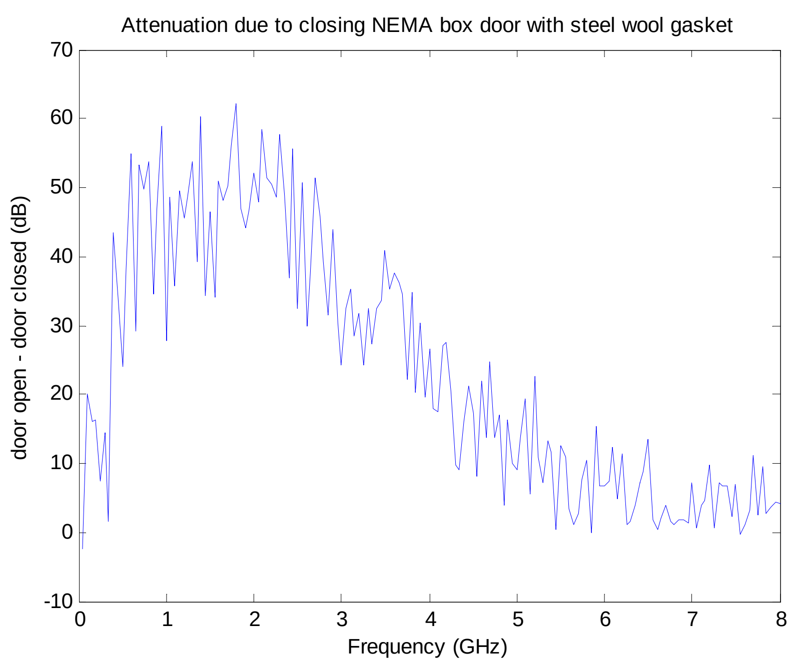

Fig. 9. Estimate of shielding provided by the NEMA enclosure.