EVLA Memo 59
Highly Shielded Boxes for the EVLA Project

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Abstract

The Extended Very Large Array will allow the existing VLA to receive 1-50Ghz, initially. The plan is to digitize each received signal at each VLA antenna element as close as possible to the feed point. Digital signal processing will replace analogue signal processing. The sampler will be kept in the vertex room of each antenna element. This "digital radio" is then very flexible and computer controllable. The difficulty begins when pseudo random RF noise, which is generated by the digital circuitry like the MIB and the sampler module, finds its way back into the microwave feed antenna as a condition of being located near it. This RFI level must be kept well below the noise floor of each VLA antenna's microwave receiver. Only then can the EVLA be as beneficial to radio astronomy as it is hoped it will be.

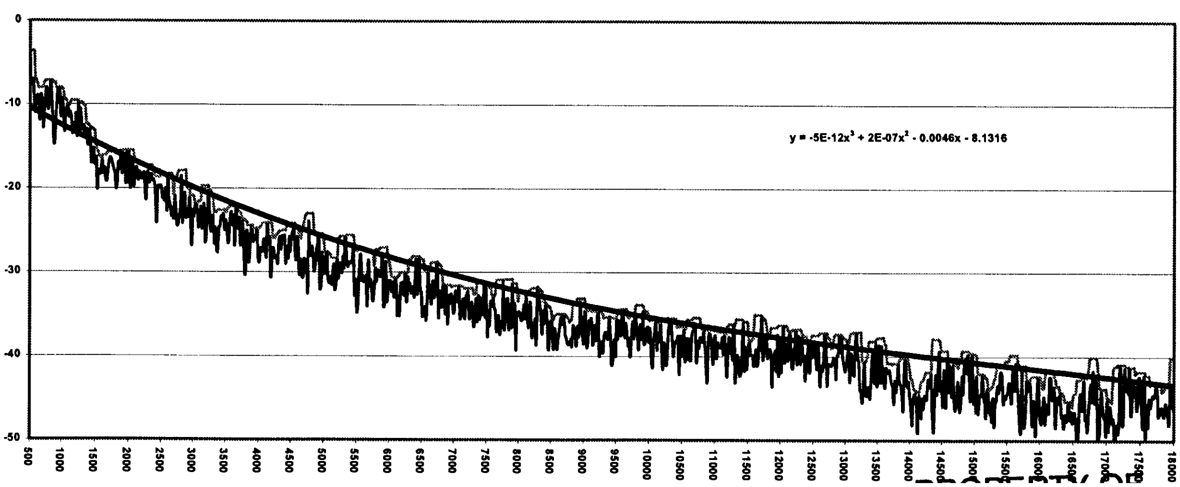
The noise floor depends on the receiver bandwidth and the integration time used in an observation. In this study of emissions levels and shielding requirements, I have devised experiments in cooperation with Dr. Pihlstroem that determined a useful RFI limit. These tests also allow the shielding requirements of various digital PCB's to be determined experimentally. We have achieved 130db of total shielding and this is expected to improve to about 160db.

Thus far I have characterized the 0.3-18Ghz shielding for the G, H, & LO racks as well as the sampler module. I have also characterized the 0.3-18Ghz emission levels for many digital circuits for use in the EVLA. Cleaning up these potential emissions before they block a large part of the desired EVLA bandwidth is where I will continue directing the IPG shielding, filtering, and RFI emission efforts here at the NRAO.

The RFI measurement chamber

The best quality of the RFI chamber is that it stops outside RFI from being included in spectral plots. It also has another less obvious characteristic in that it reduces signal losses by about 30 db as compared to what it would be for outdoor testing. It is acting like a hall of mirrors where most of the RFI of a device under test will eventually be funneled into an antenna then into our HP7000 spectrum analyzer. We use a computer to dump this data into an excel file from where we can correct and plot these data.

Finally the least expected property is in the way in which a directional antenna is rendered isotropic (within 1db) and is randomly polarized. The gain must be presumed to be 0db even if two high gain antennas are on axis. The best antennas for use in our chamber are the low loss, disk cones that seem to work with S11<20db from 300Mhz to 40 Ghz. The figure below shows the loss as a function of frequency for our RFI chamber with two identical cone antennas spaced eight meters.



Chamber loss vs Frequency (MHz)

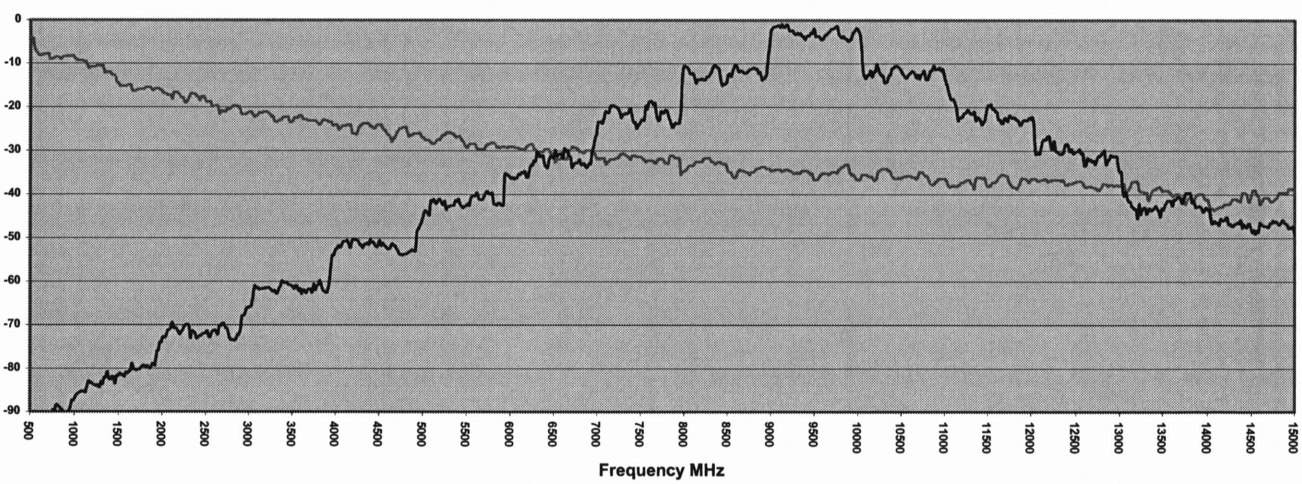
It is important to realize that we are looking through our chamber with a 3D SWR pattern that causes many nulls as the frequency is swept from .3-18 Ghz. One surprise is that for all of our antennas used in this chamber and in small metal boxes, the loss due to mismatch is not very different from its free space loss. We therefore do not try to account for this loss except outside each antenna's bandwidth where S11>-3db.

The low frequency end (< 300Mhz) becomes useless due to the limited number of modes by which the chamber can achieve coupling into the antenna probe. A sharp 300Mhz cutoff high pass filter also limits the preamplifier in the HP7000. At mid-band the chamber is quite useful and can provide well-calibrated amplitude measurements to +/- 1db. Taking only the peak amplitudes for more than three scans while in more than three locations in the chamber hot spot did this.

These hot spots are like the foci of an ellipse and are centered away from the conductive walls. Another popular method for reducing the SWR nulls uses a stirring fan as in a microwave oven to shift the modes around in an attempt to smooth out the received peak power. I am planning to try a method using moving aluminized Mylar triangles in each corner or perhaps surplus dish antenna sections.

The high frequency end of the chamber shows a large loss (45db at 18Ghz), which is preventing us from getting useful plots. I believe that is due to the loss accumulation of many bounces through wall coverings. Using a directional coupler I measured the signal loss for one bounce, as S11=0.4db for the wall paint, & 2db for the glue. I also measured the decay fall time at 1Ghz and 8Ghz. I saw 80 uS and 30 uS decay times after RF power was turned off. We can still get calibrated measurements but we are limited in our studies of shielding and emissions above 15Ghz. The figure below shows the calibration with a 0dbm equivalent isotropic radiated power (EIRP) reference, as it is stepped 10 db at a time.

RFI chamber EIRP error test, ref.=0dbm



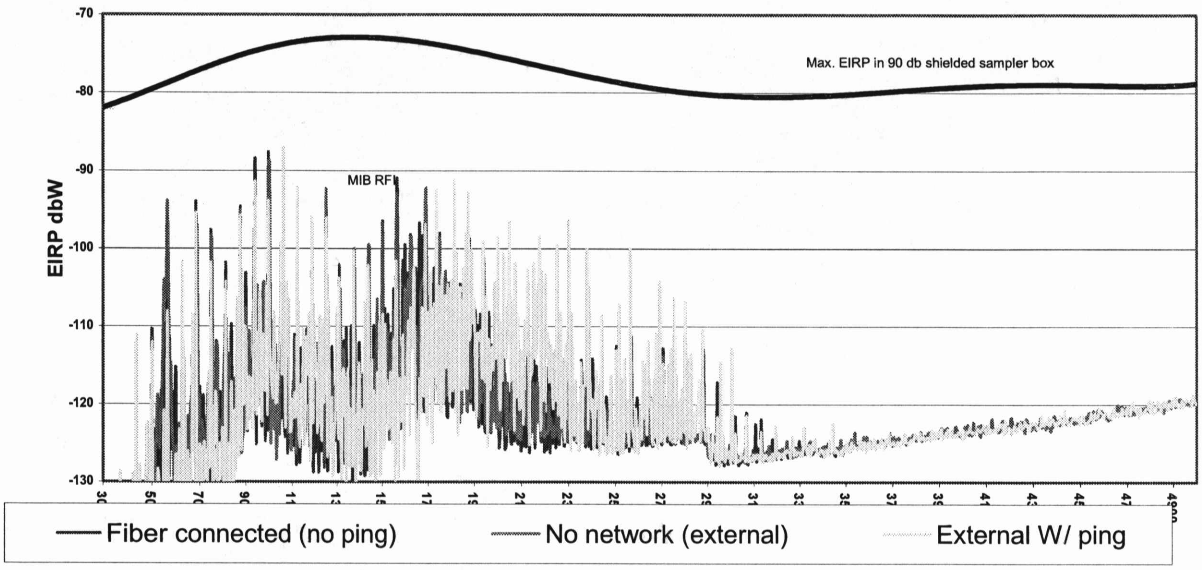
The calibration of the RFI chamber has been verified many times using two identical, broadband, disk cone antennas and a calibrated signal generator.

Future work for our chamber will include a visit to the physical sciences laboratory at UNM, where they have a similar chamber with unpainted walls. I will test and compare the 18 Ghz losses of the two chambers. I am also planning a test of reverberation decay time of these chambers. If it is determined that the paint is the cause of the –45db @18Ghz loss, then we will need to decide what actions we wish to take.

We will also be looking into synchronously stepping the spectrum analyzer with the signal generator. This will allow fast stepping while using a 10 Hz spectrum analyzer bandwidth. This will give an extra 50db of dynamic range in our RF chamber measurement system. We are running out of the dynamic range needed to measure shielding greater than 80db at L-band. After the next round of shielding improvements to the H-rack, I expect to be required to measure 160db of total shielding.

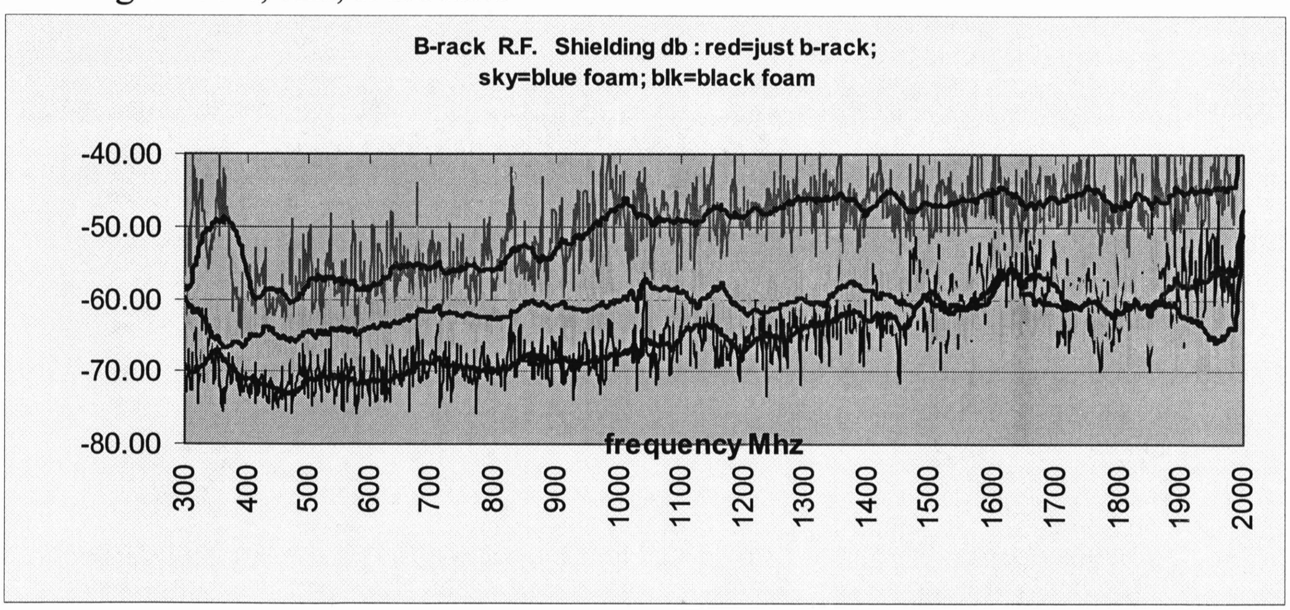
RFI levels from PCB's

The most RFI affected part of the spectrum seems to be below 15Ghz with the bulk of the offending RFI between 300Mhz – 3Ghz. However it becomes more difficult to design effective shielding above 3Ghz. Most digital circuitry I have seen using our shielded chamber emits levels < -90 dbW **[1]** (the same level used in the example in EVLA memo #46 by Rick Perley).

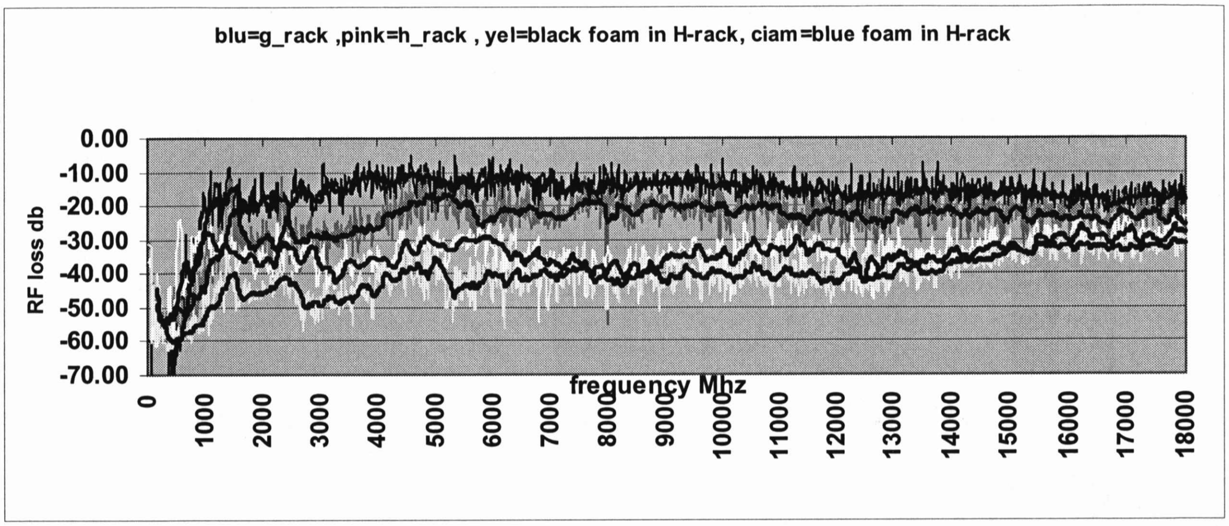


During the past year I have seen a case where harmonics in the 600ds of the WVR 500Khz clock are still ~25 db above the VLA noise floor (total power). We used the RFI chamber to verify that our improvements achieved a fix for the WVR. Imagine how high in frequency RFI could be if it is clocked at 90Mhz or 300Mhz. In the case of the "Digital Sampler Module" the clock is at 4.096Ghz!

Shielding of racks, bins, & modules

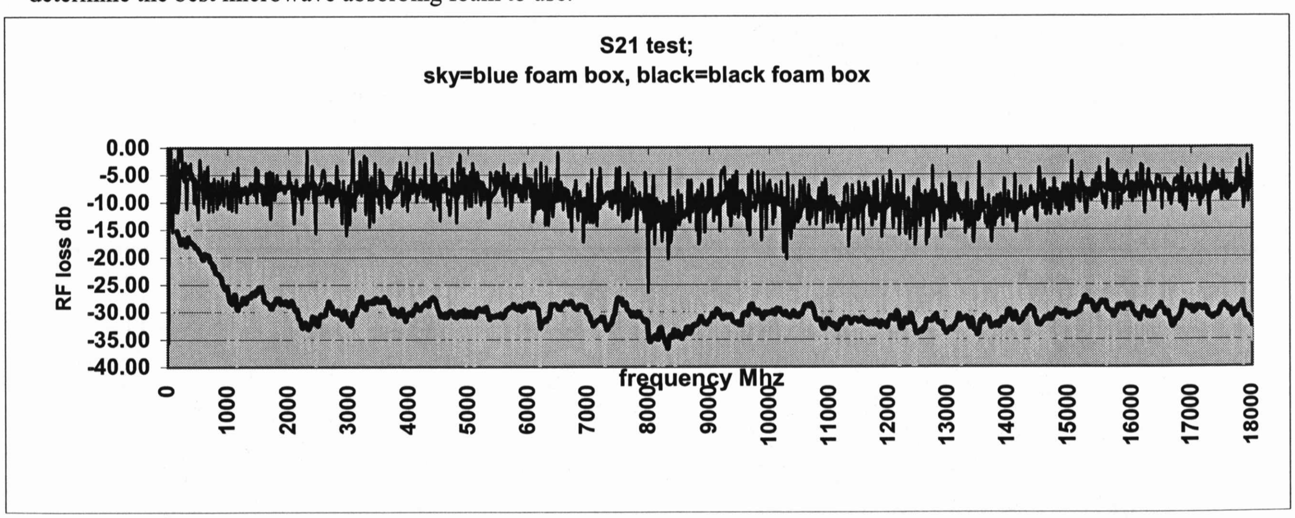


As seen in the adjacent plots, we have characterized the shielding for the G (35db), H (45db), & LO (60db) racks as well as the sampler module (90db).



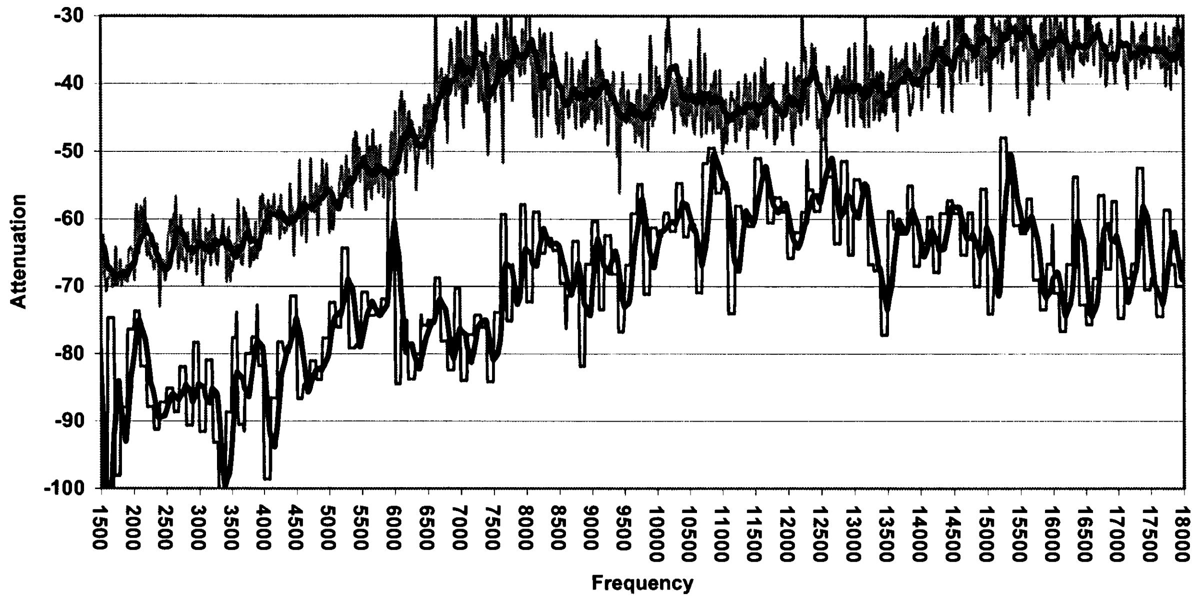
I was able to sniff and hunt down RF leaks in these boxes using a small spiral cone antenna. I discovered early that we had not quite got it right with our gasket seals being non-planar and air filters not shorted to the enclosing frames. These were fixed by using some silver conductive paint to short the honeycomb air filter to the frame then to short the frame to the sampler module. I still would like to recommend that we use two RF gaskets on both sides of any line of screws, spaced every inch or less, which join the lid and filters to the box.

The sampler module is the first "skin" of metal and absorber foam that shield the sampler PCB. The foam is carbon loaded and is placed in the E-field maximum where practical. Even though the E-field is zero at the conductive walls we are forced, by special limitations, to line these walls with 1.5 inch thick foam. Experiments were carried out to determine the best microwave absorbing foam to use.

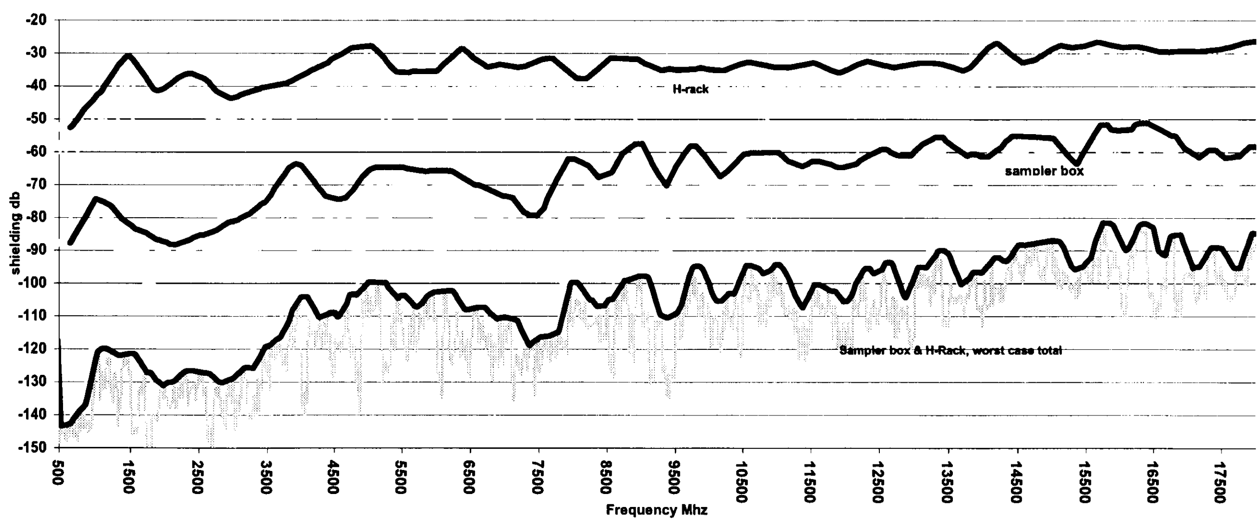


As seen in the above plot, I built two test foam boxes that completely enclosed our broadband disk cone antenna. The leakage through the foam (S21) seemed to indicate that the microwave foam produced by Cummuns microwave would be the best choice by 20db. However, when the H-rack walls were lined with the two types of foam we were surprised to see that the cheaper black Zote foam was almost as good as the blue, expensive Cummuns foam. The plot below is of the sampler module with Zote foam lined, in the RF chamber and shows about 90db of shielding below 3Ghz. This has been verified by experiments using the VLA.

Blue=Sampler Module Shielding. Pink= DC filter with wires added.

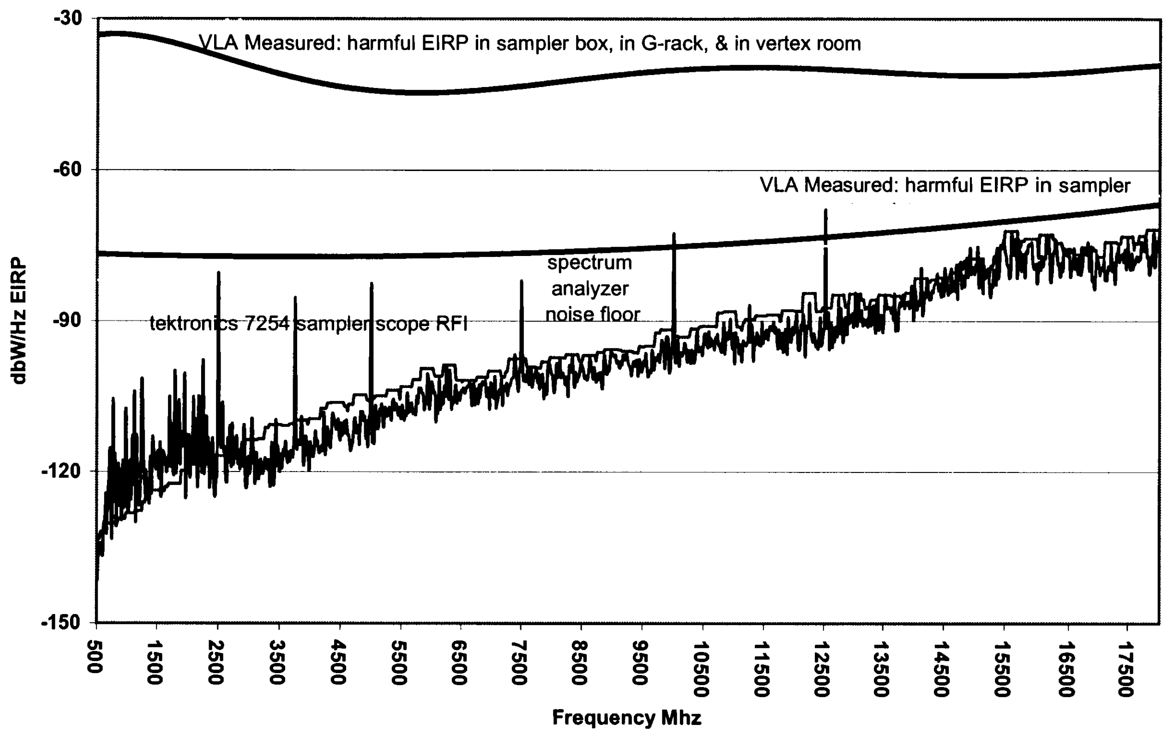


As seen in the plot, the DC feed through degraded the shielding of the sampler module to the –70db conducted leakage rating of the DC feed through. A separate shielded box was required for a second stage DC filter, which then fixed that leakage. If we want the most protection from conducted RFI on DC input wires, we need to use two of these –70db DC feed through. This sampler module will eventually be placed inside a shielded bin (h-rack) which is a "second skin" of metal and absorber foam giving improved total shielding (~130db). When these shielding layers are fully assembled the result will allow for successful RFI shielding of the sampler electronics.



If ever data lines are to be fully shielded we might also require two stages of filtering with a separate box where these filter stages join. This filtering requirement was discovered with the first attempt at the MIB PCB. Radiation from these data lines was the dominant RFI source.

I have carried out experiments with Dr Pihlstroem using the VLA, which yielded the shielding effectiveness plot below.



It shows that the maximum allowed EIRP in the vertex room (<-70dbW) using just the sampler modules shielding, is not going to be enough when you consider that the Tektronix 7254 example was also in a 20db shielded case during this measurement. If you move the Tektronix 7254 spikes up by 20 db, the safety margin for leaks is very small.

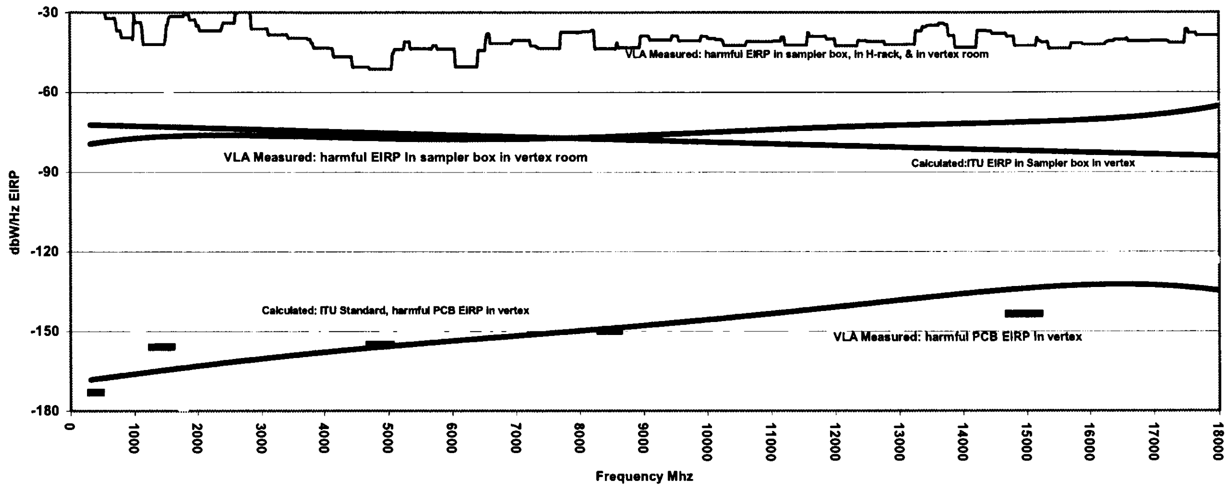
Plating types

I have tested two types metal of platting. One was tin the other was dichromate. There was a minimum of difference at most frequencies. Where only in two areas the dichromate was better by 5 db. The only other metal coating considered was Zincate with silver on top. It was not available but it may make a difference to the functioning of the RF gasket and will be tested later. For now the dichromate is non-corrosive and seems to work well.

ITU Standards & VLA measured standards

I recently measured the total loss from the vertex room to each feed antenna of the VLA. This loss can now be separated from the maximum allowed RFI levels in the vertex room to give a more accurate general case like Maximum allowed power at the feed antenna output, or SPFD at the feed antenna aperture. The table below gives the actual path loss from the vertex room to the antenna feed output connector. As seen in the plot below, when these loss measurements are applied to the ITU standard for spectral lines [2] it matches well to the VLA measured level of harmful interference.

Frequency…path loss	Frequency…path loss
330Mhz…-70db	14.95Ghz…-77.5db
1.42Ghz…-83db	22.48Ghz…-105db
4.75Ghz…-86db	40.00Ghz…-115db
8.40Ghz…-75db	



Conclusion

The design of the Sampler module PCB will require careful preventative RF confinement knowledge. It will also require the "second skin H-rack" and a second DC feed through. In my experience one RF gasket can only give 120db of shielding. This leaves us no margin for aging and abuse. We must have two RF gaskets on both sides of all rows of enclosure screws. The EVLA shielding requirements for the sampler PCB (as verified by the VLA tests) are amazingly stricter than first expected. However, now that we can relate both the VLA and the RF chamber measurements to shielding requirements, the work in the RF chamber is accurate and relevant to the EVLA hardware.

The peak spectral emissions level of the sampler PCB, are expected to be ~20db higher than the maximum allowed sampler module EIRP plot line. This means that the second layer of (~60db) shielding will be desirable if these enclosures are to be effective now and after several decades of time. A reasonable prediction is that the final total shielding will be ~130db below 15Ghz. This should make the EVLA able to run down to the narrowest of bandwidths with long integration times, and still not suffer RFI from the sampler module and bin. Now that the maximum RFI levels have been defined by experiment it is also possible to measure and control any PCB RFI emissions levels and to specify the amount of required shielding. However, prevention is better than a cure, so please contact me before the final PCB layout for your project. Preventing RFI is easier and cheaper closest to its source (the PCB). All circuitry intended to go in the EVLA antennas should be tested early in its development.

References

[1] Perley, R., 2002, EVLA Memo 46, "Minimum RFI Emission Goals for EVLA Electronics"

[2] International Telecommunication Union, Geneva, 1995, "Handbook on Radio Astronomy"

A special thanks to (Chris Patchek & Raydell Tapia) the Students who helped with some of the measurements used in this report.