



Suppression of Self-Generated RFI for the EVLA

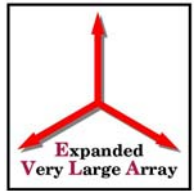
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(with important contributions from Steve Durand,
Jim Jackson, Michelle Jenkins, and many others)

National Radio Astronomy Observatory



Clicking and Clacking Everywhere



- The EVLA will be an ‘all-digital’ telescope.
- Amplified signals will be sampled at the telescope
 - 8 x 3-bit channels at 4 GSamp/sec at upper bands
 - 4 x 8-bit channels at 2 GSamp/sec for lower bands.
- All digital Monitor Interface Boards (MIB).
 - 30 MIBs per antenna.
- Digital 10 GB/sec FO system for signal transport.
 - 12 channels at 10.24 Gb/s each = 122.9 Gb/sec.
- Massive digital correlator at control building.
- Astronomical signals are weak -- $\sim 10^{-5}$ of system noise.
- We must ensure locally generated interference is prevented from reaching the antenna feeds.



Harmful Levels



- RFI is considered harmful if its PFD, F_h , entering through a sidelobe of gain G_{sl} , exceeds 1/10 of the PFD of the target source with SPFD S_{obj} , observed with forward gain G , with a bandwidth, $\Delta\nu$:

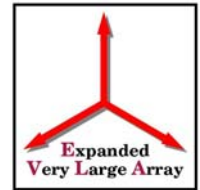
$$F_h < 0.1 S_{obj} \left(\frac{G}{G_{sl}} \right) \Delta\nu \quad \text{Watt/m}^2$$

- If we take the source SPFD S_{obj} to be the thermal noise level, we directly find:

$$F_h < \frac{0.4\pi k T_{sys}}{G_{sl} \lambda^2} \sqrt{\frac{\Delta\nu}{\tau}} \quad \text{Watt/m}^2$$



ITU and EVLA Levels



- The harmful level depends upon the telescope's resolution bandwidth and integration time.
- EVLA standard: 9-hour integration with 1 km/sec velocity resolution ($\Delta\nu = 1000/\lambda_m$ Hz), giving

| Band (GHz) | F_h (dB W/m ²) | | $\Delta\nu$ (kHz) |
|---------------|------------------------------|------|----------------------|
| | ITU | EVLA | |
| 0.3 | -203 | -212 | 1.1 |
| 1 – 2 | -195 | -204 | 5 |
| 2 – 4 | -187 | -196 | 10 |
| 4 – 8 | -180 | -188 | 20 |
| 8 – 12 | -175 | -172 | 33 |



EVLA Emission Limits



- The maximum allowed EIRP, P_E , within bandwidth $\Delta\nu$, for an array can be written as:

$$P_E \leq \frac{4\pi r_m^2}{G \cdot S \cdot A} F_h \quad \text{Watts}$$

where

$r_m = \sqrt{r_1 r_2}$ is the geometric mean distance

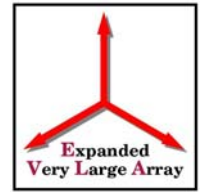
$G = \sqrt{G_1 G_2}$ is the geometric mean antenna gain

$S = \sqrt{S_1 S_2}$ is the geometric mean shielding

$A =$ Array Attenuation Factor



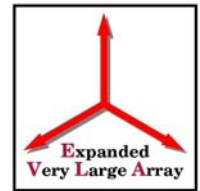
Limit on Power Emission



- For the EVLA, with an emitter in the vertex room,
 - $r_m = \sqrt{3 \cdot 33} \approx 10$ meters
 - $G \sim 1$ (but sidelobes within 20 degrees of the beam center can have $G \sim 20$ dB)
 - $S = -30$ dB (at 20cm is the ‘natural’ shielding we get with the existing vertex room and antenna reflector.)
 - $A \sim 0$. Although the fringe winding can provide attenuations better than -40 dB, it can also provide nearly nothing (e.g. 327 MHz, D-configuration), so we must assume the worst case. (See EVLA Memo 49).
- We must now estimate additional shielding, S_M , required to meet the emission standards.



Shielding Equation



- In engineering units, the relationship becomes

$$P_E (dBW) + S_M (dB) \leq$$

$$F_h (dBW/m^2) + 10 \log(4\pi r_m^2) - G (dB) - S (dB) - A (dB)$$

- For the EVLA at 20cm,

$$P_E + S_M < -204 + 31 - 0 + 30 - 0 = -143$$

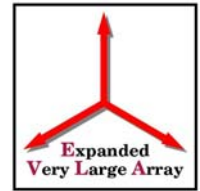
or, for a 1 μ W transmitter (in 5 kHz BW),

$$S_M < -83 \text{ dB}$$

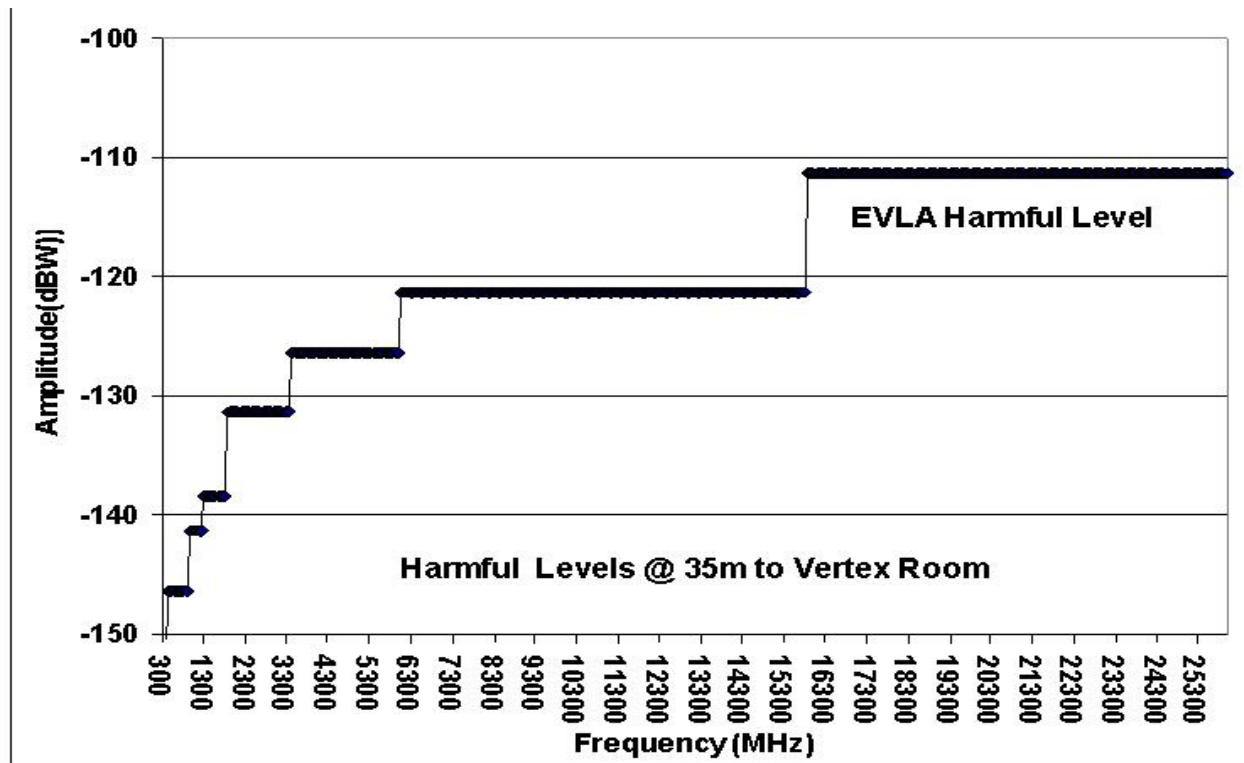
- This is the **minimum** level of shielding we need to design for, with a 1 μ W emission level.



Maximum Power Emission for Adjacent Antenna

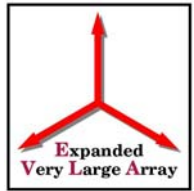


- For a distance of 35 meters (shortest EVLA spacing), the maximum EIRP of a module in the vertex room, within the minimum bandwidth assumed, must be less than:





RFI Emission Reduction



- Layered approach
 - Implement low noise PCB design techniques
 - MIB, DTS and other PCB's exceptionally quiet
 - Custom shielded and filtered module enclosures
 - Use of DoD “Tempest” certified RFI racks
 - Use of differential signaling or fiber for digital signals
- RFI chamber tests of all hardware



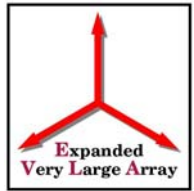
PCB Design



- Low noise printed circuit boards
 - Ground planes
 - Impedance matched traces
 - High speed traces on inner layers
 - Stitched vias
 - Differential signaling (LVDS/ PECL)
 - Layered voltage regulators
 - Final regulators at load
 - Filtered I/O signals
 - MIB processor has on-chip memory and bus drivers.
- At the next level, good module and rack design required to keep RFI from escaping.



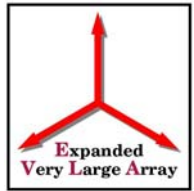
Module Design for Suppression



- Basic DTS Module design:
 - 6061-T6 Aluminum with $\frac{3}{4}$ inch thick RFI tight air filters on top and bottom.
 - Leakage problems through air filters eliminated through use of silver conductive RTV and silver paint.
 - The front panel is attached with a row of screws, with 1 screw per inch, with two RFI gaskets in dovetail grooves on each side.
 - Conductive contact of the gaskets to the metal is essential, so the gaskets must be cleaned each time the module is opened



Module Design (cont).



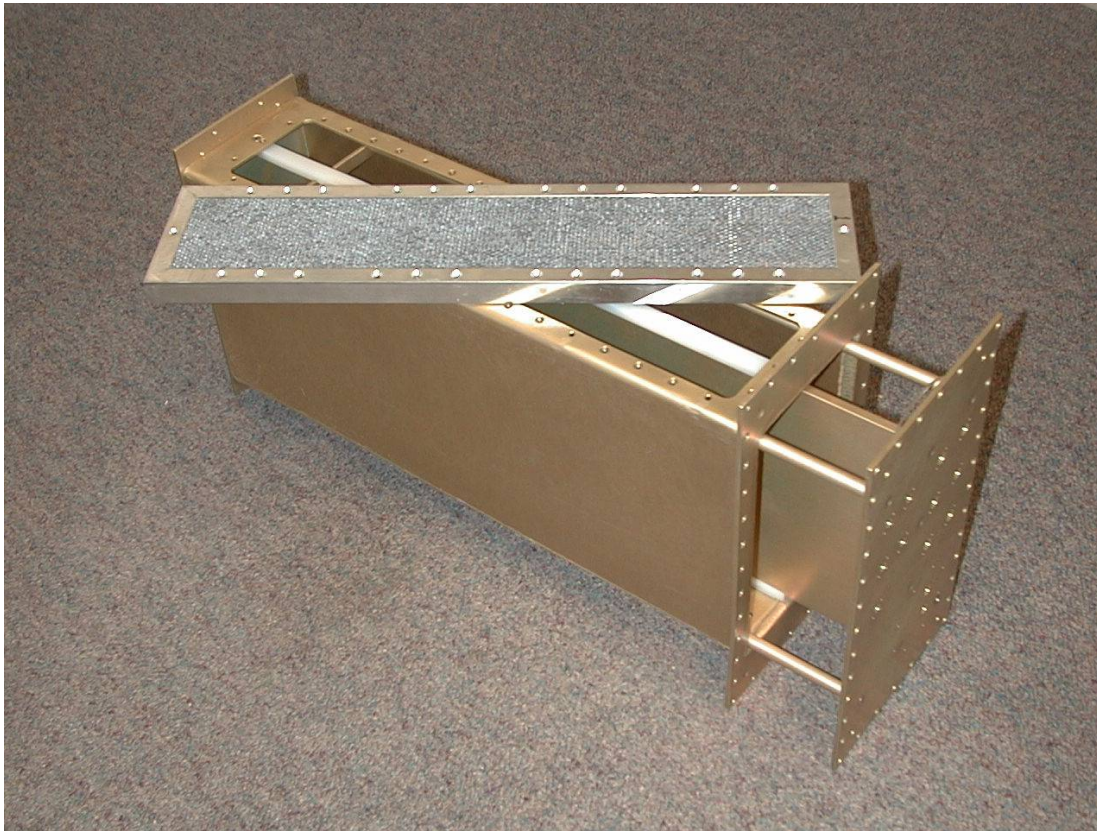
- Limited number of input/outputs
 - +48 V DC filtered (double regulated)
 - Optical outputs:
 - 3-IF, 2 Ethernet, 1 Timing
 - One Analog Timing RF Coax
- No blind mate back plane connectors
- Reusable RFI gaskets
- Tests show ~65 dB attenuation.



The D301-4 Module



- This crucial modules contains the digitizers and the data transmission system.:





Dove-Tail Gasket Groove

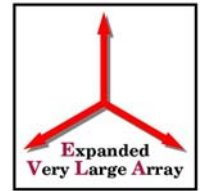


- As seen below





Measuring Module Emissions



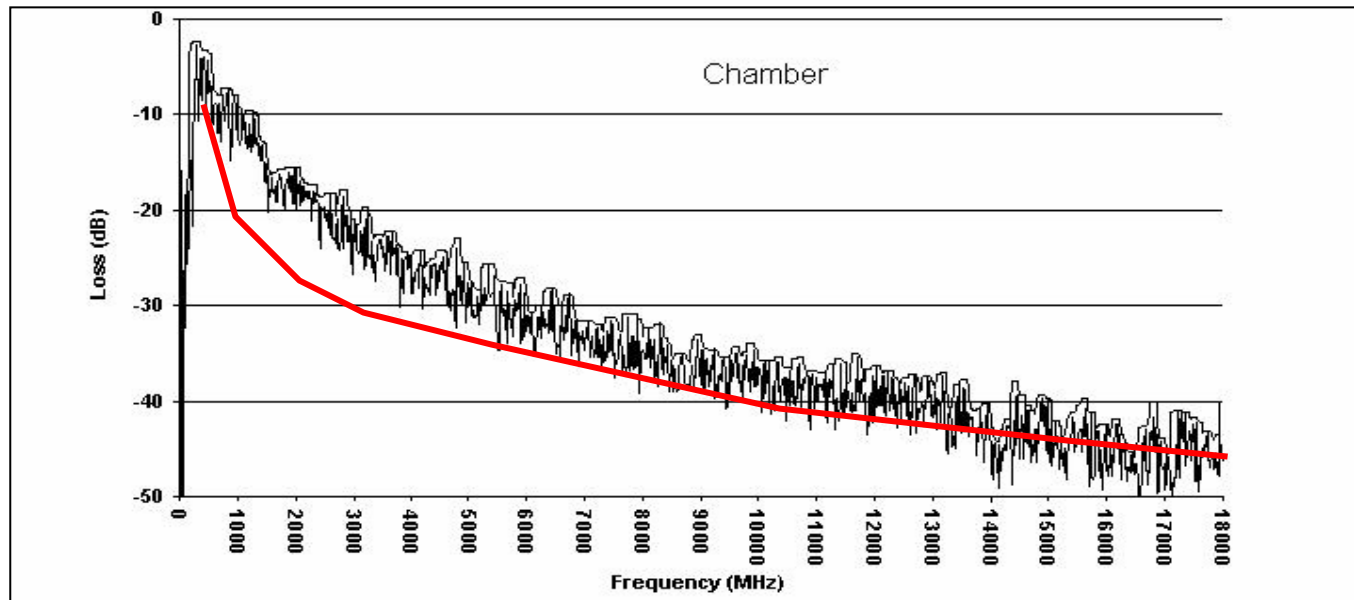
- Module emissions are measured using a shielded chamber.
- Provides ~ 70 dB attenuation from outside interference.
- No absorber in chamber
- Chamber acts like a microwave oven, and dramatically increases energy density.
- Advantage – increases SNR by 30 to 40 dB.
- Isotropizes emission characteristics (direction and poln.). Measurements use an isotropic antenna.
- Amplification factor must be calibrated out to establish true power levels.



Reverberation Amplification

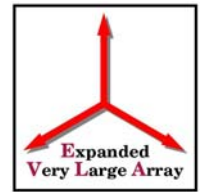


- Black trace: coupling between two isotropic antennas separated by 8 meters in chamber.
- Upper trace used to calibrate measured emission spectrum.
- Red trace: free space coupling plus 30 dB.

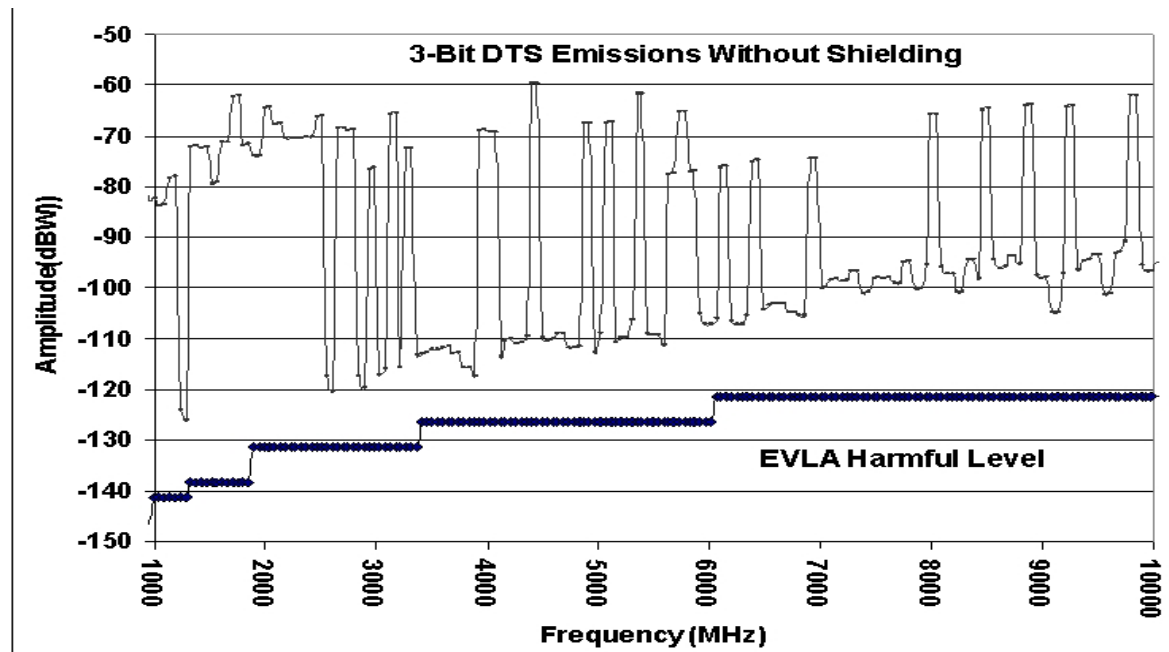




Calibrated DTS Emissions



- Calibrated spectrum (1 MHz resolution) from DTS prototype (containing two 3-bit samplers and three OF links).
- 60 to 80 dB shielding is needed to meet the minimum requirement – and we want an extra 40 dB for safety.

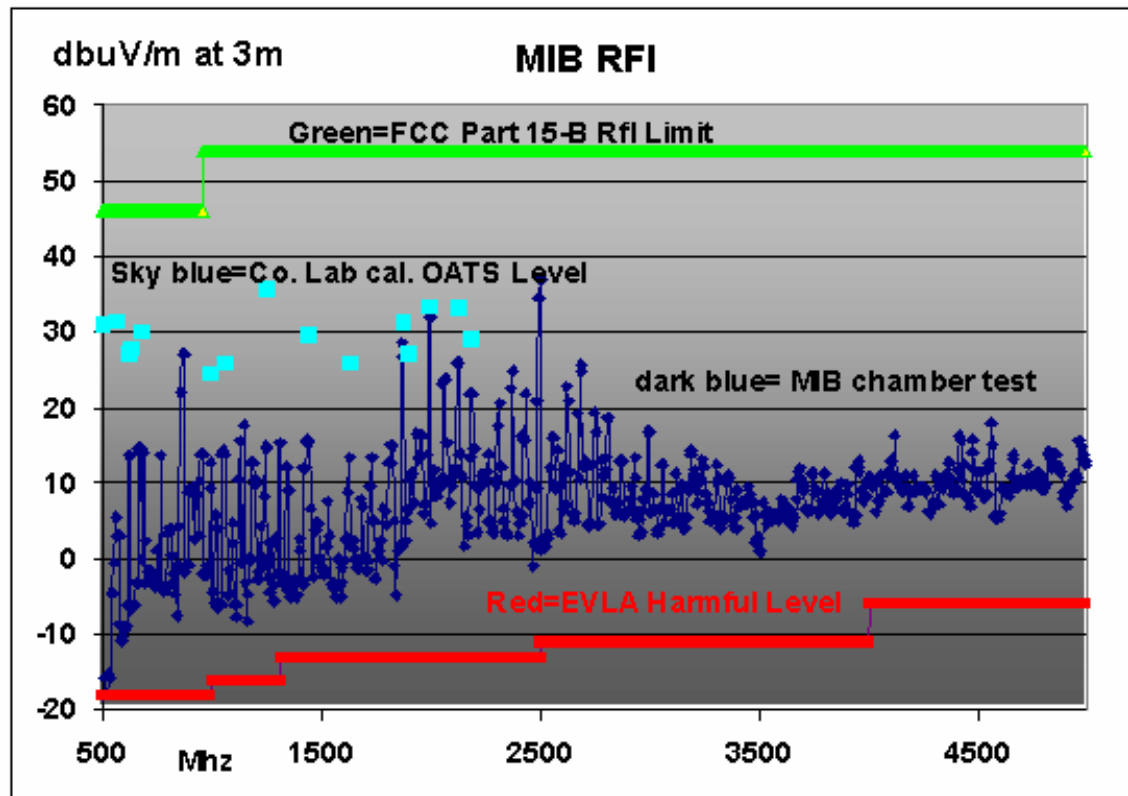




MIB Spectrum

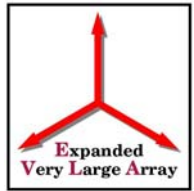


- MIB emission spectrum very good – about 30 dB less than the DTS board.

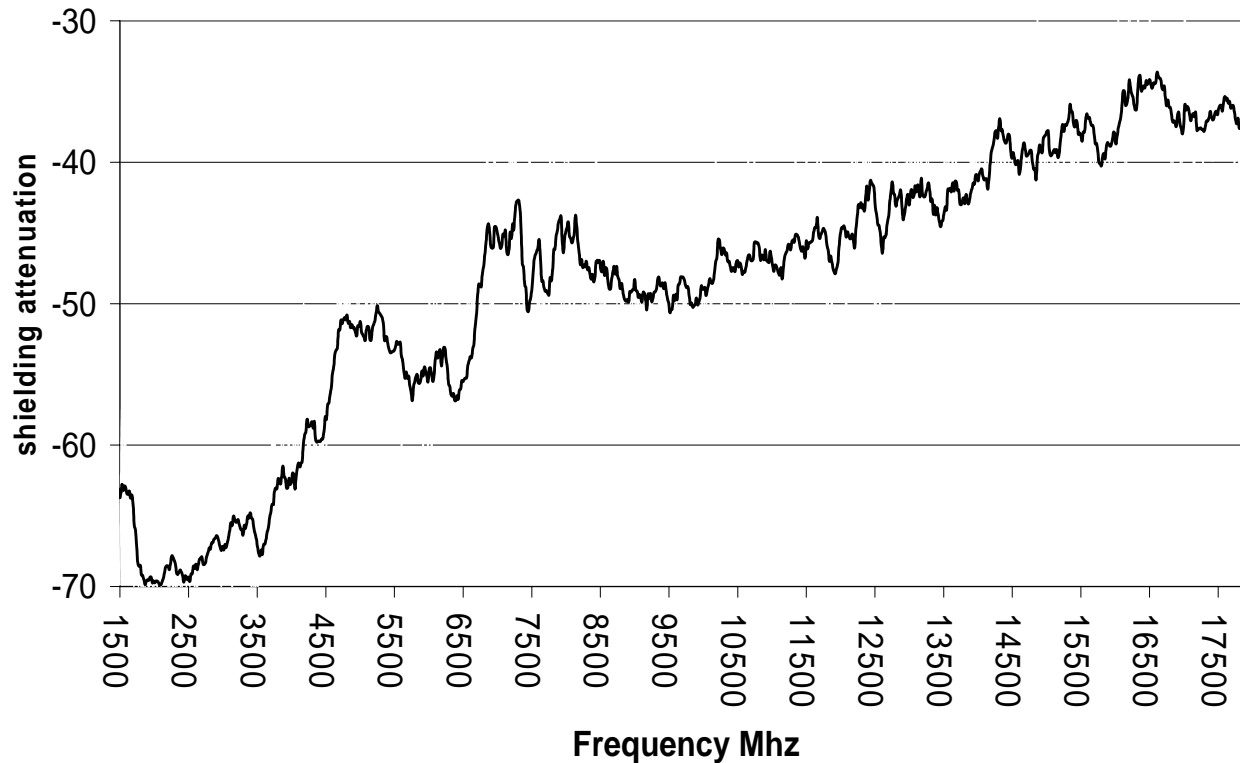




DTS Module Attenuation

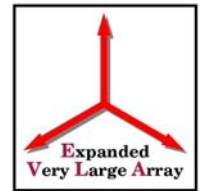


- Measured attenuation by module alone.
- This is ~40 db short of our goal.
- 25 more dB with absorber – we hope to avoid using this.





Module Rack – the next level

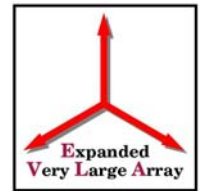


- LO/IF and Front End Racks
 - Commercial RFI racks
 - Made by Equipto Corp.
 - DoD “Tempest” rated
 - (approx 55dB @ 5GHz)
 - All I/O signals filtered or on fiber

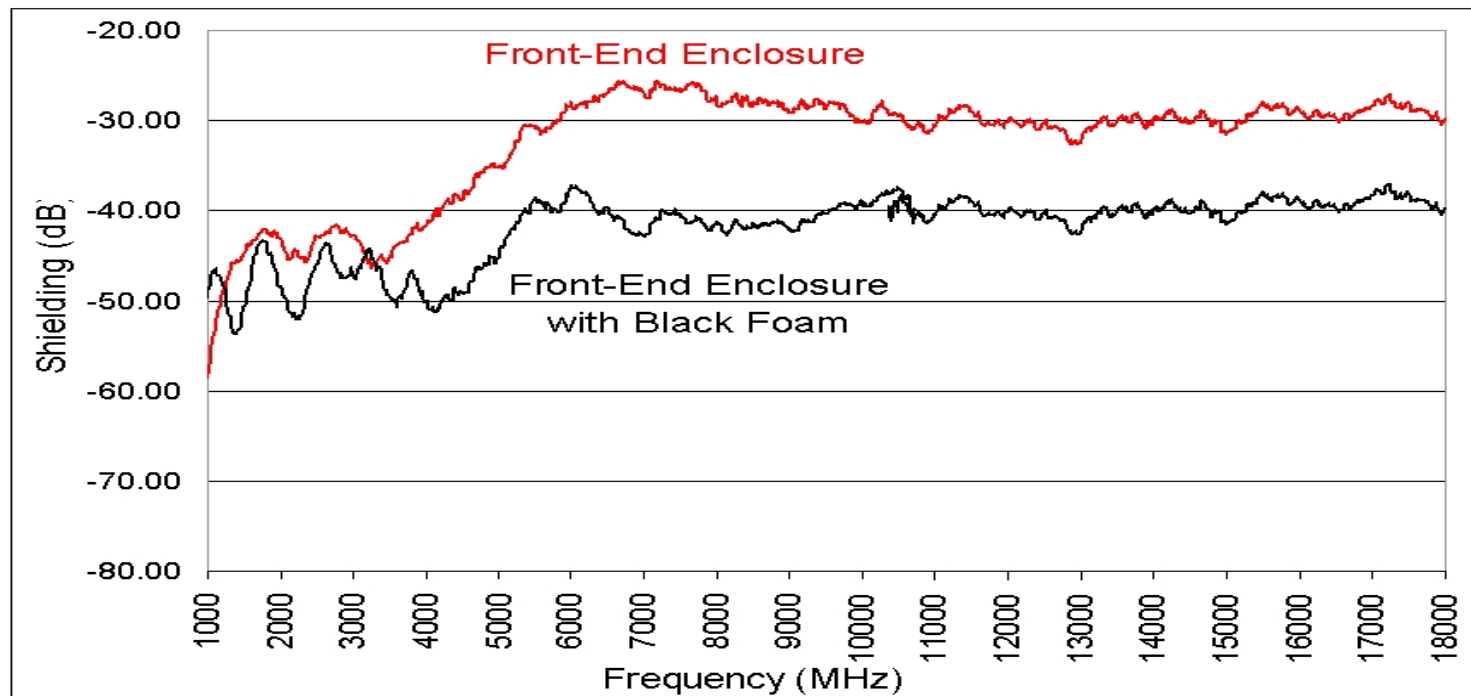




Front-End Rack Attenuation



- The module attenuation (even with absorber) is not sufficient.
- Must use RFI-tight racks as well.
- Below is the measured attenuation, with and without absorbing foam.





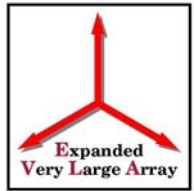
RFI Absorbing Foam



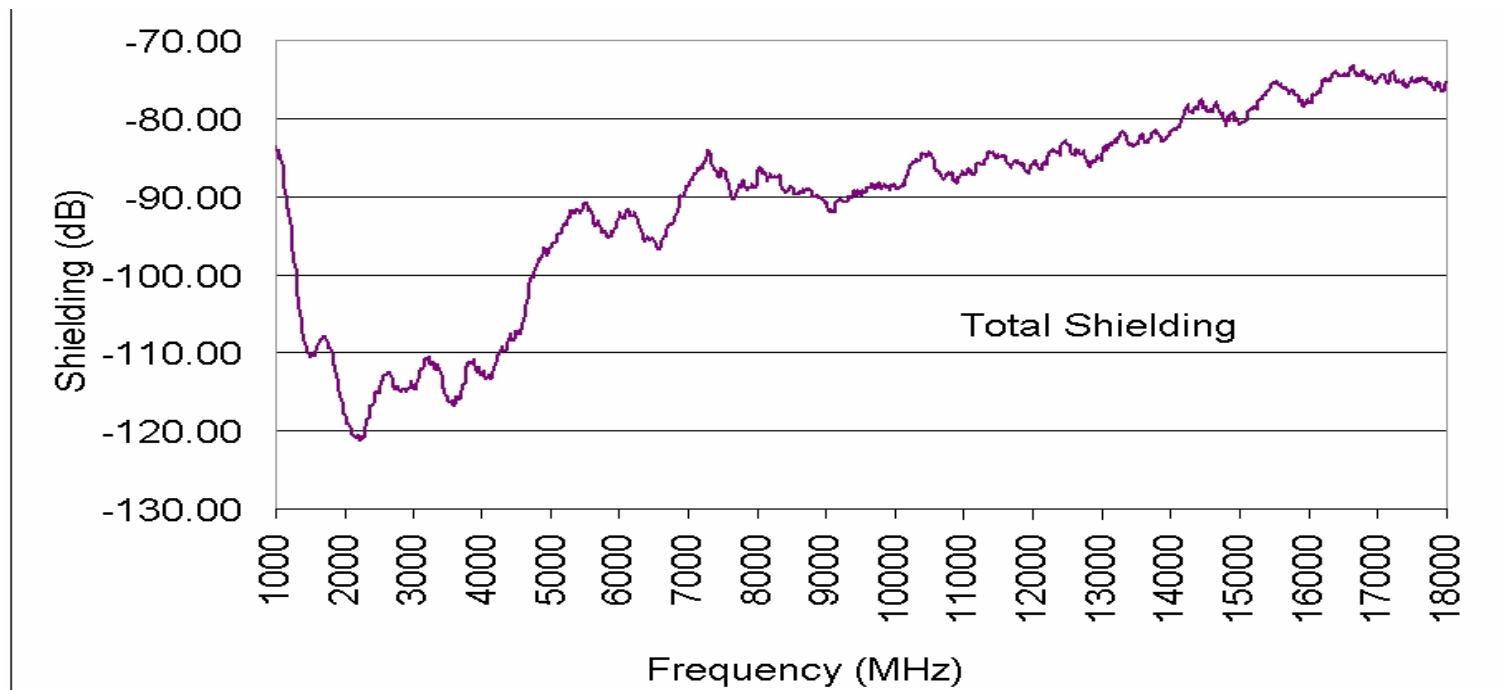
- Used to lower internal power density, and hence emission levels.
 - Cumming MicroWave Corporation
 - Blue C-Ram FLX-1.4
 - Capital City Foam Produces Inc.
 - Conductive Cross Linked Polyethylene
 - LD32-CN – 1.3” thick
 - Flame Retardant – Long Life Stable



Total Attenuation

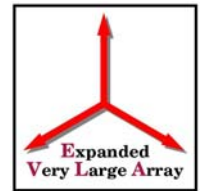


- The total attenuation is shown below.
- This includes the module and rack attenuation, plus absorbing foam in the rack (but not the module).

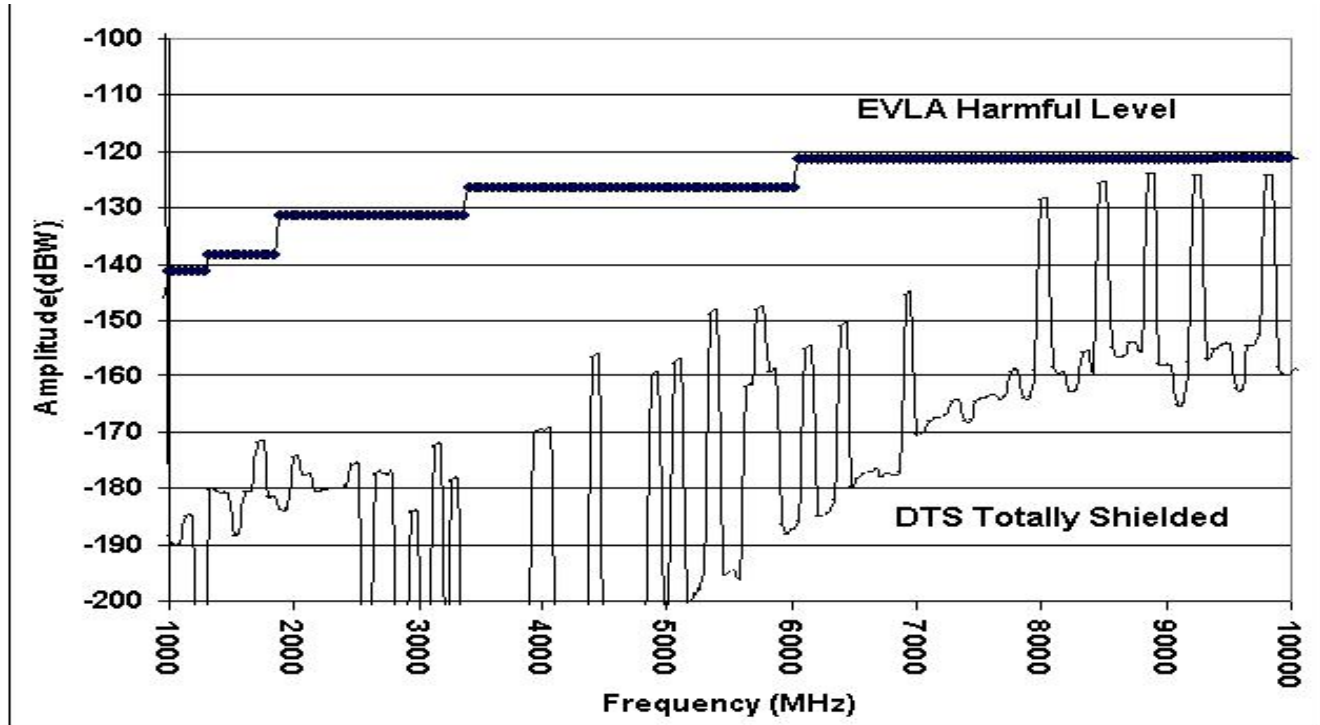




Anticipated Results



- The anticipated DTS emission spectrum, following these RFI containment strategies, is shown below.
- Up to 25 dB more attenuation possible with foam in the DTS module.





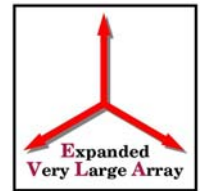
VLA Tests



- The VLA itself is the best means for testing the efficacy of these designs.
- The narrow bandwidth of the current correlator limits the tests, but results are encouraging.
- Narrow bandwidth (6 kHz) observations of test antenna with EVLA equipment shows no detectable extra emissions.
- Further tests will be done as new equipment arrives and is installed.



Summary



- EIRP levels from the antenna vertex room must be less than -110 (high frequencies) to -145 (low frequencies) dB W.
- With anticipated microwatt emission (per 5 kHz) from digital equipment, added shielding in the module and rack must exceed 80 dB, and preferably 120 dB.
- These levels have been obtained with good module and rack design, with absorbent foam in the rack.
- On-telescope tests show no detectable emissions from available modules.
- Up to 25 dB more attenuation, if needed, could be obtained with absorbent foam in the modules.