Suppression of Self-Generated RFI for the EVLA

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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 -- ~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, $\Delta\nu$:

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

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

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

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	F_h (dB W/m^2)		$\Delta\nu$
(GHz)	ITU	EVLA	(kHz)
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:

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

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 ~ 1 (but sidelobes within 20 degrees of the beam center can have G ~ 20 dB)
  - S = -30 dB (at 20cm is the ‘natural’ shielding we get with the existing vertex room and antenna reflector.)
  - A ~ 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

$$P_{E\,(dBW)} + S_{M\,(dB)} \leq$$

$$F_{h\,(\mathrm{dbW/m^2})} + 10\log(4\pi r_m^2) - G_{(\mathrm{dB})} - S_{(\mathrm{dB})} - A_{(\mathrm{dB})}$$

- For the EVLA at 20cm,

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

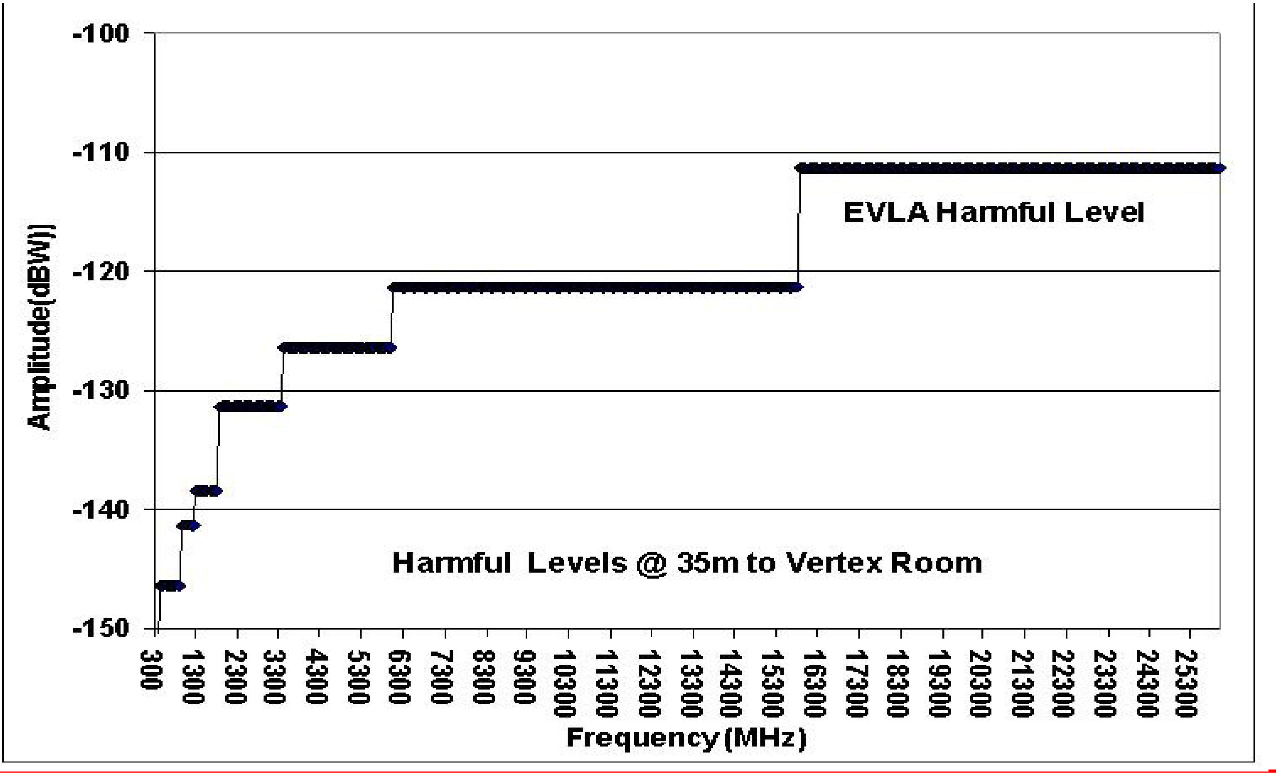
or, for a 1 μW transmitter (in 5 kHz BW),

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

- This is the **minimum** level of shielding we need to design for, with a 1 μW 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 ¾ 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

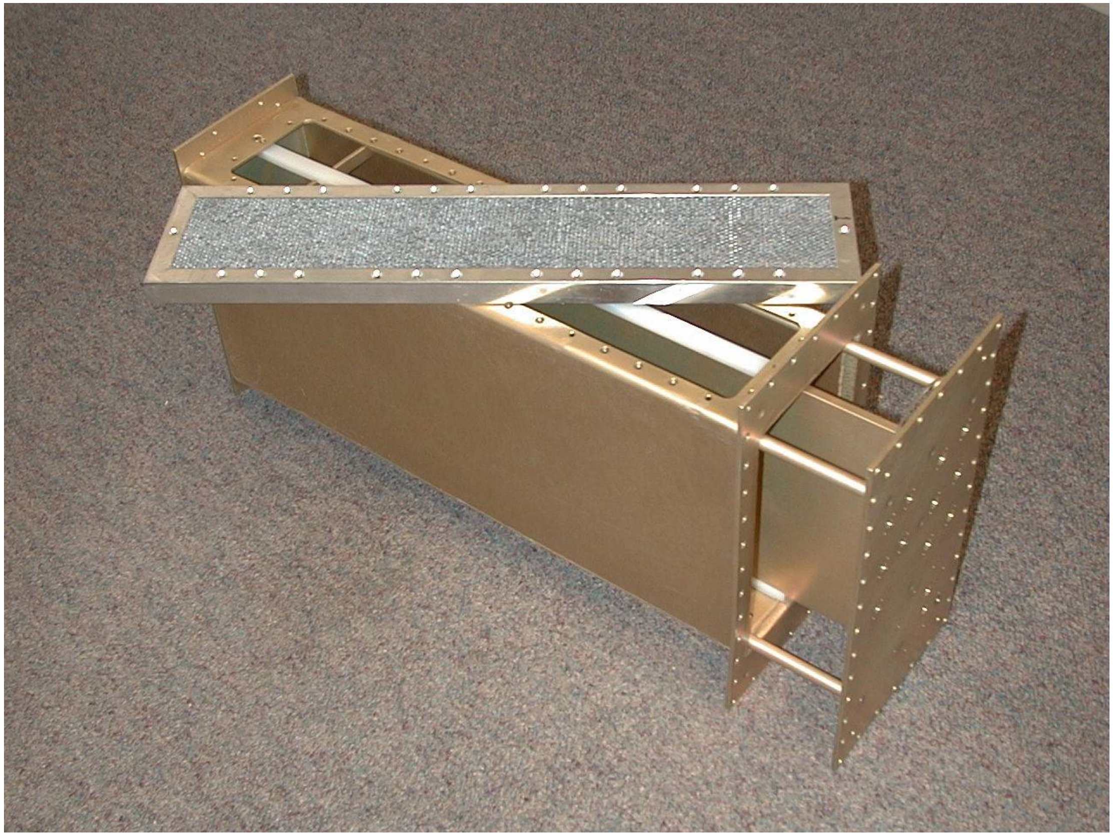
Module Design (cont).

- 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

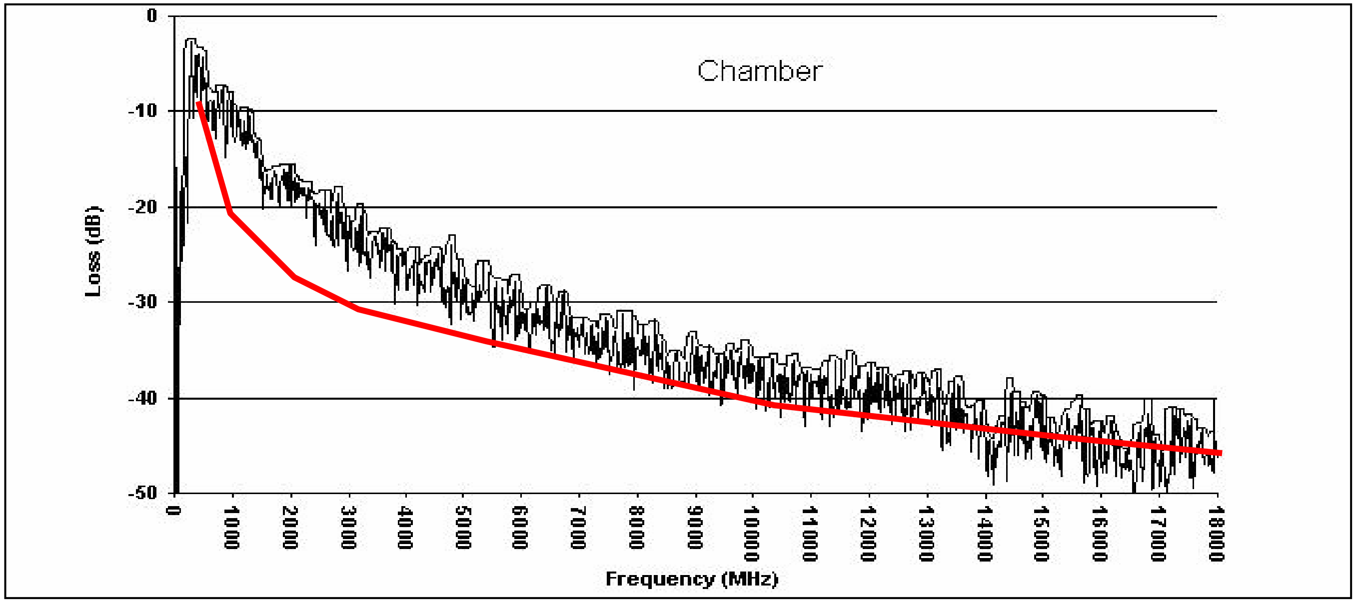
- As seen below

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.

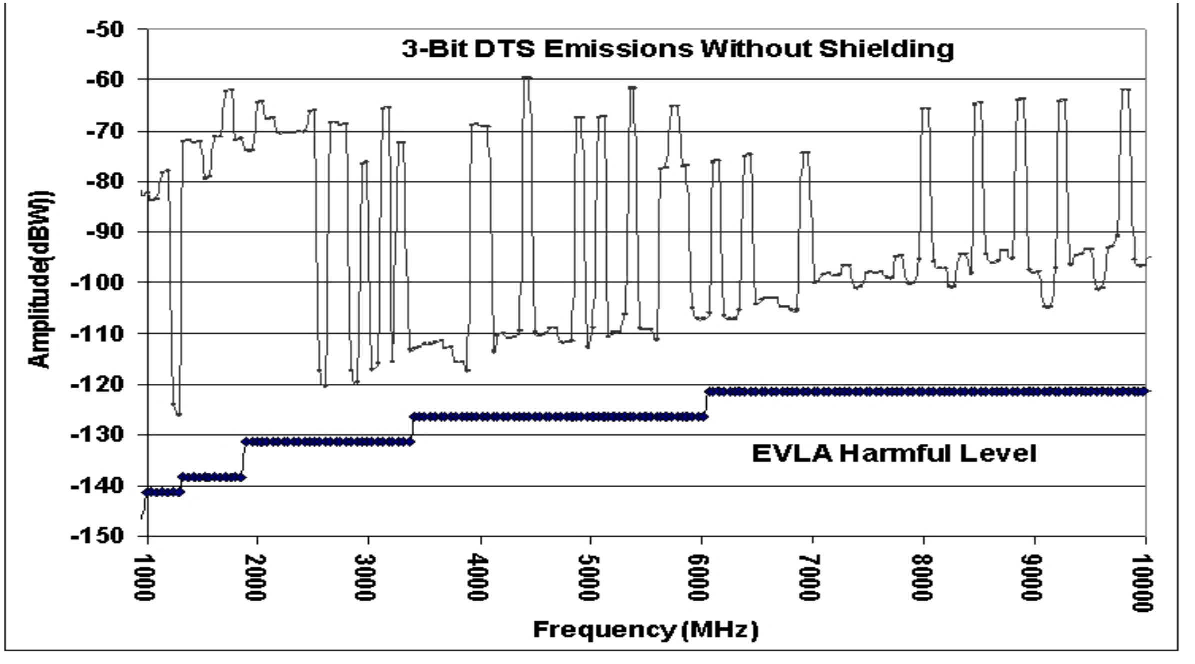
Reverberation Amplification

- 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.



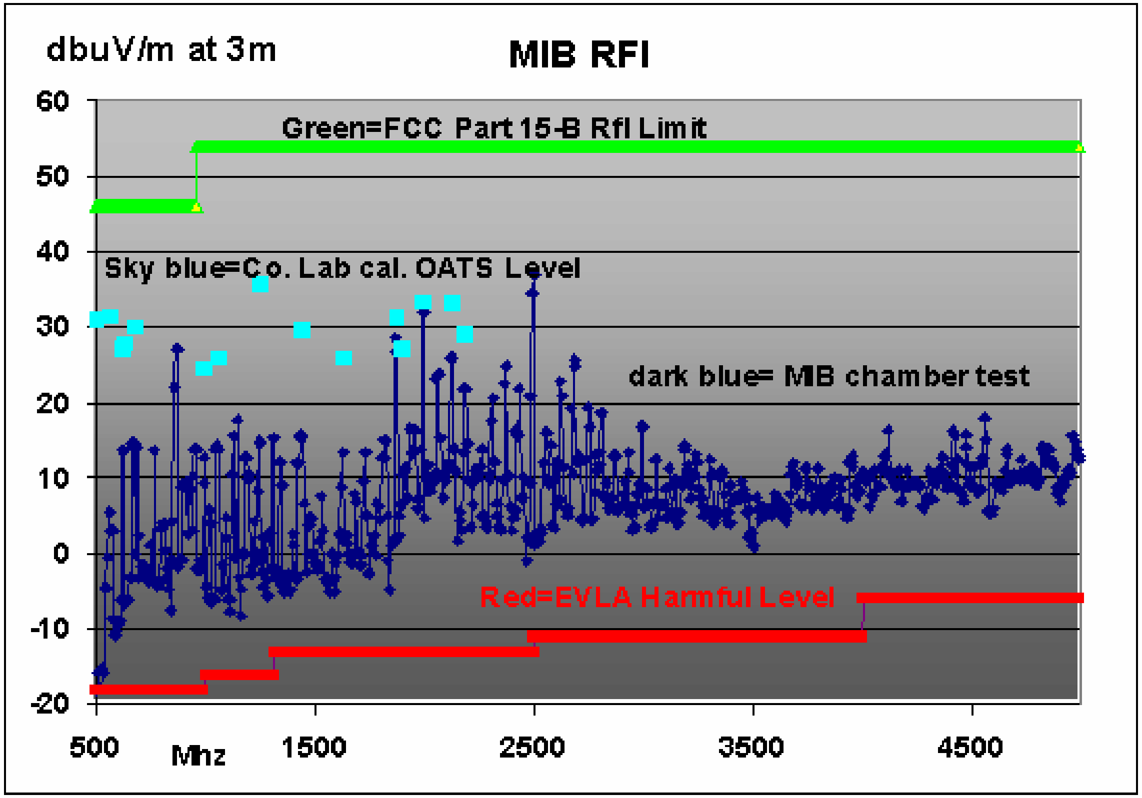
Calibrated DTS Emissions

- 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.



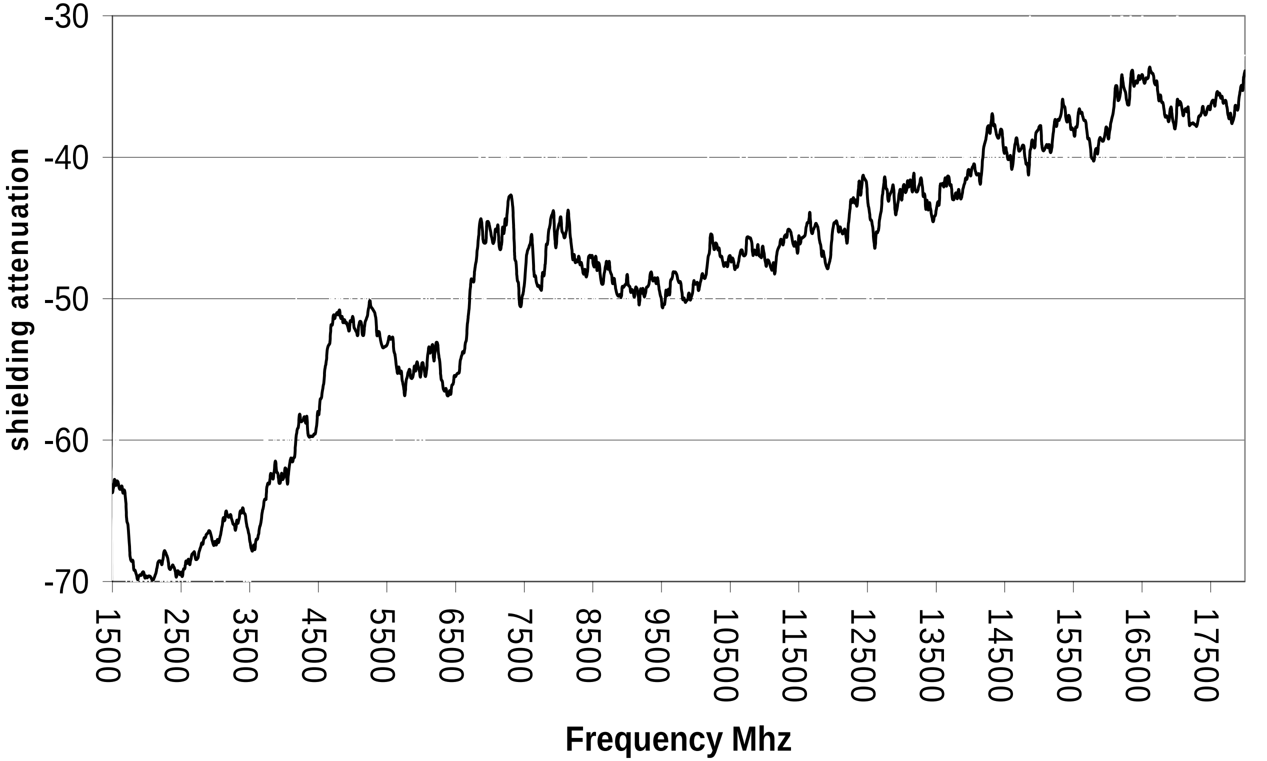
MIB Spectrum

- 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.

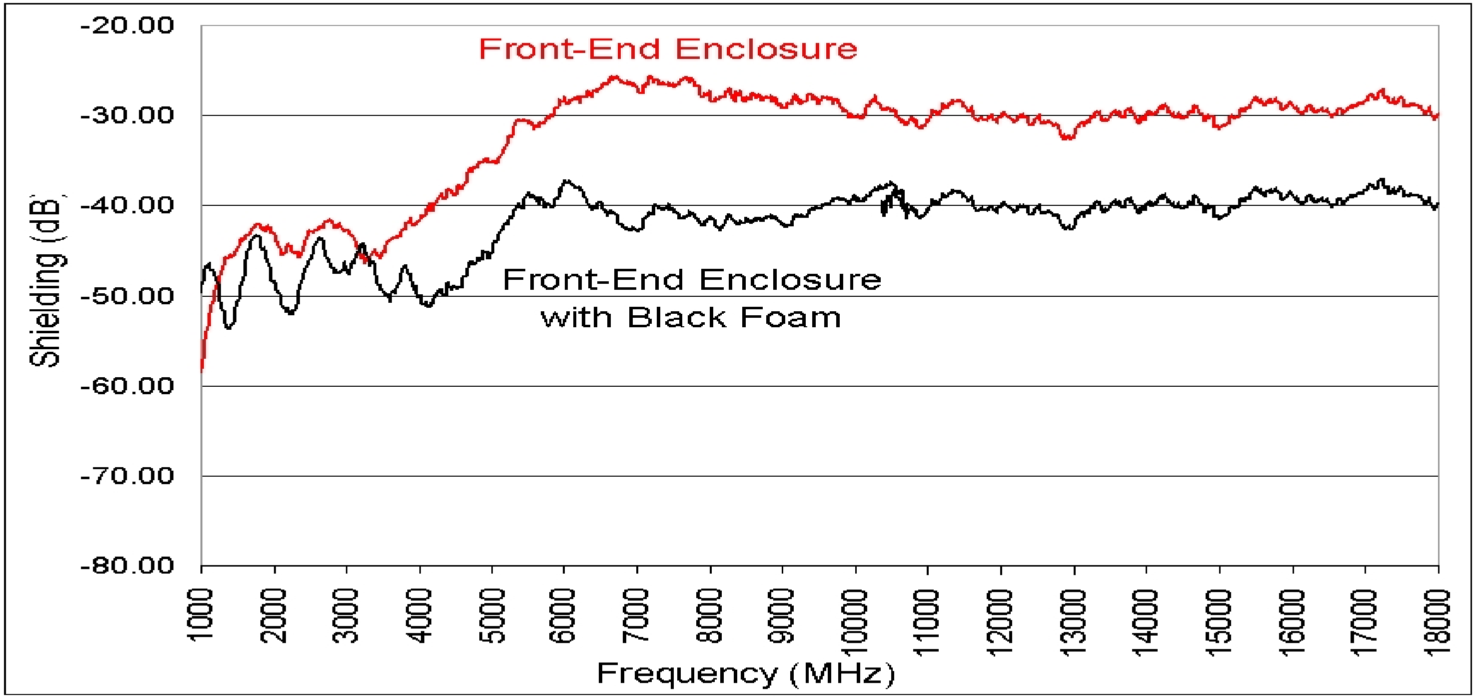


Module Rack – the next level

- 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.

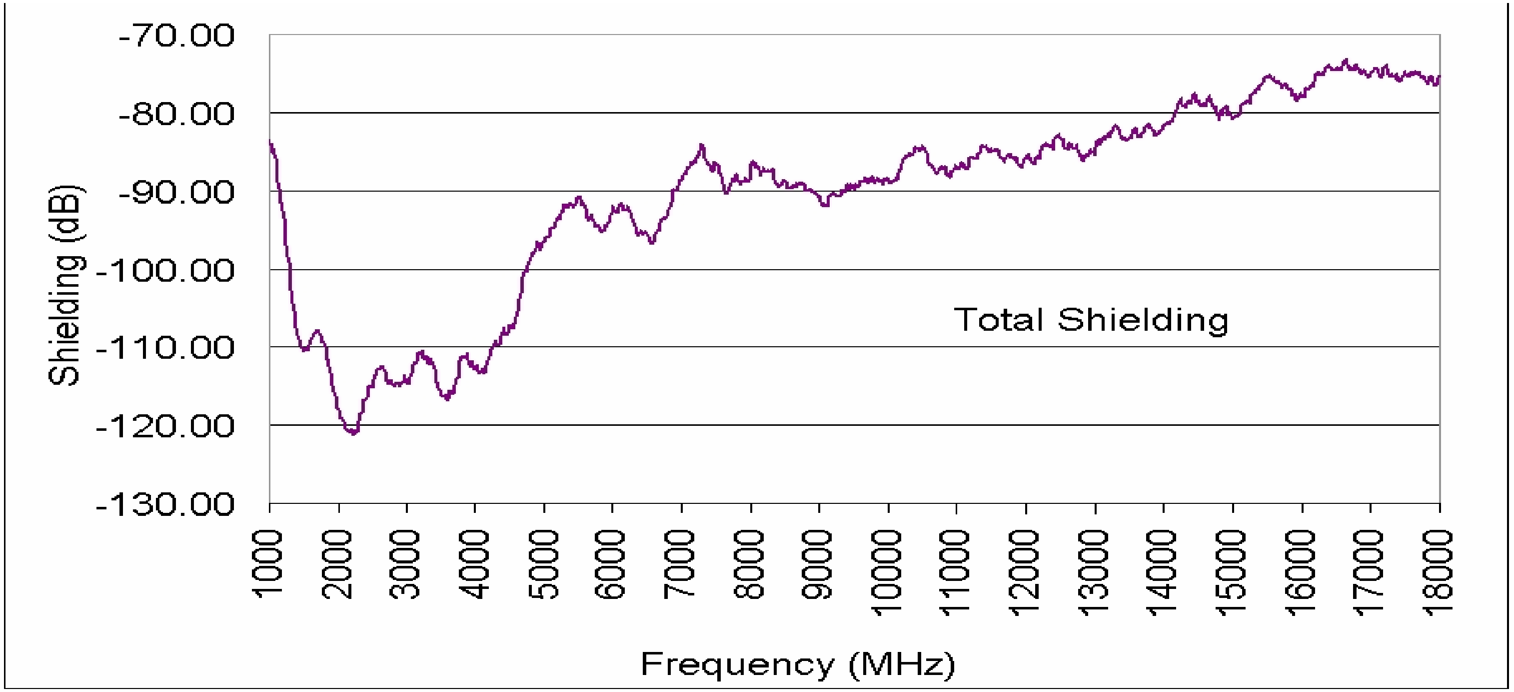


RFI Absorbing Foam

- 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

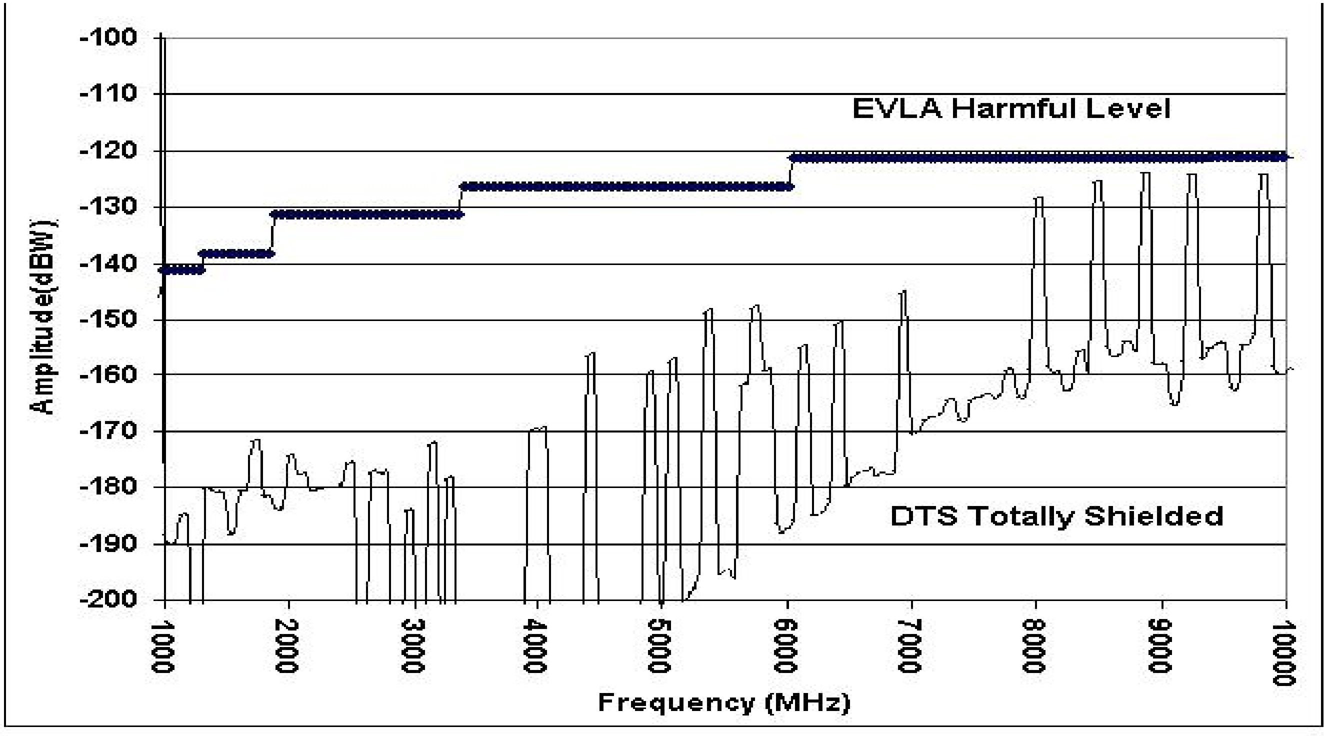
Total Attenuation

- 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.