RFI Management for the EVLA

Principles and Progress

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EVLA Emission Limits

- EVLA emission limits based on standard treatment:

$$INR = \frac{P_{RFI}}{\sigma_P} < 0.1$$

  - P_{RFI}= RFI power, as measured at the input to the receiver, within some astronomical bandwidth, $\Delta\nu$,
  - σ_P is the system noise power, referenced to the receiver input:

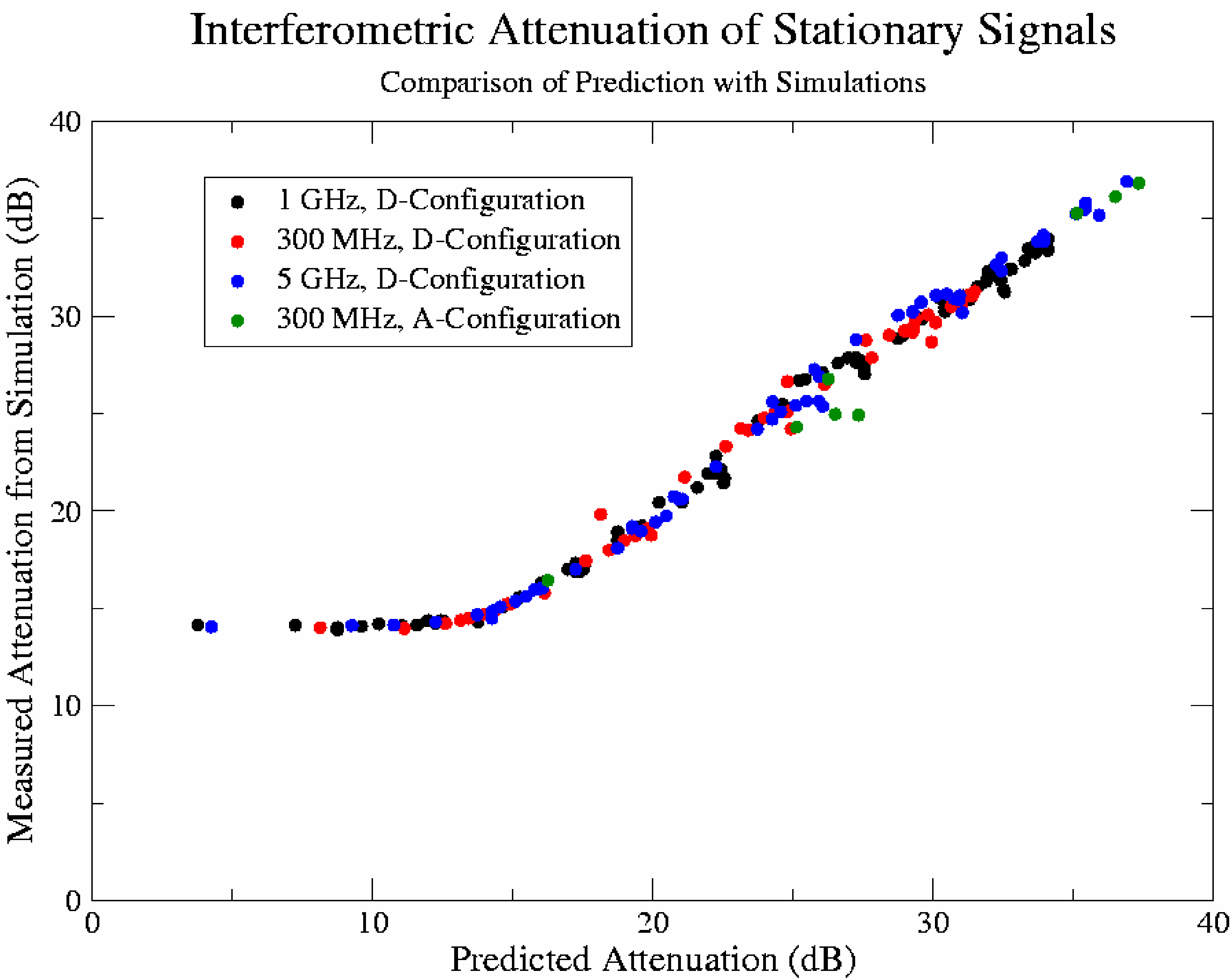
$$\sigma_P = \frac{kT_{sys}\Delta\upsilon}{\sqrt{\Delta\upsilon\,\tau}} = kT_{sys}\sqrt{\frac{\Delta\upsilon}{\tau}} \qquad \text{watts}$$

- These are combined to give the standard limit:

$$P_{RFI} < \frac{kT_{sys}}{10}\sqrt{\frac{\Delta\upsilon}{\tau}} \qquad \text{watts}$$

Application to Interferometers

- Application of the limit is simple for total power telescopes.
- It is more complicated for interferometers:
  - A 2-element interferometer is $1/\sqrt{2}$ more sensitive than a single dish.
  - Signal coherency: The signals arriving at each antenna must themselves be coherent. (We assume this to be true).
  - Imaging coherency: Each antenna impresses a different phase onto the interfering signal – different than that of the astronomical signal. In general, this attenuates the effect of the RFI in the image by a factor of up to $1/N_{ant}$ ~ -14 dB for the EVLA.
  - Fringe phase winding: Earth rotation imposes a differential phase rate upon the astronomical source. This is removed in a correlator, so stationary sources of emission suffer a differential phase slip which can be a little, or a lot – up to -60 dB!


Interferometric Attenuation of Stationary Signals
Comparison of Prediction with Simulations
1 GHz, D-Configuration
300 MHz, D-Configuration
5 GHz, D-Configuration
300 MHz, A-Configuration
Measured Attenuation from Simulation (dB)
Predicted Attenuation (dB)
0
10
20
30
40

Limits for Interferometers

- In EVLA memo # 49, I give a useful approximation for the attenuation, in an image, of external RFI, due to fringe rotation:

$$R \sim 12\sqrt{\tau \upsilon_G B_K \cos\delta}$$

  - τ is the integration time in seconds
  - ν_G is the frequency in GHz,
  - B_K is the maximum baseline length in km, and
  - δ is the source declination.
- Combining this with the INR requirement, employing the ITU velocity resolution of 3 km/sec, and assuming $N_{ant} = 27$, we find

$$P_h < 100kT_{sys}\left(2.7\sqrt{\frac{\upsilon_G}{\tau}} + 1.2\upsilon_G\sqrt{B_K \cos\delta}\right) \qquad \text{watts}$$

Application to the EVLA

- The 2nd term is nearly always larger than the first.
- The worst case for the EVLA is the D-configuration, for which $B_K = 1$.
- For practical application, we must accept a northern declination limit. We take $\delta = 85$ (north of which is only 0.25% of the observable sky).
- With all these, our final emissions limit becomes:

$$P_h < 5 \times 10^{-22} \upsilon_G T_{sys} \qquad \text{watts}$$

- An important conclusion is that the limit is independent of integration time!

Shielding and Distance

- Conversion to power flux density, at the antenna feed, requires knowledge of the antenna collecting area. For an isotropic antenna, $A_e = \lambda^2/4\pi$. We get, for the EVLA:

$$F_h < 7.0 \text{ x } 10^{-20} \upsilon_G^3 T_{sys} \qquad \text{watt/m}^2$$

- Conversion to EIRP for the radiating source requires further knowledge of shielding factor (S) and distance (r). For the EVLA, we set:

$$EIRP < 4\pi r^2 S F_h / G \qquad \text{watts}$$

- Where G is the antenna gain, relative to isotropic, through which the RFI enters.

The EVLA Limits

- From all this, we obtain the limits on power flux density, and spectral power flux density:

Band	ν_G	$\Delta\nu_k$	T_{sys}	F_h	S_h
4	.075 GHz	.75 kHz	1000 K	-195 dB(W/m^2)	3.0e3 Jy
P	.325	3.25	50	-189	3.7e3
L	1.5	15	25	-172	3.9e4
S	3.0	30	25	-163	1.6e5
C	6.0	60	25	-154	6.3e5
X	10	100	30	-147	2.1e6
U	15	150	35	-141	5.5e6
K	23	230	40	-135	1.5e7
A	34	340	45	-129	3.4e7
Q	45	450	66	-124	9.4e7

Comments on these Limits

- Our adopted limits apply for a scenario where the fringe winding provides significant attenuation.
  - This always applies for long baselines and high frequencies.
  - This will not apply for short observations (‘snapshots’) at low frequencies, and/or short baselines.
  - For such situations, a more stringent (total power-like) limit would be more appropriate.
  - However, for these scenarios, we have hope that post-correlation excision techniques can be applied.
- These limits presume a 3 km/sec velocity BW. For bi-static radar experiments, the resolution needed is 1/30,000 narrower – a limit lower by 22 dB is necessary.
  - But this limit need only apply over ~1000 channels at specific frequencies: 2.38, 8.51, and 34.32 GHz.

EVLA RFI Management Plan

- Modern radio astronomy requires high sensitivity, and full frequency coverage (ability to tune to any frequency).
- The EVLA will provide ‘full frequency coverage’ from 1 to 50 GHz.
- Much strong RFI within this range!
- We design for:
  - High linearity (maximum headroom) to prevent harmonic distortion
  - Frequency agility, to spectrally avoid strongest emitters
  - Suppression of locally generated emissions
  - Retaining capability of future post-correlation excision.

EVLA Linearity

- The first line of defense is high linearity.
- Table shows the headroom from the nominal operating point to 1 db compression.
- In addition, we will employ 8-bit sampling at P, L, S bands.
- The WIDAR correlator has up to 58 dB spectral linearity.

Band	**Headroom At Receiver**	**Headroom At Sampler**
L	47	37
S	48	36
C	43	35
X	42	33
Ku	40	32
K	33	33
Ka	35	32
Q	27	27

NB: 1% compression point is 13 db lower

Frequency Agility

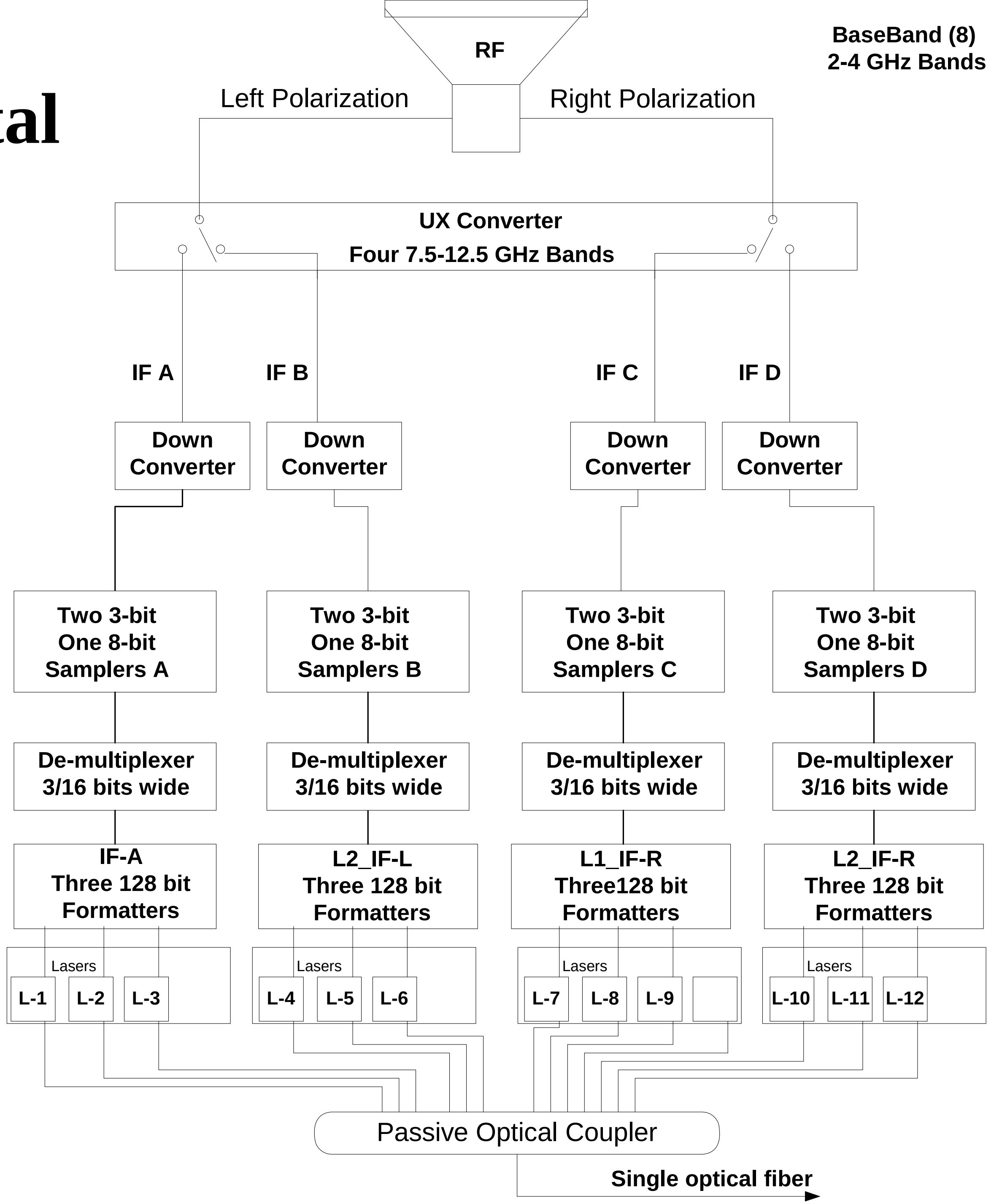
- The EVLA's WIDAR correlator has enormous frequency agility.
- Each of the eight 2-GHz inputs are spectrally decomposed via FIR filters into 16 tunable sub-bands of selectable BW (128, 64, 32, … .031 MHz).
- This feature will permit avoidance of particularly strong RFI.
- Correlator itself has ~44 to ~58 dB spectral dynamic range to prevent 3rd-order products from contaminating the spectrum.

Suppression of Internal RFI

- An early decision for EVLA design was to go `all-digital'.
- Sampling, and digital M/C done in the antenna.
- Required much careful design to minimize emissions, and to design good RFI-tight enclosures.
- MIB (module interface board) specially designed to minimize emissions.
  - ~35 of these in each antenna.

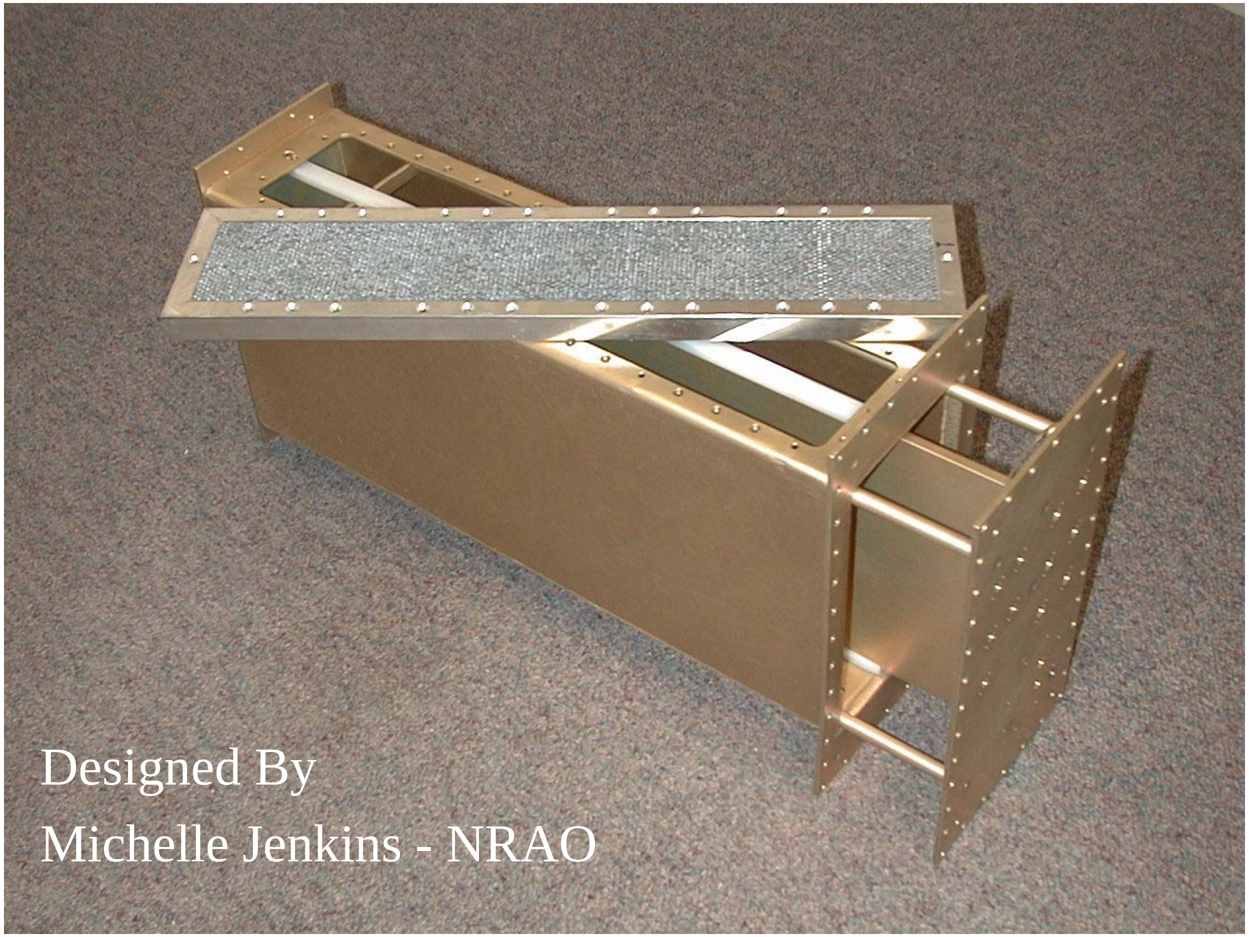
Basic Digital Design

- Simplified electronics system.
- Each antenna contains four 8-bit 2Gsamp/sec, and eight 3-bit 4Gsamp/sec samplers.
- Total traffic ~120 Gb/sec.
- 10 Gigabit/s hardware



DTS Enclosure # 2

- Spira Inc.
  1” Filter
- 140 dB
@ 1.0 GHz
- 120 dB
@ 10 MHz
- Module located within an RFI-tight Tempest rack.

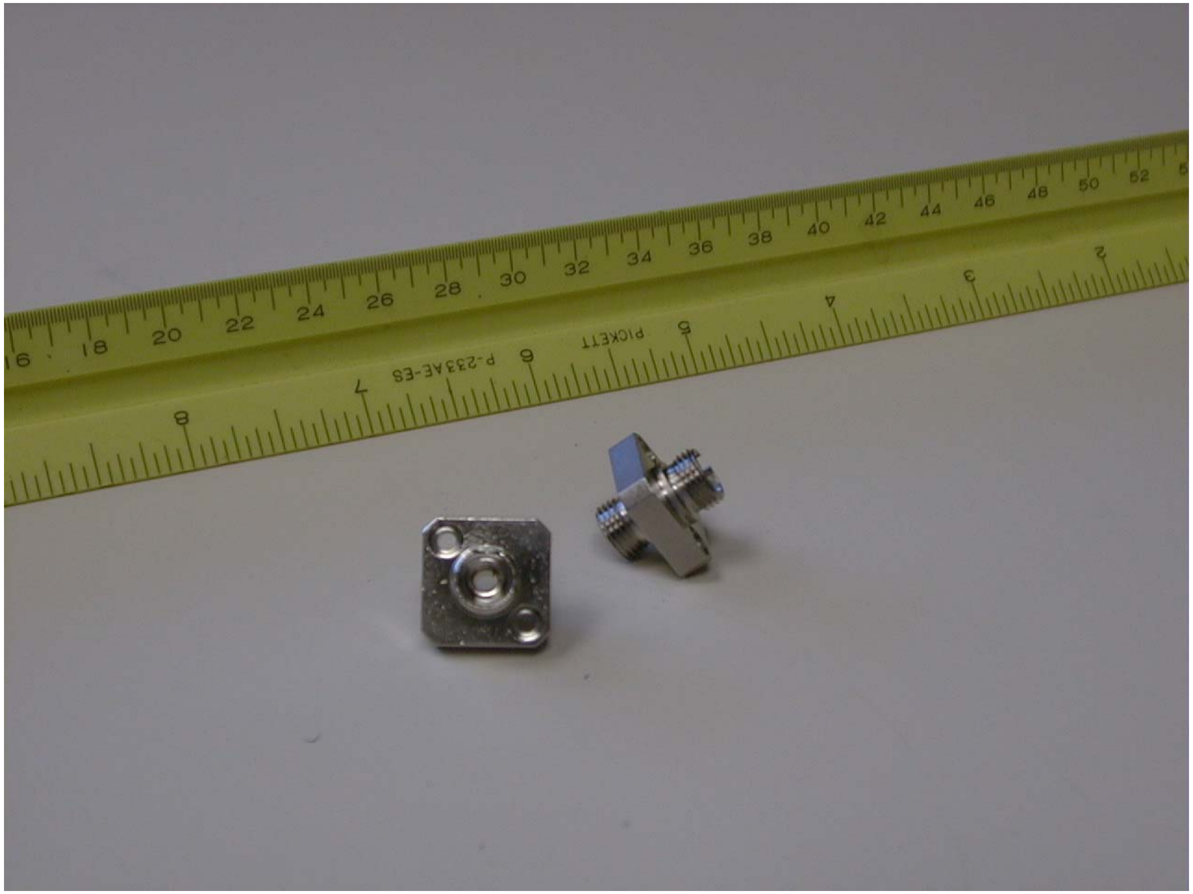


FC Fiber Connector as a Waveguide

- Wavelength below cutoff
  69 GHz

  216 dB
  @ 5 GHz

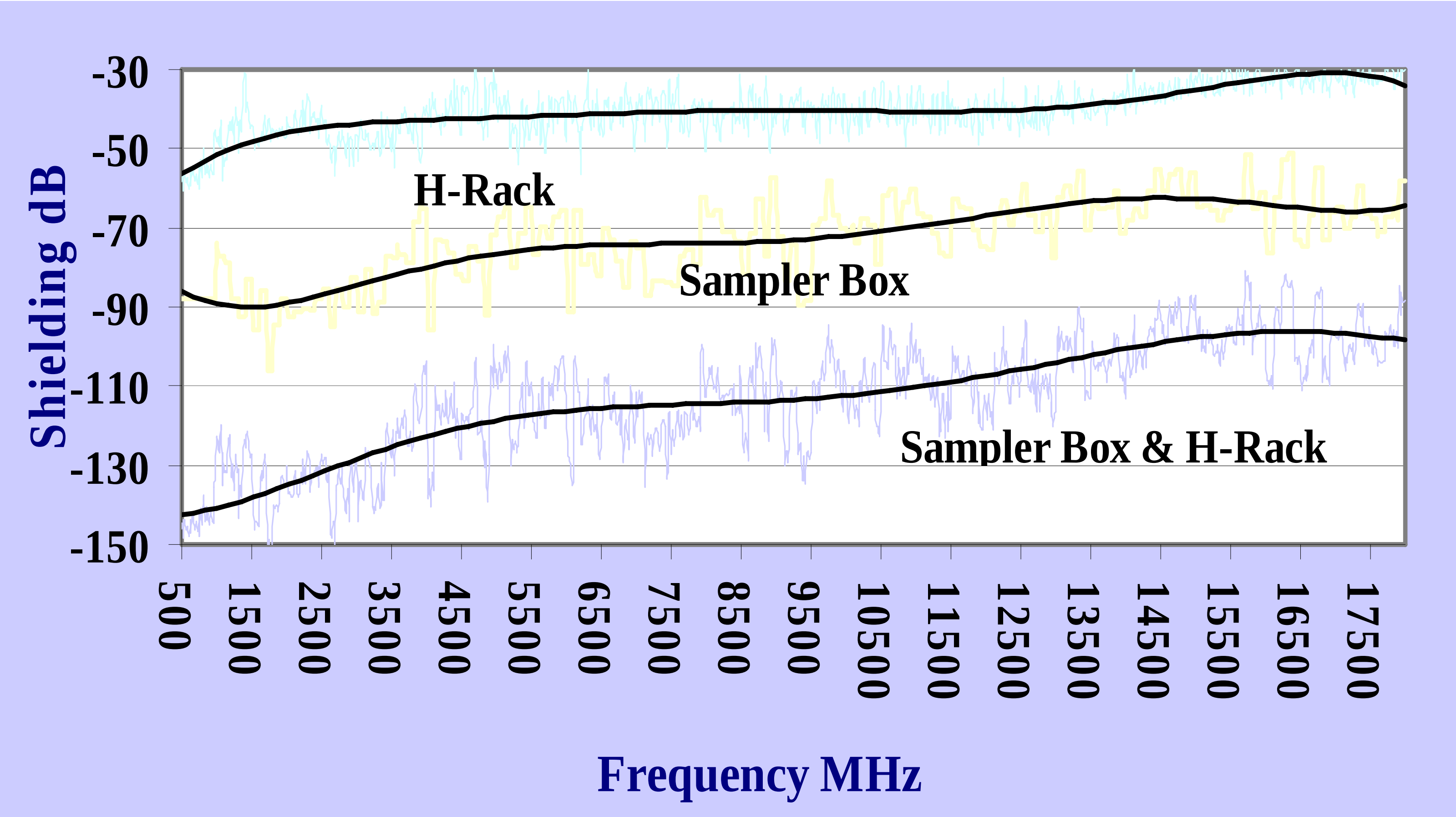
  207 dB
  @ 20 GHz



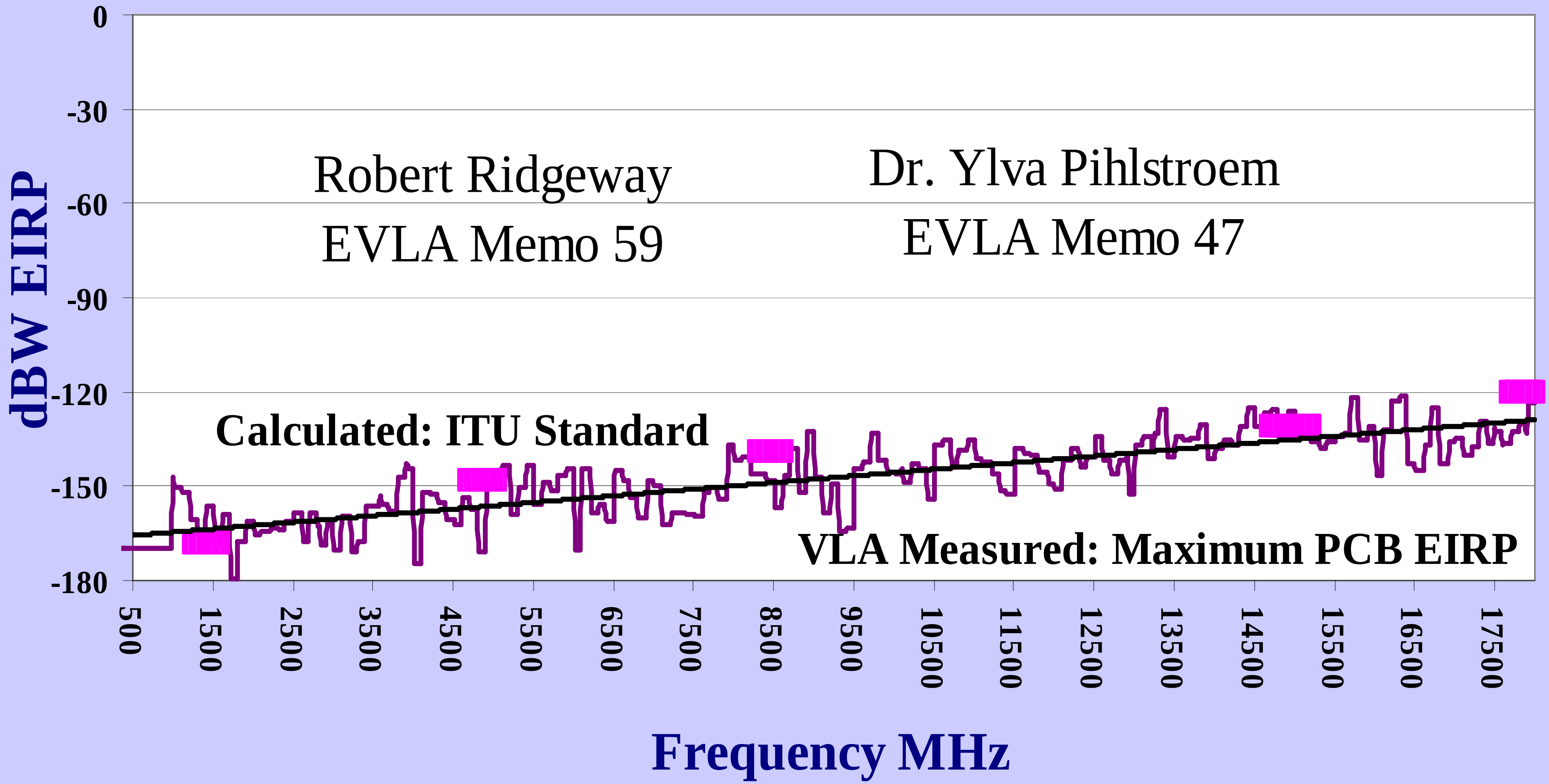
G-Rack – Enclosure #3

RF Absorber

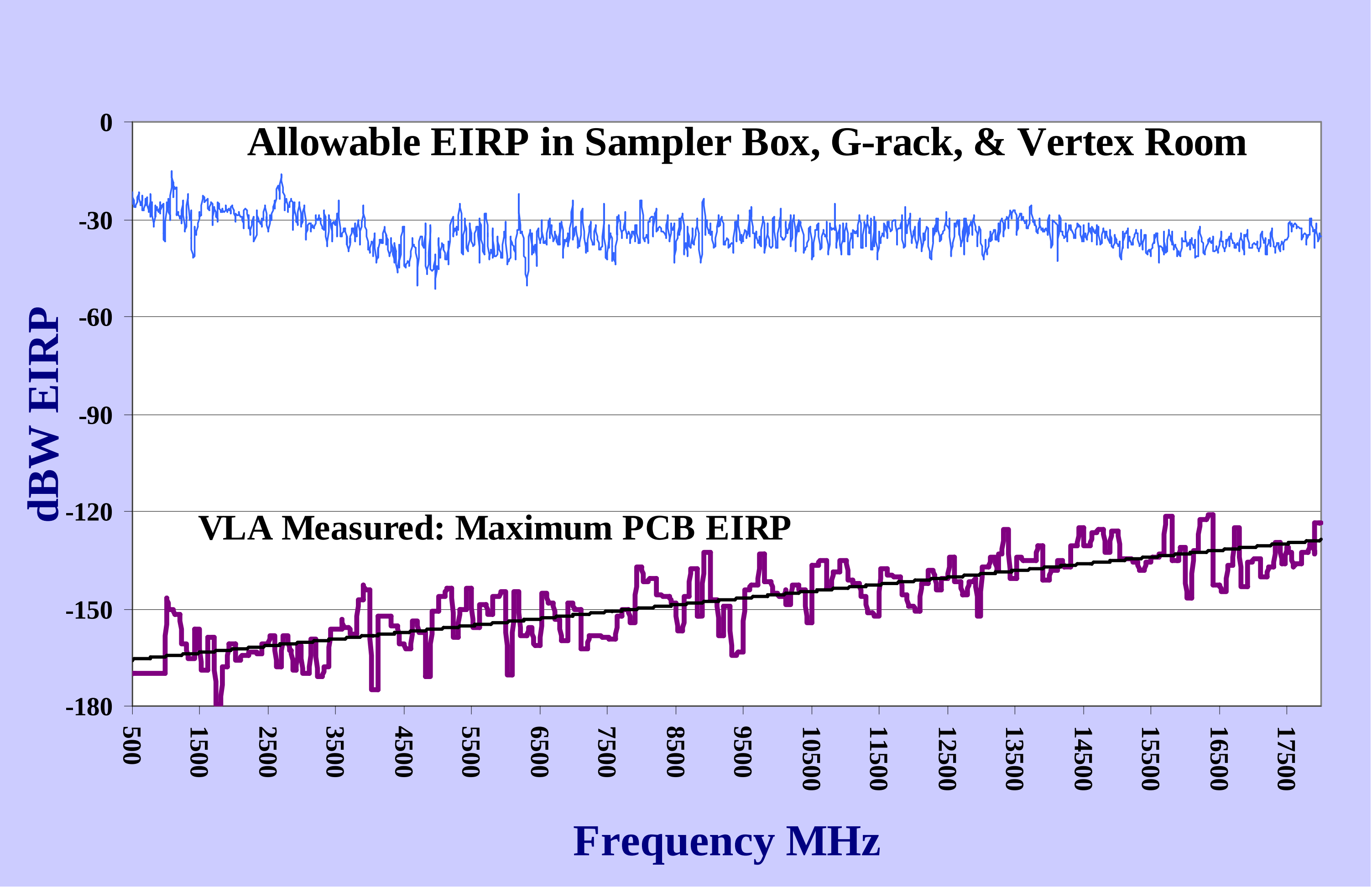
Sampler Box & H-Rack Shielding



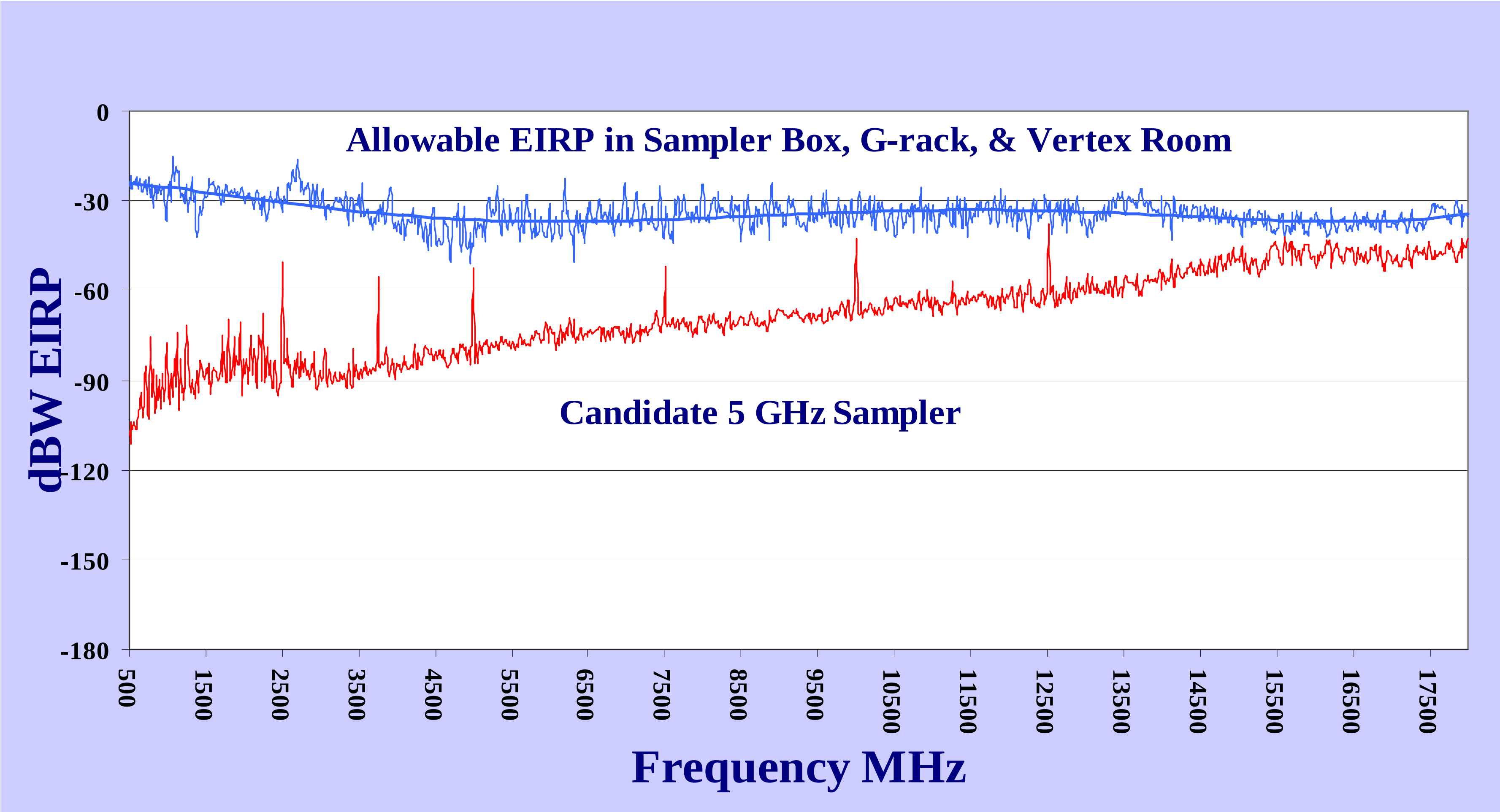
Measured Harmful EIRP from Vertex Room



Estimated Effect of Shielding



Circuit Comparison



Final Defense – RFI Subtraction

- Two methodologies being explored (mostly elsewhere):
  - Real-time subtraction on antenna-basis (using a directed element, and some knowledge of characteristics of interfering signals).
  - Post-correlation excision of interference, utilizing different phase rotation rate of interfering signal.
- Latter method attractive for large-N interferometers, as:
  - No reference antenna is required
  - The coherence information is automatically generated by the correlator.
  - Well-known methods can be easily employed.
- However, very fast sampling generally required to prevent partial decorrelation of the RFI signal we are seeking to remove.

Suggested Procedure

- Sample fast! (And preferably with narrow channelwidth).
  - N.B. This is an expensive combination!
- Phase rotate affected data to 'stop' fringe-winding of RFI.
  - Easy if the RFI is stationary (same rate as NCP).
- Use 'CALIB-like' program to solve for RFI phase and gain for every affected frequency channel.
  - Better: Solve for source and RFI at same time, allowing different gains for each.
- Subtract RFI from each affected channel, using gains.
- De-rotate data back to phase center, and integrate to reduce volume.

How Fast, How Big?

- For the VLA, with SNR = 100, we find, in **milliseconds:**

Config.	90cm	20cm	6cm	2cm	0.7cm
E	3860	860	260	85	30
D	960	210	65	20	7.5
C	300	70	20	6.8	2.4
B	95	20	6.5	2.2	.75
A	30	6.8	2.0	.70	.25
NMA	3.0	.70	.20	.070	.025

- These are very short times, leading to very large databases.
  - At 100 msec, the total rate > 1 GB/second for 16384 channels.
  - The red zone lies beyond the WIDAR correlator – but natural fringe winding provides 25 dB attenuation in 1 second!

Summary

- EVLA will be very susceptible to RFI.
- RF/IF Electronics design emphasizes high linearity
- Correlator design employs RFI-avoidance capability and high linearity.
- All digital components designed for low emissions.
- High level of shielding designed in and tested.
- Correlator will permit post-correlation excision techniques for most cases where natural fringe-winding will not be effective.
- Full effect of L-band interference environment will soon be known – wide-band OMTs almost ready for implementation.