RFI Management for the EVLA

Principles and Progress

Rick Perley
EVLA Emission Limits

• EVLA emission limits based on standard treatment:

\[ \text{INR} = \frac{P_{RFI}}{\sigma_P} < 0.1 \]

  – \( P_{RFI} \) = RFI power, as measured at the input to the receiver, within some astronomical bandwidth, \( \Delta \nu \),
  
  – \( \sigma_P \) is the system noise power, referenced to the receiver input:

\[ \sigma_P = \frac{kT_{sys} \Delta \nu}{\sqrt{\Delta \nu \tau}} = kT_{sys} \sqrt{\frac{\Delta \nu}{\tau}} \text{ watts} \]

• These are combined to give the standard limit:

\[ P_{RFI} < \frac{kT_{sys}}{10} \sqrt{\frac{\Delta \nu}{\tau}} \text{ watts} \]
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 $1/N_{\text{ant}} \sim -14$ 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) vs. Predicted Attenuation (dB)
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:

\[ R \sim 12\sqrt{\tau \nu_G B_K \cos \delta} \]

– \( \tau \) is the integration time in seconds
– \( \nu_G \) is the frequency in GHz,
– \( B_K \) is the maximum baseline length in km, and
– \( \delta \) is the source declination.

• Combining this with the INR requirement, employing the ITU velocity resolution of 3 km/sec, and assuming \( N_{\text{ant}} = 27 \), we find

\[ P_h < 100kT_{\text{sys}} \left( 2.7 \sqrt{\frac{\nu_G}{\tau}} + 1.2 \nu_G \sqrt{B_K \cos \delta} \right) \text{ watts} \]
Application to the EVLA

- The $2^{nd}$ 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:

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

- 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, $A_e = \frac{\lambda^2}{4\pi}$. We get, for the EVLA:

$$F_h < 7.0 \times 10^{-20} \nu^3 G T_{sys} \text{ watt/m}^2$$

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

$$EIRP < 4\pi r^2 SF_h / G \text{ watts}$$

- 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:

<table>
<thead>
<tr>
<th>Band</th>
<th>$\nu_G$</th>
<th>$\Delta \nu_k$</th>
<th>$T_{sys}$</th>
<th>$F_h$</th>
<th>$S_h$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>.075 GHz</td>
<td>.75 kHz</td>
<td>1000 K</td>
<td>-195 dB(W/m²)</td>
<td>3.0e3 Jy</td>
</tr>
<tr>
<td>P</td>
<td>.325</td>
<td>3.25</td>
<td>50</td>
<td>-189</td>
<td>3.7e3</td>
</tr>
<tr>
<td>L</td>
<td>1.5</td>
<td>15</td>
<td>25</td>
<td>-172</td>
<td>3.9e4</td>
</tr>
<tr>
<td>S</td>
<td>3.0</td>
<td>30</td>
<td>25</td>
<td>-163</td>
<td>1.6e5</td>
</tr>
<tr>
<td>C</td>
<td>6.0</td>
<td>60</td>
<td>25</td>
<td>-154</td>
<td>6.3e5</td>
</tr>
<tr>
<td>X</td>
<td>10</td>
<td>100</td>
<td>30</td>
<td>-147</td>
<td>2.1e6</td>
</tr>
<tr>
<td>U</td>
<td>15</td>
<td>150</td>
<td>35</td>
<td>-141</td>
<td>5.5e6</td>
</tr>
<tr>
<td>K</td>
<td>23</td>
<td>230</td>
<td>40</td>
<td>-135</td>
<td>1.5e7</td>
</tr>
<tr>
<td>A</td>
<td>34</td>
<td>340</td>
<td>45</td>
<td>-129</td>
<td>3.4e7</td>
</tr>
<tr>
<td>Q</td>
<td>45</td>
<td>450</td>
<td>66</td>
<td>-124</td>
<td>9.4e7</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Band</th>
<th>Headroom At Receiver</th>
<th>Headroom At Sampler</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>47</td>
<td>37</td>
</tr>
<tr>
<td>S</td>
<td>48</td>
<td>36</td>
</tr>
<tr>
<td>C</td>
<td>43</td>
<td>35</td>
</tr>
<tr>
<td>X</td>
<td>42</td>
<td>33</td>
</tr>
<tr>
<td>Ku</td>
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</tr>
<tr>
<td>K</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Ka</td>
<td>35</td>
<td>32</td>
</tr>
<tr>
<td>Q</td>
<td>27</td>
<td>27</td>
</tr>
</tbody>
</table>

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

16 Oct 2006
DTS Enclosure # 2

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

Designed By
Michelle Jenkins - NRAO
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

Frequency MHz

Shielding dB

H-Rack

Sampler Box

Sampler Box & H-Rack
Measured Harmful EIRP from Vertex Room

Robert Ridgeway
EVLA Memo 59

Dr. Ylva Pihlstroem
EVLA Memo 47

Calculated: ITU Standard

VLA Measured: Maximum PCB EIRP
Estimated Effect of Shielding

Allowable EIRP in Sampler Box, G-rack, & Vertex Room

VLA Measured: Maximum PCB EIRP

Frequency MHz

dBW EIRP

16 Oct 2006
CORF Meeting
Rick Perley
Circuit Comparison

Allowable EIRP in Sampler Box, G-rack, & Vertex Room

Candidate 5 GHz Sampler

dBW EIRP

Frequency MHz

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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**:

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

• 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.