The Effect of Strong RFI on Astronomical Imaging Arrays

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There's Bad Stuff Out There!

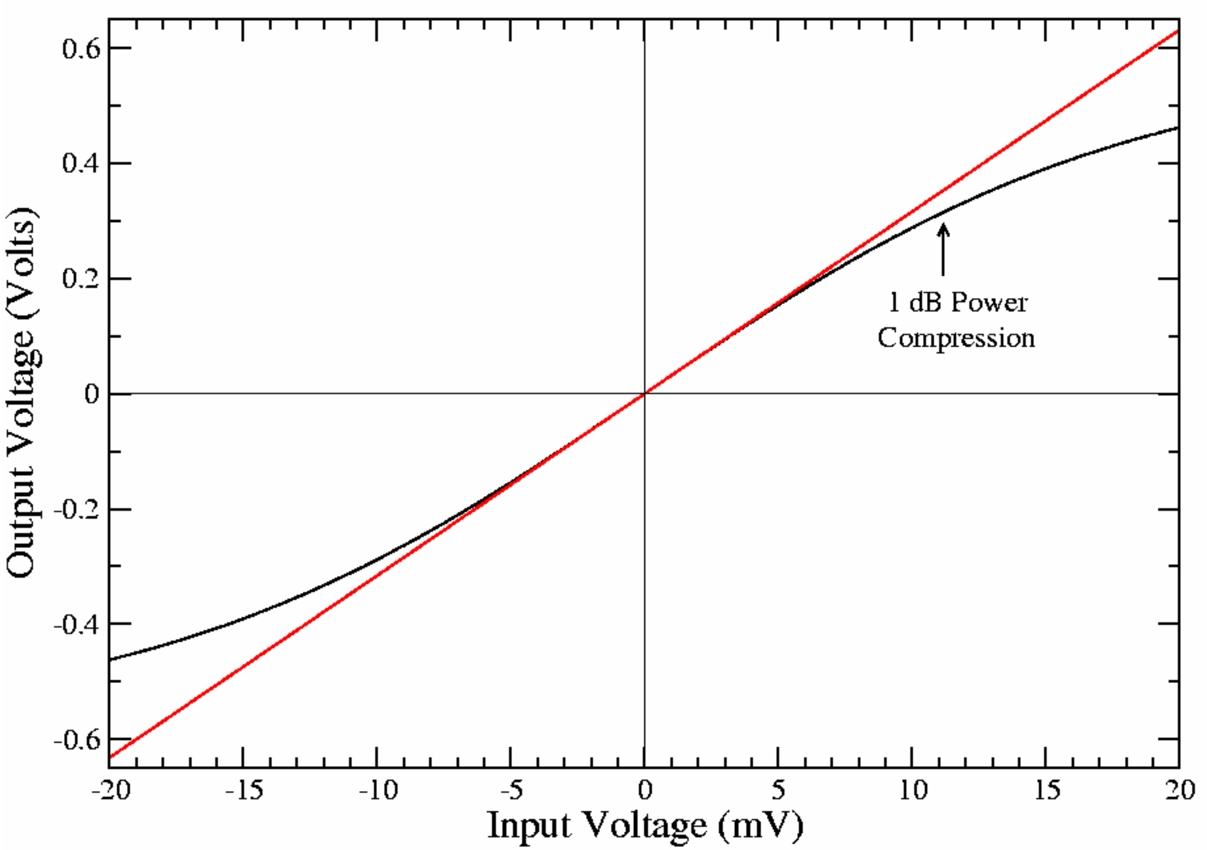
- Science requirements drive the design of new radio telescopes to wide bandwidths – 2:1 BWR.
- This obviously increases the vulnerability of these systems to high-power man-made emissions.
- These signals can easily exceed the total system noise power.
- DME signals provide a good example – peak pulse from 100 km distance exceeds $kT\Delta\nu$ by 20dB!
- Clearly, high linearity in signal processing chain is needed.

But What If…

- But linearity sufficient to prevent significant amplifier compression for all conceivable signals is not possible.
- Some will get through, and cause significant gain compression.
- What happens to imaging performance for frequencies not directly ‘wiped out’ by the RFI?
- We report here on two attempts to measure the effect, and describe a third experiment (in planning) which we hope will answer the question.

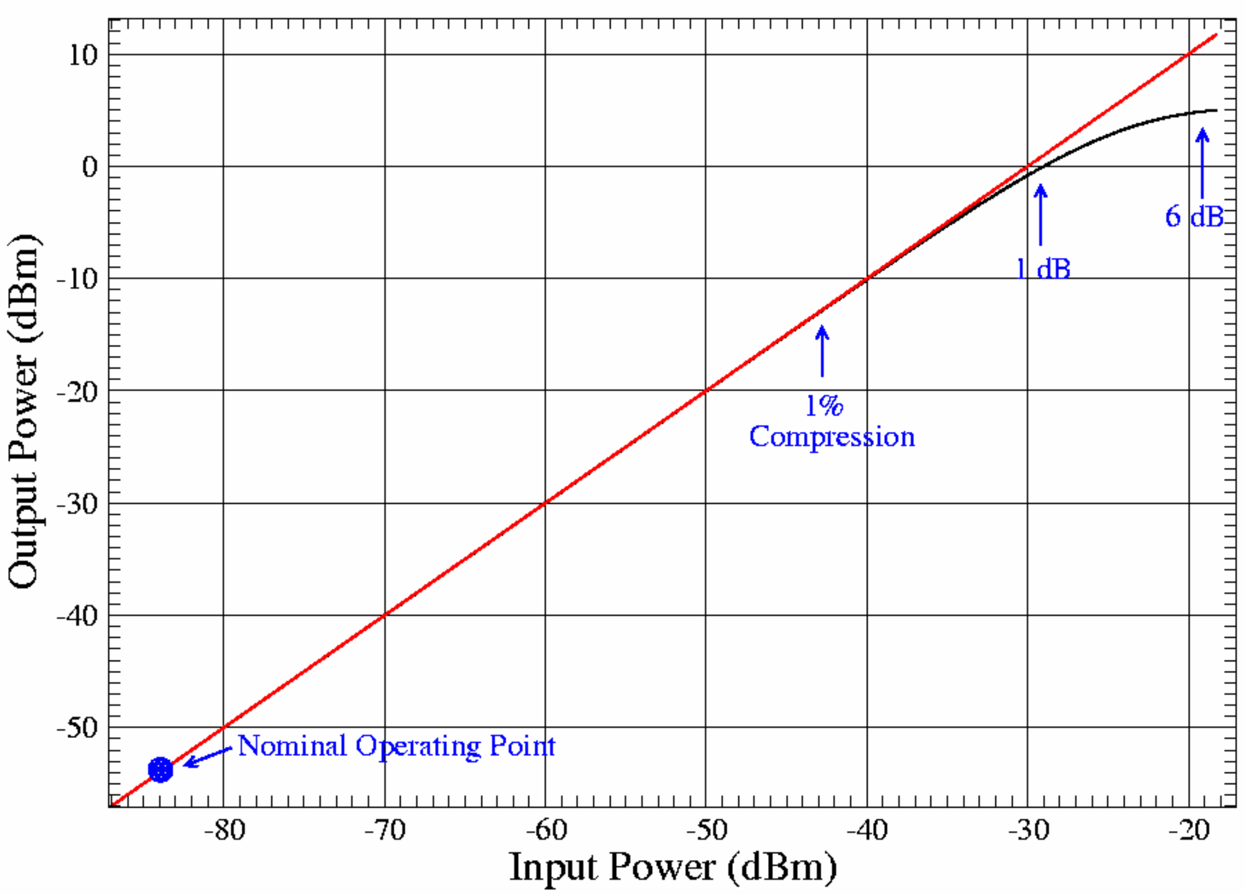
Voltage Relationship

- Showing a generic voltage transfer relation.



Defining Amplifier Compression

- The VLA's C-band FE approximate response.



Harmonic Distortion

- To understand the process, some simple analysis is needed.
- In general, (presuming no hysteresis), the voltage transfer function can be written as:

$$V_{out} = G_v V_{in}(1+\alpha V_{in}+\beta V_{in}^2+ \ldots)$$

- Because the voltage transfer curve is an odd function, $\alpha \sim 0$, and we need only consider the odd terms.
- We can then easily analyze the output harmonic content from a two-frequency input given by:

$$V_{in} = A \cos(\omega_1 t+\phi_1) + B \cos(w_2 t+\phi_2)$$

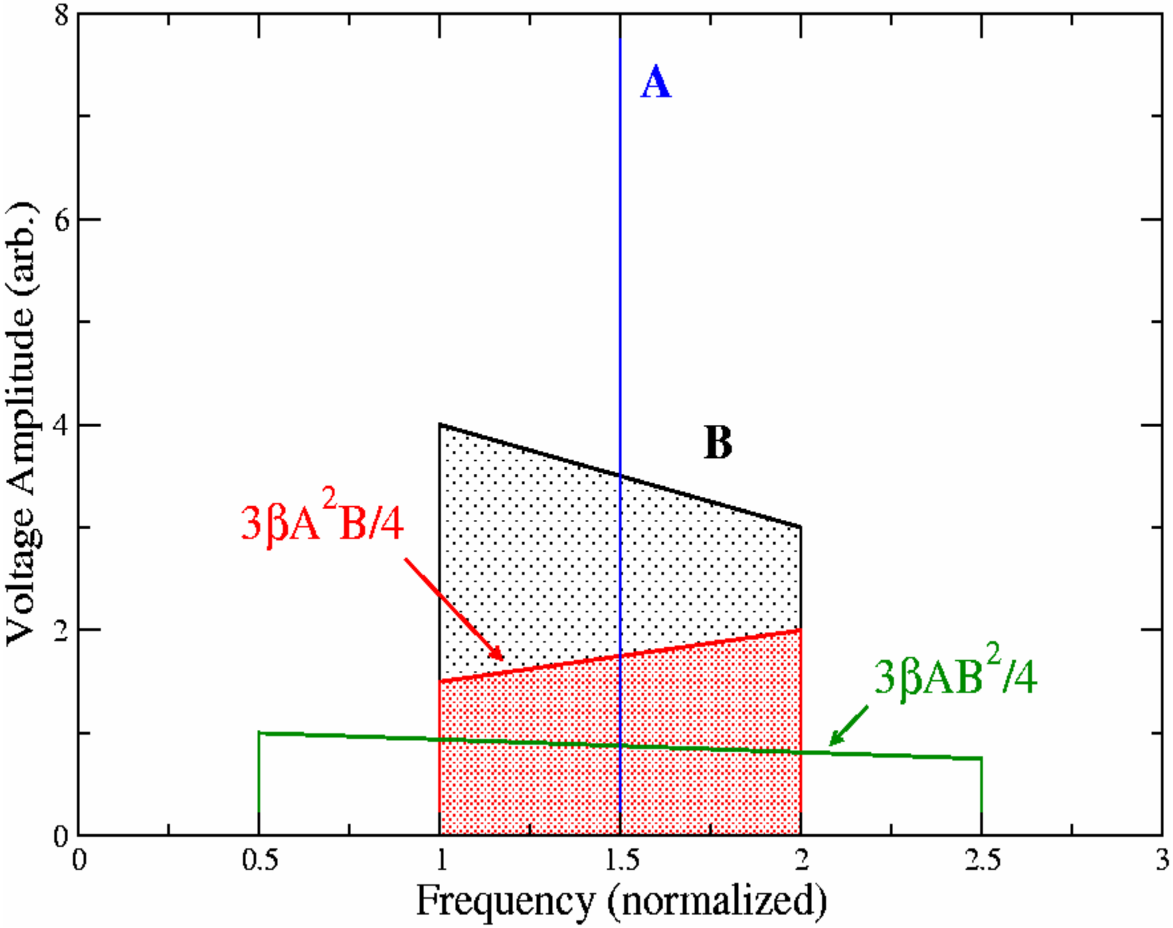
Harmonic Amplitudes (assuming A >> B)

- The amplitude in the fundamental is reduced by $3\beta A^2B/2$.
- Harmonics are produced which put power outside the passband. (Yellow)
- Two harmonic combinations fold spectral information back into the passband. (Red/Orange)

Frequency	Linear	Cubic
ω_1	A	$3\beta A^3/4$
ω_2	B	$3\beta A^2B/2$
$3\omega_1$	--	$\beta A^3/4$
$3\omega_2$	--	$\beta B^3/4$
$2\omega_1+\omega_2$	--	$3\beta A^2B/4$
$\omega_1+2\omega_2$	--	$3\beta AB^2/4$
$2\omega_1-\omega_2$	--	$3\beta A^2B/4$
$2\omega_2-\omega_1$	--	$3\beta AB^2/4$

Spectral Folding

- Two cubic terms fold spectral information back – one is especially strong.
  - A represents the RFI amplitude.
  - B gives the fundamental response.
  - Red shows the reflected, inverted stronger response.
  - Green shows the weaker, broader reflection.



What should we see?

- A reduction in the output amplitude.
  - We expect this will lower the SNR as the effective gain is reduced.
  - An alternative interpretation (B.Clark) is that the amplifier is effectively turned off when highly saturated, so the SNR drops as: $\sqrt{f_{ON}}$
- A 'mixing' of spectral information.
  - Spectral lines will appear in wrong places.
  - `Closure' errors may occur, degrading imaging performance.
- This analysis is too rough to make quantitative predictions – we need to measure these effects.

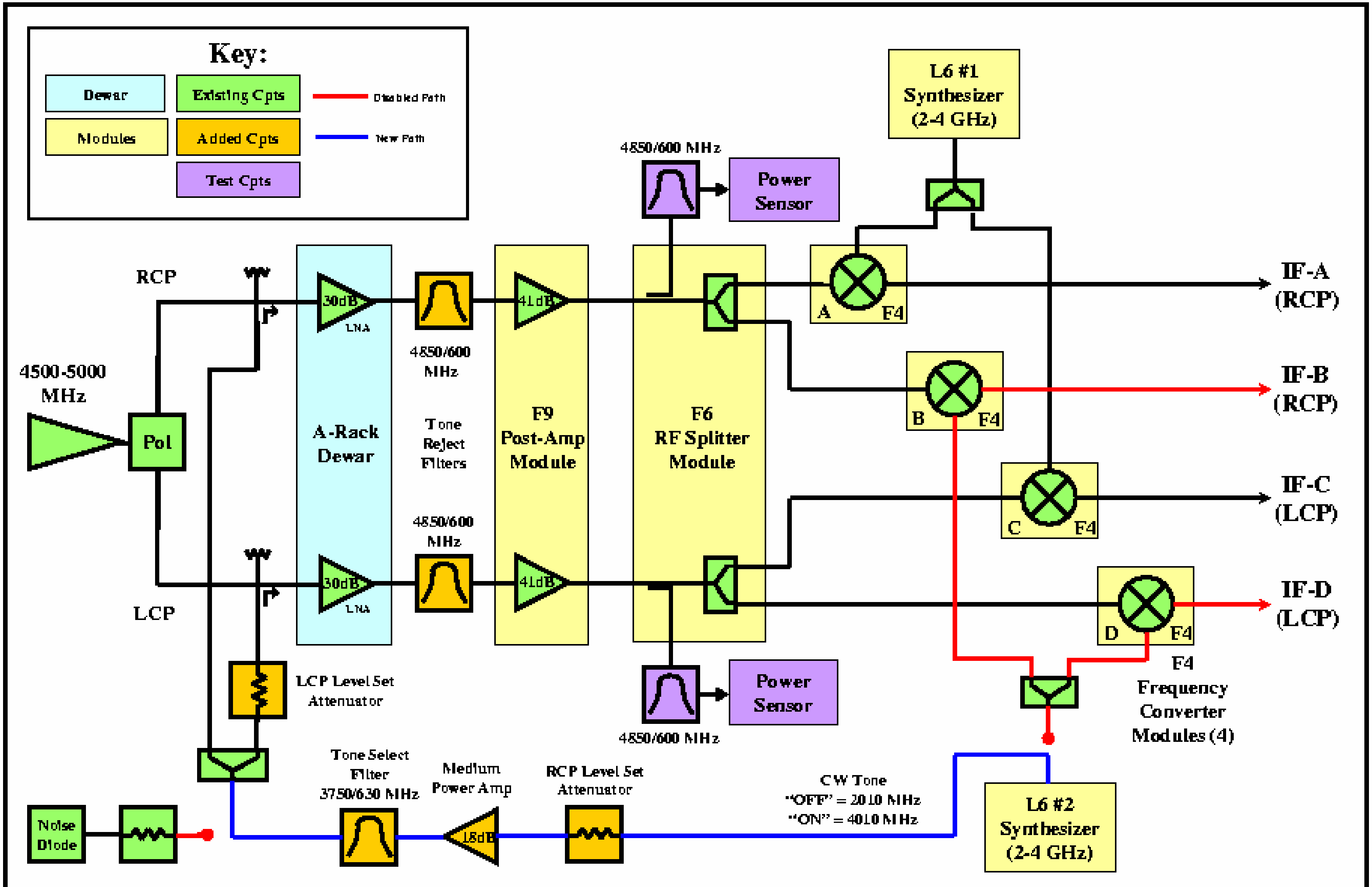
First Experiment

- In the first and simplest experiment, we simply turned on the VLA's `Solar Cals'.
- This raises the operating point by about 13 dB, which is well short of even the 1% compression point.
- Not surprisingly, no effect on imaging was found.
- Details in EVLA Memo #66.

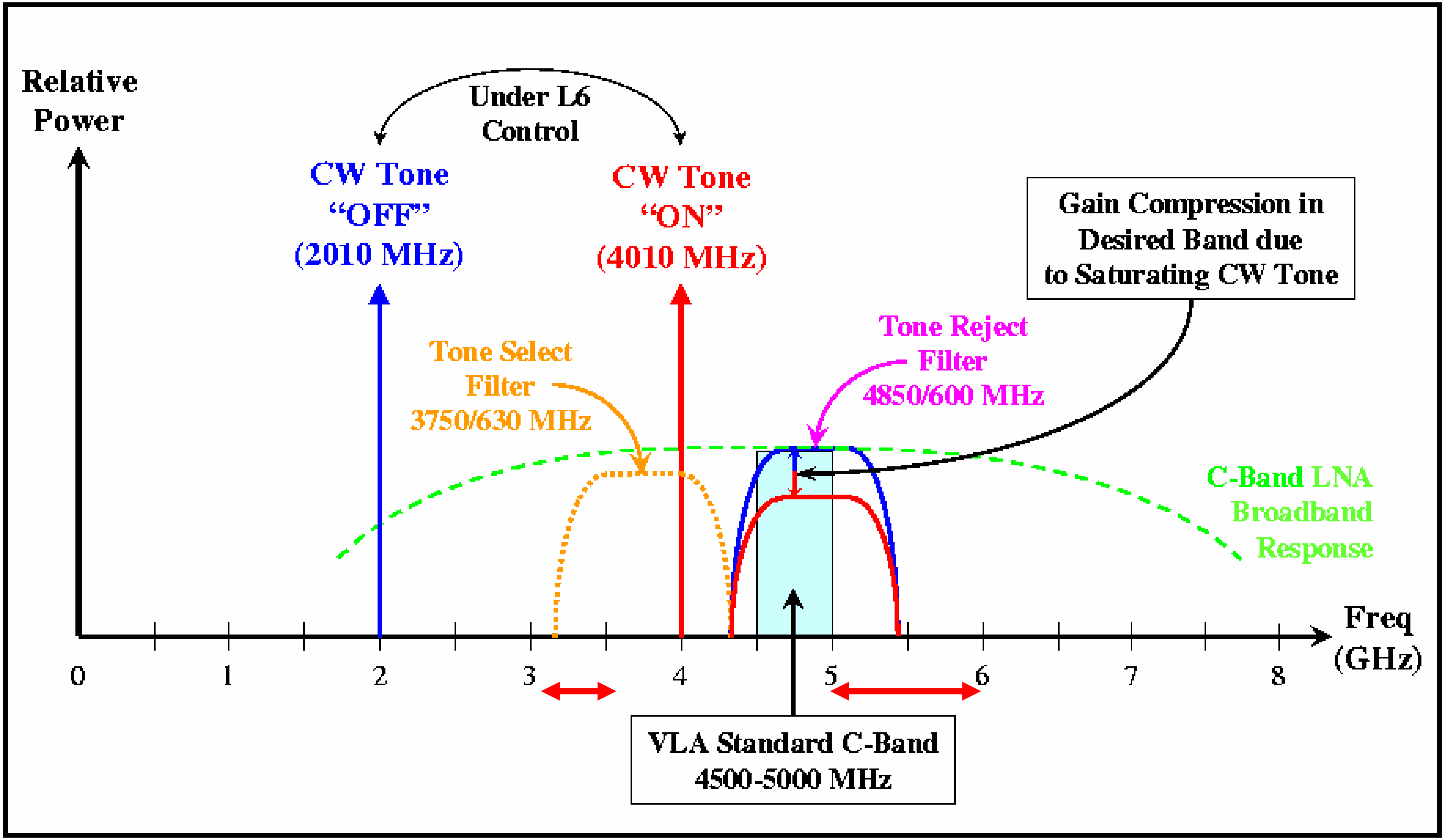
2nd Experiment

- In this attempt, we added a strong CW tone to the first-stage amplifiers.
- Expected to be a much better model of a real RFI signal.
- The tone power was set to drive the RCP side to 1 dB compression, and the LCP side to 6 dB compression.
- A filter was inserted to prevent the tone from propagating beyond the first amplifier.

C-Band Receiver Setup



Frequency Setup



Oops!

- The ‘RFI’ frequency of 4010 MHz lies outside the 4500 – 5000 MHz passband, so the two 3rd order harmonic difference reflections appeared at:
  - 3010 to 3510 MHz: outside the correlated passband, (and blocked by the Tone Reject Filters)
  - 4990 to 5990 MHz: the lower end lies within the passband, but we didn’t correlate at this frequency.
- So the imaging degradation effects we were looking for could not be present (and weren’t!).
- The loss of SNR remains, and we did measure this.

Setup

- Four antennas were modified, with compression levels (in dB) as shown in the table:

Ant.	IF 'A'	IF 'C'
1	2.5	1.1
2	5.0	0.8
22	6.0	0.8
28	6.4	1.1

- Observations made of 3C286 (7.46 Jy, nearly unresolved), for four hours, split equally between 50 MHz continuum (4885 MHz) and 12.5 MHz spectral line (390 kHz spectral resolution).

Results -- Sensitivity

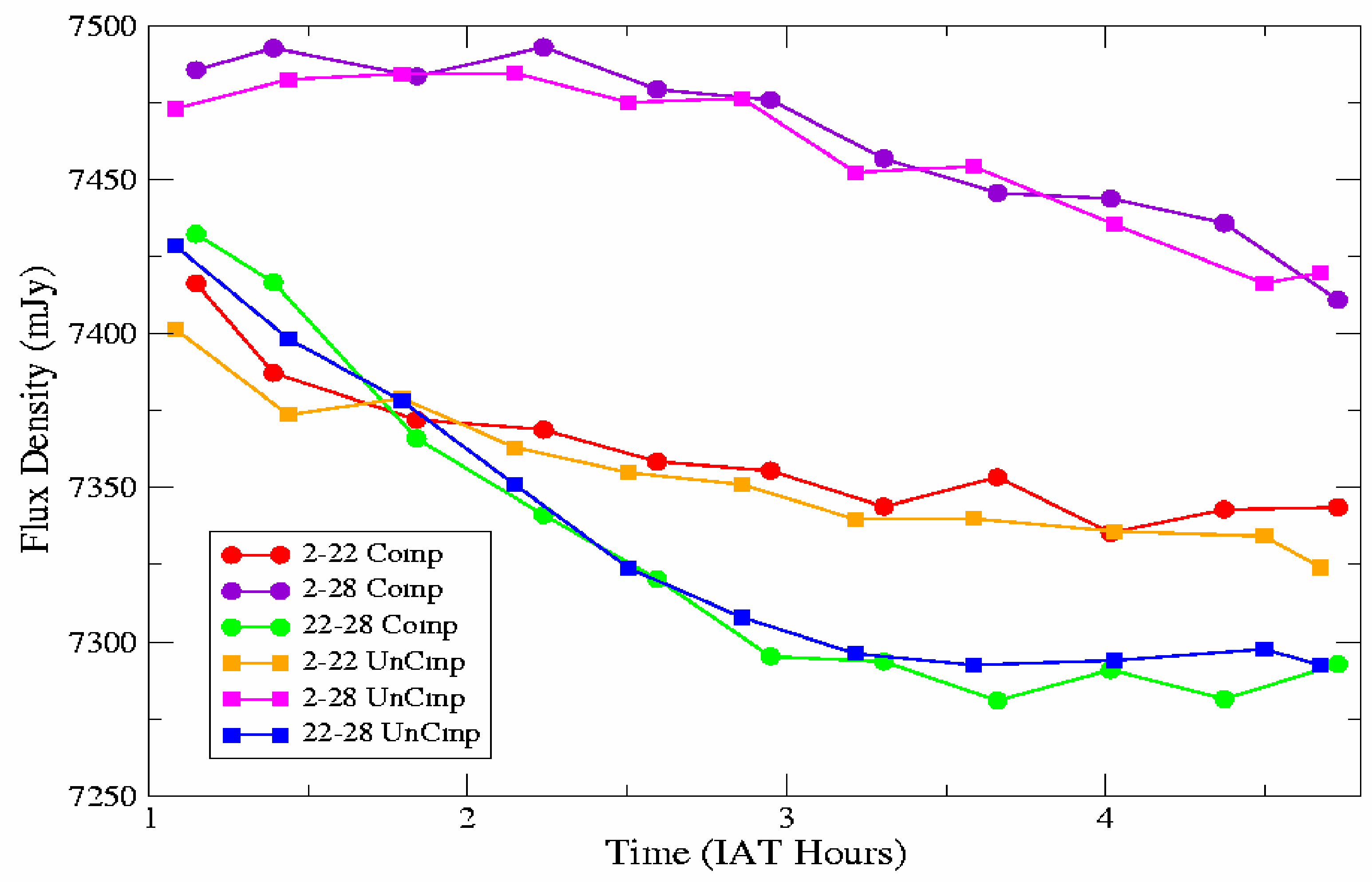
- The loss in sensitivity was measured in two ways:
  – A change in the calibration coefficient
  – Directly measuring the SNR in the correlated data.
- The results were the same for both approaches:
  – A marginal loss (1% +/- 0.5%) in SNR at 1 dB compression
  – A significant loss of 16% in SNR at 6 dB compression.

Results -- Closure

- ‘Closure’ effects (amplitude or phase changes in the correlator product which cannot be factored into antenna-based amplitude or phase) were sought in two ways:
  - Closure error calculation by comparison of observed and predicted visibilities from a standard model.
  - Direct comparison of measured visibilities between the ‘Tone On’ and ‘Tone Off’ states.
- No closure effects were detectable to a level of 0.1%. (Not surprising, but reassuring).

High Precision!

- Showing the accuracy with which we can measure the visibility.



What Next?

- We are planning a third experiment, which we expect will give us an estimate of what we want to know:
  - The leakage and imaging qualities of astronomical information which is 'reflected back' within the passband by strong RFI in that passband.
- The idea: To use a tone within L-band to `reflect' the high end of the band onto the low end.
  - More specifically: To use a tone at ~1555 MHz to make a strong OH maser line at 1665 MHz appear near 1445 MHz.
  - The `reflection coefficient' and imaging properties will then be easy to directly measure, as a function of tone strength.