EVLA Memo 79
The Effect of Strong CW Signals on Interferometer Calibration, Closure, and Imaging

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Abstract

An experiment is described in which a strong CW signal was injected into the first stage of four of the VLA's C-band amplifiers in order to study the effect of amplifier compression on interferometer calibration, sensitivity, and imaging. Signals sufficient to drive the amplifiers to their 1 dB and 6 dB compression points were used. No measureable effects were found when the first-stage amplifiers were operating at their 1 dB compression points. A drop in antenna sensitivity of ~18% was observed at 6 dB compression. After careful antenna-based calibration, no change in measured correlation greater than 0.1% was noted, as expected. An experiment designed to measure the error in correlation is described, and will be performed later this year.

1 Introduction

Modern radio interferometers utilize very wide bandwidths – both to permit observations of astronomical spectral transitions at arbitrary redshift, and to obtain the highest sensitivity for continuum observing. Unfortunately, the radio spectrum also contains strong man-made emissions which can easily overwhelm the astronomical signals. For example, the Distance Measuring Equipment (DME) pulses from a large jet aircraft have a peak power of 300 W, radiated into ~500 kHz bandwidth, at a frequency between 1025 to 1150 MHz. Such a signal, originating at a distance of 100 km, and viewed through the isotropic sidelobes of a 25-meter antenna will contribute a power more than 20 dB higher than the system noise power $kT\Delta\nu$. On an average day, we must expect many aircraft within 1000 km (and some occasionally closer than 10 km), so that observations of cosmic noise will in general be made with input power levels to the amplifiers fluctuating between the normal operating point and values 30 dB or more above that point.

Clearly, high system linearity is required to enable useful astronomical observations in such an environment. We require that there be no significant degradation of the desired astronomical information due to the high powers of man-made interference. But how much non-linearity can we tolerate, and what is the effect of a non-linear response on the imaging characteristics of a radio synthesis interferometer?

There appears to be little information on the effects of amplifier non-linearities to the imaging capabilities of a radio astronomy interferometer. We have thus set up an experiment, using the VLA's C-band system, which reproduces a situation we expect will be common for future interferometers such as the EVLA – the presence of a strong, quasi-CW signal sufficient to drive the first stage amplifiers into significant compression, but which is subsequently blocked from downstream electronics (including the digital system). In arranging things this way, we can examine the effects of amplifier saturation alone on interferometer performance. This is a situation we expect to see in real astronomical observing, as strong input signals such as radars can not in general be blocked from reaching the first stage amplifiers, but can be blocked from affecting subsequent stages of amplification or transmission through insertion of suitable stop-band filters.

Questions we are interested in answering include: What is the loss in SNR due to the saturation? What is the dependence of this loss on degree of saturation? Is there a baseline-based error in the correlation coefficient, and if so, what is its dependence on degree of saturation? Is there any change in the amplifier bandpass shape due to saturation? Of these, the most important to an imaging interferometer is that of any baseline-based dependence in the change in measured coherence. Changes which can be uniquely factored into an antenna-based effect (such as a loss in SNR), can be corrected for using well-tested and robust antenna-based calibration schemes. However, baseline-dependent changes (meaning that these effects cannot be factored into antenna-based factors) cannot in general be calibrated for, and will advsersely affect system imaging performace.

2 Non-Linerities in Amplifier Response

Amplifiers are imperfect devices – the output voltage is not a linear function of the input voltage. The output voltage 'rolls off' from a linear relationship, and asymptotes at some maximum output amplitude. Fig. 1 shows a general example of the voltage in/out relationship.

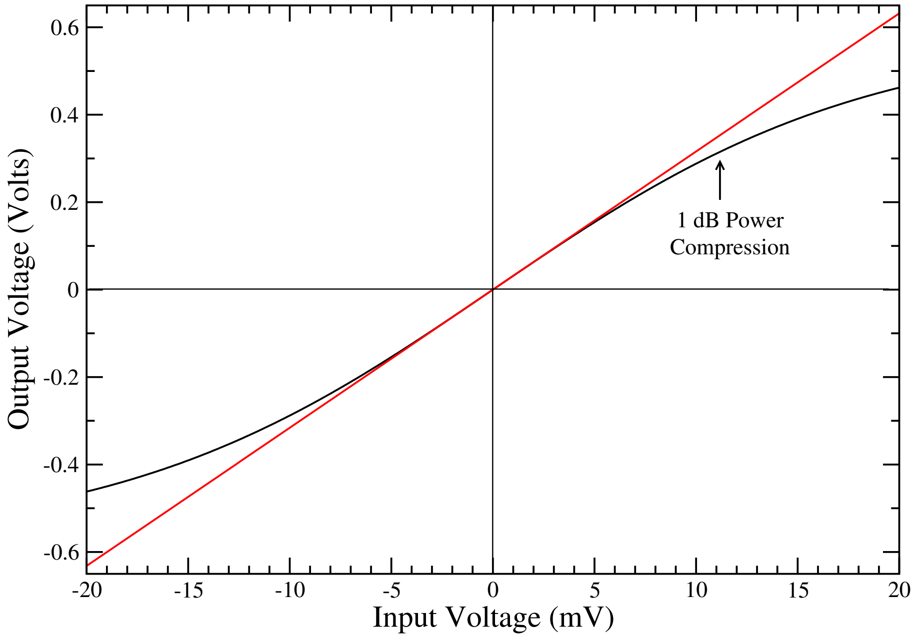

Figure 1: An amplifier model, believed to be a reasonable description of the C-band VLA system. The black line shows the actual relation between input and output voltages, the red line is the extrapolation of the low-voltage relation. The normal operating input voltage is typically a few microvolts. For comparison, the peak voltage of an input sinusoid sufficient to cause 1 dB power compression is marked.

Amplifier compression characteristics are usually described in terms of the '1dB' compression – the input power at which the output power is 1 dB below a linear extrapolation of the low-power relation. Additional characteristics occasionally used are the '1%' and '6db' compression points. These are shown in Figure 2 for the VLA's C-band amplifiers. The ideal amplifier will have a linear relationship shown by the red line. A real amplifier's output power level will fall short of this linear relation by an amount which increases with increasing input power. A standard definition of desired linearity, termed the 'headroom', is the input power difference between the normal operating point (generally defined by $kT\Delta\nu$), and the input power at which 1 dB of compression occurs.

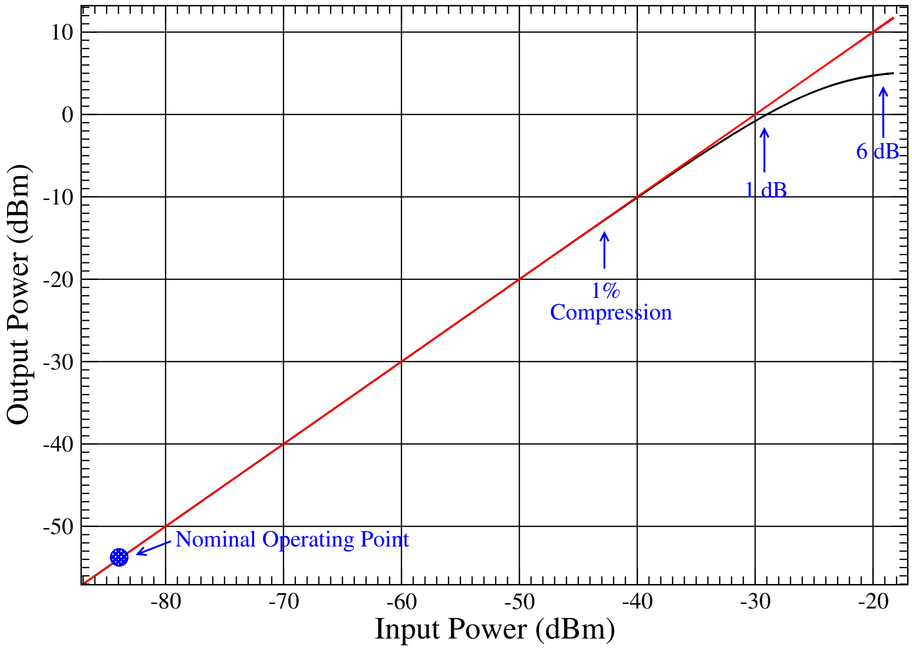

Figure 2: The approximate power response of the VLA C-band amplifiers. The power transfer curve is an approximation. The nominal operating point (defined by $P = kT\Delta\nu$, with $\Delta\nu = 8$ GHz), the 1%, 1dB, and 6dB compression points are marked.

The fundamental behavior of a system with a transfer relationship as shown in Figure 1 can be established by staightforward analysis. Presuming there are no hysteresis effects, we can write the output voltage in a Taylor series:

$$V_o = G_v(V_i + \alpha V_i^2 + \beta V_i^3 + \cdots) \tag{1}$$

where G_v is the low-voltage gain, V_o is the output voltage, and V_i is the input voltage. Presuming that the voltage transfer relationship is odd (which is clearly a desirable design goal), the coefficients of all even terms will be zero, giving

$$V_o = G_v(V_i + \beta V_i^3 + \delta V_i^5 + \cdots). \tag{2}$$

In our application, we are interested in the behavior of the system with two input tones, one of which is much larger (representing the RFI voltage) than the other. The input voltage is then written

$$V_i = A\cos(\omega_A t + \phi_A) + B\cos(\omega_B t + \phi_B) \tag{3}$$

where $\omega = 2\pi f$ is the angular frequency, A and B are the voltage amplitudes (and we will assume $A \gg B$), and ϕ represents the phase of the input voltage.

The response is obtained by inserting this into the transfer equation. The process is staightforward, although tedious, with the result summarized in Table 1, where we have considered only the linear and cubic terms.

The table shows all the harmonic responses for the fundamental and cubic (3rd order) terms. For a heavily saturated amplifier, higher order terms would also have to be included. For the case at hand, $A \gg B$, and the cubic terms at the fundamental harmonics can be approximated by $3A^3$ and $6A^2B$ respectively.

In reality, the RFI term can be approximated by a pure CW, but the astronomical information is broad band. The effect of the non-linear transfer curve on the broad-band case is best shown in a spectral plot, as shown in Figure 3.

Linear and Cubic Compression Factors			
Frequency	Phase	Linear/G_v	Cubic$*4/\beta G_v$
ω_A	ϕ_A	A	$3A^3 + 6AB^2$
ω_B	ϕ_B	B	$3B^3 + 6A^2B$
$3\omega_A$	$3\phi_A$	-	A^3
$3\omega_B$	$3\phi_B$	-	B^3
$2\omega_A + \omega_B$	$2\phi_A + \phi_B$	-	$3A^2B$
$\omega_A + 2\omega_B$	$\phi_A + 2\phi_B$	-	$3AB^2$
$2\omega_A - \omega_B$	$2\phi_A - \phi_B$	-	$3A^2B$
$\omega_B - 2\omega_A$	$\phi_B - 2\phi_A$	-	$3AB^2$

Table 1: The amplitudes of the first and third harmonics for a partly-saturated amplifier with two input tones. The coefficients in the 3rd and 4th columns are to be multiplied by G_v and $\beta G_v/4$, respectively.

Because the coefficient β is necessarily negative, we see from the table that the amplitude of the output at the fundamental frequencies is reduced, which should result in a decrease in correlation SNR. For our application in which the bandwidth ratio (the ration of the upper frequency to the lower) is two or less, the output in the third-order harmonics $3\omega_A, 3\omega_B, 2\omega_A + \omega_B$, and $\omega_A + 2\omega_B$ are of no concern, as they will lie outside the passband. The terms of most concern are the bottom two in the table, $2\omega_A - \omega_B$ and $2\omega_B - \omega_A$, which can reflect spectral infomation back onto the amplifier passband. Figure 3 shows the relative frequency relations and strengths of this form of aliasing. The effect will be to add, to any given fundamental component, a contribution from another frequency, whose correlation properties will be different than those of the 'proper' signal.

It is not immediately clear what the consequences of this 'aliased' signal will be. If the phase relationships are preserved, then we might expect a 'ghost' image to be superposed onto the correct image. If the phase relationships are not preserved, we might expect an increase in noise, and perhaps loss of closure of the correct information. Without strong theoretical guidance in this matter, and given the potential for image degradation, we were thus motivated to construct an experiment to directly measure the consequences of strong CW signals in the passband.

3 The Experiment

The goal of this experiment was to saturate the low-noise amplifiers (LNAs) in each C-Band receiver with a high-power CW tone in order to simulate strong radio interference, and determine the observational consequences. Since we are specifically interested in the effects of high-level signals which are within the range of the first amplifier, but which can be kept out of the subsequenct electronics, the frequency of the tone was chosen to be 4010 MHz, which is about 500 MHz below the standard VLA C-Band 4500–5000 MHz band. Fortunately the C-Band LNAs provide reasonably constant gain across the entire 4000-5000 MHz range so the response of the amplifiers to the saturating tone at 4010 MHz is similar to what which might occur if the tone was situated within the standard observing band. The tone was injected into the receiver directly in front of the LNA's using the noise calibration path. Filters were added at the output of the A-Rack dewar to strip the lower frequency tone from the astronomical signal so that it would not generate intermodulation products in the subsequent frequency conversion chain.

There were a number of logistic constraints and system requirements which had to be met in order to carry out the C-Band compression test:

- Care was taken to ensure minimal disruption or modification to the operational VLA C-Band front-end and LO/IF sub-systems.

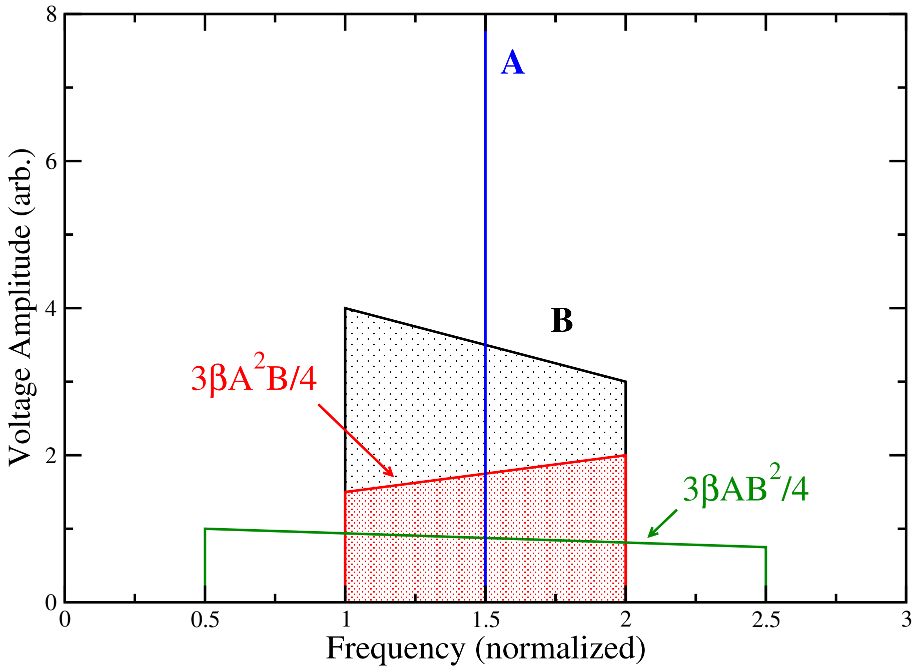

Figure 3: Showing the spectral relationships for a strong CW signal and broad-band noise power extending over a 2:1 frequency ratio. The blue spike ('A') represents the RFI tone. The black stippled area represents the actual noise at its true frequency. The red stippled area shows the stronger 'aliased' component, the green rectangle shows the weaker term.

- As we wanted to perform a phase and amplitude closure analysis, 4 modified antennas were required. Since we didn't wish to use to use laboratory test equipment (such as synthesizers) to outfit this many antennas, the existing VLA system was adapted to provide the required CW tone by using one of the 2-4 GHz L6 Synthesizer modules on each antenna.

- For comparison purposes, remote control of the CW tone was required in order to enable and disable the saturating signal. This was done using the VLA Observe file to control the L6 synthesizer frequency setting.

- Since we wanted to avoid unwanted intermods, filters were added to reject the CW tone before it reached the IF conversion chain. This helped avoid confusion from birdies and mixer intermods that might otherwise appear in the astronomical passband. The astronomical signal, of course, was preserved.

- The LNA of the LCP polarization channel on all 4 antennas was compressed to about the 1 dB point while the RCP channel was compressed much more heavily (as high as 6 dB).

The GaAs FET amplifiers used in the VLA C-Band receivers typically have gains in the range of 30 $\pm$ 2 dB. The 1 dB output compression point of these amplifiers, as measured by the Central Development Lab, is on the order of 1 $\pm$ 1 dBm. This means that the input level of the CW tone must be about -29 dBm to put the LNA into 1 dB saturation. Since the tone is being injected through the Cal path, which includes a 6 dB splitter and a 26 dB coupler, the initial drive level of the tone had to be greater than -3 dBm. To achieve higher saturation levels (on the order of 6 dB), the input power of the tone had to be considerably higher – perhaps as high as +10 to +15 dBm.

Figure 4 shows the block diagram of the test setup. Note that the L6 normally used by the B and D channels of F4 frequency converter modules has been 'hijacked' to provide the CW tone. Consequently the B and D channels were disabled. The CW tone was then amplified and injected into the C-Band front-end using the noise calibration path. A 3335-4065 MHz filter was added to pass the CW tone when it was set to 4010 MHz but to reject it when it was commanded to 2010 MHz. This is the On/Off switch that can be controlled by the Observe file.

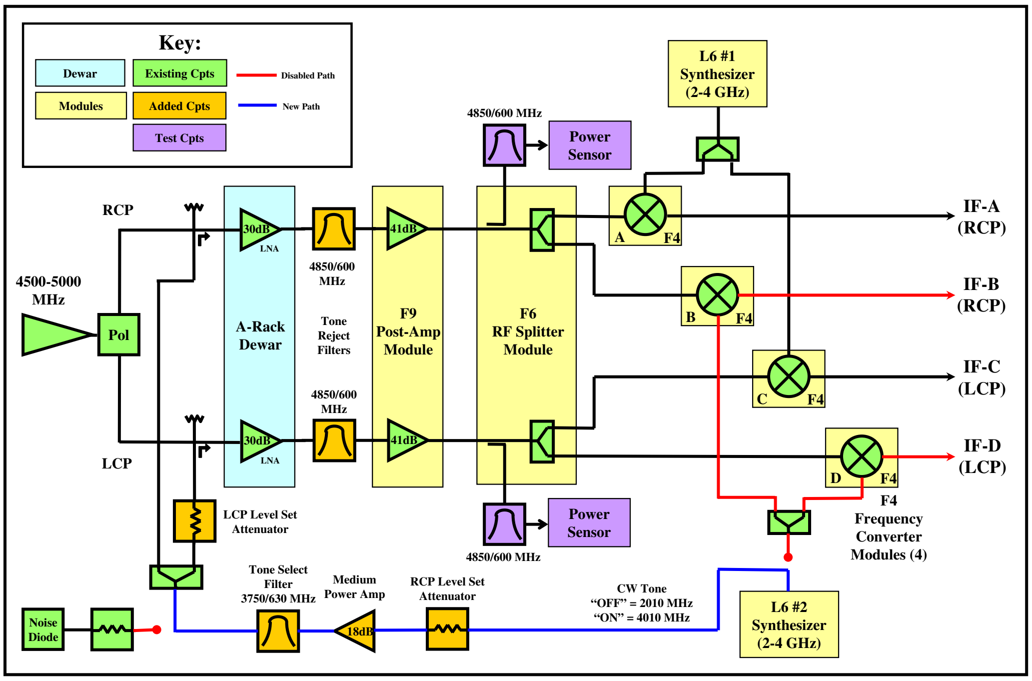

Figure 4: The setup for injecting the tones into the VLA's FE. Tone power (at 2040 or 4010 MHz) was generated by the 'BD' L6 synthesizer, and coupled into the 'AC' signal chain through the calibration couplers. Filters inserted after the front-end amplifiers ensured these tones did not pass to the subsequent stages of amplification or transmission. See the text for a more complete description.

When dealing with saturating tones, it is customary to determine the amount of compression by measuring the output power for a given input power level. For low-level signals, the Pout/Pin ratio is, by definition, the gain of the amplifier. As the amplifier begins to saturate, a 1 dB step in the input level will not produce a 1 dB step at the output. Instead, it will be somewhat less. How much less depends on how far into compression the amplifier is. After experience with the VLBA C-Band receiver and the VLBA Test Rack, it was determined that when the out-of-band saturating CW tone was stripped away (using a 4550-5150 MHz filter which provided over 45 dB of rejection at 4010 MHz), the gain of the amplifier in the desired portion of the band decreased by the same amount as the original tone had been compressed. In other words, if the tone was compressed by 1 dB, the gain at the amplifier in the standard C-Band range also dropped by 1 dB. Similarly, a 6 dB saturated tone causes the gain in the desired band to drop by 6 dB. On the antenna, the amount of saturation was determined by how far the monitored output ports of the F6 module dropped as the CW tone level was increased. Obviously, this technique was much easier to do than measuring the Pout/Pin ratio of the tone directly.

The level of the RCP compression was set using a fixed attenuator in front of the medium power amp. This was typically set for about 5 dB of compression. The LCP level was set by padding down the signal on the LCP side of the Cal splitter. This was adjusted to get as close to the 1 dB compression point as possible. It was surprising to find that when the LCP side was completely disconnected, the LCP side still showed some effects from the CW tone. This was presumed to be due to a portion of the strong tone being coupled out of the RCP Cal coupler back towards the feed. Any signal passing through the polarizer and reflected back, say from the feed or subreflector, would end up in the LCP channel thanks to the flip in polarization. This phenomena should be investigated further at some future date.

Figure 5 shows the details of the experiment on a frequency plot. The dashed green line is a projection of the broadband response of the C-Band LNAs. The light blue box shows the standard VLA 4500-5000 MHz observing band. As the CW tone is switched 'Off' (dark blue) and 'On' (red), the power through the tone reject filter will drop by the amount of compression imposed by the tone. The drop in the LNA gain of 6 dB should result in an increase in system temperature by about 3% due to the higher contribution of noise fromthe post-amps.

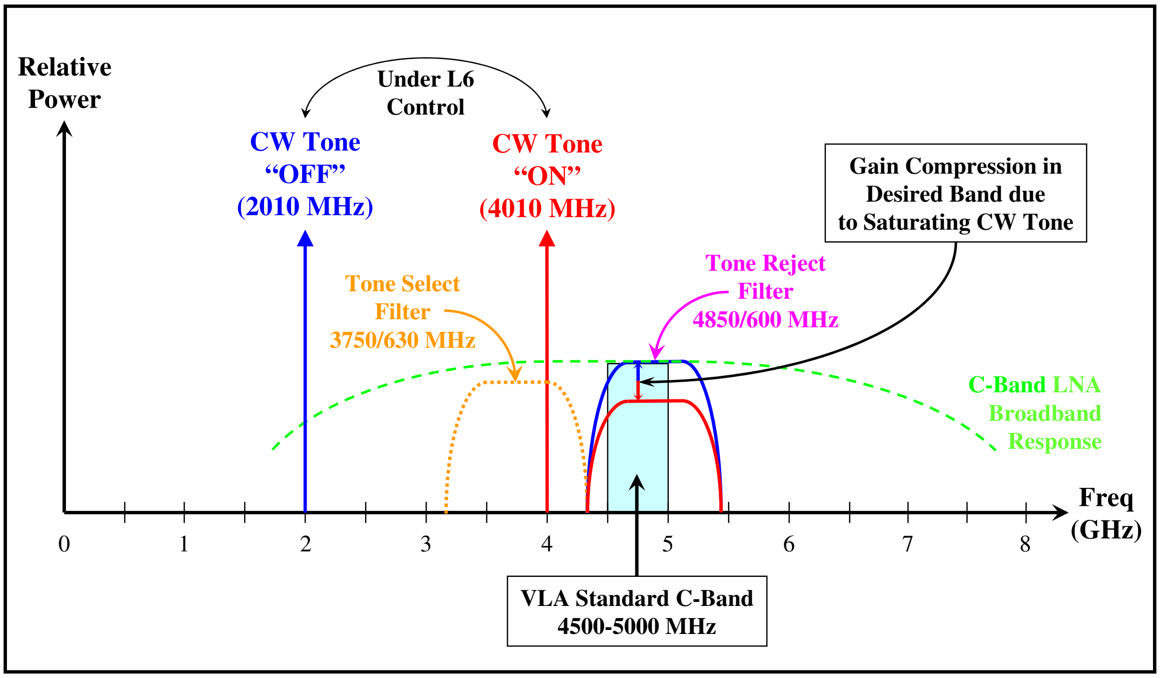

Figure 5: The approximate frequency dependence of the amplifiers and filters used in the experiment. Note that the stronger aliased response will lie between 3010 and 3510 MHz, and hence will be blocked by the Tone Reject Filter from reaching the correlator.

The setup shown for the experiment had one unfortunate consequence – because the tone frequency (4010 MHz) was not within the VLA's standard C-band passband (4500 – 5000 MHz), the stronger 3rd-order 'aliased' response will be at 3010 – 3510 MHz, and hence outside the C-band passband[1]. The weaker aliased 3rd order term was at 4990 – 5990 MHz, and thus barely within the standard band. However, we did not tune the system to cover this frequency. Thus, we were unable to measure any closure or information crossover due to this mechanism. In the final section of this report, we discuss a future experiment we are proposing to measure this effect.

One initial condition – that of preserving the Tcal injection and switched power detection features – was relaxed. The original plan would have used a 10 dB coupler for injecting the tone into the Cal path so that the Tcal switched power was essentially unaffected. Since this scheme would not have allowed the amplifiers to be compressed at the higher 4-6 dB levels, it was decided to abandon the noise calibration feature, and the system temperature information it would have provided, in order to reach higher compression levels.

One last note on the experimental setup concerning the Tcal switched power. It was initially assumed that the change in power between the Cal On and Cal Off (typically set to about 10% of

[1]In fact, this response was blocked by the same filter used to prevent the tone from propagating to the subsequent electronics.

Tsys) would be affected when the LNAs were put into compression. Tests in the lab showed this not to be the case. The difference in switched power was measured on a VLBA C-Band receiver with increasingly higher LNA saturation levels from the CW tone (up to nearly 8 dB) with no noticeable change seen in the Tcal delta to 0.01 dB (0.2%) level. While the absolute power of the amplifier dropped as its gain was compressed, the Tcal delta remained constant. This result would not be the case if, for example, the amplifier in question was providing post-amp gain and the noise power from cold sky (rather than an out-of-band tone) had been amplified so high that the amp was in compression. In this scenario, the Tcal switched power would be 'squished'.

Four antennas were modified, one at the end of each of the three arms, and one at the center of the array. The input CW power to the 'C' IFs for each of these antennas was adjusted to put the compression to 1 dB. For 'A' IFs, the powers were adjusted to put the amplifiers into 2.5 to 6.4 dB compression. The actual values as measured in the field, are given in Table 2.

Power Compression Levels		
Antenna	IF 'A'	IF 'C'
1	2.50 dB	1.06 dB
2	4.97	0.77
22	5.95	0.75
28	6.38	1.10

Table 2: The compression in the front-end amplfiers as a result of the applied CW tone.

In order to measure subtle errors in the correlation coefficients, observations must be made of a strong source with simple structure. We chose the nearly unresolved calibrator 3C286. Data were taken cyclicly in four modes: 50 MHz continuum, with and without the tones on, and in spectral line (12.5 MHz, 2AC mode (RR and LL), 32 channels in each, for 390 kHz resolution), with and without the tones. Observations at each of the four modes were 5 minutes in duration, over a total of four hours – one hour in each state. The observations were taken at 6cm wavelength (C-Band), in C-Configuration, in the evening of 13 May, 2004, with 26 antennas in the array. The averaging time utilized was 3.33 seconds. The array resolution was about 3.5 arcseconds. Observations taken with the CW tone on are referred to as Compressed ('C'), those taken with the tone off are referred to as Uncompressed ('U').

4 Data Calibration

The data were edited using standard procedures, and calibrated initially with the assumption that 3C286 is a point source of spectral flux density 7.46 Jy. Data were of excellent quality, and virtually no flagging was required.

The continuum data were calibrated and imaged first. A quick round of imaging and self-calibration demonsrated the source is slightly resolved, and images with dynamic ranges in excess of 10000:1 were produced from both the C and the U data. Closure errors, (defined as errors which cannot be factored into antenna-based amplitudes of phases) likely due to uncompensated errors in antenna delays and bandpasses created baseline-based errors in the derived coherence of up to 2% – larger than the effect we are expecting to measure. We thus turned attention to the spectral line data. The continuum data were not further analyzed.

The spectral line data were similarly edited and calibrated, then the bandpass functions were calculated for each scan, for both the C and U data. We then used the U data to produce a fiducial image of 3C286, which was used to subsequently calculate the baseline-based 'closure' errors, and the antenna-based calibration corrections (gains). The median closure error noted was about 0.1%.

The left panel of figure 6 shows the source, with 7.3 Jy removed from the center. The visible extension to the southwest is due to a 61 mJy component located 3.0 arcseconds from the slightly resolved nucleus, in p.a. -115. The dynamic range of this image is in excess of 90000:1 – from only one hour of data!

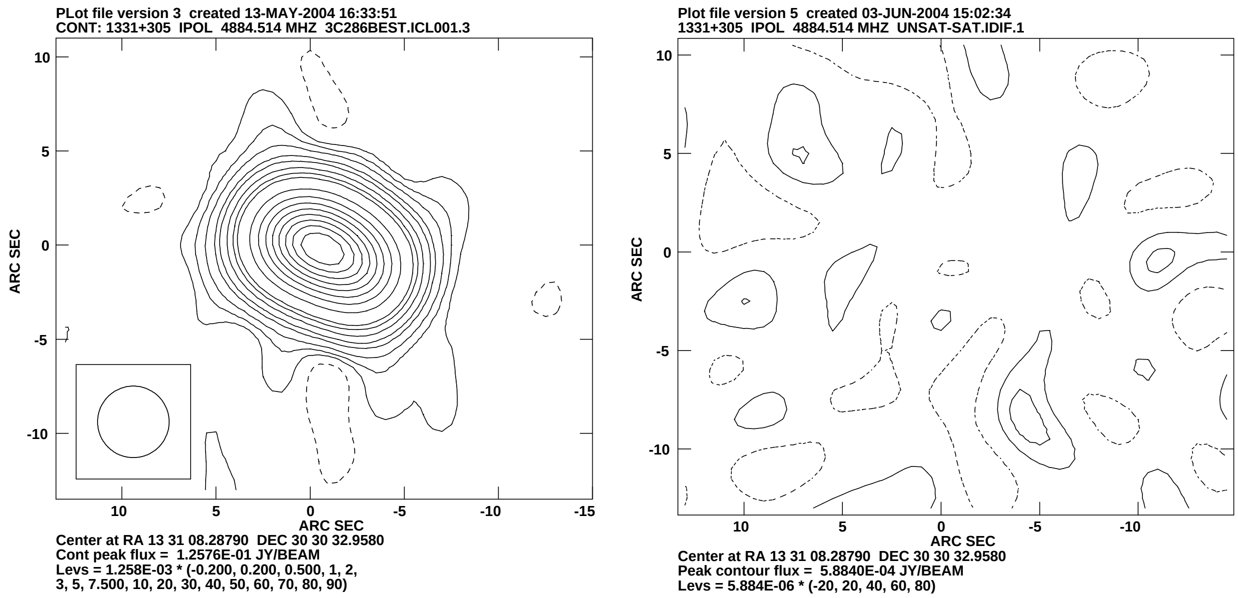

Figure 6: (Left Panel) The calibration source 3C286, at 6cm, with 3.8 arcseconds resoution. A 7.3 Jy point source has been removed from the (0,0) coordinate. This model of the source, made with the uncompressed data, was used for calibration of all data. (Right Panel) The difference image between the 'compressed' and 'uncompressed' images of 3C286. The rms noise is about 50μJy/beam. No measureable difference is seen.

The quality of the spectral line data – as evidenced by the extremely high fidelity – allows us to make careful measures of the change in coherence properties due to the amplifier compression.

5 Results

5.1 Gain Changes

As argued above, we expect a change in antenna sensitivity – or more properly, an antenna-based loss in the correlation coefficient, due to attenuation of desired harmonic components of the input spectram, and the addition of signals from other input frequencies. As the data were taken without any on-line gain corrections, other than the ALC loop, and as the injected tones were isolated from this loop, the raw correlation coefficients provided by the correlator should directly measure the change in system sensitivity. That is, it should not be sensitive to a simple change in gain caused by the imposition of the tone.

The calibration results clearly show the expected effect. Table 3 shows the amplitude gains needed to return the correlation coefficients to the correct flux density, and the ratio between the C and U observations.

The values of the amplitude gains in the table (the 2nd and 3rd columns) are not of interest here – what is important is the ratio of the required gains before and after the tones are injected, as these ratios map the change in system sensitivity. Note that the 1 dB compression is only marginally noticed in the gains, while the 6 dB compression point is marked by an average 16% drop in sensitivity. As a control, these gain ratios were also measured for the unmodified antennas: none of these antennas showed a change of gain greater than 0.5% in amplitude.

Antenna Gain Corrections				
Antenna/IF	Uncmp	Cmp	Ratio	dB
1R	238	243	1.04	2.50
1L	226	227	1.01	1.06
2R	246	269	1.18	4.97
2L	226	227	1.01	0.77
22R	207	222	1.14	5.95
22L	200	201	1.01	0.75
28R	189	212	1.24	6.38
22L	173	174	1.01	1.10

Table 3: The changes in antenna gain for the modified antennas. There is a clear relation between loss and amplifier compression. The gains shown (2nd and 3rd columns) are for the amplitude. The ratio shown is the power ratio. The right-hand column gives the amplifier compression. The measurement errors in these listed gain values are less than 0.5%.

Although care was taken to ensure the tone power (either at its fundamental frequency or at any of its harmonics) did not affect the ALC loops (which would itself create a notable change of gain), and although the individual spectra showed no evidence for CW signal contamination, there could be some mechanism by which the tone power is directly responsible for the noted gain change. This possibility can be eliminated by direct measurement of the SNR in the correlated signal. This was done by calculating the r.m.s. amplitude fluctuations, for one 5-minute period, of the calibrated visibilities. In Table 4 we show the ratio of the visibility amplitude rms between the uncompressed and compressed scans, for various antenna combinations.

Visibility SNR Loss		
C x C	U x C	U x U
1.17 ± 0.04	1.07 ± 0.01	0.98 ± 0.01

Table 4: The ratios of the visibility RMS between uncompressed and compressed data, using the IF 'A' data, for which input tone powers were sufficient to create typically 6dB compression. 'C' stands for the four modified antennas: 1, 2, 22, and 28. 'U' stands for unmodified antennas.

The loss of sensitivity when the tone is on is quite clear. These values are in good agreement with the simple gain changes shown earlier.

5.2 Closure Changes

The simplest indication of significant 'closure' errors introduced by the tone powers would be a visible degradation in the resulting image. The right-hand panel of Fig. 6 shows that no such degradation was noted – the image of 3C286 from the 'tone-on' scans was identical to within the noise to the image from the 'tone-off' scans. However, a direct image such as this is not very sensitive to any effect, as there were only 6 baselines (out of 325) on which strong saturation was created. Unless the effect was very large, the 'good' will outweigh the 'bad'.

A much more precise measure of any effect to the correlation coefficients caused by the tones is to directly compare the visibilities measured on the baselines formed by the 'toned' antennas. Fig. 7 shows the visibilities from the baselines formed from antennas 2, 22 and 28, after antenna-based calibration to remove antenna-based gain changes. The visibilities from the 'Compressed' data are plotted with dots, those from the 'Uncompressed' data are plotted with squares. The mean difference between these is less than 1 part in 1000. Hence, closure errors induced by the non-linearities in these amplifiers are less than 0.1%. Fig. 7.

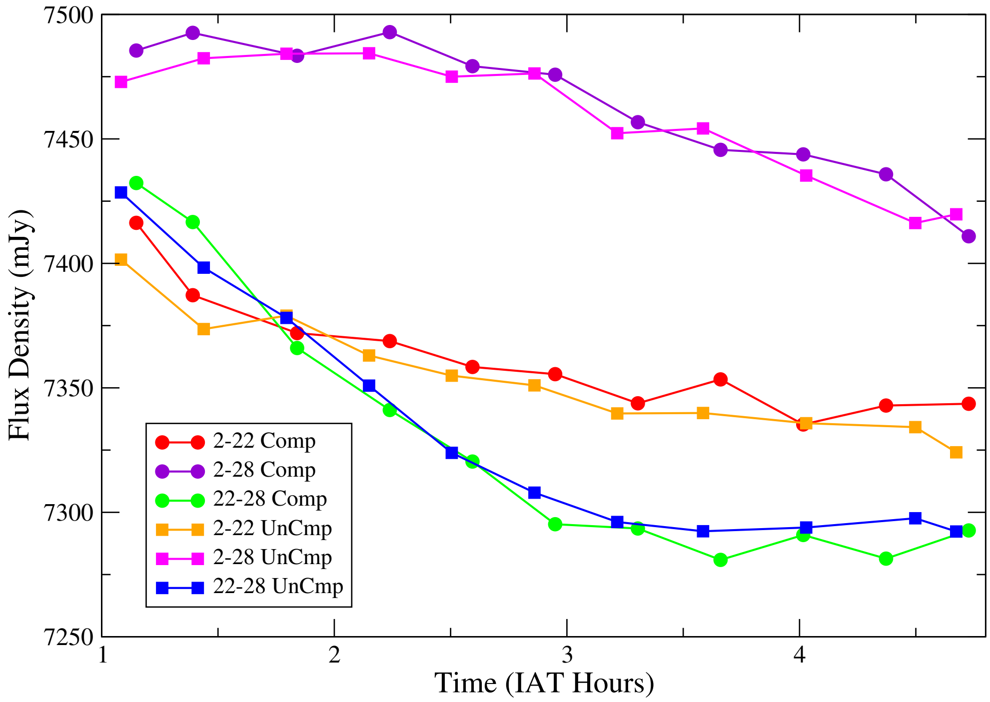

Figure 7: The calibrated visibilties for the three baselines with the maximum input signal power, with that power on and off. No significant difference is seen in these visibilities between the C and U states, indicating that any change in coherence closure caused by the high signal power level is less than 0.1%.

Another way of measuring these changes is to compute the amplitude and phase corrections needed to make the observed ('compressed') visibilities compatible with the model, and to compare these to those from the 'uncompressed' data. This can be done with the AIPS program 'BLCAL'. We would expect differences in these corrections between the 'U' and 'C' data. Figure 8 shows the closure corrections for the baselines utilizing antennas 1, 2, 22 and 28 in the 'R' data, for both the 'C' and 'U' data.

There is no statistical difference in the required corrections – to about 0.1%, for these 93 baselines, between the 'tone on' and 'tone off' states. Examination of the six baselines formed by the ~6 dB compressed antennas alone also showed no discernible changes in closure corrections.

5.2.1 Bandpass Changes

Another possible effect of a strong input CW signal is to modify the bandpass shapes, either in phase or amplitude. To check this, we calculated the bandpasses, utilizing the same 'fiducial' image model used to calculate the antenna gains. The results are shown in Fig. 9.

Changes in the bandpass amplitudes are at the levels of a few tenths of one percent – consistent with the measurement accuracy. Changes in phase (other than a general slope representing a ~ 0.25 nsec delay error) are at the level of a few tenths of one degree. Thus, we conclude there is no significant effect visible in the bandpasses between the 'tone on' and 'tone off' states.

6 Summary and Discussion

An experiment designed to measure the effects of amplifier compression on calibration and sensitivity has shown that an amplifier driven to its 1 dB compression point has no effect on the SNR or the

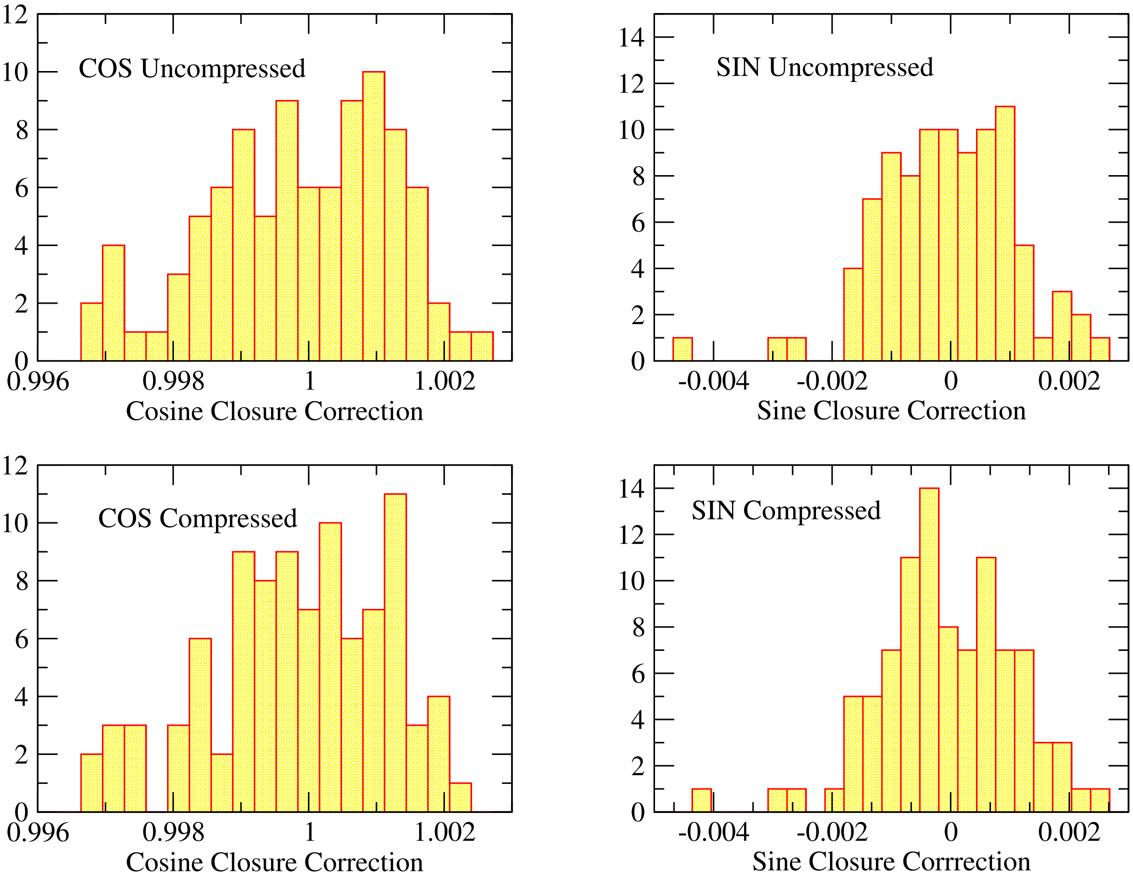

Figure 8: The closure corrections (averaged over the dataset) for the baselines utilizing antennas 1, 2, 22 and 28. The upper pair show the COS and SIN corrections for uncompressed data, the bottom pair for the compressed data. There is no statistical difference between these.

closure characteristics. With 6 dB compressions, there is a drop in antenna sensitivity of about 15%, and no measureable change in closure. It is to be noted that due to the design of this experiment, no errors in closure were expected.

To address the important point of errors in imaging due to strong RFI, we have designed another experiment which should enable a straightforwards way of measuring the 3rd-order coupling. By injecting a tone at 1555 MHz into the L-band receiver, the strong OH line at 1667 MHz would appear at 1443 MHz, where no other spectral transitions are expected. The correlator and LO system could be set to observed both frequencies, and the strength of the 'aliased' signal could be directly measured. We are currently planning to do this experiment later this year.

7 Acknowledgements

This experiment was facilitated by the expert assistance of Dan Mertely and Brent Willoughby. Advice from Ken Sowinski and Barry Clark was very useful. We are very grateful to Bryan Anderson for noting that the 3rd-order aliased signals would not appear in our correlated bandpass, so that errors in closure and imaging would not be expected.

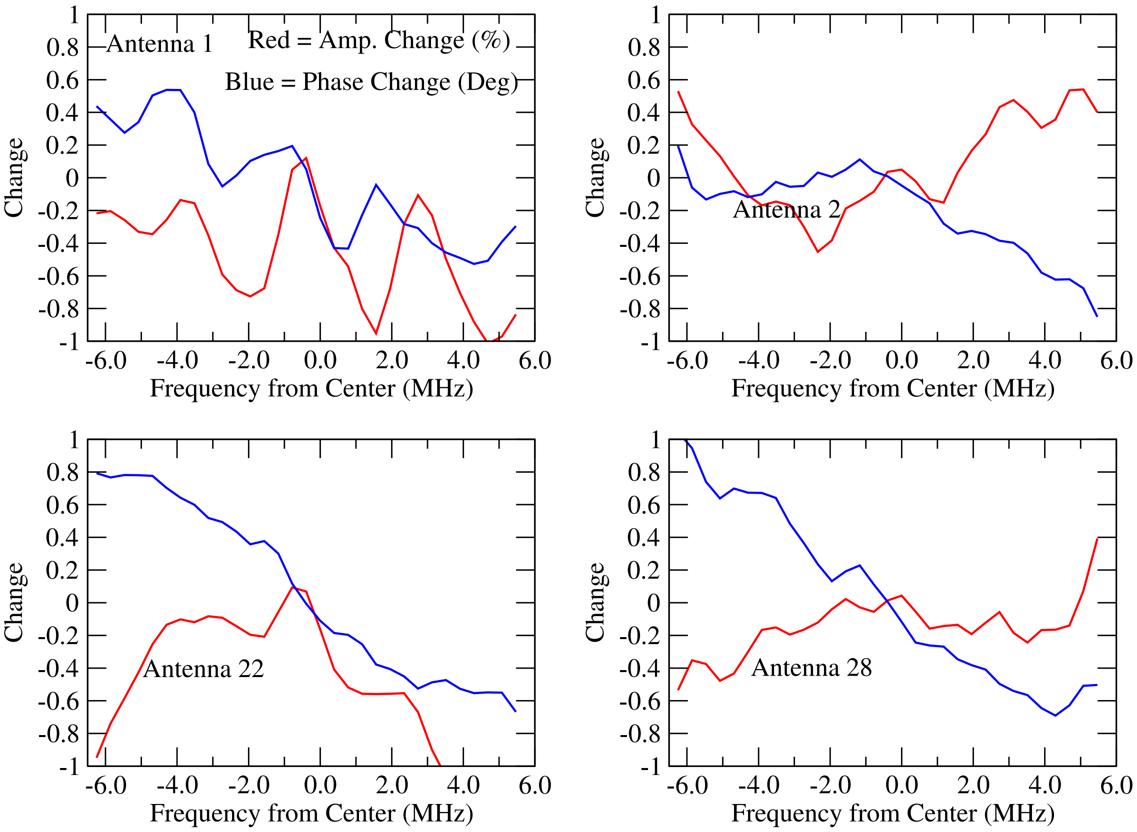

Figure 9: The difference in the bandpass amplitude (red) and phase (blue), for the four modified antennas, between the signal on and signal off states. The phase slope amounts to a ~ 0.25 nsec change in delay,