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Very Large Array Program

VLA Scientific Memo Nr. 166

Current Spectral Line Capabilities at the NRAO–Very Large Array

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1. Introduction

Over the past few years many new options have become available at the Very Large Array regarding its spectral line capabilities. The purpose of this document is to summarise the current status of the VLA spectral line system, both on–line and off–line, and to provide references to information which is somewhat scattered throughout the VLA Test and Scientific Memos and the NRAO Newsletters. Obviously, there is ample scope for further improvement. A discussion document on a VLA Upgrade can be obtained by contacting T. Bastian (tbastian@nrao.edu).

A certain level of familiarity with the VLA and its spectral line capabilities is assumed. The following references might be especially useful:

- *SLG*: Rots, A. 1990 "A Short Guide for Spectral Line Observers, version 8" (Note: a thoroughly revised and updated version 9 is due to be released soon).
- *OSR*: Perley, R.A. 1994 "VLA Observational Status Report" (Note: this document is updated on a yearly basis)

Both documents and their updates can be found by accessing the NRAO home page in "mosaic" and clicking on *Very Large Array* followed by *VLA Observational Status Summary* or *Spectral Line Users Guide.*

Although this Scientific Memo is written with the spectral line user in mind, many of the changes and improvements commissioned have greatly benefitted continuum users as well.

2. VLA Front–Ends

Over the past years the receiver system at the VLA has been expanded, by adding 7 mm, 3.6 cm, 90 cm, and 400 cm (respectively Q–, X–, P–, and 4–band). The 7–mm system is currently being installed, the other three bands became available in 1988 and 1989. Also, existing receivers have been upgraded, such as at 1.3 cm (K–Band) which was completed in mid–1989 and most recently at 18–20 cm (L–band). For frequency coverage and system temperatures the reader is referred to the latest *OSR*.

At present, 4–band is still in an experimental state with eight antennae outfitted with pairs of crossed dipoles at prime focus. It appears, though, as if these dipoles raise the system temperature at the "Cassegrain–bands" and it was decided to remove 4–band for the first part of the D–array all–sky continuum survey (see Bagri, D.S. & Lilie, P. 1993 *VLA Test Memo No. 176*).

At the time of writing, ten 7–mm receivers (nine units and one spare) have been installed at the VLA. Details about the performance at Q–band, both in continuum and spectral line mode, can be found in *VLA Test Memo No. 189* (Wood, D. 1994). It is important to note that it is essential at Q-band to improve upon the pointing by using the method of "reference pointing" (see Wood, D. & Sowinski, K. 1993 *NRAO Newsletter No. 55* and Kesteven, M. 1994 *VLA Test Memo No. 183* for further details). Although not strictly necessary, K–band observations will also benefit from "reference pointing".

The new 20–cm receivers, the last of which was installed in mid–1993, cut the system temperature almost by half to 30–35 Kelvin. This had as an unexpected effect that at low elevations ground pick–up by feed sidelobes adds appreciably to the system temperature, resulting in higher rms noise for observations at low elevations. For example, at 30 degree elevation, the T_{sys} increases by 45% and deteriorates rapidly when observing below 20 degrees (Bagri, D. 1993 *VLA Test Memo No. 167*).

3. Spectral Line System

The correlator is fed by the IF system. The VLA has two IF channels which can be tuned independently (with some restrictions); each IF consists of a pair, capable of measuring right (R) and left handed (L), circular polarisation. Historically, these IFs have been called A, B, C, and D; A and B are right, and C and D are left circularly polarised. The first IF pair consists of IFs A and C, the second IF pair is made up by IFs B and D. The correlator has four identical quadrants and the four IFs can be distributed over these quadrants in a number of ways. This leads to four basic groups of correlator modes (see e.g., *SLG*):

1- continuum: IFs A and C go into Quadrants 1 and 2; B and D go into 3 and 4; parallel and cross–products are produced allowing all four Stokes parameters to be measured.
2- line: only RR and/or LL correlations are determined.
    single–IF: one IF (A, B, C, or D) uses all four quadrants.
    two–IF: two IFs use two quadrants each.
    four–IF: IF A, B, C, and D each use one quadrant.
3- polarisation line: one IF pair (IFs A and C or IFs B and D) uses all four quadrants to deliver parallel and cross–products.
4- mixed: One IF pair measuring in continuum mode, the other in line mode, each using two quadrants.

An important difference between continuum and line mode is that in line mode positive and negative lags (time domain) are produced by the XF correlator and processed to generate complex spectra (frequency domain) whereas in continuum mode a quadrature network is used to generate cosine and sine correlation products.

Table 1: Available bandwidths and spectral line channels in normal mode

BW Code	Band Width MHz	Single IF Mode (1) No. Channels(4)	Single IF Mode (1) Freq. Separ. kHz	Two IF Mode(2) No. Channels(4) per IF	Two IF Mode(2) Freq. Separ. kHz	Four IF Mode(3) No. Channels(4) per IF	Four IF Mode(3) Freq. Separ. kHz
0	50	16	3125	8	6250	4	12500
1	25	32	781.25	16	1562.5	8	3125
2	12.5	64	195.313	32	390.625	16	781.25
3	6.25	128	48.828	64	97.656	32	195.313
4	3.125	256	12.207	128	24.414	64	48.828
5	1.5625	512	3.052	256	6.104	128	12.207
6	0.78125	512	1.526	256	3.052	128	6.104
8	0.1953125	256	0.763	128	1.526	64	3.052
9	0.1953125	512	0.381	256	0.763	128	1.526

Notes :

(1) Observing Modes 1A, 1B, 1C, and 1D.
(2) Observing Modes 2AB, 2AC, 2AD, 2BC, 2BD, and 2CD.
(3) Observing Modes 4, PA, and PB
(4) These are the numbers of frequency channels produced in the correlator. Any number of channels that is a power of 2, that is less than or equal to the number in the table (with a maximum of 512), and that is greater than or equal to 4 may be selected.

The VLA correlator has enough correlator chips to produce 16 complex frequency channels at 50 MHz bandwidth (i.e., the current maximum bandwidth per IF). Halving the bandwidth allows the chips to be "time–shared" so that the number of channels is doubled. This can be continued to a maximum of 512 channels at which point successive halvings of bandwidth leave the number of channels at 512. Note that the above mentioned 16 channels are to be shared among all IFs which are called for. The total number of available channels for a selected bandwidth and correlator mode is given in Table 1. In order to reduce "ringing", either at the edge of the band or around narrow emission or absorption features, one can opt for Hanning smoothing. When this is applied, the spectral resolution is reduced to twice the channel separation and thus only every other channel needs to be retained. The full number of channels is needed, of course, in the lag–to–frequency transform. Table 2 lists the number of channels available when Hanning smoothing is applied.

Although the above mentioned correlator modes were planned for in the design of the VLA correlator, it took until the on–line software update of May 31, 1990, for all of them to become available; an interim situation making two–IF line mode observations available existed since the correlator update of August 2, 1988 (for details see Sowinski, K.P. & Rots, A.H. 1988 *NRAO Newsletter 41*; Brinks, E., Hunt, G. & Sowinski, K. 1992 *NRAO Newsletter No. 43 & 45*). The current situation can be summarised as follows:

Table 2: Available bandwidths and spectral line channels using Hanning Smoothing

		Single IF Mode (1)		Two IF Mode(2)		Four IF Mode(3)	
BW Code	Band Width MHz	No. Channels(4)	Freq. Separ. kHz	No. Channels(4) per IF	Freq. Separ. kHz	No. Channels(4) per IF	Freq. Separ. kHz
0	50	8	6250	4	12500	2	25000
1	25	16	1562.5	8	3125	4	6250
2	12.5	32	390.625	16	781.25	8	1562.5
3	6.25	64	97.656	32	195.313	16	390.625
4	3.125	128	24.414	64	48.828	32	97.656
5	1.5625	256	6.104	128	12.207	64	24.414
6	0.78125	256	3.052	128	6.104	64	12.207
8	0.1953125	128	1.526	64	3.052	32	6.104
9	0.1953125	256	0.763	128	1.526	64	3.052

Notes :

(1) Observing Modes 1A, 1B, 1C, and 1D.
(2) Observing Modes 2AB, 2AC, 2AD, 2BC, 2BD, and 2CD.
(3) Observing Modes 4, PA, and PB
(4) These are the numbers of frequency channels produced in the correlator. Any number of channels that is a power of 2, that is less than or equal to the number in the table, and that is greater than or equal to 4 may be selected.

1- Continuum observations are (and have been) fully supported.

2- All one–IF line modes (1A, 1B, 1C, and 1D), all two–IF modes (2AB, 2AC, 2AD, 2BC, 2BD, and 2CD), and mode "4" (allowing one spectrum for each of the four IFs) fully function.

3- The spectral line polarization modes (PA and PB) producing RR, RL, LR and LL correlation products based on either IFs A and C *or* IFs B and D are available. It should be noted that in spectral line mode the round-trip phase correction is not being applied to IFs B and C. The small phase drift is normally calibrated out in the parallel hands but *not* in the cross-hand polarizations. Until the round-trip phase can be applied to IFs B and C as well, a slow apparent rotation of a few degrees per hour of the plane of the polarization should be expected.

4- Multiple subarrays in spectral line *or* continuum mode are supported, but mixed spectral line and continuum subarrays are *not* allowed.

There are several restrictions and caveats which apply to the above. They are:

i- The individual IFs may have independent bandwidths. There is a limitation, though, in the sense that correlator firmware imposes a restriction on bandwidth selection when using the multiple IF spectral line modes such that all the IFs must be at 50 MHz total bandwidth or they must all be less than 50 MHz. In other words, when multiple IFs are specified with different total bandwidths none of these can be 50 MHz. This restriction holds independently for each subarray.

- ii- The individual IFs may have independent data selection criteria, i.e., one can select for each IF independently a start channel and the number of channels one wishes to write to tape/disk. The number of selected channels should be larger than two.
- iii- Autocorrelation spectra are produced for all active antennas. The autocorrelation spectra are processed in the same way as the cross-correlation data (i.e., the options for lag spectra, Hanning smoothing and data selection are applied).
- iv- Bandpass normalization and Hanning smoothing are available with all spectral line modes. The same options, such as Hanning smoothing or autocorrelation normalisation will be applied to each IF in the multiple IF modes.
- v- Channel zero (the "continuum" channel) is incorrectly computed in the case of a four channel spectrum (before Hanning smoothing). This will arise only in the case of correlator modes 4, PA and PB with a bandwidth of 50 MHz. It is not a problem if a four channel spectrum is produced as a result of data selection. There are no plans to fix this "problem".

4 Examples of Spectral Line Observing Modes

4.1 Observations at two frequencies within the same band

The release of the correlator modes listed above and especially the introduction of the "4 mode" when doing spectral line work has introduced a whole new range of possible observing strategies (see Brinks, E. 1991 *NRAO Newsletter No. 46 & 47*, for details). In particular the following configuration has proven to be popular, i.e., to tune one IF pair, AC, to one frequency and the other IF pair, BD, to a frequency which is offset. This offset can have any value as long as the second frequency falls within the same observing band (e.g., L–band) as the first one and is not further apart than 500 MHz (this limit arises because the first LO is shared by both IF pairs and because of the 500 MHz bandwidth of the 4.5–5 GHz amplifier located further "down–stream"). This arrangement is useful when measuring, for example, two of the lines of OH in both polarizations, right hand circularly polarised for IFs A and B, and left hand for C and D. Note that the restriction that the IFs have to be tuned within the same observing band doesn't apply when observing in 4P or LP mode in which situation the AC IFs are tuned to 4–meter or 20–cm emission while the BD IFs are at 90 cm (P–band). This is possible as the 4– and P–band feeds are at the prime focus whereas the feeds for all other frequencies are at the Cassegrain focus. However, as the focus in LP mode is set at that for L–band, the 90–cm observations suffer from a poorly defined primary beam. For this and other reasons, such as RFI, these mixed modes are discouraged.

4.2 Observations with two overlapping IF pairs

An alternative use of the "4 mode" is to have the two bands partially overlap. In that case one can gain typically a factor of two in frequency resolution while preserving an adequate frequency coverage. When observing in this mode it is important to do a proper bandpass calibration (see below) to ensure a seamless match when combining the data from both bands. Autocorrelation normalization corrects only for a variation in gain across the spectrum and doesn't correct for a phase drift across the band which would likely produce a mismatch where the two bands overlap. Experience to date has shown that when doing a careful flux and bandpass calibration both bands can be made to match up correctly. Typically an overall spectral dynamic range of 500:1 can be achieved at L-band without having to resort to any special observing strategies (see also below).

4.3 Observations at the same frequency with different bandwidths

It is possible to specify a wide bandwidth for IFs A and C (e.g., 6.25 MHz) to cover the redshifts of several galaxies in a cluster within the primary beam of the VLA, while IFs B and D use a higher velocity resolution over a narrower bandwidth (e.g., 1.56 MHz) to focus on one cluster member. Although it is even possible to mix different bandwidths within one IF (IFs A and C, for example) this is in general *not* recommended. The main reason is that in that case the fringe rate is calculated with the wrong frequency for IFs B and C (IFs A and D are correct). The frequency error amounts to half the difference in bandwidths. For example, when observing IF A with a 1.56 MHz bandwidth and IF C with a 3.125 MHz bandwidth, the frequency used in calculating the fringe rate is in error by -0.758 MHz. This effect can cause decorrelation within an integration period when dealing with long baselines and/or large differences in bandwidth (which cannot be corrected for). At the least it causes phase winding in one of the IFs involved. An AIPS task (CLCOR) contains an option which calculates the phase corrections for IFs B and C after which the standard complex gain calibration can be applied.

There is a second, more subtle effect which observers contemplating this mode should be aware of. This was reported by Mehringer (1992, *VLA Test Memo No. 161*). Because the VLA beams for the two polarisations have a slightly different pointing centre, an effect known as beam squint, observations made with different bandwidths for each IF have thus different pointing centres which can in some cases affect the data.

5 Continuum Observations in Spectral Line Mode

Although most continuum observations are taken care of by the VLA in its standard continuum mode, some may benefit from using the digital correlator in spectral line mode (see Brinks, E. 1991 *NRAO Newsletter No. 49*). There are several reasons for this. At wavelengths of 6 cm or longer, bandwidth smearing can become important. Depending on how large a field of view is required one can either reduce the total bandwidth from 50 MHz per IF to 25 or 12.5 MHz and observe in continuum mode or one can select a bandwidth of, e.g., 25 MHz and observe in spectral line mode, using 3.125 MHz wide channels.

A second situation in which one might prefer spectral line mode is when trying to achieve very high dynamic range maps (larger than about 5,000:1 at P-band and of order 100,000:1 at other wavelengths). The closure errors are significantly reduced, and can be calibrated out, by observing in spectral mode (see e.g., the discussion in Chapter 16 of "Synthesis Imaging in Radio Astronomy", eds. R.A. Perley *et al.*, ASP Conf. Ser. Vol. 6 (1989)).

Lastly, at wavelengths of 20 cm or longer, spectral line mode may be preferred over continuum mode for yet another reason: strong interference. One strategy which has been successful at P-band, where interference is mainly found at multiples of 12.5, 5 and 1 MHz, is to observe in 4IF mode and to select a 3.125 MHz wide total bandwidth for each IF pair resulting in 98 kHz spectral resolution. Each IF pair is chosen to fall within a relatively clean part of P–band. In the calibration stage, the continuum channel (also known as "Channel zero" data) are discarded and a new continuum is created by selecting only those channels which are interference free. Still, extensive data editing will be necessary.

It should be noted, however, that there is a price to pay when going from standard continuum to spectral line mode. The amount of data is increased by an order of magnitude. Secondly, in a standard continuum run the two IF pairs (AC and BD) are put at different central frequencies so as to cover a total of 100 MHz. In spectral line mode the widest band which can be usefully employed is 25 MHz. After discarding the "edge" channels, choosing the band centres again in such a way that they cover different frequencies, a total bandwidth of about 35 MHz can be synthesized. This corresponds to a drop in sensitivity of $\sqrt{3}$.

Moreover, when using this set–up the cross terms, which provide information on the linear polarization, are lost. When full polarization information is essential one would have to choose the PA (or PB) spectral line mode which essentially employs one IF pair (either AC or BD) and provides all four Stokes parameters. In that case the effective bandwidth after discarding edge channels is down to about 18 MHz which, in order to achieve the same signal to noise as in a standard continuum run, would require a six–fold increase in observing time.

6 Data Handling

6.1 Hardware

Since the move from the VLA site to the AOC much has changed in terms of computing environment and resources. All calibration is nowadays done with AIPS on IBM and Sun workstations. Also, in mid–1993 the Image Storage Unit which was connected to the IIS and Convex systems was retired. All these changes had a substantial effect on data calibration and analysis which will be further discussed below.

To load data into AIPS, the task FILLM was written. Since about a year, data can be filled in near–real time, even to your private workstation! There exists a special version of FILLM, which can be run during one's observation, porting data from the on–line computers into AIPS after each integration time.

6.2 Software

AIPS has undergone some major changes which have benefitted spectral line users. For example, data can now be loaded onto disk in "compressed" format which, for spectral line files, can mean a reduction in disk space requirements by up to a factor of three! Another improvement has been to enable the mapping programmes, HORUS and MX to work on time–baseline sorted data, abolishing the disk–space consuming sorting step. Also, tasks have been added. Without claiming completeness, here are some of the new tasks which are commonly used by spectral line observers:

- HORUS optionally applies calibration tables to the raw visibilities and does the FFT, creating a datacube.

- SQASH sums or averages maps along one axis of a multi–dimensional image.
- AVSPC averages channels in a uv–dataset.
- ISPEC produces spectra.
- IMLIN fits and subtracts continuum from a data cube.
- UVLIN, like IMLIN, fits and subtracts continuum, but works on the uv–data. In addition it allows for "on–the–fly" flagging. UVLIN is based on an idea first published by Van Langevelde and Cotton (1990, A&A 239, L5) which was substantially improved upon by Cornwell *et al.* (1992, A&A 258, 583).

In case the object under study is larger than the primary beam one has to resort to mosaicing. Braun and Cornwell (1988 *NRAO Newsletter No. 34*) describe how one can in principle image objects which are larger than the field of view. This method has been used successfully for several spectral line projects.

7. Radio Frequency Interference

Radio Frequency Interference (RFI) has become a major concern, especially at frequencies below 1800 MHz. At 4– and P–band a lot of the interference is generated locally. At L–band, RFI comes from external sources such as aircraft, radar, microwave communications and satellites. To cut down on RFI a new programme has been initiated to reduce local interference (Brundage, W. & Janes, C. 1994 *VLA Test Memo No. 188*). In addition, B–rack shields have been designed and are being installed on all antennae to reduce RFI, a task which should be finished by mid–1996.

At L–band the situation has deteriorated rapidly over the past few years. It is instructive to compare the L–band interference plot which is generated on a regular basis of, say, 8 years ago with the current one in the *OSR*, especially upward of 1520 MHz (see Figures 1 and 2). Some RFI is generated outside the band but finds a way to enter the system. For example in the case of the "Forest Service birdies", transmissions at 1839 and 1849 MHz mixed with the second harmonic of the first local oscillator (LO) to produce an unwanted response at $(3200 - \nu)$ MHz. These signals could be blocked by inserting suitable filters (see for example Brinks, E. & Crane, P. 1992 *VLA Test Memo No. 162* for details). Similarly the birdie at 1404 MHz could be suppressed. Although somewhat expensive, this method is effective in removing these sources of interference.

When the RFI is due to emission within the band, not much can be done other than trying to avoid it. This was the reason behind the change of central frequency for one of the L–band continuum, 50 MHz bands from 1515 MHz to 1385 MHz (Dhawan, V. & Brundage, W.D. 1993 *NRAO Newsletter No. 54*). Table 3 lists the default frequencies which were in use for L–band continuum, 50 MHz bandwidth per IF pair. For some projects, such as observations of redshifted HI, there is no alternative. Brinks *et al.* (1994 *VLA Test Memo No. 185*) show the effects of observing in the presence of a strong radar signal. Satellites pose a particular problem, as there is no terrain shielding. Observations at 1612 MHz (OH) are still severely hampered by the series of GLONASS satellites, although there now exists an agreement which, among other things, specifies that filters will be installed on the newly developed GLONASS–M spacecraft from 1994–1998, and that from 1999 all broad band RFI due to these satellites will have been dealt with. At present narrow band RFI (1610.6–1613.8 MHz) is already being avoided. For experiments near this frequency

Table 3: L–band Default Frequency

Date	IF AC [MHz]	IF BD [MHz]
1975–1983	1465	–
1983–1993	1465	1515
1994–	1465	1385

Note: The D–array all–sky survey uses for the second IF pair a central frequency of 1365 MHz which is likely to become the L–band default.

range one should contact one of the frequency coordinators to find out what the optimum scheduling times would be. Another satellite system causing RFI at several frequencies within L–band is formed by the GPS family of satellites.

8 Solar Interference

L–band observations during solar maximum in C– and D–array suffer from solar interference. Usually, the most sensitive observations are scheduled at night. As we are heading for a solar minimum, observations are expected to be less affected, although night–time observing is still the preferred choice for the most sensitive experiments. Table 4 list some recent minima and maxima. Note that the Sun is active well before and after the years listed and that the peak of activity, and thus solar interference, can fall early as well as late with regard to the mid–points of the 11 year cycle.

Solar interference is particularly troublesome since the source moves as a function of time. Furthermore, the Sun is difficult to "image" as it comes in through one of the sidelobes which are not identical on the different antennae. Moreover, due to the usually large angular distance, the fringes due to the Sun move appreciably from one to the next spectral line channel which makes modelling virtually impossible.

There exist a few methods which can mitigate the effect of solar interference. The most drastic one is to delete the affected short spacings altogether. Obviously, this can only be done if there is no extended emission from the source of interest or if one has certain hour angle ranges during which there is no solar interference and which contain enough information for a deconvolution programme to converge. A simple but less accurate method is to first subtract all radio continuum emision from the data (e.g., UVSUB or UVLIN in AIPS) and to inspect a line–free channel (task TVFLG). Apply a "clip" level, flagging all affected visibilities in this channel *and* the same visibilities in all other channels. Because of the frequency dependence, this method has to be repeated on a few line–free channels.

There is another, more effective approach. The Sun is usually several degrees to several tens of degrees away from the object under study. As explained by Cornwell *et al.* (1992), UVLIN can be used with a SHIFT option. Apparently most, if not all Solar interference can be removed by shifting to the approximate position of the Sun. A second UVLIN without shift on the data set from which the Sun has been removed takes care of the continuum emission near the source under study. Although some good results have

Table 4: Solar maxima and minima

Solar Cycle	Min	Max
20	1964	1969
21	1976	1980
22	1986	1992
23	(1997)	(2002)

been obtained, further tests will be necessary.

For completeness I will briefly describe another option which has been used with varying degrees of success. This method relies entirely on UVSUB and was pioneered by P. McMahon and J. van Gorkom. First, split the data in two parts, the affected short baselines and the unaffected long baselines. Split the short baseline data into approximately one hour long chunks (to avoid problems due to the fact that the Sun moves in the course of an observation). For each chunk, select one spectral line channel and make an image at the location of the Sun. Attempt to find a set of clean components which describe the necessarily very ugly looking image of the Sun and subtract these components from the corresponding chunk of short baseline data, from all spectral line channels with the appropriate frequency (UVSUB in AIPS will do just that). Finally, merge the Sun–subtracted short baseline data with the untouched long baseline data and proceed as usual. The UVSUB method to subtract the Sun, although perhaps the most correct way to proceed, is very labour intensive.

9 Bandpass Stability

Projects which need a high spectral dynamic range ($> 1000:1$ at L–band or $> 100:1$ at P–band) pose a particular challenge. As it turns out, high dynamic range spectra show a time–variable sinusoidal ripple with a period of about 3 MHz (altough other periods have been seen). This ripple is present after the complex bandpass correction is applied. Spectral dynamic range is the ratio of the peak continuum flux density with the rms noise in a spectral line channel. In case of a residual ripple, the ratio should be taken with the amplitude of this ripple. The current hypothesis is that the 3 MHz ripple is a standing wave in the VLA waveguide system which runs from the B–rack modem to the coupler which connects a single VLA antenna with the main waveguide. This is compatible with the observation that the ripple exists at all bands, although the rate at which the ripple drifts in time has been found to be different at other bands which casts some doubts on this interpretation. If it were constant in time, it could be calibrated out completely when applying a complex bandpass correction, as implemented in AIPS. It is not known what causes the variability. The fact that it is time variable ultimately limits the achievable spectral dynamic range.

There exists a write–up of what we currently know about the 3 MHz ripple (Carilli, C. 1991 *VLA Test Memo No. 158*). This can be summarised as follows:

- Only some antennae have a large residual 3 MHz ripple, most antennae behave well.

- The residual ripple changes smoothly as a function of time and can roughly be described as a linear drift in time of the phase of the standing wave.
- The 3 MHz ripple is not affected by source changes.

These observations suggest a few strategies to obtain a high spectral dynamic range. One can inspect the individual bandpasses and flag those antennae which have a large standing wave (normally a few out of the 27). Alternatively, one can spend more time calibrating, trying to follow the time evolution of the 3 MHz ripple by observing a suitably strong bandpass calibrator at about 30 minute intervals. In AIPS one would use the option of "nearest neighbour" when applying the complex bandpass calibration (true interpolation is not implemented, yet). Sometimes one has to do both. Without special precautions, spectral dynamic ranges of 500:1 can be achieved. Using the approach outlined above this can be improved by almost an order of magnitude.

It should be noted that using the on–line normalisation (also known as Autocorrelation Normalization) will not improve matters (as demonstrated by Carilli, 1991).

10 Autocorrelation Normalization

Because the on–line normalisation merely corrects the amplitudes, not the phases, this method of correcting for the bandpass is not recommended. There are other reasons why this method should not be used. It was recently discovered that there is some low level interference around 1414.9 MHz, and possibly at other locations within L-band, which is mostly incoherent. This means that this signal will not show up when inspecting a spectral line channel. It is present, however, in the autocorrelation spectrum and enters as such in the autocorrelation normalization. This effect can give rise to a spurious spectral feature (Brinks, E. 1991 *NRAO Newsletter No. 46*). Of course, one should never use on–line normalisation when there is any real signal which is strong enough to enter the auto–correlation spectra, such as when observing Masers. Moreover, this option should be avoided when RFI is expected to be a problem. In summary, the usage of auto–correlation normalisation is *strongly* discouraged.

Figure Captions

Figure 1: Sweep of L–band from 1300 to 1750 MHz showing the level of RFI which was typical in the mid–eighties (1986).

Figure 2: As Figure 1, but for 1994.

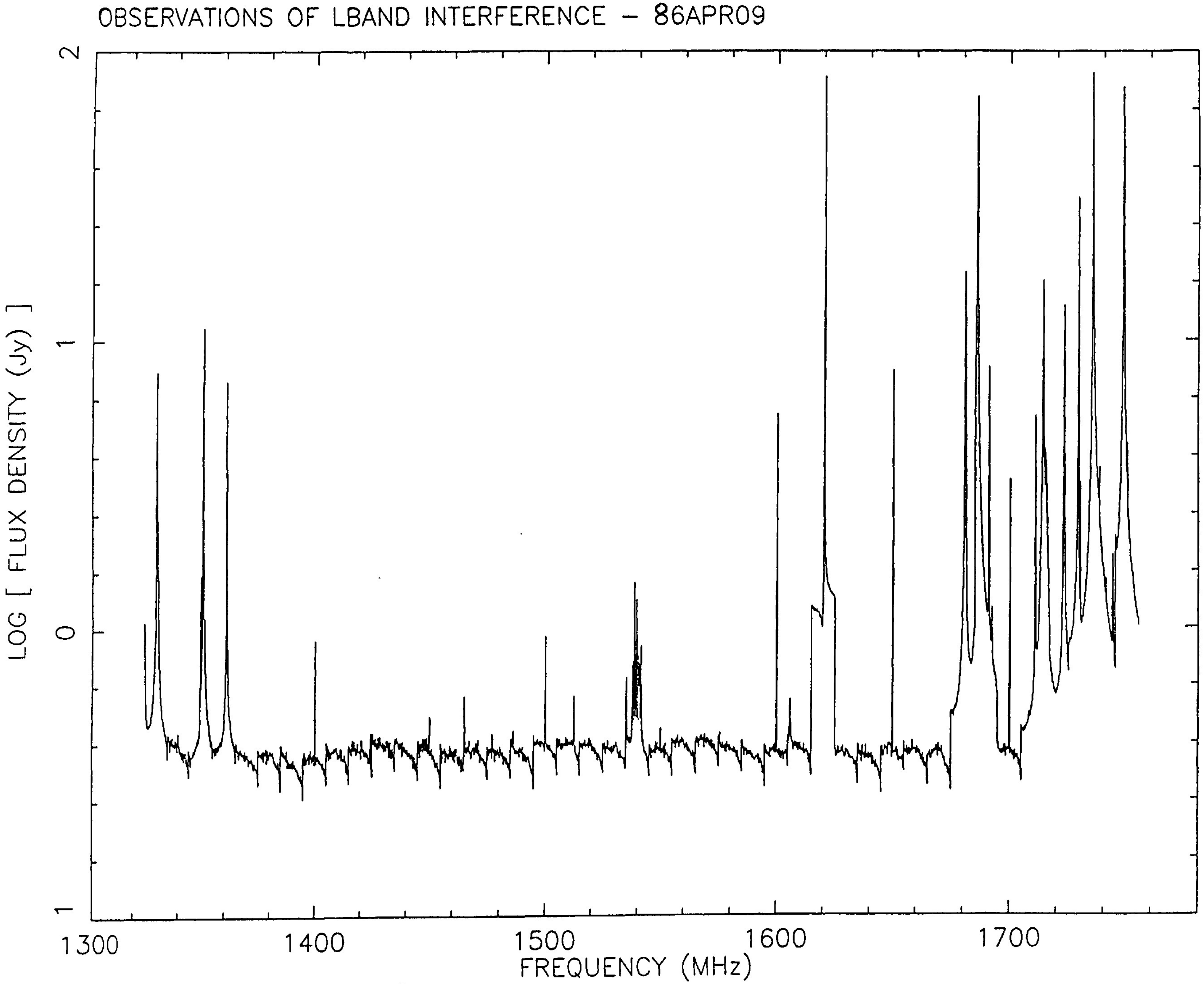
OBSERVATIONS OF LBAND INTERFERENCE – 86APR09
LOG [FLUX DENSITY (Jy)]
2
1
0
-1
1300
1400
1500
1600
1700
FREQUENCY (MHz)

FIGURE 1

L-Band RFI 940511 BnA array

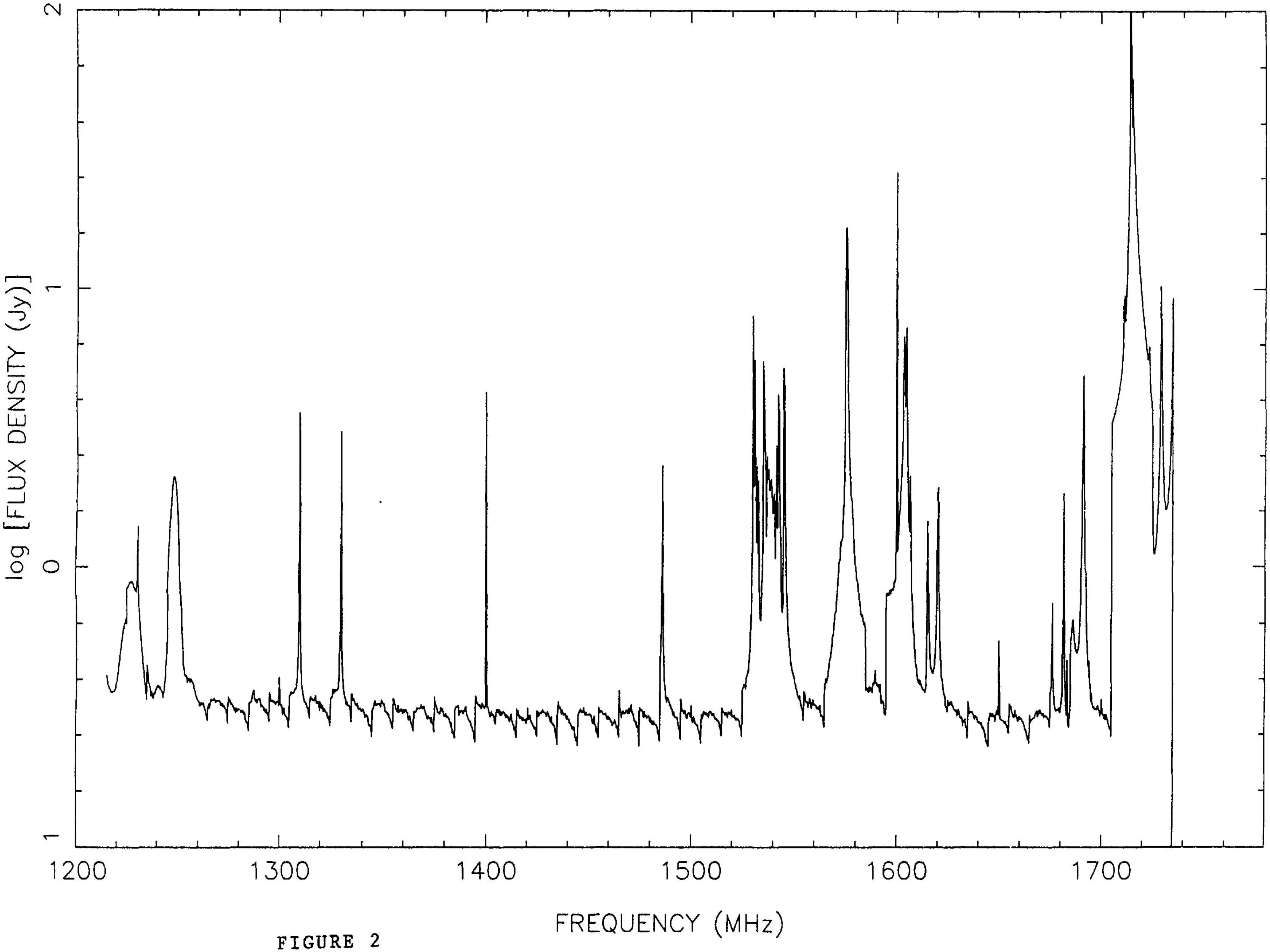

FIGURE 2