BIMA Memo 52
3 mm VLBI at Hat Creek
1995 - 1997

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1. Introduction

VLBI at millimeter wavelengths provides very high resolution images of active galactic nuclei and galactic masers. Currently, VLBI at wavelengths shorter than 7 mm λ is not supported by the National Radio Astronomy Observatory Very Long Baseline Array and must be performed with a network of millimeter observatories. The Coordinated Millimeter VLBI Array at Haystack Observatory serves as the network hub for such observations.

Hat Creek has a history of involvement in 3 millimeter λ VLBI dating back to 1981. Recently, Hat Creek has become reinvolved in VLBI. Four experiments have been conducted in April 1995, December 1995, April 1996 and October 1996. Fringes were found in all four.

This memo describes the current approach for using the Hat Creek array as an element in a VLBI array. Theoretical and practical questions are addressed. The principal elements of a VLBI station are the antenna, a phase stable receiver and IF system, a stable frequency standard, usually a hydrogen maser, and a backend for recording the IF (Figure 1). We consider each of these in Sections 2 through 5. We also discuss procedures for the setup and execution of a VLBI experiment at Hat Creek in Sections 6 through 8. Finally, we give a wish list for improvements and technical innovations in Section 9.

2. The Antenna

We maximize the collecting area of our station by phasing together the signal from more than one antenna. Ideally, we would sum together the signals from each antenna; however, this is not always possible. In fact, for the measurement of phasing efficiency, we always exclude at least one antenna.

To phase the array, we observe a source for a few minutes prior to the VLBI scan. We then self-calibrate the phases and apply the solutions to the phase offsets for LO1.

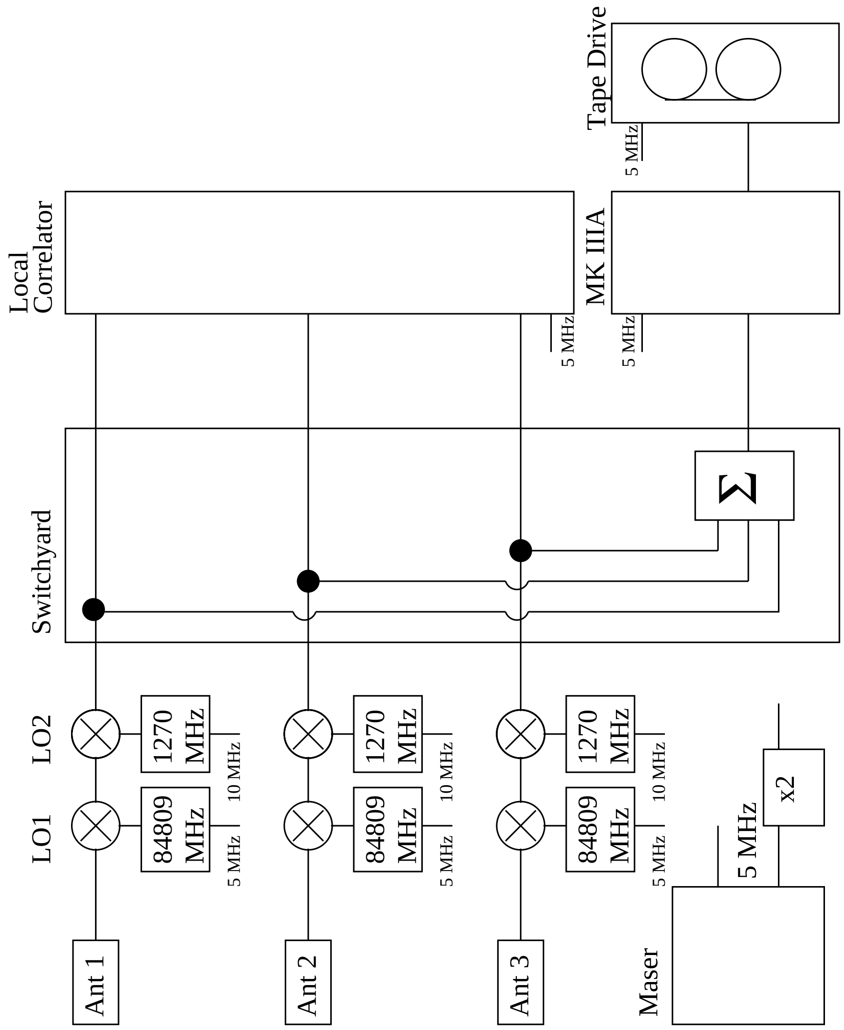

Fig. 1.— A schematic diagram of the VLBI setup at Hat Creek Radio Observatory showing principle elements for three antennas, the maser, the backend and the distribution of the common reference frequency.

Currently, only the upper sideband is phased; however, it is possible to phase both sidebands by applying upper and lower sideband solutions to both LO1 and LO2.

The efficiency of phasing depends on the atmospheric conditions and the array configuration. An extended array can lead to significant atmospheric decorrelation but a compact array can suffer from shadowing. Observers must judiciously choose which antennas to include. Under excellent conditions in April 1996, we phased together seven antennas in the B array with a maximum baseline of 852 feet. Under good conditions in October 1996, we phased together eight antennas in the C array with a maximum baseline of 316 feet. In both cases, phasing efficiencies were near 90%.

2.1. Phasing Efficiency and Limits

We discuss here the limits placed on measurement of phasing efficiency and on measurement of the instrumental phase.

The antenna temperature on a single baseline is given as

$$T_a^{12} = \frac{S_0}{g_1 g_2}, \tag{1}$$

where S_0 is the source flux density and g_1 and g_2 are the inverse voltage gains for antennas one and two. Typically, $g \approx 12\sqrt{\text{ Jy/K}}$. The noise power is

$$T_n^{12} = \frac{\sqrt{T_{sys}^1 T_{sys}^2}}{\sqrt{2B\tau}} = 1.9 \left(\frac{T_{sys}}{300\text{K}}\right) \text{ mK}, \tag{2}$$

where T_{sys} is the geometric mean of the single side band system temperatures and we assume a bandwidth $B = 800$ MHz and an integration time $\tau = 15$ s. The phase error, which derives from an analysis of the coherence (e.g., Thompson, Moran and Swenson, 1991, section 9.3), is approximately

$$\sigma_\phi(\text{rad}) \approx \frac{1}{\text{SNR}} = \frac{1}{3.7} \left(\frac{S_0}{1 \text{ Jy}}\right)^{-1} \left(\frac{T_{sys}}{300 \text{ K}}\right) \left(\frac{\tau}{15 \text{ s}}\right)^{-1/2} \left(\frac{g_1 g_2}{140 \text{ Jy/K}}\right). \tag{3}$$

An error in the phase, either from noise or from the atmosphere, leads to an error in the phasing efficiency that goes as

$$\epsilon = e^{-\sigma^2/2}. \tag{4}$$

For $\sigma = 30^o$, $\epsilon = 0.87$. To keep the thermal error below 15 degrees, we require

$$\left(\frac{S_0}{1.04 \text{ Jy}}\right) > \left(\frac{T_{sys}}{300 \text{ K}}\right) \left(\frac{\tau}{15 \text{ s}}\right)^{-1/2} \left(\frac{g_1 g_2}{140 \text{ Jy/K}}\right). \tag{5}$$

Increasing the integration timescale is not an effective solution since we wish to measure the atmospheric fluctuations that are occurring on short timescales. This result implies that the efficiencies measured at low elevation are not noise-dominated. Further, with knowledge of the source flux density we can remove the effects of noise from the observed phasing efficiency if we assume

$$\sigma^2_{measured} = \sigma^2_{thermal} + \sigma^2_{atmosphere}. \tag{6}$$

We note as an example that the low phasing efficiencies measured on Sgr A*, as compared to those measured on NRAO 530 in the April 1996 experiment, cannot be fully accounted for by additional thermal noise. For example, in the time range 118 0900 to 118 1120, the efficiencies, $\epsilon_{N530} \approx 0.75$ and $\epsilon_{SgrA*} \approx 0.45$, require an additional radian of phase error. For $S_{SgrA*} = 1$ Jy, we calculate $\sigma_\phi = 0.55$ rad. The additional noise probably originates in the lower elevation path through the atmosphere. The efficiencies on Sgr A* match those of lower elevation NRAO 530 scans.

The accuracy of measuring the instrumental phase is determined similarly. The error in that measurement is

$$\sigma'_\phi = \frac{\sigma}{\sqrt{N-1}\sqrt{M}}, \tag{7}$$

where N is the number of antennas and $M = T/\tau$ is the number of integrations of length τ. The phase error σ comes from both the thermal and atmospheric noise. In the case of thermally dominated noise, the condition $\sigma'_\phi < 15^o$ requires

$$M \geq \frac{1.1}{\sqrt{N-1}} \left(\frac{S_0}{1\mathrm{Jy}}\right)^{-2} \left(\frac{T_{sys}}{300\mathrm{K}}\right)^2 \left(\frac{\tau}{15\mathrm{s}}\right)^{-1} \left(\frac{g^2}{140\mathrm{Jy/K}}\right)^2. \tag{8}$$

Here,

$$T_{sys}g^2 = \frac{\sqrt{T^i_{sys}}g_i}{\sqrt{N-1}} \sum \sqrt{T^j_{sys}}g_j. \tag{9}$$

Accordingly, under good conditions, with $M = 12$ we should be able to phase up accurately on a source with $S_0 = 0.1$ Jy. Under more typical conditions ($T_{sys} = 450$ K, $g^2 = 200$ Jy/K), $M = 12$ is sufficient for $S_0 > 0.2$ Jy. Therefore, we conclude that phasing up is usually dominated by atmospheric rather than thermal noise. For all but the weakest sources, 3 to 4 minutes of integration are sufficient to measure a stable atmospheric phase.

Not all bright sources can serve as phasing sources, however. Sources that do not appear as point sources to the local array must be phased up on another source or a good structure model must be employed in the self-calibration. Two significant examples of this are the Galactic Center object, Sgr A*, and M 87.

Silicon monoxide maser sources also need to be phased up on continuum sources due to their low flux density over the full bandwidth.

2.2. Optimum Weighting for a Phased Array

Dewey (1995) has written a detailed account of the effects of correlated noise in phased-array observations of radio sources. In this the optimum weights to be applied when summing voltages in the case of no correlated noise are derived for the case when antenna gains and system temperatures of the individual elements differ. The answer is:

$$w_i = g_i/T_{s,i}, \tag{10}$$

where w_i is the voltage weight, g_i is the voltage antenna gain (magnitude), $T_{s,i}$ is the system temperature, and i is the index of the individual antenna.

The derivation is straightforward and the reasoning is clear once derived. One starts with equating optimization with maximizing the ratio of power gain ($G = g^2$) to system temperature (T_s). In the case of an array it is the ratio of effective gain to effective system temperature. The effective gain is proportional to the source intensity (or antenna temperature) at the map center and the effective system temperature is proportional to the noise at the map center (which requires accounting for correlated noise if present which we won't discuss here).

The effective system temperature T_{eff} is proportional to the absolute value of the summed voltages:

$$T_{eff} = \frac{1}{k_B B} < |\mathbf{v_\Sigma}|^2 >, \tag{11}$$

$$T_{eff} = \frac{1}{k_B B} < \Sigma_{i=1}^{N} w_i \mathbf{v_i} \Sigma_{k=1}^{N} w_k \mathbf{v_k}^* >, \tag{12}$$

$$T_{eff} = \frac{1}{k_B B} \Sigma_{i=1}^{N} \Sigma_{k=1}^{N} w_i w_k < \mathbf{v_i} \mathbf{v_k}^* >, \tag{13}$$

where $\Sigma w_i^2 = 1$ is required for normalization, N is the number of antennas in array and B is the bandwidth. The cross terms in final equation above cancel with averaging to leave:

$$T_{eff} = \frac{1}{k_B B} \Sigma_{i=1}^{N} w_i^2 < |\mathbf{v_i}|^2 > . \tag{14}$$

Here $T_{s,i} = \frac{1}{k_B B} < |\mathbf{v_i}|^2 >$. The normalization of voltage weights is the result of this final expression for the effective system temperature, and is simply the result of noise power addition.

The effective power antenna gain follows similarly as it is the ratio of the effective antenna temperature from source to the source flux, $G_{eff} = T_{a,eff}/S_{\circ}$.

$$G_{eff} = \Sigma_{i=1}^{N} \Sigma_{k=1}^{N} w_i w_k g_i g_k. \tag{15}$$

The final step then is to maximize the ratio of G_{eff}/T_{eff} with respect to the voltage weights. Note that in practice we use the power weights, $W_i = w_i^2$, and measured system temperatures, $T_{s,i}$, to match detected power level contributions to summed signal from individual antennas with optimum values. Antenna gains are measured with self-calibration procedure on standard correlator outputs. The maximization proceeds as in Dewey's Appendix C.

$$\frac{\partial}{\partial w_j} \left[\frac{G_{eff}}{T_{eff}} \right] = 0. \tag{16}$$

$$0 = \frac{2\Sigma_k w_k g_j g_k}{\Sigma_i w_i^2 T_i} - 2 w_j T_j \frac{\Sigma_i \Sigma_k w_i w_k g_i g_k}{[\Sigma_i w_i^2 T_i]^2}. \tag{17}$$

$$0 = g_j \Sigma_i w_i^2 T_i \Sigma_k w_k g_k - 2 w_j T_j \Sigma_i \Sigma_k w_i w_k g_i g_k. \tag{18}$$

This has simple solution of:

$$w_j = \frac{g_j}{T_j}, \quad \text{or} \quad \text{voltage weight} \quad = \quad \frac{\text{voltage antenna gain}}{\text{system temperature}}. \tag{19}$$

An example of two antennas with equal system temperatures and antenna temperatures in the ratio of 2:1 suffices to illustrate this weighting.

$$T_{a,1} = 2 \times T_{a,2}. \tag{20}$$

$$G_{eff} = w_1^2 g_1^2 + 2 w_1 w_2 g_1 g_2 + w_2^2 g_2^2. \tag{21}$$

But by assumption the voltage gains follow $g_1 = \sqrt{2} g_2$. Then

$$G_{eff} = 2 w_1^2 + 2\sqrt{2} w_1 w_2 + w_2^2. \tag{22}$$

A set of possible normalized voltage weights is:

$$w_1, w_2 \rightarrow G_{eff}$$

$$0, 1 \rightarrow 1.0$$

$$.45, .9 \rightarrow 1.7$$

$$.5, .86 \rightarrow 2.5$$

$$.6, .8 \rightarrow 2.7$$

$$.71, .71 \rightarrow 2.9$$

$$.8, .6 \rightarrow 3.4$$

$$.86, .5 \rightarrow 3.2$$

$$1, 0 \rightarrow 2.0$$

The w_1, w_2 values above lead to G_{eff} values given in third column; optimum occurs near the (.8,.6) pair, the ratio of which is near the optimum given by the ratio of the voltage gains as predicted.

If the tropospheric phase fluctuations are large during a coherent integration interval, then one might want to weight antennas appropriately. For example, if the rms phase from the troposphere grows as $\phi_t = ab^\alpha$, where a, α are constants and b is the baseline. Then the more distant antennas, when averaged over the scan during which no self-cal is done with the local array, will have an effective voltage gain of $g = \exp[-\phi_t^4]$. Use of this additional factor will taper the use of the outer antennas in a manner consistent with their possible effective contribution. The baseline b needs to be measured from a central antenna.

We measure the power gains of the individual antennas by connecting a digital voltmeter to the output of a video converter. The IF power is turned on for individual antennas sequentially. The power level is read through a GPIB connector by a program called *measwgts*. We adjust the gains of individual antennas by inserting small attenuators (1, 2 or 3 dB) at the inputs to the switchyard.

2.3. Amplitude Calibration

An amplitude self-calibration with $S = 1$ Jy is performed to determine the gains, g_i^2, in units Jy/K which are related to the antenna temperature in K by

$$T_{a,i} = g_i^{-2}. \tag{23}$$

The self-calibration is performed on data during the PREOB phase.

The total system temperature is given by

$$T_{sys} = \sum w_i T_{sys,i}, \tag{24}$$

where $T_{sys,i}$ is the system temperature on antenna i and w_i is the weight of the IF power delivered to the video converter by antenna i. The system temperatures are determined with the standard interferometer calibration mode which involves placing a flap in front of the feed. The weights are determined by selectively turning off and on the IFs of each antenna. This is done during the MIDOB by the program *measwgts*.

The contribution of each antenna to the total antenna temperature is

$$T_a = \left[\sum (w_i T_{a,i})^{0.5}\, e^{j\phi_i}\right]^2, \tag{25}$$

where ϕ_i are the phases of each antenna. For perfect phasing, $\phi_i = \phi_0$ and

$$T_a^{\rm perfect} = \left[\sum (w_i T_{a,i})^{0.5}\right]^2. \tag{26}$$

There are two contributions to variability in the phase. The first is offsets between phase in the digital correlator and phase of the IF going into the Mark IIIA system. This is likely to be constant throughout the run and we believe it to be small. The second source is change in the atmosphere and line lengths.

We can measure this second effect. During the VLBI scan, we keep one or more antennas out of the sum. We measure the phases of each of the summed antennas relative to the excluded antenna. The deviation of the phases from perfect alignment gives a measure of the phasing efficiency. For bright sources, this is equal to the atmospheric and line length fluctuations. For weak sources, a correction for thermal noise is necessary. We describe how to make that correction in Section 2.1.

Much of the work of calibration is done with a routine called *vlbical*. *Vlbical* also calculates the ideal weights for IF power. A ragged ensemble of awk scripts assist in the calibration. These are called by the csh script *postcal*. Effort is being put into writing a single MIRIAD program to handle calibration.

2.4. Polarization

The standard for VLBI observation is left circular polarization. We install polarizers in each antenna to convert LCP to linear polarization. The E-field sampled is horizontal when the antenna is in the service position. Thus, following the 1981 Backer diagram (Figure 2), the polarizers are oriented such that as viewed from the secondary reflector the grooves, which are parallel to the slow axis of the plates, run from the bottom left to the upper right. There are two reflections in the system: one in the primary and one in the secondary.

These polarizers are now standard and controllable by software in the new antennas. However, they must be installed manually in antennas 1 and 3.

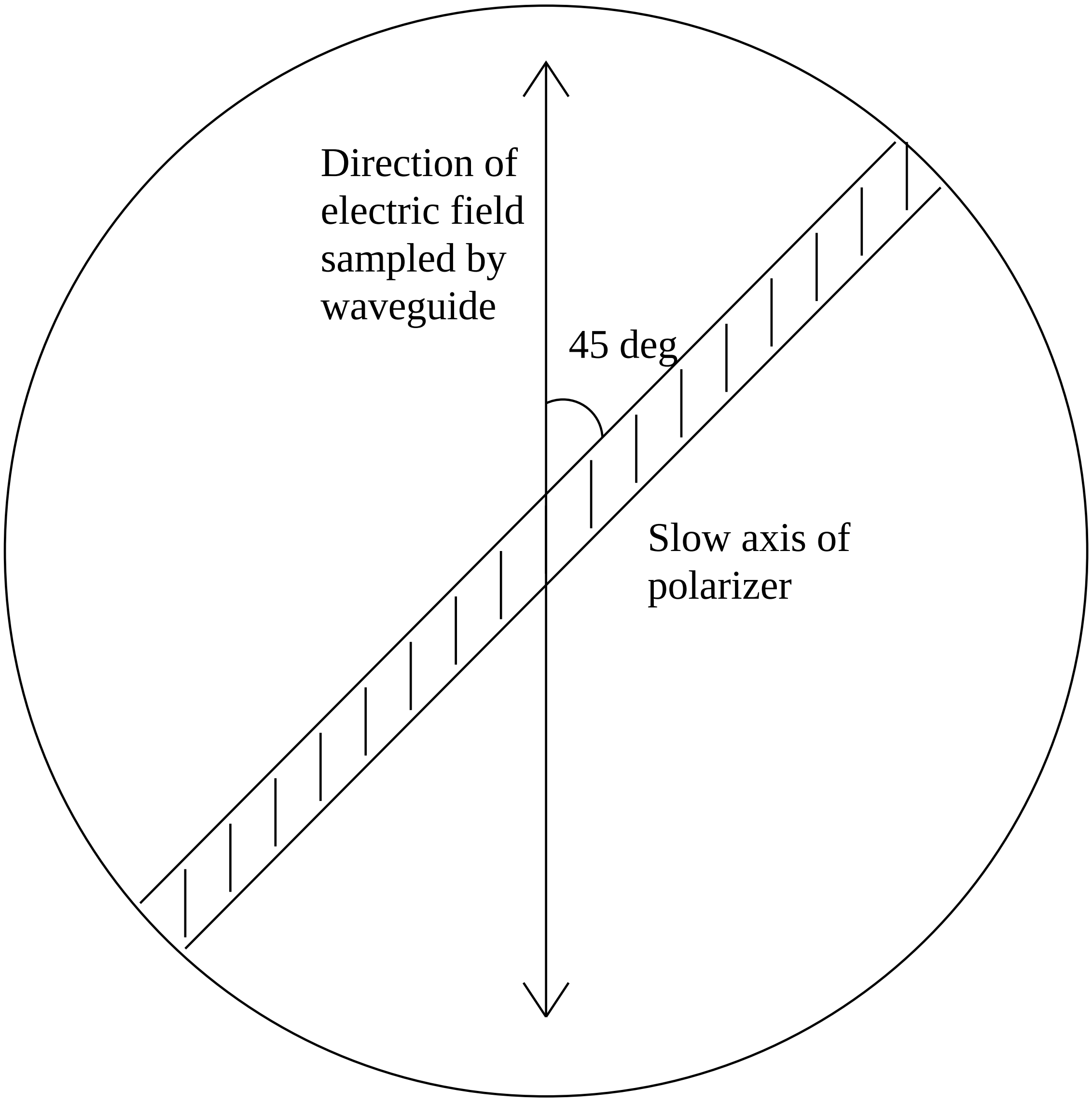

Fig. 2.— Orientation of the polarizer for left circular polarization on a BIMA antenna. This is the view looking down the polarizer and feed from the Cassegrain focus.

We performed dual polarization observations only once. In that case we switched one antenna to RCP and sent its IF directly to the MK IIIA rack. The LCP antennas were passed normally through the switchyard. In the future, it may be useful to sum several antennas in each mode of polarization. To accomplish this we need an analog summing device. Both LCP and RCP signals can be sent to the local correlator and the antennas phased independently. The RCP signals will be collected from the continuum correlator outputs and summed by the analog device.

3. The Receiver and IF System

The sky signal is detected in each antenna and mixed down to an IF frequency in the receiver. The two local oscillators in each antenna are phase locked to the 5 MHz signal that originates in the maser. We currently tune such that ν_{sky} = 86216.99 MHz goes to 137.99 MHz. This frequency is mixed to baseband by the video converter. The range of IF frequencies is constrained by the oscillator ranges in the MK IIIA.

Below we give the LO chain necessary to tune for a standard experiment. Note that there is a 46 Hz offset from the standard frequencies. We also describe the path of the signal through the switchyard and into the MK IIIA system.

3.1. LO Chain

For USB tuning,

$$\nu_{sky} = \nu_{LO1} + \nu_{LO2} + \nu_{VC}. \tag{27}$$

ν_{LO1} is derived from the HP 8662A setting in the following manner:

$$\nu_{LO1} = (\nu_{8662} * XHARM + \nu_{XLOCK}) * MMHARM + \nu_{MMLOCK} + \nu_{off1}. \tag{28}$$

ν_{XLOCK} and ν_{MMLOCK} are fixed at 20 and 70 MHz, respectively. For the standard experiment, ν_{8662} = 1208.5571428 MHz, $XHARM$ = 10, $MMHARM$ = 7 and ν_{off1} = 45 Hz, producing

$$\nu_{LO1} = 84809.000041 \text{ MHz}. \tag{29}$$

The frequency in the second LO is $\nu_{LO2} = 1270 \text{ MHz} + \nu_{off2}$ where ν_{off2} = 5 Hz. The sky frequency is

$$\nu_{sky} = 86079.000046 \text{ MHz} + \nu_{VC}. \tag{30}$$

Video converter settings are given in the section on the MK IIIA.

The HP 8662A frequency is common to all antennas. It is locked to 5 MHz supplied by the hydrogen maser 5 MHz. X and millimeter band signals are generated separately in each antenna and phase locked to the 10 MHz reference, which also derives from the maser. We found that 60 Hz noise is significantly increased if we lock the HP 8662A to the 10 MHz output of the doubler box rather than from 5 MHz direct from the maser. This noise is detected during the test tone experiment, which is described below. The doubler box normally converts the 5 MHz from the crystal to 10 MHz.

The frequency offset cards produce ν_{off1} and ν_{off2}. During the course of the experiment the rates for individual antennas are offset from ν_{off1} and ν_{off2} to account for their separation from the delay center in both upper and lower sidebands.

Phase switching is introduced through walsh functions generated in both frequency offset cards. For sideband separation, 90 degree phase switching takes place in LO1. For suppression of DC drifts, 180 degree phase switching takes place in LO2. The local correlator removes these walsh functions after sampling.

3.2. The Switchyard

The IF signals are combined and routed in the switchyard. Signals for antennas to be summed are sent to the summer card. The summer card sums the input signals. The output is the IF input to the MK IIIA terminal.

We found that a leaky switch in the splitter card permitted feedback. We remove the summer-splitter cable to eliminate this feedback. This prevents us from performing passband calibration, which makes use of the summer-splitter connection.

The Walsh functions must not be present in the IF sent to the MK IIIA. Unfortunately, we found that the dewalshing function of the switchyard cards degrades the IF output to the MK IIIA. Hence, we operate with no walshing and no dewalshing in antennas that are to be phased. The unfortunate consequence of the absence of phase switching is that on baselines with no walshing the visibilities detected in the local correlator are not real. Keeping a single antenna with walsh functions out of the sum permits us to measure visibilities in the local correlator on baselines to that antenna. Normally, we keep antenna 1 out due to its relatively poor performance.

A question of particular importance is whether the self-calibration solution that derives from visibilities in the local correlator creates a phased output to the MK IIIA. In principle, this should be true. Cables were cut to the same length; delays must be substantial at 100

MHz to cause appreciable phase shifts. Nevertheless, we have attempted to measure the success of the phasing through several methods.

The best test of the phasing replaces the IF input into the correlator of a single antenna with the summed IF. Under this scheme, we would be able to measure directly the phased amplitude. We have been stymied in this attempt by: 1) the failure of the dewalshing; 2) the need to separate the splitter from the summer; and 3) correlator software that adjusts attenuators in the switchyard. The last difficulty arises because a change in the level of one antenna will change the level of the summed input. We have never seen visibilities in the local correlator between an antenna and a summed signal.

We have compared the summed output with the IF of a single telescope in the continuum correlator while looking at the transmitter. We did see that adding antennas with phases determined from self-calibration increased the amplitude of the beat note between the summed and single antenna. (The beat note was created by putting a low frequency offset into the LO of the reference antenna). We were able to anti-phase antennas and cancel their signals. However, there was a fair degree of drift in the phase of the beat note. This method suffers from several deficiencies. One, since no cosmic source is bright enough to be seen in the continuum correlator, we must experiment using the transmitter, which is at a low elevation and is so bright that there are closure errors in the digital correlator. Two, we observe the beat note in an oscilloscope which is a non-integrating and non-recording device.

We performed a phasing test during the December 1995 experiment summing antennas into the IF through a VLBI scan. The results showed the amplitude increasing as the number of summed antennas increased. A signficant decrease in the amplitude occurred at one point in the scan. This may correspond to poor phasing or to a decrease in the coherence. A coincident decrease in coherence was seen in the local correlator.

3.3. Controlling the Switchyard

The switchyard is controlled by the program *swyard*. Usage of *swyard* is as follows:

```
swyard antslot atten w1 w2 opcal onoff modebit aux
```

where *antslot* refers to the switchyard card number, which is one less than the antenna number; where *atten* refers to the digital attenuation set in the card; where *w1* and *w2* refer to the dewalshing functions in the switchyard card; and where *opcal*, *onoff*, *modebit* and *aux* are switches in the cards. Note that the dewalshing functions are in reverse order than those of the walshing system. The 180 degree walshing and dewalshing takes place in LO2 and w1, respectively. The 90 degree walshing and dewalshing takes place in LO1 and w2, respectively. For normal interferometer operation, only the *onoff* switch is on. For VLBI operation, both the *onoff* and *modebit* switches are turned on. This sends output to both the summer and to the local correlator. For example, to send the output of antenna 6 to the summer and to the local correlator with no attenuation while dewalshing, one would use

```
swyard 5 0 19 213 0 1 1 0
```

The Walsh functions chosen here are the standard values for antenna 6. The program *testoffset* can be used to set the walsh functions in the LOs. It is described later in this document.

The program *mint* also sets the switchyard by reading settings in the file *$HATTAB/swyard.tab* and the common variables *walants*. The values of the *walants* may be read by the command

```
value name=walants
```

There are 24 values for *walants*, two for each antenna slot. On antenna n, the walsh function for LO1 is given by *walants*-n; the walsh function for LO2 is given by *walants*-$n + 12$. The original values of the walsh functions can be read into walants with the command

```
setwalsh to=on
```

walants can be zeroed with

```
setwalsh to=off
```

The contents of the *swyard.tab* file determine the switch settings in the switchyard cards. There is a table containing one number for each antenna. That number is the base ten representation of the binary number that the switch settings make. Normal operation is 4. VLBI operation is 6. There are a number of versions of *swyard.tab* in the directory *$HATTAB* corresponding to the different modes for the switchyard. For VLBI operation with all antennas directed into the summer except for antenna 1, the *swyard.tab* file reads:

```
# swyard.tab -- Switchyard normal switch settings
```

```
# In order of physical antenna ID.  Antenna 1, first element, etc.
# Currently have 12 slots allocated
# The bits are assigned, thus
#       AuxWal = 1      State 0=>de-Walsh for VLBI if W1,W2>0
#                             1=>modulate IF output with W2 also
#       Mode   = 2      State 0=>Connect input to Summer, if OnOff=0 too
#                             1=>connect VLBI (deWalshed) to summer
#       OnOff  = 4      State 0=>Connect IF input to Mode switch
#                             1=>Connect IF to OpCal switch (passthru)
#       OpCal  = 8      State 0=>Connect splitter to OnOff (passthru)
#                             1=>Connect Output of Summer to splitter
# Examples:
#       Normal interferometry passthru: Set all to 4 (OnOff 1, others 0).
#       Input passthru, but also input to Summer: Set to 6 (OnOff+Mode).
#       Collect VLBI output from Summer: Set to 12 (OnOff + OpCal).
4       6       6       6       6       6
6       6       6       6       6       12
```

There is no fiber optic connection to the VLBI card in the switchyard. If control of the card is necessary (to change the attenuation, for example), connect the fiber optic connection from one of the other cards temporarily to the VLBI card.

3.4. Test Tone Experiment

The test tone experiment determines that frequency settings are correct and measures the purity and stability of a signal mixed down through the entire system. A RF tone, phase locked to the maser but derived from an oscillator independent of the local oscillator, is injected into the receiver of an antenna. The frequency of the tone is chosen such that it is mixed to 10 kHz in one of the video converters. We examine the spectrum of the tone with a low frequency spectrum analyzer for $n \times 60$ Hz sidelobes and for stability. The sidelobes are often reduced by tightening and moving cables. We have found that the sidelobes are significantly reduced by sending 5 MHz from the maser directly into the lab 8662. We have seen a fair degree of jitter in the phase of the test tone that we cannot account for.

A typical setup for generating the test tone is as follows:

To check the LO chain, a test tone derived from an independent 8662 synthesizer was injected into rcvr 7. The extra synthesizer was located in antenna 7's receiver cabin; it was locked to the 5 MHz signal taken directly from one of the distribution amplifiers on top of the maser, sent through 2 50-foot lengths of purple Goretex cable (plus some short lengths of ordinary cable at each end) from the correlator room through the wall into the observers' room, and out the sliding glass door directly to the antenna. An extra xband YIG oscillator was phaselocked to the synthesizer using an xband synchronizer and our standard harmonic generator/mixer assembly. The 10 MHz signal from the back of the 8662 synthesizer was used as the reference tone for the synchronizer. The YIG output, attenuated by 6 dB, was coupled into a Pacific MM Products mixer mounted on a U-shaped bracket attached to the band B beamsplitter brackets. No feed horn was used.

The 8662 was set to 1230.242858 MHz, the YIG to $7 \times 1230.242858 + 10$ MHz $= 8621.700006$ MHz. The 10th harmonic of the YIG is then at 86217.000060 MHz. With our standard observing frequencies and a 64 Hz offset in LO1, this mixes down to 138.0000000 MHz. A VC set for 137.99 MHz will mix this down to 10.000 kHz. We view the signal in the low frequency spectrum analyzer. A recording device for the HP would ve very useful for analyzing output and comparison with future experiments.

The offset frequency cards can be controlled with the program *testoffset*. It is important to zero the walsh functions in the offset frequency cards and in the switchyard for this test. The program *swyard* controls the switchyard. The program *testoffset* controls the frequencies generated in the offset frequency cards. Zeroing frequencies and Walsh functions for LO1 for a single antenna is accomplished with

```
testoffset ants=6 freqs=0 walsh=0 los=1
```

4. The MK IIIA Backend

The backend consists of a MK IIIA terminal and tape drive and a field system (FS) control computer supplied by NASA/GSFC. The contact at NASA/GSFC is Ed Himwich. He is reachable by e-mail at weh@vega.gsfc.nasa.gov. His phone number is 301 286-4876.

The IF is split and mixed to baseband with 14 different video converters in the terminal. The settings for each of the video converters are given in Table 1. These correspond to the LO settings given in section 3 for the standard experiment setup. The baseband signals are sent to the formatter which passes them through to the tape drive.

The phase cal box generates a 1 MHz comb that is injected into the IF. Measurement of the phase of the phase cal provides a measure of the delay in each band. The phase cal is injected after attenuation through an Anzac T-1000 splitter. The signal should be less than 5% of the IF, measured at the MK IIIA. The phase cal signal declines significantly with frequency. Quantization of this fall off could be provide the necessary information for an equalization filter.

Table 1: Video Converter and Sky Frequencies

VC	ν_{VC} (MHz)	ν_{sky} (Hz)
1	137.99	86,216,990,046.0
2	113.99	86,192,990,046.0
3	145.99	86,224,990,046.0
4	121.99	86,200,990,046.0
5	153.99	86,232,990,046.0
6	129.99	86,208,990,046.0
7	161.99	86,240,990,046.0
8	193.99	86,272,990,046.0
9	169.99	86,248,990,046.0
10	201.99	86,280,990,046.0
11	177.99	86,256,990,046.0
12	209.99	86,288,990,046.0
13	185.99	86,264,990,046.0
14	217.99	86,296,990,046.0

Recording is done in mode A which provides 4 MHz of bandwidth in the upper and lower sidebands of each of the 14 video converters for a total of 112 MHz of bandwidth. The data is recorded in single bit mode. Thin tapes with a length of $\sim$ 18000 feet are used. With double speed recording (266 inches per second), a pass is 390 s. Twelve passes are made per tape.

The schedule is run from the FS computer. To run the schedule, one must login as oper. The command *fs* starts the field system software. A schedule is run with the command

```
schedule=xxxx,#nnnn
```

where *xxxx* refers to the schedule name and *nnnn* refers to the line in the schedule to begin. The SNAP file, which is the schedule, sits in the directory */usr2/sched* and has the form *xxxx.snp*. The procedure file resides in the directory */usr2/proc* and has the form *xxxx.prc*.

Modification of the procedure file is sometimes necessary. In particular, the video converter settings must be set correctly. Calls are also made to procedures for single dish installations to measure system temperature and weather variables. It is best to comment these procedures out.

The FS computer is connected to the network and known as bima5. Its disks are not cross-mounted with the other local systems.

5. The Hydrogen Maser

The hydrogen maser provides the frequency standard for the VLBI experiment. The maser, known as NX-II, is on loan from Owens Valley. We describe in Appendix A a service mission for the maser.

The maser provides four 5 MHz spigots on the upper rear of the rack. One of these is connected directly to the back end of the HP 8662A synthesizer, one to the doubler box producing 5 MHz and one is sent to the MK IIIA. When the crystal or the maser is disconnected from the doubler the multibus clock faults. This needs to be reset with the command *settimegps*. Performing this reset requires knowledge of the offsets between IAT and UTC. These are usually posted near the hat workstation.

A log exists for monitoring of the maser's vital signs. This log should be updated several times a year. Significant meters to monitor are the IF amp and the current from the battery backup. During autotuning the IF amp will oscillate high to low. The IF amp is a measure of the 21 cm current generated by the maser. The pink glow from the hydrogen disassociation chamber is also a sign that the maser is functioning.

5.1. Measurement of the Maser Frequency

The delay between the maser 1 pps from the MK IIIA terminal and the GPS 1 pps is measured with the HP 5334A Universal Counter, on loan from the undergraduate astronomy lab. The GPS signal employed comes from the Totally Accurate Clock (TAC). Clock 1 pps, corresponding to the maser, was connected to channel A. House 1 pps, corresponding to the GPS, was connected to channel B. The TI A $\rightarrow$ B function was selected. This measures the time interval between the leading edge of the signal in A and the leading edge in B, i.e. $t_A - t_B$. Proper impedance matching is necessary to get a good reading of the time delay. To limit the data flow, 100 gate averaging is usually set. The performance of the TAC can be observed with the proprietary software installed on the PC, bima4. This software is known as *showtime.exe*. The TAC is 5 to 10 times more accurate than the TRAK GPS receiver.

The output of the HP 5334A is read through a GPIB port by the field system computer bima5. The program that runs this sits in the directory */home/gcbower/timing* and is called *clockoff*. This is usually called by a script known as *monitor.csh*, which repeatedly calls *clockoff* and sends the output to a file. A particular failure of this software is that it cannot set the HP 5334A; it can only read what is currently available. Analysis of the file is done on bima2 by a program located in */falcon/bimausers/bima/gcbower/vlbi/maser* and called *newrate*. This program accepts the output of *clockoff* as standard input and performs a linear regression analysis. There are some bells and whistles that permit data selection by date and quality. The data is passed through with an additional column that is the delay less the model and stored in a file named *corrected*.

Long term monitoring of this delay allows for a measurement of the maser's rate. The most recent measurements have the rate at less than 10^{-13} s/s. The VLBI correlator uses this information to constrain its search for fringes.

5.2. Auto Tuning the NX-II Maser

5.2.1. Theory

The purpose of the auto tuner is to adjust the cavity size in the maser by thermal methods so that the cavity resonant frequency matches the frequency of the hydrogen 21 cm line. The auto tuner operates by the following principle: the dependence of the oscillator frequency on the cavity frequency is a function of the flux of hydrogen into the cavity. This technique allows the auto tuner to operate with a crystal whose frequency is not known but is stable. The theory for this technique is layed out in Thompson, Moran and Swenson section 9.4.

The relationship between the cavity frequency, ν_C, the oscillator frequency, ν_0, and the hydrogen line frequency, ν_L is

$$\nu_0 \approx \nu_L + \frac{Q_C}{Q_L}(\nu_C - \nu_L)\,.$$

Q_C is the Q-factor for the cavity and is of order 5×10^4. Q_L, the Q-factor for the line, is the ratio of the line frequency to the line width and is of order 10^9. The line width increases with the hydrogen flux.

One can determine the cavity frequency by measuring the frequency offset between maser and a stable crystal for high and low hydrogen fluxes. One measures

$$\nu^h_{off} = \nu^h_0 - \nu_{crystal}$$

and

$$\nu^l_{off} = \nu^l_0 - \nu_{crystal}.$$

Using the first relation, one then finds

$$\nu^h_{off} - \nu^l_{off} = (\nu_C - \nu_L)\left(\frac{Q_C}{Q^h_L} - \frac{Q_C}{Q^l_L}\right).$$

The rightmost term is positive. Hence, a higher frequency read for high flux implies that the cavity frequency is higher than the line frequency and should be decreased.

5.2.2. Practice

The NX-II reads out the offset period between the maser and crystal outputs and adjusts the thermal control through the cavity register. In these terms, a lower period count read for high flux implies a cavity register increase to decrease the resonant frequency.

The period count display on the front panel displays eight digits. The leftmost digits has units of seconds and the rightmost, 100 nano-seconds. The number shown is the period of the beat note between the maser and crystal outputs. The outputs are multiplied from 5 MHz to 200 MHz before they are mixed together.

A typical value for the period count is 01000000. The 0.1 sec period that this refers to is chiefly determined by an 0.25 Hz offset in the auto tuner crystal (multiplied by 40 to 10 Hz). This technique makes the comparison sensitive to fractions of 10^{-6} Hz.

These values are translated by voodoo into cavity register offsets. The sign of the change is correct. The value of the change is numerically equal to the difference in the periods (in units of 100 ns) divided by 10 unless the value exceeds 5.0, in which case it is 5.0.

The values for the cavity register are shown in four digits, a sign and another digit. Although it appears that the cavity register change is represented by the sign and single digit, this is not true. The total value of the cavity register is the four digits plus or minus the single digit divided by 10. We determined during autotuning in October 1996 that a cavity register digit corresponds to 1×10^{-15} s/s.

The thermal control is accomplished through both the cavity register and the cavity pot. The pot is accessible through the cap on the top of the maser (skewered with a brass rod known as the degaussing rod). The fourth screw, the one on the right as you face the maser, is the cavity register pot.

The cavity register and pot are coupled in a bridge circuit. They are required to match. The suggested method for tuning when the register reaches one end of its scale differs from that in the OVRO notes. First, turn the cavity register to the opposite end of its scale. Second, adjust the cavity register pot until the cavity register thermal current returns to the value prior to the first step. The thermal current will then be near the same value as previously and the cavity register will be ready to change. This method is equivalent in effect but faster than the OVRO method.

A counterclockwise turn of the pot cools the chamber. A clockwise turn of the pot warms the chamber.

6. Experiment Setup

6.1. In Advance of the Experiment

As an experiment approaches, the following steps are necessary for preparation:

• Check out Mark IIIA equipment, including video converter locks and levels, ability to communicate with FS, phase cal signal and tape drive playback. Write a tape of noise and send to Haystack for check of phase cal, time stamp and levels.

• Make sure tapes, labels and tape drive cleaning equipment are available.

• Determine appropriate method for shipping tapes. The best method appears to be UPS Second Day Air. Do not send by US Postal Service or any other non-traceable route.

• Check out maser. Turn on auto-tuning. Check H level and other readings.

• Obtain schedule. Convert to interferometer format.

• Select phasing sources for weak and complex sources.

• Check frequency, polarization, times.

• Identify software for local interferometer.

• Make and install source catalog.

• Schedule appropriate setup time at Hat Creek.

• Obtain hardware from undergraduate lab: HP 5334A universal counter and low frequency spectrum analyzer.

• Locate polarization plates.

6.2. Immediately Before the Experiment

The following should be done in the two days before the experiment:

- Exercise schedule on local interferometer.
- Exercise FS schedule.
- Test phasing and determine configuration.
- Install polarization plates.
- Switch interferometer reference oscillator to maser.
- Turn off maser autotuning.
- Synchronize formatter clock to GPS.
- Disconnect splitter from summer.
- Connect IF to MK IIIA.
- Connect digital voltmeter to multi-bus and to FS.
- Perform test tone experiment.
- Walsh function test.
- Trim IF levels in swyard and in MK IIIA.
- Trim phase cal level.
- Fringe test on transmitter.

7. Observing

Observing alternates between a short phasing observation with the local correlator and observation in the VLBI mode. Timing is quite important for the schedule. The VLBI scan lasts for 390 s, a time interval determined by the length of a thin tape and the recording speed. Scans are usually separated by 20 minutes to allow time for phasing and slewing between sources. We describe here the many practical aspects of running the interferometer.

We do not use the project environment for observing. Instead, we run a csh script that calls *mint* directly. This avoids overhead in the calculation of start and stop times and complications that result from a multi-day schedule. The main script must be run from the archive area. A typical path for the archive area */obs/obs/archive/newdata/07jan97/vlbi*. The scheduling software is kept in the directories of */obs/obs/vlbi*. The data structures are organized on the UT of the observation, which we refer to with *$ut*.

A script called *START_VLBI* is used to set up before observing. An example is given in Appendix B. With this script, we set the file *$HATTAB/swyard.tab* for proper summing. We tune to the observing frequency. We set the correlator in wideband mode with no cable length measurement. We set the common variable *jyperka* to unity for each antenna with the script *jyperka_to_one.csh* so that the units of antenna temperature are in K.

The main script and source catalog are generated from the drudg observing file by a program called *mydrudg2hc*. This program is slightly outdated. Its output requires a small bit of editing to keep up with the changing demands of the programs it refers to. Its principal features are an LST based schedule that interleaves *PREOB* and *MIDOB* calls for each scan. Examples of *PREOB* and *MIDOB* are listed in Appendix B. *PREOB* is responsible for phasing the array. *MIDOB* is responsible for observing during the VLBI scan and for calibration information.

PREOB sets Walsh functions to their standard values, runs *mint*, performs a self-calibration on the visibilities and calls *phasem* to set the phase of the offset frequency card. *PREOB* visibilities are written into a file *$ut.p*. In addition to the regular visibility items, an item called *phasemlog* records information about the phasing.

MIDOB runs *tpscan* in the background to collect total power information, sets to zero the Walsh functions of all antennas in the summed output, runs *mint*, calls *measwgts* to measure the weight of individual antennas in the IF, performs a *powercal* and calls the calibration software. *MIDOB* visibilities are written into a file *$ut.m*; total power data are written into *$ut.tp* and powercal information are written into *$ut.tpcal*. The measwgts results are written into a visibility item called *vlbiwgts*.

Both *PREOB* and *MIDOB* call *vpause* as a final step. This routine waits until the appointed end time.

The catalog is created with the use of a simple program *Sources*. The output of *Sources* is fed into the catalog program with

```
catalog catalog=oct96vlbi.cat initials=vlbi < Sources.out
```

The catalog must be stored in the appropriate user area for catalogs, which is currently *$UCAT*. Be sure to update *PREOB* and *MIDOB* to point to the correct catalog.

Focusing should be done daily throughout the experiment.

Several tools exist for examining data quality during the experiment. These tools are also in the */obs/obs/vlbi* directories. To plot the total power information from a given scan use the script *tpwip*. To summarize the weight information recorded by *measwgts*, use *wgtstable.csh*. To summarize the phasing information, use *listphaselo1.csh*. It is often useful to inspect the quality of the local correlator visibilities with the MIRIAD task *uvplt*. The script *uvp* provides a shorthand for use of this task.

8. After the Experiment

Restoring the interferometer following a VLBI experiment includes the following steps:

- Reconnect the frequency standard to the crystal.
- Reset the multi-bus clock with the command *settimegps*.
- Reconnect splitter and summer.
- Remove any attenuators in the switchyard.
- Restore walsh functions.
- Restore *$HATTAB/swyard.tab*.
- Restore *jyperka* to standard values. We currently have a script *jyperka_restore.csh* that performs this task.
- Disconnect IF to MK IIIA.
- Remove polarization plates from antennas 1 and 3.
- Communicate with archivist for proper archiving techniques.
- Backup local correlator visibilities and total power data on tape.

A summary should be sent to the VLBI correlator. The summary should include clock rates and offsets, frequency information, calibration tables and description, weather information and tape and scan summaries. The FS log files should be e-mailed to the correlator.

9. Wishlist

• A smart algorithm for phasing of weak sources. This algorithm would recognize if the observed phases are sufficiently determined. If not, antenna phases determined previously on a bright source will be employed.

• A phasing test in the local interferometer. This test should identify the efficiency of the summed signal. In the best case, this test would be performed during each VLBI observation.

• A clean, stable test tone. A better test tone may be achieved through the use of a test tone generator available from Haystack Observatory.

• A single program for data calibration and monitoring. This development is underway.

• Improved absolute timing in interferometer control software. We currently lose a few minutes due to inefficiencies in the timing in *mint*. An improvement would be the implementation of a version of *mint* that does not include slew times in its determination of stop times and that is accurate in absolute stop times to fractions of a minute. The extra time could be used for improved phasing observations.

A. Maser Maintenance

Don Rhine (Allied) and Geoff Bower visited Hat Creek to rehabilitate the NX-II maser from January 16 through January 23, 1996. This document summarizes the steps made in the repair of the maser.

Before servicing, the maser rate was on the order of one millisecond per day. The maser was observed to be far out of tune and was successfully tuned. A reduction by 10^5 of the frequency rate was accomplished. We describe the different steps involved in this tuning.

A.1. Hydrogen Added

Hydrogen was added to the tank on January 17 and a marked improvement in performance was observed.

The hydrogen was taken from tank KD 12454, 99.9995% pure. The tank had a pressure of 1200 psi. We increased the maser hydrogen tank pressure from 25 to 400 psi. It is important in this procedure to bleed hydrogen out of the regulator and out of the maser tank before filling the maser tank.

The performance of the maser went to approximately 10 microseconds per day.

A.2. Phase Lock

The phase lock was improved by tuning the VCO.

A.3. Synthesizer Frequency

The original frequency setting 365 C64F4 corresponded to a frequency of 5.751 692 kHz, only 5 mHz higher than the hydrogen line frequency. We found that by tuning away from the hydrogen line frequency we could reduce the rate. We kept the setting at its original value.

A.4. Zeeman Test

We performed a Zeeman test. We found that the magnetic field had to be set to low in order for the Zeeman test to work. The frequency was determined to be 550 ± 5 Hz.

Lowering the cavity magnetic field improved the maser rate to $\sim -5 \times 10^{-12}$, a twenty-fold decrease.

A.5. Tuning

The cavity was far out of tune. We adjusted the coarse tuning pot about one half-turn CCW, equivalent to roughly twice the range of the cavity register, until we found the rough tuning point. We observed the bend in the maser delay relative to GPS indicative of a change in the cavity resonant frequency.

The rate improved to 1×10^{-13}.

A.6. Vac Ion Pump

We were warned that a high vac ion current indicates a faulty vac ion pump. It is most likely that it is the hydrogen pump, the pump on the right. These items need to be replaced every few years. The recorded replacements are September 1984 and February 1990. The meter is suspect.

A.7. Power Supply & Battery Backup

It was recommended that we use two higher amp batteries to replace the four we currently use. Wet cell batteries would be acceptable. It was also recommended that we move the power supply away from the maser.

B. Sample VLBI Observing Scripts

B.1. START_VLBI

This is the text of *START_VLBI* from the October 1996 experiment:

```
#! /bin/csh -f

echo "START VLBI"

echo "-------------------------------"
echo "Disconnect Splitter from Summer"
echo "-------------------------------"

cp $HATTAB/swyard.tab.23456789 $HATTAB/swyard.tab
echo "swyard.tab:"
cat $HATTAB/swyard.tab

jyperka_to_one.csh

setfreq freq=86.21699 iffreq=137.99 ants=123456789
setcorr cormode=8 coptions=nopass,nocable corf=205,405,605,805 \
  corbw=100,100,100,100
testpolly ants=123456789 polar=LLLLLLLLL

#/export/obs/obs/vlbi/dec95/exp/OBgen.csh
#cp /export/obs/obs/vlbi/apr96/exp/PREOB.mint .
#cp /export/obs/obs/vlbi/apr96/exp/MIDOB.mint .
```

B.2. PREOB

This is the text of *PREOB* from the October 1996 experiment:

```
#!/bin/csh -f
#
alter name=project value=PREOB

set BELL=`echo X | tr X '\007'`
alias FEcho 'set X = '"\!*"'; echo "$BELL$X"; comment is="ALARM: $X"; unset X'
#

setenv VDATA `pwd`

unset source
unset stop
unset ut
set line=wide,1,2
set rcpant=""
set slew="n"
set refant=6
set cat=vlbioct96.cat
set ants=123456789
set xant=""
#
#  Get the command line arguments.
#
while ($#argv)
  set check = `echo $argv[1] | awk -F= '{print NF}'`
  if ("$check" > 1) then
    set $argv[1]
  endif
  shift
end
#
#  Check that the required inputs have been given.
#
```

```
if ($?source == 0) then
  FEcho "### Fatal Error: Missing argument source="
  exit 1
endif
if ($?stop == 0) then
  FEcho "### Fatal Error: Missing argument stop="
  exit 1
endif
if ($?ut == 0) then
  FEcho "### Fatal Error: Missing argument ut="
  exit 1
endif
#
echo "PREOB source=$source lststop=$stop ut=$ut line=$line \
slew=$slew refant=$refant rcpant=$rcpant ants=$ants xant=$xant"

setwalsh to=on

if ($slew == "y" || $slew == "Y") then
   mint source=$source vis=$ut.p itime=7.68 stop=$stop-4 catalog=$cat \
nchan=0 ants=123456789 polar=LLLLLLLLL
else
   mint source=$source vis=$ut.p itime=7.68 stop=$stop-4 catalog=$cat \
nchan=0 ants=123456789 polar=LLLLLLLLL
endif

#if ($rcpant != "") then
#  set select="select=-ant($rcpant)"
#else
#  set select=""
#endif

#rm -f antfile
#echo $ants > antfile
#set select=`nawk -f selants.awk antfile`

if ($xant != "") then
  set select="select=-ant($xant)"
```

```
  set xselect="select=ant($xant)"
else
  set select=""
  set xselect=""
endif

echo $select

if (-e $ut.p ) then
   if ( $xselect != "") then
     uvflag vis=$ut.p flagval=f "$xselect" line=wide
   endif
   selfcal vis=$ut.p refant=$refant line=$line interval=15 minants=3 \
"$select"
   phasem vis=$ut.p log=$ut.p/phasemlog

   value name=phaselo1
   value name=phaselo2
endif

vpause ut=$ut offset=-4
exit ($status != 0)
```

B.3. MIDOB

This is the text of *MIDOB* from the October 1996 experiment:

```
#!/bin/csh -f
#
alter name=project value=MIDOB

set BELL=`echo X | tr X '\007'`
alias FEcho 'set X = '"\!*"'; echo "$BELL$X"; comment is="ALARM: $X"; unset X'

setenv VDATA `pwd`
setenv VEXP '/obs/obs/vlbi/oct96/exp'
```

```
#
unset source
unset stop
unset ut
set ants=123456789
set cat=vlbioct96.cat
set xant=""
#
#  Get the command line arguments.
#
while ($#argv)
  set check = `echo $argv[1] | awk -F= '{print NF}'`
  if ("$check" > 1) then
    set $argv[1]
  endif
  shift
end
#
#  Check that the required inputs have been given.
#
if ($?source == 0) then
  FEcho "### Fatal Error: Missing argument source="
  exit 1
endif
if ($?stop == 0) then
  FEcho "### Fatal Error: Missing argument stop="
  exit 1
endif
if ($?ut == 0) then
  FEcho "### Fatal Error: Missing argument ut="
  exit 1
endif
#

setwalsh to=on

rm -f antfile
echo $ants > antfile
```

```
set alist=`nawk -f walants.awk antfile`

foreach a ( $alist )
  alter name=walants-$a value=0
end

echo "MIDOB source=$source lststop=$stop ut=$ut ants=$ants"

tpscan > $ut.tp &
mint vis=$ut.m stop=$stop itime=7.68 catalog=$cat \
ants=123456789 nchan=0 source=$source polar=LLLLLLLLL

powercal ants=123456789 > $ut.tpcal


if (-e $ut.m) then
  measwgts 123456789 > $ut.m/vlbiwgts

  if ($xant != "") then
    uvflag vis=$ut.m flagval=f select="ant($xant)" line=wide
  endif

  selfcal vis=$ut.p line=wide,1,2 options=amplitude,noscale refant=6 interval=0.1
  rm -f $VEXP/vlbical.tmp $VEXP/junk

# new calibration cycle
  ~obs/vlbi/oct96/exp/myvlbical visp=$ut.p vism=$ut.m window=2 ref=1 \
> $VEXP/vlbical.tmp
  tail -1 $VEXP/vlbical.tmp >> $VEXP/newcal

# old calibration cycle

# vlbical visp=$ut.p vism=$ut.m window=2 > $VEXP/vlbical.tmp
# grep 'AMPS' $VEXP/vlbical.tmp > $VEXP/junk
# uvlist vis=$ut.m line=wide,1,2 recnum=1000 select="ant(1)" \
| sed 's/-/ -/g' >> $VEXP/junk
# nawk -f $VEXP/awkscript $VEXP/junk >> $VEXP/vlbical.tmp
# awk -f $VEXP/awkscript3 $VEXP/vlbical.tmp >> $VEXP/newcal
```

```
# strip ideal wgts from vlbical.tmp
  echo $ut.m >> $VEXP/idwgts.dat
  nawk -f $VEXP/ideal.awk $VEXP/vlbical.tmp >> $VEXP/idwgts.dat

endif

vpause ut=$ut offset=6.5
exit ($status != 0)
```

REFERENCES

Dewey, R. 1995, ApJ, 108, 337.

Thompson, A.R., Moran, J.M., and Swenson, G.W., Jr., 1991, Interferometry and Synthesis in Radio Astronomy, Wiley, New York.