

HTRP Operations Guide

Mark M. McKinnon

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Contents

1	Introduction	2
2	System Description	2
3	Sky Frequency Selection	5
4	HTRP Operating Modes	9
4.1	Procedural Aspects of Continuous Sampling	10
4.2	Procedural Aspects of Gated Sampling	14
4.3	Procedural Aspects of Pulsar Timing	17
5	Array Operations	18
5.1	Interacting with the Array Operator	18
5.2	Phasing the Array	19
6	Trouble-shooting	20
7	Improvements	22
8	Revisions	23
8.1	Documentation Revisions	23
8.2	Software Revisions	23
8.2.1	collect.c	23
8.2.2	sth.c	24
8.2.3	ae77.c	24
8.2.4	trigger.c	24
8.2.5	ht.c	25
8.2.6	view.c	25
8.2.7	loset.c	25
8.2.8	comport.c	26
8.2.9	control.c	26
8.3	Hardware	26

1 Introduction

The HTRP Operations Guide describes the operation of the High Time Resolution Processor (HTRP) at the Very Large Array (VLA) radio telescope. It focuses on the user's interaction with the hardware and the process of data acquisition. The HTRP is designed to be used with the VLA in its phased array mode. The HTRP provides the VLA with the capability to collect data on timescales (~ 10 microseconds) that are short when compared to the integration time (~ 10 seconds) of the VLA correlator. The advantages the VLA phased array offers over other radio telescopes include (1) the VLA is fully steerable and (2) the VLA phased array has the equivalent collecting area of a 130-meter diameter antenna. These advantages coupled with the low system temperatures, especially the 35K at 8.5 GHz, provide the sensitivity required for short timescale observations of a variety of astrophysical phenomena. The HTRP has been used for pulsar timing, pulsar polarimetry, directed pulsar searches, observations of solar flares, and searches for Saturn electrostatic discharges.

In addition to describing the operations of the HTRP, the HTRP Operations Guide documents modifications to HTRP hardware and software. The idea here is to keep HTRP users informed of changes which may affect the user's data or HTRP operational procedures. The most recent version of the HTRP Operations Guide will be made accessible to the user community as the file `opnguide.ps` on `zia/u/htrp/opnguide/`. Users are welcome to copy this file at any time. Comments, questions, and constructive criticism are also welcome at the email address `htrp@zia.aoc.nrao.edu`.

2 System Description

Figure 1 is a block diagram of the HTRP. Each antenna of the array produces signals of right and left circular polarization in the A and D IF's, respectively. The maximum bandwidth of the signals is 50 MHz. All antenna signals of the same polarization are added together in the analog sum. The baseband summed signals are upconverted with a 150 MHz local oscillator before entering the MkIII filter bank. The filters, usually called videoconverters, have selectable bandwidths of 2 and 4 MHz and tunable local oscillators for sky frequency selection. The filter bank contains 14 videoconverters, 7 for each IF. Since each videoconverter has upper and lower sideband outputs, a total of 14 different sky frequencies can be selected within each IF. The videoconverter outputs are sent to a multichannel multiplying polarimeter. The polarimeter consists of quadrature phase-shift networks, detectors, and RC integrators. For every sky frequency selected at the videoconverters, the polarimeter produces four detected signals (RR, LL, RL, and LR). The block diagram in Figure 2 shows how the polarimeter produces the detected signals from input signals of right and left circular polarization which are out of phase by the angle ψ . These

detected signals completely specify the polarization of the observed radiation. The integration time for each detected signal can be 25, 50, 100, 200, 500, 1000, 2000, or 5000 microseconds. The detected signals are sampled with a commercial analog-to-digital converter (A/D). The A/D is driven by an external frequency synthesizer. Sampling intervals can be as short as 10 microseconds between samples of consecutive channels. In the simplest of data acquisition modes, the digitized data is written to the hard disk of an IBM-PC compatible computer. Data can be copied from disk to 40 megabyte cassette tape. The computer also communicates with the polarimeter to configure integration times and monitor power supply voltages.

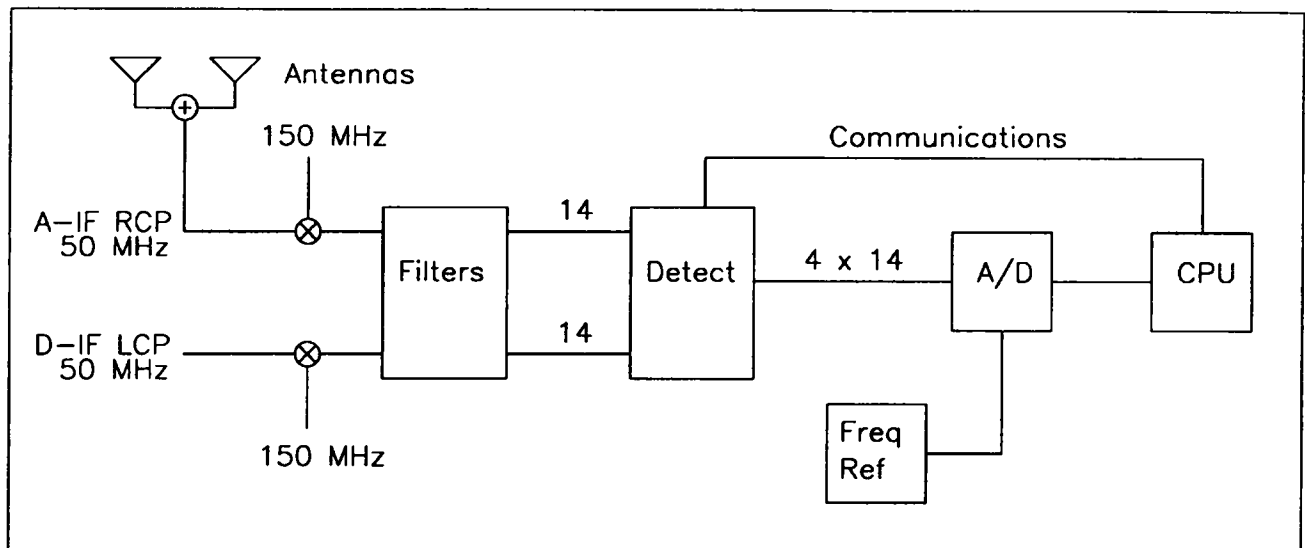


Figure 1: HTRP block diagram

The HTRP has two sample-and-hold circuits. One circuit compensates for the waveguide drop out, called data valid, which occurs once every 52 milliseconds (19.2 Hz, exactly). The data valid sample-and-hold circuit holds the last 'good' value of the analog sum signal before the drop out occurred. The other sample-and-hold circuit compensates for the consecutive channel sampling executed by the A/D. Consecutive sampling causes different frequency channels to be sampled at different absolute times. The channel sample-and-hold circuit holds all channel samples in a buffer until the A/D has sampled all frequency channels. Consequently, all frequency channels represent the same instant in time.

Given the minimum filter bandwidth and smallest A/D sampling time of the

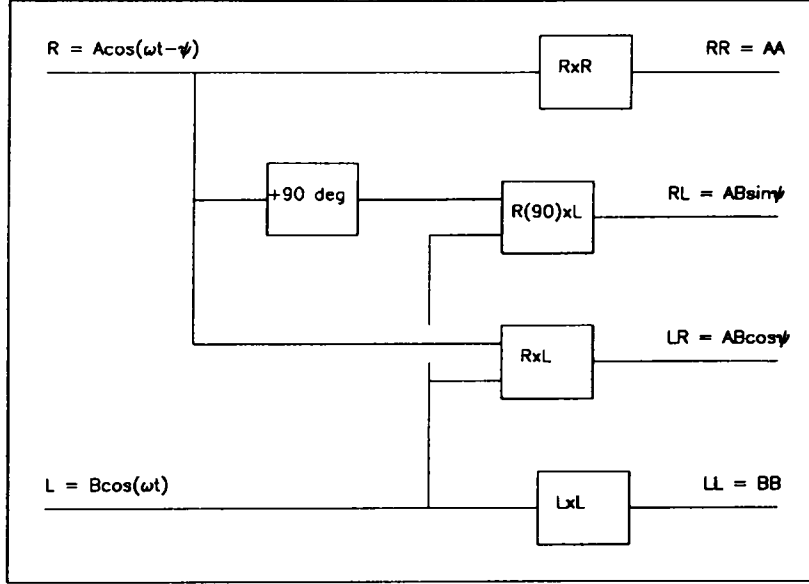


Figure 2: Schematic of the multiplying polarimeter used by the HTRP

HTRP, one can determine an allowable parameter space for pulsar polarization observations. First, assume that 512 samples across the pulsar period is adequate. If the dispersion smearing time is comparable with this sampling interval, then the pulsar dispersion measure and the 2 MHz bandwidth of the HTRP determine which pulsars are observable. The solid line in Figure 3 represents this dispersion sweep time criterion for a sky frequency of 1.4 GHz. All pulsars above and to the left of the solid line can be observed with the HTRP. (The figure neglects the signal-to-noise of individual pulsars). Since 64 HTRP detected outputs must be sampled in a polarization observation, the A/D sampling interval places an additional constraint on the HTRP pulsar parameter space. The shortest pulsar period observable with 512 sample resolution is $64 \times 512 \times 10 \mu\text{s} = 0.328 \text{s}$. This criterion is shown as the dashed line in Figure 3. Neglecting the additional constraint of signal-to-noise, Figure 3 shows, roughly, that more than half of the known radio pulsars are available for polarization observations with the VLA HTRP. At lower sky frequencies, dispersion smearing becomes worse, and only a few pulsars are observable with adequate time resolution.

For pulsar searches where time resolution across the pulsar period is not as critical as in a polarimetry experiment, the HTRP pulsar parameter space expands greatly. Since 32 channels are sampled in a total intensity experiment, the shortest pulsar period observable is $32 \times n_p \times 10 \mu\text{s}$ where n_p is the number of samples across the pulse. For Nyquist sampling ($n_p = 2$), the shortest observable

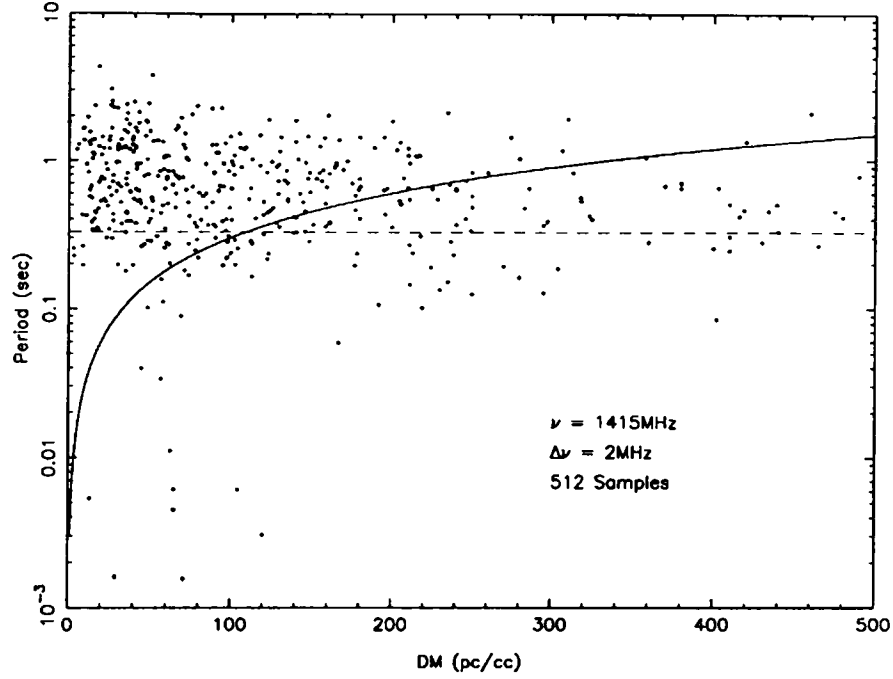


Figure 3: HTRP pulsar polarization parameter space. The solid line denotes the limitation of dispersion smearing, and the dashed line represents the limiting A/D conversion rate. Only pulsars above and to the left of the lines are available for HTRP polarization observations. However, for pulsar searches, the limiting period can be as small as 0.64 ms.

period is 0.64 ms¹, which is comparable with theoretical estimates of the shortest allowable rotation period of a neutron star.

3 Sky Frequency Selection

The 150 MHz local oscillator at the MkIII filter bank upconverts the 50 MHz VLA baseband signal to a video signal at 150-200 MHz. The VLA sky center frequency occurs at 175 MHz in this video signal. The sky frequencies of a videoconverter's upper (USB) and lower (LSB) sidebands are selected by adjusting the videoconverter local oscillator to a value between 150 and 200 MHz. The videoconverter sky frequencies also depend upon the videoconverter bandwidth. The details of the sky frequency calculation are discussed in HTRP Memorandum #110, and the actual calculation is performed by the program `loset` on the HTRP computer. Table 1 lists the videoconverter sky frequencies for a VLA

¹However, for reasons cited in subsection 4.1, the smallest sampling interval for continuous sampling is 40 us, and the limiting pulsar period becomes 2.56 ms.

sky frequency of 1415 MHz centered on 50 MHz bandwidth. The table assumes a 4 MHz videoconverter bandwidth. Since the filter bank produces 14 signals with 4 MHz bandwidth, the frequency coverage is 56 MHz. Consequently, the last two entries have frequency components which lie outside the VLA observing band of 50 MHz.

VC Pair	VC LO Freq. (MHz)	Sideband	VC Sky Freq. (MHz)
1	154	LSB	1392
		USB	1396
2	162	LSB	1400
		USB	1404
3	170	LSB	1408
		USB	1412
4	178	LSB	1416
		USB	1420
5	186	LSB	1424
		USB	1428
6	194	LSB	1432
		USB	1436
7	202	LSB	1440
		USB	1444

Table 1: The sky frequencies of the center of the sideband for each videoconverter (VC) pair for a given local oscillator (LO) frequency. The entries assume a VLA sky frequency of 1415 MHz centered on 50 MHz bandwidth and a VC bandwidth of 4 MHz. The sky frequencies in the last two entries lie outside the VLA observing band.

Since the pulsed emission of pulsars is dispersed by the interstellar medium, pulsar observations can be used to check the sky frequencies of the videoconverters. Figure 4 shows portions of the PSR 0823+26 pulse profile at the 14 different frequencies of the MkIII videoconverters. The profile formed at the highest frequency is shown at the top of the figure, and the profile formed at the lowest frequency is shown at the bottom of the figure. The low frequency pulses arrive later in time than the high frequency pulses. When the profiles are corrected for the known dispersion measure ($DM = 19.4634$) of the pulsar, all the pulse profiles align in time (see Figure 5) except for the noisy profile which

is the fourth from the bottom of the figure. The videoconverter which produced the signal for the nonaligned profile has a malfunction in its local oscillator.

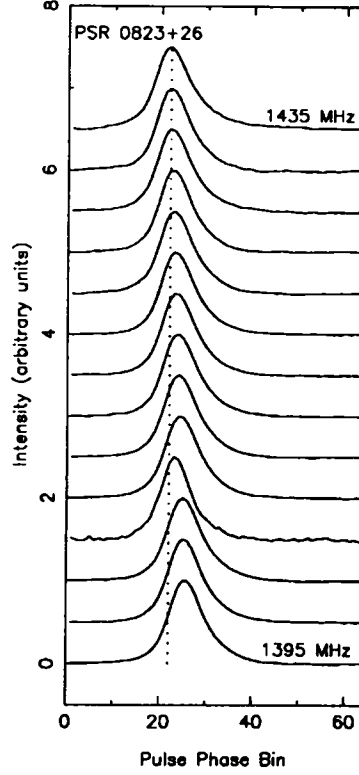


Figure 4: Portions of the pulse profile of PSR 0823+26 at the 14 different frequencies produced by the MkIII videoconverters. Sky frequency increases from bottom to top. The lower frequency pulses arrive later in time (pulse phase bin) because of interstellar dispersion.

Phased array observing at P-band presents unique problems because of the radio frequency interference (RFI) in the band. The nominal range of P-band frequencies is 300-350 MHz, and the 25 MHz front end filters on the P-band feeds limit the bandwidth to 25 MHz. Strong RFI occurs in this frequency range at 5 and 12.5 MHz intervals (e.g. 305, 310, and 312.5 MHz). Weak RFI occurs at 1 MHz intervals. The presence of RFI makes the process of broadband array phasing nearly impossible. A two step observing technique has been developed to minimize the effects of RFI. The first step is to phase the array on a calibrator at a combination of bandwidth and sky frequency where strong RFI is not present. A sky frequency of 333 MHz with a bandwidth of 3.125 MHz has been used successfully. The second step is to maintain the narrow-

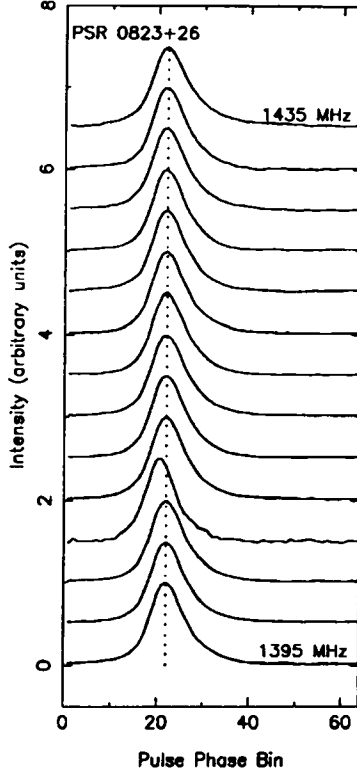


Figure 5: The frequency-dependent profiles of PSR 0823+26 compensated for interstellar dispersion. All profiles align in time except for the fourth from the bottom because of a local oscillator malfunction.

band array phasing while slightly changing the sky frequency and increasing the bandwidth for the observation of the source of interest. Only sky frequencies of 315 and 335 MHz are allowable with 25 MHz bandwidth. The videoconverters are configured with a local oscillator frequency and bandwidth setting which cause the videoconverter upper and lower sidebands to dodge the known RFI. The videoconverter configurations described by Table 2 have been used successfully in pulsar timing observations. Although some of the videoconverter bands overlap, the frequency coverage is about the best one could hope for given the presence of RFI. This observing technique has not been applied to polarization observations because the effect on signal phase is not completely understood.

VC Pair	VC LO Freq. (MHz)	Sideband	VC Sky Freq. (MHz)
1	152.5	LSB	324.0
		USB	326.0
2	155.0	LSB	326.5
		USB	328.5
3	157.5	LSB	329.0
		USB	331.0
4	160.0	LSB	331.5
		USB	333.5
5	162.5	LSB	334.0
		USB	336.0
6	165.0	LSB	336.5
		USB	338.5
7	167.5	LSB	339.0
		USB	341.0

Table 2: The sky frequencies of the center of the sideband for each videoconverter (VC) pair for a given local oscillator (LO) frequency. The LO settings have been selected to reduce radio frequency interference. The entries assume a VLA sky frequency of 335 MHz centered on 25 MHz bandwidth and a VC bandwidth of 2 MHz.

4 HTRP Operating Modes

This section of the HTRP Operations Guide is a detailed discussion of the operating modes used in HTRP data acquisition. Currently, there are three HTRP operating modes: continuous sampling, gated sampling, and pulsar timing. Continuous sampling is the most general (and flexible) operating mode whereas gated sampling and pulsar timing are specifically designed for pulsar observations. The subsections on continuous and gated sampling describe how the data acquisition software works in each of these operating modes. The software description is followed by a list of start up procedures required by each mode. Since the pulsar timing software is described elsewhere [3], the subsection on pulsar timing consists only of the list of start up procedures. The gated sampling and pulsar timing modes are highly specialized versions of continuous sampling; therefore, almost all of the items in the continuous sampling mode start up check list are relevant to the other observing modes.

All data acquisition programs on the Compaq 386/20 computer utilize direct memory access (DMA) for fast data acquisition rates. DMA is used in conjunction with a ‘circular’ memory buffer to allow data to be written to half the buffer while data in the other half is being sent to the computer hard disk [5]. Each half-buffer contains 16384 2-byte samples. Each sample has 12-bit resolution over ± 5 volts, giving 2.44 millivolts per integer unit. The data file data format is a two dimensional array where the columns of the array are number of channels and the rows of the array are samples of a channel. The relative channel ordering, along with the signal assigned to each channel, is displayed in Tables 5 and 6 at the end of this document. However, the absolute channel ordering is not always the same between data files because of a problem with the A/D hardware. This is why data valid (DV) is included in the sampling. Once DV is known, the location of all other channels is known. DV can be recognized by its high (~ 1500 integer units) to low (~ 20 units) transitions every 52 ms.

A precautionary note to those observers carrying out polarization observations. The image-rejecting mixers in the MkIII videoconverters introduce an inversion (a 180° phase shift) in the upper sideband (USB) RLSIN signals. The easiest way to compensate for this is to multiply the USB RLSIN data by a factor of -1 in the data analysis. See HTRP Memorandum #113 or McKinnon (1991b) [6] for details. For some ideas about polarization calibration, consult McKinnon (1991a) [7].

4.1 Procedural Aspects of Continuous Sampling

There are three computer programs on the Compaq 386/20 which are used for continuous sampling, `collect`, `sth`, and `ae77` with `collect` being the most popular. These programs have subtle differences which are briefly discussed in the section entitled Software Revisions. Another program, `mcollect`, which writes data directly to an Exabyte tape, is currently being developed. The following discussion of `collect` is applicable to the other continuous sampling programs.

The input parameters required by `collect` are output data file name, sampling interval in microseconds, number of data blocks, starting channel, and frequency reference (1 or 5 MHz). A data block is 1024 samples (2048 bytes). The number of data blocks, N , should be an integer multiple of 16 because a disk write occurs every 16384 samples when the DMA buffer is full. Since the number of data blocks is counted by a 16-bit counter, the number of data blocks cannot exceed $2^{16} = 65536$. Otherwise the counter will overflow, and the desired amount of data will not be collected. In practice, the counter overflow limits data file sizes to 65535×1024 samples. The starting channel, n_s , is usually determined by the type of experiment. Data collection starts in channel 32 for a total intensity observation, and starts in channel 0 for a polarization observation. The number of channels sampled is $n_c = 64 - n_s$, and should always be a factor of two. The frequency reference is set at the Fluke 6160B frequency

synthesizer. The frequency reference input value in `collect` essentially notifies a counter what to expect when determining the sampling interval. The sampling interval, Δt_s , should not be less than 40 μ s. This problem is caused by the duration of a disk write. For sampling intervals less than 40 μ s, the disk write takes longer than the sampling of a channel, causing a sample to be missed every disk write. For pulsar searches, it is beneficial to use a synthesizer frequency which is an integer multiple of 60 Hz and an integer multiple of the waveguide cycle (19.2 Hz). This insures that all the power in these instrumental effects falls within a single frequency bin in a Fourier transform power spectrum.

Table 3 summarizes the properties of a data acquisition session after configuring `collect` with a particular set of input parameters. The sampling interval for a single channel is $\Delta t_c = n_c \times \Delta t_s$, where n_c is the number of channels sampled and Δt_s is the sampling interval entered into `collect`. For the highest time resolution total intensity observations, the number of channels sampled must be decreased to reduce Δt_c . The operation of `collect` can be checked by verifying that disk writes occur on time intervals of $\Delta t_s \times 16384$. (The hard disk access light turns on every disk write). The size of the file created by `collect` is $N \times 2048$ bytes, and the duration of data collection is $N \times 1024 \times \Delta t_s$ seconds.

Data Blocks	N
Channels	n_c
Sampling Interval (sec)	Δt_s
Channel Interval (sec)	$n_c \times \Delta t_s$
Disk Writes (sec)	$\Delta t_s \times 16384$
File Size (bytes)	$N \times 2048$
Duration (sec)	$N \times 1024 \times \Delta t_s$

Table 3: Data acquisition session properties with the program `collect`

The following check list describes how the entire HTRP system is configured for continuous sampling. All but a few of these steps are also required by the gated sampling and pulsar timing observing modes.

1. Turn on the Compaq 386/20 computer. NOTE: *Execute these first three steps in the order listed!*
2. Turn on the VERO power supply located at the back of the enclosure which contains the HTRP detectors.
3. Turn on both power supplies at the top of the HTRP instrument rack. The switches are located on the front of the rack.

4. At the computer keyboard, change the working directory to HTRP\DATA by typing `cd \htrp\data`.
5. Switch in 32 dB of attenuation into both IF's with the IF attenuation switches located towards the base of the MkIII videoconverter rack. The additional attenuation prevents unnecessary saturation of the HTRP detectors while the system is being configured for operation.
6. Turn on the Fluke 6160B frequency synthesizer located at the bottom of the HTRP instrument rack. Insure that the frequency range is set for 1-12 MHz, and that the output power level is maximum.
7. Insure that the synthesizer output signal is connected to the A/D trigger. This connection is made at the HTRP patch panel with the BNC connectors labelled Ext Synth Out and LabMaster Trig. In.
8. Insure that DV and SH are connected together at the back of the HTRP detector module. The connectors are located near the VERO power supply switch. These signals are routed to the two sample-and-hold circuits in the detectors. The input to both DV and SH should come from pin 38 of the blue AMP connector (C10) on the back of the HTRP interface module.
9. Insure that the VLBI DELAY CALIBRATOR switch is turned off. This switch is located midway on the MkIII videoconverter rack on the right hand side. If the switch is left on, a 1 MHz comb is injected into both IF's, producing birdies in the pass band every 1 MHz.
10. Insure each videoconverter is configured for manual operation by placing the selector switch in the LOCAL position. The REMOTE position allows the videoconverters to be configured by the VLBI HP computer.
11. Insure each videoconverter has 10 dB of attenuation on both upper and lower sideband outputs. The attenuation is inserted by turning on a switch at each videoconverter. An LED will turn on when the attenuation is switched in.
12. Select the desired bandwidth (usually 2 or 4 MHz) for each videoconverter with the bandwidth select pushbutton.
13. Configure each videoconverter for the desired local oscillator (LO) frequency with the frequency select pushbuttons (LO FREQ SELECT). The LO frequency is displayed in the LCD window when the LCD DISPLAY switch is in the LO FREQ position. If the LO is not locked, an LO UNLOCK warning light will turn on. To compute the sky frequency which corresponds to a videoconverter LO setting, run the program `loset` on the Compaq computer [4].

14. Route the analog sum outputs to the videoconverter inputs (see Figure 6). To do this, connect the new analog sum A IF and D IF outputs to the inputs of the two 25 dB amplifiers on the analog sum patch panel. Connect the output of each amplifier to one of the 3-way power splitters. Take the power splitter output representing the A IF signal and connect it to the ODD VC input. Take the power splitter output representing the D IF signal and connect it to the EVEN VC input. (The power splitter doesn't have to be used, but the additional outputs are convenient for troubleshooting).
15. Run the HTRP monitor and control program by typing `ht` at the computer prompt. `ht` displays monitor points, and allows the user to configure integration times and bias offsets. NOTE: *Everytime you run `ht`, all detectors are automatically reconfigured for 500 us integration times and 0.0 volt bias offsets.* Select the desired integration times and bias offsets by using the function key commands displayed in the menu on the computer screen. The parameters you set will remain until you execute the program `ht` again. Insure that the power supply (PS) monitor points are in reasonable agreement (± 0.2 volts) with their nominal values.
16. Exit the program `ht` by pressing the function key F6, and execute the program which displays the HTRP detector outputs by typing `view`. All detector levels displayed by `view` should be zero because you switched in 32 dB of attenuation in step 5. Adjust the RR and LL detector output levels to reasonable values (2.0 - 3.0 volts) by removing attenuation with the MkIII IF attenuation switches. No signal appears in the RL and LR channels because the signals and noise in the A and D IF's are generally independent.
17. Exit the program `view` by pressing the keyboard space bar (or any other key).
18. If you want to use the channel sample-and-hold feature of the HTRP by running the data acquisition program `sth`, connect pin 40 of the HTRP Interface Module connector C10 to the BNC connector labelled SH on the back of the HTRP detector module. But, do not disconnect the BNC connector labelled DV. If you want to run the program `collect`, which does not generate the sample-and-hold signal, insure that SH and DV are connected together. (`sth` will still work if DV and SH are connected together. It will behave just like `collect`). The program `view` will not run properly if SH is disconnected from DV because `view` doesn't generate the sample-and-hold signal.
19. The system is now ready for data acquisition. Run the data acquisition computer program of your choice (`collect`, `sth`, `ae77`).

20. Once you have completed your observations, turn off all equipment. Switch in 32 dB of attenuation with the IF attenuation switches to prevent inadvertent saturation of the HTRP detectors.

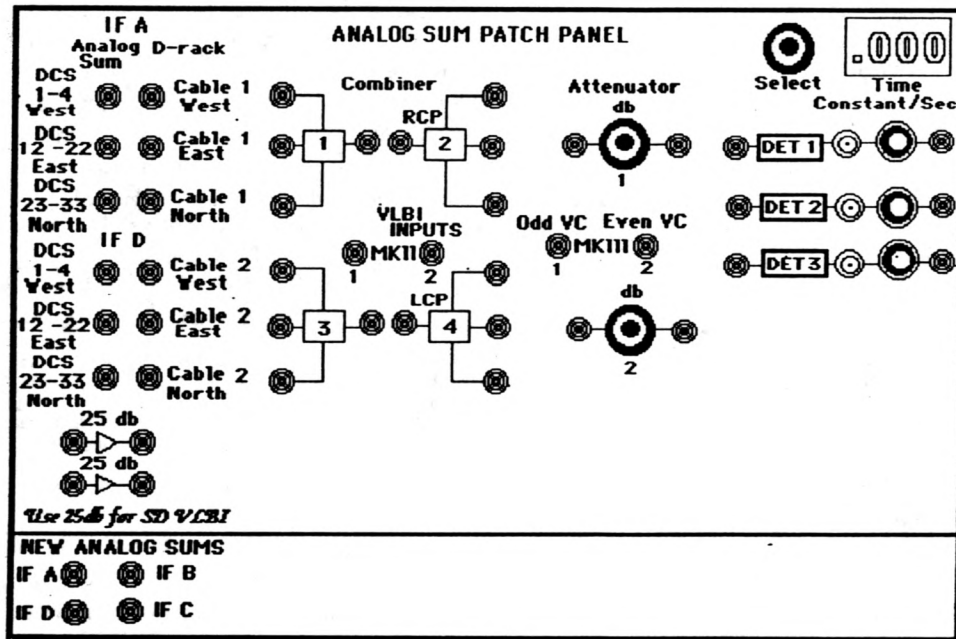


Figure 6: VLA analog sum patch panel

4.2 Procedural Aspects of Gated Sampling

Gating of HTRP data sampling was developed for observations of pulsed emission from pulsars. If an observer is only interested in the pulsed emission, there is no need to sample the off-pulse noise. The gating of data acquisition reduces the required capacity of computer disk and/or magnetic tape by about 90% of that required by continuous sampling because pulsar duty cycles are typically less than 10%. The computer program which executes the gated sampling is called **trigger**. The specific details of the software and A/D hardware configuration for gated sampling are presented in HTRP Memorandum #111 [5].

The input parameters required by `trigger` are output data file name, number of pulsar periods, frequency source (1, 2, or 3), divisor, number of channel samples, and starting channel. The number of pulsar periods determines the duration of the observation. The duration is just $N \times P$, where N is the number of periods and P is the pulsar period. The frequency source ultimately drives the A/D, and code 1 represents an internal 1 MHz oscillator, code 2 represents an internal 100 kHz oscillator, and code 3 represents an external frequency source which is connected to pin 6 on connector C10 of the HTRP Interface Module. The sampling frequency is determined by dividing the source frequency by the divisor. The sampling interval can be as short as 10 us in `trigger`. The number of channel samples is the number of samples taken of a single channel (detected output) when an external trigger occurs. This parameter sets the duration of the gate. The duration is the product of the sampling interval, number of channels, and number of channel samples. The number of channel samples must be a power of 2. The starting channel is configured the same as in `collect`: data collection starts in channel 32 for a total intensity observation, and starts in channel 0 for a polarization observation.

To insure that a DMA buffer change and disk write occur when data is not being sampled, the total number of samples collected each pulsar period must be a power of two and less than or equal to 16384. (Remember that a disk write occurs every 16384 samples). For example, assume that all 64 HTRP detected outputs are sampled 64 times each. A disk write will occur every four (16384/4096) pulsar periods. The size of the resulting data file will be $8192 \times N$, where N is the number of periods.

The gate durations should be selected based upon the actual pulsar pulse width and the desired sampling resolution across the pulse. The user should properly account for dispersion smearing in calculating the gate duration to insure that all HTRP frequency channels are adequately sampled during the gate.

Table 4 summarizes the properties of gated data acquisition when `trigger` is configured with different divisor values for a 1 MHz frequency source. The Channel Interval entry in the table assumes all 64 HTRP detected outputs are sampled. The Gate Duration entry further assumes that each detected output is sampled 64 times. The number of channel samples (Max Channel Samples in Table 4) is limited by the 16-bit counters to $N_{max} = 65536/n_c/D$, where n_c is the number of channels and D is the divisor.

Gated sampling is effectively pulse-modulated continuous sampling. The pulse is initiated by an external trigger source. Therefore, the major difference between the gated and continuous sampling modes is the operation of the A/D. The analog sum patch panel and MkIII videoconverter configurations do not differ between the sampling modes. The following list describes how the Intel signal averager designed by T. H. Hankins is integrated into the HTRP to provide the trigger source for the A/D. The HTRP can accept trigger sources from timing systems other than the Intel.

Sampling Interval (us)	Channel Interval (ms)	Gate Duration (ms)	Max Channel Samples
10	0.64	41.0	102
11	0.70	45.1	93
12	0.77	49.2	85
13	0.83	53.2	78
14	0.90	57.3	73
15	0.96	61.4	68

Table 4: Gated Sampling with a 1 MHz Frequency Reference

1. Execute steps 1 through 17 of the continuous sampling start up check list.
2. Configure channel A of the dual channel square law detector labelled Dual Pulsar Detector in the HTRP instrument rack for an analog sum input. At the analog sum patch panel, take one of the power splitter outputs on A or D IF and connect it to A Analog In at the HTRP patch panel.
3. Prepare the Intel timing system for data acquisition. At the HTRP patch panel, connect Buffered 5MHz to Intel 5MHz In. Connect A Analog Out to Intel Analog In. Connect Data Invalid to Intel Data Invalid.
4. Adjust the Dual Pulsar Detector channel A output operating level to about zero volts using the attenuation switches and bias offset control. Select the desired RC time constant for the Intel at the Dual Pulsar Detector.
5. Turn on the Intel computer and its MacIntosh terminal. Run the program **sigav** in accordance with the Sigav User's Manual [2].
6. After insuring that the VLA Gate control switch on the Intel is in the **manual** position, connect the Intel VLA Gate on the HTRP patch panel to Ext Trig on the HTRP Interface Module. (It is sometimes convenient to install an in-line switch in this cable because the gate control will be turned off and on during data acquisition.)
7. Observe the pulsar, and set up a gate on the pulsar pulse displayed on the MacIntosh terminal. The gate should be logical high on pulse. Note the gate width, and insure that it is compatible with the parameters you plan to enter in **trigger**. The gate width can be measured by displaying the Intel VLA Gate on an oscilloscope.

8. If you want to use the channel sample-and-hold feature of the HTRP, connect pin 40 of the HTRP Interface Module connector C10 to the BNC connector labelled SH on the back of the HTRP detector module. (This is the recommended operational configuration for gated sampling). Otherwise, insure that SH and DV are connected together.
9. At the Compaq 386/20, run the program **trigger**. This program will request the starting channel, sampling interval, channel samples (typically 64) and number of pulses to sample. **trigger** will then instruct the user to turn on the external trigger. Do this by switching the Intel VLA Gate control switch to **computer**. When **trigger** is finished, it will request that you turn off the external trigger.
10. Turn off all equipment once your observation is complete.

4.3 Procedural Aspects of Pulsar Timing

A pulsar timing experiment uses the MkIII videoconverters and HTRP detectors no differently than an HTRP continuous sampling experiment. The major difference is the Princeton timing system in a Dell 286 IBM-PC compatible performs the data acquisition instead of the Compaq 386/20. To use the timing system, the detected signals from the HTRP and the frequency synthesizer output must be connected to the Dell 286 instead of the Compaq 386. The following list describes how the timing system is set up and used.

1. Execute steps 1 through 15 of the continuous sampling start up check list. (Except step 7 is not necessary for timing).
2. Send the frequency synthesizer output to the Dell 286 by connecting "Ext. Synth. Out" on the HTRP patch panel to Master Clk In on the timing system aluminum connector box.
3. Switch the frequency synthesizer to its maximum frequency output range, and configure the output frequency for 20 MHz.
4. Insure that the 10 second tick signal on pin 41 of connector C10 on the HTRP Interface Module is connected to 10 Sec Tick In on the timing system aluminum connector box. Connector C10 is the blue AMP connector located on the back of the HTRP Interface Module. An in-line switch should be placed on this interconnecting cable. This 10 second tick connection is permanently installed, and should not be modified.
5. Look in the back of the HTRP Interface Module, and you should see an LED blinking every two seconds and another LED blinking every 10 seconds. Using the in-line switch, synchronize the 10 second LED with a 10 second interval of universal time (UT). UT is displayed on the GPS

receiver on top of the HTRP instrument rack. UT is also displayed near the base of the videoconverter rack.

6. Using the programs `ht` and `view` on the Compaq 386, adjust the detector bias voltage offset until all detector voltage levels displayed with `view` are within ± 2.5 volts (the closer to zero volts, the better). This step is necessary because the operating range of the timing system A/D is ± 2.5 volts.
7. Two 64-pin ribbon cables are connected to the HTRP detector module and the HTRP Interface Module. Disconnect the cable in the connector labelled RR-LL at the back of the detector module.
8. Take the 64-pin ribbon cable from the timing system, and connect it to the RR-LL connector. Be sure the arrowheads at pin 1 on the cable and connector are aligned.
9. Remove the cover of the Dell 286 computer (the timing system hardware causes the enclosure to overheat). Turn on the Dell 286 computer, and insure that the computer date and time are the the same as the UT date and time. Typing `date` at the keyboard displays the current computer date. The command also allows the user to modify the date. The command `time` displays the computer time, and allows the user to change the time.
10. Execute the timing system software. The details of the timing system software are discussed in the Princeton Timing System User's Guide [3].
11. When the timing experiment is complete, turn off all equipment and restore the 64-pin ribbon cables to their original locations.

5 Array Operations

5.1 Interacting with the Array Operator

The nature of phased array HTRP observing is highly hardware interactive. This interaction goes on with the VLA via the telescope operator in addition to the HTRP itself. The array phasing process is not automatic, and the telescope operator will expect the observer to determine if array phasing is good enough during the 'phase-up' observation. When the array is pointed towards a source of interest, the array will eventually dephase, and it is the observer who must determine when it is time to rephase the array.

Most phased array observations will require a reference antenna, noise tubes turned off, and noise tube switching turned off. These items are accounted for in what is called a subreflector file. The subreflector file is created by the telescope operator by modifying an existing system subreflector file. Since the

subreflector position depends upon observing band, a subreflector file must be produced for every observing band included in the observation. The observer forwards the subreflector file information to the telescope operator in the special instructions section of the observe file. The observer must also identify in the observe file the name of the subreflector file to be used for each source. It is generally a good idea to verify that the operator has created the subreflector file before the observation begins.

5.2 Phasing the Array

The process of phasing the array forces all antenna phases to that of a reference antenna so that the individual antenna signals add coherently in the analog sum. The array is phased by computing the phase of each antenna, calculating the difference in phase from the reference antenna, and inserting the calculated phase offset into the local oscillator which converts the front end output to IF [1]. The phasing process is executed every VLA correlator integration time (10 or 30 seconds) when the correlator is in autophasing mode (VA). The 10 second integration time is usually preferred because the array phases much faster with shorter integration times. Only the A (RCP) and D (LCP) IF's are phased by the fringe generators [1]. The B and C IF's are "slaved" to A and D. Consequently, A and D IF's will phase sooner than B and C IF's.

The timescale for dephasing of the array depends upon array configuration, observing frequency, and atmospheric conditions. Observing experience has shown that one can conservatively expect to lose about 10° rms in antenna phase difference over 30 minutes of 21-cm observing in A-array with good observing conditions. The 10° rms in phase difference corresponds to a loss of about 2% in gain as shown by Figure 7 [7], which displays array gain as a function of rms phase for N antennas in the array. Smaller array configurations and lower frequencies give longer phase stability timescales. Keep in mind that lower frequencies are more susceptible to RFI and ionospheric Faraday rotation. Figure 7 also shows that the array gain is essentially optimal for rms phase differences less than 5° . A consequence of this is an observer is better off proceeding with the observing program than spending an additional five minutes trying to get a half degree reduction in phase rms.

An observer can witness the phasing process by looking at the **f** display on a MODCOMP monitor terminal. The display shows the phase difference between the reference antenna and every other array antenna in addition to the rms in phase difference for each IF. The objective is to phase the array until all phase offsets and rms phases are approximately zero. To invoke the **f** display, type an **f** at the MODCOMP dollar sign (\$) prompt. Useful commands in the **f** display are **p** for display phases, **a** for display amplitudes, **s** for scroll toggle, and **e** for exit. Displaying amplitudes verifies that the calibrator is in the telescope beam. Amplitudes are typically ≥ 0.1 .

Another useful array monitoring program is **aoi** (array operations interface).

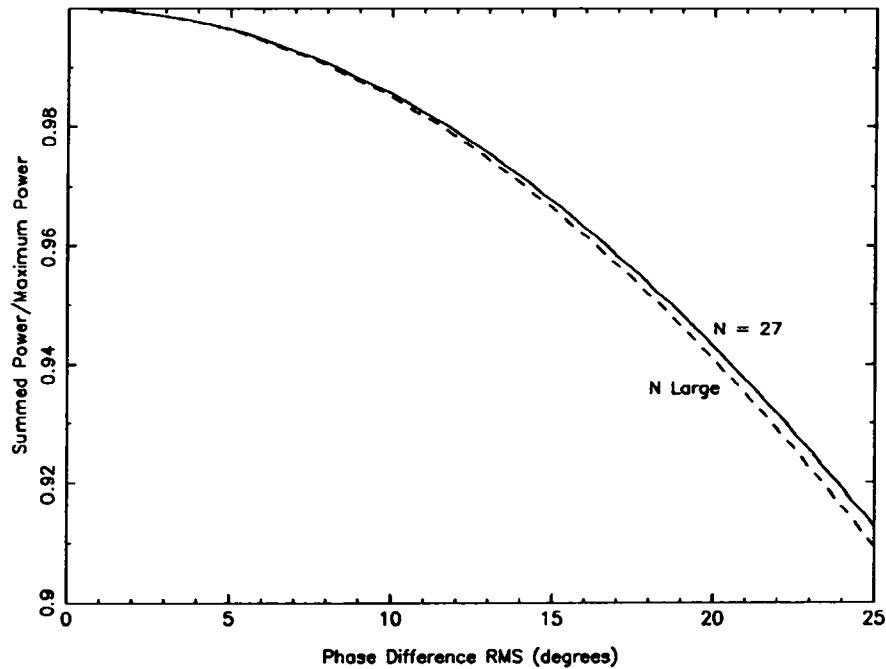


Figure 7: Degradation of phased array gain as a function of rms in antenna pair phase difference. N is the number of antennas in the array.

To invoke `aoi`, type `aoi` at the `$` prompt, followed by two carriage returns. The user can monitor just about anything with `aoi` by selecting a topic with a carriage return. Useful displays are `VL` for VLA, `SM` for subarray monitor, `BB` for baseband, and `ANASUM` for analog sum. To exit any one of the displays, press carriage return. To exit `aoi`, type control `c`.

The monitor terminals have a screen saving feature which makes them appear to be turned off. To get the attention of the monitor computer (`MONTY`), type control `a`, and the prompt `MONTY>` will appear. Next, type `run bat`, and the `$` prompt will appear, allowing you to run `f` or `aoi`.

6 Trouble-shooting

This section gives some ideas about what might be wrong when equipment doesn't perform as promised or expected. The listing which follows identifies in bold face type the most common problems encountered in phased array observing with the HTRP. The regular font text which follows the bold face type discusses possible causes of the problem.

1. **The message Failed to establish MC communications is displayed after the program ht is run.** (1) The VERO power supply is not turned on. (2) The HTRP power supplies were switched on in the improper order. (3) The RS-232 connector cable between the computer and the HTRP detector module is disconnected.
2. **The detector levels displayed by view are too low.** (1) Too much attenuation is in each IF at the MkIII videoconverters. (2) The 64-pin ribbon connectors are not connected to the HTRP detector module. (3) The analog sum outputs are not connected to the MkIII videoconverter inputs. (4) No power in the analog sum as shown by the power meters on the analog sum patch panel. Ask the array operator to send a 'command word' to the array by temporarily taking a single antenna out of the array.
3. **The detector levels displayed by view are too large.** (1) Not enough attenuation in each IF at the MkIII videoconverters. (2) The detectors have not been configured for integration times and bias offset. Run the computer program ht. (3) The cable which carries the data valid track and hold signal is not connected to the HTRP detector module.
4. **The data acquisition program doesn't appear to write data to the computer disk.** (1) The frequency synthesizer is not turned on. (2) The frequency synthesizer power output level is too low. Increase the output power with the dial on the front of the synthesizer. (3) The output of the frequency synthesizer is not connected to the HTRP computer A/D trigger.
5. **The array doesn't phase.** (1) The phase calibrator has extended structure; therefore, there is no phase solution. Use a different calibrator. (2) The reference antenna has hardware problems. Evidence for this is all antennas except the reference have bad phase solutions. Change reference antennas, and remove the old reference antenna from the analog sum. (3) Radio interference. Since interference is highly localized, it is usually seen as phase jumps in data from antennas which occupy similar array locations. Interference can usually be seen on the spectrum analyzer in the electronics room (4) The Sun or a planet is in the beam sidelobe.
6. **An antenna has a phase of about $\pm 180^\circ$.** The antenna is not on source. Have the array operator 'bump' the antenna by driving it off, then back on, source.
7. **The program trigger doesn't appear to work in gated sampling data acquisition.** (1) The external trigger is not turned on. (2) The program is hung on the external trigger logic. Reboot the Compaq 386/20 with ctrl-alt-del.

7 Improvements

As the HTRP has evolved, users have identified features they would like to see incorporated into the system. There are also deficiencies in both hardware and software which need to be corrected. Despite the deficiencies, the HTRP is a working system which produces reliable results when properly used. These features and deficiencies are listed in this section to make users aware of system shortcomings.

1. Low frequency observations of pulsars are limited by dispersion smearing. Narrow band filters ($\Delta\nu \leq 1\text{MHz}$) are needed in the MkIII videoconverters.
2. The sampling interval of the continuous sampling data acquisition programs is limited by the software overhead associated with disk writes. The A/D hardware is capable of 10 us sampling, but software limits the sampling interval to 40 us. The time required to write the data to disk is longer than 10 us, resulting in missed samples between disk writes. The existing C code needs to be optimized to take advantage of the hardware's full capability or the code should be written in assembly language. This problem does not exist with gated sampling because the time available for a disk write is comparable with the pulsar period.
3. A new user interface should be incorporated into the data acquisition programs. Since the data acquisition programs are designed to minimize CPU loading during data acquisition, the current interface is not very 'user friendly'. The new interface should, for example, monitor data acquisition progress, automatically name data files and insert data file headers, and monitor available disk space.
4. When the MkIII Hewlett-Packard computer is retired, the HTRP computer can be used to configure the MkIII videoconverters. The communications software exists for this task in the programs `comport.c` and `control.c`, but the programs have not been rigorously tested. Some code optimization may need to be done.
5. The program `loset.c` calculates incorrect sky frequencies for X-band observations.
6. A command should be included in the program `ht` to adjust the output of each HTRP detector to zero volts by inserting the appropriate bias offset. The motivation for this feature is the ± 2.5 volt range of the pulsar timing A/D converter. Since videoconverter and detector circuit gains vary, a global bias offset inserted into all detectors causes some detector voltages to be outside the range of the A/D. `ht` has the capability to sample data, so it can potentially custom-configure each A/D channel.

7. A circuit should be built to simplify the synchronization of the pulsar timing 10 second tick with UT.
8. The analog sum D-IF baseband rolls off by about 3 dB more than the A-IF baseband. The D-IF baseband should be improved for dynamic range considerations.
9. The MkIII videoconverters have different gains. These gains should be equalized for dynamic range considerations.

8 Revisions

Any signal processing system will evolve as more demands are placed upon it. The revisions to HTRP software and hardware and the revisions to this document are listed in this section to keep HTRP users informed of HTRP evolution. Although the specific details of the revisions will not be discussed here, the date and a brief summary of the revision will be presented to provide an audit trail if future problems arise. Software revisions are listed under specific computer program names.

8.1 Documentation Revisions

- Ver 0.0 November 20, 1991. Original version of the HTRP Operations Guide.

8.2 Software Revisions

8.2.1 `collect.c`

A data acquisition program which continuously samples the HTRP detector outputs. The user can specify the sampling interval, the amount of data to collect, and the output data file name. The amount of data collected is specified in blocks (1024 samples or 2048 bytes). Data is collected in a circular buffer, and written to disk every 16384 samples (32768 bytes).

- Ver. 1.0 March 15, 1991. Installed provision for 1 or 5 MHz A/D source.
- Ver. 0.5 January 28, 1991. Converted to 1 MHz source. Input into back of HTRP interface module on connector C10 at pin 6. Pin 6 is connected to LabMaster SRC5.
- Ver. 0.1 August 9, 1990. Added the integer variable 'start' to allow software control over the first channel sampled.
- Ver. 0.0 June 28, 1989.

8.2.2 sth.c

A modification to the program `collect` which generates a sample-and-hold signal for the HTRP. `sth` uses the LabMaster AMD9513 counter 4 to generate a signal which notifies the HTRP that all channels have been sampled. This provision insures that all channel samples represent the same instant in time. Otherwise, the channels are sampled at different times because the A/D samples the channels consecutively.

- Ver. 2.5 March 15, 1991. Revised for external frequency reference at pin 6 on connector C10. Reference can be 1 or 5 MHz. Pin 6 is connected to LabMaster SRC5.
- Ver. 2.0 October 9, 1990. Counter 4 of the LabMaster AMD9513A Timer/Counter counts the rising edge of SRC3. OUT4 is ANDed with stretched START A/D.
- Ver. 1.5 August 13, 1990. Added the integer start to allow software control over the first channel sampled. Made counter 4 count on falling edge of END A/D which is initiated by SRC3. Counter 4 no longer gets input from counter 3. Renamed the program `sth.c`.
- Ver. 1.0 Implemented sample-and-hold into `collect.c`. Designated new program as `ct4.5mhz.c`.

8.2.3 ae77.c

`ae77` is the same as `sth`, except `ae77` skips 'writbuf' data buffers before an actual write-to-disk. `ae77` also performs a bit-stuffing operation where the top four bits of each data sample are thrown away. Therefore, data written to disk is 12-bit instead of 16-bit. The program was designed to reduce hard disk storage space requirements by 25%. The sign bit is lost in the bit-stuffing, so this program is only good for total intensity observations.

- Ver 0.0 May 9, 1991. Created `ae77.c` as Ver. 3.0 of `sth.c`.

8.2.4 trigger.c

A data acquisition program which uses an externally generated gate edge to trigger data collection on a pulsar pulse. The gate must be synchronous and in phase with the pulsar. The advantage provided by `trigger` is only on-pulse data is sampled, resulting in about a 90% savings in data storage requirements (assuming the pulsar duty cycle is 10%).

- Ver 2.0 January 28, 1991. Switched order of checking status bit in the function `run()`. Counter 2 status is now checked before counter 3 status. Ver. 1.0 checked counter 3 before 2. Added provision for external frequency reference of 1 MHz at pin 6 of connector C10.

- Ver. 1.0 January 3, 1991. Added second frequency source to allow for wider pulse widths. Changed master mode frequency source division control from binary to BCD, so $F1 = 1$ MHz and $F2 = 100$ kHz.
- Ver. 0.0 September 13, 1990.

8.2.5 `ht.c`

The HTRP monitor and control program. Allows the user to configure integration times and bias offsets. Monitors HTRP power supply voltages with a VLBA standard interface board via RS-232/RS-485. Can also take HTRP data with software controlled A/D conversions.

- Ver. 1.7 July 9, 1990. Converted to TurboC 2.0. Abandoned DMA A/D and programmed for software start conversion. Samples 64 channels and displays them. Renamed `ht.c` for brevity.
- Ver. 1.6 June 27, 1990. Had to change the conversion constant in the function `show()` from 204.8 to 409.6 because the hardware gain was changed from 10V dipolar to 5V dipolar.
- Ver. 1.5 April 14, 1990. Added the functions `high()`, `low()`, and `show()` for monitoring multichannel averages.
- Ver. 0.0 July 5, 1989. Original name was `htrptest.c`.

8.2.6 `view.c`

This program is designed to be used for establishing HTRP operating levels. It displays a histogram of 14 columns by 4 rows of data sampled from the HTRP. The 4 rows are RR, LL, RL, and LR. A red horizontal line appears at the top of a histogram bar if a detector approaches saturation.

- Ver. 0.0 July 9, 1990.

8.2.7 `loset.c`

Allows one to compute sky frequencies for given MkIII videoconverter local oscillator settings. Additional inputs needed are VLA baseband bandwidth, videoconverter bandwidth, and VLA center sky frequency. All inputs are in units of MHz.

- Ver. 0.0 August 10, 1990.

8.2.8 `comport.c`

Library of functions which provides support for VLBA standard interface board (monitor control card) via direct COM1 or COM2 port access. Functions are RS-232 specific, and can service other communication protocols (namely MkIII videoconverters). An interrupt service routine receives the incoming data.

- Ver. 1.5 March 23, 1990. Added reset line status register in `Initialize()` to avoid invoking `kermit`.
- Ver. 1.0 May 19, 1989. Added `Print_Message()` and `MkIII_Install()`.
- Ver. 0.0 April 3, 1989.

8.2.9 `control.c`

Configures each videoconverter of the MkIII for local oscillator setting and bandwidth by computer control.

- Ver. 1.0 August 31, 1990. Converted to TurboC 2.0 and changed RS-232 port to COM2.
- Ver. 0.0 August 10, 1990.

8.3 Hardware

- November 1, 1991. The cables at the videoconverter outputs are rearranged such that cables with the suffix label 'A' are connected to the LSB outputs and cables with the suffix label 'B' are connected to USB outputs. Before November 1, 'A' was on USB and 'B' was on LSB. The rearrangement causes the channel ordering in frequency to be more intuitive.
- August 13, 1990. The output of counter 4 and END A/D are wired to an AND gate to produce the sample-and-hold used by the HTRP.
- June 27, 1990. The LabMaster hardware gain is changed from 10 volt dipolar to 5 volt dipolar.

Acknowledgements

Special thanks to P. Hicks for providing Figure 6.

References

- [1] Thompson, A. R., 1975, *Module L7, Fringe Generator*, VLA Technical Report #6.

- [2] Horton, E. R., 1987, *Sigav User's Manual*
- [3] Thorsett, S. E., 1990, *Princeton Timing System User's Guide*.
- [4] McKinnon, M. M., 1990, *Determination of MkIII Videoconverter Sky Frequency*, HTRP Memo. #110.
- [5] McKinnon, M. M., 1991, *Gated Sampling of the HTRP*, HTRP Memo. #111.
- [6] McKinnon, M. M., 1991b, *Instrumental Origin of a 180 Degree Phase Shift in Polarization Data*, Astron. and Astrophys., in prep.
- [7] McKinnon, M. M., 1991a, *Point Source Polarization Calibration of a Phased Array*, Astron. and Astrophys., submitted October 12.

Channel Number	VC Sideband	Signal	Cable Number
0	-	Spare	-
1	-	Spare	-
2	-	Spare	-
3	-	Spare	-
4	-	Spare	-
5	-	Spare	-
6	-	Spare	-
7	13&14 USB	RLSIN	13&14B
8	13&14 USB	RLCOS	13&14B
9	13&14 LSB	RLSIN	13&14A
10	13&14 LSB	RLCOS	13&14A
11	11&12 USB	RLSIN	11&12B
12	11&12 USB	RLCOS	11&12B
13	11&12 LSB	RLSIN	11&12A
14	11&12 LSB	RLCOS	11&12A
15	9&10 USB	RLSIN	9&10B
16	9&10 USB	RLCOS	9&10B
17	9&10 LSB	RLSIN	9&10A
18	9&10 LSB	RLCOS	9&10A
19	7&8 USB	RLSIN	7&8B
20	7&8 USB	RLCOS	7&8B
21	7&8 LSB	RLSIN	7&8A
22	7&8 LSB	RLCOS	7&8A
23	5&6 USB	RLSIN	5&6B
24	5&6 USB	RLCOS	5&6B
25	5&6 LSB	RLSIN	5&6A
26	5&6 LSB	RLCOS	5&6A
27	3&4 USB	RLSIN	3&4B
28	3&4 USB	RLCOS	3&4B
29	3&4 LSB	RLSIN	3&4A
30	3&4 LSB	RLCOS	3&4A

Table 5: Lower 32 A/D channels of the HTRP

Channel Number	VC Sideband	Signal	Cable Number
31	1&2 USB	RLSIN	1&2B
32	1&2 USB	RLCOS	1&2B
33	1&2 LSB	RLSIN	1&2A
34	1&2 LSB	RLCOS	1&2A
35	13 USB	RR	13B
36	14 USB	LL	14B
37	13 LSB	RR	13A
38	14 LSB	LL	14A
39	11 USB	RR	11B
40	12 USB	LL	12B
41	11 LSB	RR	11A
42	12 LSB	LL	12A
43	9 USB	RR	9B
44	10 USB	LL	10B
45	9 LSB	RR	9A
46	10 LSB	LL	10A
47	7 USB	RR	7B
48	8 USB	LL	8B
49	7 LSB	RR	7A
50	8 LSB	LL	8A
51	5 USB	RR	5B
52	6 USB	LL	6B
53	5 LSB	RR	5A
54	6 LSB	LL	6A
55	3 USB	RR	3B
56	4 USB	LL	4B
57	3 LSB	RR	3A
58	4 LSB	LL	4A
59	1 USB	RR	1B
60	2 USB	LL	2B
61	1 LSB	RR	1A
62	2 LSB	LL	2A
63	-	DV	-

Table 6: Upper 32 A/D channels of the HTRP