MMA Memo #258

OPERATING THE VERY LARGE ARRAY, THE VERY LONG BASELINE ARRAY, AND THE MILLIMETER ARRAY: A COMPARATIVE STUDY

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NRAO/NM
1999MAR26

Abstract

The operation of a radio telescope is, unfortunately, not rocket science. Operating requires that the majority of the decisions made must be based on common sense, which, as Will Rogers pointed out, is not really very common. Most aspects of what is termed 'operations' cannot be defined by an equation, nor be chiseled in stone. Equipment operation requires a solid understanding of "How things should work" along with a successful merging of the "What the hell do I do now?" principles. Decisions must be made often times without much forethought, and trying to do the same thing the same way in two different, yet similar situations is not always successful nor appropriate. This emphasizes the fact that both the principles governing operator actions and the tools used by the operators to control the instrument must not be structured to the degree required by disciplines such as rocket science, or even radio astronomy. Having had the opportunity over the past thirteen years to be both an Array Operator of the Very Large Array and the Chief Operator of the Very Long Baseline Array, and because during that time I have become quite familiar with the inner workings of both instruments, I have decided to record a few notes concerning the general structure of the Millimeter Array command and control system that should be thought about during the construction phase. I will also outline several areas where current and past mistakes can be avoided in the evolution of the Millimeter Array monitoring and control system and the operation of the instrument.

I. Introduction

For the purpose of this paper I will define what is meant by the term "observing system." In the control of a telescope enough information must be collected from various sources to point the telescope at an object and set up the equipment in the desired configuration. It is that point in the operation where all of the required data for an observation to be conducted comes together that I consider to be the beginning of the observing system. How the data is received from the observer, and through what mechanism it is prepared for presentation to the system is not, in my opinion, part of the observing system proper (with the exception of the task which is required to get the observing information into the system, be it read from a standard observing file or extracted from a formal database system). Likewise, I do not consider any real-time imaging system to be part of the observing system. If a Cray supercomputer is required to produce real-time images of MMA sources then so be it, but I doubt that the same computer will be used to control the array, nor should it be.

A. An overview of the VLA and VLBA observing systems

The following sections are not completely accurate. Several details have been left out and some processes have been restructured to make the information more readable. But, in essence, they are correct.

Both the VLA and the VLBA observing systems use ASCII text file lists of sources and observing parameters for control of the telescopes. These files are known as "observing files." The internal processing of observing files within the observing systems of both instruments, while both performing the same basic function – to control the telescopes and set up equipment in accordance with the observer's wishes – accomplish their tasks in quite different ways.

The VLA observing files start out as multi-line, column-formatted text files. These files are generated usually by the observer or data analysts and are authored using the program OBSERV. The observation of a source begins with a source card. In the beginning the observing files were fed into the control computers using Hollerith cards, hence, each line in an observing file is referred to as some type of card. This line contains such items as the source name, the RA and Dec of the object, the amount of time to be spent on the source (the actual end time in Local Sidereal Time or the amount of hours/mins/secs), and the observing frequency/wavelength band to be used. If the default sky frequency and correlator settings for a particular observation are desired then a source card may be followed by another source card specifying the parameters for the observation of the next object. However, if the observer wishes to observe, for example, a fast-moving body (comet, planet, etc.), at an alternate sky frequency, and in a correlator line versus continuum mode then these details must be supplied to the observing system using modifier cards that specify the non-default parameters. Modifier cards follow the source card with which they are associated. In the example above the cards that would follow the source card would be a PM (proper motion) card, an LO (local oscillator) card and an IF (intermediate frequency) card to control the sky frequency, and a DS (data select) card to control the correlator mode.

[See the sample VLA observing file at the end]

The observing file is copied to an area named OBS on the Modcomp computer that controls the array named BOSS. The file name of the observing file is edited into a list of other observing file names in a system text file named SUB1 by the Array Operator. For this example we will assume that it is time for a currently running observing project to end (the end time has been reached for the last source in the observing file). A software task that runs at the beginning of each source change, NEWD, running on the array control computer BOSS, determines that the current project has ended and that it is time to start the next observing file. NEWD examines the list of observing file names in the system file SUB1 and reads the next observing file name. This disk file corresponding to this observing file is then opened and read until the first source card is reached, as most observing files have several comment cards at the beginning. The system then looks to see if there are any additional modifier cards following the source card. If there are, then the default commands that are prepared to be sent to the antennas and control building equipment are altered accordingly. Next, all of the antenna position commands and all of the equipment configuration commands are issued to the antennas and the control building equipment. Once the antennas are on source the observation begins.

The observing system for the VLBA is a bit more complicated because of the geographically distributed nature of the instrument. Like the VLA the VLBA antennas are controlled by a list of sources and commands contained in what is called an observing file. These files are prepared either by the observer or by the data analysts for the observer. Depending on the needs of the project they can be quite large. They are not column formatted like the VLA files, but are instead free form.

VLBA observing files are divided into scans. Each scan performs the same function as a source card (and any additional modifier cards) in the VLA observing file. All control items in the observing files are of the general form: $< commandtag > = < parameters >$. For example "sname=3c84" informs the system that the source name of the item to be observed is "3c84". "tape=(2,+run)" command would inform the system to start the tape recorder drive number 2 in the forward direction. Commands in the observing files are remembered from one scan to the next. If the first scan sets the equipment for a specific observing frequency then scans that follow are not required to have commands that do the same thing. A previous set of commands are carried forward to the next scan. Only those parameters altered by a new scan change.

Once an observation has been scheduled, the required observing files are produced and are then copied to the directory named OBS on the array control computer Jansky. There is usually one observing file for each antenna that will participate in the observing run. Prior to the observation the files are copied out to the station computers at each of the antennas. The station computers monitor and control all of the equipment at each of the antenna sites. The copying of the observing files is accomplished by the Array Operator using a program that transmits commands from Jansky to the station computers through a TCP/IP socket connection. This program is also used to send commands for general array control and for the initiation of various antenna equipment tests. After acknowledging the file copy command, the station computers copy the designated observing file to the station computer hard disk using an NFS type of copy. Once the files have been copied to the station computers, the operator edits a text file on Jansky named OBSERV.TX. This file performs a similar function to the SUB1 file at the VLA. The name of the observing file to be used for the upcoming project is edited into the file along with the Universal Time (UT) time range when that file will be active and a list of antennas that are involved in the observation. This file is then copied out to all of the station computers in the same manner as the observing files. The observing system running on the station computers examines OBSERV.TX approximately once per minute to look for changes in the file. At the appropriate time listed in OBSERV.TX (assuming the antenna was not observing) the observing system 'comes to life' and begins processing the source scan commands in the designated observing file. Once this happens the operator commands the antenna(s) to point and the observing run begins.

[See the sample VLBA observing file at the end]

B. Defaults

With only a few exceptions, both the VLA and VLBA observing files are capable of controlling nearly all aspects of the two instruments. This gives an observer a wide range of control and allows very non-standard observations to be conducted usually for the sake of testing. Even though this control is provided, most observers only require their observations to be conducted using the standard or default equipment parameters.

Most of the default parameters for the VLA are contained in a collection of ASCII text files that reside in the OBS directory on the Modcomp array control computers. These files specify such things as the default focus and rotation settings for each observing wavelength/frequency band and the equipment frequencies to be used in obtaining the default sky frequency for each observing band. Other text files contain additional equipment parameters such as the baseline positions of each antenna (X, Y, Z), the antenna pointing equation coefficients, the peculiar equipment delays (transmission delay) for each IF channel, the total delay for each antenna (based on its position along the arm), and each antenna's array pad location (AE1, DW6, etc.). Having these default values on-line for regular, non-test observing, frees the observer from having to worry about placing the correct values into the observing file. These files are read at each source change so any changes to the information in the files are picked up by the observing system at the next source change. The operator can cause the observing system to restart the current source observation and thus begin using the updated values whenever necessary.

Default observing parameters are handled in a different manner on the VLBA. When items such as pointing parameters and focus/rotation settings are determined, the new values are entered into one of several data input screens on the individual station computers. An updated binary file is then written onto the local hard disk. This binary file also contains various parameters for controlling the tape recorders and items such as the antenna's location (Lat., Long.). While this information is only used by the station computers when they are rebooted, it is also sent down in the monitor data to Jansky and is archived each time it is updated. Some parameter changes take effect right away, some take effect at the beginning of the next scan, and some require a reboot of the station computer. None of the other types of information required to make a standard observation using the default or standard sky frequencies and equipment setups is contained in the binary parameter files. This data is supplied to the system only through the observing files that are loaded when an observation is started. The default settings are usually supplied via the various setup files to Craig Walkers SCHED program which is the normal means by which observing files are created for the VLBA. These setup files and their contents are completely external to the antenna observing system.

C. Monitor Data

The data from the antennas and the control building equipment used to determine the status of the equipment and the observation is collectively known as "monitor data" for both instruments. While the manner in which this data is generated, collected, massaged and displayed is quite different between the two instruments, the end use for the data is generally the same. The monitor data is used by the operators to monitor the condition of equipment and to provide feedback in response to issued commands. Since the correlation of the VLBA astronomical data does not occur in real time, the monitor data is used by the correlator to reconstruct the status of the equipment at the time the observations were conducted. Monitoring of the equipment by the operators of both instruments is accomplished by systems which allow for both a general overview mode of monitoring, and a low level and more detailed mode of monitoring. All of the data shown on the operator displays at the VLA is obtained from the monitor data. Most of the data shown by the operator displays for the VLBA is taken from the monitor data. The VLBA operators can also access displays that show more details about the condition of equipment by running programs directly on the antenna station computers.

Monitor data for the VLA antennas and control building equipment is collected by modules called data sets. Each data set is responsible for collecting the data from one logical group of equipment. This means that there is one data set that monitors all of the equipment associated with the focus and rotation unit, one for the front-end receiver equipment, and so on. All of the monitor points are sampled and the data sent to the control building via the waveguide every 50ms. These data sets also handle the distribution of commands to their respective groups of equipment. The monitor data coming from the four data sets at each antenna, each monitoring about 50 monitor points, is collected by the Modcomp array control computer MONTY and placed into an area of memory called "global common." Any task executing on the array control computers and requiring access to the monitor data can obtain it from this area.

The VLA operators use the system of programs named the Array Operator's Interface (AOI) to both monitor and control the array. This program provides individual screens, called overlays which: display groups of related data for individual antennas, such as all of the positions and voltages associated with the subreflector subsystem of a specific antenna; show the general condition of all of the antennas (the VL overlay which shows the current source, the stop time of the current source scan, and the weather); and which show selected equipment parameters for all 27 antennas at the same time. AOI is one of the tasks that accesses the monitor data collected in the global common area. AOI looks at the data required to fill in or update a requested overlay and performs the necessary conversions.

Another task on the Modcomp computers is the CHECKER task. This task scans through the monitor data in the global common area and checks various points to see if their values are in range, if equipment is out of position, or if the antenna is off source. When a condition is found that is not allowed, a message is generated and displayed on a monitor in the control room. When the error condition clears the message is removed from the display by the task.

Monitor data for the VLBA, like most aspects of the instrument, is affected by the geographic nature of the instrument. All of the equipment in each VLBA antenna is monitored by that antenna's station computer. This is accomplished by three different tasks.

The first task, LOGGER, reads a list that tells it which monitor points in the equipment to look at and how often to look at them. There is a set of monitor points that are examined when the antenna is idle and a different set that is examined when the observing system is active. The two lists can be altered, but not easily, as they are part of the observing system software and must be compiled into an object module and then copied to the station computers and loaded with a reboot. Alternate lists can be compiled and loaded into the software on the station computers and then selected by name from the observing files. The observing file command is "logging = $< name >$". This is used for special tests of the antenna equipment. Logging periodicity can range from once a second to once a day. Once LOGGER has collected a package of data it is combined with a header of information and sent to Jansky as a record of monitor data.

The second task, CHECKER, runs once every two seconds and queries most of the equipment in the antenna and control building looking for the same types of out of range and out of specification conditions as the CHECKER task at the VLA. When a condition is found, or when a previously existing condition clears, the text of the message and the value of the monitored point associated with the condition are combined with a header of information and is sent to Jansky.

The third task, FLAGER, runs once each second. It performs nearly the same function as the CHECKER task, except that it only checks for several specific conditions that could be detrimental to the condition of the astronomical data. Some of these conditions are the antenna being off source, the subreflector not being in the correct position and various frequency synthesizers in the LO chain being out of lock. When conditions are found or when they clear, a set of flag bits are assembled, combined with a header of information and sent down as a record of monitor data. FLAGER records are used extensively by the Socorro correlator software in the determination of whether data recorded on the data tapes is good of bad.

Under normal circumstances the VLBA is almost exclusively monitored through its monitor data. The station computers monitor their respective antennas and generate approximately 1-3MB of data each day. This data is sent over the Internet through socket connections by each of the station computers to Jansky in a more or less continuous stream. A program running on Jansky, NETMON, collects the incoming data and places the data from each antenna into separate files, one for each UT day. This data is archived. Once a day selected portions are read into an Ingres database, and this data, combined with data from several other sources, is used to generate the job scripts to recreate an observing run for the Socorro correlator. For array monitoring, the program VLGET, running on Jansky, reads in real-time the monitor data files written by NETMON. VLGET creates and maintains a global common of shared memory in Jansky. This global common contains all of the current observing information such as the source being observed, receiver cryogenics temperatures and pressures, astronomical signal power levels for Tsys calculations, and various other antenna and control building parameters. The VLGET program also maintains a list of the current checker messages and creates a running log of all of the events occurring on the array. There is only one copy of VLGET running on Jansky. It is started when Jansky is booted after NETMON is started. Running in concert with VLGET is the program VLDIS. VLDIS handles the display of all of the data collected and massaged by VLGET. This program is used by the operators and any other curious individuals to see what is happening on the VLBA. There can be any number of copies of VLDIS running (generally one per person), but because the program is linked to VLGET through the use of shared memory all copies of the program must be run from user accounts on Jansky.

While the VLGET/VLDIS programs provide a near real-time view of the general interest items, instantaneous and much more detailed information can be obtained by connecting to the station computers (through sockets) and running a suite of tasks collectively known as the Screens Package. This package uses a character-based windowing system which allows monitoring and control of all of the various voltages and positions associated with the antenna and control building equipment. This package runs directly on the station computers and sends its data back in a VT100 compatible format.

Now that we have a general overview of the two observing systems we will begin to look at the strengths and weaknesses of the two with respect to operation of the MMA.

II. Antennas

We will start at the beginning, the antennas, and work our way back into the control room, and then beyond.

If we view a VLBA antenna and station computer combination as a complete unit, we can describe it as being a smart antenna. A VLBA antenna is designed to be loaded with a list of sources to be observed and then turned loose. The station computer handles all aspects of the control and monitoring of the antenna. If the weather should deteriorate, or power interruptions occur, the antenna and all associated equipment will take care of itself without any commanding from the Array Operations Center. Generally speaking, there is no central control of the antennas during observing projects, only central command and monitoring. A VLA antenna on the other hand cannot move (for observing purposes) without the Modcomp array control computers located in the control building. The pointing information (in the form of motor current commands) for each antenna is updated 20 times per second and all equipment positioning or control commands are sent by the Modcomp computers. In addition, with respect to equipment monitoring, an antenna generally only sends back numbers. If the cryogenics system of a receiver is unexpectedly warming, the antenna merely reports the temperature. It is up to the monitoring software in the control building computers to identify the rising temperature as a possible problem.

One of the basic questions concerning the control and monitoring of the MMA is whether to make smart antennas like the VLBA, or not-so-smart antennas like the VLA. Having one computer to monitor and control the MMA makes everyone's life much easier if there is an unlimited amount of computing power and a completely reliable communication infrastructure with no bottlenecks. But the critical timing nature of the antenna positioning commands (not the initial 'let's go there' commands, but the tracking commands) and the amount of mathematical computations that go into the positioning commands restricts the amount of activity on that one computer while the array is observing. This was the case during the Voyager spacecraft observation sessions at the VLA. People were encouraged to not touch anything connected with the Modcomp computers for fear of distracting the computers and causing a glitch in the data, or even causing the Modcomp computers to crash. It would also require a real-time operating system running on the array control computer. Currently there are no real-time systems that are user friendly or widely supported outside engineering circles. The Modcomp operating system is a good example. VxWorks is another.

Another problem is the timing of the pointing information. If the pointing commands between the controlling computer and the Antenna Control Units (ACUs) are not sent at the correct time, or if there are brief interruptions, the pointing will be off. However, if the pointing commands (just the RA and Dec of the source) sent by a controlling computer to the antennas are late this would be acceptable since all of the antennas would still be doing the same thing (going to look at a source at the same time for example).

I would propose that smart antennas be built. Each antenna would have its own local computer similar to the VLBA antenna station computers. The antennas would be sent pointing and equipment setup commands by the central control computer (CCC) which the antenna control computers (ACCs) would then ensure were executed. The ACCs at each antenna would handle the required antenna azimuth and elevation calculations and then assume responsibility for the tracking. Alternate modes of control would be available for issuing corrected and uncorrected (for pointing) azimuth and elevation commands directly from the CCC for testing and maintenance needs. The computers of 2001 and the communication line between the MMA control building and the antennas would probably be able to handle the load of a centralized form of pointing control. However, making the antennas point themselves will allow more flexibility. With this scheme the central control computer could be placed in Socorro if there is a reliable communication line between Socorro and the array site in South America. This type of system would also keep the CCC from being intimately tied to the antenna hardware (and vice versa), which would make the whole system easier to upgrade. It would also leave the CCC free to perform other miracles.

While I have touched on the subject I would like to say that just because the computers of 2001 may be able to handle the operating requirements for the MMA, I am not convinced those systems will be purchased. NRAO tends to be conservative when it comes to computer systems for telescope operations. To this end I think it would be prudent to plan on a system capable of making do with a computing system a couple notches below the dream system we would like to have.

The MMA needs to be able to change sources quickly. The amount of time required to calculate and disseminate all of the data associated with a source change at both the VLA and the VLBA points out that the design of these systems is inadequate for a rapid switching mode of observing. The VLA observing system takes about ten seconds to complete a source change (not including antenna slew time). Although recently a faster switching mode has been implemented by cutting corners and doing something that could be described as a 'source change lite' which seems to work well. The VLBA system tried to deal with the problem of rapid source changes by loading about 60 observing file scans into the memory of the station computers ahead of time. This resulted in fairly fast switching times (on the order of a few seconds), but the pre-loading of scans precludes any interactive mode of control of the antennas. This system works by pre-calculating the effects of precession and proper motion based on the known times that each scan will be observed. In an interactive mode of observing this will not be possible since the length of each scan will be need to be variable. It is obvious that a division of labor between the CCC and the ACCs will aid in making the MMA more responsive both in terms of source changes and interactive control.

Positioning of the antennas during 'on the fly' observing can be handled in a much more reasonable manner by having a local control computer handle the pointing of the antenna. In this mode the antenna is commanded to scan across the area of a source which is several times the beamwidth of the antenna. As the antenna sweeps across the area the total power and the position of the antenna is recorded. The required recording rate of this data could be as high as once every 2msec. When the antenna has moved from one side of the object to the other the antenna drops down and conducts another scan across the source in the opposite direction. This back and forth motion continues until the desired amount of area on the sky has been scanned. With the antennas controlling themselves only the end points of each scan would need to be commanded by the CCC. In between those points only the position of the antenna (and the astronomical signal level) would need to be recorded as the antenna slews. This could be done by the ACC. If the antennas are fitted with their own control computer they could be given only the upper left and lower right corner points of the scan box, a step size distance between each scan line, and the command to go. Each antenna would then independently perform the scan and send the results for analysis by the real-time imaging system without further supervision.

In the area of monitor data the antennas would be more like the VLA antennas in that they would not diagnose the condition of their own systems. They would simply collect and send the monitor data to the CCC for analysis when requested. For example, when the CCC decides it is time to examine all of the cryogenic system temperatures, it would request the antennas to send that information, and a CHECKER-type task on the CCC would then scan the data for possible problems. Requiring the CCC to request information from the antennas is more like the VLBA antennas that only report information when the station computers ask them to. A non-synchronized mode where an antenna is told to send the data for a monitor point or points (usually at an accelerated rate) without having to request the data each time would also be required. This is often done for equipment testing and troubleshooting and would not be difficult to implement. Having the antennas not analyze the monitor data would allow the ACCs to be a bit smaller, saving in both hardware and software development costs. The amount of computing power required to look through a list of numbers by the CCC does not warrant making the control programs in the ACC any more complicated than necessary. The prospect of having to deal with VLBA-style station computer freeze-ups and crashes, multiplied by 36 antennas, in part because of more complex than necessary software, could be viewed as a potential reliability problem.

The exception to normal mode monitor data requesting by the CCC would be data indicating the gross general condition of the antenna and problems that could affect the quality of the astronomical data. The ACC would perform and report on the on- and off-source status of the antenna, the lock status of the LO chain synthesizers and, other equipment such as the position status of the subreflector. This information would be sent to the CCC as the status of the monitored equipment changed states. This function would be similar to the FLAGER task on the VLA control system and VLBA antennas. Information of this type is also used to control the correlator and the data flow from the correlator at the VLA and would likely be used for the same purposes in the MMA.

If the overall design of the MMA antennas is that of a smart antenna, care should be taken to make sure that the antenna control computers function as gateways for information and monitor data and not as bottlenecks as in the VLBA station computers. In the VLBA, if a program like the control room display system (VLDIS) wants to look at some obscure monitor data point such as the Maser Ion Pump Current, it cannot. That monitor data point is not regularly sent down in the monitor data and a request for that specific monitor point cannot be made on the fly even though the CHECKER task running on the station computer may generate messages about it being out of range. To look at the current value of this monitor point you must connect to the station computer and use the Screens Package displays. To have the point automatically logged by the observing system requires a modification of a C programming language structure which must then be compiled, copied to the station computer and loaded before the observing system starts an observation – very cumbersome. Even after the change is made it will not actually go into effect in a permanent way until the next online software update.

Making an antenna a little bit smarter than the average antenna would also make it easy for a laptop terminal to be used for local control and testing of equipment during maintenance and overhaul periods. In fact a laptop could probably be not just a data terminal, but a whole antenna control computer. It could be loaded up with something like the QNX Real-time Operating System and be quickly put into service.

Semi-smart antennas should be capable of booting themselves without a central server. This would allow them to run and/or come back online by themselves so equipment in the antenna could be monitored locally during reconfigurations or in the event that the CCC goes down or communication is lost for an extended period of time (especially if the CCC is not physically in South America). Another consideration for the software running on the antenna control computers would be to make the control system small enough to fit on to a memory card instead of requiring the antenna control computers to have a (failure prone) hard drive. Hard drives may also be difficult to keep running at the altitude of the site in Chile, and moving the antennas during reconfiguration could be detrimental to their health. In general, the fewer moving parts the better.

All normal tests should be able to be accomplished without the need of an observing file. In fact, a smart antenna could be commanded, for example, to do some pointing checks independent of the rest of the array and the central control computer. This would eliminate having to start up something (i.e. an observing file) to do pointing or other types of testing. The antenna could look at some sources, collect and analyze its own data and present the results to the operator for approval. The VLBA antennas are almost capable of doing this now in the form of an observing file directed scan. A pointing check is conducted and the computed pointing corrections are applied to the system for the scans that follow the pointing check. For more detailed pointing determinations, an observing file covering several hours worth of calibration source observation must be run. The resulting monitor data is analyzed after the run has been completed.

The system of equipment communication within the VLBA antennas with the RS-422/485 based serial transmission system (Monitor and Control Bus) and the standard interface cards has worked quite well. I would propose that the MMA equipment configuration be designed in much the same way. However, instead of using the same system as the VLBA, I would propose that the serial transmission system be based on the Universal Serial Bus (USB) standard if it doesn't cause any RFI problems. It is apparently easy to implement and it should be more than fast enough. Memory mapping all of the VLBA equipment in a 64k address space has also worked out quite well as a method of selecting the monitor and command points.

Subreflector design and control for the MMA needs to be better than the systems at the VLA and VLBA. With 36 antennas, and the weather conditions at the site in Chile, the system needs to be much more robust and weatherproof than either of the current designs. The VLA and VLBA subreflector systems freeze up too easily in bad weather. Though the MMA probably will not be observing during periods of bad weather, we will not want to spend time waiting for the subreflectors to thaw out after a storm. The smaller physical size of the antennas and the subreflector systems should make it easier to protect these systems from becoming inoperative in bad weather.

This raises a general observation on equipment reliability. Not problems that cause outright failures, but problems that fall into the category of "nagging little equipment problems." Most of the problems in this category crop up at source changes. A rapid source switching time of 10 seconds with 36 antennas creates 12,960 opportunities for a problem to develop per hour. This is not realistic, but it is probable if the issue of reliability is not actively monitored. Controlling 27 antennas in the winter at the VLA, and even 10 VLBA antennas (even when some of the antennas are not in winter weather), can be a lot of work, especially when rapid source changes are combined with frequency band changes requiring movements of the subreflector assemblies. Preventing 36 antennas from becoming an uncontrollable mess needs to be taken seriously.

How detailed a level of hardware control should we have? This question was once asked by Peter Napier when it seemed like the equipment at the VLBA antennas could not be monitored from the Array Operations Center down to a fine enough level. The MMA will have technicians available on site like the VLA. Troubleshooting a problem deeper than the subsystem of a module should not be required from the control room. However, if all of the project engineers are located 4,000 miles away this premise could be wrong. There was a small problem with the VLBA when it was realized that the site technicians had very little, if any, troubleshooting information at their disposal when looking directly at the VLBA equipment. There are very few status indicators and nearly everything must be read through computer display screens. This situation will need to be addressed when designing the MMA equipment given the altitude of the site and its affects on technician performance. Simpler and more easily obtained information in the form of status indicators may be prudent.

III. Communication

The intent of this section is to present a few ideas concerning the general flow of data between the antenna control computers and the central control computer for monitoring and command functions. The overall goal is to build a system that can handle anything, but that will not have to.

As far as the hardware is concerned, I stated in the previous section that the antennas should be wired using the Universal Serial Bus to allow the equipment to communicate with the antenna control computer. The antenna control computers should be connected to the central control computer using a fiber optic line running an Ethernet TCP/IP protocol at no less than 10Mbps (what else?). A faster network could be built, but communication between the VLBA antennas and the station computers operates on a communication system that runs at only 56kbps (which at times may actually not be fast enough), and the waveguide system at the VLA only transmits data on the order of hundreds of bits per second per antenna. Stability and reliability are more important than speed. Nothing is worse than having a buggy communication network. The fast communication system can be saved for the astronomical data. Off-loading the pointing control of the antenna on to the ACCs, instead of having a central control computer direct the pointing, is one (large) way of reducing the traffic on the array monitoring and control communication system.

On the software side one of the problems with the VLBA monitoring and control system (but less so with the VLA because of its all in one computer design) is that there is no clear division between the low level and high level portions of the system. Items such as hardware codes for the Baseband Converter (BBC) bandwidth settings, for example, have to be dealt with throughout the software whether it is the software module that commands the BBCs directly, or the application that picks the BBC bandwidth settings out of the monitor data long after an observing run is finished. For example, the code for a 2MHz bandwidth is 1108h, and for 16MHz it is F040h. These values must be looked up repeatedly. I would propose for the MMA that the only piece of software that knows how to decode or pass on hardware codes and other forms of bit fiddling codes like these should be the module drivers in the software running in the ACUs just before the USB drivers. This would allow the command messages and equipment responses to take on a much more manageable and human form. For example, the actual command string that could be sent to the antennas to set their BBC bandwidths to 4MHz (yes, I know, MMA antennas will not have BBCs) could literally be something like "BBC BW 4MHz". A request for the current bandwidth setting could literally be something like "BBC BW ?", with a response from the ACC being "BBC BW 4MHz". The actual hardware bandwidth code would, of course, be available with a command such as "BBC HWBWC ?".

This form of command structure would greatly simplify several areas of the software by allowing someone, or some computer, to issue commands like "ALL AZENCOFFSET ?" and receive a list of the azimuth encoder offsets for all of the antennas without the need for specialized display software or interpretation code. If the source position is not quite right, the RA could be corrected with something like "ALL RAOFFSET +45S" which would tweak the RA position 45 seconds to the left. This would all feed directly into the need for making the MMA more interactive than the VLA and VLBA. Reducing the amount of traffic on an adequate communication system by making the antennas smart would allow simple ASCII commands and messages to be passed back and forth between the systems and would eliminate large amounts of software that would be required to interpret all of the binary data such as is generated by the VLA and VLBA equipment. This scheme of software construction would also make construction and troubleshooting of the whole system much easier since we would be able to directly see what was going on. Problems would not be hidden in the binary and hex numbers. Control room monitoring and control software could be developed in a very short amount of time and in a practically unlimited number of 'looks and feels.' This form of array control could also lend itself well to allowing foreign control of the antennas and correlator for the purpose of collaborative observing. The foreign control computers (belonging to the Japanese perhaps?) would not be required to know things like BBC bandwidth hardware codes or binary encoded antenna position values. They would instead have to know things like "RA 22h45m56.7s DEC +06d34m23.7s" and "SYN 4.5GHZ". And commands could be further simplified by constructing macros like "SETUP STANDARD 6CM" which the antennas would interpret as a command to set up the antenna equipment for standard 6cm observing. (Yes, I know the MMA will not have 6cm receivers.)

I played with this form of command structure on the VLBA when I wrote the RCMD program which is the main command interface used by the VLBA Array Operators to control the array. The program on Jansky sends simple ASCII command strings to its counterpart daemon running on the station computers, which perform the requested actions (like commanding the antenna to point) and then echo back the commands as a simple check. RCMD was designed to allow any sort of graphical point and click interface to be built on top of it to allow the operators to control many aspects of the array with the array control computer mouse. No graphical interface was ever written.

In the interest of internationalization the use of Unicode character representation should be considered versus straight ASCII throughout the MMA software.

IV. The Central Control System

A. Equipment

This section will cover overall hardware issues for the central control system.

For the systems that will be used for array control purposes, purchase the fastest, largest, most powerful computing systems available without concern for cost, and equip them with the most advanced operating systems. This has never been done before. This should be done to preempt the development of systems that are forced to cut corners or make design compromises (a.k.a. "We'll add that feature later") and end up not satisfying basic operational needs of Version 1.0 of the instrument when the antennas are ready to be pointed. It is very difficult to figure out what you need when the system lacks the ability to do anything. The decision (requirement) to upgrade all of the basic control equipment along with the software during construction is not a pleasant event. Lack of control computing horsepower as well as a lack of fully functional control system software also makes testing the instrument during construction very difficult. If you do not have the time to do it right when will you find the time to do it over? When it is least convenient seems to be the answer.

Although it was not recognized until it was too late, an example of one way not to build the control system is the original plan for the VLBA control system. It was based around a Motorola MVM121 VME-1000 CPU board at each site running the Motorola VERSAdos operating system, and a Digital MicroVAX computer running the VMS operating system as the central control computer in the Array Operations Center. The MVM121 CPU card was too slow, the VERSAdos operating system failed to support any networking, and the MicroVAX was just too clumsy and was quickly being replaced by what some would term 'quick and dirty' UNIX-based workstations. To correct the situation the antenna-based station computers were upgraded to MVM147 CPU boards running Wind River Systems' VxWorks operating system, and the MicroVAX was replaced by a Sun Microsystems 3/260 computer running UNIX. This move also brought the antenna software/hardware in line with the software and equipment that was being used in the development of the Socorro Correlator. A majority of the slowness problems were solved by the MVM147 CPU, nearly all of the networking problems were handled by the VxWorks operating system, and the antennas and the central control computer were now both 'leaner and meaner' and more compatible in that they were both running UNIX and UNIX-like (VxWorks) operating systems. Yet even after these improvements, and to this day, the overall structure is still based on the original design which requires a large amount of fiddling around just to get observing up and running and extract the results required for post-processing of the data. No direct/interactive control of the antennas for any observing mode is possible with the exception of a couple of testing items, but none of those involve the observation of an astronomical source.

Loosely coupled with the pleasure of changing horses in mid-stream in going through a nearly complete overhaul of the software and hardware systems is the apparent rule of software evolution that dictates that as new software is written, as old machines are retired, the users are left with programs that never seem to get finished and that keep losing features because the newer platforms make some things "too difficult" to implement. If an operating system/hardware environment is selected carefully at the start with the intent of it lasting for a while and not just because it is the cheapest and easiest solution available, then the array operating system will have a chance to grow up before it needs to be replaced. Portions will, of course, need to be upgraded, but the major control portions should be built to last and to be extended, and not be so inadequate that they need to be replaced before they are even finished.

Many of the equipment checker messages at the VLBA are triggered by equipment errors that 'latch' and do not clear when the error condition no longer exists. The firmware for the VLBA tape recorders and formatters are especially bad about this. The only way to clear these conditions is to start up the Screens Package at each of the antennas and clear the error flags manually or, in some cases, wait for the next scan change. This is not a practical solution in some cases and will certainly not be acceptable with 36 antennas. This situation should be avoided with the MMA equipment. If this sort of error trapping is required for a piece of equipment then suitable means to clear the condition should be provided either in the software running in the antenna control computers or in the central control computer. Error trapping modes like this should be made available as part of a test mode of the software or hardware instead of a normal mode of operation.

B. Software

The amount of work required to operate remotely controlled devices such as the VLA, VLBA and MMA is ultimately determined by the quality of the control system software. If the software is well designed, complete, and designed to support the operation of the telescopes first and do astronomy second then the instruments can be controlled by the proverbial trained monkey. If not, then it may not even be possible for a team of trained dock workers to wrestle them under control.

While the temptation to place the operators close to the antennas is great, the operation of the VLBA has demonstrated that it is not necessary. However, the quality and the completeness of the command and control software plays a large part in the 'joy' felt while operating the instrument. And no, live video cameras are not the next best thing to being there. If the operators cannot see the antennas then they must be able to get a clear view of what is going on from the software and information driving the control room displays.

If the operators cannot see the actual antennas then it is also very important that the operating software be exactly what the operators require since there will be a greater amount of interaction between the operators and the array control software than there would be if the operators could just look outside to make sense of what was appearing on the operating display screens. Software bugs of various sizes and annoyance levels can be tolerated when software is used only for periodic/routine monitoring of the equipment. But software that is actively (i.e. heavily) used to simulate what is going on with equipment must be of a higher quality. This also brings up the need to prevent the practice of operators being stuck with broken software for a month, or months, at a time between on-line software updates with no way of backing out to older versions of the software. This is really a cruel thing to do to operators, yet it happens all the time.

In general the division of software labor can be summarized by the rule that if it affects one antenna do it at the antenna, and if it affects more than one antenna then do it in the central control computer. For example, do not load MMA observing schedules to individual antenna control computers and make the antennas smart enough to control themselves like the VLBA. Rarely will individual antennas be involved in doing their own thing for any length of time in an array such as the MMA. Then, of course, there is the axiom that if all of the antennas are going to do it then do it at the antennas, and if it only needs to be done once then do it at the central control computer. Complicated, isn't it? But such is the nature of operations. Issues such as these will need to be addressed on an individual basis.

It would be nice if a system could be created that the operators did not feel obliged to reboot once a week in an attempt to keep strange things from happening. The VLBA station computer software is much better than it was in the old days, but a good fix for strange behavior is still to reboot. And with the loading of the latest version of Solaris even the array control computer, Jansky, is rebooted once a week just to be safe. This is not good.

Some people say that a more graphical interface for controlling the array (the VLBA in this case) is needed. Why? Admittedly it looks nicer, but is it really necessary? It seems to me that the more graphical an interface is the more room it has for buttons and the less room it has for real information. As soon as a graphical representation shows a problem the first thing everyone wants to know is what the actual value is, so why not just have these values displayed in the first place? This came up quite often in the evolution of the VLBA control room displays. The VLBA display program, VLDIS, presents the operators with all of the information they need to initially assess just about any situation. They do not have to go hunting for information. Any additional information they might need is only a keystroke away. The use of colors, blinking, and go/no-go flag indicators was also implemented very carefully. A VLBA operator can determine the overall health of the array by just glancing at the control displays. Any control room displays that are created must be easy to read, use colors and blinking effectively and consistently, present as much information as possible and not be made 'pretty' just so they can be labeled as 'modern' by those that do not use them very often.

The frequency of monitoring a given point should determine the type of display to be used to present that data. For example, fluctuations in a cryogenic system temperature is important, but displaying the value constantly in a graphical form is not very productive if a reading is only taken once every 30 minutes.

The writers of the control software should make sure that everything from individual pieces of equipment, up to the whole antenna (and maybe even a whole sub-array) can be placed on- and off-line. It is really annoying for both operators and technicians when the observing system keeps resetting parameters when equipment is being tested, or if there is an attempt to stop something from happening (usually something bad) and the observing system keeps taking control away. This happens both at the VLA and the VLBA.

There will be an immediate need for a portable version of the control software to allow testing of sub-assemblies (e.g. a laptop hooked up to an individual rack of equipment). Whatever is developed should be simple enough to easily port to just about anything. Using ASCII text commands and monitoring messages between the equipment and the control computers will help in this area. Different compilers and computer operating systems often interpret binary data and pack software structures differently.

From experience with the development of the VLBA and from the Voyager era at the VLA, it is apparent that operator displays that show a set of values at all of the antennas at the same time, or summary displays, are particularly useful. When a problem arises they provide the operator with a means of quickly determining if what is going on is a single antenna problem or a whole array disaster.

The observing system should be able to go through UT midnight without any special events occurring. This was a problem at the VLA prior to the Voyager era, and on the VLBA in the beginning.

C. Operations

The initial design philosophy of the VLBA was based on the assumption that the antennas would be loaded up with instructions and then turned loose to take care of themselves with only periodic operator monitoring during the course of an observing run. It was a nice idea, but it became apparent that neither the user community, nor the Chief Operator at the time (me) would allow the instrument to be operated that way. The robustness of both the initial control software as well as various portions of the antenna hardware contributed greatly to that decision. The user community at the time (the engineers and staff scientists) also required a greater amount of control and monitoring for the purpose of testing the instrument. The original philosophy of operating is still readily apparent in the overall design of the observing system running on the station computers. The VLBA observing system is designed to be running – not started, not stopped, and not changed from its assigned course – but just running. Neither the unattended operation of the antennas, nor the non- interactive nature of control of the VLBA will be appropriate for the MMA. Aspects of this approach need to be prevented from creeping into the early forms of the control system (usually by building a temporary control system first and then not purging this system later) since it is easier to make a system that takes care of itself and does its own thing, than it is to build a system that has to put up with meddling humans. The earlier in the construction period the desired approaches to operating are defined, implemented as far as they can be, and built into the system, the better since the design of the hardware has a much more than generally perceived affect on how the instrument can be operated. Saying that something will be built a certain way does not mean that it can be operated that way.

The non-interactive form of operating works fine for the long VLBI-type projects that the VLBA normally performs. The added complication of having to record all of the astronomical data on tape makes long, predictable (in terms of time and tape usage) projects the easiest to accommodate. The VLA also performs most of its projects in this batch form. But with the lack of tape constraints, and with immediate correlation and feedback as to the condition of the array the VLA can be operated in a much more flexible manner if the need arises.

An interactive style of operation seems to be imperative for the MMA. We need to plan along the lines of a Titanic that has the look and feel of a speedboat (the eventual fate of the Titanic notwithstanding). During the first Remote Observing Workshop that was held in Tucson in 1993, I noticed that most of the optical telescopes were operated in a highly interactive manner. Our own 12m telescope at Kitt Peak has the capability of being interactively controlled. The builders of the MMA should ensure that they do not overlook these observatories as resources of inspiration as to how things should and should not be done.

In general the VLA, which is much better than the VLBA in terms of interactive control, is also lacking. But changes to various observing parameters are capable of being made at scan changes which greatly improves things. Parameter changes on the VLBA generally cannot be made without rebooting the station computers or restarting the observing file and thus interrupting the observing. Some items in the VLBA, such as starting up observing schedules, are only checked for by the system on a timed basis (approximately once every minute) rather than at predictable or forced times.

The User Interface vs. The Operator Interface vs. The Technician Interface... Should they be different, or should they be the same? While the specific information that each group will be interested in will be different, they will all be interested in the same basic information. So that is a vote for an interface all three groups can use. In addition, anything of interest to the technicians or astronomers is usually useful for the operators. However, it must not be forgotten that while the specific pieces of information that each group requires/desires may be similar, the method by which that information is obtained may need to be quite different. An astronomer who has all day to access his or her favorite array parameter may not object to the number of mouse clicks or keystrokes required to light up the display with the numbers of their desire. But the number of actions required to obtain a piece of information by an operator with a group of astronomers breathing down his neck, several stuck antenna subreflectors, and a hand full of other anomalies occurring all at once is a slightly different matter. In my opinion the whole system must be tailored to the needs of the operators first and everyone else second. Once the system can be easily and efficiently operated, anything necessary for other people to use the system can be added.

Since I have proposed using a simple command language between the CCC and the ACCs to allow for foreign control of the array, and I have also advocated the use of Unicode throughout the observing system, I might as well go the last step and propose that the monitoring and control displays be multilingual as well. If the observers will be allowed to monitor and/or control the MMA from their home institutions I am sure that it would be a welcome sight for some. Help and on-line documentation should also be made available in more than just English.

Personally I still like the old overlay system at the VLA when compared to all of the menu-driven interface implementations on the VLA and the VLBA (though use of a mouse is helpful in some situations). The old system was simple and straightforward and it worked very well. There was no hunting for information. If you wanted to look at the focus/rotation unit on antenna 17 you entered the command "FR 17" and all of the information for the FRM on antenna 17 filled the display terminal. No hunting or pecking, pulling down or jumping through sub-menus was required. Monitoring and control display software should be developed with function in mind first and looks second. Slowly wading through a collection of overlapping graphical interface screens that look pretty just to click one button or enter one number versus just typing a "Y" or "N" on a command line is not good tradeoff when things are going wrong.

It is also my feeling that the idea of making an operator's interface easy to learn should not be given too much consideration when the implementation of such a scheme causes it to be difficult and slow to use when the pressure is on. Operators typically spend a couple of months training, and several years operating. The system should be tailored for ease of use over ease of learning. This was not the case when the new Modcomps were installed at the VLA. Generally speaking an operator spends much more time learning where everything goes than he does learning how to run the display systems. It took me about two days to learn the old overlay system at the VLA when I started working there in 1986, and this was, theoretically, the most difficult operator interface to learn. Online help is useful as long as it does not get in the way and is easy to keep up to date. Too much help is no help at all.

Controlling more than three sub-arrays is an operational handful. Can this be overcome or will we just have to limit the number of things going on? If the MMA antennas take care of themselves during pointing observations, for example, the operator would be relieved of a lot of stress. If tests like pointing can be conducted without the use of administrative details like observing files, then more things going on at the same time will probably not be a problem. As an aside, I feel that there should never be more than one interactive observer (i.e. person in control of the antennas).

Checker messages. We should not repeat the nearly complete failure of the VLBA checker message system to provide any useful information and guidance. The operators practically go out of their way at times to ignore the checker messages in the control room. The CHECKER task in the station computer is in a world of its own and fails to do simple things like checking to see if the subreflector is moving to a new position before it reports that the subreflector is not where it should be. In addition there are too many checker messages. This is caused by a lack of attention to the set points (which are generally not accessible as they are hardwired into the observing system code), and by the fact that they cannot be tailored to individual antennas. Some antennas 'run hotter' than others even though they are supposed to be identical in construction. The software should be able to accommodate that. Not using the VLBA checker message system is in direct contrast to the VLA checker message system that, while not being perfect, is almost exclusively the only system of information that the operators of that facility rely on for basic array monitoring. When the VLA operator hears the control room printer 'beep' and print an important checker message (referred to as three- or four-star message) it, in most cases, is for a good and real reason.

In the beginning no simple method for prioritizing checker messages was built into the VLBA observing system. This had to be added later when it became impossible for the operators to tell what was going on because of too many checker messages being generated – and this was only with 5 antennas running. The overall structure of the checker message system is also not quite right for effectively prioritizing messages. For example, if the ACU rack temperature becomes too hot, a message stating that the temperature is "not 10 to 30 degrees" is generated. Clearly if the temperature is greater than 30 degrees (C) this should be cause for concern. But if the temperature is less than 10 degrees then there is no immediate cause for alarm. Also there are generally no messages that indicate that a parameter is "almost out of range," that a parameter is "out of range," and that the parameter has ended up "way out of range." This is quite helpful for monitoring some types of problems. These problems could be solved with an extensive review/rewrite of the CHECKER software. A system with a bit more flexibility for the MMA in the beginning would be nice.

Creating a system where specific checker messages can be ignored by the system for any length of time to prevent the operator from being overloaded with messages is a bad idea. The system generating the messages should have the ability to note that the synthesizers are in the middle of changing frequencies and not report out of lock errors. The system should not be capable of hiding equipment problems such as firmware errors that have existed for years just because no one wants to correct the firmware programming or the monitoring system. That is being done for numerous messages by VLDIS with the VLBA formatter and tape transports. Do not build a system whose basic items, like set points, are so difficult to change that no one wants to change them.

The overall design of the observing system needs to support some sort of 'synthetic' observing files versus real ASCII lists of objects to be observed. Currently with the VLBA, an observing file (usually of inconvenient proportions) must be produced each time a pointing run is conducted. Clearly this kind of routine test observing should be capable of being performed without an actual disk file having to be created, moved around, and left to suck up disk space. Surely this whole area of requiring actual observing files could somehow be modernized in the MMA. There are many ways to do it. However, good old ASCII observing file capability of some type will probably still be needed for some types of test observing.

If the use of a traditional form of observing file is maintained files that are formatted rather than free form are much more easily read when there is trouble with the contents. Free form files are a nice idea, but observers rarely read them, nor make them up from scratch with a text editor (except maybe for Durga Bagri) which was one of the original selling points for the

VLBA observing file format. Of course this whole area will be better defined once a suitable OBSERVE program is developed for MMA observing. Also, a very interactive and adaptively scheduled instrument such as the MMA could make the whole concept of observing files and even observing projects obsolete if it is done correctly. But these are topics for another paper.

Remote observing. Does this include allowing the observer to control the telescope from outside the MMA control room? Allowing this will greatly affect the way the instrument is operated and the initial design of the equipment to support the mode. It seems as though it has always been NRAO's policy to have operators available to run the telescopes instead of letting observers operate the equipment. Will the MMA break with this tradition?

Are there going to be antennas that will not be moved during reconfigurations? Antennas like these are relied upon to 'find' (set the total and peculiar IF delays) other antennas during reconfigurations at the VLA. Special attention in the control software should be paid to automating the finding procedure as much as possible. Finding antennas following the movement of antennas used to be quite a taxing task for the operators at the VLA. They now have some overlays that help the process. The software in the station computers for determining the best focus position on new VLBA antennas was produced just as the last antenna came on line. It was done with paper, pencil and patience for the first nine antennas. The overall design of the control system software should ensure that tools like this can easily be made available from the start.

These are the kinds of things that are intuitively known to operators and it is for this reason that I feel that operators should not be left until last to be hired. Operators are involved in all aspects of the instrument after construction is finished. Why should they not be involved long before then?

V. Leftovers

These are random thoughts about items that do not fit neatly into any of the other sections.

Is there going to be an over the top mode of operation? This always seems to complicate matters. I am not sure why it does, but it always has. Along with this is wrap prediction, where the antenna attempts to place itself on the correct wrap at the beginning of a project. The piece of software that tried to do this for the VLBA was finally removed in the early phases of construction.

Develop the core operating/observing systems first and make sure that they are rock solid. Trying to build the whole system on a shaky foundation has not worked in the past so it probably will not work in the future either, no matter how powerful the computers of 2001 are.

During the construction of the VLBA, as the number of installed receivers increased it became increasingly difficult to keep track of which receiver was which. The engineers would refer to the receivers in terms of frequency, the observing files and the online software was in wavelength band, the maintenance reporting system was wavelength, and in general conversation between the operators, site technicians, and engineers used frequency, wavelength and the letter designations. It was decided to standardize on the designations used by the software and go with the wavelength band designations. Thus "P-band," "400MHz," "90cm," became just "90cm." It would be convenient if this decision was made earlier in the MMA project so that all parts of the instrument and support systems could be made the same.

How will the observing time be scheduled? It is much easier for operators to relate to observing schedules and observing systems that operate in Universal Time (UT) rather than Local Sidereal Time or International Atomic Time.

What are the security concerns related to the MMA observing system? To break into the VLBA observing system you must break into, and at least be in the correct area on Jansky, but it is still relatively open to losing control. However, if someone does get in and cause some disruption they would have to do it ten times to damage everything (which is not entirely true, but, for the most part, correct). With the VLA being a very closed system it seems to be less susceptible to intrusion. But if access is gained then a lot of damage can be done easily to all of the control software running on the Modcomp computers. With the layout I've proposed for the MMA the security aspects will be closer to that of the VLBA.

The creation of a huge and complex database and associated software to cover all aspects of the administrative side of operating a telescope sounds like a good idea, but its development and implementation should be approached with caution. The development of this type of database system should be viewed as an aid to the operation of the observatory, and not viewed as an answer to everything, or worse yet, as a crutch that must be relied upon. Databases are very useful things if it is easy to get data into them, and out of them, without it being altered by bugs in the system. The implementation of a database system should compliment the operation of the telescope, not take it over. NRAO is still a paper oriented organization (try counting the number of printers and copiers in the AOC). A program like this must be built with the intention of helping everyone do their job, and not built with the intention of being the answer to everything or worse yet as just giving some programmers something to do. The output of a system like this should have a place ready for it in the observing system and not require that its output be 'shoe horned' into an existing system that was not designed to handle input from a database system in the first place.

There is definite need to talk to professional testers like Durga Bagri and others during the construction of the operating system software to see what they will need. This wasn't handled very well during the VLBA construction which made software for testing purposes very difficult to come by and/or use.

The processing of the astronomical data in real time will, I assume, be completely out of the control of operations and will be tied more to developments within the realm of AIPS++. That is why I have not mentioned it. I will say that because of the computing power required to perform this task it should be a separate entity with an output ready for display. I would also hope that it will be available and ready for use as soon as possible. An important tool for operators at the VLA is a fringe display that shows the fringe powers for each IF of each antenna when the array is observing a calibrator source. This would also be a useful tool for the Socorro correlator operators to have, but it has not been produced yet. But then this is another area deserving of its own paper.

VI. Conclusions and Closing Arguments

In the construction of the Millimeter Array it can be seen how not to do things. We have many fine examples and several projects worth of experience. I am not saying everything should be perfect from the start, nor should this even be a goal, but whatever the array starts with should at least be better than similar items in the VLA and VLBA. In the early days of the VLBA the degree to which general operational philosophies at the VLA (the VLBA's closest relative) were ignored was quite remarkable.

Try not to start simple and add all of the complex items later. The complex functions become harder to implement as the list of legacy idiosyncrasies gets longer and longer. In many cases it seems to be better to throw in small portions of complex ideas early on so that they are assured of at least getting a foot in the door and therefore obtaining the possibility of showing up (at all) at a later date. Even a blank control display with the appropriate title in the title bar is better than nothing. Also, the creation of one system for the initial testing and another system for the real thing seems to me to be a bad idea. If you work towards building a system that can tolerate the stress of the initial testing then you will have a much more robust final system. Who wants to work on a system that is only going to be thrown away? And the more complete the initial system is the higher the quality the testing results will be.

I also believe that a bottom up approach to the development of the MMA is not a good way to do things. From what I understand different portions of the system are going to be developed by different groups and organizations. If an overall, high level system is not in place for all of those different groups to build towards then they will most likely produce many systems that cannot coordinate with each other causing the system required to force them all to work together to be much more complicated than necessary. Build a system of systems that can work together and not one that must be forced to work together. From what I understand this situation exists to some extent at the GBT. All of those little details that are important to the engineers and technicians may not be enough to support operations. Being able to monitor everything in a piece of equipment does not always guarantee that it can be controlled in a reasonable manner. There are several examples of this on the VLBA where the operators are unable to obtain the information, or send the necessary commands they need in a reasonable manner because the software (and to some extent the hardware) will not support it. Software systems are built with a top down approach. Why would we want to build the rest of the project the opposite way? The MMA will be built in a relatively short amount of time when compared to the amount of time it will be in use. Do not build for the moment. There are very few test procedures that we did in the early days of the VLBA that are not still used. If time and effort is going to be spent creating the software and hardware for a test it should become a part of the final s ystem. Do not think in terms of disposable systems. Think in terms of building a test system that can be expanded into the final product.

NRAO does not seem to think in terms of solutions. It thinks in terms of problems. Too many times the answer to problems is "It will take too long" or "It's too difficult." Everyone says it, but no one seems to want to prevent the old routine of crisis management where we react instead of act to the needs of operations. It takes more effort, but it is a lot easier in the long run to do the obvious things. You end up with a product that is built because it was a good idea to build it that way instead of because it had to be built that way ("We had to do it this way because we were in a hurry.").

I think that the watch words with respect to the MMA observing system should be simplicity and flexibility. Just as programming projects should be approached by breaking the problems into small blocks, the construction of the observing system should be out of many small blocks that, when stacked together in various ways, can be made to do many tasks. Do not build a system made of parts that cannot be touched. It should be built with a common goal in mind and not in a free-for-all manner.

When there is doubt as to what to do, experiment! This should be a somewhat automatic response to a situation at a research institute, but that does not seem to always be the case. NRAO seems to study situations with respect to operations until it runs out of time and then is forced to make decisions.

Everyone correctly says that temporary solutions usually end up becoming permanent bad solutions. This is, in fact, true. But only because it is allowed. If something does not work, THROW IT OUT and start again. Never come to the point where it is decided that something is so finished that it cannot be changed. If something needs to be changed then change it. Do not create layer upon layer of fixes to compensate for something that no longer works, or that would be difficult to change. Things change. Maybe the software or the procedure was good in the beginning, but was not designed to handle later requirements. If that is the case then bite the bullet and replace it.

NRAO builds custom systems because that is the nature of our 'product.' We cannot rely on a set of constantly changing, consumer driven standards. We are in the business of science, not in the business of commerce. If NRAO is expected to turn a profit, so to speak, I feel that the MMA should stay away from bleeding edge software technologies. As soon as you set off on this sea of never ending change you will quickly find yourself at the bottom. I am writing this in a window next door to a monitor that is running software developed by me over seven years ago. The program went from having no idea what to do to a fully functional, bug free, version 1.0 in three weeks. How many new releases or notices of impending upgrades of popular software packages have there been in the last three weeks? I am not saying that these new technologies should be ignored, but to build a core system with them would be a big mistake. Yes, you do not get all of the fancy features in an in-house, custom designed system that you can get from commercially available packages (just look at the maintenance database system), but we need stable (both in terms of well written and not constantly changing) software systems first and not fancy features. In addition, commercial software vendors are only providing a general purpose solution. We are not a general purpose operation and their product stability and longevity is certainly not geared towards worrying about the needs of NRAO. We build antennas that are designed to last 30 years. Should not the observing systems we build be made to last longer than the current three year (or less) software cycle in the commercial industry at large? How long was the MkII correlator or the 300' telescope around?

I feel that what all the operators and users of the MMA should have for operating, monitoring and testing the array is a system that is simple, stable, reliable and does what is needed. I do not feel that it is too much to ask, as an operator, personally responsible for the health and safety of a multi-million dollar project, to not be faced for months at a time with a buggy system or one that does not provide you with the information you need to perform your job.

This paper does not even come close to covering all of the bases or all of the details that will be encountered during construction of the MMA. It does not even cover all of the issues that I thought of as I wrote it. But that is the nature of operating. Rarely are you able think of everything beforehand. But if the initial design of the equipment and software with respect to operating is not taken into account, then the final stages of construction become more and more difficult and time consuming as patches and fixes must be produced to make up for initial unnecessary shortcomings. If the experience of building the VLBA is any indication I would suggest that the details be allowed to present themselves when their time comes instead of studying and delaying and waiting to find all of them before starting to put the operational pieces together. The longer the delay the less time there will be, which is usually the case even when you start early. As the amount of time to get things done decreases, there is a tendency to add more people to solve the problem. Everyone likes to use the expression "designed by committee," but no one seems willing to prevent it from happening. The fewer number of people involved the better the result will be – if there is enough time. The longer the lead time, the better the operation will be. The VLBA had to be thrown together in a big hurry towards the end of construction and it shows. Nearly the whole operational end of the MMA can be ready to go long before an antenna is even ready to point, mainly because most of the items required to initially point the antennas are the same elements that will be used throughout the life of the instrument. It's not like NRAO has never built an array before. We know what needs to be done. Only a few broad, general, hardware and software interface decisions need to be made to get things started. But aspects directly involved with the operation of the instrument should not be ignored, and those aspects show up much earlier in the construction phase than might be expected. If you build a machine that cannot be operated, then you have failed.

```
SYSTEM   64
//* OBSERVING FILE FOR VLA
/DEF
CCDS            10
UUDS            10
KKDS            10
LLDS            10
LPDS            10
PPDS            10
XXDS            10
/EDEF
3C84          09 00     3 19 48.1581  41 30 42.095C    CC   C 5 0000
3C84          09 00     3 19 48.1581  41 30 42.095C    UU   C 4 0000
3C84          09 00     3 19 48.1581  41 30 42.095C    KK   C 3 0000
3C84          09 00     3 19 48.1581  41 30 42.095C    LL   C 4 0000
3C84          09 00     3 19 48.1581  41 30 42.095C    XX   C 6 0000
3C84          09 00     3 19 48.1581  41 30 42.095C    XX IRC 6 0000
3C84          09 00     3 19 48.1581  41 30 42.095C    QQ   C 3 0000T
3C84          09 00     3 19 48.1581  41 30 42.095C    KK   C 3 0000T
3C84          09 00     3 19 48.1581  41 30 42.095C    UU   C 4 0000T
3C273         16 30    12 29 06.7007  02 03 08.532C    CC   C 5 0000
3C273         16 30    12 29 06.7007  02 03 08.532C    UU   C 3 0000
3C273         16 30    12 29 06.7007  02 03 08.532C    KK   C 3 0000
3C273         16 30    12 29 06.7007  02 03 08.532C    LL   C 4 0000
3C273         16 30    12 29 06.7007  02 03 08.532C    XX   C 6 0000
3C273         16 30    12 29 06.7007  02 03 08.532C    XX IRC 6 0000
3C273         16 30    12 29 06.7007  02 03 08.532C    QQ   C 3 0000T
3C273         16 30    12 29 06.7007  02 03 08.532C    KK   C 3 0000T
3C273         16 30    12 29 06.7007  02 03 08.532C    UU   C 3 0000T
3C345         23 00    16 42 58.8099  39 48 36.987C    CC   C 3 0000
3C345         23 00    16 42 58.8099  39 48 36.987C    UU   C 2 0000
3C345         23 00    16 42 58.8099  39 48 36.987C    KK   C 1 0000
3C345         23 00    16 42 58.8099  39 48 36.987C    LL   C 2 0000
3C345         23 00    16 42 58.8099  39 48 36.987C    XX   C 4 0000
3C345         23 00    16 42 58.8099  39 48 36.987C    XX IRC 4 0000
3C345         23 00    16 42 58.8099  39 48 36.987C    QQ   C 1 0000T
3C345         23 00    16 42 58.8099  39 48 36.987C    KK   C 1 0000T
3C345         23 00    16 42 58.8099  39 48 36.987C    UU   C 2 0000T
```

```
/REWIND      $
//* PBAND SOURCES
//* LOW ELEVATIONS AT 19:30 LST.
3C48        0 03 30 00 01 37 41.3040 +33 09 35.400C    PP   C 4 4444
3C48        0 03 30 00 01 37 41.3040 +33 09 35.400C    LP   C 4 4444
3C147       0 09 30 00 05 42 36.1280 +49 51 07.180C    PP   C 5 4444
3C147       0 09 30 00 05 42 36.1280 +49 51 07.180C    LP   C 5 4444
3C286       0 19 30 00 13 31 08.2840 +30 30 32.940C    PP   B 4 4444
3C286       0 19 30 00 13 31 08.2840 +30 30 32.940C    LP   B 4 4444
/BACKUP     6
//*
//*   LINE STUFF
//*
3C84          09 00    03 16 29.569  +41 19 51.94      CC   B 8 0000
//DS 1A
3C84          09 00    03 16 29.569  +41 19 51.94      CC   B 8 0000
//DS 1C              4     0
3C84          09 00    03 16 29.569  +41 19 51.94      CC   B 8 1111
//DS 1A              5     0
3C84          09 00    03 16 29.569  +41 19 51.94      CC   B 8 1111
//DS 1C
3C273         16 30    12 26 33.248  +02 19 43.29      CC   B 8 0000
//DS 1A
3C273         16 30    12 26 33.248  +02 19 43.29      CC   B 8 0000
//DS 1C              4     0
3C273         16 30    12 26 33.248  +02 19 43.29      CC   B 8 1111
//DS 1A              5     0
3C273         16 30    12 26 33.248  +02 19 43.29      CC   B 8 1111
//DS 1C
3C345         21 30    16 41 17.608  +39 54 10.82      CC   C 8 0000
//DS 1A
3C345         21 30    16 41 17.608  +39 54 10.82      CC   C 8 0000
//DS 1C              4     0
3C345         21 30    16 41 17.608  +39 54 10.82      CC   C 8 1111
//DS 1A              5     0
3C345         21 30    16 41 17.608  +39 54 10.82      CC   C 8 1111
//DS 1C
/BACKUP    12
```

```
!*  Schedule for VLBA   *!
!*  Experiment SYSSTART *!
!*  Version 19911029    *!
   program=SYSSTART
   logging=standard
   date=99Dec31

   format=MARKIII
   nchan= 16
   pcal=1MHz

   baseband=(1,1),(2,1),(3,2),(4,2),(5,3),(6,3),(7,4),(8,4)
   baseband=(9,5),(10,5),(11,6),(12,6),(13,7),(14,7),(15,8),(16,8)
   sideband=(1,U),(2,L),(3,U),(4,L),(5,U),(6,L),(7,U),(8,L)
   sideband=(9,U),(10,L),(11,U),(12,L),(13,U),(14,L),(15,U),(16,L)
   bbfilter=(1,2M),(2,2M),(3,2M),(4,2M),(5,2M),(6,2M),(7,2M),(8,2M)
   bbfilter=(9,2M),(10,2M),(11,2M),(12,2M),(13,2M),(14,2M),(15,2M),(16,2M)
   level=(1,-1),(2,-1),(3,-1),(4,-1),(5,-1),(6,-1),(7,-1),(8,-1)
   level=(9,-1),(10,-1),(11,-1),(12,-1),(13,-1),(14,-1),(15,-1),(16,-1)
   period=(1,1),(2,1),(3,1),(4,1),(5,1),(6,1),(7,1),(8,1)
   period=(9,1),(10,1),(11,1),(12,1),(13,1),(14,1),(15,1),(16,1)
   bits=(1,1),(2,1),(3,1),(4,1),(5,1),(6,1),(7,1),(8,1)
   bits=(9,1),(10,1),(11,1),(12,1),(13,1),(14,1),(15,1),(16,1)
   track=(1,2),(2,3),(3,4),(4,5),(5,6),(6,7),(7,8),(8,9)
   track=(9,10),(10,11),(11,12),(12,13),(13,14),(14,15),(15,16),(16,17)
   samplerate=4M

!*  7mm setups  *!
   fe=(1,7mm),(3,7mm)
   noise=(1,low-s),(3,low-s)
   ifdistr=(1,0),(3,0)
   synth=(1,14.9),(2,7.6),(3,11.6)
   ifchan=(1,A),(2,A),(3,A),(4,A),(5,A),(6,A),(7,A),(8,A)
   ifchan=(9,C),(10,C),(11,C),(12,C),(13,C),(14,C),(15,C),(16,C)
   bbsynth=(1,722.00),(2,722.00),(3,722.00),(4,722.00),(5,722.00),(6,722.00)
   bbsynth=(7,722.00),(8,722.00),(9,722.00),(10,722.00),(11,722.00),(12,722.00)
```

```
  bbsynth=(13,722.00),(14,722.00),(15,722.00),(16,722.00)

!*  Scan    62   *!
  sname='CYGA'  ra=19h59m28.9s    dec=40d44'16"
  stop=23h59m59s
!NEXT!

!*  Scan    63   *!
  sname='CASA'  ra=23h23m22.8s    dec=58d50'16"
  stop=23h59m59s
!NEXT!

!*  Scan    64   *!
  sname='TAUA'  ra=05h34m31.6s    dec=22d01'15"
  stop=23h59m59s
!NEXT!

!*  Scan    65   *!
  sname='3C274'  ra=12h30m49.4s    dec=12d23'28"
  stop=23h59m59s
!NEXT!

!*  Scan    66   *!
  sname='3C84'   ra=3h19m48.2s     dec=41d30'42"
  stop=23h59m59s
!NEXT!

!*  Scan    67   *!
  sname='3C273'  ra=12h29m06.7s    dec=02d03'08"
  stop=23h59m59s
!NEXT!

!*  Scan    68   *!
  sname='3C345'  ra=16h42m58.8s    dec=39d48'37"
  stop=23h59m59s
!NEXT!
!QUIT!
```