How Quickly Can the MMA Reconfigure?

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Abstract

It should be possible to move an MMA antenna from one pad to another in 45 to 85 minutes. This assumes no time is lost to detailed alignment of the antenna with its new pad. Using three transporters and two antenna crews working 6 hours each, it will take under a day to reconfigure between hybrid arrays and under two days to reconfigure all 40 MMA antennas. If hybrid configurations are used (as at the VLA) and only ~20 antennas need to be moved, a reconfiguration might proceed smoothly with only two transporters. Observations to determine the pointing parameters and the baselines should take on the order of an hour each. High winds will hinder reconfiguration. During the winter, daytime winds exceed 30 mph about 25% of the time, and exceed 40 mph about 8% of the time, so we must either design the transporter/antenna system to be able to withstand fairly high winds, or we must be prepared for many reconfiguration delays.

1 Introduction

With four planned MMA array configurations, it is important to understand how quickly the 40 element array can be reconfigured. We will estimate the antenna move time for the MMA using the experience of the VLA's antenna group, modifying the times of various operations which will differ between the VLA and the MMA.

2 Reconfiguring the VLA

According to Jim Ruff and others at the VLA site, a typical VLA antenna move consists of the following operations:

15 min	lift the antenna
15 min	turn railroad wheels between spur and main track
$2d/100$ min	two way rail travel time to cover d meters at 100 meters per minute (4 miles per hour)
20 min	align with bolt holes
15 min	put antenna down
15 min	attach modem
15 min	attach waveguide

Hence, for a short VLA move of 1500 m, an individual antenna move consists of about 95 minutes of disconnection/reconnection overhead, 30 minutes of move time, and perhaps 30 minutes of miscellaneous overhead. At this rate, 6 antennas can be moved per day with two transporters. Obviously, with 40 antennas, the MMA will need to move the antennas in less time.

2.1 Pointing and Baselines

A newly moved antenna cannot participate in any observations until its pointing parameters have been determined. During reconfiguration at the VLA, pointing solutions are determined each night for the subset of antennas which were moved earlier that day. Interferometric determination of the pointing parameters is much faster than single dish pointing determination. Gross pointing offsets are often several beam widths, making standard "five point" pointing observations impossible. A simple pointing procedure makes a rough solution for the dominant pointing errors with about 30 minutes of observing. In order to solve for the full seven parameter pointing model, the VLA covers its AZ-EL space by observing $\sim$80 bright calibrator sources, one ever 3 minutes, over 4 hours.

Accurate baseline solutions are usually made after all antennas have been reconfigured, using all antennas for the solution. Observations performed with bad baselines can be corrected for the new accurate baseline solutions retroactively. The baselines are determined from observations of about 80 sources taken over 4 hours, covering AZ-EL space.

3 Reconfiguring the MMA

The VLA proceeds with useful astronomical observations during the few days required for each reconfiguration, often performing flux monitoring of unresolved sources which does not require a good synthesized beam. However, it would be advantageous to reconfigure the MMA antennas more quickly, making the array more flexible. We may want to cycle through the entire ensemble of configurations during the winter months so the best phase stability benefits every kind of observations. Significant reductions in the time required for a single antenna move may be achieved for the MMA:

- The VLA's shortest move, from the 3 km to the 1 km array, is comparable to the MMA's longest move, so MMA moves will usually be dominated by the disconnect and reconnect operations, while the transporter travel time is often a significant part of the VLA moves.

- The MMA antennas will be about 40 tons, while the VLA antennas are 220 tons. The lighter MMA antennas will be moved with a rubber tire transporter rather than on a rail system. Hence, the 15 minutes spent turning the wheels between the main track and the spur are not required.
- We should be able to eliminate the 20 minutes required at the VLA to align the bolt holes. One way this might be achieved is for the transporter to have the capability of rotating the antenna azimuthally before it is set down. Using a conical protrusion from the bottom of the antenna leg which mates with a conical cavity on the pad can reduce the precision with which the antenna needs to be placed on the pad. We should pay careful attention to this aspect of the transporter/antenna/pad design.
- The VLA antennas must be reconnected to modem and power cables and also to the waveguide. Rather than reconnect these cables in series, we could save time by designing a parallel reconnection for power and all communications. We assume that the total reconnection time will be 15 minutes.
- The cable reattachment does not need to be performed prior to moving the next antenna, but can be performed by a second crew which follows the antenna move crew. Likewise, this crew can disconnect cables and prepare each antenna for its move before the transporter arrives.
- We will assume the MMA transporters will move at 5 mph (the SMA spec), although they might operate at higher speeds in practice.

Hence, we expect each MMA antenna move to require these operations:

15 min	lift the antenna
$2d/125$ min	two way rail travel time to cover d meters
	at 125 meters per minute (5 miles per hour)
15 min	put antenna down
15 min	attach cables (may not add in)
15 min	miscellaneous overhead

The transportation The actual two way transportation time would be about 2 minutes in moving from a D to a C array station, about 7 minutes in moving from a C to a B array station, and about 25 minutes in moving from a B to an A array station. Hence, the move time for a single MMA antenna will range from 45 to 70 minutes if a separate crew reattaches the cables, or 60 to 85 minutes if one crew performs all move operations.

3.1 Work Shifts and Antenna Transporters

The work shifts at 5000 m in Chile will probably be less than 8 hours to prevent physical exertion, and we assume 6 hours. The "Sistema de Turno" as envisioned by Mark Gordon for the MMA operation entails two staffs of ~30 workers changing about once a week. Reconfiguration could be performed when the two staffs overlap, enabling about 12 hours of reconfiguration work each day. If a single antenna transporter is used, reconfiguration of all 40 antennas would take about four days. If three antenna transporters were used, a reconfiguration could take just over one day. If the "Sistema de Turno" is not used, we may need to make special arrangements for two shifts during reconfigurations in order to keep the move time down.

We are investigating the utility of hybrid configurations to aid in low declination observations, and possibly to provide different Fourier plane distributions. Reconfiguring between a regular array and a hybrid array requires moving about 20 antennas, which could be performed by two transporters in one day.

3.2 High Winds

The reconfiguration will be slowed down by bad weather, which will come mainly in the form of high winds on the Chilean site. The VLA does not move antennas when the winds are above 20 mph. The daytime wind speed during the months June through October on Chajnantor is higher than 30 mph about 25% of the time, and higher than 40 mph about 8% of the time. We would want to design the antenna transport vehicle to be able to function, loaded with an antenna, in winds *at least* as high as 30 mph. Since the atmospheric pressure is half of the sea level pressure and the force on the antennas goes like v^2, the 30 mph specification might not be unreasonable. Even so, we will need to expect significant delays in the reconfiguration. Hence, we boost the full reconfiguration time estimate from a bit over a day to two days.

The nighttime winds on the Chilean site are fairly benign, typically half as strong as the daytime winds. If we were able to reconfigure antennas at night, it would eliminate numerous delays and relax the specifications on the transporters. However, night antenna moves may not be possible.

3.3 Pointing and Baselines

The MMA will rely heavily upon the 30 GHz system for pointing and baseline determination. The 30 GHz system will be very sensitive due to the low system temperature and the high fluxes of the calibrator sources, and the long wavelength will largely eliminate wavelength ambiguities in the baselines. The raw sensitivity of the MMA will far exceed that of the VLA due to its large bandwidth (8 GHz as compared to 50 MHz), and the MMA's agile antennas and operating system will enable the array to leap around the sky quickly. We assume 80 sources can adequately sample AZ-EL space (as at the VLA), and that each of the 80 sources will be brighter than 1 Jy at 30 GHz (there are about 200 sources over the entire sky which are brighter than 1 Jy at 90 GHz). We will have adequate SNR on a 1 Jy source for pointing in just a few seconds, or 15-30 s to perform a "five-point" observation, including move time. The next source will typically be about 15° distant, requiring a slew of 7-15 s. Hence, the entire 80 source pointing run will take under one hour. Atmospheric phase fluctuations and opacity will almost never limit pointing observations at 30 GHz.

The requirements of the global baseline determination are similar to the pointing, so they can also be completed in under one hour. The requirement of no coherence loss across a 8 GHz bandwidth implies that the baselines need to be known to only about 4 mm. With observation of ~80 calibrator sources on 780 baselines, the atmospheric phase fluctuations will permit this level of accuracy on even the longest baselines (3 km) essentially all the time. While the atmosphere will usually limit the accuracy of the baseline determinations, accuracy of a few tens of microns will often be achievable. With phase calibration being performed on minute time scales with calibrators a few degrees distant, phase errors from baselines determined with millimeter accuracy will yield acceptably small phase errors.

4 Repeating Important Points

If the MMA is designed with fast reconfigurability in mind, we should be able to reconfigure the entire array in under two days with three transporters. If hybrid configurations are used, as at the VLA, and only some of the antennas need to be reconfigured, each partial reconfiguration can be done in under one day, and only two transporters may be required. The transporters must be designed to operate in *at least* 30 mph winds. Even so, delays due to high wind speeds will preclude antenna moves about a quarter of the daytime during the winter months at the Chilean site.

Reconfiguration would probably proceed during the day, when the opacity, phase noise, and wind velocity are all highest. Hence, we will not usually lose quality observing time to moving antennas. Shortly after sunset when the phase stability and winds settle down, pointing and baselines will be determined. The 30 GHz system will be important for pointing and baselines due to the brightness of quasars at this frequency, the sensitivity of the low frequency system, the large beam size, and the reduction of wavelength ambiguities in the baseline determination.

Features of the transporter, antenna, pad, array, and operations design which will speed up array reconfiguration include:

- specially consideration in the design of the transporter, antenna, and pad to reduce the time spent aligning the antenna and pad bolt holes.
- parallel connection of all cables (power, control and monitor, data, LO).
- use of two separate reconfiguration work shifts per day and use of two or three transporters.
- the fast slewing capabilities of the antennas and the high sensitivity of the array result in fast pointing and baseline determination.