MILLIMETER ARRAY
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Sharing Time and/or Antennas Between Total Power and Interferometric Observations

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Operation of the MMA will involve total power observations with antennas operating singly, as well as the usual cross correlation measurements between antenna pairs of the array. The total power observations provide the visibility data at the origin of the (u,v) plane and in the case of maps derived by the mosiacing technique they contribute strongly to the data close to the origin. In total power observing, beam switching, achieved by vibrating the subreflector, is effective in separating the power from the source from the system noise including the contribution from the atmosphere. The amount of time spent on the source of interest is halved by the beam switching, but the comparison with respect to a reference level is essential. In interferometry with the MMA it is proposed to devote about half time or half the antennas to observation of a phase calibrator. Thus if total power and interferometer observations are made at the same time, beam switching may waste half the interferometry time and phase calibration may waste half the total power time. Will this result in a significant loss in performance?

1. Incompatibility of Calibration Requirements

Since beam switching reduces the interferometer time on the source under investigation, it is relevant to ask if beam switching is in any way useful with regard to interferometer observation. When the beams are pointed at cold sky, or any uniformly bright background, the output of an interferometer is ideally zero, except for the random fluctuations resulting from the noise. In practice there may also be small outputs from the correlators resulting from low-level spurious signals of instrumental origin or errors in the setting of the sampler levels. These should be at least two orders of magnitude lower than the unwanted response to the system noise of a total power radiometer that the beam switching is designed to eliminate. Beam switching would certainly provide a means of removing instrumental responses in interferometry, but generally these can be sufficiently well suppressed by phase switching of an early local oscillator which does not incur a loss of observing time. The natural fringe oscillations are also very effective in separating source responses from unwanted instrumental effects. (For example, with an east-west spacing of 8m, the closest possible MMA antenna spacing, and a source at declination 60° and hour angle zero, the fringe frequency at 3mm wavelength is 0.1 Hz, i.e. one fringe oscillation in 10 s.) In long-duration observations the important factor in helping to separate the source response is the number of fringe cycles in crossing a cell in the (u,v) plane, which can still be large near the (u,v) origin because the antenna-spacing vectors move relatively slowly there. Beam switching might conceivably be useful in interferometry if the source is very weak, or highly resolved, and in addition the observing time is so short that there are not enough fringe cycles on some baselines.

In mosaicing observations the beam-switching action could move the beam between two positions on the source being mapped, in which case useful interferometer data would obtained from both positions. Cornwell et al. (1993) briefly note this possibility, without discussion. The total power measurements would then represent differences in brightness levels in the source. In the process of determining absolute brightness values from such measured differences at least one measurement on cold sky would be required, and errors could be cumulative. Thus, for total power observing it would be preferable to beam switch onto cold sky at all times. For the general run of interferometry it would be preferable to avoid beam switching.

Similarly, one can ask whether the schemes considered for interferometer calibration of the atmospheric phase might be helpful in total power observations, and provide an alternative to beam switching. For total power, the noise power from the atmosphere that one seeks to cancel out by beam switching may contribute several degrees of antenna temperature, and thus exceed the power from the source by something like three orders of magnitude. Thus the cancellation requirement is much more stringent than the interferometric requirement for correction of the atmospheric phase to an accuracy of a few degrees. Alternating between the source under study and a nearby point-source calibrator would be too slow to be effective for total power calibration. Also the antenna temperature at the reference position would depend critically on the flux density of the calibrator and the accuracy of the pointing. Thus if it is necessary to perform total power and interferometer measurements simultaneously, a good scheme would be to beam switch only on the source being mapped, and spend twice as long on that source as on the phase calibrator. Then for each type of observation only one third of the time would not be useful.

2. Total Power Observing Requirements

The overall reduction in sensitivity of the array resulting from the effective loss in observing time depends upon how many antennas are needed for the total power measurements, and for what fraction of the total observing time. This, in turn, depends upon the signal-to-noise ratio required in the total power measurements. Consider an image obtained from a single pointing. In the (u,v) plane the total power measurement adds only the point at the origin, and the noise that it contains is diluted by that of the much greater number of visibility data from the interferometer measurements. For example, with a 64x64 (u,v) grid, the rms noise level in the resulting image would be increased by only 1% by the addition of noise at the (u,v) origin with variance one hundred times the mean variance of the of the noise at the other (u,v) grid points. From this viewpoint a small fraction of time spent on total power would suffice. However, the total power measurement provides the base level of brightness in the image, and is an important parameter. A better approach, suggested by Cornwell (1990), would be to aim for similar signal-to-noise level in the visibility data that provide the major features of the image. The signal-to-noise ratio of the visibility data tends to decrease with distance from the (u,v) origin due to resolution of the source and decrease in the integration time. Thus the signal-to-noise level at the visibility origin should be similar to that of interferometer data at neighboring grid points in the (u,v) plane. The same conclusion applies to each pointing of a mosaicing observation.

The output signal-to-noise ratio for an interferometer is approximately twice that for a similar total power system. During a long observation (~8 hours) the contribution of each of the shortest-spacing antenna pairs will be spread over three or four cells in the (u,v) plane: for a snapshot it will be confined to a single cell. Thus to make the signal-to-noise ratio at the (u,v) origin approximately equal to that at the neighboring (u,v) points, the number of antennas operating in total power mode should be in the range one to four. If the source is wide enough that the visibility is significantly reduced at the shortest spacings, the number of total power antennas required is reduced. It seems safe to say that no more than four antennas, operating for the complete observing period, would suffice for the total power observations. Similarly, all 40 antennas operating in total power mode for about 10% of the observing time would also suffice. Cornwell et al. (1993) give more detailed discussion of the total power requirement, supported by numerical simulations. They also conclude that only a fraction of the full the array or the full observing time would generally be needed.

3. Concluding Remarks

Simultaneous total power and interferometer observation for 10% of time would result in an effective overall time loss of order 3%. Thus the overall loss in sensitivity is small and need not cause concern. Conclusions reached here should not affect the current plan to outfit all antennas for beam switching, to allow operation as 40 independent total power systems for some non-interferometric applications. Note that Cornwell et al. (1993) point out that it may be desirable to taper the antenna aperture illumination for total power observing to reduce ground pickup, so some compromise in the feed design may be necessary.

A related concern is whether the receiving system for total power observations will need to have tighter specifications than for interferometry. For example, low-level spurious signals in the local oscillator that are tolerable in interferometry could be deleterious to total power observations. The answer may not become clear until we have built and tested a fully instrumented antenna. If special measures are necessary for the total power electronics, these could first be applied to a small subset of antennas which would be used mainly to satisfy the total power requirement. The rest of the array could subsequently be brought up to the same standard, thus minimizing delay in bringing the array into operation.

References

Cornwell, T. J., Letter to the MMA Radio Panel, April 30, 1990.

Cornwell, T, J., Holdaway, M. A., and Uson, J. M., Radio-interferometric imaging of very large objects: implications for array design, Astron. Astrophys., 271,697-713, 1993.