Submillimeter Array Technical Memorandum

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Timing Accuracy for the SMA

Summary

I discuss the requirements for absolute time accuracy of the SMA clocks and of the accuracy of the phase synthesizers and computers at the antennas. The phase synthesizers will have to be synchronized by a timing pulse from the control building. This pulse can also be used to synchronize the antenna computers. The tightest requirement (12.5 μs) is set by phase switching but is comfortably greater than the expected cable delay of about 2.5 μs.

1 Introduction

The positional accuracy of the SMA will be determined by the accuracy with which the time is known, both absolutely and as time differences between the antennas. In addition, if separate phase synthesizers are used in the antennas to generate the phase-switching signals, the time at the antennas must be synchronized with the time at the control building to match up the modulation and demodulation patterns.

Figure 1 shows the pattern of interconnections which control the timing of the interferometer. The

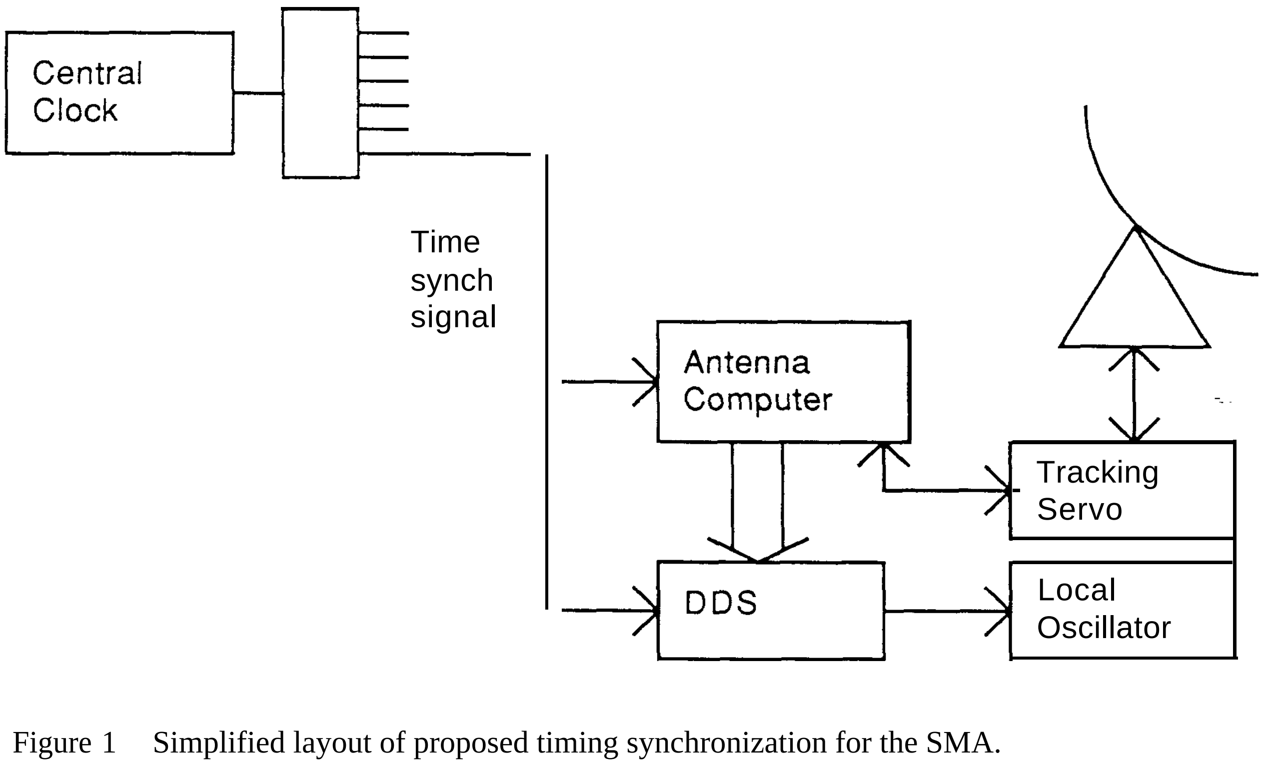

Figure 1 Simplified layout of proposed timing synchronization for the SMA.

central clock is derived from a standard broadcast signal, such as GPS, and a derived synchronization signal at some convenient frequency is sent out to the antennas. This could be at some standard interval, such as 1 pulse per second, or it might be more convenient for it to be at the update interval for the Direct Digital Synthesizer (DDS) which controls the antenna phase. This time synch signal is shown as driving both the computer and the DDS, but as will be shown below, the DDS is more critical, and some derivative of this signal may be used for the antenna computer. At a much slower rate, the complete time information will be transmitted by ethernet to the antenna computer so that it can determine the absolute time of one synch pulse and resolve the ambiguities.

In the analysis below, we will assume the following parameters for the instrument. The limits used are very conservative, so that no problems will arise if the interferometer is expanded by a modest factor (e.g. to 1 km baseline).

Baseline	500 meters		
Wavelength	350 microns		
DDS update	12.5 millisec	(based on Tech memo 56)	
λ/B	0,144 arcsec	(for 500m baseline and 350 microns)	
1.2 λ/D	14.4 arcsec	(for 6 m antenna and 350 microns)	
Allowed r.m.s.errors	0.01 fringe for interferometer		= 0.00144 arcsec
	0.01 beam for single-dish pointing		= 0.144 arcsec

These errors are absolute in that no allowance is made for frequent calibration by observations of pointing or phase calibrators. However static errors will be absorbed into baseline vectors and pointing constants, so these tolerances represent the maximum allowed changes over approximately a 1 month timescale between times when pointing constants and baselines are determined.

2. Position accuracy of interferometer

This can be considered as the accuracy of pointing of the synthesized beam of the interferometer. We have set a very tight specification here of 0.01 fringe, roughly 0.01 of a synthesized beam at maximum resolution, to make sure that timing errors will never be a problem in normal operation, and to allow for occasional special experiments which will require very high precision in position measurement.

As mentioned above, an overall constant time error will have no effect on the interferometer. If the clock is always slow by X milliseconds, the baselines measured astrometrically will all be rotated from their true values by 15 X arcseconds about a polar axis. This error in baseline orientation will exactly compensate for the clock error. Any clock drift between the time when the baselines are determined and the time of an astronomical observation will, however, give rise to position errors. For a pointing error of 0.00144 arcsec, in the worst case we require that the clock should be accurate to 0.00144 / 15 sec = 96 μs.

The part of the system which requires to be maintained at this accuracy is the the phase rotator, which, in effect, controls the pointing of the synthesized beam. In our system we plan to have the phase of each LO controlled by an independent DDS in each antenna. This DDS provides a programmable phase offset which is added to the LO signal which is distributed equally to all antennas. To maintain an accuracy of 96 μs for the difference between any two DDS's, each one should be accurate to 68 μs. This sort of accuracy might be just attainable by a computer controlled system, if a very fast operating system was used and care was taken in sychronizing the antenna computers, but it would not be easy. Therefore it seems much simpler and more robust to distribute a timing signal directly to the DDS in each antenna. This could take a separate fiber, or it could be multiplexed on to one of the existing fibers. The time delay for a 500 m fiber path should be no more than about 2.5 μs, if the velocity is 0.75c.

In normal operation, then, the antenna computer would prepare the phase information in advance for the DDS. On receipt of the timing pulse, the information would be clocked into the DDS, which would then adjust the LO phase appropriately. Then the antenna computer needs to be accurate only to about 6 msec, or half of the DDS update interval. It should be easy to achieve this without any special precautions.

The hardware requirement is to have a buffer arrangement which will allow the phase information to be stored until the timing pulse arrives. If the timing pulse interval does not match that of the DDS updating, then some mechanism must be provided to derive the DDS signal from the timing pulse.

3. Pointing of individual antennas

Since the beam of the individual antennas is much larger than that of the interferometer, the timing tolerance is correspondingly relaxed. For the required accuracy of 0.144 arcsec, in the worst case we require that the clock should be accurate to 0.144 / 15 = 9.6 ms. This is a loose enough spec. that it can be handled directly by the antenna computer, which is already required to maintain a better accuracy (6 msec) for updating the phase rotators. As in the case of the interferometer, any fixed time error will just be subsumed into a pointing constant, and will have no effect.

4. Phase switching

The final requirement is that the timing of the phase-switch modulation at the antennas must match the demodulation at the correlator. This is a slightly different effect from the errors discussed above, since it does not cause erroneous measurements, but any timing offset will reduce the signal/noise ratio. For the signal loss to be less than O.l%, the time offset should be less than 0.1% of the phase switch period, which is equal to the DDS update period. The time difference between the correlator and the DDS should be less than 12.5 / 1000 msec, or 12.5 μs. This is a tighter constraint than the 68 μs required for good positional accuracy, but still achievable with simple direct distribution of a timing signal from the control building if the cable delays are about 2.5 μs. This error is also different from the ones above in that it is only a relative tolerance between two parts of the interferometer system. There is no absolute timing precision required for this function.

5. Chopper control and demodulation

A final timing constraint is set by the demodulation of signals received in the mode where the chopping subreflector is operating. With operation at 10 Hz, and mechanical transit times of several msec, the timing accuracy required here is no more than 1 msec. This should be easily achieved with a system which can match the requirements described above, although a mechanism should be included for sending timing signals back from the antennas to the correlator with lmsec accuracy. Again this is a relative tolerance only.

6. Summary

The tightest timing requirement is set by the synchronization of the phase switching at the DDS in each antenna with the demodulation at the central correlator. For 0.1% loss, the time accuracy should be less than 12.5 μs. This is too tight a constraint to be handled by the antenna computer directly, but can easily be handled by synchronization of the DDS's by a timing signal distributed from the control building. The antenna computer should be synchronized to an accuracy of about 6 msec to handle single antenna pointing and about 1 msec for the chopping subreflector.

Tony Stark points out that it is possible to buy VXI clock boards which automatically synchronize to an IRIG B time signal, with an accuracy of about 1 μs. They also have timers which could be used to strobe the phase control, and they provide features like event-capture (recording the time of an external trigger).