Submillimeter Array Technical Memorandum

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SMA Timing Signals
From The Phase Rotator to The Correlator

I. Introduction

This memo examines some of the timing signals which are required for operation of the SMA telescope. In particular, I will consider the clocking and timing signals which run the IF, baseband converters and correlator. This is the first step towards the design of a central timing generator that will produce the necessary waveforms. Also, these issues require some clarification to ensure the proper hooks exist within the system.

II. 10 msec tick

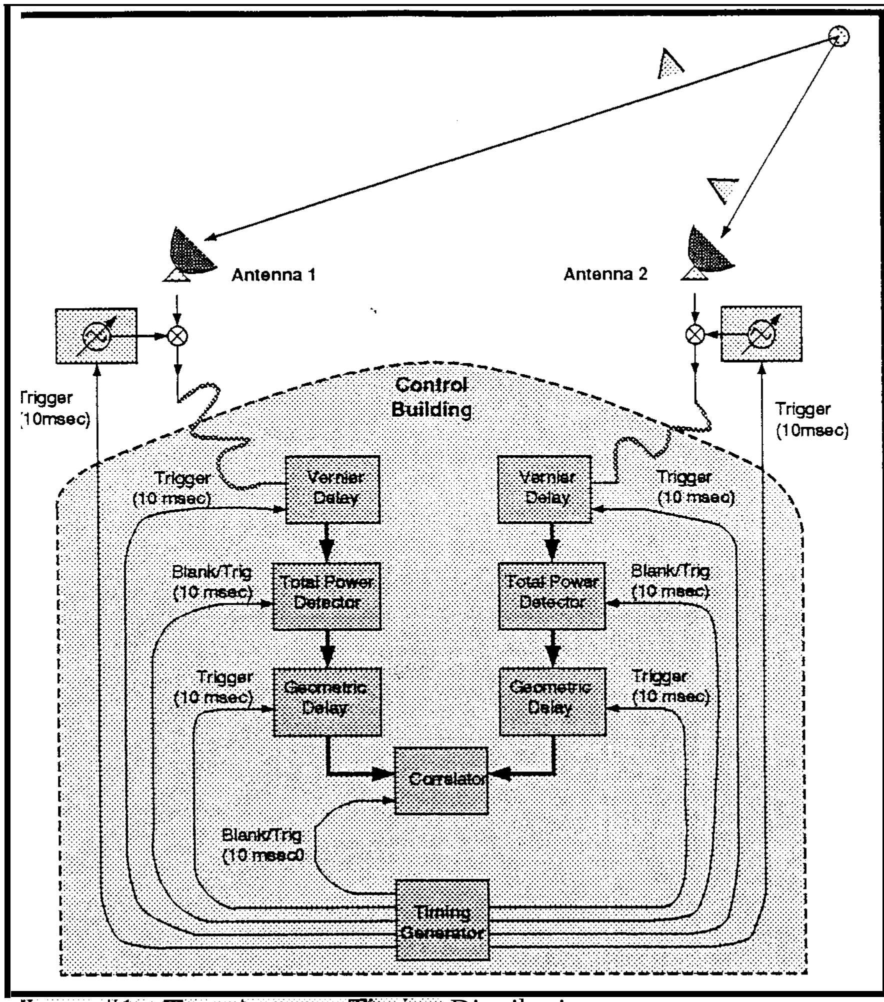
The fundamental timing interval and data acquisition cycle in the SMA telescope is a 10msec period. During this interval, most system parameters are held constant. At the end, data is unloaded from the correlator chips. The 10msec timing must be distributed to numerous locations in the data processing path, including all the telescopes. Also, the software in the correlator must stay synchronized with this cycle to properly process data as it is read. Not surprisingly, the synchronization of this timing interval is essential for the operation of the SMA.

The following discussion will address some of the synchronization issues of this fundamental cycle. The first part deals with delays in the data path. Second,I propose a method for tracking the timing cycle for the DSP chip on the correlator board. Finally, I briefly consider phase synchronization at the telescopes.

II.A. Data Skew and Blanking

Please note, this analysis makes a few assumptions about the location of signal processing elements. Some of these decisions are not final. If these items move, it may alter some of my conclusions.

After detection at the telescope, the astronomical data undergoes a succession of signal processing operations. Each of these operations must be performed synchronously with respect to the 10 msec data acquisition cycle. (Referred to the astronomical source, data synchronization refers to a point in time on the same plane wave.) In general, changes to system parameters (delay, phase,etc.) occur only between 10 msec cycles. To allow for transients in the data produced by changing parameters, there will be a dead period (or blanking), when data is ignored by the correlator. The length of this blanking time must encompasses all settling times of the transitions which occur in the data. The application of a parameter change occurs at varying locations in the data path. Consequently, the blanking period must consider any delay between the generation of a transient and its arrival at the correlator (where blanking occurs). This leads to the problem of how best to control the timing signals



'igure #1 - Two Antenna Timing Distribution

of the instrument to minimize blanking time (i.e latency) between 10 msec data windows.

Figure #1 presents a sketch of the telescope system. The size of the array is such that the propagation delay of signals cannot be ignored. For example, consider a triggering signal which is generated at the control building. This pulse is used to signal a change in the phase rotation (at an antenna) and the vernier delay (in the control building). Because of delays in transmitting this trigger to an antenna, the phase rotation will appear in the data stream 2 usec after the change in vernier delay. Half of this skew is caused by the transmission of the signal, while the rest of the time is spent getting the data back to the control building.

The previous scenario was based on a centrally generated trigger which is distributed without regard to propagation delay. In practice, this option

Timing Signal	Time delay until completion of transient in data stream at correlator	Time delay unit completion of transient in data stream at Power Detector
Phase Rotator	2 *Tc(C) + Tv(A,P) + Td(A,P) + Sp	2 *Tc(C) +Tv(A,P) + Sp
Vernier Delay	Tv(A,P) + Td(A,P)+ Sv	Tv(A,P) + Sv
Geometric Delay Compensation	Td(A,P) + Sd	N/A

Table #1 - Transient times referenced to the data taking points.

Where

Tc(C) = Delay in fibre optic cable to telescope {function of array configuration (C)}

Tv(A,P) = Vernier delay time {function of antenna (A) and source position(P) }

Td(A,P) = Time in digital delay unit

Sp = Settling time of phase rotator

Sv = Settling time of vernier delay

Sd = Settling time of digital delay

Sa = Settling time of ALC in baseband converter is quite reasonable if the data blanking period is extended to encompass both the switching transients and the propagation times. In summary, one possible approach would utilize a single triggering pulse (centrally generated) to define the 10msec period and then extend the data blanking period to cover all the disruptions in the data. As a results, parameter changes will appear in the data stream at various times in the blanking period. This approach is very easy to implement, but obviously requires a somewhat extended blanking period, thereby reducing the effective sensitivity of the SMA. (Worst case, the blanking period would need to be extended about 10 usec for a loss of 0.1%)

Table #1 gives a listssome of the systematic delays referenced from the correlator. Data blanking would begin with the 10 sec trigger and continue for the worst case listed in Table #1.

One notable complication concerns the total power detectors. These detectors perform a data acquisition before the geometric delay compensation (digital delay) is applied. Ideally, the measurement taken by the total power detectors and the correlator should be from the same time window. A small skew in the acquisition windows would probably be an acceptable simplification. However, it would not be acceptable to allow switching transients to enter the power detector. (If the same signal is used to control triggering and blanking, then cable lengths are critical to ensure the blanking arrives at the power detectors at, or before, the vernier delay) In the simple scheme, an extended blanking period must provide complete blanking for the total power detectors. In the simple trigger scheme, the data acquisition window used by the power detectors will be out-of-sync with the correlation data by the depth of the digital data delay network (worst case about 3 usec).

Now consider an improved alternative (refer to Figure 2). By delaying the application of the 10msec timing signals to compensate for systematic delays, it is possible to synchronize the “interruptions” to the data. Thus, the application of all parameter switches will occur during the same effective position in the data stream. These delays are the complements of the expected data delays. The necessary delays to the trigger/blanking signals are listed in Table #2. If this is done perfectly, the data blanking can be reduced to the period of the slowest switching

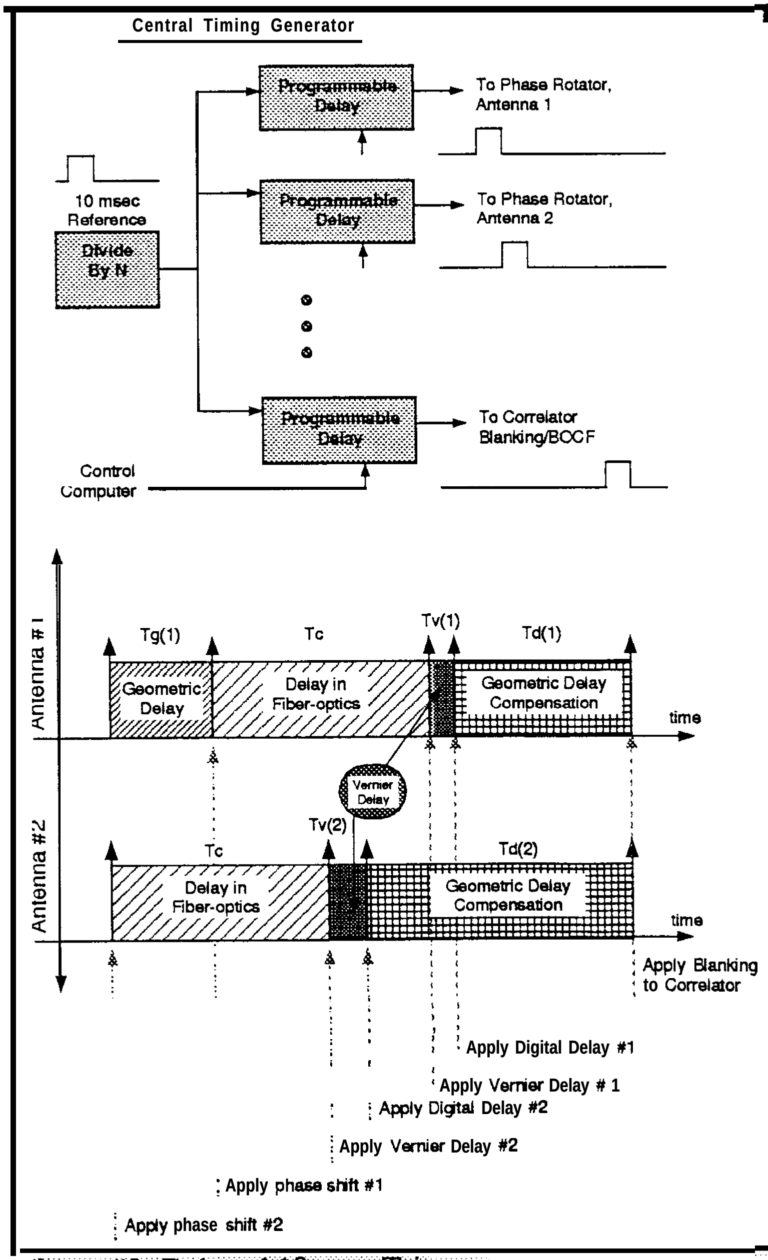


Figure #2- Delayed 10msec Triggers

Timing Signal: Antenna: A Configuration: C	Delay applied to Timing signal to ensure application on same position in data stream
Apply Phase Rotate	Tp(A)
Apply Vernier Delay	Tp(A) + 2 Tc(C)
Power Detector Blanking Start: Period:	Tp(A) + 2 Tc(C)+Tv(A) Max(Sp,Sv,Sd,Sa)
Apply Digital Delay Compensation	Tp(A) + 2 Tc(C) + Tv(A)
Correlator Data Blanking Start: Period:	Tp(A) + 2. Tc(C) + Tv(A) + Td(A) Max(Sp,Sv,Sd,Sa)

Table #2 - Compensationing delays in trigger generation

Where

Tp(A) - delay-of this antenna from delay center of array (free space]

transient. The first signal to be sent is the trigger for the phase rotator. Conversely, the last 10msec signal will be the blanking to the correlator.

The blanking for the power detectors would be treated like any other timing parameter and shifted to cover the same effective data acquisition window as the correlation measurement. In this scheme there is no skew between the data measured in the correlator and power detectors.

A glance at table 2 raises some issues. First, the number of separate adjustable delays networks that are needed to implement this network is 5 per antenna for a total of 31 for the whole telescope (the blanking to the correlator will be identical). The delay will need adjustment when the antenna configuration changes. Also, the delay will need to track the changing geometric delay during an observation. Thus, this circuitry approaches the complexity (but not quite the size) of the digital delay network in the data.

In practice some simplifications are possible. As noted before, a longer blanking period can be used in place of timing delay. A hybrid scheme is possible where some of the delays are simply

Timing Signal: Antenna: A Configuration: C	Delay applied to timing signal Simplification #1: 13 flavors of trigger	Delay applied to timing signal Simplification #2: two flavors of trigger
Apply Phase Rotate	Tp(A,P)	0
Apply Vernier Delay	Tp(A, P) + 2 Tc(C)	2 Tc(C)
Power Detector Blanking Start Blank: Period of Blank:	Tp(A,P) + 2 Tc(C) Max{Tv} + Max{Sp,Sv,Sd,Sa}	2 Tc(C) Max{Tv + Td} + Max{Sp,Sv,Sd,Sa}
Apply Digital Delay Compensation	Tp(A, P) + 2 Tc(C)	2 Tc(C)
Correlator Data Blanking Start Blank: Period of Blank:	Tp + 2 Tc + Td - see- note- Max{Tv} + Max(Sp,Sv,Sd,Sa)	2 Tc(C) Max{Tv + Td} + Max{Sp,Sv,Sd,Sa}

Table #3 - Simplified compensating delay approaches

Note - Min{Tc + 2 Tc + Td} should be equal for all antennas in a given configuration. This is because the digital delay (Td) is an active attempt to compensation for Tp. Thus, only one blanking signal is required for all correlator data.

ignored with extensions to the blanking period used to correct this simplification. For example, the "vernier delay" is very small. Therefore, if we trigger the vernier delay and the digital delay with the same signal, the extra data blanking required is equal to the maximum delay in the vernier delay (≈100 psec). Similarly, this same pulse could be used to define the V/F blanking. This would reduce the number of required delay networks to 13. As in the previous scheme transients from different antennas will converge on the correlator at roughly the same time. Thus a single blanking period applied to the data will be very close to optimum.

Another possible simplification is to generate only two timing pulses: one for the antennas and one for the control room. The delay to the telescopes is virtually identical in a given telescope configuration. Thus with only two flavors of timing it is possible to eliminate one major source of skew (i.e. the propagation in the fibre optic cable). Implementation of this scheme is very simple because the compensating delay will not change unless the antennas are moved to different pads. Thus, the computer interface to the timing generator can be very slow. The necessary timing is given as option 2 of Table 3.

There are some disadvantages of the two-flavor method to consider. First, the power detectors and correlator will operate in slightly skewed data windows (which is related to the length of the digital delay). Also, transients will arrive at the correlator at different effective times. Consequently as with the simple case, blanking must be extended by the worse case propagation through the digital delay network. This could be as much as 3usec.

Initial it seems prudent for the SMA to implement the two-flavor trigger method. However, as time permits, more elaborate methods maybe considered, particularly if longer baselines are implemented.

II.B. Phase Synchronization at The Correlator Board

There is another aspect of the 10 msec timing which is critical to SMA operation, i.e. the need for data window identification. When data is read from the correlator chips (by the on-board DSP), it must be properly classified for post-integration. Each of the 48 (or 64) correlator boards must know which phase of the data it is reading. It may be possible to synchronize this timing over the VME bus with a trigger. However, my preference would be to incorporate some simple hardware on the correlator board. It is quite conceivable that the software could maintain the 10msec clocking. However, the additional hardware is quite modest. Therefore, if it proves unnecessary, it can be used as a sanity check.

(Note, there is a longer cycle of 320 msec which is made up of 10 msec blocks. This cycle timing is easily handled over the VME bus.)

Figure #3 gives a sketch of a possible timing implementation. At the beginning of a 10 msec integration cycle, all 48 DSP computer must know where to integrate the data that is sitting in buffers within the correlator chips. Most likely, the DSP will have a lookup table supplied by the central control computer which defines the anticipated Walsh function switching pattern. To integrate the data, the DSP must know the phase of the buffered data. The simplest solution would be an on-board register which is loaded from the central timing unit. Since the central timing unit issues the triggers to the phase rotators, synchronization can be readily achieved. A pure software scheme for this timing may be possible, but would require a relatively (in software terms) fast communication path from the central timing control to the correlator controller. A software solution would force the correlator control computer to have 10 msec visibility, which is otherwise unnecessary. Although possible, I submit that a pure software scheme is more complicated and prone to errors than the simple and direct

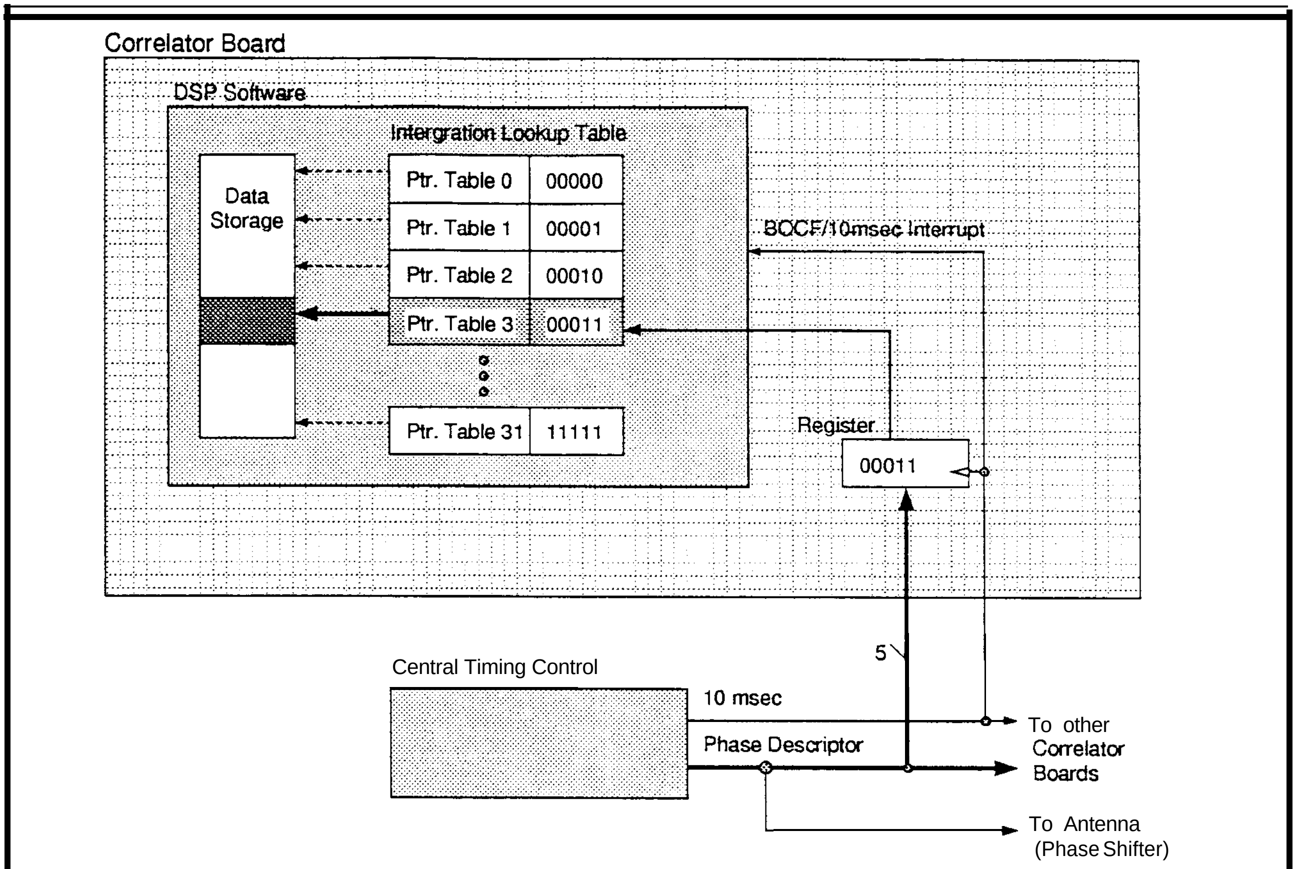


Figure #3 - Correlator board: 10msec assignment

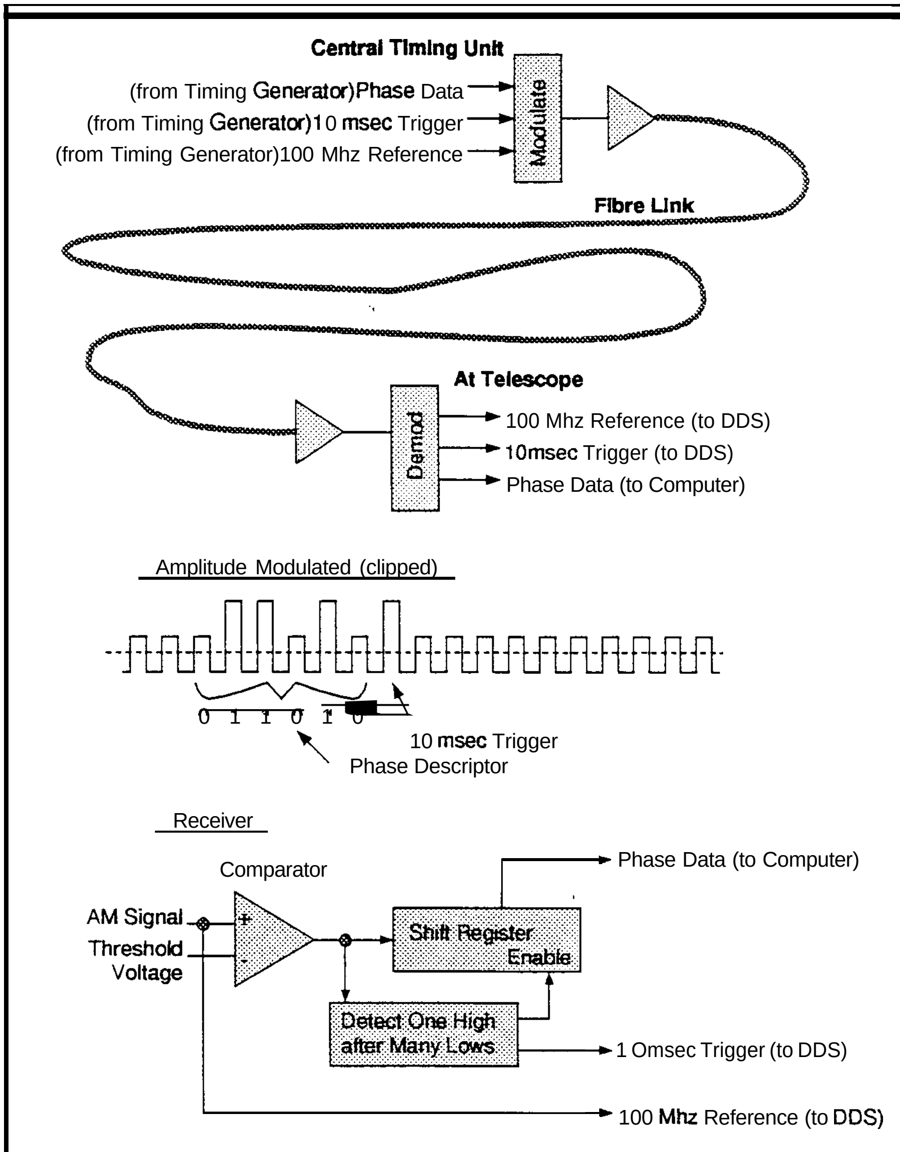
schemesuggested in Figure 3.

II.C. At the Telescope

To perform Walsh function sideband separation and phase switching requires an accurate relative phase shift in the LO of each antenna. To ensure relative phase requires each LO circuit to perform a given phase change on the same pulse of the reference clock. This reference clock is 100 MHz (proposed). Therefore, the trigger to initiate a phase shift must maintain a minimum10 nsec precision. Although, this is not an extremely difficult problem, it has the unpleasant consequence that small errors (missed cyckles) would be difficult to trace. If one antenna were to be off by one cycle the instrument would operate, but with an annoying loss in sensitivity and image rejection.

This synchronization raises a number of issues. How should phase changes be triggered? What method should be used to verify they are operating properly? How often should this be checked? There many ways to implement this synchronization. I will sketch one possibility for this circuitry.

In practice there are three pieces of information that we would like to transfer to the antennas with accurate timing: the Reference clock, 10msec trigger and a phase descriptor. The phase descriptor is equivalent to the identifier number sent to the correlator board. It will inform the LO control of the phase it will apply during a given 10msec cycle. Over a short distance, these signals could be sent over independent cables (like the interface to the correlator board). However, for transmission to the telescope it will be necessary to module this information over one fiber optic link. One option would simply place all this information on different frequency bands of the cable. However, this would



igure #4 - Telescope triggering . . .

complicate the fiber optic system. Another possibility is to code all these pieces of information into one signal before the fiber.

The encoding (modulation) of the information can be done in several ways. For example, the reference clock could act as the carrier of an amplitude rnodulated signal. (See figure #4). The trigger could be rnarked as the first high power cycle (logical one) after a string of low power clocks cycles (logical one). The phase descriptor could be encoded in an equivalent manner in the cycles which precede the trigger. The clock extraction is very simple in this case. The data can be detected with a high speed comparator (much like the one used in the correlator). A computer at the antenna could perform a large number of sanity checks given this information. For example, there should always be a fixed number ofreference cycles between a trigger, otherwise an error has occurred. Also, the antenna computer know the sequence of expected phases, and therefore can detected a missing phase. A large number of self-recovery modes are also possible. The main difficulty in this scheme is the modulator. But this is not an insurmountable problem and has the advantage that only one modulator is needed for the whole instrument, so cost is not critical.

Other encoding schemes are possible, such as phase modulation. The application of different coding schemes will depend on available hardware.

One practical concern for the proposed scheme is the jitter which is created in the reference clock by modulating it. In general it should be possible to limit any significant jitter to the period when the triggering is encoded. During this period, data is blanked, so clock jitter is not especially critical.

Short List of necessary timing control signals

Name	Freq(Period)/Duty Cycle	Form	Note
Sampler Clock	212 (160) Mhz	ECL Levels	
Correlator Clock	53 (40) Mhz	TTL Levels	Always 1/4 Sampler Clock
V/F Converter Clock	2-4 Mhz	TTL Levels	