

# Technical Systems Configurations -- Electrical

Subsystem: Instrumentation - Timing

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## 1. Requirements:

Global Timing provides two critical signals to all parts of the ~30 km machine complex: An RF phase reference clock that is a sub-multiple of the system master clock; and a precise time marker (fiducial) for pulse timing that is phase locked to the master clock and is distributed with the reference clock to all parts of the machine complex. All RF power sources are stabilized with respect to the reference clock (and therefore the master), and all pulsed signals are triggered in one way or another from the fiducial clock. Both phase and timing must be stable to very high accuracy at any point in the machine: Phase should be stable at least to  $<20^\circ$  X-band, or 5 picoseconds long-term,  $<1^\circ$  X-band during beam phase measurement; and triggers to  $<5$  picoseconds with minimum step size for beam pulse bunch train generation of 1.4 nsec. This performance requires a highly stabilized distribution system from the central master clock. Additionally, the timing system must be very robust against single point failures that could bring machine operations to a halt.

## 2. Technical Description

2.1 Block Diagram: A block diagram of the global timing system is shown in Fig. 2.1 (J.Frisch et al). The system origin is near the interactions region between the two linacs. Redundant master clocks at 714 MHz, locked to a Rubidium source or GPS satellite and to one another, drive completely redundant fiber optic links to the sector alcoves of the main linacs, as well as to appropriate receiver locations in the injection/ damping ring and beam delivery areas. The fibers reside in a separate tunnel (away from radiation) that is stable to about  $5^\circ\text{C}$  with diurnal and annual temperature excursions. Stabilization may be accomplished either by burying the cable deep enough, or by temperature stabilizing the cable.

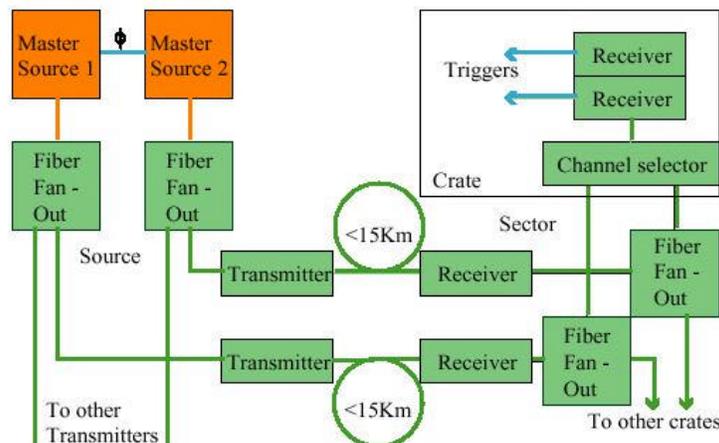


Fig. 2.1: Simplified Block Diagram – Typical Sector Channel

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2.2 Redundancy: Note that because machine protection requires that no single-point failure can be allowed to drive the beam into the wall of the structure, which could cause irreparable damage and necessitate replacement of the structure, a fully redundant system is planned. As shown in Fig. 2.1, each sector receives *two* fibers, each carrying the needed clock and timing fiducial, both of which are used (OR-ed) to generate local signals. If one channel fails, the other automatically takes over, and the control system senses that one of the channels has failed so appropriate remedial action can be taken at the next maintenance opportunity. Meanwhile, operations continue without interruption.

2.3 Fiber Stabilization: The stability of uncompensated fiber is insufficient, so a stabilization scheme has been developed based on oven control of a separate length of fiber in series with each of the  $\sim 100$  long-haul fibers. Control is achieved by sending a laser diode generated 714 MHz signal to the end of the  $\sim 15$  km maximum length fiber, reflecting a portion of the signal from a mirror back along the fiber. During a short interval when the laser is pulsed off, the reflection phase is compared to the transmitted signal (Fig. 2.2).

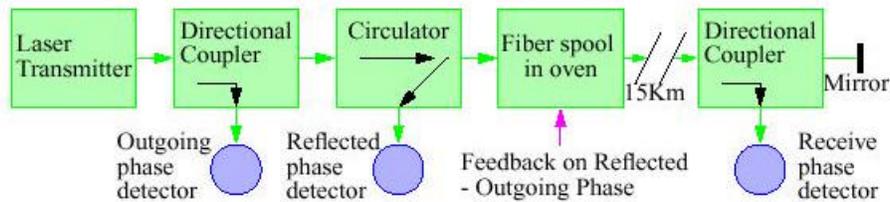


Fig. 2.2: Fiber Length Compensation Scheme

The phase error-signal drives the temperature of the compensating fiber to keep the phase/length constant to  $\sim 1^\circ$  X-band. A laboratory prototype test has successfully demonstrated this performance.

2.4 Laser Diode Frequency Stabilization: The laser diode sources also need local stabilization of temperature or they will drift and mode hop, resulting in timing jitter. For this reason, the laser diodes are included in a phase stabilized loop, as well as temperature controlled.

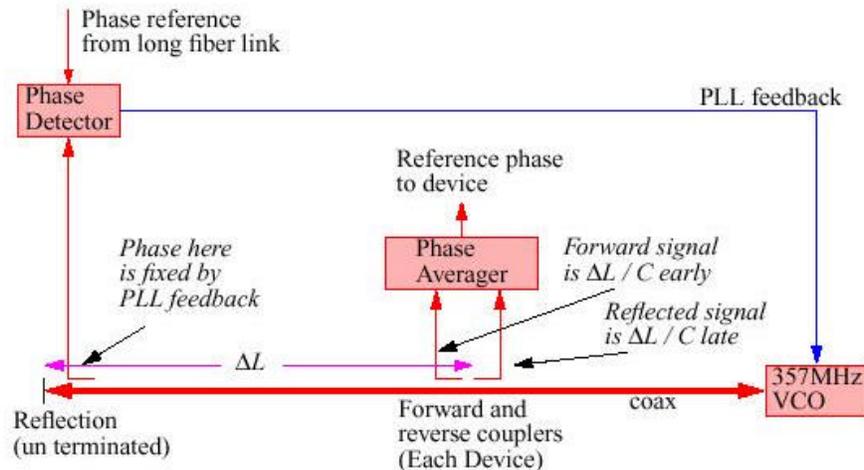


Fig. 2.3: Sector Phase Reference Coaxial Cable Distribution

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**2.5 Sector Tunnel Distribution:** Within the ~450m sector, fibers will not survive, so timing must be transmitted in the radiation environment of the tunnel using a coaxial cable and a combination of temperature and feed-forward compensation. The concept is shown in Fig. 2.3. In this scheme, tunnel cooling water can maintain temperature to ~0.3°C, but the reference cable stabilization should be the equivalent of 0.03°C. There are ~100 pickoff taps along the sector cable, each supplying a reference to a Tunnel Electronics Enclosure (TEE). The coax is fed from one end and reflects from its far end, setting up a standing wave. Each TEE location taps off a forward and reflected signal to obtain an average phase reference that is stable regardless of small length variations due to temperature.

**2.6 Sector Alcoves:** In protected areas such as the sector alcoves, fibers can be used for timing signals that travel only short distances. These do not need separate temperature compensation, since the machine areas are relatively temperature stable once operating conditions are achieved.

**2.7 Reference Frequency:** For the power RF sources, the master clock reference of 714 MHz is locally multiplied to obtain the 11.424 GHz for the klystrons in the main linacs, for example, and the lower pulsed and CW frequencies needed for damping rings and injection linacs.

**2.8 Timing Fiducial Generation and Detection:** For instrument and pulse source timing, the master clock reference has superimposed a phase modulation of single cycle duration that is demodulated at each sector to generate a time marker. A special receiver chip, located in each device needing triggers, detects the fiducial and under internal program control, generates triggers that have the appropriate widths and delays.

**2.9 Parameter Tables:** Table 2.1 shows the basic requirements for the RF distribution and timing system, together with test results achieved as of March 2000. Beam phase measurements at S-Band on the existing SLAC linac are also included.

Parameter	NLC System	Test System (Measured)
<b>1. Fiber Optic Long Hauls</b>		
Fiber Transmission Distance	1-15 kilometers	15 kilometers
Fiber Temperature Range	±5°C*	±5°C
Fiber Type	Single mode – fused silica	
Fiber Expansion Coeff.	5*10**-7/°C	
Fiber Phase Coeff. (15 km)	2800°X-band/°C/15km	2200°X-band/°C/15km
RF Transmission Frequency	714 MHz	357 MHz
RF Frequency Stability	3*10**-9	
RF Phase Stability – Long Term	<±20°X-band (+/-5 psec)	±3°X-band (3-day test)
RF Phase Stability – Short Term (1 second)	<±1° X-Band RMS	<.02°X-Band RMS/°C
RF Phase Temperature Coeff. – Closed Loop	<4° X-band/°C	<2.5° X-band/°C
RMS Phase Noise – Closed Loop	<0.3°X-band, <10 KHz BW	0.9°X-band, <10 KHz BW
Timing Minimum Step	1.4 nsec	
Timing Resolution (vernier)	1 psec	
Timing Stability (long term)	<5 psec	
Timing Jitter (RMS)	<10 psec	

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<b>2. Sector Distribution Cable</b>	<b>NLC System</b>	<b>Test System (Measured)</b>
Coaxial Cable Type	RG – XXX Reflecting lines w/ averaging F/R pickoffs	
No. Pickoffs/460m sector	~100	
Pickoff Phase/Timing Jitter		
Short term		
Long Term	<0.3° X-band/600M	
Temperature Variation	0.3°C RMS	
<b>3. Beam Phase Measurement (S-Band)</b>		
Single pulse noise		0.3° S-band RMS (Calib'n)
Linearity		<0.3° S-band over 20 dB
Drift Beam vs. RF		±2° S-band over 10 Hours

\*Based on SLAC summer/winter temperatures and 1m burial depth.

2.10 Timing Receiver & Local Generation: The Fiducial Receiver is shown in Fig. 3.1. The trigger generator circuit is similar to the existing SLAC PDU, but includes several extra functions. The Receiver/Trigger Generator will exist in two forms; as an imbedded device and as a module. Using Xilinx technology, the unit can be realized in two chips. The following triggering outputs would be provided, (counted in cycles of 714MHz):

- Pulse would start Tstart cycles after the fiducial.
- Pulse would stop Tlength cycles after Tstart.
- Pulse would repeat after Tperiod cycles.
- Repetition would continue for Npulses number of repetitions.

The triggers should have the following set of default actions:

- No new pattern received: Select either repeat previous output, or disable output.
- No fiducial received: Select either continue previous output (at a locally determined fiducial time), or disable output.

### 3. Technical Issues

3.1 Basic Approach: The long-haul fiber optic compensation feasibility has been demonstrated on a bench prototype. The sector coaxial distribution has not yet been demonstrated but is planned.

3.2 Phase Locked Loops: Loop range of control in the prototype is marginal and needs improvement. Thermal properties of laser diodes need further study.

3.3 Fiber Trench Temperature: The expected diurnal and annual range is based on calculation for a California site. The trench model needs detailed examination.

3.4 Timing Fiducial: The generation and detection of timing fiducials has been demonstrated at 357 MHz in a bench test. Proper detection may be difficult from the sector cable with many reflections due to a large number of pickoffs. A demonstration system is in progress.

3.5 Packaging & Reliability: The present prototype contains many parts that need a large packaging design effort to develop a field model. Design effort is needed to create a

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robust unit from the many strung-together parts. The current prototype plan is modeled on the block diagram of Fig. 3.1.

**3.6 Temperature and Field Tests:** A packaged prototype is needed for proof of principle in which the electro-optics package as well as the fibers are subject to realistic temperature excursions. Immunity to electromagnetic interference also needs testing under realistic conditions.

All of the above issues are addressed in the current R&D plans.

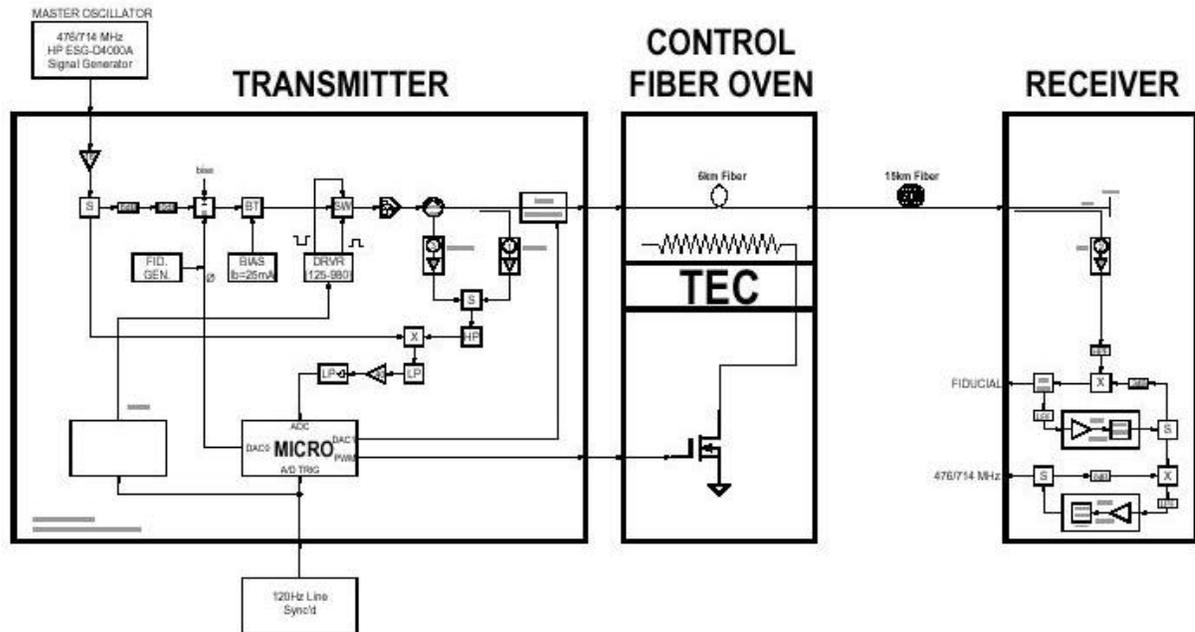


Fig. 3.1: Packaged Prototype Development – Block Diagram

## 4. Discussion of Configuration Choices

**4.1 Fiber Optic Length vs. Laser Wavelength Tuning:** The first approach envisaged was to feed back phase errors due to fiber length changes to control the wavelength of a source laser for each sector. This was found not to work because of limitations of the source in responding without mode-hopping and losing the information. The second approach, to use a compensating section of about 1/10th the fiber length and feeding back to an oven to raise or lower its temperature (E. Cisneros proposal) was then tried and has worked well. The first scheme would avoid the use of ovens, which is advantageous, but currently no promising devices are available for further tests.

**4.2 Fiducial Generation:** Generation and extraction by phase modulation of 357 MHz has been demonstrated on the bench. The scheme should extrapolate to X-Band without difficulty. The base frequency in the gallery and tunnel will be raised to 714 MHz to accommodate 1.4 nsec bunch spacing more easily.

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### 5. References

1. *NLC Phase and Timing Distribution System*, D. Bernstein et al, Lehman presentation, May 1999, <http://www-project.slac.stanford.edu/lc/local/Reviews/lehman99/pdf/FrischTimingtalkCD1.pdf>. Talk by J. Frisch on original concept of wavelength tuning solution, status and future R&D plans.
2. *The NLC RF Phase and Timing Distribution System*, J. Frisch, D. Brown and E. Cisneros, May 30, 2000, [http://www-project.slac.stanford.edu/lc/local/Reviews/May2000Review/Presentations/Timing5\\_30\\_2000-JFrisch.pdf](http://www-project.slac.stanford.edu/lc/local/Reviews/May2000Review/Presentations/Timing5_30_2000-JFrisch.pdf), Talk by J. Frisch to MAC Committee at Fermilab on fiber temperature compensation feedback test results and R&D plans.
3. NLC Timing System Meeting Notes, E. Cisneros, <http://www.slac.stanford.edu/cgi-wrap/search-mtg?L=accel/nlc/local/notes/timing/&L=http://www-project.slac.stanford.edu/lc/local/notes/timing/>. Notes from meetings including activities and measurement results of prototype testing, future plans.