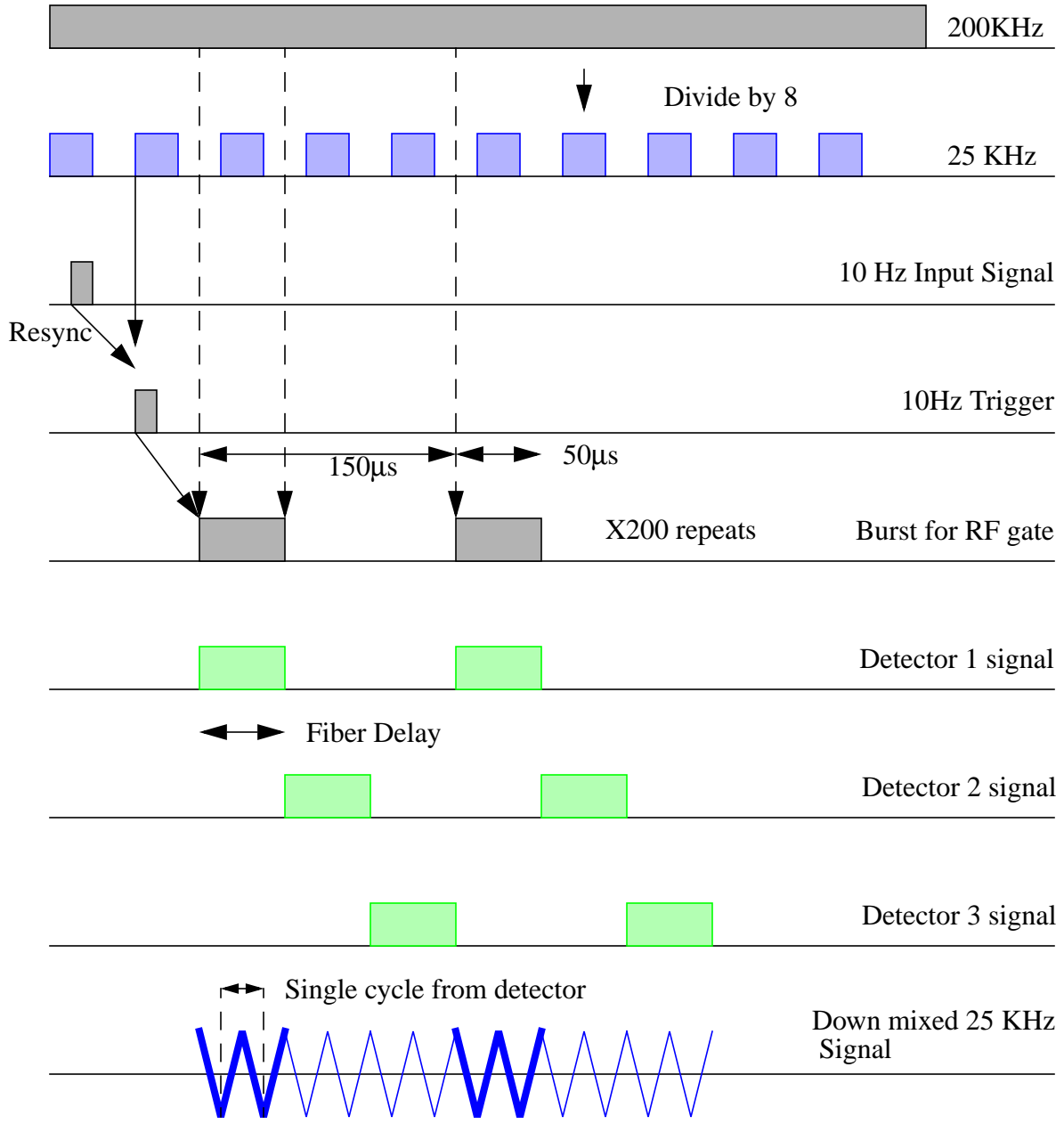




### System Timing:



Entire cycle repeats at 10Hz. Note that burst spacing is determined by fiber length.

## System Detailed Operation

The primary frequency source is a 357MHz synthesizer. This is 1/32 sub harmonic of the accelerator X-band, and is used to transmit phase information.

Direct digital phase detection is used. A 16 bit (~13 bit effective) digitizer operating at 200KHz is used to 8X over sampled a 25KHz IF. The I and Q components are obtained by

$$I = \sum_n f(n) \cos(\omega t_n) \text{ and } Q = \sum_n f(n) \sin(\omega t_n). \text{ The phase is determined by } \phi = \text{atan}\left(\frac{I}{Q}\right).$$

The use of 8X over sampling provides immunity to second and third harmonics present in the IF signal.

A 50 $\mu$ s optical pulse is transmitted through the system. The fiber delay (65 $\mu$ s for 15Km) allows time multiplexing of the signals. The pulse will be down mixed to a single cycle of 25KHz plus a few samples at the pulse ends. This pulse is repeated 200 times for each 10Hz data set. The resulting IF is digitized and averaged over the 200 cycles. The resulting averaged signal is used for phase measurements.

The 25KHz is generated with a 357.025MHz LO. The IF is phase locked to the 200KHz master clock. Note that a low frequency (25KHz) mixer is used in this loop for convenience. A precision analog multiplier would provide better performance.

For the actual fiber tests, only the phase differences between the detectors are important, the individual phases are not important. We have attempted also to stabilize the individual detector phases relative to the initial RF to allow easier debugging, and to study phase detection for the final system.

For these tests, the RF switch and optical systems were bypassed. We were testing only the phase detection circuit itself.

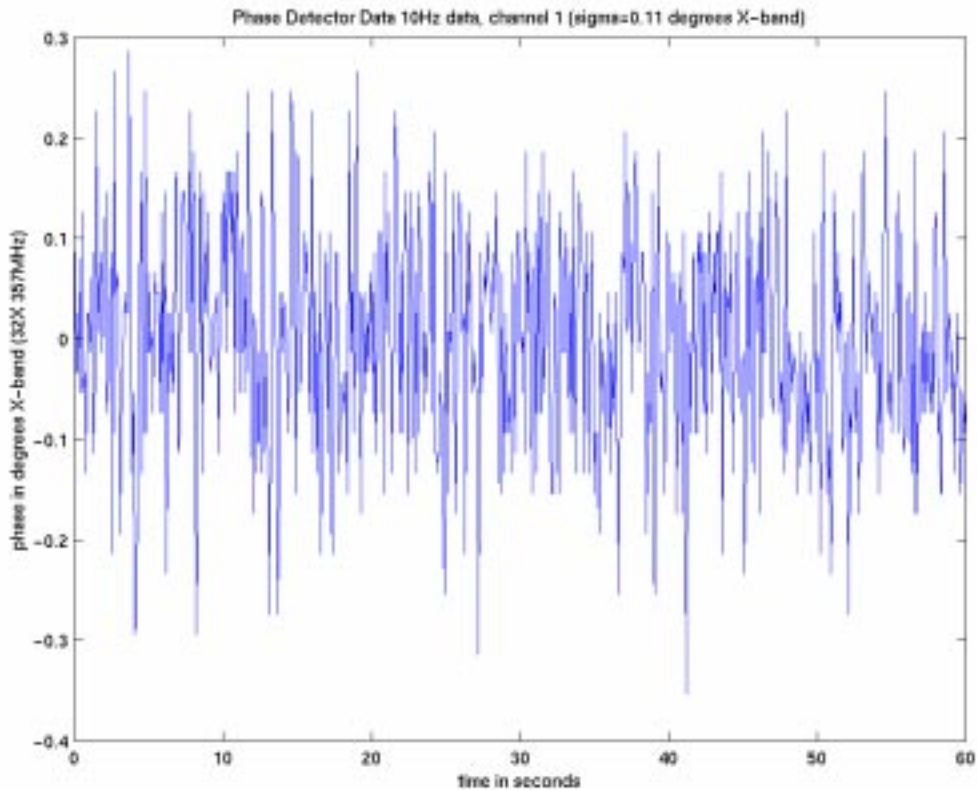
Note that the data rate was limited to 10Hz due to the non-real-time nature of the PC operating system (NT). A small percentage of pulses (<1%) are still missed due to PC interrupts.

Note that the final system will need a higher frequency IF, probably about 500KHz, with a 4MHz digitizing rate in order to allow use with shorter fibers.

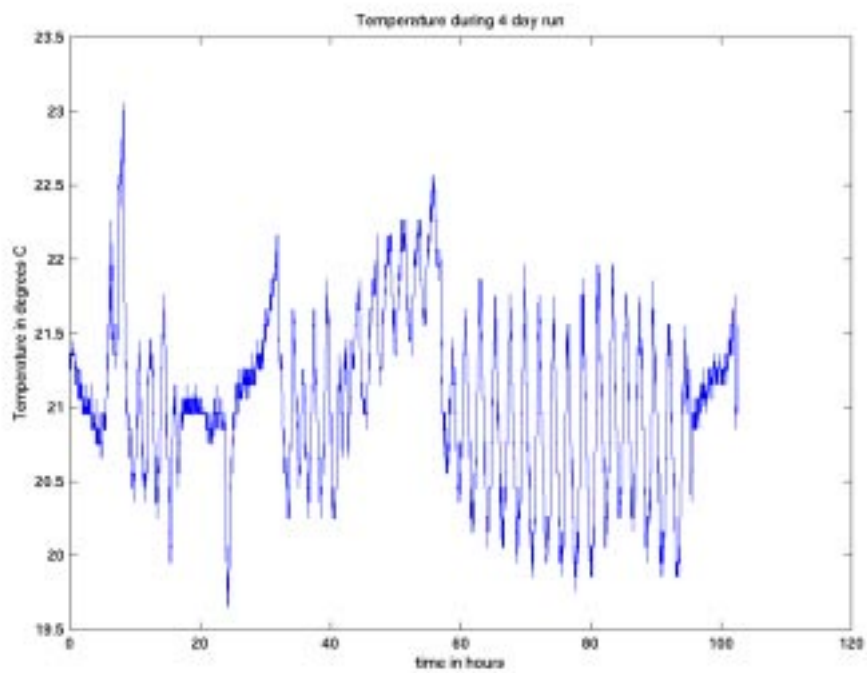
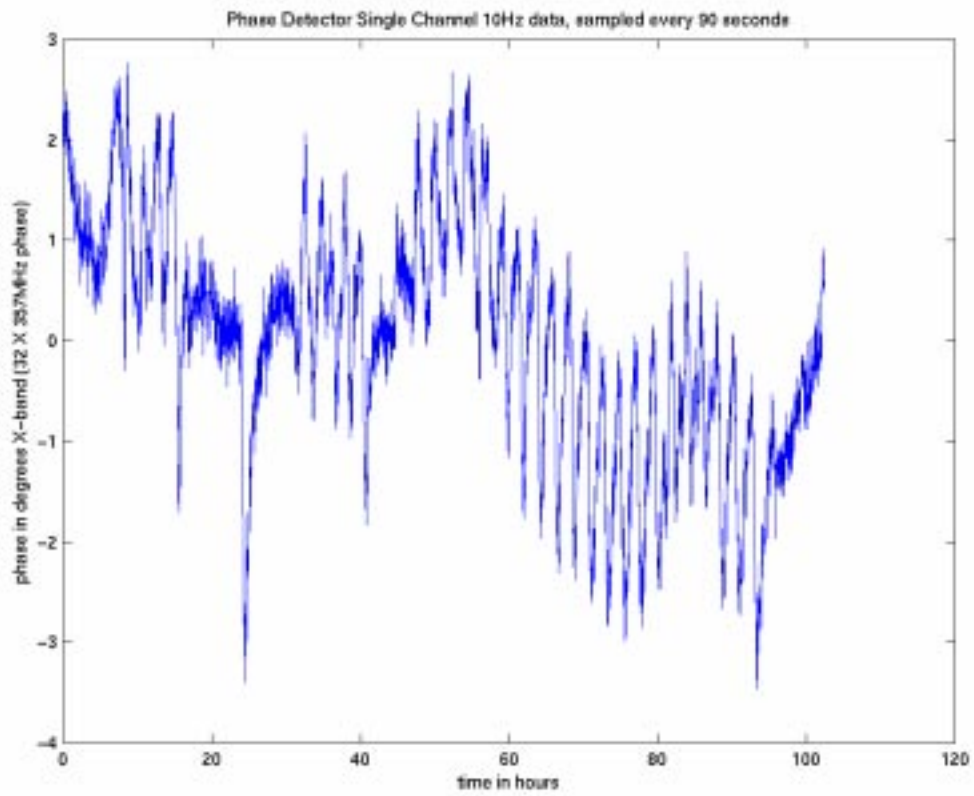
## Test Results

**Phase calibration:** An RF trombone was placed in line. The phase change for a trombone length change of 4" was measured. The result gave a trombone phase speed of 0.93 C. This is consistent with the expected phase delay due to spacers in the trombone. This test indicates that there are no gross errors in the phase calculation. More accurate tests were deemed unnecessary.

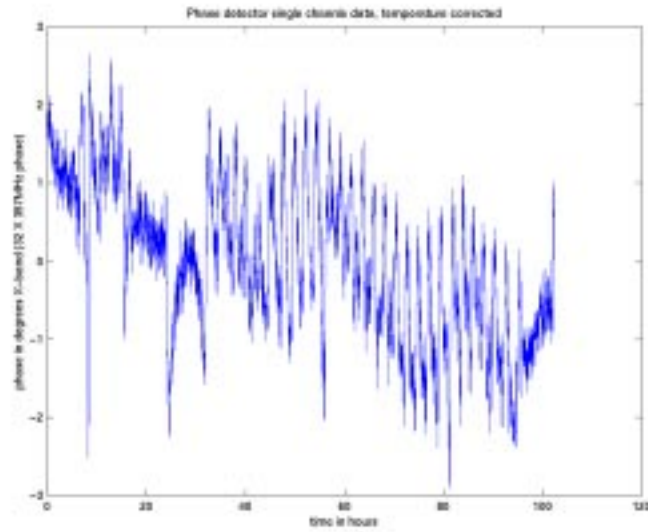
**Single channel 10Hz data:** This data was taken after a 1 hour warm up. Data sets (each a burst of 200 averaged pulses) were taken at 10Hz. Data is plotted with offset removed and 32X phase to represent X-band phase. The data had a sigma of 0.11 °X-band.



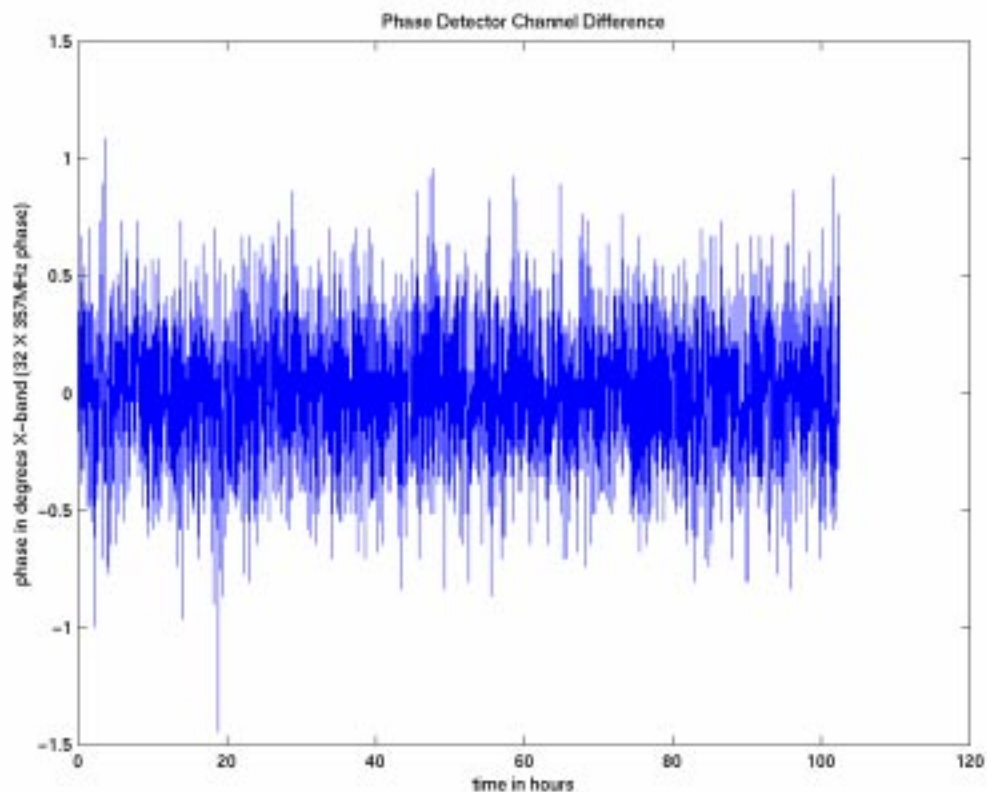
**Single channel long duration data.** A 4 day data run gave approximately  $\pm 3^\circ$  X-band phase drift.



**Temperature corrected data:** A fitted correlation of  $1.15^{\circ}\text{X-band}/\text{C}^{\circ}$  was removed from the data. The temperature sensor was in the room air. The fairly poor correction is believed to be due to the different time constants for the temperature sensor, and the phase detection equipment. The experiment will be repeated under more controlled conditions.



**Channel to Channel phase difference data:** A 4 day run gave a channel to channel difference sigma of  $0.28^\circ$ X-band. No drift was observed.



### Previous Tests

**Intensity sensitivity of phase.** Nonlinearity in the mixer can convert intensity changes to phase. From previous experiments we believe that signal levels  $<-15\text{dBm}$  in the RF input of the mixer will not produce significant amplitude to phase conversion. This corresponds to about 5 mV out of the mixer. Johnson noise on this level signal should correspond to  $\sim 13$  bits in a 200KHz bandwidth (OK). Note that the most recent experiments were performed at 1dBm RF input. They will be repeated at  $-20\text{dBm}$ .

**Optical detector phase temperature coefficient:** Earlier tests have shown that the phase drift of the optical detectors is approximately  $5^\circ \text{ X-band} / \text{C}^\circ$ . These tests were performed with the old test system, and will be repeated with the newer, more accurate system. This suggests that with  $0.1^\circ\text{C}$  temperature control, the detector phase drift is acceptable.

**Optical System Phase Noise:** The measured detector noise with a 15Km fiber is compatible with  $0.3^\circ\text{X-band}$  noise in a 50Hz bandwidth. The measurement was limited by problems with the DFB laser. This experiment will be done more carefully when the new system is complete.