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Research on the Influence of SNSPDs Using Multimode Fiber in Space Target Laser Ranging Receiving system

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Research Background

The Tianqin laser ranging station has applied multimode fiber(MMF) coupled four-pixels superconducting single photon detector (SNSPDs) to the space target laser ranging system and achieved lunar laser ranging in the near-infrared band. SNSPDs is used to receive echo photons from the corner reflector of the space target. When there is a deviation angle between the optical axis of the telescope and the echo beam, it affects the coupling efficiency between the spatial light and the multimode fiber at the front end of SNSPDs, further affecting the effective photon number of the echo. When the echo beam enters the multimode fiber, it causes dispersion jitter and introduces the random error.

Research Objectives

- Determine the change of coupling efficiency of MMF caused by the deviation angle of telescope.
- Determine the random error in SLR/LLR caused by the mode dispersion in MMF.

Theory Analysis

Simulate the effect of the telescope offset angle changes of the receiving optical system, then calculate the optical field intensity and phase of the beam transmitted to the front surface of optical fiber based on the difference changes, and finally consider the Fresnel reflection loss.

Optical fiber coupling calculation formula:

$$\eta = \frac{\langle |E_A(r)F_A^*(\mathbf{p})\mathrm{d}\mathbf{p}^2|\rangle}{\langle \int_R |E_{nm}(\mathbf{p})|^2 \mathrm{d}\mathbf{p}\rangle} \quad (1)$$

The light beam generates reflection loss at the interface of coupling with the optical fiber, thereby reducing coupling efficiency. Therefore, the change of light spot displacement and the edge light are considered, as shown in Figure 1.

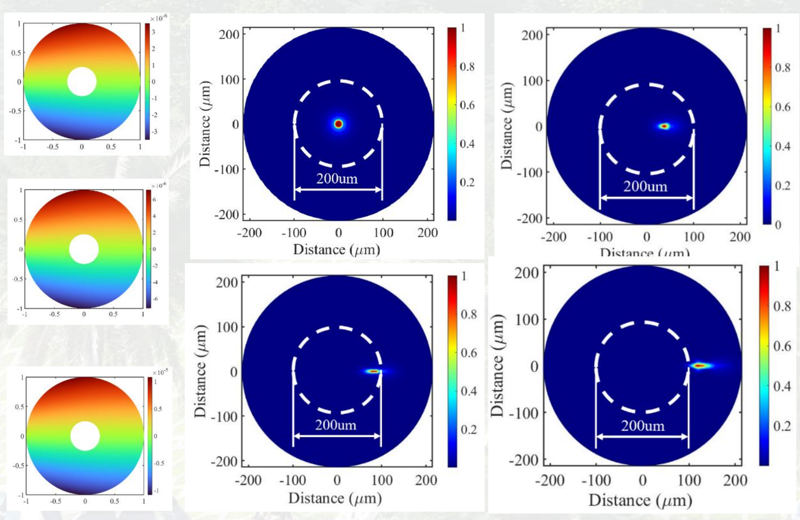

Figure 1. The optical field intensity and phase.

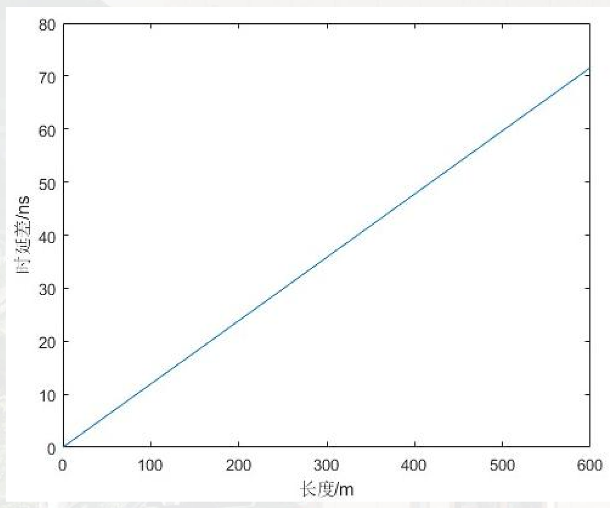

Figure 2. The change of time delay with the length of MMF.

Calculate the time delay introduced by the mode dispersion of MMF. The difference between the longest and shortest paths of light transmission is in Figure 2.

$$\Delta\tau_{\max} = T_{\max} - T_{\min} = \frac{Ln_1}{c\cos\theta} - \frac{Ln_1}{c} = \frac{\Delta Ln_1^2}{cn_2} \quad (2)$$

Experiment Results

Using stars to measure changes in coupling efficiency at different angles of inclination. The experimental schematic is shown in Figure 3. When the offset angle of telescope increases from 0" to 4 ", the position of the light spot on the fiber front surface is shifted to the edge of the fiber core diameter of the receiving front face, and the coupling efficiency decreases significantly. When the offset angle of telescope increases from 4 "to 6", the coupling efficiency decreases at an accelerated rate. Until it reaches 8", the coupling efficiency approaches 0. The result is shown in Figure 4.

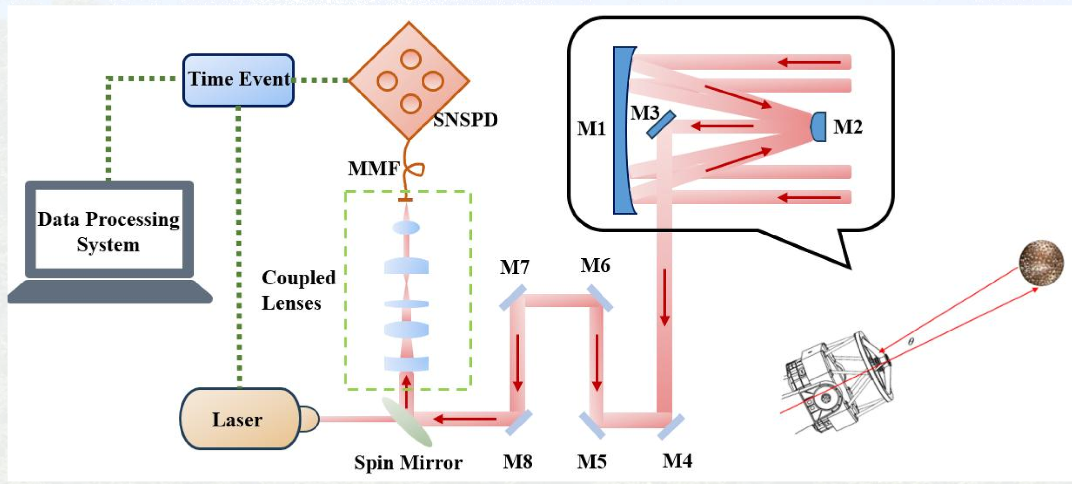

Figure 3. The schematic diagram of the receiving optical path of the ranging system.

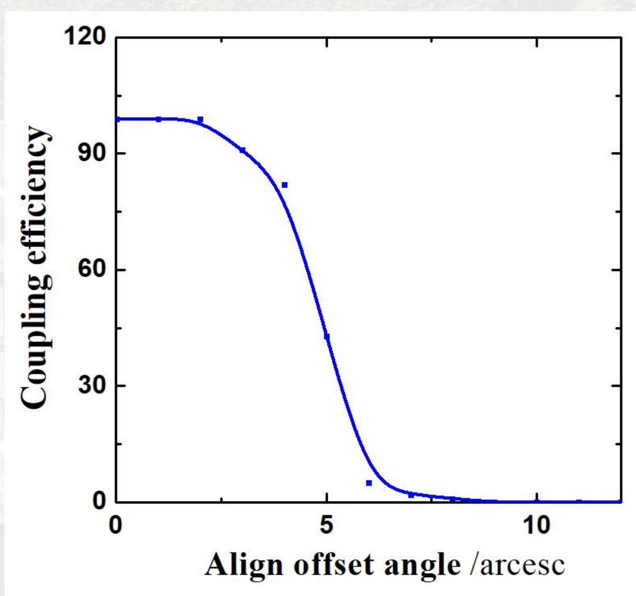

Figure 4. The variation of optical fiber coupling efficiency with offset angle.

Regarding the influence of mode dispersion of the optical fiber on the laser ranging, the same type of MMF of 50m, 100m, and 500m were added to the front of SNSPDs to do the laser ranging on the synchronous orbit satellite(qz2), and the introduced random errors were analyzed. By analyzing the ranging data, the results show that the echo broadening and random error per picosecond increase with the length of MMF respectively.

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