A novel distance measurement system with a planar lightwave circuit

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Abstract: We developed a novel distance measurement (DM) system with a planar lightwave circuit (PLC). Its performance was evaluated by carrying out the outdoor DM and by checking the linearity. We obtained the good result that is almost same as the one by the conventional system that utilizes bulky optics.

1. Introduction

The long-range and precise DM is important for construction and civil engineering. The distance is measured by the round-trip time of the light that is reflected by the target object and the conventional system consists of bulky optics. However, bulky optics have various problems such as reliability, difficulty in alignment and compactness. It has the moving parts such as motors for switching the optical path and actuating the optical attenuator. They degrade the reliability of the system under severe circumstances. We intended to replace the bulky optics with PLC and fiber optics to achieve robust and compact DM system. The operating wavelength of the system is around 1.55 μm because it is widely used for telecommunications and high-quality parts are easily available.

2. Description of the DM system

Figure1 shows the layout of the conventional system. For canceling the effect from the drift of the electrical circuit of the system, the optical path between the pulse-modulated laser diode (LD) and the avalanche photo diode (APD) is separated into the signal path and the reference path via the beam splitter and the beam combiner. When the shutter1 is opened, the shutter2 is closed and vise versa. The reference path includes a fixed optical attenuator that is used for coarse balance of the optical power at the end of the two paths. The signal path includes a telescope and variable attenuators. The telescope has two functions of sending the light to the object and receiving the reflected light. The

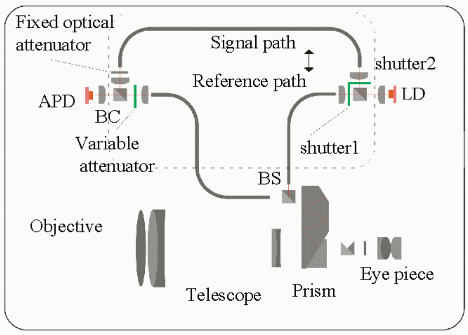

Fig. 1. Layout of the conventional DM system

variable optical attenuator is used for fine balance of the optical power at the end of the two paths. The optical elements are connected each other by multimode fibers and collimating lenses. It takes a lot of time to align them. The shutters and the variable optical attenuator are actuated by the electric motors.

By measuring the time interval between the electric signal that triggers LD and the signal generated at the APD by the return light, the traveling time of each path t is obtained. The distance to the object is calculated approximately by the following expression:

$$(t \text{ (signal path)} - t \text{ (reference path)})/2c \qquad (1)$$

, where c is the speed of light in a vacuum (3.0×10^{8}m/s). Due to the statistical reason, the value is averaged over 4096 times.

3. System characteristics

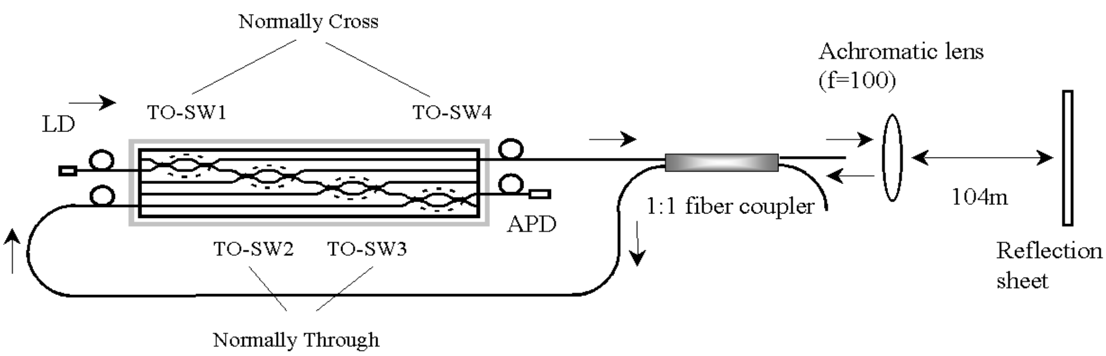

Fig. 2. DM system with a plarnar lightwave circuit

Figure2 shows our DM system. We fixed the layout of the PLC and it was manufactured by NTT Electronics. The material of the clad and the core of the PLC are SiO_2 and Ge doped SiO_2 respectively and the dimension of the PLC is 22 (mm) by 130 (mm) including the case. It has four thermo-optic switches (TO-SW'es) that utilize the index change caused by thermo-optic effect. The insertion loss and the isolation of each TOSW are <2.5dB, 18dB (through), 23dB (cross) respectively. The TO-SW1 is used for the switching of the optical path. The TO-SW2 and the TO-SW3 correspond to the fixed optical attenuator in the bulky optics. The TO-SW4 corresponds to the variable optical attenuator. The LD and the APD are already pig-tailed and connected to the PLC via single mode fiber. The peak power, the pulse width, the repetition rate of the LD are 80mW, 7ns and 5kHz respectively. The multiple factor (M) of the APD is 20 and the minimum sensitivity of our system is set to 50nW. The 1:1 Fiber coupler corresponds to the beam splitter and the beam combiner of the bulky optics. Anti-reflection-coated achromatic lenses is used for the objective of the telescope. Because the input port and the output port are optically conjugate, the return light always couples into the fiber and this reduces the burden of the alignment.

4. Experimental Results

Figure2 also shows the schematic diagram of the outdoor DM. For targeting, the measurement was carried out at night with an infrared camera. We adopted the Reflexsite reflection sheet as the target. We obtained the sufficient signal level for DM at the distance of 104m. This suggests that DM at the distance of 1km is possible with a high reflective target such as a corner-cube prism.

We evaluated the linearity of the DM system. Figure3 shows the schematic diagram of the measurement. A pair of collimating lens (f=20mm) slid on the rail. The distance between them was changed by the 10mm step. To separate the time interval between the signal and the noise from the reference path, 100m-delay fiber was inserted in the signal path. Figure4 shows the result where the vertical and horizontal axis shows the scale of the rail and the calculated value of the distance between lenses by expression (1) respectively. The latter value was the half of the former one in our system. By the minimum least square root method, the resolution of the system was determined to be 1.7mm (1 σ) and no cyclic error was observed caused by the PLC.

The background noise caused by the sunlight was checked during the daytime. The setup was almost the same as the Figure3. There was no shield against the sun between the end of the fiber and the lenses and they were on the identical meridian. And the angle of the elevation of the sun was about 40 degrees. The electrical high pass filter (f_c=100MHz) was inserted in the electrical circuit to eliminate the DC noise. No signal

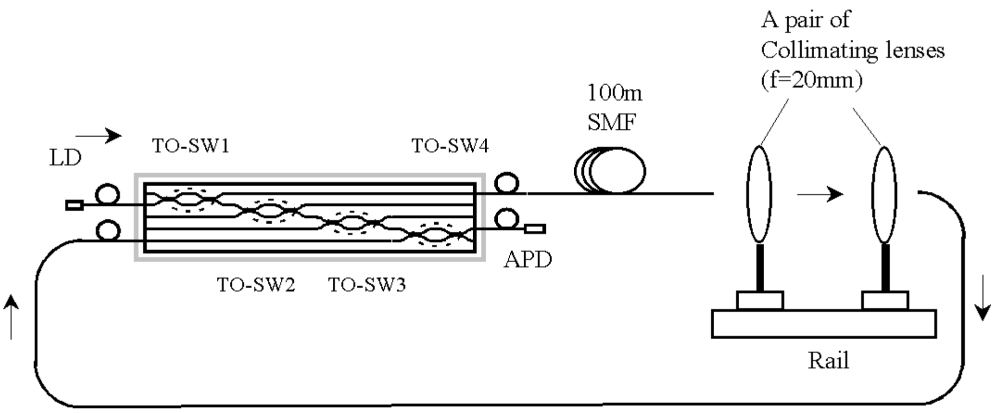

Fig. 3. Setup of linearity measurement

level difference was observed whether the target reflection sheet was present or not and this means that sunlight didn't couple the propagation mode of the single mode fiber virtually.

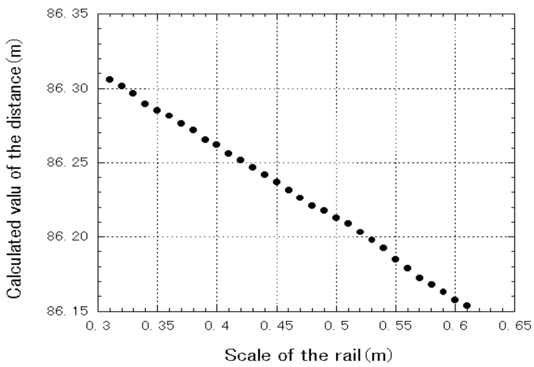

Fig. 4. Result of linearity measurement

5. Conclusions

We developed the novel distance measurement system with a PLC and fiber optics. The outdoor measurement at the distance of 104m was succeeded with the commercial reflection sheet and the measurement at the distance of 1km with a corner-cube prism is possible. The resolution of the system was about 1.7mm (1σ). Moreover, the system has many advantages as robustness, compactness, noise free and easiness in alignment.