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THERMAL COEFFICIENT OF DELAY MEASUREMENT OF THE NEW PHASE STABLE OPTICAL FIBER *

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Abstract

The Thermal Coefficient of Delay (TCD) is an essential parameter of optical fiber which determines a fiber's phase transfer stability due to temperature variation. The TCD of a new phase stable single mode optical fiber (YPSOC) from Yangtze Optical Fibre and Cable Company (YOFC) is measured. The radio frequency (RF) signal is modulated to optical wave by a laser module which is transmitted through the 400-meter long YPSOC to be measured. The returned optical wave is demodulated to RF signal by the photodetector. A phase detector and a data acquisition module (DAQ) are used to acquire the phase difference between the forward and returned signals. Two temperature-stabilized cabinets are designed to maintain and control the ambient temperature of the measurement system. The TCD of less than 10 ps/km/K at room temperature is obtained. YPSOC and the measurement platform can be applied on signal transmission or measurement system that need to compensate the temperature drift.

INTRODUCTION

In the long-distance optical wave transmission system, the optical path length will change due to the different temperatures on the transmission path, which will introduce phase drift to the RF/digital transmission system. The TCD range of most standard single mode fibers (SMFs) is from 33.4 to 42.7 ps/km/K.

But, The TCD of phase stable optical fiber (PSOF) by Furukawa is below 5 ps/km/K [1]. And the strong tether fiber optic cable (STFOC) from Linden Photonics is nearly as good as PSOF, its TCD is below 7 ps/km/K [2].

Using this kind of phase stable optical fiber instead of a conventional one will reduce the delay change of the stable RF transmission system.

TESTED CABLE

The phase stable optical fiber is generally composed of standard optical fiber and negative expansion coefficient materials, therefore it has a good temperature performance and tensile strength. YPSOC is coated with liquid crystal polymer (LCP). A purpose of LCP coating is to make the temperature dependence of transmission delay time small [1]. YPSOC has a 250 µm tight buffered cable core, followed by a tight buffered LCP coating and a soft outer jacket (Fig. 1) [3].

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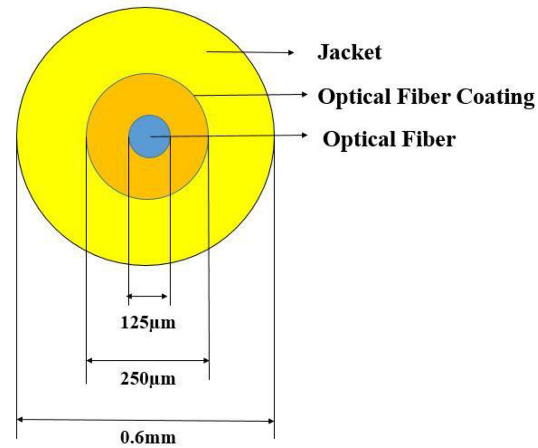

Figure 1: Cross sectional view of YPSOC.

MEASURE CONCEPT

There has several methods to measure the TCD of a fiber. For example, the TCD of a fiber which is coupled with jacket can be calculated by a formula. But it is complex and difficult to calculate TCD by using this formula [4].

On the other hand, an electronic and optical system can be used to measure the TCD by changing the ambient temperature of the fiber and detecting the time shift. This method is simple and operational. So, the TCD of a fiber can be calculated by the following formula.

$$\mathrm{TCD} = \frac{\text{Delay shift}}{\text{Temperature change} * \text{Fiber Path}} \quad (1)$$

A TCD measurement system based on the second method is designed. The layout of the fiber measurement system is shown in Fig. 2. The black lines are RF signal path and the green lines are optical wave path. The RF signal is sent to the power splitter from an analog signal generator, and transmitted to the laser module and the phase detector. The optical wave (1552 nm) from the laser module is propagated to the receiver through the optical circulator and the 400-meter long YPSOC, then retroreflected by a Faraday rotation mirror (FRM) at the end of the fiber. The round trip optical wave goes through the same fiber. The retroreflected optical wave is converted to RF signal by the photodetector, and transmitted to the phase detector through the amplifier, then compared with the local RF signal. Since the delay through fiber and other RF components is temperature dependent, RF and optical components are temperature stabilized to ±0.01 °C.

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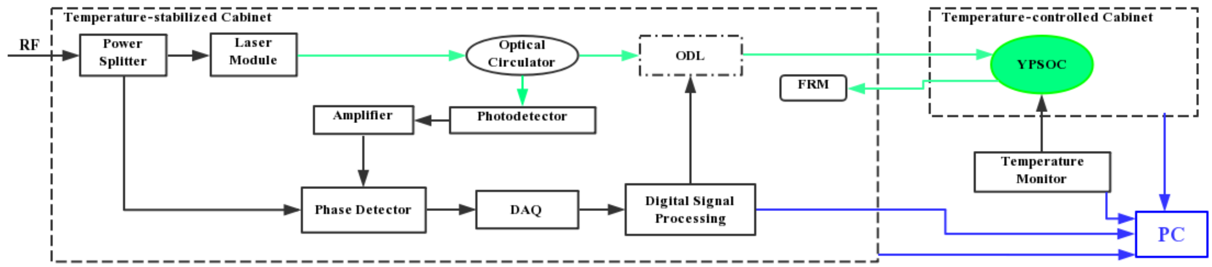

Figure 2: The layout of the fiber measurement system.

The fiber cable can be set in another temperature-controlled box, in order to change the ambient temperature of the fiber manually. A temperature probe is pasted on the fiber and connected to a temperature monitor to obtain the accurate ambient temperature of the fiber.

PHASE DETECTOR TEST

The phase detector unit is based on the Analog Devices HMC439 IC, its measurement stability is determined by temperature stability and low noise power supply. Its corresponding phase detection range is -180°~180°. The phase detector's coefficient of the delay and phase detector output is measured with the system shown in Fig. 2. A motorized optical fiber delay line (ODL) is used to change the delay of the system, its variable delay ranges from 0 to 560 ps, but a FRM is inserted at the end of the fiber, so the range of the total delay could be from 0 to 1220 ps.

Measurement of the phase detector is repeated three times, the delay change vs. phase detector output curve is obtained as shown in Fig. 3. The linear fitted result shows that the phase resolution of this phase detector is 2.5 mV/ps.

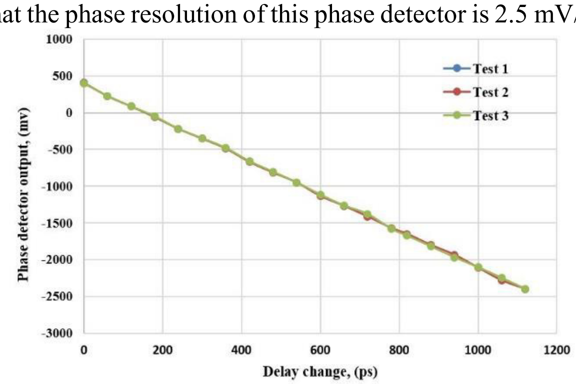

Figure 3: The fitted curve of delay change and phase detector output.

PHOTODETECTOR TEST

An important parameter with photodiode detection of RF is amplitude-to-phase conversion. If the average optical power varies, the photodiode junction capacitance will be modulated because of the changes in carrier density, then resulting in a shift of RF phase [5]. The amplitude-to-phase response of an EOT's >12.5 GHz Photodetector is measured twice. An optical attenuator is used to change the input optical power of the photodetector, and the phase detector is used to detect the time shift between the local RF signal and the output RF signal of the photodetector.

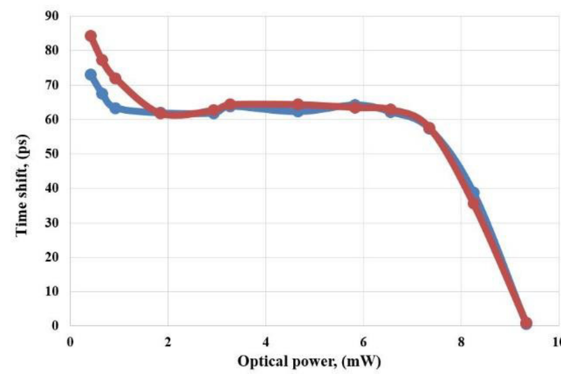

Figure 4: Photodetected phase of 500 MHz RF vs. incident optical power, for an EOT's Photodetector.

In Fig. 4, time shift is stabilized when incident optical power of the photodetector is between 2 mW~7 mW.

TEMPERATURE-CONTROLLED CABINET DESIGN

The Peltier cooling units are used to stabilize the temperature of all the key components of the measurement system such like laser module, amplifier, photodetector, fiber jumpers, phase detector and ODL. Also the fiber under test is enclosed into a temperature-controlled cabinet to change its ambient temperature. The temperature stability is within ±0.01 °C.

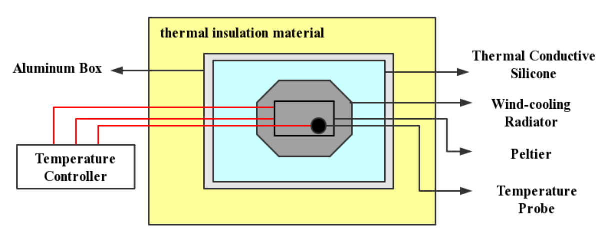

Figure 5: The layout of temperature-controlled cabinet.

We fabricated two temperature-controlled cabinets for the transmitter and the tested fiber. The layout of temperature-controlled cabinet is shown in Fig. 5. The outside of the box is made by thermal insulation material to isolate the heat change. The inside of the each box is made by aluminium to keep the controlled temperature at whole area. The temperature stability is shown in Fig. 6.

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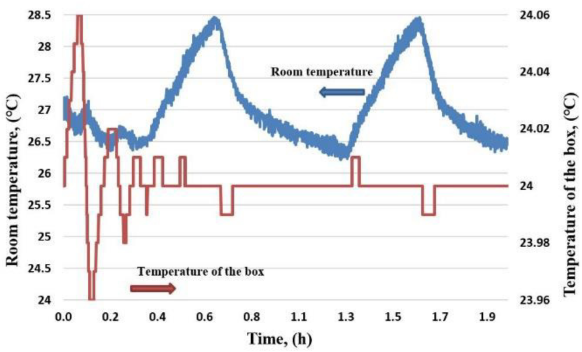

Figure 6: Temperature stability measurement of the temperature control box.

The blue line shows the room temperature, which changes about ±1 °C. The red line shows the temperature of the temperature control box, which keeps the temperature about ±0.01 °C over 1.5 hours. The achieved temperature stability depends on the room temperature, the heat generated by the component and the ability of the cooling system. The system could keep the temperature stability less than ±0.02 °C for a long time measurement.

MEASUREMENT RESULT

After 8.5 hours of testing, the ambient temperature of fiber and the phase delay curves are shown in Fig. 7. The temperature vs. delay curve is shown in Fig. 8, as the temperature changes from 17.2 °C to 45.6 °C, the delay totally shifts 166ps. Because the optical wave passes the optical fiber twice, the path length of the optical wave transmitting through the optical fiber is 800 m. So, the average TCD of YPSOC is 7.3 ps/km/K (temperature between 17.2 and 45.6 °C).

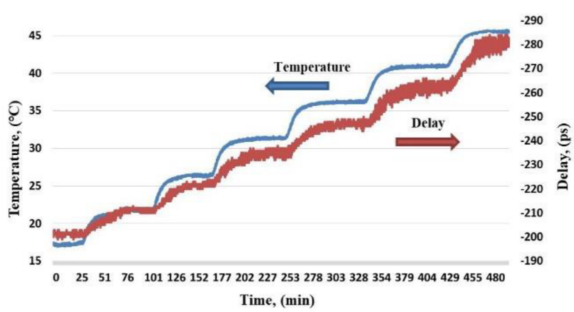

Figure 7: Ambient temperature of the fiber versus the phase delay.

In order to calculate the TCD of the fiber at different temperatures, the corresponding curve slope is required at different temperatures, this slope value is the TCD at this temperature. As the temperature-dependent TCD curve shown in Fig. 9, the fiber's TCD ranges from 5 to 10.5 ps/km/K and grows as the temperature increases as the temperature ranges from 17.2 to 45.6 °C.

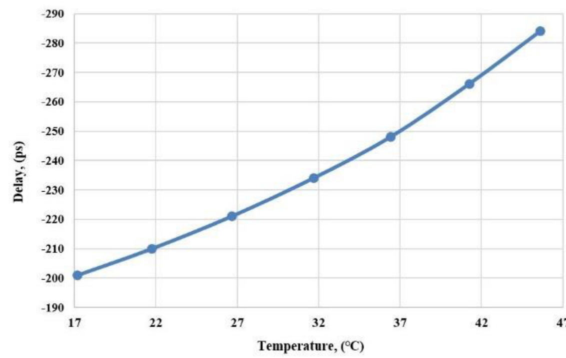

Figure 8: Curve of phase delay vs. temperature change.

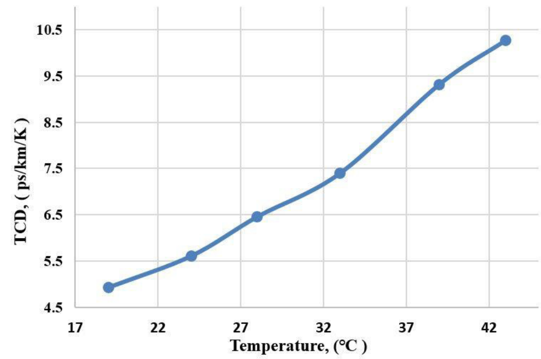

Figure 9: TCD of Yangtze's fiber curve with temperature.

CONCLUSION

The TCD of YPSOC ranges from 5 to 10.5 ps/km/K (average 7.3 ps/km/K) under the usual operating temperature (17.2 °C~45.6 °C). The measurement result matches the TCD specification provided by YOFC, and YPSOC will be used for the stable phase reference line of BEPC-II and HEPS in the future.

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