Athermal Demodulator for 42.7-Gb/s DPSK Signals

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Abstract *We report an athermal optical-delay-interferometer capable of demodulating any OC-768 DPSK signal on the ITU 50-GHz-grid over the C+L band. Receiver sensitivity of –35.5 dBm is achieved for a 42.7-Gb/s non-return-to-zero DPSK signal.*

Introduction

Optical differential-phase shift keying (DPSK) has recently attracted attention as a promising modulation format [1] that offers high receiver sensitivity, high tolerance to major nonlinear effects in high-speed transmissions [2], and high tolerance to coherent crosstalk [3]. In DPSK, data information is carried by the optical phase difference between adjacent bits. For direct detection of DPSK signal (by conventional intensity detectors), a demodulator is needed to convert the phase-coded signal into an intensity-coded signal. Conventionally, the demodulator is an optical 1-bit delay interferometer (1-bit DI) based on an all-fiber design or a planar lightwave circuit design. These designs are intrinsically temperature sensitive. Since precise control of the phase difference between the two optical paths of the DI is required [4], accurate temperature control and stabilization of the DI are required. Here, we report the demonstration of an athermal DI, based on a free-space optical design, for demodulating any OC-768 DPSK signal on the ITU 50-GHz-grid over the entire C+L band in the temperature range of 0~70°C.

Design and Characteristics of the Athermal DI

The schematic of the athermal DI is shown in Fig. 1. This device is based on a free-space optical Michelson interferometer with a free spectral range (FSR) of 50 GHz, consisting of an optical beam splitter (BS) and two reflection mirrors. The incident beam from the left-hand side of a BS splits into two beams, which are reflected by the two mirrors before interfering with each other at a slightly different location (than that of the input beam) on the BS. The round-trip differential time delay (Δt) between the two optical paths of the DI satisfies: $\Delta t = 20ps \pm M/(2f_0)$, where f_0=193.100 THz (the reference frequency of the ITU grid), and *M* is a small integer. In order to obtain good extinction ratio and to minimize the polarization-dependent frequency shift, the power splitting ratio of the beam splitter (BS) is very close to 50/50 and the phase of the BS is insensitive to the state of polarization. In addition, to achieve the athermal property, the length difference between the two paths varies less than 10 nm over the operational temperature range between 0°C and 70°C. This is accomplished by connecting the mirrors with the BS through zerodur, which has an extremely low thermal expansion coefficient. An air gap of ~3 mm in one optical path is used for a final adjustment that locks the passband of the athermal DI onto the ITU grid. The device is hermetically sealed.

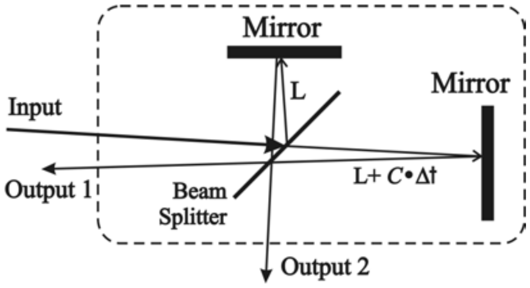

Fig. 1. Schematic of an athermal DI based on a free-space optical Michelson interferometer.

The insertion loss from the input port to either of the output ports is less than 1.5 dB. Worth mentioning is its small form factor: 27mmx27mmx10mm. The measured polarization-dependent frequency shift (PDFS) is <0.3 GHz. With the athermal design, the frequency drift is less than ±0.75 GHz from 0°C to 70°C. This corresponds to a temperature dependence of ~0.02 GHz/°C, which is >50 times smaller than conventional DIs. Fig. 2 shows the transmission curves at the constructive port of the athermal DI at temperatures of 0°, 30°, and 70°C over the C+L band. The extinction ratio is greater than 25 dB. The maximum frequency offset from ITU is also measured to be less than 0.8 GHz across the entire C+L band in the temperature range of 0~70°C.

Experimental results

To verify the performance of the athermal DI, we performed receiver sensitivity measurements for OC-768 DPSK signals, as compared to the results obtained by using a temperature-controlled 1-bit DI. While return-to-zero (RZ) DPSK is the modulation format of choice for some record-setting high-capacity, long-haul transmissions [1,5], non-return-to-zero (NRZ) DPSK shows similar performance as RZ-DPSK in tightly filtered transmissions [6]. We investigate the performance of the athermal 20ps-DI for a NRZ-DPSK signal. The transmitter consisted of a DFB laser operating at 193.2 THz, followed by a dual-drive $LiNbO_3$ Mach-Zehnder modulator (MZM), biased at null, for phase modulation. This modulator was driven by a 42.7-Gb/s NRZ electrical data stream (assuming a 7% overhead for forward error correction), which was a pseudo-random bit stream (PRBS) of length $2^{31} - 1$. The differential delay of the reference 1-bit DI was 23.4 ps, the PDFS was <0.5 GHz, and the extinction ratio was greater than 25 dB. Fig. 3 shows the eye diagrams measured with a balanced receiver for the 42.7-Gb/s NRZ-DPSK signal demodulated by the 1-bit DI (set at the optimal temperature) and the athermal 20ps-DI. The eye diagram obtained with the 20ps-DI shows almost the same eye openings as those with the 1-bit DI. Fig. 4 shows the corresponding BER performances using an optically pre-amplified receiver. The athermal DI performs essentially as well as the temperature-controlled 1-bit DI. Our simulation results show that the penalty due to the imperfect matching between the bit period and Δt in the 20ps-DI is ~0.2 dB for NRZ-DPSK. The measured penalty is smaller probably because of its smaller PDFS as compared to the 1-bit DI.

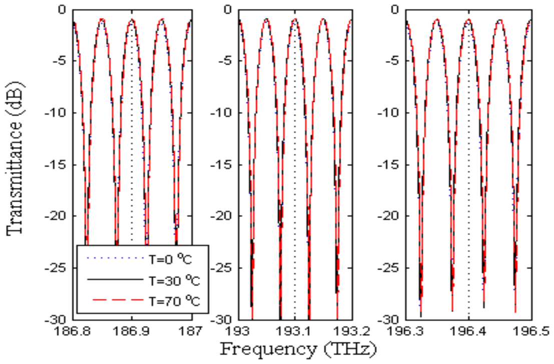

Fig. 2. The measured transmission curves at the constructive port of the 50-GHz athermal DI at 0°, 30°, and 70°C.

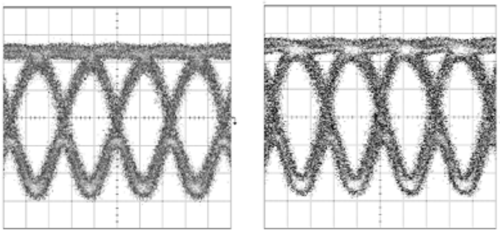

Fig. 3. Measured eye diagrams of a 42.7-Gb/s NRZ-DPSK signal demodulated by an 1-bit DI (left) and the athermal 20ps-DI (right).

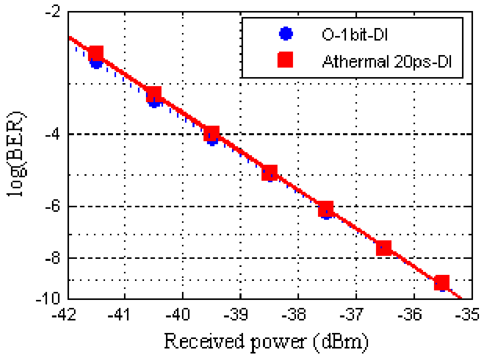

Fig. 4. Measured BER performance of the 42.7-Gb/s NRZ-DPSK signal.

Fig. 5 shows the optical signal-to-noise-ratio (OSNR) penalty (at BER=6x10^{-5}) vs. temperature at 1551.72 nm. In the temperature range from 0 to 70°C, the temperature-induced penalty is <0.15 dB. Fig. 7 shows the OSNR penalty for 42.7-Gb/s NRZ-DPSK signals over the C-band at T=35°C. The OSNR requirement only varies within ±0.3 dB across the entire C-band. Given the similarly small frequency drift in the L-band as shown in Fig. 3, we expect the athermal DI to have similar performance in the L-band.

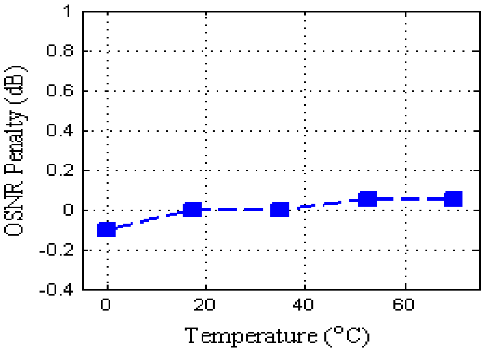

Fig. 5. Measured OSNR penalty vs. temperature for a 42.7-Gb/s NRZ-DPSK signal with the athermal 20ps-DI.

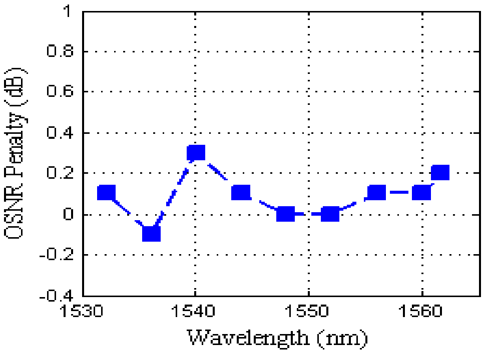

Fig. 6. Measured OSNR penalty of 42.7-Gb/s NRZ-DPSK signals over the C-band. The channels are set on the ITU grid using a wavemeter.

Conclusion

We have demonstrated an athermal optical delay interferometer capable of demodulating OC-768 NRZ-DPSK signals that are on the ITU grid, with negligible penalty over a temperature range of 0~70°C. With its simplicity, compactness, and no need for temperature control and stabilization, this DPSK demodulator may be attractive for reliable and cost-effective product implementations.

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