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Optical fiber distributed acoustic sensing based on the self-interference of Rayleigh backscattering

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Abstract: In order to detect the weak underwater acoustic signal, a Distributed Acoustic Sensing (DAS) scheme based on the self-interference of Rayleigh backscattering is presented. Rayleigh backscattered light which contains a phase change induced by acoustic signal along the sensing fiber which is a standard telecom single-mode fiber is split and fed into an imbalance Michelson interferometer. With the self-interference of two Rayleigh backscattered beams, the phase change is amplified theoretically compared with phase-sensitive OTDR. We designed an experiment to prove the scheme, and successfully restored the acoustic information, meanwhile, the DAS system has preliminary realized around the acoustic phase sensitivity of -151 dB (re rad/μPa) at 600Hz, and the minimum detectable acoustic pressure of 6 Pa in the experiment.

Keywords: Distributed Acoustic Sensing, Rayleigh backscattering, self-interference , acoustic phase sensitivity,

1.Introduction

With the comprehensive utilization of marine science and technology research and the development of national defense, demand for submarine environment monitoring is increasing, especially in the field of the ocean background noise, underwater target feature extraction and recognition, acoustic warning and submarine pipeline leak detection[1,2], etc. The submarine detection technology is restricted by the adverse factors such as the bad environment and difficulty of the sensor arrangement to cover the large areas of monitoring, and so on. However, the unique advantage of optical fiber distributed sensing technology is that the fiber itself can act as the sensing element, then the technology segregates the fiber into an array of individual "microphones", so the distributed information of the whole sensing area can be measured in real time, so the optical fiber distributed sensing technology is becoming a research hot spot because of the sensor arrangement simplicity and wide detection range.

Up to now, optical fiber distributed sensing technology mainly consists of optical time/frequency domain reflection technology and optical fiber dual interferometer technology [3,4]. Optical time/frequency domain reflection(OTDR/OFDR) technology makes use of Rayleigh, Raman and Brillouin effects induced by external disturbance on the optical fiber[5].Currently the Coherent optical time domain reflectometers (COTDR)[6,7], phase-sensitive OTDR(Φ-OTDR)[8,9]and Brillouin scattering[10,11] based sensors are effective technologies for vibration detection but not acoustic sensing. On the other hand, Dual interferometers have been developed to get the acoustic position and acoustic information (phase, amplitude and frequency) along the sensing fiber, such as Sagnac–Sagnac[12,13] Sagnac–MZ[14,15], Sagnac–Michelson[16] and MZ–MZ[17,18]. However the optical path design and demodulation algorithm of dual interferometers are complex, making it difficult to be implemented in practical application.

To solve above problems, utilizing the elastic reflection and Gaussian phase distribution characteristic of Rayleigh backscattering[19],we proposed the optical fiber Distributed Acoustic Sensing (DAS) technology based on self-interference of Rayleigh backscattering in the paper. This scheme differs from the previous schemes in that phase information of self-interference light of the Rayleigh backscattering from the sensing fiber which record location, frequency, amplitude and phase of the acoustic wave are amplified. Furthermore, in our experiment, self-interference light phase of the Rayleigh backscattering recorded acoustic wave generated by an underwater speaker, then we simultaneously restored the acoustic wave information such as location, frequency, amplitude and phase with the DAS technology and the Phase Generated Carrier (PGC) technology. This scheme really has realized the distributed acoustic sensing with the optical fiber sensing technology.