Suppression of beat noise in low-coherence fiber interferometric system

QINGSHAN CHEN[a,b*], NAIGUANG LU[b], XINZHU SANG[a], FENG JIANG[b]
[a]*School of Electronic Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China*
[b]*Department of Electronic Information Engineering, Beijing Institute of Machinery, Beijing 100085, China*

To suppress the beat noise of a low-coherence fiber interferometric system, noise constitutes in the system is analyzed and an optical fiber filter is used in the experiment. Experimental result shows that, with a filter with FWHM of 4nm, the spectral mismatch between test arm and reference arm decreases from 49 nm to 4 nm, so the beat noise in the recorded interferogram is significantly suppressed and the visibility is also noticeably improved.

(Received August 16, 2007; accepted August 31, 2007)

Keywords: Beat noise, Low-coherence interference, Fiber filter

1. Introduction

The low-coherence interferometric system was developed since the late of 1980's in optical low coherence reflectometry to detect the defects in long distance fiber in optical fiber communication systems. For a high coherence system, it typically comprises of a broadband light source, so it has a short coherence length. Commonly, it is configured in two forms, fiber Michelson interferometer and fiber Mach-Zehnder interferometer. Both are adopted in high precision detection system, such as optical low coherence reflectomter, sensor systems, low coherence optical tomography etc. [1-4] For all these system, noise suppression is a critical to realize the good technical specifications , such as sensitivity, resolution, dynamic range, accuracy and so on.

To achieve a low coherence interferometric system for detecting the dispersion characteristics of chirped fiber Bragg grating(CFBG), which is view as an excellent candidate to compensate the fiber dispersion in optical communication system, an approach to suppress the noise of low coherence system with a fiber filter is investigated theoretically and experimentally.

2. Experimental setup

The experimental setup is shown as in Fig. 1. It is composed of a broadband light source (an EDFA source), a fiber filter, a 2×2 coupler serving as beamsplitter, the CFBG under test, an OPD(optical path distance) scanning system and a numerical sampling and processing system. The mumiercal sampling and processing comprises a photo detector, a signal amplifier, an A/D converter and a computer. The above devices and instruments make up of a typical Michelson fiber interferometer.

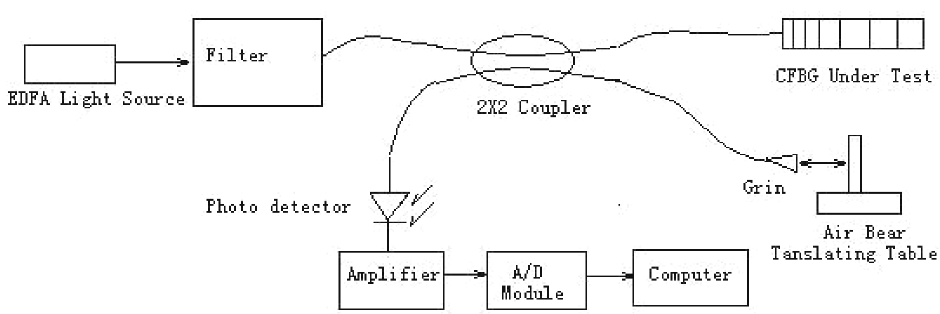

Fig.1 Experimental setup of the low coherence interferometric system.

The light from light source is launched after a tunable filter into the 2×2 coupler and is split into a measurement arm, in which a CFBG(chirped fiber Bragg grating) under test is connected, and a reference arm in which a scanning mirror is mounted on a air-bear translating table. Reflected light from the CFBG under test and the reflected light from the scanning mirror are combined by the coupler. The unsymmetrical measured interferogram in shape is due to the dispersive caused by different reflection position along the axis of CFBG, which is recorded under control of the computer during the translation of scanning mirror, by the sampling and processing system. This setup is extensively employed in micro-waveguide detection system, sensor system and low coherence optical tomography system etc.

3. Noise of fiber low coherence interferometric system

Generally the noise in the above system involves receiver noise, intensity noise and beat noise. The receiver noise includes shot noise, dark current noise, surface leakage current noise and thermal noise, which are given as the following.

$$\left\langle i_{st}^2 \right\rangle = 2qI_p BM^2F(M), \left\langle i_{Db}^2 \right\rangle = 2qI_D M^2 F(M) B, \left\langle i_{DS}^2 \right\rangle = 2qI_L B \quad (1)$$

and $$\left\langle i_T^2 \right\rangle = 4k_B TB / R_L \quad (2)$$

where q is the charge of electron, I_p is the mean photocurrent of received light, B is bandwidth, F(M) is noise coefnt and is approximated as M^x (depend on the material, 0≤x≤1.0), both M and F(ficieM) can be taken as 1 for pin photodiode, I_D is the origin bulk dark current of detector, I_L is surface leakage current, k_B is Boltzmann constant, T is absolute temperature and R_L is load resistance. Synthesis of all these noises is written as equation (3), which forms detection limit the system.

$$\left\langle i_N \right\rangle = 2q(I_p + I_D)M^2F(M)B + 2qI_L B + 4k_B TB / R_L \quad (3)$$

Comparatively, the thermal noise is relatively small and is masked by shot noise, intensity noise and beat noise [5,6].

Intensity noise is due to the intensity unequality between the return light CFBG under test (teat arm) and return light from the scanning mirror (scanning arm). This unequality is not only caused by the fact that the reflectivity of reference arm is much greater than that of test arm, but also caused by the reflectivity variation due to the mechanic dithering of scanning mirror during scanning movement and the intensity fluctuations of the source itself. This leads to degradation of contrast of the measured interferogram. Responsivity of the photodetector is denoted as R, the detected powers of test arm and reference arm as P_{dut} and P_{ref} respectively, the fractional intensity noise in a 1 Hz bandwidth as R_{In}, then the relative intensity noise can be expressed as:

$$i_{in} = \mathrm{R_{In} R^2 \; P_{ref}^2 B} \quad (4)$$

Selectively attenuation the intensity of light from scanning mirror by a variable attenuator and cancel the DC components of the photocurrent by AC coupling circuit is capable of overcoming this noise in a significant degree.

The beat noise is caused by the beating of various Fourier components within the broad-band spectra of the source. As shown in Fig. 1, there is a spectral mismatch between two arms of the interferometeric system, this beat noise will become considerable and even mask the effective inteferferogram. In this system, the spectral bandwidth of reflected light from the scanning mirror is the same as that of the light source and is wider than that of reflected light from the CFBG under test. According to interference theory, the oscillatory component of the interferogram is proportional to the real component of the mutual coherence function defined by $\tilde{\Gamma}_{12}(\tau) = \left\langle \tilde{E}_1(t+\tau), \tilde{E}_2(t) \right\rangle$, where $\langle \; \rangle$ donates a time average, $\tilde{E}_1(t), \tilde{E}_2(t)$ are respectively the real field of test arm and reference arm. As the conclusion of reference [7], if the photocurrents of incident electric field vectors $\tilde{E}_1(t), \tilde{E}_2(t)$ are denoted as $\langle I_1 \rangle$ and $\langle I_2 \rangle$, the current noise spectral density is expressed by $\left\langle \Delta I_{be}^2 \right\rangle = 2\dfrac{\langle I_1 \rangle \langle I_2 \rangle}{\Delta \nu}$, $\Delta \nu$ has a dimension of frequency and gives the dependence of the spectral density on the spectral width.

4. Noise suppression through a fiber filter

Fig. 2 shows the spectrum of the broadband light source in Fig. 1. Its FWHM(full width at half magnitude) is about 50 nm from 1520 nm to 1570 nm. Without of the CFBG under test and the filter, the produced interferogram is recorded as shown in Fig. 3 under the end face Fresnel reflecting light. This figure is obvious the Fourier transform pair of the light source's power spectral density. Compared with magnitude of the interferogram, contribution of all above-mentioned noise is neglectable under the precondition that the spectrum bandwidths of both arms are equal.

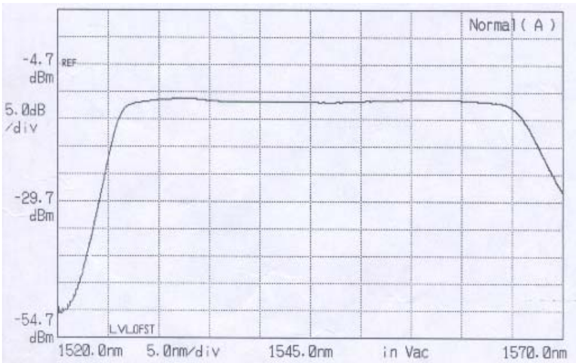

Fig. 2. Spectrum of the broadband light source.

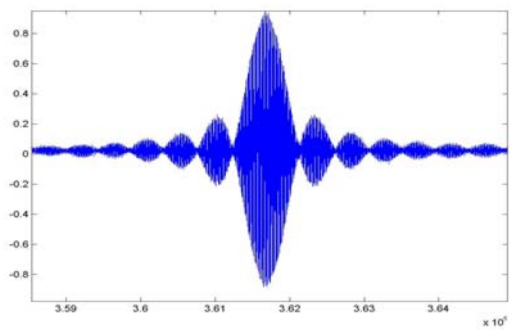

Fig. 3. Fresnel reflection interferogram.

The reflection spectrum of the CFBG under test is given in Fig. 4. Its FWHM is about 1.1 nm from 1548.8 nm to 1549.9 nm. Because the scanning mirror reflects all the components of light source, the spectral mismatch quantity between the spectral components of the test arm and the reference arm is approximately 49 nm. As shown in Fig. 5, this mismatch leads to a serious beat noise of being nearly the same magnitude as the effective interference signal.

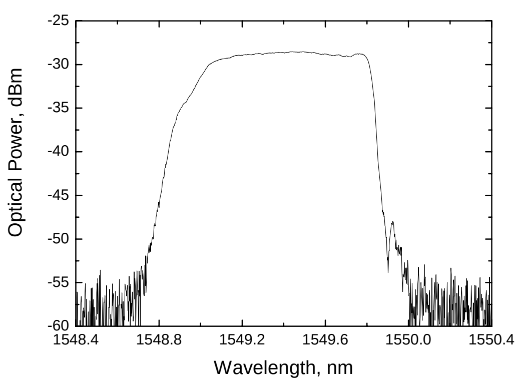

Fig. 4. Reflection property of the CFBG under test.

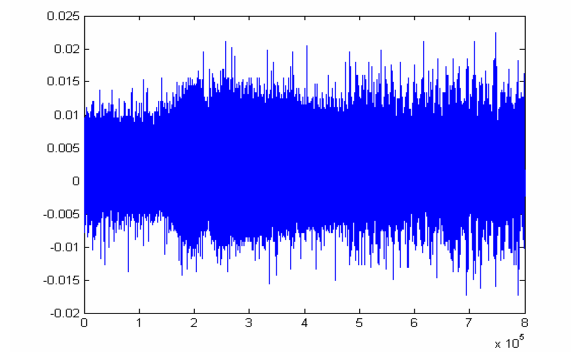

Fig. 5. The interferogram without the filter in the system shown in Fig.1.

A fiber filter with the spectrum property shown in Fig. 6 is inserted in the system. The FWHM of the filter is about 4nm from 1547.4 nm to 1551.4 nm. The spectral mismatch quantity described above is much decreased. The recorded interferogram, shown in Fig. 7, is significantly improved not only in terms of noise but also in terms of visibility. From the above analysis, this improvement in the interferogram is attributed to the suppression of the beat noise by using a fiber filter.

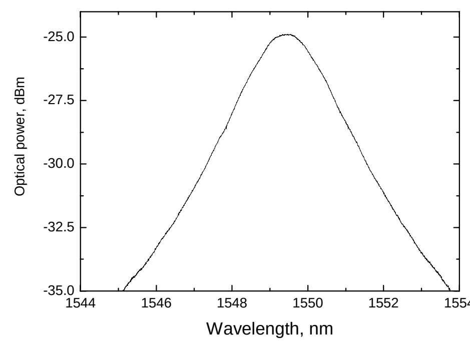

Fig. 6. Spectral property of the fiber filter.

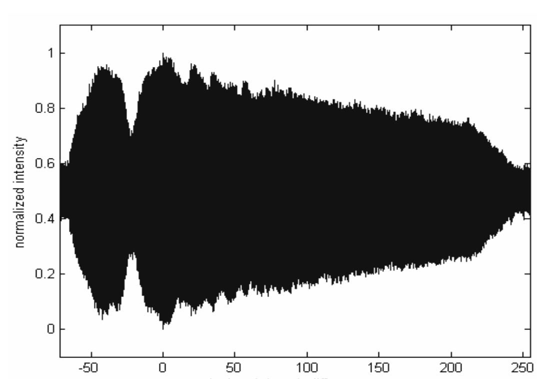

Fig. 7. Interferogram of the system shown in Fig. 1.

5. Conclusions

With a fiber filter, the beat noise of a low coherence fiber interferometric system can be suppressed. Under the precondition that the spectral bandwidth of both arms are equal, and only the AC components of the interferogram are recorded. Compared with the magnitude of interference signal, noises in the interferometric system such as thermal noise, shot noise, intensity noise and beat noise can be neglectable. It is also discovered that with a decreasing of spectral mismatch between test arm and reference arm from 49 nm to 4 nm through a fiber filter, the beat noise in the interferogram is effectively suppressed and the visibility is so as to improved significantly.

Acknowledgement

This paper is supported by Scientific Research Common Program of Beijing Municipal Commission of Education (KM200411232005).

References

[1] E. Simova, P. Berini, C. P. Grover, IEEE Instrumentation and Measurement Technology Conference, USA, May 18-21, 712-715 (1998).
[2] P. L. Francois, M. Monerie, C. Vassallo, Y. Durteste, F. R. Alard, J. Lightwave Technol., **7**(3), 500-513 (1989).
[3] K. Naganuma, K. Mogi, H. Yamada, Opt. Lett. **15**(7), 393-395 (1990).
[4] B. L. Danielson, C. Y. Boisrobert, Appl. Opt. **30** (21), 2975-2979 (1991).
[5] W. V. Sorin, D.M. Baney, IEEE Photonics Technology Letters **4**(12), 1404-1406 (1992).
[6] Kazumasa Takada, Journal of Lightwave Technology, **20**(6), 1001-1017 (2002).
[7] Kazumasa Takada, Noise in optical low-coherence reflectometry, IEEE Journal of Quantum Electronics **34**(7), 1098-1108 (1998).

*Corresponding author: chenqqss_xiaotu@126.com