Performance improvement of PGC method by using lookup table for optical seismometer

Changdong Tian, Liwei Wang, Min Zhang, Huayong Zhang, Xiaohui Chu, Shurong Lai, Yanbiao Liao
Department of Electronic Engineering, Tsinghua University, Beijing,100084, China

Abstract

A new demodulation method is proposed to eliminate the light intensity disturbance(LID) due to the Phase Generate Carrier(PGC) modulation method for the optical marine seismometer which is based on the fiber interferometer. A look up table by the use of a nonlinear function has been demonstrated. The experimental results show that the performance of the system has been improved with the harmonic suppression ratio(HSR) of the demodulation results increasing 30dB and the dynamic range of the system increasing 26dB, comparing with the Differential Cross-Multiplying(DCM) algorithm for the PGC method. The new method approaches a dynamic range of 130dB@100Hz with the HSR more than 50dB.

keywords: seismometer, Phase Generate Carrier,light intensity disturbance, harmonic suppression ratio, dynamic range

I. Introduction

The optical fiber sensors based on the fiber interferometer have been proposed to be one of the most promising technologies in the marine seismometer. In a lot of practical applications, the Michelson interferometer has been specially designed as a marine seismometer and the Phase Generator Carrier(PGC) method by the use of Differential Cross-Multiplying(DCM)[2] algorithm has been well developed for its high sensitivity and large dynamic range. In our project demonstrated in this paper, the optical marine seismometer is designed for the seismic streamer system in Fig.1, which is made up of several parts of streamer cables with 100 meter each in length. In each part, 32 seismometers have been separated symmetrically along the cable. All of the optical sensors, demodulation circuits as well as the laser sources are all integrated in the cable whose diameter is less than 45mm. In such cable system, the distribute feedback(DFB) laser source is used for its small size, while it comes up with light intensity disturbance(LID) when the wavelength is demodulated to generate the phase carrier by changing the driving input current density[1],[3]. As is analyzed in section II, the LID deteriorates the performance of the DCM demodulation method and limit the application of the seismometer system. We demonstrated a new demodulation method based on the LID model. The new method uses lookup table of nonlinear function and achieves remarkable improvement on the system performance.

In this paper, the principle of the new method is described in section II, and the comparison between the performance of the two methods is described in section III. The experimental results show the new method approaches higher harmonic suppression ratio(HSR) , better linearity and larger dynamic range.

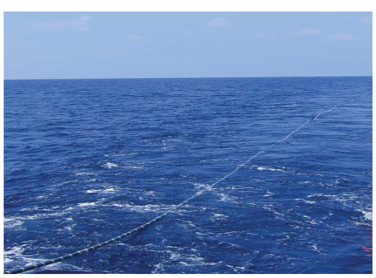

Fig. 1. seismometer

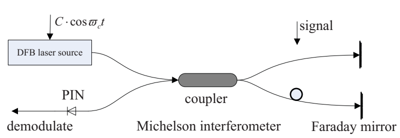

Fig. 2. Michelson interferometer using PGC modulation method

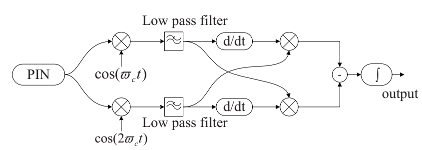

Fig. 3. demodulation with DCM method

II. Principle

The structure of seismometer using Michelson interferometer with PGC modulation method is shown in Fig.2. The output light intensity of interferometer $I(t)$ can be expressed as (1), where ϖ_c is the frequency of phase carrier, B is the interference intensity, which is determined by both the input intensity and the splitting ratio of the coupler in the interferometer, C is the modulation depth and Φ is the interferer signal caused by environment variable, which is the expected output signal.

$$I(t) = B \cdot \cos(C \cdot \cos(\varpi_c t) + \Phi(t)) \quad (1)$$

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Fig.3 shows the demodulation process of the DCM method. The demodulated signal is described as (2).

$$\Phi_{out}(t) = B^2 J_1(C) J_2(C) \Phi(t). \tag{2}$$

In this system, considering the LID due to directly current demodulation on the DFB laser, (1) can be rewritten as

$$I(t) = (1 + m\cos(\varpi_c t)) \cdot \{\kappa B + B \cdot \cos(C \cdot \cos(\varpi_c t) + \Phi(t))\} \tag{3}$$

where κ is the index determined by the splitting ratio of the coupler in the interferometer and m is the depth of LID. Then the demodulation results turn to

$$\begin{aligned}\Phi_{out}(t) &= B^2\{J_1(C)J_2(C) - \frac{m^2}{4}[J_0(C) - J_2(C)][J_2(C) - J_1(C)]\}\Phi(t) \\ &+ \frac{\kappa Bm}{2}\{\frac{Bm}{2}[J_3(C) - J_1(C)]\sin\Phi(t) - BJ_2(C)\cos\Phi(t)\}\end{aligned} \tag{4}$$

As is shown in (4), the HSR will be declined and the linearity of the output results will be deteriorated, and the dynamic range of the system will be reduced. Fig.4 shows that the HSR of the DCM results is decreased by the influence of LID with $m = 0.2$. Fig.5 shows HSR reduces with the increase of the LID depth. In practical application, the HSR should be larger than 50dB, which means the LID depth should be less than 5%, but in fact, the LID depth is easy to get larger than 10%, with the length difference of interferometer arms less than 10cm and the modulation depth $C = 2.6$, when $J_1(C) \approx J_2(C)$.

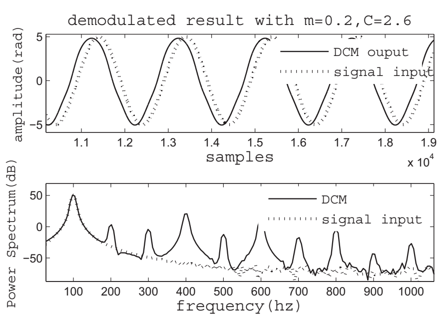

Fig. 4. demodulation result of DCM influenced by LID

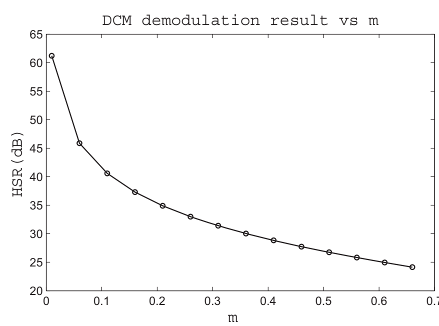

Fig. 5. HSR of DCM influenced by LID

However, in the seismometer system, the length difference of the sensor arms should be reduced to inhibit the phase noise of the laser source and improve the dynamic range of the system, and that requires stronger modulation current to keep the modulation depth of the phase carrier, while stronger modulation current leads to deeper LID[4].

In order to overcome the shortcomings of the DCM method, we design a new method for PGC demodulation as is shown in Fig.6. The output of PIN is multiplied by $\cos(\varpi_c t)$ and $\cos(2\varpi_c t)$, and then filtered out the high frequency components. The division result of the two components is

$$\Psi(t) = a\frac{\sin\Phi(t) + b}{\cos\Phi(t)} + c \tag{5}$$

where a, b, c are parameters determined by modulation depth C, LID depth m and splitting ratio of interferometer coupler κ. Then Ψ is used to look up signal $\Phi(t)$ from lookup table based on inverse function of (5).

The new method is much simpler in structure and easier to realize with the all digital system. The experimental results show it has removed the influence of the variance of light intensity, and archived better performance in HSR of demodulation results, linearity and dynamic range of the system.

III. Experiment results

In this paper, the seismometer system uses an unbalance interferometers with arm length difference less than 10cm. To keep the carrier modulation depth $C \approx 2.6$, the LID depth m is always between 0.1 and 0.4. The experiments are performed based on such an unbalance interferometer system by using a DFB semiconductor laser.

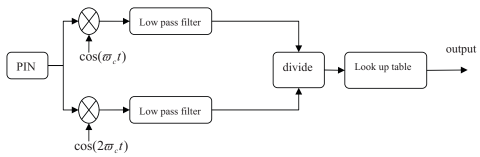

Fig. 6. structure of new method for PGC demodulation

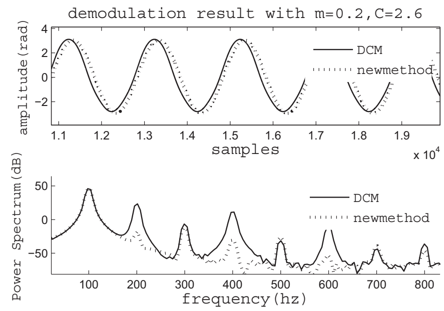

Fig. 7. demodulation result of DCM and new method with m=0.2 and C=2.6

A. Harmonic Suppression Ratio

The new method significantly improves the HSR of the demodulation results of system with LID. Fig.7 shows that the new method eliminate the harmonic components due to LID, and the HSR is more than 50dB.

With the LID depth of 0.2, the new method increases the HSR of demodulation results by nearly 30dB, as is shown in Fig.8. The variance of HSR of the demodulation results of the two methods with the increase of the LID depth is shown in Fig.9. The HSR of output is expected to be larger than 50dB, thus for DCM method, m should be less than 5%, while for the new method algorithm, m can be as much as 68%. Fig.9 also shows that the HSR of the new method is not impacted by LID with $m \in [0, 0.4]$, which contains the majority of application cases.

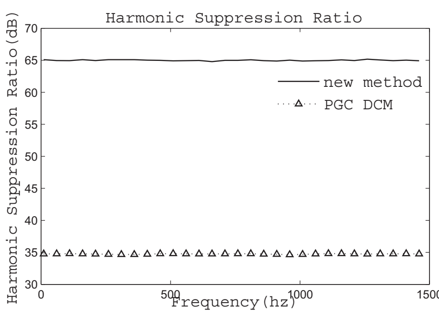

Fig. 8. Harmonic Suppression Ratio Comparison

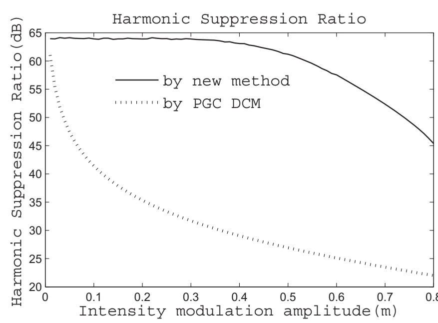

Fig. 9. Variance of HSR with increase of m

B. Linearity

Equation (4) and (5) show that the change of light intensity will impact the performance of DCM method, while it makes no influence to the new method.

Fig.10 shows slight disturbance in light intensity introduces a false signal to the output of DCM algorithm, and it changes the amplitude of the output signal, then impacts the linearity of the demodulation. Fig.11 shows 5% random disturbance in light intensity reduces the linearity of DCM algorithm by 10%. Fig.10 and Fig.11 also show that the change of light intensity has no influence to the performance of the new method.

The characteristic of low pass filter will also impact the performance of the linearity of PGC algorithm. Fig 12 shows with the same low pass filter, DCM method has a bad linearity performance, while the linearity of the new method is the same as the ideal result. That means we can achieve better performance with less source using the new method in all digital system.

C. Dynamic Range

Dynamic range is one of most important feature of sensor system. The upper limit of the seismic detector system is limited by the characteristic of the low pass filter and the modulation frequency. Fig.13 shows the upper limit of the two algorithm with the same LPF , a 100 order Least Square Filter, and the modulation frequency 11.2kHz. The upper limit of the new method is 6dB greater than that of DCM algorithm in low frequency band, and the new method approaches the ideal upper limit with lower order LPF.

The new method also approach significant improvement in noise performance. To keep the demodulate depth at about 2.6, and the HSR more than 50dB, Fig.9 shows that DCM method requires the arm length difference be more

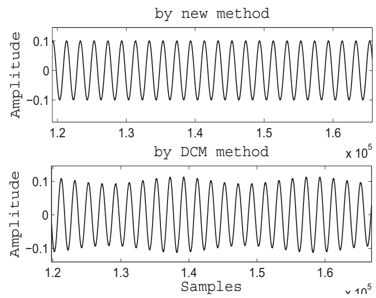

Fig. 10. output with 5% light intensity disturbance

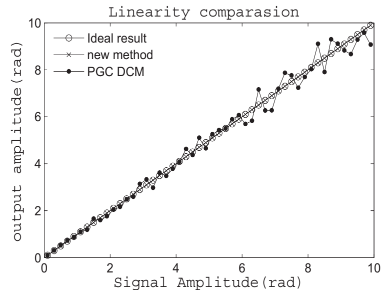

Fig. 11. Linearity Comparison with 5% disturbance in light intensity

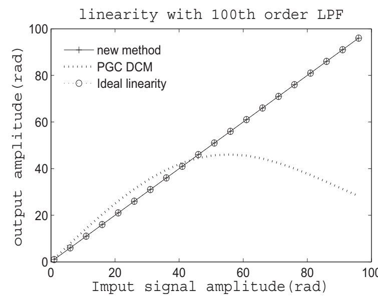

Fig. 12. Linearity comparison with 100th order low pass filter

than 10cm, while the new method is available with a arm length difference less than 1cm. As is shown in Fig.14, the phase noise power spectrum density of 10cm arm length difference system is 20dB greater than that of 1cm ones. It means that the phase noise of the new method is at least 20dB lower than that of DCM method.

With higher upper limit and better noise performance, the new method approaches a dynamic range 26dB more than that of the old algorithm. As is shown in Fig.13 and Fig 14, the upper limit and the phase noise at 100Hz is respectively 35dB and -95dB, which means the new method achieves a dynamic range of 130dB@100Hz.

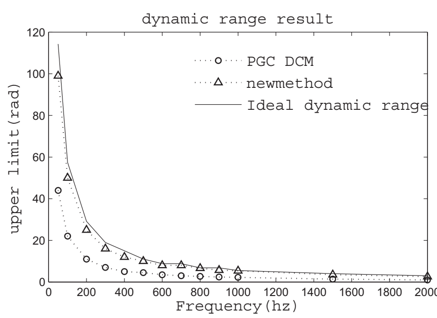

Fig. 13. dynamic range comparison

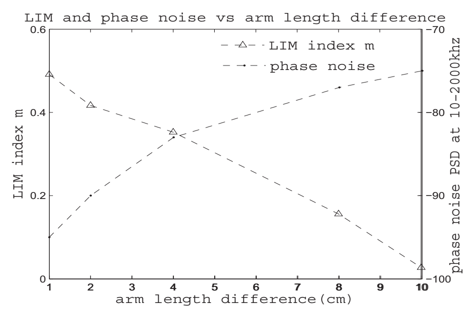

Fig. 14. LID depth and phase noise

IV. CONCLUSION

In this paper, a new demodulation method for the PGC system based on the LID model is proposed and analyzed. The new method has better performance than DCM method in demodulation HSR, linearity and dynamic range of the system.

The experimental results show the new method has eliminated the influence of the LID. With the same depth of LID, HSR of the demodulation result using the new method is 30dB higher than that using DCM algorithm.

In practical application, the HSR of the output results should be larger than 50dB. The experimental shows that in the DCM system m should be less than 5%, while with the new method, it can be as much as 68% .

In the same situation, the new method approach higher upper limit and lower phase noise. It turns out the dynamic range of the new method is 26dB higher than that of DCM algorithm.

All these results show that the new method has significant improvement over DCM algorithm for seismic optical detector system. It approaches a dynamic range of 130dB@100Hz with the distribute feedback laser source.

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