Intensity Modulated Acoustic Sensing Using a Distributed Feedback Fibre Laser

Author:
Leung, Ian; Whitbread, Trevor; Peng, Gang-Ding; Zhou, Shaoling; Zhu, Qing; Chen, Xiao-Bao

Publication details:
BGPP/ACOFT 2005
pp. 529-531
1877040339 (ISBN)

Event details:
BGPP/ACOFT 2005
Sydney, Australia

Publication Date:
2005

DOI:
https://doi.org/10.26190/unsworks/643

Intensity Modulated Acoustic Sensing Using A Distributed Feedback Fibre Laser

Ian Leung[1], Shaoling Zhou[2], Qing Zhu[2], Trevor Whitbread[1], Xiao-Bao Chen[2], Gang-Ding Peng[1]
[1] *Photonics and Optical Communications Group*
School of Electrical Engineering and Telecommunications
The University of New South Wales, Sydney 2052, Australia
Phone: +61-2-9385 5411 Fax: +61-2-9385 5993 Email: G.Peng@unsw.edu.au
[2] *The Electronics 23rd Research Institute*
China Electronic Technology Group Corporation
35 Yi Xian Road, Shanghai 200437, China

Abstract

Here we present our investigation into the use of a distributed feedback fibre laser (DFBFL) as an intensity-modulated sensor. In our preliminary experiments, we demonstrated the construction of this simple intensity fibre acoustic sensor system and attained good sensitivity.

Background. Reported interests concerning fibre laser based sensing system designs are predominantly interferometric oriented [1]-[6]. Systems utilizing polarization characteristics of DFBFL have also been demonstrated [7], [8]. But as far as we can tell, intensity modulated DFBFL sensors have not been reported. Traditional fibre optic intensity modulated sensors used various methods to allow the desired measurand to modulate the output power. Such sensors are reputed for being simple, reliable and cheap, but with the major shortcomings of having poor sensitivity and performance.

By adopting a DFBFL sensor head, sensitivity, performance and efficiency of a fibre optic intensity modulated system can be improved, due to its active resonance structure and low relative intensity noise (RIN). As the pump source and fibre laser technologies mature, associated costs of such systems should continue to decrease, adding to the advantages of a much simpler design and ease of maintenance. Such characteristics should be attractive to a variety of low-cost process-control/engineering applications.

It was reported in [9] that the output power of a DFBFL has a proportional relationship with the effective cavity length. Therefore as the effective cavity length is modulated by the acoustic field, the output signal power should change accordingly. The effective cavity length of the fundamental mode of a π-phase shifted DFBFL can be approximated [10] by $L_e \approx \kappa^{-1}$, which is independent to the device length. For the typical coupling coefficient κ of 150m^{-1}, the effective cavity length is around 6.5mm, a small fraction of the typical device length in the order of 10cm. A further contribution towards the intensity modulation effect could be due to the frequency dependence of the effective reflectivity which leads to cavity loss dispersion of a non-ideal π-phase shifted DFBFL [11].

Experiment Setup. The system setup is depicted in Fig. 1. The analog output of the detector is digitized, and all of the calculated FFT spectra presented have frequency resolution of 6.1Hz. A simple computer speaker (powered by a signal generator) was used to generate the acoustic wave to disturb the tightly horizontally suspended DFBFL [12]. The speaker was placed such that the acoustic wave vector is along the longitudinal axis of the fibre laser. Analysis is limited to sinusoidal signals below 40kHz due to our primary interest in hydrophone applications. The speaker and fibre laser were placed inside a rudimentary isolation box.

The DFBFL used was a symmetric π-phase shifted, single polarization design. The emission spectrum was centered at 1551.2nm, with RIN less than 80dB/Hz. The 3dB linewidth is between 10kHz to 20kHz.

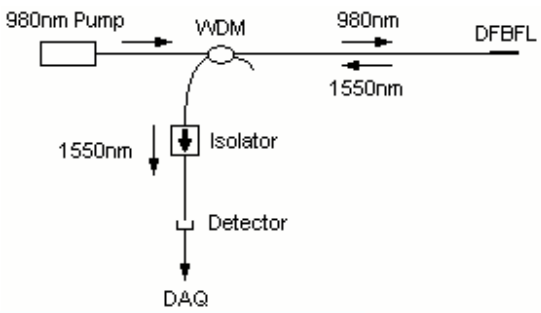


Fig.1 System components.

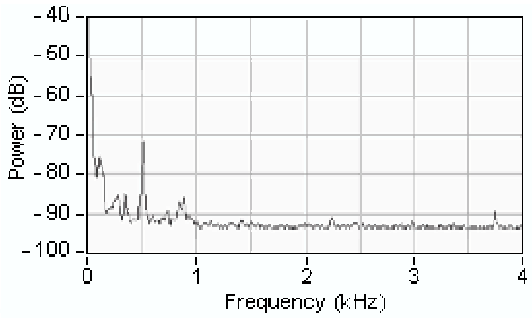


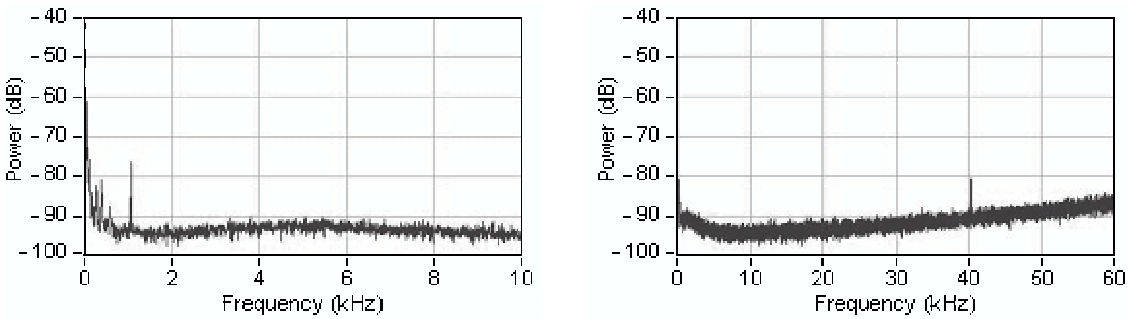
Fig.2 Calculated power spectrum of DFBFL output with signal generator set to 504Hz, 3.6mV peak-to-peak. Spectrum calculated using exponentially weighted RMS averaging (60 averages).

The length of the DFBFL spans over approximately 10cm of erbium doped fibre. No coating sensitivity enhancements were applied.

Results. Fig. 2 shows a DFBFL (pumped at 35mW) output power spectrum obtained from applying a 3.6mV peak-to-peak at 504Hz to the speaker. We were unable to determine the actual acoustic pressure emitted from the speaker, but 3.6mV peak-to-peak was the minimum output amplitude of the signal generator. The spectrum was calculated using an exponentially weighted RMS averaging algorithm with 60 averages. A stable -70dB spectral spike at approximately 500Hz can be clearly observed. It was also observed that the background RIN does fluctuate up to the -80dB level, reducing the SNR to 10dB. The fluctuations are attributed to poor isolation conditions.

Fig. 3 shows two DFBFL (pumped at 35mW) output power spectra obtained from applying the minimum signal amplitude at 1kHz and 40kHz. The spectra were obtained using an exponentially weighted RMS averaging algorithm with only 10 averages. Despite the reduction in the number of averages, the SNR is still almost 10dB for the 40kHz case.

In all three cases, the small signals were intensity modulated, and can be detected directly from the output power spectra. Such simplicity in the detection process is the single most valued advantage of an intensity modulated system. Beyond 40kHz, the SNR is further reduced due to an increase in the RIN [6], [13].

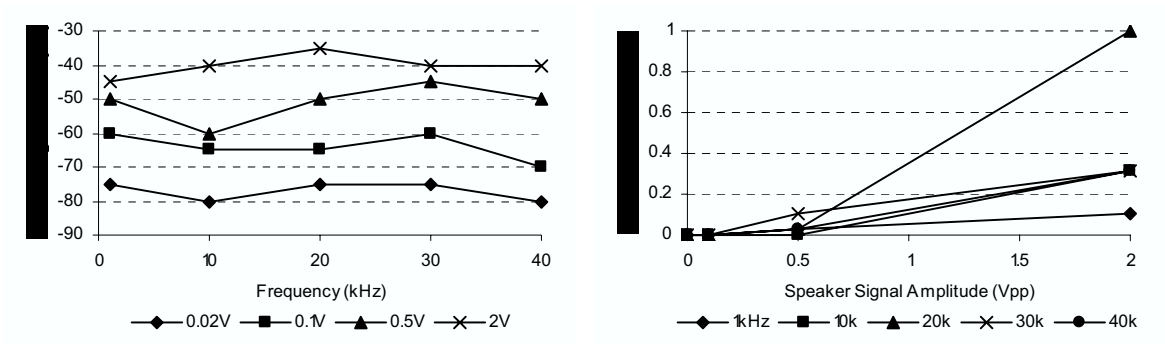


(a) *(b)*

Fig.3 Calculated power spectra of DFBFL output with signal generator set to (a)1kHz, (b) 40kHz at 3.6mV peak-to-peak. Spectra calculated using exponentially weighted RMS averaging (10 averages).

Fig. 4 displays results when higher signal amplitudes were applied. As desired in an intensity modulated system, larger acoustic field strengths induced higher spectral peaks. From Fig. 4(a) it seems that the

frequency response of the intensity modulation process varies for different frequencies. Fig. 4(b) suggests that the amount of intensity modulation induced is non-linear, also reported in [12].



(a) *(b)*

Fig. 4 Relative power of signal peak plotted as functions of (a) frequency and (b) amplitude.

Conclusion. The preliminary results showed that a DFBFL can be used in intensity modulated sensor system with high sensitivity. Frequency and amplitude characteristics of the acoustic signals from 500Hz to 40kHz can be determined directly from the returning DFBFL emission. The signal frequency peaks for the low signal level of 3.6mV peak-to-peak were at least 10dB above the noise floor of the detected power spectra. Such results from our provisional setup hint at the simplicity vs. performance of such a sensor system. The combination of simplicity, robustness and electrical-passive characteristics of fibre sensors should be attractive to industrial applications with relaxed sensitivity requirements from interferometric oriented systems.

References

[1] A.D. Kersey and A. Dandridge, *'Applications of Fiber-Optic Sensors'*, IEEE Transactions on Components, Hybrids, and Manufacturing Technology, Vol. 13, No. 1, pp.137-143, Mar. 1990

[2] A.D. Kersey, M.A. Davis, H.J. Patrick, M. LeBlanc, K.P. Koo, C.G. Askins, M.A. Putnam and E.J. Friebele, *'Fiber Grating Sensors'*, IEEE J. Lightwave Tech., Vol. 15, No. 8, pp.1442-1463, Aug. 1997

[3] C.K. Kirkendall and A. Dandridge, '*Overview of high performance fibre-optic sensing'*, Institute of Physics Publishing, J. Phys. D: Appl. Phys. **37** (2004) R197-R216

[4] K.P. Koo and A.D. Kersey, *'Bragg Grating-Based Laser Sensors Systems with Interferometric Interrogation and Wavelength Division Multiplexing'*, IEEE J. Lightwave Tech., Vol. 13, No. 7, pp.1243-1249, Jul. 1995

[5] D.J. Hill, P.J. Nash, D.A. Jackson, D.J. Webb, S.F. O'Neill, I. Bennion and L. Zhang, *'A fiber laser hydrophone array'*, SPIE Vol. 3860, pp.55-66, Sep. 1999

[6] I. Leung, Z. Brodzeli, T. Whitbread, X.B. Chen, G.D. Peng, '*A distributed-feedback fibre laser based optical fibre hydrophone system with very high-sensitivity*', accepted for presentation at Photonics Asia 2004, Advanced Sensor Systems and Applications II., Beijing, China, Nov. 2004

[7] E. Rønnekleiv, M. Ibsen and G.J. Cowle, '*Polarization Characteristics of Fiber DFB Lasers Related to Sensing Applications*', IEEE J. Quantum Electronics, Vol. 36, No. 6, pp. 656-664, Jun. 2000

[8] A. Frank, K. Bohnert, K. Haroud, H. Brändle, C.V. Poulsen, J.E. Pedersen and J. Patscheider, '*Distributed Feedback Fiber Laser Sensor for Hydrostatic Pressure'*, IEEE Photon. Technol. Lett., Vol. 15, No. 12, pp.1758-1760, Dec. 2003

[9] K. Yelen, L.M.B. Hickey and M.N. Zervas, *'A New Design Approach for Fiber DFB Lasers With Improved Efficiency'*, IEEE J. Quantum Electronics, Vol. 40, No. 6, pp 711-720, Jun. 2004

[10] Scott Foster, *'Spatial Mode Structure of the Distributed Feedback Fiber Laser'*, IEEE J. Quantum Electronics, Vol. 40, No. 7, pp. 884-892, Jul. 2004

[11] G.R. Cranch, *'Frequency modulation properties of erbium doped DFB fiber lasers using cavity strain'*, IEEE, 0-7803-7289-1/02, pp. 519-522, 2002

[12] S. W. Løvseth, K. Bløtekjær and J. T. Kringlebotn, *'Contributions to Wavelength Shifts of DFB Fiber Lasers used as Acoustic Sensors in Air'*, European Workshop on Optical Fibre Sensors SPIE Vol 3483•0277-786X/98, pp. 69-73, 1998

[13] G.A. Cranch, M.A. Englund and C.K. Kirkendall, *'Intensity Noise Characteristics of Erbium-Doped Distributed-Feedback Fiber Laser'*, IEEE J. Quantum Electronics, Vol. 39, No. 12, pp. 1579-1586, Dec. 2003