Linearly Optical Frequency Chirped DFB Laser with Pre-distorted Modulation Waveform for High Resolution FMCW Ranging System

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Abstract: Optical frequency chirp of a DFB laser is linearized by modifying the modulation waveform using an interference signal of an interferometer, and high spatial resolution FMCW ranging system was realized.
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1. Introduction

Frequency-modulated continuous-wave (FMCW) ranging system is a high-resolution ranging system using an optical frequency-chirped laser source and an unbalanced two-beam interferometer as shown in Fig. 1 for system configuration and in Fig. 2 for waveform of optical frequency chirp. The spatial resolution is seriously affected by linearity of the optical frequency chirp, and much attentions have been paid to compensate for the nonlinearity by using an auxiliary interferometer [1-2] and to linearize the optical frequency chirp with optical and electrical feedback loop [3-5]. Although the first method is simple and effective, the measurement range is limited to less than half of the optical path difference of the auxiliary interferometer to satisfy the Sampling theorem. The second method has no limitation in the measurement range, and is preferable to achieve long measurement range.

Here we demonstrate linearizing method of the optical frequency chirp of a DFB laser by modulating the injection current with pre-distorted triangular waveform. The DFB laser is modulated with a slightly distorted triangular waveform modified by using the interference signal of an interferometer. The spatial resolution is enhanced by more than 50 times as compared to that without the modified modulation waveform.

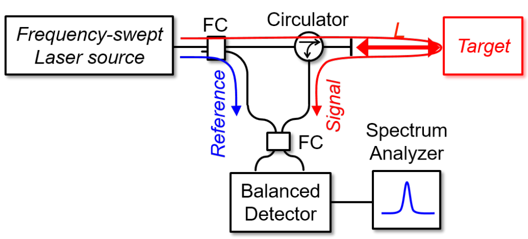

Fig.1. System configuration of FMCW ranging system.

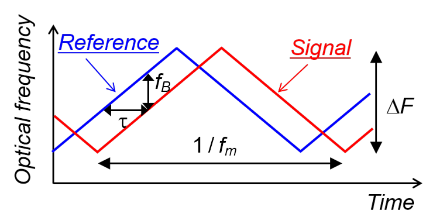

Fig. 2. Waveform of optical frequency chirp.

2. System configuration

Figure 3 shows the setup for modifying the modulation waveform. A DFB laser emitting at 1550 nm wavelength was used as a laser source, and the injection current was modulated with a triangular waveform with the repetition frequency f_m = 500 Hz. The modulation amplitude was 40 $mA_{p\text{-}p}$, which gives the optical frequency chirp range ΔF (shown in Fig 2) of 8.7 GHz. A part of the emitted light from the DFB laser was coupled to a Mach-Zehnder interferometer with differential fiber length ΔL = 15 m. Since the optical frequency of the DFB laser is chirped by injection current modulation, the interference signal has a beat frequency corresponding to ΔL. The modulation waveform was sampled with the interference signal after converting to a TTL signal. The sampled modulation waveform was transferred to the function generator and was used as a new modulation signal of the DFB laser. As a result, the modulation waveform is slightly distorted so that the optical frequency of the DFB laser is linearly chirped. The procedure is repeated several times to improve linearity of the optical frequency chirp.

3. Experimental results

Figure 4 shows the modulation waveform with and without the waveform modification. The blue curve is an original triangular modulation waveform, and the red curve is the modulation waveform after 3-times modification. The modified waveform is found to be slightly curved.

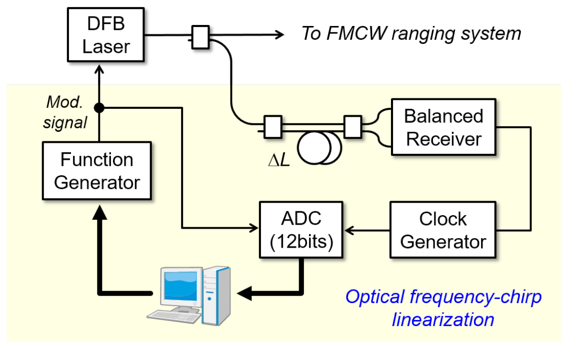

Fig.3. Experimental setup for linearizing optical frequency chirp.

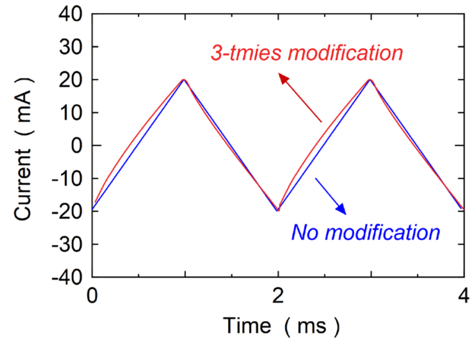

Fig. 4. Modulation waveform after modification.

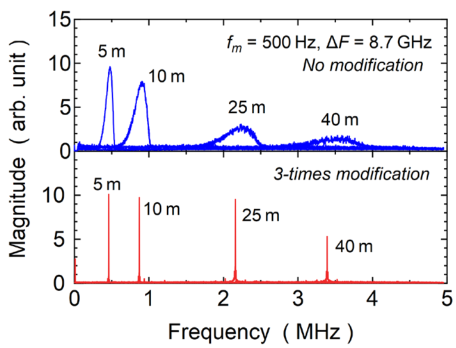

Fig. 5. Measured beat spectrum with and without modification.

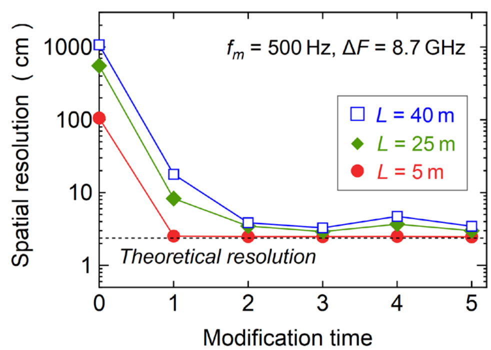

Fig. 6. Spatial resolution against the modification time.

The linearly optical frequency-chirped DFB laser is applied to FMCW ranging system, and optical fibers are used as the target. Figure 5 shows the measured beat spectrum from the end of the optical fibers without waveform modification and with 3-times waveform modification. In the measurement, the interference signal in the increasing section of the modulation waveform is sampled and the beat spectrum is calculated by FFT after multiplying the Hanning window. The theoretical spatial resolution δz is given as $\delta z = 2c/(2n\Delta F)$, where c is the light speed in vacuum, n is the refractive index of the fiber, ΔF is the optical frequency chirp range, and the coefficient "2" is a scaling factor due to multiplying Hanning window for FFT, and is $\delta z = 2.4$ cm in the experiment. The beat spectrum is spread out without waveform modification, indicating the beat frequency is varied in time attributed to nonlinear optical frequency chirp. After 3-times waveform modification, very fine beat spectrum is obtained due to linearized optical frequency chirp. Figure 6 shows the spatial resolution against the modification times. The spatial resolution is greatly enhanced with 1-time modification, and then is gradually enhanced with the modification time. The final spatial resolution is almost the same with the theoretical resolution shown in the dot line in Fig. 6.

4. Conclusions

We have successfully linearize optical frequency chirp of a DFB laser by modifying the modulation waveform by using an interference beat signal. Then high resolution FMCW ranging system was successfully realized. The demonstrated method is useful for long-range FMCW ranging systems and laser radar systems.

5. References

[1] U. Glombitza and E. Brinkmeyer, "Coherent frequency-domain reflectometry for characterization of single-mode integrated-optical waveguides," J. Lightwave Technol., **11**(8), 1377–1384 (1993).
[2] K. Iiyama, et. al., "High resolution FMCW reflectometry using a single-mode vertical cavity surface emitting laser," IEEE Photon. Technol. Lett., **23**(11), 703-705 (2011).
[3] K. Iiyama, L.T. Wang, and K. Hayashi, "Linearizing optical frequency-sweep of a laser diode for FMCW reflectometry," J. Lightwave Technol., **14**(2), 173–178 (1996)
[4] N. Satyan, et. al.," Precise control of broadband frequency chirps using optoelectronic feedback," Opt. Express., **17**(18), 15991-15999 (2009).
[5] J. Qin, et. al., "Coherence enhancement of a chirped DFB laser for frequency-modulated continuous-wave reflectometry using a composite feedback loop," Opt. Lett., **40**(19), 4500-4503 (2015).