Photonic Generation of Linearly Frequency-modulated Radar Signal Using Gain-switching Laser

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***Abstract*—A simple photonic linearly frequency-modulated waveform generation with multiplying bands and bandwidth based on gain-switching laser is proposed and experimentally demonstrated. The time bandwidth product of generated LFM signals are N times of applied signal.**

Keywords—microwave photonics, multi-band, pluse compress, gain switching laser

I. Introduction

Nowadays, pulse compress radar system, has great application prospect due to its superior advantages in the ranging, imaging and sensing [1]. The performance of a radar largely depends on the signal it transmits. The linear frequency modulated (LFM) waveforms play a significant role in radar systems and are usually used to increase the pulse compression ratio and range resolution. Besides, multi-band radar is the development trend of the next generation performance enhanced radar system for simultaneously implementing different functions, such as detection, tracking, and imaging [2]. C-band (4-8 GHz) radars have good angular resolution and precision when used in airport terminal surveillance radar. X-band (8-12 GHz) radars are often used to generate narrower beams with improved spatial resolution for highly resolved target imaging [3]. Ku-band (12-18 GHz) and K-band (18-27 GHz) radars are mainly used for satellite communication.

In this paper, we propose and experimentally demonstrate a photonics approach to generating multi-band LFM signals based on gain-switching laser. This system has so simple structure, without any complex external modulator, high-speed electrical amplifier or expensive high quality microwave source. The bandwidth increases with the carrier frequency, and they are both N times of the applied LFM signal from AWG. Thus, it could generate multi-band LFM signals with large TBWP. Moreover, the generator is also reconfigurable since the carrier frequency, bandwidth and time duration of the generated LFM signals can be easily adjusted. The rate equations of gain-switching lasers under modulation of high-level LFM signals are also given in next section. A proof-of-concept experiment is carried out and the results of autocorrelation are also given.

II. Principle and Experimental Setup

A. Principle of gain-switching laser

Direct modulation is an electrical signal as the driving current of the modulated laser, so that the output light intensity varies with the modulated current.

$$S(f)=\sum\left| J_n\left(\frac{\Delta f}{f_{CF}}\right)-\frac{M}{4}\left\{J_{n+1}\left(\frac{\Delta f}{f_{CF}}\right)e^{I_0\phi_f}+J_{n-1}\left(\frac{\Delta f}{f_{CF}}\right)e^{I_0\phi_f}\right\}\right|^2 \quad (2)$$
$$\bullet\delta(f-(f_0+nf_{CF}))$$

J_n is the first order Bessel function, f_0 is the frequency of optical wave, Δf is the maximum frequency offset caused by modulation. Although the change of the modulation frequency will cause the change of the β, the difference between the center frequencies of the adjacent optical comb lines is unchanged, and equal to the f_{CF}. Besides, from the Eq. (2), we can find that optical spectrum of the directly modulated laser will appear multiple sidebands, when the sidebands power of each order is close, the OFC spectrum is formed. The sidebands power is related to I_0 and M, and M is determined by power of modulation signals.

B. Experimental setup

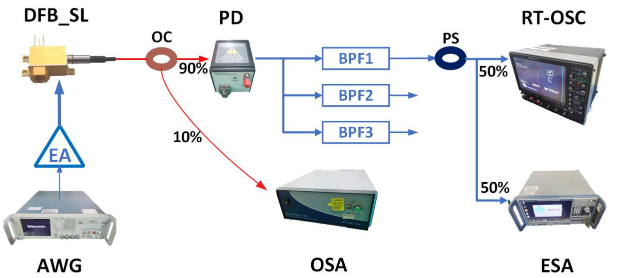


Fig. 1. Experimental diagram of the simple multi-band LFM signals generation. DFB SL: distributed feedback semiconductor laser; EA: electrical amplifier; PD: photodetectors; AWG: arbitrary waveform generator; OSA: optical spectrum analyzers; ESA: electronic spectrum analyzer; RT-OSC: real-time oscilloscope; OC: optical coupler; PS: power splitter. BPF: bandpass filter.

Fig. 1 illustrates the experimental diagram of multi-band LFM waveform generation based on gain-switching DFB SL. In this experiment, an arbitrary signal generator (AWG Tektronix AWG70002A) is used to offer the reference signal., and its carrier frequency, time duration and bandwidth is tunable. The maximum output power of reference signal could only reach up to 0 dBm, and it cannot meet the requirements of gain-switching state. Thus, the modulation signal is amplified 20 dB by an electrical amplifier (EA) with bandwidth of 10 GHz before it is loaded onto the DFB SL. Then the optical signal is spilt by an optical coupler (OC), 10 % optical signal is sent to the optical spectrum analyzer (OSA, FINISAR WaveAnalyzer 1500s) with a resolution of 0.001 THz and 90 % is introduced to a photodetector (PD, TELEDYNE LECROY OE6250G-M) with the maximum input power of 10 dBm and the responsibility of 0.65 A/W to convert optical signal to electricity signal. After that, we could get the electrical spectra and temporal waveform by using an electronic spectrum analyzer (ESA, ROHDE&SCHWARZ FSW-26SIGNAL&ANALYZER) and a real-time oscilloscope (RT-OSC, Lecroy SDA 830Zi-A) respectively. We can also use the bandpass filters (BPFs) with different pass-band to obtain the single-band LFM signal for further analysis by using digital signal processing (DSP).

III. Results and Discussion

The real-time oscilloscope (RT-OSC, Lecroy SDA 830Zi-A) with sample rate of 40 Gsample/s and 20 GHz bandwidth is used in the experiment. The time-frequency diagrams of the generated multi-band LFM signals are given in Fig.5. The number of frequency bands is concerned with f_{CF}. We could obtain LFM signals with any frequency bands by tuning the carrier frequency (f_{CF}) and bandwidth (f_{BW}) of reference signal.

The quality of the generated signals in each frequency band is analyzed and the result graph of autocorrelation is obtained. In our laboratory, only three BPFs with passbands of 8.5-13.5 GHz, 10-18 GHz and 18-26.5 GHz can be used to filter the single-band LFM signal. Thus, we take the limitations of electrical filters into consideration and set the reference signal with 4.75 GHz carrier frequency and only 500 MHz bandwidth. The electrical spectrum of the amplified reference signal from AWG and generated signals are given in Fig. 3(a) with orange color. The generated signals are represented by blue line. Thus, this system could generate multi-band LFM signals without any high-speed electric amplifier. Fig. 3(b) demonstrates that the linearity and purity of generated LFM signals are good.

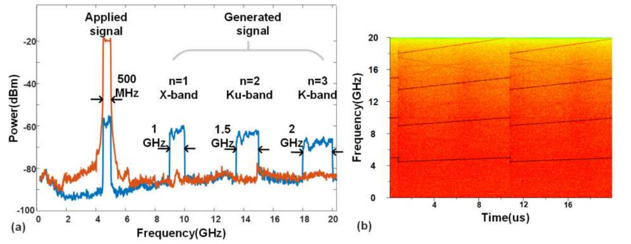
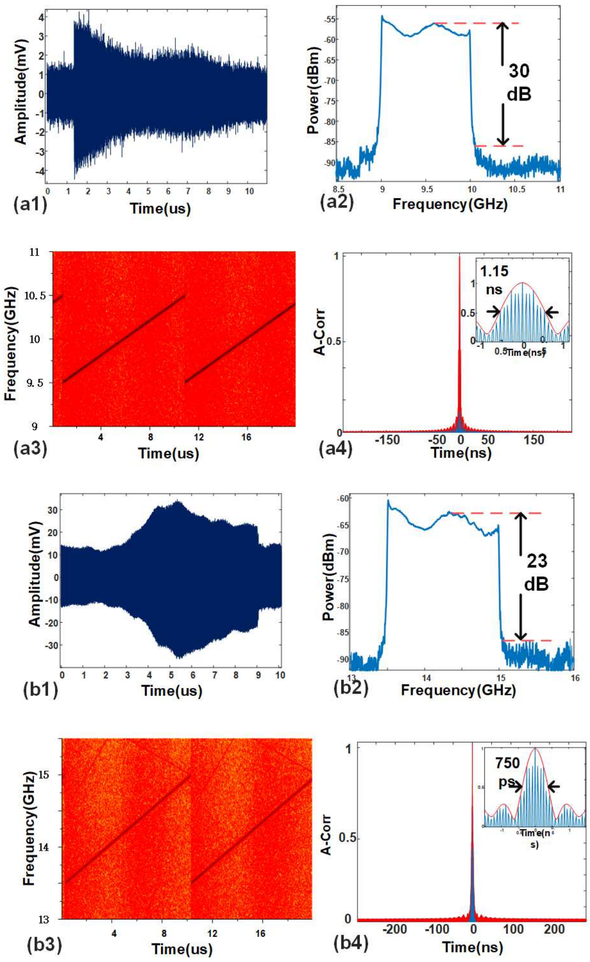


Fig. 3. (a) Electrical spectrum of the generated multi-band LFM signals with multiplying bandwidth (VBW=1 MHz, RBW=1 MHz); (b) the corresponding time-frequency diagram (X-band: 9-10 GHz, Ku-band: 13.5-15 GHz, K-band: 18-20 GHz).

Fig. 4 shows the auto-correlation peak of the X-band signal with theoretical TBWP of 10000. The FWHM of the peak is 1.15 ns. The PCR is calculated to be 8695, which is close to the theoretical TBWP. In the same way, in Fig. 4(b4), the FWHM is 750, PCR is calculated to be 13333, which is close to the theoretical TBWP of 15000. In Fig. 4(c4), the FWHM is 560, PCR is calculated to be 17857, which is close to the theoretical TBWP of 20000. Thus, auto-correlations of the generated LFM waveforms exhibit good pulse compression performance.



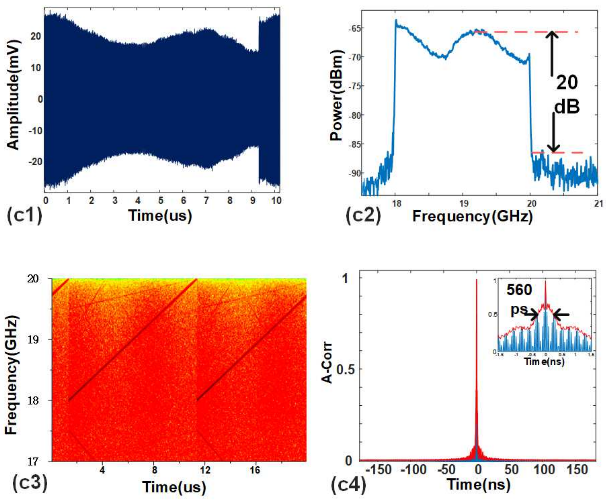


Fig. 4 The characteristics of generated LFM signals in different frequency bands (a) 9.5 GHz (b) 14.25 GHz (c) 19 GHz; (a1-c1) temporal waveforms; (a2-c2) electrical spectrums (Res=500 kHz, RBW=1 MHz); (a3-c3) the time-frequency diagrams;(a4-c4) the auto-correlation peak (red line curve is the fitted envelope) and zoom-in view of the it

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