Vernier Transceiver Architecture for Side-Lobe-Free and High-Entendue LiDAR

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Abstract:A Vernier-based LiDAR transceiver for high side-mode suppression optical phased arrays is proposed and investigated. This architecture enables side-lobe-free 180° viewing angle with multiple-wavelength waveguide spacing thereby easing fabrication requirements.

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1. Introduction

Automated technologies such as industrial robots, autonomous driving vehicles, and drones for defense applications require a high level of situational awareness for safe and effective operation [1, 2]. This is commonly achieved with a combination of passive and active sensors such as cameras, RaDAR, and LiDAR. Compared to RaDARs, LiDAR, owing to a very high carrier frequency, is characteristic of a narrow beamwidth, leading to superior angular resolution while maintaining a high range resolution not achievable with camera based sensors[3]. These attributes make LiDAR ideal for many applications where high resolution 3D performance is required such as environmental mapping and vehicle navigation. The most common LiDAR technology is based on scanning LiDAR whereby a single collimated beam scans the entire spatial volume to create a 3D map of the environment. The beam is commonly collimated with bulk optical components (lenses) and mechanically steered, leading to large size and weight, and, in harsh environments, reliability issues. To overcome these limitations, the development of optical phased array (OPA) solutions has come to the foreground. The principal challenge of OPAs is achieving sub-wavelength spacing for the array emitters, therefore these systems are prone to secondary lobes in the field of view. These lobes strongly limit system sensitivity and system entendue. Several techniques have been proposed to increase the unambiguous field of view, and these are based primarily on non-uniform OPA element spacing [4]. To date, these have demonstrated poor side-mode suppression ratio (SMSR) or require computationally heavy optimization methods to meet the desired OPA performance.

This work presents the simulation results of a novel Vernier-based LiDAR transceiver architecture capable of being fully integrated. The proposed scheme exploits two separated OPAs, one for the transmitter and one for the receiver, with wide (multi-wavelength) element spacing. Along with the potential for much simplified fabrication, this architecture enables high suppression of the sidelobes, thereby significantly increasing the system unambiguous field of view.

2. System description and simulation results

The Vernier-based LiDAR transceiver architecture is described schematically in Fig. 1(a). The transmitter laser is modulated by a Mach-Zehnder modulator (MZM) and coupled to the transmitter OPA. A portion of the transmitter laser light is directed to the receiver tunable coherent reception, thus improving system sensitivity while allowing simultaneous measurement of the target distance and velocity [5]. The receiver comprises a second OPA, which collects the light scattered by the target and routes it to the coherent receiver. The OPAs are composed of M transmitting elements and N receiving elements, respectively. M and N can be different or equal in value. The element spacing is respectively d_{tx} and d_{rx}, and are strictly different.

Studying a single OPA, the angular separation between two sidelobes, which corresponds to the OPA unambiguous field of view, is a function of the array element separation, d, and signal wavelength, λ, as described in Eq. 1. In order to avoid the presence of sidelobes within the total 180° field of view angle of the OPA, the maximum waveguide separation is equal to half of a wavelength, which, according to Eq. 1 would correspond to a waveguide separation d<750nm for λ=1550nm.

$$\Delta\theta = \arcsin\left(\frac{\lambda}{2d}\right) \tag{1}$$

$$G(\theta) = G^{Tx}(\theta)G^{Rx}(\theta) \tag{2}$$

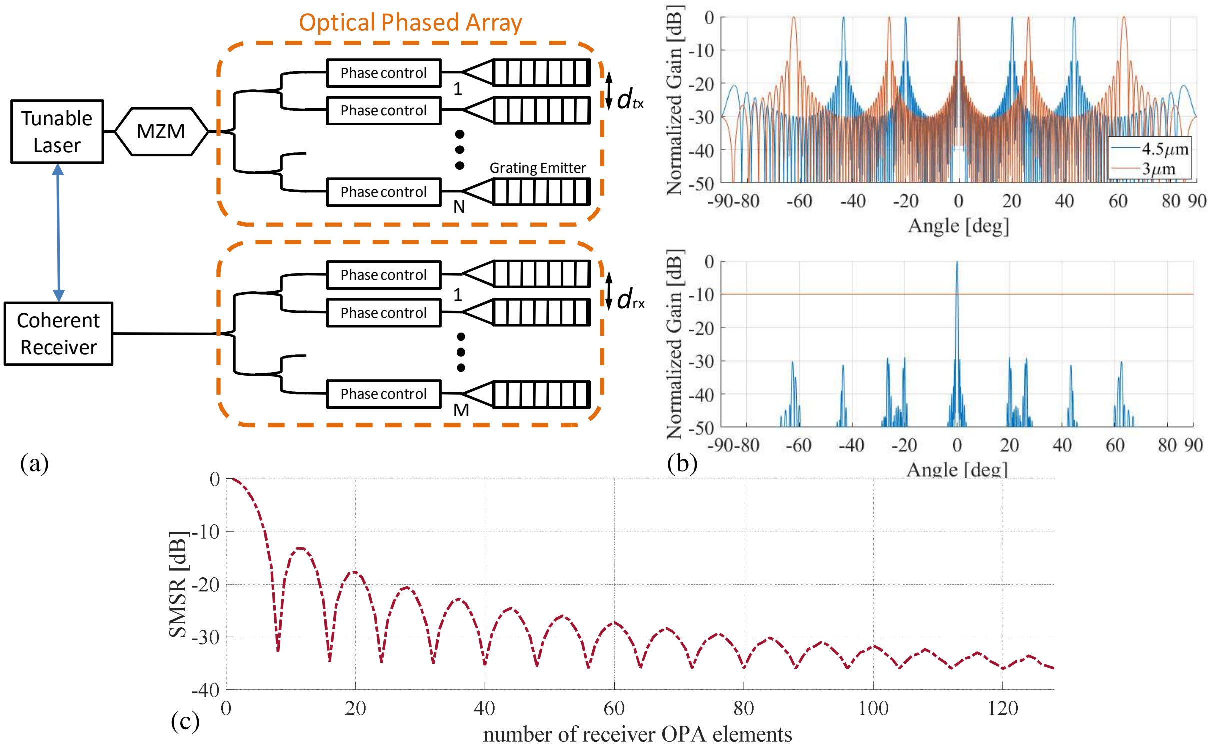

Figure 1: (a) Schematic of Vernier LiDAR architecture.(b) Radiation pattern for 3-µm spacing (red curve) and 4.5-µm spacing (blue curve) OPAs (top) and Vernier radiation pattern (bottom). (c) SMSR vs receiver radiating elements (transmitter elements = 128).

Considering a two OPA system, as the one proposed, the total gain associated with the transmitter and receiver chain (Eq. 2) is equal to the product of the transmitter and receiver gains. Based on Eq. 2, it is possible to design the two OPAs to yield a minimum of the transmitter gain where a sidelobe of the receiver is present, and vice versa, allowing for suppression of the unwanted sidelobes and expanding the sidelobe-free field of view of the system. This behavior is depicted in Fig.1(b). The top plot shows the normalized gain as a function of the view angle for the two arrays (the transmitter and receiver OPAs) each one with 128 radiating elements and, respectively, a distance between the elements equal to 3µm (red curve) and 4.5µm (blue curve) for a wavelength of λ=1550nm. The two spacings, optimized to minimize the SMSR, yield radiation patterns with several sidelobes, with the two main lobes (0° angle) perfectly aligned, while the sidelobes, spaced about 20º, are slightly shifted with respect to each other. As a result, for the system gain reported in the bottom of Fig. 1(b), only the main lobe is preserved while the sidelobes are suppressed by more than 30dB. The OPA full width half maximum beam width (FWHM-BW) is 0.9º. As shown in Fig. 1(c) which reports the SMSR for a 128 elements transmitter OPA for different receiver OPA element count, good SMSR performance (SMSR>30dB) can be achieved even with significantly smaller receiver OPA, thus permitting a significant system size and cost reduction, at the cost of a slightly broadened beamwidth. This approach is therefore extremely promising for high performance and simplified fabrication enabled by the larger afforded emitter element spacing.

3. Conclusions

A novel LiDAR transceiver architecture based on the Vernier effect has been investigated. This scheme can be implemented in an OPA to enable side-lobe-free performance and high entendue with a waveguide spacing significantly greater than the signal wavelength, thereby simplifying fabrication. A SMSR greater than 25dB across the entire 180° viewing plane was theoretically demonstrated.

4. References

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