X-band Optically Steered Phased Array Antenna with Ultra-fast Beam Scanning

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ABSTRACT

A photonic-based phased array antenna (PAA) with ultra-fast beam scan is proposed and experimentally demonstrated using dispersion-based true time delay lines. The ultra-fast angle scan is realized using an ultra-fast wavelength-swept laser source which is constructed by a gated multi-wavelength laser (MWL) and a dispersion compensation fiber (DCF). The wavelength switching time is about several nanoseconds. In the results, we also successfully realized an ultra-fast angle scan from 0 to 43° within 12.48 ns.

Keywords: *Photonics-based Phased-array radar, ultra-fast beam scan*

1. INTRODUCTION

In recent years, many wavelength-controlled TTD beamforming systems have been proposed and demonstrated [1-5]. The beam steering angle is determined by the wavelength of light wave. The speed of angle scan is proportion to the wavelength switching time. Up to now, many wavelength-swept lasers have been demonstrated with wide wavelength sweeping range. Normally, the optical source consists of a fast tunable optical filter and a wideband gain medium. The wavelength sweeping range and speed is determined by the bandwidth of the gain medium and the tuning speed of the filter. In [6], a wavelength-swept optical source is reported with a wavelength sweeping range of 117 nm and a scanning repetition rate of 20 KHz using a diffraction grating and polygon scanner filter. In [7], a Vernier-Tuned Distributed Bragg Reflector (VTDBR) structure as a monolithic semiconductor is employed to achieve a wavelength-swept with 200 KHz repetition rate. Using a microelectromechanical system (MEMS) tunable vertical-cavity surface-emitting laser (VCSEL), a wavelength sweeping repetition rate is up to 760 KHz [8] by modulating the dielectric mirror. For the reported wavelength-swept lasers, the wavelength sweeping repetition rates are limited at kilohertz due to the fact that the change of wavelength is realized with slowly mechanical movement, which is normally at a level of millisecond. A significant improvement of the sweeping repetition rate is realized using optical absorber, which enables a high repletion rate of several megahertz [9]. However, it is still a challenge for those laser sources to be used in a fast scanning PAA system, which requires an angle scan repetition rate at gigahertz level and time duration of nanoseconds.

In this paper, we propose a photonic-based phased array antenna with ultra-fast angle scan using an ultra-fast wavelength-swept optical source. The key unit of the proposed photonics-based PAA is the ultra-fast wavelength-swept laser source which is realized using a dispersed gated multi-wavelength laser (MWL). Wavelength-sweep time between two adjacent wavelengths is only several nanoseconds for wavelength spacing of 0.8 nm and 2.4 nm. Moreover, we incorporate the proposed optical source into a previously constructed TTD-PAA system. An ultra-fast angle scan from 0 to 43° within 12.48 ns is realized, which is hundred times faster than previous results.

2. PRINCIPLE AND EXPERIMENT

Figure 1 shows the schematic architecture of the proposed photonic-based PAA which mainly includes an ultra-fast wavelength-swept optical source section and a TTD network section. In the ultra-fast wavelength-swept optical source section, it consists of a MWL, a polarization controller (PC), a Mach-Zehnder modulator (MZM), an arbitrary waveform generator (AWG), a low-noise amplifier (LNA) and a spell of DCF, as shown in the inset of Fig. 1. In the TTD network section, each TTD line is made of a DCF and a single mode fiber (SMF). Physical lengths of the TTD lines are the equality but provide different dispersion. The beam scanning angle is depended on the wavelength of the MWL and the scanning speed is determined by the sweep repetition rate of the wavelength-swept optical source. The time interval between two adjacent wavelengths after dispersion $\Delta\tau$ can be expressed as

$$\Delta\tau = DL\Delta\lambda \qquad (1)$$

where D is the dispersion coefficient, L is the length of DCF, $\Delta\lambda$ represents the wavelength spacing of MWL. The duration Δt and period T of the electrical square signal should meet the following conditions

$$\Delta t = \Delta\tau, T = N\Delta\tau \qquad (2)$$

If the Eq. (2) conditions can be well satisfied, we will achieve a fast wavelength-swept optical source. The wavelength directional angle is determined by the wavelength of the MWL and the sweep period is controlled by the electrical time gate signal.

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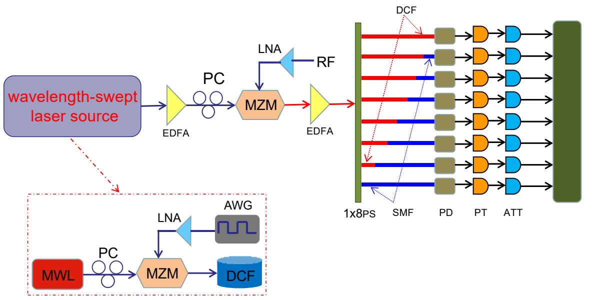

Fig. 1. Schematic architecture of the proposed photonic-based PAA system. MWL: multi-wavelength laser; PC: polarization controller; MZM: Mach-Zehnder modulator; LNA: low-noise amplifier; AWG: arbitrary waveform generator; DCF: dispersion compensation fiber; EDFA: erbium-doped optical fiber amplifier; PS: optical power splitter; DCF: dispersion compensation fiber; SMF: single mode fiber; PD: photodetector; PT: phase trimmer; ATT: attenuator.

To demonstrate the wavelength-switch time, the MWL with wavelength spacing of 2.4 nm and 0.8 nm were employed in our experiment, as shown in Fig. 2(a)-(b). The dispersion coefficient of the DCF is measured to be 848.38 ps/nm. To satisfy the conditions described by Eqs.(1)-(2), The high level duration of square signal and the period of the square signal are set to be (2.04 ns, 12.24 ns) and (0.68 ns, 5.44 ns), respectively. Fig. 2(c)-(d) show the square signal generated from AWG. Fig. 3(a)-(b) show the photocurrent of the detected wavelength-swept optical source with wavelength spacing of 2.4 nm and 0.8 nm, respectively. When the MWL was turned off for every other channel, the output signal turned to be a pulse train with duty ratio of 50%, as shown in Fig. 3(c)-(d), which demonstrated a wavelength can realize fast sweep without overlapping. The pulse durations of the output signals are 2.08 ns and 0.72 ns, respectively, coinciding with the time gates shown in Fig. 2(c)-(d). In other word, each adjacent wavelength is completely separated without overlap. According to the above analyzing, a fast wavelength-swept laser source with tunable sweep duration can be realized by changing the wavelength spacing of the MWL and the time gated signal.

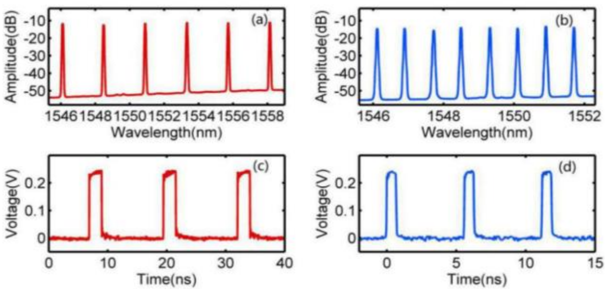

Fig. 5. (a)The measured spectrum of 6 channel laser source with Δλ=2.4 nm ranging from 1546 nm to 1558 nm and (b) 8-channel laser source with Δλ=0.8 nm ranging from 1546 nm to 1551.6 nm. The waveform of the electrical pulse corresponding to (c) Δλ=2.4 nm with a time duration of 2.04 ns and (d) Δλ=0.8 nm with a time duration of 0.68 ns.

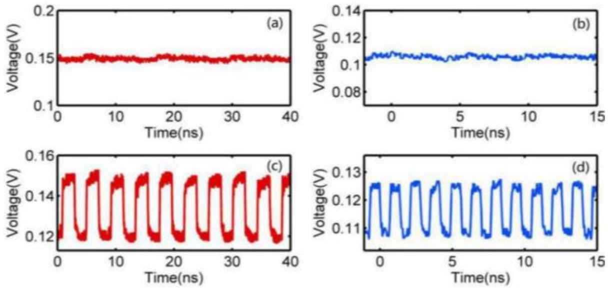

Fig. 3. The detected photocurrent of the dispersed and gated optical signal with (a) Δλ=2.4 nm and (b) Δλ=0.8 nm. The detected multi-pulse with a temporal width of (c) 2.08 ns and (d) 0.72 ns after removing optical signals every other channel.

To verify the performance of the angle scan based on the proposed wavelength-swept laser source, a linearly chirped microwave waveform (LCMW) with the frequency from 9.5 GHz to 10.5 GHz, is used as a microwave feed signal. The time temporal width of the LCMW is equal to the pulse width of time gate. As shown in Fig. 4, the delayed LCMW, emitted from 8 antenna elements, is received by the standard horn antenna and sampled by an OSC.

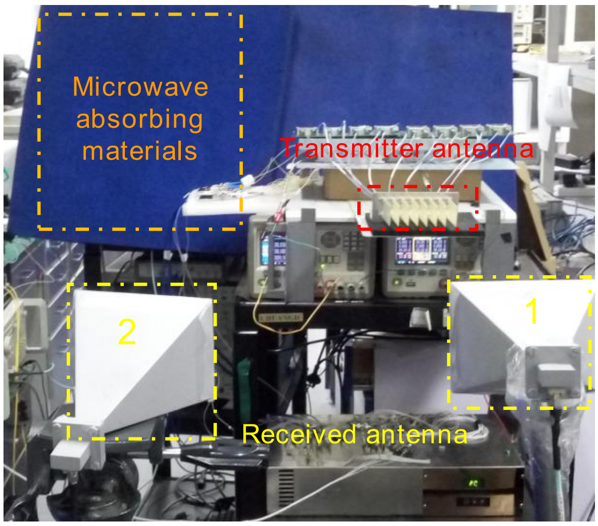

Fig. 4. Experimental layout of the ultra-fast angle scan PAA system.

To verify the scanning angle and the beam switching time of the PAA system, the wavelength spacing of 2.4 nm is employed into the experiment. The received signals as shown in Fig. 5, have a scan periodicity about 11.24 ns with a resolution of 2.81 ns. The measured angles from channel#1 (λ1) to channel#6 (λ6) are [0°, 9°, 17°, 25°, 34°, 43°] with an beam width of 8.8°, which is close to the simulated value of 9.6°, which means the angle scan in the order of nanosecond was achieved and the angle resolution can be improved by decreasing the wavelength spacing of MWL. In addition, more accurate beam steering angle can be obtained by increasing the channel of TTD network. Those improvements create more possibilities for the application of TTD-PAA system in fast spatial detection.

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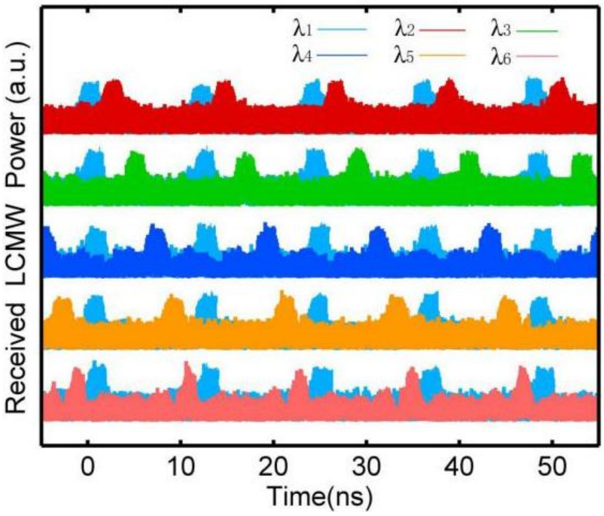

Fig. 5. The received signals of the PAA system with wavelength spacing of 3.2 nm

3. CONCLUSIONS

In this paper, we have proposed and experimentally demonstrated a wavelength-controlled TTD-PAA system with ultra-fast angle scan. The key novelty of our work is the ultrafast scan using an ultra-fast wavelength-swept laser source which is constructed by a dispersed and gated MWL. The wavelength sweep time between two adjacent wavelengths is several nanoseconds for wavelength spacing of 2.4 nm and 0.8 nm. We have successfully realized an ultra-fast beam steering angle from 0 degree to 43 degree within 12.48 ns by employing the proposed ultra-fast wavelength-swept optical source into the TTD-PAA system. This system also shows a great tunability. The angle resolution can be easily adjusted when the wavelength spacing and the pulse duration of time gates are changed.

4. ACKNOWLEDGMENTS

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