Photonic RF true time delays for phased array antennas with microcombs

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Abstract: A microwave photonic true time delay line based on an integrated Kerr comb source with 49 GHz free spectral range was proposed and demonstrated. We theoretically analyze the performance of a phased array antenna and show that this large channel count results in a high angular resolution and wide beam-steering tunable range.

1. Introduction

In modern radar and communications systems, RF photonic true time delay lines (TTDLs), which introduce multiple progressive time delays by means of RF photonic technologies, are basic building blocks with wide applications in phased array antennas (PAAs), RF photonic filters, analog-to-digital or digital-to-analog conversion, and arbitrary waveform generation [1]. Extensive effort has been devoted to developing diverse methods for TTDLs, including using dispersive elements such as single-mode fiber [1], dispersion compensation fiber [2, 3], slow-light device based on stimulated Brillouin scattering, integrated resonators [4], and more [5].

For RF photonic TTDLs, increasing the number of delay channels can lead to a significantly improved performance. In PAAs, the number of radiating elements determines the beamwidth, and so an improved angular resolution can be achieved by increasing the channel number [2]. Consequently, RF photonic TTDLs with a large number of channels are highly desirable for PAAs with high angular resolution. In conventional methods, discrete lasers arrays [6] or fibre Bragg grating arrays [2] are employed towards implementing multiple optical true time delay channels, where system cost and complexity are significantly increased with the rising channel number, thus greatly limiting the number of available channels in practical systems. In contrast, for a broadband Kerr optical microcomb generated by a single micro-resonator, a large number of high-quality wavelength channels can be simultaneously provided for the RF photonic TTDLs, thus greatly reducing the size, cost, and complexity of the system.

In this paper, we demonstrated photonic microwave TTDLs based on an integrated microcomb source with a free spectral range of 49 GHz, achieving high performance when applied to PAAs in terms of beam resolution and angular tuning range. We experimentally demonstrate an 81-channel true time delay and then calculate the key performance parameters for a phased array antenna based on our device, thus verifying the feasibility and effectiveness of our approach.

Fig. 1. (a) Schematic of the proposed TTDL based on an integrated optical comb source. BPF: optical bandpass filter. EDFA: erbium-doped fiber amplifier. PC: polarization controller. MRR: micro-ring resonator. WSS: WaveShaper. MZM: Mach-Zehnder modulator. SMF: single mode fiber. WDM: wavelength division multiplex. PD: photodetector. (b) Optical spectrum of the generated soliton crystal combs with 100nm span.

2. Operation principle and experimental results

Figure 1(a) shows a schematic diagram of a multi-channel RF photonic TTDL with a microcomb source. The optical true time delay is constructed with three modules. The first module generates the microcomb with a large number of wavelength channels using a micro-resonator. The micro-resonator used to generate the Kerr microcomb was fabricated on a high-index doped silica glass platform using CMOS-compatible fabrication processes [7]. The radius of the MRR was $\sim 592 \mu\text{m}$, corresponding to a free spectral range of $\sim 49 \text{ GHz}$. To generate Kerr microcombs, the pump power was set at $\sim 30.5 \text{ dBm}$ and the wavelength swept from blue to red. When the detuning between the pump wavelength and the MRR's cold resonance became small enough such that the intra-cavity power reached a threshold value, modulation instability is driven oscillation was initiated. As the detuning was changed further, distinctive 'fingerprint' optical spectra of soliton crystals were observed (Fig. 2 (b)) that are indicative of soliton crystals [8-10]. The second module shapes the microcomb and directs it to a Mach-Zehnder modulator, where replicas of the input RF signal are generated on each wavelength to establish multiple RF channels. After that, time delays were introduced between those RF channels by dispersive elements in the third module.

Fig. 2. (a) Measured RF phase responses of the 81-channel TTDL and (b) corresponding time delays of each channel; the inset shows flat delays over a wide RF frequency range. (c) Calculated array factors with RF frequencies varying from 2 to 17 GHz. (d) Calculated array factors of the PAAs with m varying from 1 to 27.

The RF phase response was characterized by a vector network analyser (Anritsu 37369A), Fig. 2(a), in which the channel at the central pump wavelength (channel 40) was set as the reference. The time delays corresponding to the measured phase slopes are shown in Fig. 2(b), in which a time delay step of $\sim 14.8 \text{ ps/channel}$ can be observed. Based on the proposed TTDL, as indicated in Fig. 2(c), the beam steering angle θ_0 remain 20.7° while the RF frequency varies from 2 GHz to 17 GHz. In Fig. 2(d), we present array factors of PAAs with vary m and M , where $M = [\text{Channel Number} / m]$. As can be seen, the 49 GHz free spectral range Kerr comb enables a large M as m varies, thus leading to small beamwidth and to a greatly enhanced angular resolution.

3. Conclusion

We demonstrate a microwave photonic true time delay line based on an optical microcomb with a free spectral range of 49 GHz. The performance of a phased array antenna based on our TTDLs is investigated, which shows that the large channel count can lead to a high angular resolution and wide tuning range of the beam steering angle.

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