Ring resonator-based true time delay for indoor wireless communication

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Optical ring resonators (ORRs) have been widely studied for use in beam forming systems, and although it can have high tuning range, it has inherently narrow bandwidth. In this paper, we propose a novel technique to increase both the bandwidth and tuning range of ORR-assisted true time delays by employing switched delay lines to supplement the ORRs. The design of an optical beam forming network employing the true time delay based on a generic InP platform technology is also presented. Furthermore, we study the feasibility of ORRs for indoor wireless communication based on the unique requirements for the 60 GHz band.

Introduction

The increasing demand for high speed multimedia data communication has prompted the growing interest in the mm-range frequencies for wireless applications to augment the spectrum shortage in the 2.4 GHz and 5 GHz band. Among these frequencies, spectrum at 60 GHz is plenty with about 9 GHz allocated in the EU [1]. Because of its high attenuation due to atmospheric conditions, the 60 GHz band is more suited for close-range, indoor applications [2]. Higher loss in common building materials can also be exploited for increased security and dense frequency reuse [1,3]. To compensate for the propagation attenuation as well as to boost link quality and enable spatial reuse, highly directional beams are recommended and as such, transceivers using phased array antennas (PAA) are employed. At higher frequencies the RF antennas can be made smaller and as such can be incorporated into converged indoor networks as shown in Fig. 1.

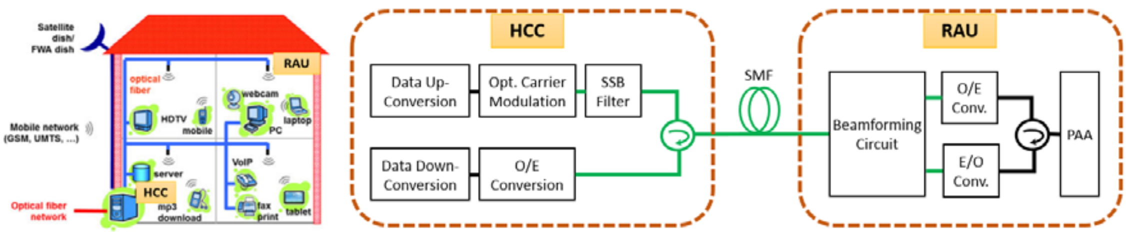


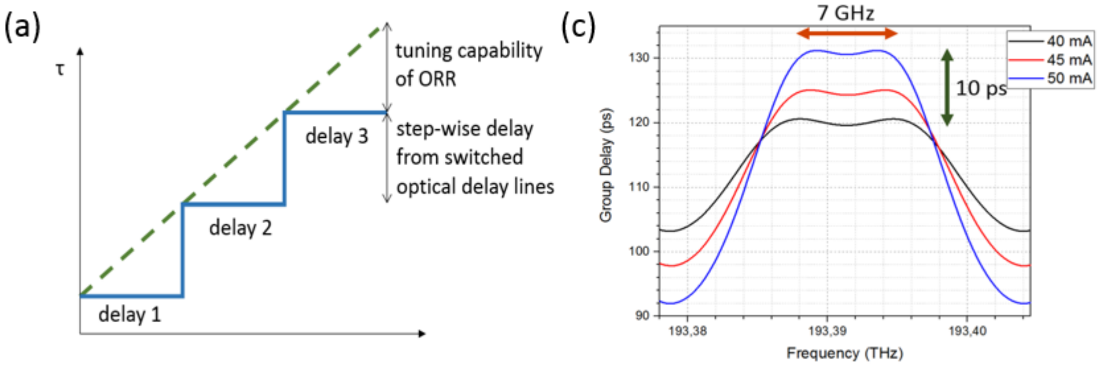
Figure 1. Converged indoor network

In such a network, a home communication controller (HCC), in addition to acting as an interface between the home network and various access networks, hosts centralized functions such as radio signal generation and processing to simplify the functions at the remote access units (RAU) [4]. For a half-duplex system at the RAU, the radio over fiber (RoF) signal is beamformed, converted to electrical format and fed into the antenna array during transmission, and the reverse during reception. The circulators in the HCC and RAU are in place to separate the transmitted and received signals. For wide bandwidth applications, phase shifters introduce beam squint, such that different frequency components are steered to different angles. As such, optical true-time delay (TTD) implementation of beamforming is advantageous for avoiding beam squinting, as

well as for its potential to be fully integrated on-chip. A prominent implementation of TTD is by using optical delay lines as in [5-7]. While these can provide high bandwidth, switchable delay lines only allows discrete delay tuning. On the other hand, optical ring resonators (ORRs) have been greatly studied and have previously been employed in beam forming applications in other frequency bands [8,9]. While ORRs can have high tuning range, it has inherently narrow bandwidth making it difficult for use in high bandwidth applications such as in indoor wireless communication.
In this paper, we propose a simple optical true-time delay beamformer for indoor, wide-bandwidth applications. The combination of delay lines and tunable ORRs allows for beamforming for signals with up to 7 GHz bandwidth and high tuning range.

Beamforming Chip Design

With cascaded ORRs it is possible to generate wider bandwidths than a unit ORR. Since the delay-bandwidth product of the ORR response is constant, tuning to higher bandwidths limits the delay tunability range. To augment the tunability without sacrificing bandwidth, delay lines are employed such that the signal modulated by the optical carrier is first delayed in a step-wise manner and then finely-tuned by the cascaded ORRs. The principle of operation of an ORR-assisted TTD employing switched delay lines is shown in Fig. 2a.



(b)

AE	0	30° (ps)	60° (ps)
1	0	0	0
2	0	4.2	7.2
3	0	8.3	14.4
4	0	12.5	21.7

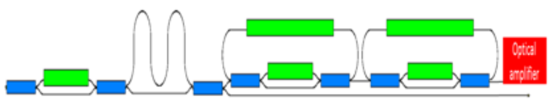


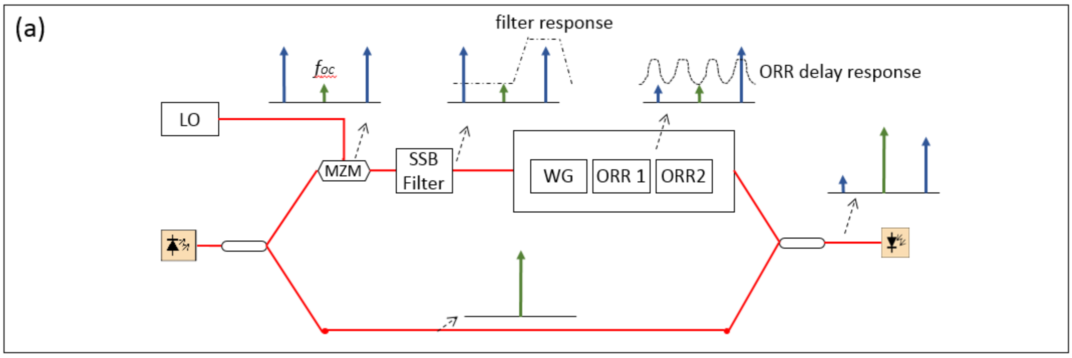
Figure 2. (a) Principle of operation; (b) Delay values for a 4x1 PAA; (c) Group delay response for two cascaded ORRs; (d) Schematic of the ORR-assisted true time delay employing switched delay lines.

For a system employing a 4x1 array of antennas spaced 2.5 mm apart, corresponding to $\lambda_{RF}/2$, delay values for steering up to 60° is shown in Fig. 2b. Based on this operation, a 4-channel beamforming circuit is designed consisting of one input and four outputs on InP platform using generic MPW technologies. Each channel is composed of a Mach-Zehnder interferometer (MZI) switch which acts as a binary switch to two delay lines which have a length difference of 10 ps. A cascade of two ORRs after the delay lines is designed with an FSR of 24 GHz, with each ORR tuned by a coupling heater and a resonance peak tuning heater. Varying the current at the coupling heater corresponds to different coupling coefficients and by tuning the resonance of one or both ORRs, 7 GHz bandwidth could be maintained with a tuning range of 10 ps and delay ripple of less than 1.7 ps as shown in Fig. 2c. Hence, in combination with the waveguide delay, up to

20 ps of delay tuning can be achieved with a wide bandwidth. The ring resonators and the MZI switches are thermo-optically tuned. At the output, an SOA is placed to compensate for the loss as well as to control the amplitude response of each channel. The schematic diagram of one channel is shown in Fig. 2d.

Simulation

Simulation was performed on **VPItransmissionMaker™** to verify the tuning capability of an ORR-assisted TTD beamformer employing switched delay lines. We consider a system in transmission mode as shown in Fig. 3a. An RF signal, from 56.5-63.5 GHz, is modulated on to an optical carrier via a Mach-Zehnder modulator (MZM). Single sideband suppressed-carrier (SSB-SC) modulation is performed by suppressing the carrier at the MZM and filtering out one sideband. This effectively reduces the bandwidth of the optical signal and relaxes the bandwidth requirement for the OTTD beamformer. TTD is performed by a cascade of an optical waveguide and two ORRs. Finally, the part of the optical carrier coupled out prior to RF modulation is reinserted with the delayed signal before photodetection and the RF phase for different RF input is analyzed.



(b)

Setting	WG delay (ps)	κ	BW (GHz)	τ (ps)
1	0	0.96	8	0
2	0	0.95	7.3	4.1
3	0	0.93	7	9.6
4	0	0.90	5.2	19.7
5	10	0.96	8	10.1
6	10	0.93	7	19.4

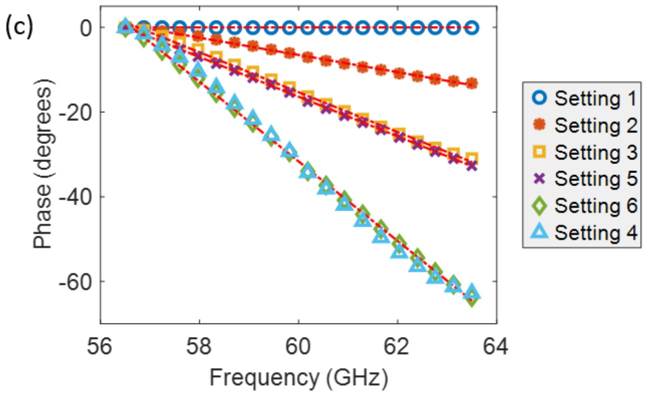


Figure 3. (a) Schematic diagram of the system for simulation; (b) Different beamformer settings and the corresponding delay; (c) Phase response for different beamformer settings.

Different beamformer settings shown in Fig. 3b corresponds to different optical delay (0 or 10 ps) and ORR coupling coefficient (κ). For all settings, the ORR peak resonance is tuned such that a bandwidth of 7 GHz is maintained except for setting 4. The phase response is shown in Fig. 3c and the resulting group delay is calculated via the phase-shift method such that $\tau_g = \Delta\phi_{RF}/2\pi f_{RF}$. The setting with the minimum delay, Setting 1, is set as the zero delay reference. Without waveguide delay, for settings 1-3, a linear phase response is obtained up to 10 ps of delay tuning. However, for larger delays as in

Setting 4, the resulting phase response deviates from linear response with a deviation of 2°. By employing a 10 ps waveguide delay, as in settings 5-6, up to 20 ps of delay tuning can be achieved with a linear phase response.

Conclusion

We have designed a simple optical true-time delay beamformer employing switched delay lines and tunable ORRs for indoor wireless communication. Simulation results have shown a linear phase response is possible for up to 7 GHz of bandwidth with a tuning range that can drive a 4x1 PAA.

Acknowledgement

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