Novel Ring Resonator-Based Optical Beamformer System and Experimental Results

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A novel squint-free, continuously tunable beamformer mechanism for a phased array antenna system is proposed. It consists of filter-based optical single-sideband suppressed-carrier modulation, a fully integrated optical beam forming network using cascades of optical ring resonators as tunable delay elements, and balanced coherent optical detection. The proposed system brings advantages in optical bandwidth requirement, system complexity, and dynamic range, without introducing the problem of beam squint or limited tuning resolution. Some experimental results are presented in order to demonstrate the feasibility of the proposed concept.

1 Introduction

Nowadays, optical technology prevails in many modern transmission systems. One example in wireless transmission systems is optical beam forming in phased array antennas [1]-[3]. Direction-sensitive transmission/reception can be realized with a phased array antenna by processing the antenna signals through an optical beamformer circuit, which has the advantages of compactness, small weight, low loss, frequency independence, high bandwidth, and EMI immunity over the electrical counterpart. Most known optical beamformers are based on optical phase shifters [1] or switchable true time delay (TTD) arrays [2], having the disadvantage of beam squint or limited tuning resolution, respectively. An alternative that does offer both continuous tunability and TTD is based on chirped fiber gratings (CGFs) [3], but this has the disadvantage of requiring bulky optical components and a tunable laser. In this paper a novel squint-free, continuously tunable beamformer mechanism for a phased array system is proposed that does not need a tunable laser, and has advantages in optical processing bandwidth, system complexity, and dynamic range. The system consists of filter-based optical single-sideband suppressed-carrier (SSB-SC) modulation, a fully integrated optical beam forming network (OBFN) using cascades of optical ring resonators (ORRs) as tunable delay elements, and balanced coherent optical detection. The optical beam forming principles and complete system setup are explained in Section 2. In Section 3, some experimental results are presented to demonstrate the feasibility of the proposed concepts. Conclusions are formulated in Section 4.

2 Novel optical beamformer system principles

A. Setup and core of the system

Basically an optical beamformer system is a cascade of optical modulation, optical signal processing by means of an OBFN, and optical detection. Herewith we propose an advanced beamformer system using filter-based optical SSB-SC modulation, an ORR-based OBFN, and balanced coherent detection. The system setup is shown in Fig. 1.

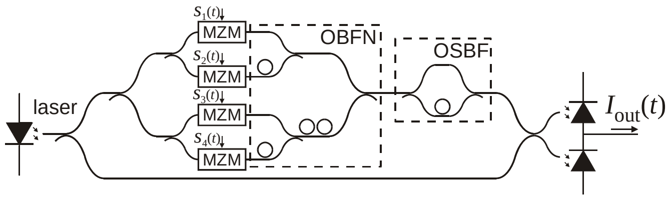

Fig. 1. *Schematic of the optical beam forming system (MZM: Mach-Zehnder modulator, OBFN: optical beam forming network, OSBF: optical sideband filter).*

The core of the system is an ORR-based OBFN chip for signal processing. The principle of the cascaded-ORR TTD element and binary-tree structure of a 1×8 ORR-based OBFN have been presented in [4]-[10]. The structure of the OBFN is shown in Fig. 2.

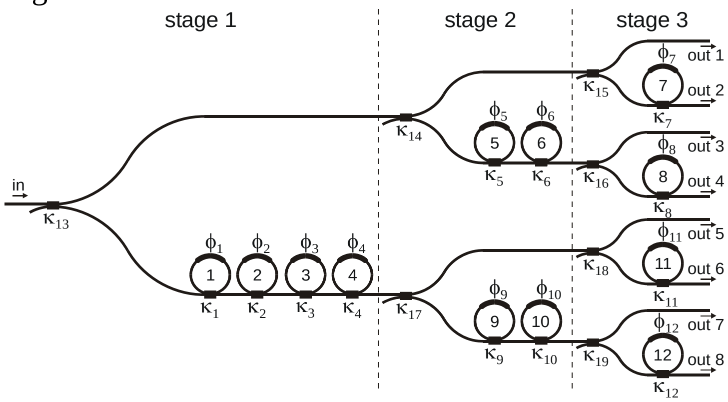

Fig. 2. *Binary-tree structure of a 1×8 ORR-based OBFN and measured group delay responses of the OBFN chip.*

B. Filter-based SSB-SC modulation and balanced coherent detection

The main reason for using optical SSB-SC modulation instead of the straightforward optical double sideband (DSB) modulation in the proposed system is to reduce the bandwidth of the modulated optical signal, so that the limited bandwidth of ORR-based OBFN can be used more efficiently [5]-[10]. The resulting optical bandwidth equals the RF bandwidth, which is the smallest that can be achieved without splitting the RF signals in sub-bands prior to electro-optical conversion. Since the optical bandwidth directly relates to the OBFN complexity, namely the number of ORRs [5]-[10], applying SSB-SC modulation can significantly reduce the OBFN complexity. Several techniques are known for implementing optical SSB modulation [7]. In the proposed system optical SSB-SC modulation is implemented by means of Mach-Zehnder modulators (MZMs) and optical sideband filters (OSBFs). When the MZM is working in push-pull mode and properly biased, the optical carrier can be inherently suppressed [11], so that the OSBF only needs to suppress one sideband. Sideband filtering could be performed directly after the MZMs, but then every RF input requires its own OSBF. Since the OSBFs and OBFN are both linear devices, their order can be reversed, so that the OSBFs can be placed after the OBFN, which means only one common OSBF is required, as shown in Fig. 1. Filter-based SSB-SC is preferred for the proposed system because of the easy implementation. Moreover the OSBF can be realized with the same building blocks as in the OBFN, which is preferable for the purpose of integration. Realization and measurements of the OSBF will be described in the next section.

Optical SSB-SC modulation requires coherent optical detection, which implies that the unmodulated optical carrier has to be re-inserted prior to optical detection. This can be implemented by routing one output signal of the splitter after the laser around the OBFN, and combining it with the OBFN's output signal by means of a 2×2 directional coupler, as shown in Fig. 1. Optical detection is performed by means of a balanced detector configuration, which has significant advantages over single-ended detection by means of just one photodiode. The output current includes no DC, baseband, and double frequency terms as in the DSB modulation with direct detection case, but only the desired RF term [7]. As a result, the square-law behavior of the photodiodes will not introduce second order intermodulation distortion, even when the relative bandwidth of the RF signal is more than one octave. An additional advantage of balanced detection is that the effect of relative intensity noise in the optical signal is significantly reduced [12], which enhances the dynamic range of the system.

Frequency down conversion could be performed prior to optical modulation, by mixing the element signals with a common local oscillator signal and low-pass-filtering. Lower-speed optical modulators and detectors could then be used [7].

3 Measurements of OBFN and OSBF chip

Both the OBFN and OSBF chip have been realized in the TriPleX waveguide technology of LioniX [13]. The realization and measurement details of the 1×8 ORR-based OBFN chip have been presented in [8], [9]. The measured group delay responses of the OBFN chip are shown in Fig. 3(a). The OSBF chip consists of an ORR and an MZI, as shown in Fig. 1. It has a total of five tuning elements, namely two couplers and one phase shifter on the MZI, and one coupler and one phase shifter on the ORR. The FSR of the MZI is twice as large as that of ORR. Ideally, such a filter provides flat and wide passbands and stopbands, and sharp cutoff regions [14]. Fig. 3(b) shows the measured power transmission of the OSBF chip in comparison with the theoretical curve. The measured filter isolation is larger than 25 dB. By performing curve fitting, the chip waveguide loss was estimated to be 0.3 dB/cm.

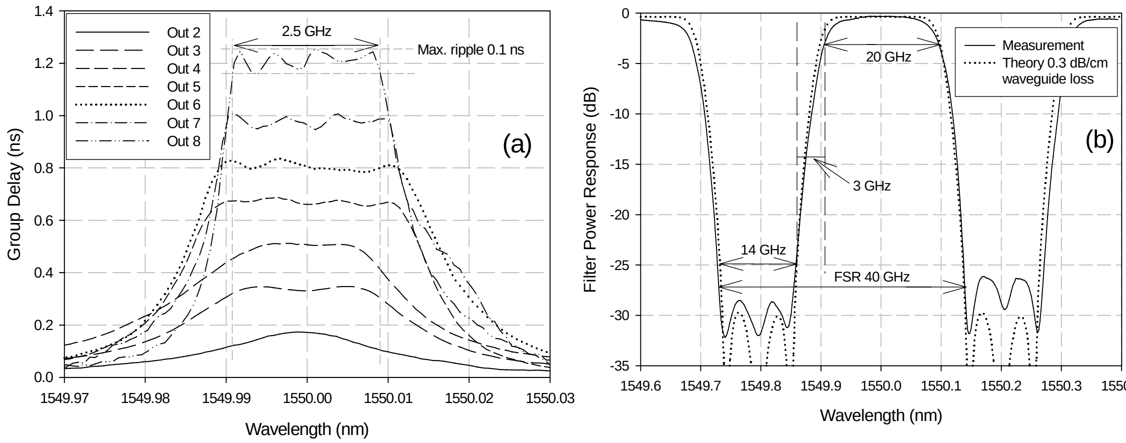

Fig. 3. (a) *Measured group delay responses of the 1×8 ORR-based OBFN chip. (b) Measured power transmission of the MZI+Ring-structured OSBF chip, in comparison with theoretical curve.*

4 Conclusions

A novel squint-free, continuously tunable beamformer mechanism for a phased array antenna system has been described. It consists of filter-based optical SSB-SC modulation, an integrated ORR-based OBFN chip, and balanced coherent detection. This new scheme minimizes the bandwidth requirements on the optical modulators, OBFN and optical detector, prevents intermodulation distortion, and enhances the dynamic range. Measurement results on a 1×8 OBFN chip and an OSBF chip have been presented, showing good agreement with theory. Currently a complete beamformer demonstrator is being built with OBFN, OSBF and carrier re-insertion integrated in one single chip. We expect to present it in the near future.

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