Simultaneous Dual RF Beam Reception of an X-Band Phased Array Antenna Utilizing Highly Dispersive Photonic Crystal Fiber Based True-Time-Delay

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Abstract: We report dual RF beam reception of an X-band phased array antenna using photonic crystal fiber based delay network. We accurately detect RF signals at 8.4GHz and 12GHz coming from -7.4 and -21.2 degrees respectively.

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1. Introduction

Phased Array Antenna (PAA) is a key component in many of the modern military and commercial radar and communication systems. One of the advantages that this technology offers is a physical movement-free RF beam steering. Conventional electrical phase shifters are inherently narrowband. Optical true-time-delay (TTD) provides a broad bandwidth and squint-free operation apart from advantages such as EMI-free operation, small size, light weight etc . Many optical schemes have been proposed and demonstrated to form a photonic feed for true-time delay (TTD) [1-8]. The dispersive fiber technique can provide a very compact and light weight system. Compared to conventional single mode fibers, highly dispersive photonic crystal fibers can reduce the size of the system by a factor of 30 or more.

Photonic crystal fibers (PCFs) with a W' index profile PCF, like the ones used in conventional dispersion compensation fibers [9], can be used to achieve high dispersion. Photonic crystal fibers with a dual-concentric core design have been designed to exhibit high dispersion coefficient values [10]. Our fabricated fiber design is also based on a dual concentric core structure and the dispersion value of the fiber is ~ -600 ps/nm/km, measured at a wavelength of 1550nm.

In our previously reported research, photonic crystal fiber based delay lines for a single RF beam steering was presented [11, 12]. Recently, we also demonstrated simultaneous multiple beam transmission capability of our PAA system utilizing highly dispersive fibers [13]. Here, we report with experimental confirmation the working principle of a photonic crystal-based TTD module with multiple beam receiving capability for application in a phased array antenna. Previous architectures used high dispersion fibers with a dispersion coefficient of -88ps/nm/km fibers [14]. Using our highly dispersive PCFs, the length of the TTD lines can be reduced by a factor of 7.

2. Demonstration of 2 beam receiving operation

The schematic for the experimental setup used for demonstrating 2 beam receiving operation is shown in Fig. 1. We use two adjacent antenna elements, two modulators and two adjacent delay lines in order to demonstrate dual-beam receiving capablity

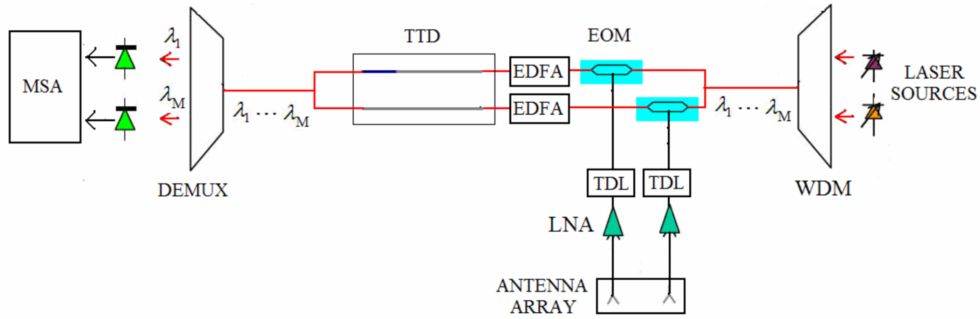


Fig. 1. Schematic of the experimental setup: LNA: low noise amplifier, WDM: wavelength division multiplexer, TDL: tunable delay line, MSA: microwave spectrum analyzer, WDM: wavelength division multiplexer, TTD: true-time-delay, EDFA: Erbium doped fiber amplifier (The RF sources and the transmitting horn antennas of the setup are not shown in the figure).

The 2 delay lines consist of 0 meters of PCF : 10.5 meters of dispersion shifted fiber (DSF) and 3.5 meters of PCF : 7 meters of DSF respectively. The difference in the lengths of PCF sections between adjacent elements is 3.5m.

The lengths of the SMF sections are trimmed such that at 1545nm, the delays in each of the delay lines are equal. That is, for an RF signal incident normally on the antenna array, modulating a wavelength of 1545nm, the signal detected at the photodetector will be a maximum. At a different wavelength, the time delay difference between the two lines (neglecting the contribution by DSF) is given by:

$$\tau = (3.5).\int_{\lambda_0}^{\lambda} [D_{PCF}(\lambda)].d\lambda \tag{1}$$

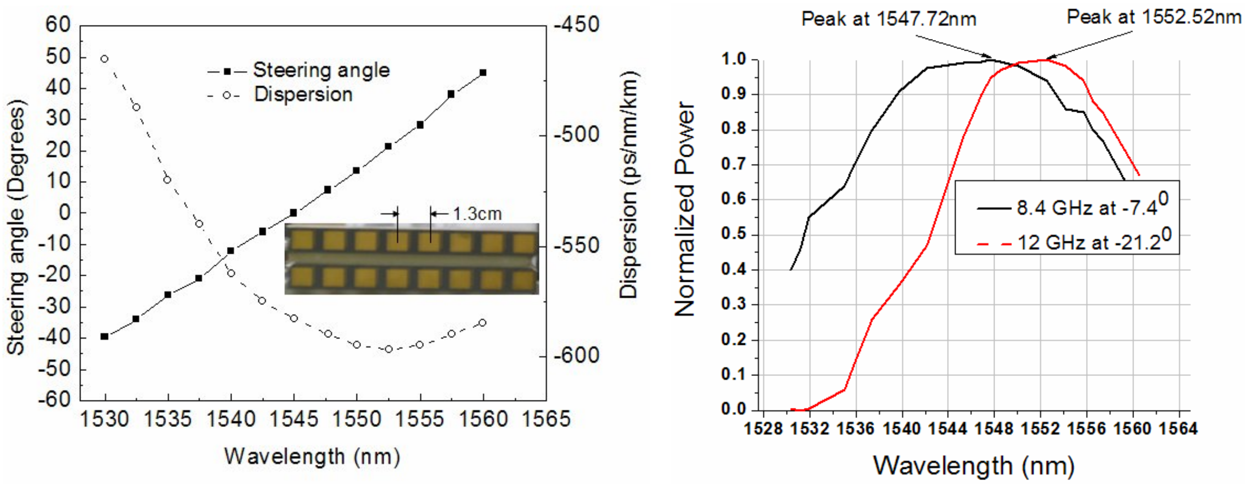
The signal at the photodetector will be a maximum if the incoming beam arrives from angle ‘θ’ on the antenna array given by [2]:

$$\tau = -\frac{d.\sin\theta}{c} \tag{2}$$

where τ is the time delay difference between adjacent lines, d is the antenna element spacing, and c is the speed of light in free space. ‘θ’ is measured with respect to the normal to the antenna array. Therefore, different angle of arrival of RF signal will require a different wavelength to equalize the phase difference between adjacent elements in the TTD lines and generate a maximum at the photodetector output. The steering angle (of the transmitting mode) versus the wavelength is calculated for the TTD setup and the result is shown in Fig. 2 (a). Therefore, if a wavelength ‘λ’ corresponds to an angle ‘θ’ in Fig. 2 (a), then the same wavelength can be used to detect a signal impinging from negative ‘θ’. Note that the spacing of the X-band phased array is 1.3 cm which is shown in the inset of Fig. 2 (a). By having a look-up table in the signal processing unit showing the wavelength-angle relationship, the angle of arrival can be determined for any RF signal of interest due to the squint-free nature of the true-time delay lines.

Using the above setup, we measured the output power at the photodetector for two incoming signals at 8.4 GHz and 12GHz from -7.4 and -21.2 degrees respectively. The plot of power versus wavelength is shown in Fig. 2 (b). It can be seen clearly from the figure that at wavelengths of 1547.72nm and 1552.52nm, there are peaks for 8.4GHz and 12GHz signals respectively. These correspond to complementary angle of 7.4 and 21.2 degrees in Fig. 2 (a). The two tunable sources were used to independently lock the two incoming beams.

We are limited by the available hardware to conduct multi-beam reception. In principle, the total number of RF beams that can be simultaneously detected is limited by the bandwidth (Δλ) of the WDM. As a result, hundreds of RF beams are detectable in the same time domain.



(a) **(b)**

Fig. 2. (a) The solid curve shows the calculated steering angle of the beam as a function of wavelength. The dashed curve shows the measured dispersion coefficient of the PCF. The inset shows the X-band antenna array with an element spacing of 1.3cm. (b) Signal power measured at the photodetector vs. wavelength. The signal power peaks appear at 1547.72nm and 1552.52nm for 8.4GHz and 12GHz respectively.

3. Conclusion

In conclusion, we present an optical beamformer based on highly dispersive fibers that can receive two beams simultaneously. Two incoming RF signals are simultaneously detected and their angles of arrival are determined using the knowledge of the TTD lines. The true time delay module is compact as the dispersion of the fabricated PCFs is as high as -600ps/nm/km at 1550nm, and the system can be extended to receive many beams without increasing the overall complexity of the system.

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