

# All optical receive beamformer at 1310 nm

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## ABSTRACT

We demonstrate an optical two-channel receive beamformer at 1310 nm using fiber Bragg grating arrays for producing true time delay. The antenna beam patterns are measured for broadside targets at several RF frequencies ranging from 40 MHz to 1 GHz. These results compare favorably with theoretical calculations.

## INTRODUCTION

Phased array antennas are attractive as they allow beam steering without the need to physically move the antenna. Beam steering is accomplished by shifting the relative phases between neighboring antenna elements. This phase shift is accomplished electrically by creating some time delay between the channels while the magnitude of this delay corresponds to a desired angle of the beam. As the size of these arrays increases however, the amount of hardware required for beamforming increases drastically since each channel has to be processed individually. By using dense wavelength division multiplexing (DWDM) technology however, one is able to take advantage of parallel processing to significantly reduce the amount of hardware required to accomplish beamforming. This concept is demonstrated by Wu et al., where the optical delays are provided by a programmable dispersion matrix constructed from fiber Bragg grating (FBG) arrays.<sup>1</sup>

## EXPERIMENT

A schematic of the two-channel receive beamformer with binary FBG arrays for true-time delay (TTD) is shown in Figure 1. Two DFB lasers, with center wavelengths at 1314.4 nm and 1317.1 nm, each with an optical power output of approximately 6.7 mW are used to provide optical carriers for the system. Both lasers can be internally modulated

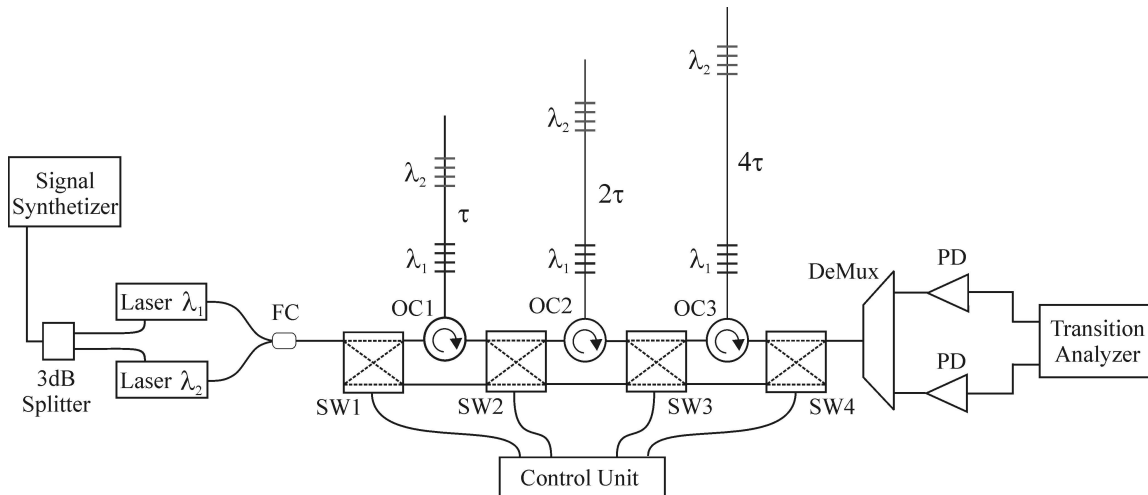


Figure 1. Schematic of 2-Channel Beamformer, OC: Optical circulator; SW: optical switch, FC: fiber coupler; PD: photodiode.

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with RF signals ranging in frequency from 100 MHz to 10 GHz. The TTD array consists of a series of switches, circulators, and FBG delay lines and the total system loss is measured to be 12dB. Four 2×2 optical switches are used in the array to select each individual FBG delay line or a combination of lines.

The FBG separation in each delay line is measured to be 0.361 m, 0.722 m, and 1.444 m as shown in figure 1. The phase-shift for each steering angle is given by  $\Delta\phi = 2\pi(2m n \Delta L_{\min}/\lambda)$ , where  $m=0,1\dots7$  for possible delays,  $n=1.469$  is the refractive index of the fiber,  $\Delta L_{\min}=0.361$  m is the smallest spacing of two adjacent FBGs. The required RF frequency for obtaining only one main lobe in the beam pattern is calculated by setting the maximum value of the phase-shift to  $\pi$ . This condition gives the minimum RF frequency of 40MHz. In general, incrementing the value of delay should produce a constant increase in the relative phase between the two channels/signals. To measure this relative phase difference, a Transition Analyzer is configured to average 10000 samples of phase difference between the two channels. In order to verify consistency over a wide range of frequencies measurements are carried out for RF frequencies of 40MHz, 100MHz, 200MHz, 400MHz, 800MHz, and 1GHz.

Figure 2a shows the measured antenna beam pattern for an RF center frequency of 40 MHz. The initial results indicate a beam pattern with the peak in the main lobe occurring at approximately 38 degrees. This phase-shift is due to the optical path difference between both channels with the delay set at zero. The difference in path length is caused by the difference in the lengths of the laser fiber pigtailed, the difference in the demultiplexer path at the output of the system, and the difference in the length of the cables from the detectors to the input terminals of the transition analyzer. This shifted beam pattern is the exact beam pattern that would be obtained for targets at 38 degrees to the antenna. In order to obtain a beam pattern for a broadside target, the relative phase shift between channels for zero delay is subtracted from each delay measurement. These adjusted values are shown as circles in figure 2a. Figure 2b shows the results of the beam pattern measurements at 200MHz RF center frequency. Again, to obtain the beam pattern for a broadside target, phase values are measured and corrected for each delay.

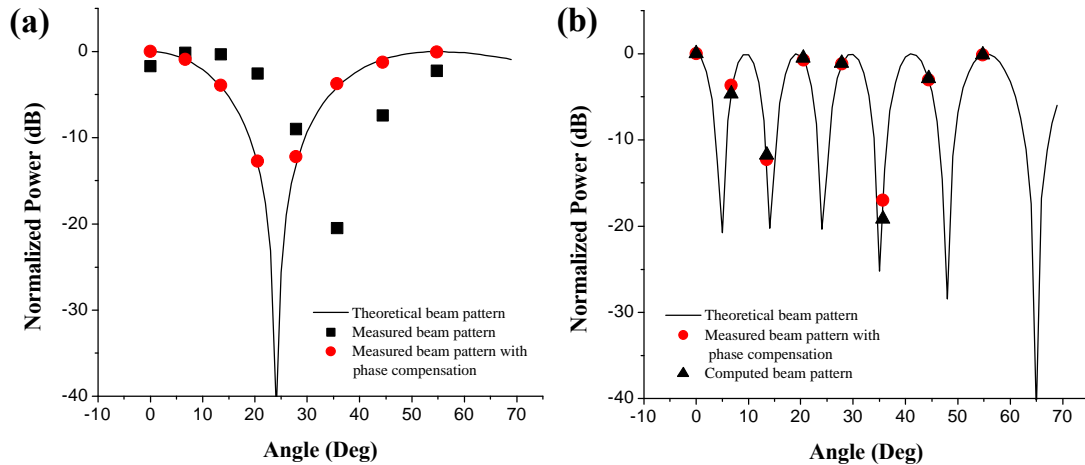


Figure 2. (a) Antenna beam pattern measured at 40 MHz. (b) Antenna beam pattern measured at 200 MHz.

Using PHOTOSS, a commercial photonics simulation package, a beam pattern for RF center frequency of 200MHz is generated. The triangle points in the figure 2b indicate the simulation results. Component parameters used in PHOTOSS are set to match the specification values of the corresponding experimental components.<sup>2</sup> Both the simulated and the measured beam patterns yield good agreement with the theoretical model of the beam pattern. The slight discrepancies in the data points may be attributed to small errors in the measurement of the relative phase between channels.

We have demonstrated the beamforming capabilities of a two-channel binary FBG-arrays at 1310 nm operating in the receive configuration. The measured beam patterns at RF 40MHz and 200MHz compare favorably with both the simulated and theoretical models.

## REFERENCES

1. D. T. K. Tong and M. C. Wu, *Electron. Lett.*, **32**, 1532 (1996).
2. B. A. Black, A. Siahmakoun, L. Slaybaugh, D. Thalen and J. Chestnut, *Proc. SPIE*, **4532**, 494 (2001).