

Loss Compensated Photonic True-time Delay for Phased-array Antenna¹

Yihong Chen*, Kevin Wu, Feng Zhao, Ray T. Chen²
Omega Optics, Inc., Austin, TX

²*The University of Texas at Austin, Austin, TX*

Abstract: In this paper, we present a loss compensated photonic true-time delay module, employing Erbium-amplified polymer waveguide (EAPW). The reconfigurable TTD line incorporates optical switches and fixed length waveguides, to provide numerous time delays with minimum hardware. The passive optical properties are simulated and the active properties are measured. A 0.5 dB gain was measured from a 2cm device when pumped with 75mW.

1. Introduction

Microwave phased-array antennas (PAAs) are important in both military and civilian applications. However, ultra-wide bandwidth is not available employing traditional electrical feeding networks due to their intrinsic narrow band nature. Many optical schemes have been proposed to take advantages of a photonic feed for true-time delay (TTD), including acousto-optic (AO) integrated circuit technique [1], Fourier optical technique [2], bulky optics techniques [3], dispersive fiber technique [4], fiber grating technique [5], and substrate guided wave techniques [6]. However, there is no monolithic integrated optical feed with affordable loss.

In this paper, we demonstrate a photonic true-time delay module, employing Erbium-amplified polymer waveguide (EAPW), which overcomes the huge insertion loss inherent with photonic integrated circuits. We believe that this is the first time that an Erbium-doped glass and polymer material has been practically considered as a platform for the integration of the various components involved. Waveguides defined by photolithography provide the greatest control, up to sub-micron, over the total waveguide length, compared with optical-fiber-based delay lines.

2. True-time delay line design

We proposed and demonstrated a monolithic reconfigurable TTD line in [7]. Reconfigurability among difference frequency bands was built into the structure by combining the waveguides and optical switches, with the structure shown in Fig.1. The inclusion of optical switches is critical for applications where power-consumption is a sensitive issue. Another advantage of using optical

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switches is the establishment of the scaling architecture with a minimum number of hardware devices. For example, we can achieve $2^N = 1024$ time delays with $N = 10$ segment waveguides (Fig.1). The differential delay time through one reconfigurable true-time delay line is

$$T_i = \sum_{j=1}^N S_{i,j} \Delta t_j = \sum_{j=1}^N S_{i,j} 2^{j-1} \tau; \quad S_{i,j} = 0,1, \quad (1.1)$$

where $S_{i,j}$ is the state of the j -th optical switch in the i -th TTD line.

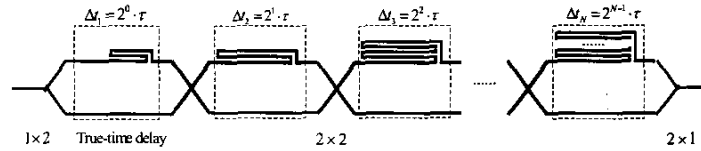


Fig.1 Schematic diagram of a reconfigurable true-time delay line.

However, for any deployable phased-array antenna system, the maximum delay time could be up to tens of nanoseconds, corresponding to tens of meters of waveguide length. After an optical signal passes through such a waveguide, there is no signal can be detected due to the huge insertion loss. In order to overcome the huge loss encountered by optical feeds, we present here a loss compensated approach. Fig.2 shows the formation of the innovative loss compensated reconfigurable true-time delay lines. N -bit polymer delay lines of lengths ranging from 0 to tens of meters are dispensed on an Erbium-doped glass substrate. Constant differential lengths are maintained among the waveguides.

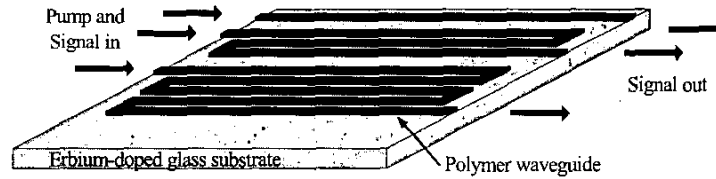


Fig.2 The formation of a true-time delay unit on an Erbium-doped glass substrate.

The principle of the amplifying effect is shown in Fig.3. Pump of 980nm and signal are fed into a polymer waveguide. Proper design of the waveguide structure will assure single-mode operation for both pump and signal. Also, the modes will have a large amount of overlap with the Erbium-doped glass as illustrated in Fig.3. The evanescent fields within the glass are used to excite the Erbium ions, therefore increase the intensity of the laser beams passing through stimulated emission. Therefore, the polymer waveguides based on Erbium-doped glass substrate not only provide true-time delays, but also work as Erbium-amplified waveguide amplifiers (EDWAs), which can compensate the

propagation loss and even provide optical gain. This technique eliminates the huge insertion loss encountered by other integrated photonic delay lines.

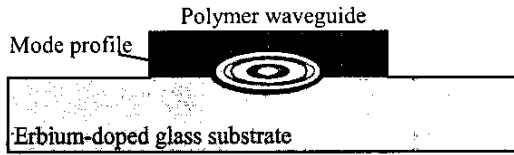


Fig.3 The principle of the amplifying effect.

3. Passive optical properties

Several passive optical properties of waveguide fabricated on top of Erbium-doped glass were investigated, in particular, the shape and size of the fundamental mode, the coupling efficiency to a single mode fiber and the amount of mode in the glass substrate. Fig.4 shows the simulated 2-D profile of the fundamental mode of $\lambda=1550\text{nm}$ signal and $\lambda=974\text{nm}$ pump. The evanescent tails penetrate into the substrate. The percentage of the fundamental signal and pump mode that overlaps with the erbium glass was calculated to be 17.17 and 5.79, respectively.

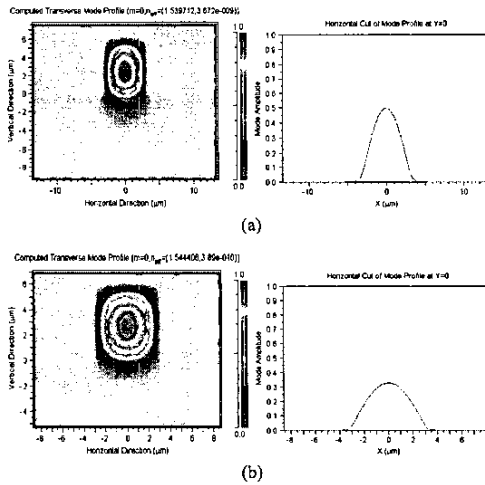


Fig.4 (a) 1550nm signal mode profile (b) 974nm pump mode profile.

3. Active optical properties

The Erbium/Ytterbium co-doped phosphate glass substrate was obtained from Kigre Inc, with the absorption peak is at 974nm. The erbium content is known to be 3% and the ytterbium content 7.4%. The active properties were

studied using a 974nm pump laser from Bookham Technology. The fabricated device is 2cm in length. The output from the 974nm laser was combined with a signal from a 1550 nm laser in a fiber wavelength multiplexer. The output pigtail of the multiplexer was aligned to the input facet of the composite polymer/glass waveguide. The input and output fibers were aligned to the Erbium amplified waveguide using the Newport auto-aligner (Fig.5 (a)). The measured output far field beam image and near field mode profile are illustrated in Fig.5 (b) and (c). The output light has a symmetric near field mode profile. The enhancement of a transmitted signal at a wavelength of 1550nm was studied. The transmitted signal was found to be increase as much as 0.5 dB when pumped with 75mW. The gain depends on many factors, such as the erbium content, the ytterbium content, the pump power, and the waveguide structure. All these factors will be further analyzed to obtain the maximum gain in the future.

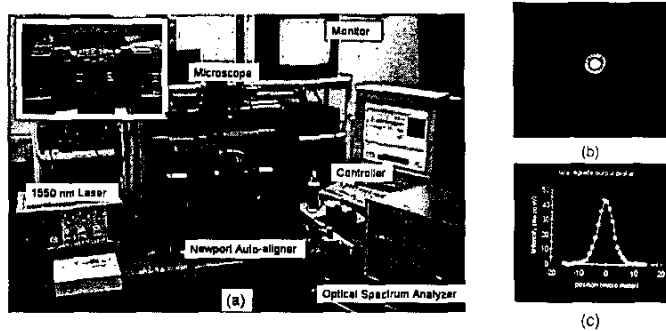


Fig.5 (a) Experiment setup for waveguide performance measurement (b) measured far field beam image (c) measured near field mode profile.

5. Reference

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