Photonic Switched True Time Delay Beam Forming Network Integrated on Silica Waveguide Circuits

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ABSTRACT

This paper proposes an integrated variable true time delay (TTD) beam forming network (BFN) on the Silica-based optical waveguide circuits. This BFN has thermooptic switches and variable time delay lines. The variable TTD unit test was carried out under the 2.5GHz microwave frequency range. The experimental results show that the phase error, that is the difference from the designed value, is less than or equal to 0.6 degrees and the amplitude error is less than or equal to 0.5 dB. These results also show adequate performance for a variable delay line. This Silica-based beam former will be one of the excellent alternatives for the phased array antennas.

INTRODUCTION

Both coherent techniques and non-coherent techniques are now in progress to realize optically controlled phased array antennas. [1] The former is represented by a heterodyne method [2,3], and the latter is represented by a true time delay (TTD) method [4,5]. Since the low loss and dispersion characteristics of fibers makes the systems much easier to realize in the optical domain, the TTD method usually uses an optical fiber distribution network. One of the solutions is the combination of planar optical switching networks and different-length optical fibers. This switching network is implemented on the polarization-dependent devices of Lithium Niobate [4] or Gallium Arsenide [5], so the use of polarization-maintaining fibers makes it difficult to integrate the system. Another approach is the switching of optical path length fabricated on a planar substrate. However, this routing is accomplished in the electrical domain. [6]

Silica-based waveguides, we name planar lightwave circuits (PLC), have the characteristics of low loss of 0.1 dB/cm or less, far easier polarization maintenance than LN or GaAs, patterning flexibility, and active circuit capability by thermooptic effect. [7] The PLC can be treated as not only delay line elements but also switching elements. Therefore, the PLC has the potential to realize a novel integrated beam forming and steering network for active phased array antennas.

This paper proposes a newly developed PLC-based beam forming network (PLC-BFN).

SYSTEM CONFIGURATION

Figure 1 shows the configuration of the PLC-BFN for four-element linear antenna array.

As is well known, when the linear antenna array elements are equally spaced, the feeding with the uniform phase difference can form a beam and steer the beam by changing the phase difference value. This PLC-BFN has four variable delay lines and gives five phase-difference feeding patterns by selecting delay lines. The designed time delay deviations are summarized in Table 1.

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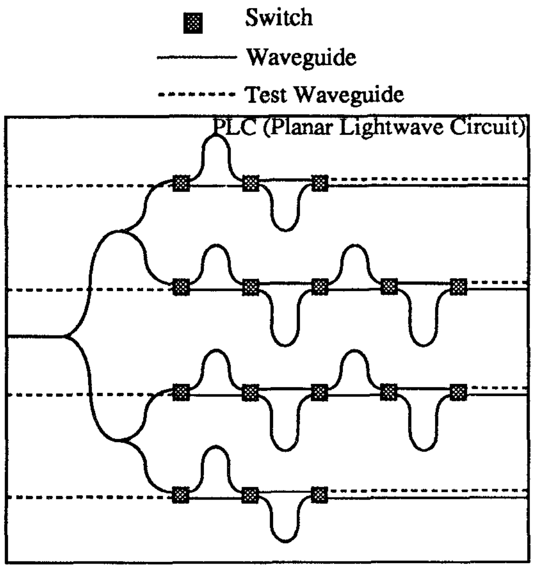

Fig.1 PLC-BFN Configuration (1-beam·4-element)

Table 1 Designed Relative Time Delay

		Beam Direction No.				
		#1	#2	#3	#4	#5
Output Port No.	#1	$3T_2$	$3T_1$	0	0	0
	#2	$2T_2$	$2T_1$	0	T_1	T_2
	#3	T_2	T_1	0	$2T_1$	$2T_2$
	#4	0	0	0	$3T_1$	$3T_2$
Time Delay Deviation		**$-T_2$**	**$-T_1$**	**0**	**T_1**	**T_2**

The time delay deviation of [T] forms a beam with the direction of [D] as explained in the following equation at the RF signal frequency of [F].

$$D = \cos^{-1}\left(\frac{2\pi FT}{kd}\right) - \theta_0 \qquad (1)$$

where

k : wave number ($2\pi/\lambda$)

d : spacing duration

θ_0 : reference angle

Figure 2 shows the configuration of a 2x2 thermooptic switch on PLC. This switch is composed of two 3dB-$\pi/2$ couplers and a thin film heater. This balanced structure connects cross path at the off-state of the switch. The thin film heater works as an optical phase shifter and is biased to give a phase difference of π between two paths.

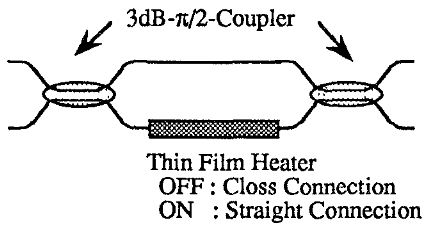

Fig. 2 2x2 Thermooptic Switch on PLC

The performance of the thermooptic switch is shown in Fig. 3. A switch isolation of 22 dB in the optical domain was achieved.

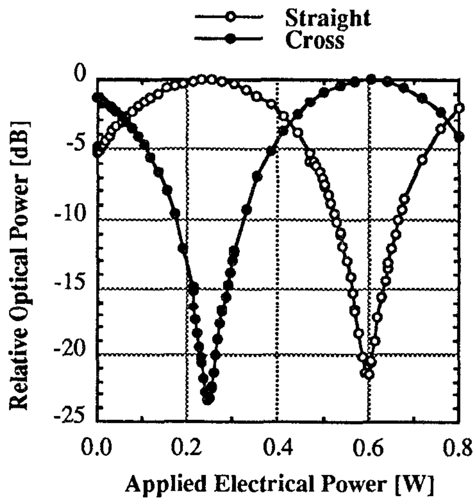

Fig. 3 PLC Switch Performance

EXPERIMENTAL RESULTS

The tested switched TTD unit composed of three switches and two delay lines is shown in Fig. 4. These two delay lines have the time delay of 129 psec, respectively. This delay time is equal to the phase delay of 116 degrees of the 2.5 GHz signal. The experiment was done by using an optical source, an external optical mudulator, a PD, and a network analyzer.

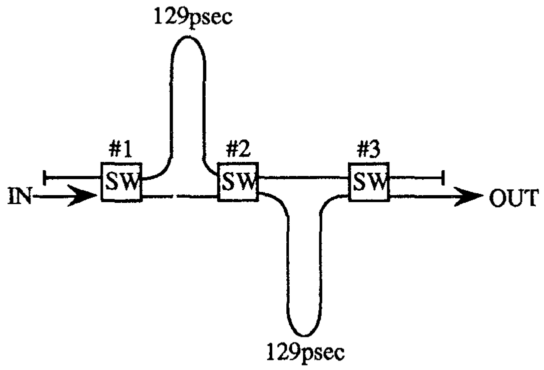

Fig. 4 Tested PLC Variable Delay Line

The test results using the RF signal frequency of 2.5 GHz are shown in Table 2.

Table 2 Experimental Results
(Frequency : 2.5 GHz)

SW state			Relative Phase [deg]	Relative Amplitude [dB]
#1	#2	#3		
ON	OFF	OFF	Reference	Reference
OFF	ON	OFF	116.6	0.1
ON	ON	ON	116.0	0.2
OFF	OFF	ON	232.6	0.1

The phase error, that is the difference from the designed value, is less than or equal to 0.6 degrees and the amplitude error is less than or equal to 0.2 dB. These results show adequate performance for a variable delay line.

CONCLUSION

This paper proposed a switched true time delay beam forming network integrated on the Silica-based optical waveguide circuits. The switched TTD unit test was carried out under the microwave frequency range. The experimental results show that the proposed Silica-based beam former will be one of the excellent alternatives for the phased array antennas.

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