Available online at www.sciencedirect.com
SCIENCE DIRECT
Optics & Laser Technology 37 (2004) 29–32
Optics & Laser Technology
www.elsevier.com/locate/optlastec

Thermally tuned optical fiber for true time delay generation

Brie Howley*, Zhong Shi, Yongqiang Jiang, Ray T. Chen

Microelectronics Research Center, The University of Texas at Austin, Austin, TX 78758, USA

Received 5 December 2003; received in revised form 7 February 2004; accepted 9 February 2004

Abstract

A new technique for generating a continuous range of true time delay values is introduced. Heating optical fiber in order to change the effective index of the guided mode produces time delays. A 45-m section of single-mode silica fiber is demonstrated to produce a continuous range of time delay values from 0 to 211 ps over a temperature tuning range of 50°C (30–80°C). A thermal time delay factor is introduced and found to be 0.096 ps/m°C for Corning LEAF fiber. A 7.66-m section of multimode Lucina polymer fiber is demonstrated to produce a range of time delay values from 0 to 32 ps over a temperature tuning range of 30°C (30–60°C). The thermal time delay factor for this fiber is −0.1427 ps/m°C.
© 2004 Elsevier Ltd. All rights reserved.

Keywords: Optical fiber; Phased array antenna; True time delay

1. Introduction

It is generally expected that future phased array antennas (PAA) will be designed to operate across ultra-wide bandwidths. It will be necessary to use true time delay (TTD) steering techniques rather than phase delay techniques in order to meet these large bandwidth requirements and avoid beam squint. Optical TTD systems have many advantages over electrical TTD systems including immunity to electromagnetic interference, reduced system size and weight, and non-dispersive behavior over the large radio frequency and microwave bandwidths in which most PAA systems operate.

Numerous optical TTD generation techniques for phased array systems have been demonstrated. These include waveguide hologram-based tunable delays [1–3], fiber and waveguide delay lines with optical switches [4–7], chirped fiber gratings [8], and wavelength tunable dispersive delay lines [9,10]. However, these techniques have disadvantages such as limited total time delay, discrete time delay values rather than continuously tunable time delay, and high loss.

In order to steer a large bandwidth phased array antenna beam anywhere within the typical ±45° angle of operation, a continuously tunable time delay generation method is needed with a sufficiently large maximum time delay value and low loss. Fig. 1 shows the time delay requirements for a 4 × 4 subarray of a PAA with ±45° scanning angles covering the frequency range from 8 to 26.5 GHz (X, Ku, and K-bands) by taking the antenna element spacing as half the wavelength at each calculated frequency.

In this paper, a continuously variable optical time delay module, based on a thermally tuned optical fiber, is presented and demonstrated. This type of fiber true time delay module can be implemented into an optically fed phased array antenna system similar to that described by Shi et al. [11]. To the authors' knowledge, this work is the first time that a thermally tuned bare optical fiber is demonstrated to generate time delay values for a phased array antenna. Discussed herein is the physical operating principle of the thermally tuned fiber delay lines as well as experimental results for single-mode silica fiber and multimode polymer optical fiber.

2. Principle

The normalized propagation constant for single-mode optical fiber, β, can be approximated by [12]

$$\beta = \frac{n_{eff} - n_2}{n_1 - n_2} \approx (1.1428 - 0.996/V)^2, \quad (1)$$

where n_{eff} is the effective index of the guided mode and

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$$

* Corresponding author. Tel.: +1-512-232-2586; fax: +1-512-471-8575.
E-mail address: brie@ece.utexas.edu (B. Howley).

0030-3992/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.optlastec.2004.02.006

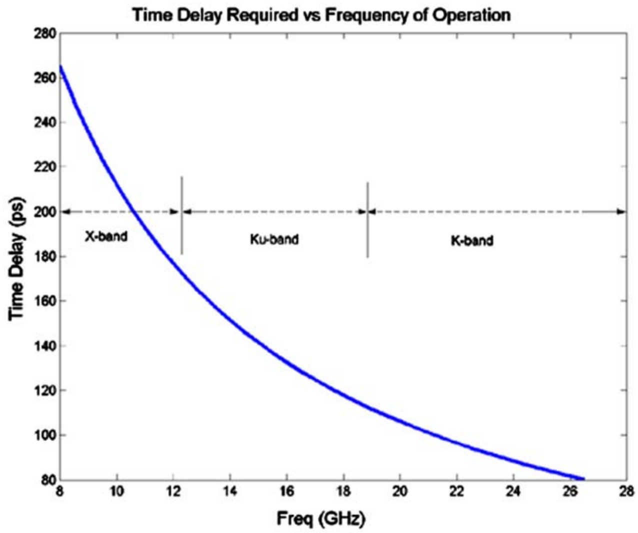

Fig. 1. The time delay requirements for a 4×4 subarray of a PAA with $\pm 45°$ steering angle across X, Ku, and K frequency bands.

and a is the core radius, n_1 and n_2 are the refractive indices of the core and cladding, respectively, and λ is the free space propagating wavelength. Empirically, this approximation is accurate to within 0.2% for a V parameter in the range of 1.5–2.5. From Eq. (1), the change in the effective index for a given change in temperature can be derived to be

$$\frac{\mathrm{d}n_{\mathrm{eff}}}{\mathrm{d}T} = \frac{\mathrm{d}n_1}{\mathrm{d}T}(A+B) + \frac{\mathrm{d}n_2}{\mathrm{d}T}(C-A), \tag{2}$$

where

$$A = \left(1.1428 - \frac{0.996\lambda}{2\pi a\sqrt{n_1^2 - n_2^2}}\right)^2,$$

$$B = \frac{\sqrt{A}n_1(n_1 - n_2)0.996\lambda}{\pi a(n_1^2 - n_2^2)^{3/2}},$$

$$C = 1 - \left(\frac{\sqrt{A}n_2(n_1 - n_2)0.996\lambda}{\pi a(n_1^2 - n_2^2)^{3/2}}\right).$$

The overall time delay produced, $\Delta\tau$, will be

$$\Delta\tau = \frac{\mathrm{d}n_{\mathrm{eff}}}{\mathrm{d}T}\frac{\Delta T\, l}{c}, \tag{3}$$

where ΔT is the change in temperature of the fiber, l is the length of the fiber, and c is the speed of light in vacuum.

For standard telecommunication single-mode fibers, the $A + B$ constant is approximately three times the value of the $C - A$ term. This gives a larger weighting to the $\mathrm{d}n/\mathrm{d}T$ factor of the core material. From this solution, it is seen that in order to maximize the $\mathrm{d}n_{\mathrm{eff}}/\mathrm{d}T$ value and hence $\Delta\tau$, the magnitude of $\mathrm{d}n/\mathrm{d}T$ for both the cladding and core should be as large as possible.

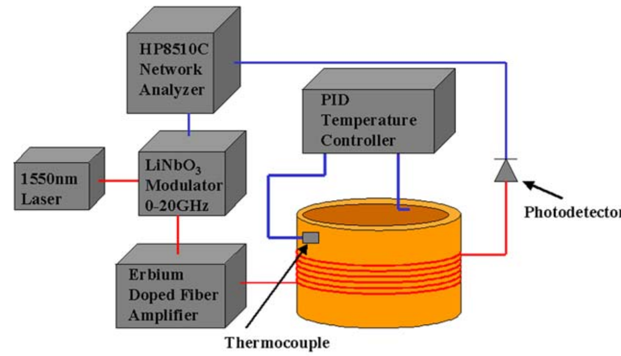

Fig. 2. Schematic of the setup used to control the temperature of the thermally tuned fiber delay line and measurement of the respective time delay.

3. Experiment and results

A test structure was developed in order to demonstrate the time delay properties of thermally tuned fiber. Fig. 2 shows a schematic of the closed-loop system used to measure the time delay as a function of temperature.

A copper pipe, three inches in diameter by 2 in. in height, was lined with a heating blanket that was connected to a proportional integral derivative (PID) temperature controller. A thermocouple was externally attached to the copper pipe with thermally conductive epoxy. The thermocouple was connected to the PID controller to form a feedback loop. The section of the fiber to be tested was wrapped around the outside of the copper pipe. Because the thermocouple and fiber are both in intimate contact with the outer surface of the copper pipe, any temperature gradient from the heater, through the thickness of the copper pipe, is irrelevant. Temperature gradients along the length of the pipe are also negligible due to the high uniformity of heating from the heating blanket.

An HP 8510C network analyzer was used to generate sinusoidal waveforms of frequencies ranging from 2 to 14 GHz. The output electrical signal from the network analyzer was fed into a lithium niobate electro-optic modulator. A CW laser operating at 1550 nm was also fed into the optical modulator. The modulated output was amplified by an erbium doped fiber amplifier (EDFA) and then connected to the input end of the thermally tuned fiber that was wrapped around the copper heater. The output of this fiber was connected to a PIN photodetector with a bandwidth of 0–18 GHz. The electrical signal from the photodetector was fed back into the network analyzer in order to measure the phase. The phase angle of the received signal was measured at 2 GHz increments between 2 and 14 GHz at temperature intervals starting at 30°C and increasing in 10° increments to the maximum operating temperature of the fiber. The 2–14 GHz measurement range was chosen in order to collect data points over a wide range of frequencies in order to enable accurate curve fitting. Larger measurement frequencies were not possible due to bandwidth limitations of

Download English Version:

https://daneshyari.com/en/article/10407982

Download Persian Version:

https://daneshyari.com/article/10407982

Daneshyari.com