OPTICAL POLARIZATION EFFECT IN DISCRETE TIME FIBER-OPTIC STRUCTURES FOR MICROWAVE SIGNAL PROCESSING

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ABSTRACT

We report the effect of the optical polarization in discrete time fiber-optic devices for microwave signal processing applications. Experimental results show that even in the incoherent working regime of these devices, the polarization state of the optical carrier can strongly affect the overall microwave response. A new analysis based on the optical S-matrix representation is developed in order to model correctly these devices. It is found that the optical polarization can be exploited efficiently for tuning the microwave response.

INTRODUCTION

Discrete time fiber-optic devices have been proposed for various microwave applications such as filtering, pulse-train generation, data rate transformation [1]-[2]. Both incoherent and coherent working regimes of these devices have been considered [1]-[5]. In order to obtain higher order transfer functions, cascaded fiber-optic structures must be used. In previous works [1],[6], when dealing with the incoherent working regime, the optical interference effect was simply ignored in the analysis because the coherence time of the light source is assumed to be much smaller than the used unit delay time. Then the microwave behavior of these structures was calculated using a chain matrix formalism. However, experimental evidences show that in these structures, the optical interference can occur and have a drastic effect on the microwave frequency response (**MFR**). This problem is due to the optical polarization coupling effect and indeed cannot be explained by previously reported analysis.

EXPERIMENTAL INVESTIGATIONS

We investigated the MFR of two types of cascaded fiber-optic structures using the Unbalanced Mach-Zenhder Interferometer (**UMZI**) and the Recirculating Delay Line (**RDL**) as building blocks. The optical structures were realized using standard single mode fiber components (3-dB fused couplers and connectorized fibers). The measurement set-up consists of a microwave network analyzer HP8510B and a lightwave component analyzer HP84320A for E/O and O/E signal conversions. The optical source (DFB laser at 1.3 μm) was intensity modulated in the

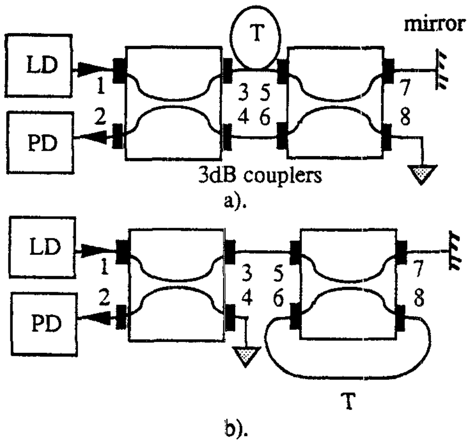

Fig.1 a)Equivalent structure of a two-stage cascaded UMZI and b)Equivalent structure of a cascaded RDL.

microwave frequency range 1GHz-1.04GHz. The unit time delay T (which is determined by the 20 m length of the delay fiber) in these

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structures was chosen to be much greater than the coherence time of the light source (about 100 ns compared to about 13 ns) in order to obtain an incoherent working regime. The measured MFR of the one-stage UMZI and that of the one-stage RDL were stable as one might expect and the measured results were reported elsewhere [8]-[9].

In order to study the MFR of a cascaded two-stage UMZI, we terminated the port 7 of the UMZI with a mirror and measured the reflected optical signal at the port 2 (Fig.1a). Thus the realized structure is equivalent to a real two-stage cascaded UMZI. Contrary to the one-stage case, we observed that the MFR of the cascaded structure becomes unstable and can change drastically when touching the fiber delay line. Fig.2a shows the measured MFR of the structure in three different situations and Fig.2b displays the corresponding impulse responses. The impulse response consists of 3

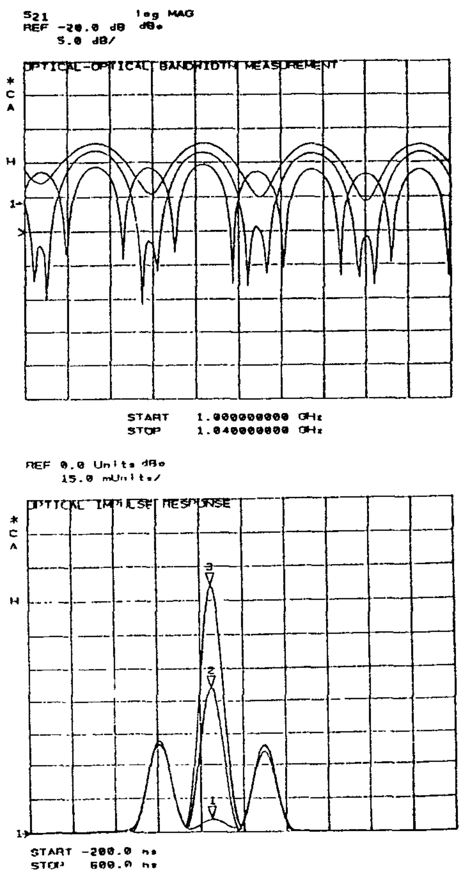

Fig. 2 a) Measured MFR's of the UMZI terminated with a mirror; b)Corresponding impulse responses

delayed pulses arriving respectively at the moments 0T, 1T, and 2T. The amplitude of the first pulse and the third one remain practically unchanged, however, the amplitude of the second one can strongly fluctuate depending on the external perturbations.

Similar results were also observed in the case of the cascaded RDL.(Fig.1b). The measured MFR's and the corresponding impulse responses are given respectively in Fig.3a and b. In this case, the impulse response consists of an infinite pulse train due to the feedback loop.

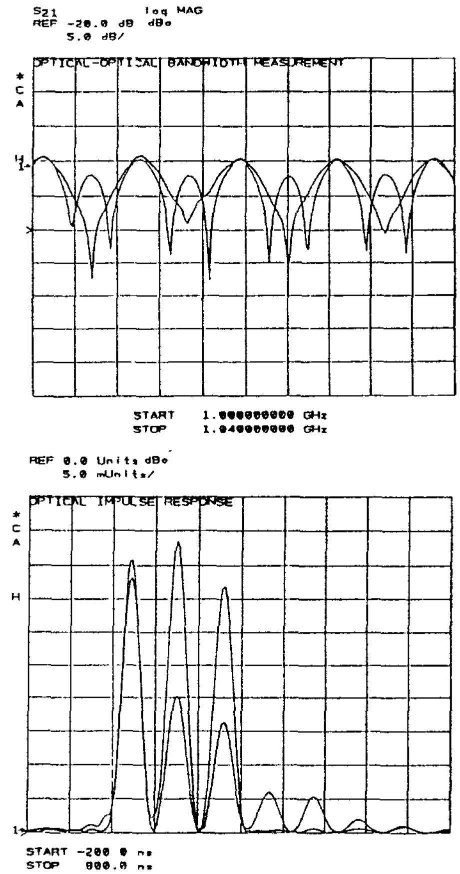

Fig. 3 a) Measured MFR's of the RDL terminated with a mirror; b)Corresponding impulse responses

THEORETICAL ANALYSIS

In the case of a two-stage UMZI, the optical signal is divided in 4 different optical paths (with their corresponding delay time 0T, T, T and 2T) and recombined at the output. In previous analysis [1],[6], it was commonly supposed that these optical signals add on an intensity basis. This assumption is, however, not valid because the two optical signals delayed by T will add rather on a field basis. Thus the optical interference can occur resulting in the change observed in the impulse response.

In single mode fiber components, it is known that the optical wave consists of two nearly degenerated orthogonally polarized modes. Therefore, we represented the input optical field by a Jones vector :

$$[\mathbf{E}] = \begin{bmatrix} E_x \\ E_y \end{bmatrix} \sqrt{1+ M\cos\Omega t}\ \exp(j\omega t)$$

where Ω denotes the microwave modulating frequency and M is the modulation index.

We modelled the optical components by their optical S-matrix. The S-matrix of a lossless and reciprocal fiber of length L can be expressed by:

$$[\mathbf{S_F}] = \begin{bmatrix} 0 & 0 & F_x & 0 \\ 0 & 0 & 0 & F_y \\ F_x & 0 & 0 & 0 \\ 0 & F_y & 0 & 0 \end{bmatrix}$$

where $F_x = \exp(j\omega L n_x/c)$ and $F_y = \exp(j\omega L n_y/c)$ with n_x, n_y representing the effective indexes corresponding to the two polarization modes. A lossless, reciprocal and polarization maintaining coupler can be characterized by :

$$[\mathbf{S_C}] = \begin{bmatrix} [\mathbf{O}] & [\mathbf{O}] & [\mathbf{A}] & [\mathbf{B}] \\ [\mathbf{O}] & [\mathbf{O}] & [\mathbf{B}] & [\mathbf{A}] \\ [\mathbf{A}] & [\mathbf{B}] & [\mathbf{O}] & [\mathbf{O}] \\ [\mathbf{B}] & [\mathbf{A}] & [\mathbf{O}] & [\mathbf{O}] \end{bmatrix}$$

The 2x2 sub-matrices **A** and **B** are given by:

$$[\mathbf{A}] = \begin{bmatrix} \sqrt{1-K_x} & 0 \\ 0 & \sqrt{1-K_y} \end{bmatrix} \text{ and } [\mathbf{B}] = \begin{bmatrix} j\sqrt{K_x} & 0 \\ 0 & j\sqrt{K_y} \end{bmatrix}$$

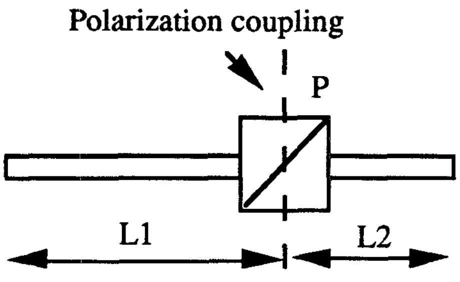

Fig. 4 Representation of the lumped polarization coupling in a fiber delay line.

where K_x and K_y represent respectively the intensity coupling ratios for the two polarizations.

To model the polarization coupling effect due to fiber deformations, we supposed a lumped polarization controller whose S-matrix is given by:

$$[\mathbf{S_P}] = \begin{bmatrix} 0 & 0 & \cos\theta & \sin\theta \\ 0 & 0 & -\sin\theta & \cos\theta \\ \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \end{bmatrix}$$

where θ characterizes the coupling between the two polarization modes. The real fiber delay line can than be considered as a combination of a polarization controller sandwiched in between two birefringence fibers L1 and L2 as shown Fig.4.

Based on the above defined S-matrices, we calculated the detected photocurrent at the output of the cascaded UMZI and the cascaded RDL for a linearly polarized input light. To do this, the output optical intensities were determined separately for each moment 0T, T, 2T by means of the transfer functions of the individual optical paths.

The simulated results agreed well with the measured results. Fig.5 a and b show respectively the simulated MFR's in the modulation frequency range 0-1GHz and the corresponding impulse responses of the cascaded UMZI. These MFR's were obtained respectively for three different values of $\theta = 0°, 45°$ and $90°$. In this simulation, the delay line fiber length was chosen to be 1m and the polarization controller was placed at 0.1 m from one end of the fiber delay line. We assumed that the average effective index is 1,5 and the fiber birefringence is characterized by $n_x - n_y = 10^{-6}$. The 3 dB couplers were assumed to be polarization independent. With the same conditions, the simulated MFR's and the impulse responses of the cascaded RDL are given respectively in Fig.6a and b.

CONCLUSION

In practice, the polarization coupling in standard optical fibers depends strongly on external perturbations and can vary randomly the frequency response of the cascaded fiber-optic structures. Thus for maintaining a stable response of these devices, the use of polarization maintaining fiber components is needed. On the other hand, as shown in the present analysis, it is possible to exploit advantageously the optical polarization effect to control the MFR of these structures by using polarization controllers. This could find interesting applications for realizing tunable microwave filters in fiber-optic form.

REFERENCES

[1] B. Moslehi, J.W.Goodman *et al*, "Fiber-optic lattice signal processing", *Proc.of the IEEE.* Vol.72, No.7, July 1984.

[2] K.P.Jackson, S.A.Newton *et al*, "Optical fiber delay-line signal processing", *IEEE trans. on Microwave Theory and Techniques.* Vol.MTT-33 No.3, March 1985.

[3] B. Vizoso, C. Vazquez *et al*, "Amplified fiber-optic reciculating delay lines", *J. of Lightwave technol*, Vol.12 No.2, February 1994.

[4] H. Okamura, K.Iwatsuki, "A finesse-enhanced Er-doped fiber ring resonator", *J. of Lightwave technol*, Vol.9 No.11, 1993.

[5] K. Sasayama, M.Okuno *et al* ,"Coherent optical transversal filter using silica-based waveguides for high-speed signal processing", *J. of lightwave technol*,. Vol.9, No.10, October 1991

[6] J. Capmany and J. Cascon, "Discrete time fiber-optic signal processors using optical amplifier" *J. of Lightwave technol*,. vol.12 No.1, January 1994.

[7] R. C. Jones, "New calculus for the treatment of optical systems", *J. Opt. Soc . Am*, 31, pp.488-503, 1941.

[8] A. Ho-Quoc, S. Tedjini, "Experimental investigation on the optical unbalanced Mach-Zehnder interferometer as microwave filters", *IEEE Microwave and guided wave letters*, June 1994.

[9] S.Tedjini, A.Ho-Quoc *et al*, "All-optical networks as microwave and millimeter-wave circuits", *IEEE trans. on Microwave Theory and Techniques.* Vol.43 No.9, September 1995.

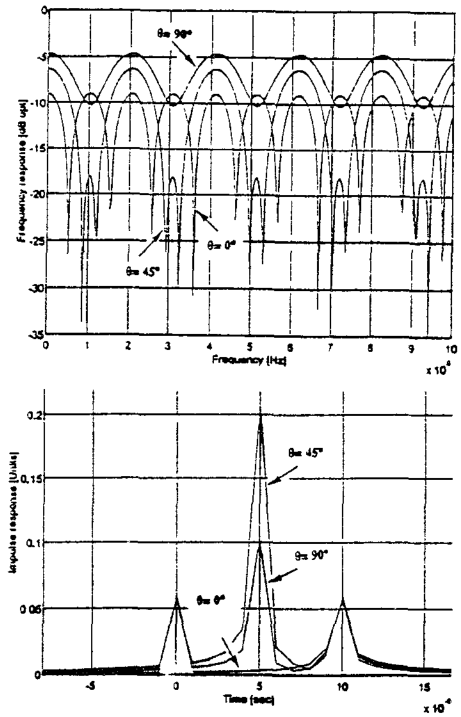

Fig. 5 a) Simulated MFR's of the cascaded UMZI as a function of the polarization coupling θ; b)Corresponding impulse responses.

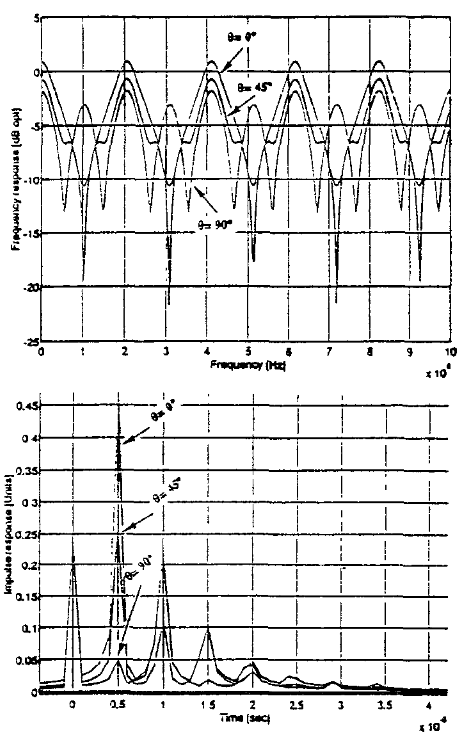

Fig. 6 Simulated MFR's of the cascaded RDL as a function of the polarization coupling