Active Controlled Fiber Optical 90°Hybrid for Coherent Communications

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Abstract—**This letter presents the realization of an active controlled fiber optical 90° hybrid, for use in phase diversity receivers. The four output signals are proportional $E_1 \pm E_2$ and $E_1 \pm E_2 \cdot \exp(j90°)$, where E_1 and E_2 are the complex amplitudes of the two input signals. A hybrid comprising four 3-dB monomode fiber couplers and two phase shifters was designed for the 1.5 μm wavelength range. The principle of operation is described and experimental results are presented. The maximum phase error is smaller than 0.5°.**

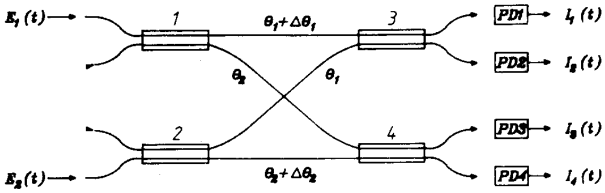

Fig. 1. Configuration of the fiber optical 90° hybrid.

INTRODUCTION

COHERENT optical receivers offer an improvement in sensitivity compared to IM/DD systems. Homodyne receivers have advantages over heterodyne receivers first in providing better sensitivity and second requiring only baseband bandwidth in the photodiode electrical circuit. The disadvantages of homodyne receivers are the stringent requirements of optical phase locking. Phase-diversity (multiport) receivers also require only baseband receiver module bandwidth, but have the great benefit of avoiding both phase locking and high stability frequency locking [1]. Different types of 90° hybrids, which can be used in phase-diversity receivers, have been designed, as well as lossless passive devices as active configurations involving losses [2]-[5]. In this letter, we report on a lossless, active controlled fiber optical 90° hybrid consisting of four fiber couplers for use in a phase-diversity receiver [6].

PRINCIPLE OF OPERATION

Fig. 1 shows the diagram of the 90° hybrid and indicates the notations. It represents an eight-port device; however, only two input ports are used. Assuming two input signals polarized linearly and parallel to each other, the amplitudes at input 1 and input 2 are

$$E_1(t) = 0.5 \cdot \hat{E}_1 \cdot [\exp\{j(\omega_1 t + \rho_1)\} + \text{c.c.}], \quad (1)$$

$$E_2(t) = 0.5 \cdot \hat{E}_2 \cdot [\exp\{j(\omega_2 t + \rho_2)\} + \text{c.c.}] \quad (2)$$

where c.c. denotes the complex conjugated. Supposing lossless 3-dB monomode fiber couplers and lossless monomode fibers between the couplers, we get the following currents at the output of the photodetectors

$$I_1(t) = 0.25R[\hat{E}_1^2 + \hat{E}_2^2 - 2\hat{E}_1\hat{E}_2 \cos(\omega_1 t - \omega_2 t + \rho_1 - \rho_2 - \Delta\Theta_1)], \quad (3)$$

$$I_2(t) = 0.25R[\hat{E}_1^2 + \hat{E}_2^2 + 2\hat{E}_1\hat{E}_2 \cos(\omega_1 t - \omega_2 t + \rho_1 - \rho_2 - \Delta\Theta_1)], \quad (4)$$

$$I_3(t) = 0.25R[\hat{E}_1^2 + \hat{E}_2^2 + 2\hat{E}_1\hat{E}_2 \cos(\omega_1 t - \omega_2 t + \rho_1 - \rho_2 + \Delta\Theta_2)], \quad (5)$$

$$I_4(t) = 0.25R[\hat{E}_1^2 + \hat{E}_2^2 - 2\hat{E}_1\hat{E}_2 \cos(\omega_1 t - \omega_2 t + \rho_1 - \rho_2 + \Delta\Theta_2)] \quad (6)$$

where $\Delta\Theta_1$ signifies the relative phase shift caused by the length difference of the fibers between coupler 1 and 3 and between coupler 2 and 3, respectively, and $\Delta\Theta_2$ is the relative phase shift between coupler 1 and 4 and between coupler 2 and 4, respectively. R is the detector responsivity ($\eta e/hf$). The ac terms of the currents I_1 and I_2, respectively I_3 and I_4, are oppositely phased. The phase difference between the currents I_1 and I_4 and between I_2 and I_3, respectively, can be varied by changing $\Delta\Phi_1$ and/or $\Delta\Phi_2$. For the 90° hybrid we get the condition

$$\Delta\Theta_1 + \Delta\Theta_2 \overset{!}{=} 90° \pm n \cdot 180°. \quad (7)$$

EXPERIMENTAL SETUP AND MEASUREMENT RESULTS

To verify the properties of the hybrid, one can heterodyne two lasers by means of the hybrid and determine the phase difference of two beat signals. Another possibility is shown in Fig. 2. The output of an active frequency-stabilized 1.52 μm HeNe laser [7] is fed to a 3-dB monomode fiber coupler. One output path of the coupler is connected with one

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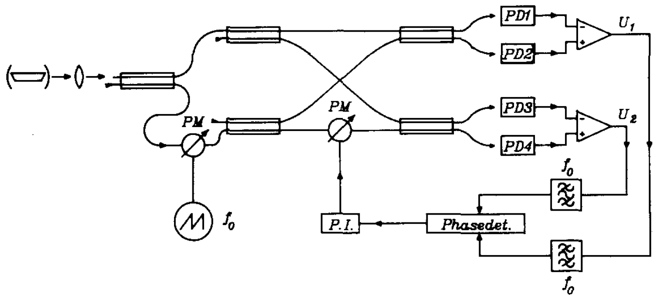

Fig. 2. Experimental setup used to verify the properties of the 90° hybrid.

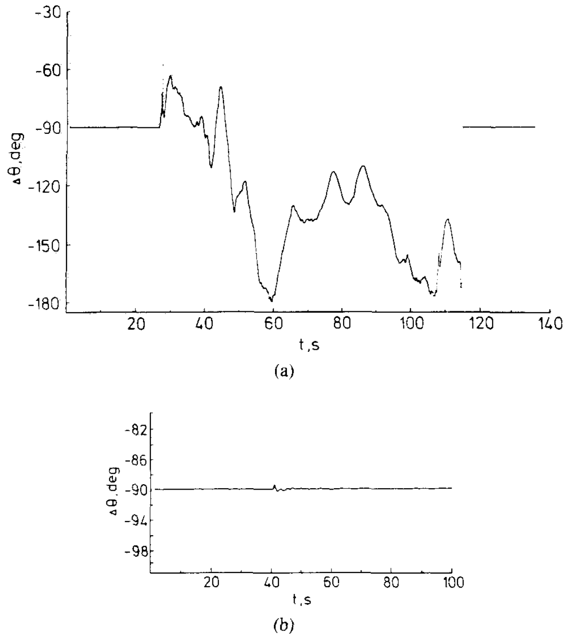

Fig. 3. Results of phase deviation measurements. (a) Closed/open/closed loop, t = 140 s. (b) Closed loop with disturbance, t = 100 s.

input port of the optical hybrid while the other signal path is phase modulated by a sawtooth function which causes an optical frequency shift. This phase modulated signal is then fed to the other input port of the hybrid. The photodiode currents I_1–I_4 are subtracted in differential amplifiers; the output voltages are bandpass filtered and connected with the phase detector. The output signal of the phase detector is used as the input for a P.I. controller which generates a phase control signal for the phase modulator (PM) in the optical hybrid. The phase modulator we use to vary $\Delta\Theta_2$ is a piezoelectric ceramic disk which is wrapped round with a few turns of fiber. By applying a voltage, the diameter of the disk change and therefore the length of the fiber turns, respectively the relative phase $\Delta\Theta_2$. Fig. 3(a) and (b) shows some examples of phase deviation measurements using the output signal of the phase detector, which is recorded on an X–Y plotter. Fig. 3(a) presents results obtained with open and also closed loop. In the case of open control circuit, the maximum phase deviation is about 180°, caused by the temperature dependence of the refractive index and length of the interconnecting fibers of about 1.5 m length. On the other hand, there is no significant phase error in the case of closed control loop. Fig. 3(b) illustrates a 100 s measurement of the phase deviation with disturbance at t = 40 s (squeezing one of the fibers). The maximum phase error is smaller than 0.5°.

CONCLUSIONS

An active controlled fiber optical 90° hybrid, for use in a phase diversity receiver, has been designed, built, and tested. To obtain a control signal for the 90° hybrid, the IF frequency of the receiver must be nonzero. The circuit presented here guarantees a phase difference of 90° between two of the outputs of the hybrid without power loss. The other outputs are oppositely phased to the former. The same principle can be used to create an arbitrary phase relationship between two of the outputs of the hybrid.

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