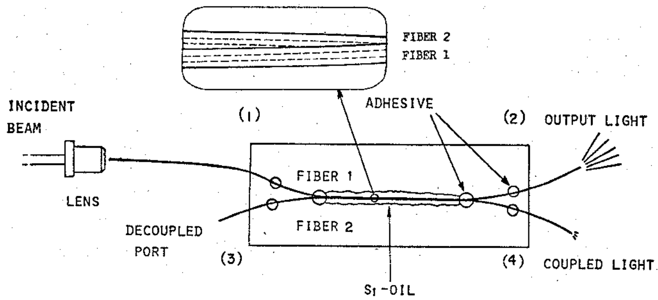


Fig. 1. Directional coupler made up of two parallel fibers.

TABLE I
CALCULATION OF THE COUPLED POWER

MODE	COUPLING COEFFICIENT C_{PP} (M^{-1})	COMPLETE POWER TRANSFER LENGTH $\ell = \pi/2C_{PP}$ (M)	POWER TRANSFER $SIN^2 C_{PP}Z$
HE_{11}	0.1199×10^{-7}	1.3100×10^{8}	2.500×10^{-19}
HE_{12}	0.9445×10^{-7}	1.6631×10^{7}	1.849×10^{-17}
HE_{13}	0.4882×10^{-6}	3.2175×10^{6}	5.018×10^{-16}
HE_{14}	0.2787×10^{-5}	5.6361×10^{5}	1.644×10^{-14}
HE_{15}	0.2157×10^{-4}	7.2823×10^{4}	9.848×10^{-13}
HE_{16}	0.2737×10^{-3}	5.7391×10^{3}	1.585×10^{-10}
HE_{17}	0.7852×10^{-2}	2.0005×10^{2}	1.304×10^{-7}
HE_{18}	$0.1333\times10^{+1}$	1.1801×10^{0}	3.756×10^{-3}

Z=0.046 M

ACKNOWLEDGMENT

The authors wish to thank Associate Prof. Fujii for his helpful advice and the members of the Fujitsu Laboratories, Ltd., for providing the fiber and the reviewers of this letter.

REFERENCES

[1] E. Snitzer, "Cylindrical dielectric waveguide modes," *J. Opt. Soc. Amer.*, vol. 51, pp. 491–498, May 1961.
[2] A. W. Snyder, "Coupling mode theory for optical fibers," *J. Opt. Soc. Amer.*, vol. 62, pp. 1267–1277, Nov. 1972.
[3] A. L. Jones, "Coupling of optical fibers and scattering in fibers," *J. Opt. Soc. Amer.*, vol. 55, pp. 261–271, Mar. 1965.
[4] N. S. Kapany, *Fiber Optics, Principles and Applications.* New York: Academic, 1967.

A Semi-Transparent Mirror-Type Directional Coupler for Optical Fiber Applications

H. KUWAHARA, J. HAMASAKI, AND S. SAITO

***Abstract*—A directional coupler for optical fiber applications is constructed of two pieces of optical fibers cut obliquely and a thin dielectric film. Coupling coefficient −20 dB to −10 dB depending on the refractive index of the dielectric film, insertion loss 1 dB, and directivity −20 dB are measured. They agree with the analytical results.**

In an optical fiber circuitry, a directional coupler which extracts an appreciable amount of power directly from the fiber into an outside detector is often needed. This letter describes results of experiments of a semi-transparent mirror-type directional coupler for multimode optical fibers.

Manuscript received March 27, 1974; revised July 29, 1974.
H. Kuwahara is with Fujitsu Laboratory, Kawasaki, Japan.
J. Hamasaki and S. Saito are with the Institute of Industrial Science, University of Tokyo, Tokyo, Japan.

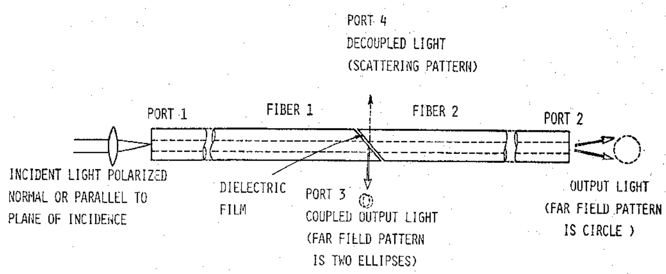


Fig. 1. The directional coupler by dielectric film and its far-field pattern.

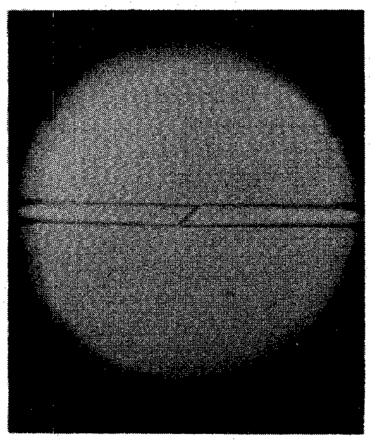


Fig. 2. The optical directional coupler observed in microscope.

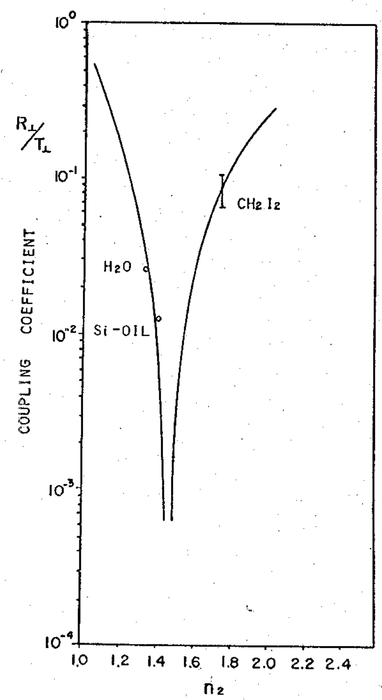


Fig. 3. Coupling efficiency versus refractive index of the dielectric film (n_2).

Fig. 1 shows the construction of the directional coupler. Two pieces of fibers are cut and polished at a 45° angle, and a dielectric film is inserted between the polished surfaces.

Since the diameter of the fiber is much larger than the wavelength of the guided light wave, the characteristics of the coupler are analyzed based on the superposition of plane waves which propagate almost parallel to the fiber axis [1]. The ratio R/T of the power

TABLE I
THE MEDIUM OF DIELECTRIC FILM AND THE INSERTION LOSS

DIELECTRIC MEDIUM	REFRACTIVE INDEX n	INSERTION LOSS dB
H_2O	1.33	-0.73
Si-OIL	1.40	-0.56
CH_2I_2	1.74	-1.19

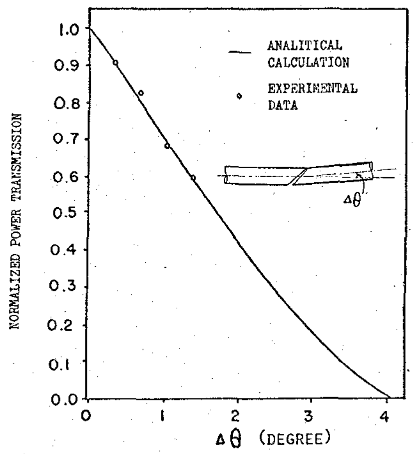


Fig. 4. Decrease of power transmission caused by angular misalignment $\Delta\theta$.

of the reflected and transmitted wave is given by

$$\frac{R}{T} = \frac{|r_{\|}|^2 \cos^2\phi + |r_{\perp}|^2 \sin^2\phi}{|t_{\|}|^2 \cos^2\phi + |t_{\perp}|^2 \sin^2\phi} \tag{1}$$

where r and t are, respectively, the reflection and transmission coefficients of the film for an incident plane wave [2], where the symbols $\|$, $\perp$ indicate the direction of the ploarization to the plane of incidence, and ϕ is the angle between the polarization of the incident wave and the plane of incidence. (See Fig. 2.)

The coupling coefficient is calculated from the ratio R/T of (1), and the measured coupling coefficient for the wave of the electric field polarized normal to the plane of incidence is shown in Fig. 3 with the analytical results. Several kinds of liquids, H_2O ($n = 1.33$), Si-oil ($n = 1.40$), CH_2I_2 ($n = 1.74$), are used for the dielectric film medium.

The analytical results of reflectivity for the wave of parallel polarization become very small because the angle of the film is close to the Brewster angle, and the resulting output is a scattered light which is about 10 dB larger than the analytically expected coupled power.

The insertion loss is obtained from the ratio of the power of port 1 and port 2. The measured insertion losses of the directional coupler by using respective dielectric films are tabulated in Table I.

If two fibers are not aligned in a straight line, the transmitted power decreases with the angular misalignment $\Delta\theta$ (Fig. 4). The analytical result is derived from a common area in the spatial frequency domain of the input and output light which is determined by the acceptance angle of the two fibers. Experimental data reasonably agree with the theoretical results. Directivity is obtained from the ratio of the output light power from port 3 and port 4 and is measured to -20.4 dB.

The experimental directional coupler has the advantages of relatively large coupling coefficient and small size in an optical fiber applications. By choosing an adequate inserting medium, a 3-dB coupler for optical transmission system can be obtained.

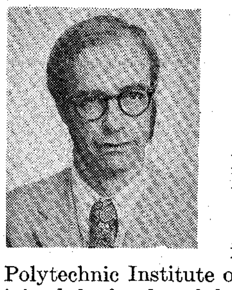
ACKNOWLEDGMENT

The author would like to thank Associate Prof. Fujii for his helpful advice and the members of the Fujitsu Laboratories, Ltd., for their providing and polishing the fibers.

REFERENCES

[1] S. Iiguchi, "Michelson interferometer type hybrid for circular TE_{01} wave and its application to band splitting filter," *Rev. Elec. Commun. Lab.*, Tokyo, vol. 10, pp. 631–642, Nov.–Dec. 1962.
[2] Born and Wolf, *Principles of Optics*. New York: Pergamon.

Contributors



Henry L. Bertoni (M'67) was born in Chicago, Ill., on November 15, 1938. He received the B.S. degree in electrical engineering from Northwestern University, Evanston, Ill., in 1960, and the M.S. degree in electrical engineering, and the Ph.D. degree in electrophysics from the Polytechnic Institute of Brooklyn, Brooklyn, N. Y., in 1962 and 1967, respectively.

From 1966 to 1967 he was an instructor in the Electrophysics Department of the Polytechnic Institute of Brooklyn (now, of New York). In 1967 he joined the faculty of the Electrophysics Department, and is currently an Associate Professor. His past research has dealt with the propagation and scattering of electromagnetic waves in anisotropic media and in lossy media. Currently, his interests are in the excitation and guiding of elastic surface waves for microwave acoustics and in integrated optics.

Dr. Bertoni is a member of Commission VI of the URSI, Sigma Xi, Eta Kappa Nu, and Tau Beta Pi.

★

Angel Cardama (S'67–M'73) was born in Santiago, Spain, in 1944. He received the Ingeniero de Telecomunicación degree from the Universidad Politécnica de Madrid, Madrid, Spain, in 1968, and the Sc.M. and Ph.D. degrees in electrical engineering from Brown University, Providence, R. I., in 1970 and 1973, respectively.

In 1972 he joined the faculty of the E.T.S. Ingenieros de Telecomunicación at the Polytechnic University of Barcelona, Barcelona, Spain, where he is presently Profesor Agregado.

Dr. Cardama is a member of the Optical Society of America and Sigma Xi.