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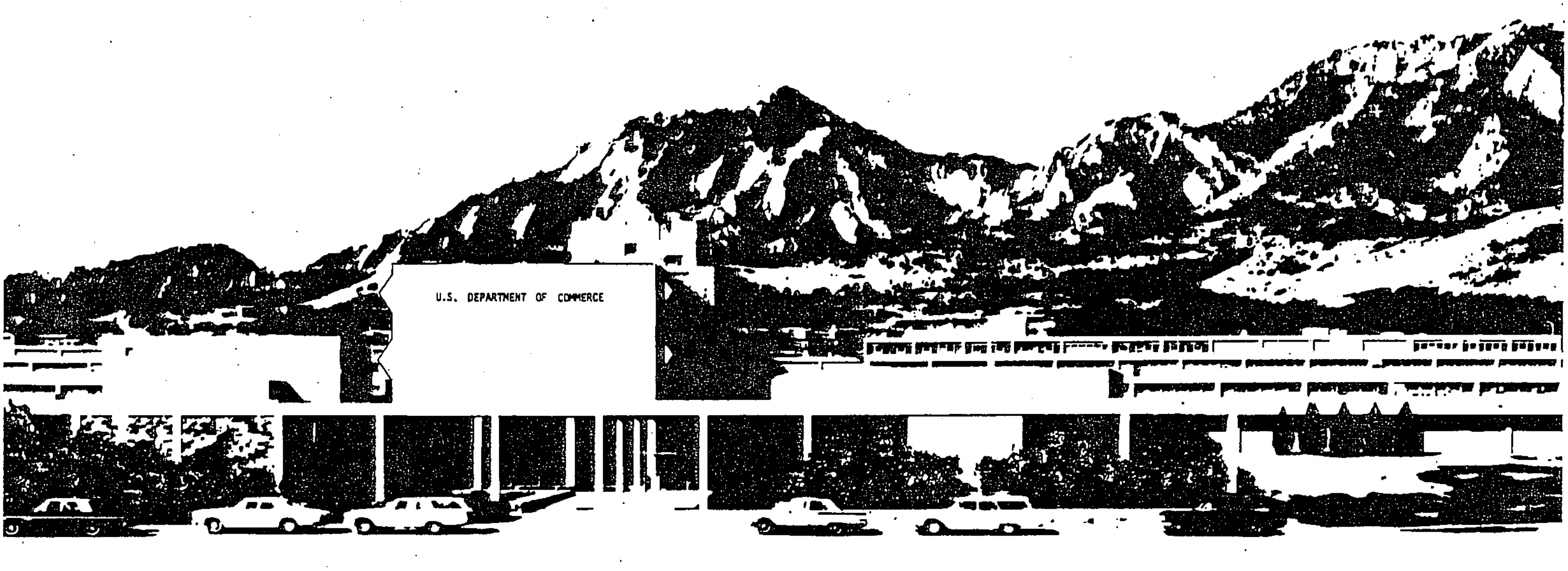

A SINGLE LAUNCH TECHNIQUE FOR DETERMINATION OF MODE TRANSFER MATRICES

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Introduction:

Component intensive multimode fiber systems such as those presently finding application in fiber optic local area nets and premise wiring require more characterization than simply loss statistics. This fact is due to the mode dependency of the fiber compatible components and the fact that the propagation distances of a component intensive system preclude the achievement of any steady-state modal distribution. Mode transfer matrices, as were first introduced by Holmes [1] are powerful tools for multimode system characterization. Unfortunately, as is shown in a recent work [2], mode transition matrices are launch dependent and, as measurement of a mode transfer matrix requires various different launches, the mode transfer matrix of a given component cannot be unique. This lack of uniqueness could be alleviated by standardizing the measurement procedure. However, a lack of uniqueness tends to put into question the repeatability of a measurement technique.

In the present work, we take a slightly different approach to the standard one. The mode transfer matrix is actually just a representation of mode transmission function [2], which is an object which should truly represent the transmission characteristics of a fiber or component. Determination of the transfer function therefore allows one to determine any of its representations and, therefore, all the possible non-unique forms of the mode transfer matrices. A simple model of the mode transfer function for low loss ($\leq$ 0.5 dB) components is derived and determined experimentally, and the results of the use of the mode transmission function to derive mode transfer matrices is compared with direct measurements of mode transfer matrices.

Theory:

The mode transfer function $T(R,R')$ for a component can be defined by the relation [2]

$$p^0(R)m(R) = \int dR' T(R,R')p^i(R')m(R') \tag{1}$$

where $p^0(R)$ is the modal power distribution exiting the component, $m(R)$ is the mode density, $p^i(R')$ is the modal power distribution incident on the component, and R is the mode parameter as defined in any of various works [3]. $T(R,R')$ is a function of two continuous variables R and R' and is therefore not generally to be found directly from (1). However, one can make a parameterized model for $T(R,R')$ and use (1) as a fitting equation to determine the parameters. In essence, this procedure does not differ too greatly from fitting procedures used to determine matrix elements [4]. To derive a parameterized model, one can assume that the mode-continuum approximation holds but that coupling only occurs between modes at the same frequency, as was assumed in the experimentally verified model in reference [5]. The resulting transfer function is

$$T(R,R') = \delta(R-R') - \int dR'' m(R'')\alpha(R'',R)\delta(R-R') + m(R)\alpha(R,R') \tag{2}$$

where the coupling function is a characteristic of the component under test. Assuming the component causes (low) loss and symmetric coupling, one can assume the coupling function to be

$$\alpha(R,R') = \frac{1}{2}\,\alpha_0 e^{-|R^2-R'^2|/2\tau} \tag{3}$$

where α_0 and τ are the fitting parameters.

A Single Launch Measurement Technique:

Once the α_0 and τ of the $\alpha(R,R')$ function are determined, matrices of any order can be determined from the transfer function. A standard measurement made on components is that of overfilled loss. The overfilled loss L can be related to α_0 and τ by the relation

$$L = \alpha_0 V^2 \tau\, 2\tau(1+2\tau)\left[1-2\tau(1-e^{-1/2\tau})\right] \tag{4}$$

where V is the fiber V number. Equation (4) can be derived from (1) together with (2) and (3). where $p^i(R)$ is taken to be unity. Clearly, α_0 can be eliminated from (3) using (4), and the resultant $T(R,R')$ is a function of only τ. If, when one measures L, however, one were also to record the $p^0(R)$ that results from an overfilled launch, one could use τ to fit the relation (1). The resultant best fitted τ could then be used to determine $T(R,R')$. As this $T(R,R')$ is a complete representation of the component under test, any size matrix can be generated from it, and therefore the transfer matrix of the component can be generated from data taken for a single launch.

Experimental Verification:

To truly verify that the measurement technique outlined above is a viable one, one needs to both verify the ansatz of (3) and to compare matrices generated by the above technique with matrices generated directly. In order to do this, a fiber concatenation experiment was carried out in which four 1 meter pieces of fiber were spliced together using input and output fibers with five fusion splices. Comparison of the measured near-fields and those computed using mode transfer functions are given in Figure 1. Typical comparison of mode transfer matrices calculated from the mode transfer function are given in Table 1. Agreement in all cases was good.

Conclusion:

By overfilling an input fiber and recording the total loss and near-field output of a test component, it is possible to find a transfer function for the component. From this transfer function, it is possible to generate any of the non-unique transfer matrices for this component. This technique is preferable to presently applied techniques for two reasons. One is simply that only a single launch is necessary, and therefore intricate submicron scanning techniques of questionable repeatibility are not necessary. Second, the transfer function contains more information about a component than do any of its associated transfer matrices. It is safe to conclude that the transfer function approach to the multimode fiber characterization problem is a most desirable one to follow.

References:

[1] G. T. Holmes, "Estimation of Concatenated System Response Based on Measured Transfer Functions for Low and High Order Modes," *Proc Seventh European Conf on Opt Comm*, Copenhagen, 3.4-1–3.4-4 (September 1981).

[2] S. Yang, I. P. Vayshenker, D. R. Hjelme, and A. R. Mickelson, "A Transfer Function Analysis of Measured Transfer Matrices," manuscript in preparation.

[3] A. R. Mickelson and M. Eriksrud, "Mode-Continuum Approximation in Optical Fibers," *Opt Lett* 7, pp. 572–574 (1982).

[4] See, for example, the technique described in A. R. Mickelson, M. Eriksrud, S. Aamlid, and N. Ryen, "Rôle of the Fusion Splice in the Concatenation Problem," *Journ Lightwave Tech* **LT-2**, pp. 126–138 (1984).

[5] A. R. Mickelson, Ø. Klevhus, and M. Eriksrud, "Backscatter Readout from Serial Microbending Sensors," *Journ Lightwave Tech* **LT-2**, pp. 700–709 (1984).

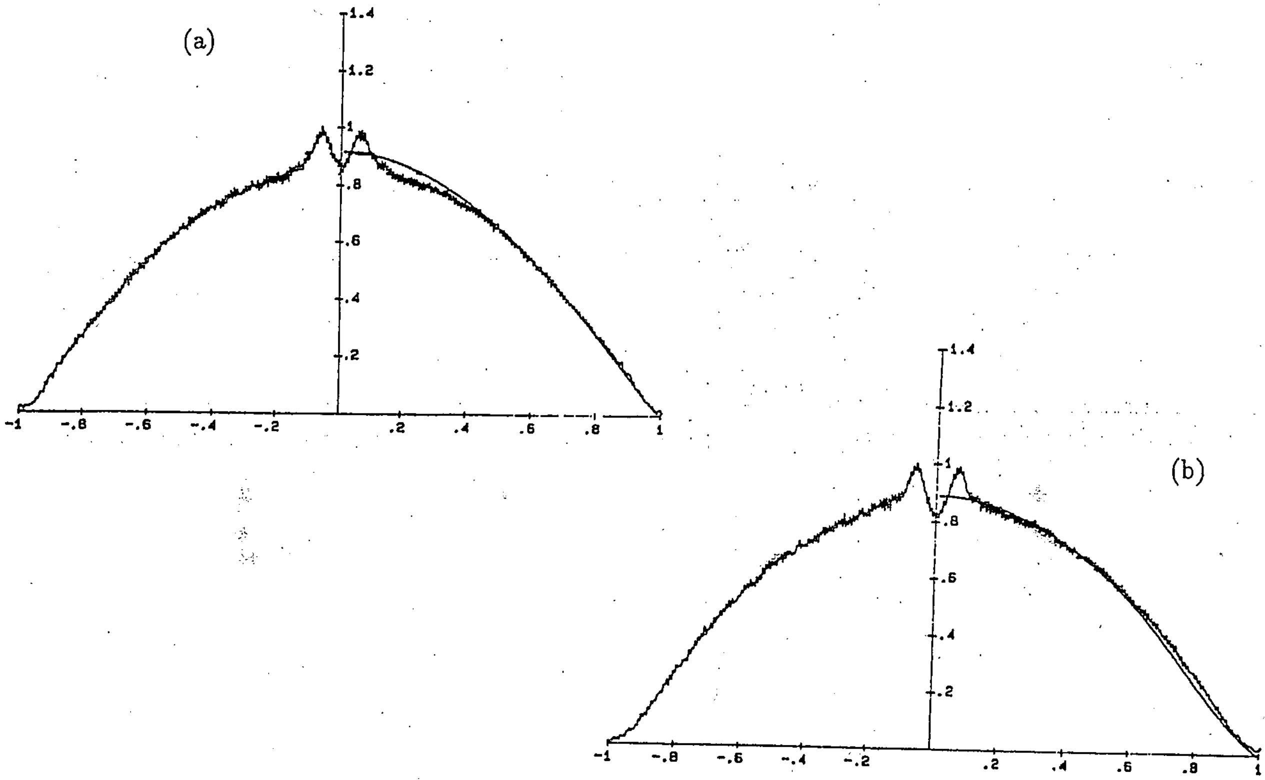

Figure 1: *(a) Measured (noisy) and theoretical (smooth) input near-field distribution for overfilled launch. (b) Output near-field distributions measured (noisy) and calculated from the transfer function (smooth).*

L	τ		T_{11}	T_{12}	T_{21}	T_{22}
.09	.08	Tc	.9963	.0066	.003	.9573
		Tm	.983	0	.001	.978
.16	.085	Tc	.9932	.0064	.0052	.9229
		Tm	.992	.006	.007	.924
.28	.1	Tc	.9835	.0115	.0116	.8599
		Tm	.941	.002	.001	.930

Table 1: *Comparison of measured matrices (Tm) and matrices calculated from the transfer function (Tc) for three splices. The transfer functions are determined from the same experimental data for the corresponding transfer matrices. L is the overfilled loss and τ is the coupling coefficient.*