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Asymmetric multimode couplers for local area networks

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New types of polished fibre couplers are presented which are especially suitable for LAN (Local Area Network) applications. An X-type asymmetric coupler made from the same type of multimode gradient optic fibre has been prepared and characterized.

1. Introduction

The coupling of optical signals to and from the main line is an essential function of optical couplers in both telecommunication lines and local area networks applications.

Uniform 3dB multimode couplers used so far decrease the energy of signals in the main line and thus make the addition of new users to the main line impossible. The array of 3dB couplers connected to the main line decreases the energy of signals and strongly limits the number of users in the line. The use of asymmetric multimode couplers consisting of two different multimode fibres [1], [2] is inconvenient in this case. In the paper, a design and description of a new type of coupler made of the same kind of multimode gradient fibre 50/125 μm is presented.

2. Theory and notation

Optical couplers are usually characterized by the parameters which, when related to the coupler diagram in Fig. 1, are as follows [3]:

$$\begin{aligned} &- \text{excess loss EL} = -10\log(P_2+P_3)/P_{\text{in}} \text{ [dB]},\\ &- \text{coupling ratio of one branch CR} = 100P_3/(P_2+P_3) \text{ [\%]},\\ &- \text{directivity D} = -10\log(P_4+P_{\text{in}}) \text{ [dB]}. \end{aligned} \tag{1}$$

Assuming a linear system, one can write the transfer relation between the ports of the four-terminal couplers in the form of matrix equation, according to accepted standards [4]

$$T = \begin{vmatrix} t_{11} & t_{12} & t_{13} & t_{14} \\ t_{21} & t_{22} & t_{23} & t_{24} \\ t_{31} & t_{32} & t_{33} & t_{34} \\ t_{41} & t_{42} & t_{43} & t_{44} \end{vmatrix}. \tag{2}$$

Fig. 1. Scheme of coupler: 1, 2, 3, 4 – numbers of coupler ports.

The matrix elements t_{ij} represent ratios of the optical power P_{ij} transferred out of the port j to the input power P_{in} introduced into the port i, *i.e.*

$$t_{ij} = P_{ij}/P_{in}. \tag{3}$$

An asymmetric branching device is a device characterized by a diagonally asymmetric transfer matrix, *i.e.*, having at least one i and one j for which t_{ij} and t_{ji} are nominally unequal.

The terms of the first diagonal describe the reflections at the ports while the terms of the second diagonal characterize the directivity of the device. Parameters related to these terms are ignored in the following discussion.

The asymmetric couplers presented in the paper were obtained in an experimental way, *i.e.*, traditional parameters were being measured as well as the transmission matrix terms during assembly of the couplers. Efforts have been made to optimize those transition matrix terms, which would make them suitable for applications in LAN and telecommunication lines.

3. Experimental setup

A diagram of the experimental setup for coupler parameter evaluation is shown in Fig. 2. The source of optical signals is a light-emitting diode at $\lambda = 0.85$ µm powered by a square wave generator. A part of the optical signal decoupled by CC coupler is fed to P_0 photodiode in order to control the power level of the source and therefore the power P_{in} applied to the adjustable coupler C. The optical signal is transferred to the coupler with the required launch conditions.

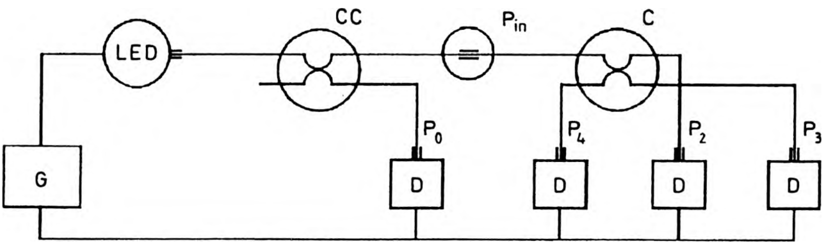

Fig. 2. Diagram of the measurement system.

The main optical signal P_{in} from CC coupler is led via the fibre connector to the coupler under investigation with the use of a special connector. Signals from the three remaining terminals of the adjustable coupler are directed to the photodiodes P_2, P_3 and P_4. The power level P_{in} was determined by the cut-back method.

Coupler parameters were set using quartz cubes, into which the optical fibre GI-50/125 μm was glued following an arc of a predetermined radius R. The fibre was then ground down to a given depth h. Two cubes prepared in this way were subsequently coupled using a micromanipulator and an immersion liquid of the refraction index n_i was placed between them.

The adjustment of couplers consisted in relative positioning of the cubes until optimal coupler parameters were obtained. The parameters were real-time measured and displayed by a measurement system.

4. Experimental results

For the purpose of our investigation the optical fibre ports 1–2 of the coupler has been inserted into the main line. The following terms of the transitions matrix have been selected: t_{31} and t_{42} as an effective input to the main line, and t_{13} and t_{24} as an effective output from the main line. In the couplers designed for unidirectional lines (Fig. 3): $t_{13} \neq t_{24}$ and $t_{31} \neq t_{42}$, while in those for bidirectional lines: $t_{13} = t_{24}$ and $t_{31} = t_{42}$. Asymmetrical couplers have been made by connecting two fibres bent following arc of different radii. The radii R_1, R_2 and depths h_1 and h_2 have been checked out and proved satisfactory (see Fig. 4). Figure 4 presents asymmetrical coupler for unidirectional lines. For $\Delta z = 0$ we have asymmetrical coupler for bidirectional lines.

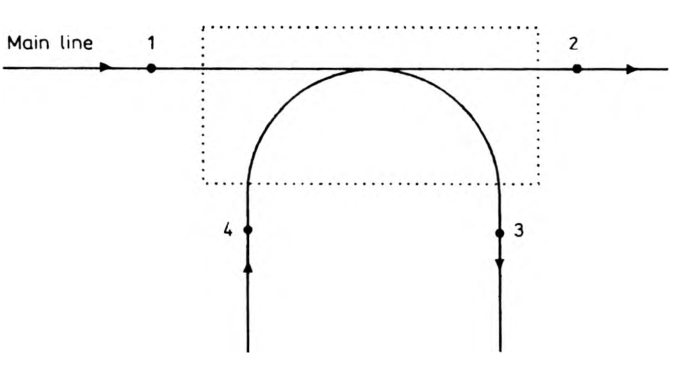

Fig. 3. Diagram of fiber optic line with couplers inserted: 1, 2, 3, 4 – numbers of coupler ports.

Figure 5 shows sample results of the measurement, with coupler parameters being presented as a function of appropriate design parameters. The results apply to couplers for bidirectional lines (see Fig. 4), *i.e.*, such for which $t_{13} = t_{24}$ and $t_{31} = t_{42}$. With bending radius R_1 and grinding depth h_1 for the first cube set constant, variations of parameters t_{31} (t_{42}) and t_{13} (t_{24}) in the couplers were observed with

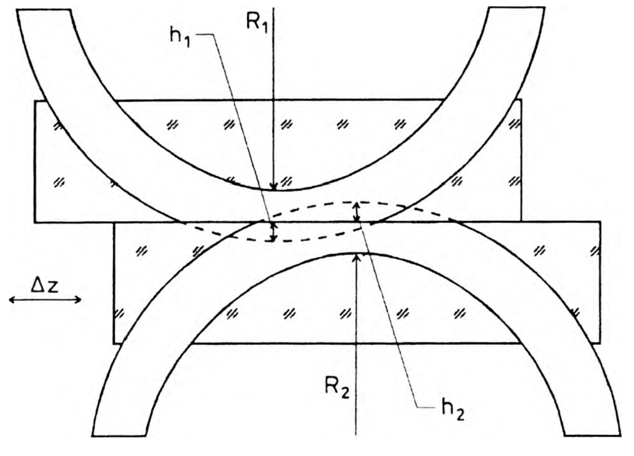

Fig. 4. Asymmetric coupler design.

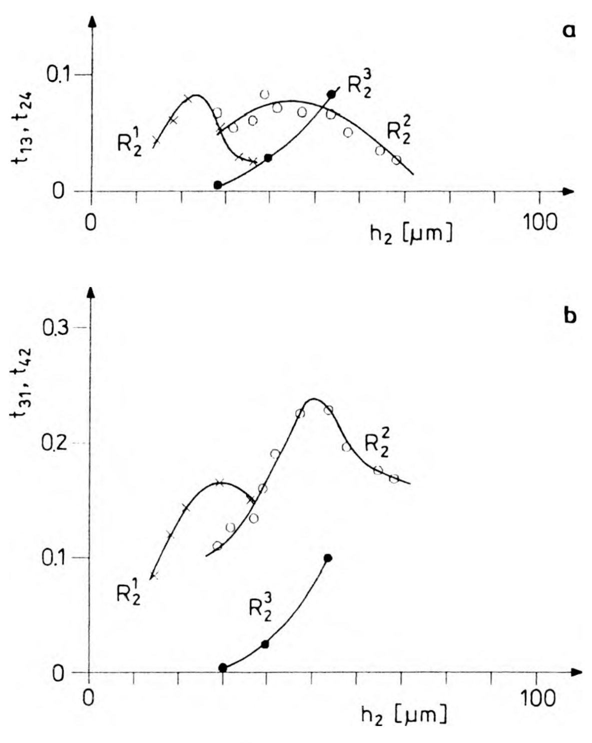

Fig. 5. Relation between the effective coupling/decoupling ratios, for various curvature radii R_2 and various depths h_2 (R_1 = const, R_2 = const, h_1 = const).

the second cube's bending radius R_2 predetermined and grinding-depth parameter h_2 varying. The refraction index of the immersion liquis was assumed to be a constant parameter. It seems that for exactly determined values h_2, the best coupler parameters can be obtained for the assumed technological parameters R_1, R_2, h_1.

Figure 5**a** presents experimental results for an element of the transfer matrix $t_{13} = t_{24}$, under the assumption that the input power P_{in} is being introduced into the port 1 (or 2) of the coupler under investigation. Figure 5**b** shows experimental results for the elements of the transfer matrix $t_{42} = t_{31}$, coupling ratio CR and excess loss EL, assuming that the input power P_{in} is being introduced into the port 3 or 4 of the coupler.

The experimental results of Fig. 5 are given for three different radii R_2 at $h_1 = \text{const}$ and $R_1 = \text{const}$. This figure shows the dependence of matrix elements $t_{13} = t_{24}$ and $t_{31} = t_{42}$ on the grinding depth h_2. The figure clearly reveals how essential it is to properly select the parameters R and h in order to obtain optimal characteristics. Based on the results presented in Fig. 5, the maximal value of coupling coefficient can be determined and the bending radius R_2 of the second optic fibre can be chosen, as well as the grinding depth for h_2, R_1 and h_1 assumed previously.

An increase in coupling efficiency t_{42} can be obtained through asymmetrization of the above couplers, *i.e.*, by relative displacement of the fibre-glued cubes along the fibre axis Δz (Fig. 4). A coupler of this type, in which $t_{13} \neq t_{24}$ and $t_{31} \neq t_{42}$, may be applied in an unidirectional line (Fig. 3).

Table. Transfer matrices for symmetric and asymmetric couplers, respectively.

Symmetric 10 percent coupler				Symmetric 50 percent coupler			
0.0	0.8	0.1	0.0	0.0	0.4	0.4	0.0
0.8	0.0	0.0	0.1	0.4	0.0	0.0	0.4
0.1	0.0	0.0	0.8	0.4	0.0	0.0	0.4
0.0	0.1	0.8	0.0	0.0	0.4	0.4	0.0
Asymmetric coupler for bidirectional lines				**Asymmetric coupler for unidirectional lines**			
0.0	0.8	0.1	0.0	0.0	0.8	0.1	0.0
0.8	0.0	0.0	0.1	0.7	0.0	0.0	0.1
0.3	0.0	0.0	0.3	0.1	0.0	0.0	0.3
0.0	0.3	0.3	0.0	0.0	0.6	0.2	0.0

The Table shows typical coupler parameters in the form of a transmission matrix for uni- and bidirectional lines and, for comparison purposes, also in the form of a transmission matrix for typical 10% and 50% uniform couplers. As can be seen, asymmetric couplers combine advantages of uniformity of 10% couplers and 50% couplers. They decouple relatively low-level signals from the line (as 10% couplers do) while making it possible to couple high-level signals to the main line at the same time (as 50% couplers do).

Parameters of directivity were measured and they exceeded 40 dB (for both symmetrical and antisymmetrical couplers). These parameters were neglected in the above discussion.

5. Conclusions

It seems that the coupler design presented will prove useful in fibre optic networks growing rapidly nowadays. Application of asymmetric couplers ensures better economy of power distribution over the main transmission line, which in turn allows more users to be added to the line. It is of crucial importance that the couplers presented are made of one kind of fibre, unlike the ones that have been discussed in the literature so far.

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