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Measurement technologies of few-mode fiber

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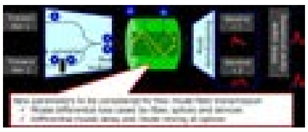
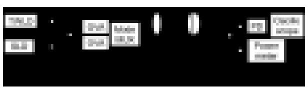
Space division multiplexing (SDM) technology has been received increasing attention to increase transmission capacity extremely, which can overcome the capacity limit of the existing single-mode fibers (SMFs). The SDM transmission can be realized by using a multi-core fiber (MCF) or few-mode fiber (FMF). In particular, the FMF can increase the number of spatial channels greatly by utilizing the mode division multiplexing (MDM) technology with the MIMO processing. Here, the MDM transmission raises some new issues which have not been considered in the SMF based transmission system. In particular, the differential modal delay (DMD) and the mode dependent loss (MDL) are unique of the FMF based transmission line. The larger DMD increases the complexity of the MIMO receiver. The MDL severely restricts the transmission speed and/or distance. Therefore, it is important to specify these parameters of the FMF to construct the MDM transmission line. The DMD measurement method is well-established based on the time-of-flight method since it is also necessary to specify the bandwidth of existing multi-mode fibers. The MDL is induced by some factors in the transmission line such as differential modal attenuation of fibers, splices and devices and the mode conversion in the fiber and at splices. Therefore, it is important to specify the modal dependence of the loss factors for the FMF. The loss measurement of the FMF can be conducted with the conventional test procedure by utilizing the mode multiplexer which has sufficiently high mode extinction ratio. However, the increase in the number of modes degrades the mode extinction ratio, which degrades the measurement accuracy. Recently, measurement methods of each mode in the FMF have been proposed by considering the mode power ratio, which is the variable mode power ratio method and the mode filter based OTDR method. They can offer sufficiently high accuracy of less than 0.005dB/km for two-mode fibers. The splice loss is estimated by using the mode-field diameter (MFD) for SMFs in general. We have investigated the applicability of the conventional near-field pattern (NFP), far-field pattern (FFP) and variable aperture (VA) methods to the higher-order modes in the FMFs. We found that the MFD values from the FFP and VA methods provided the splice loss value which well-agreed with the experimental results. Therefore, it can be considered that the effective MFD value by utilizing these two methods is appropriate to consider the splice loss properties of the FMF. The loss and spice characteristics of the FMF directly effects on the transmission performance and it is essential to establish the specifications and their test procedures of the FMF for the interconnectivity and mass productivity. It can be considered that new approaches to control the characteristics of each mode are required to reduce the DMD and MDL for the FMF based transmission line.


Biography

Takashi Matsui received BE, ME and PhD degrees in electronic engineering from Hokkaido University, Sapporo, Japan, in 2001, 2003 and 2008, respectively. He also attained the status of Professional Engineer (P.E.Jp) in electrical and electronic engineering in 2009. In 2003, he joined NTT Access Network Service Systems Laboratories, Ibaraki, Japan. He has been engaged in research on the design and measurement techniques of optical fibers, in particular, has studied on the photonic crystal fibers, bending-loss insensitive fibers and the multi-core fiber technology for telecommunication use and related fiber design, measurement methods and applications of Brillouin scattering phenomena. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan and an expert of technical committee 86 for international standards for fiber optics technology in International Electrotechnical Commission (IEC).

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