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MIMO enabled 40 Gb/s transmission using mode division multiplexing in multimode fiber

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Abstract: Transmission of 40Gb/s intensity modulated NRZ data over 1.1km of multimode fiber has been experimentally demonstrated using modal diversity and receiver based 2x2 MIMO digital signal processing with direct detection.

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1. Introduction

Methods to increase the capacity of the installed single mode fiber base are presently receiving significant attention as demand for increasing data rates continues. Attention is now also been given to enhancing the capacity of multimode optical fiber (MMF) which makes up the majority of fiber that is installed within buildings and used within local area networks (LANs). Recent work has pushed the boundaries of communication over multimode fiber by demonstrating the transmission of 40Gb/s NRZ signals over 3.7km [1] and 107Gb/s over 100km using coherent OFDM [2]. However, both techniques require precise mode coupling at both the transmitter and the receiver, and the second also requires a complex transmitter and a coherent optical receiver. Another approach to increasing the bandwidth of a MMF is to exploit its inherent modal diversity and use the different modes to multiplex signals in what is known as mode division multiplexing. This technique was first proposed and demonstrated by Stuart who demonstrated 100Mb/s transmission over 1km of MMF on RF subcarriers [3]. This scheme exploits the concept of multiple-input multiple-output (MIMO) signal processing that is used extensively in multipath wireless systems.

Here the feasibility of this approach is demonstrated using a 2x2 MIMO system to transmit two intensity modulated 20Gb/s NRZ signals over 1.1km of 62.5µm MMF using direct detection. This system is also compared with conventional offset launch MMF transmission at 20Gb/s.

2. Experimental setup

The experimental set-up used to demonstrate the performance of the modal diversion multiplexing is shown in figure 1. The two transmitters each consisting of a DFB laser, at wavelengths 1550nm and 1553nm respectively, were modulated with a 12^{12}-1 PRBS NRZ data at a bit rate of 21.328457 Gb/s using external $LiNbO_3$ MZ modulators, designed for 10Gb/s operation, with a 3dB bandwidth of 13.5GHz. Note the choice of wavelength or indeed the stability of the wavelengths is not important in this work as long as they differ by more than the bandwidth of the receiver (~ 15GHz) such that the beat terms arising from direct detection fall outside the receiver bandwidth. In this work it is assumed that FEC will be used thus the bit rate per channel chosen corresponds to 2 times OC192 with a 7% FEC overhead.

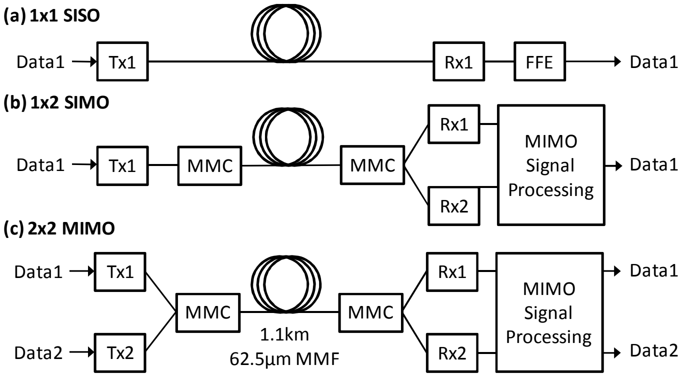

Fig. 1 Experimental setup transmission system showing the three systems that have been investigated.

A 2x2 multiple input multiple out system as shown in fig. 1(c) is implemented. The spatial diversity at the transmitter is achieved by using a commercial 2x1 multimode coupler (MMC) to combine the signals from each transmitter into the MMF. Because the MMC uses evanescent coupling the signal launched into the coupled path is preferentially coupled into the higher order modes, whilst the signal launched into the through path tends to remain in the lower order modes and hence diversity is achieved between the two channels. The MMF used is 62.5-µm core-diameter graded-index multimode silica fiber. Similarly before the receiver a 1x2 MMC is used to split the signal to the two receivers and provide spatial diversity at the receiver.

The optical receivers are large area 10Gb/s PIN and linear TIA devices (Eudyna ES/ERP1412FS-01) with an effective active diameter of 60µm and a 3dB bandwidth of 12.3GHz in a ROSA package. These are connected directly to a Tektronix real time oscilloscope (DPO72004) sampling at 50GS/s with an effective resolution of 5 bits in order to digitize the received signal. The signal processing required to recover the data is carried out offline in Matlab. The sampled data is firstly resampled to give two samples per bit. The signal is then equalised using a fractionally spaced ($T_b/2$) adaptive feedforward equaliser (FFE). The equaliser is arranged in a standard butterfly configuration in order to recover the original data sequences from the MIMO system. The length of each equaliser is chosen to be longer than the impulse response of the MMF channel to allow for compensation of the modal dispersion. The equaliser is initially adapted using a decision-directed recursive least squares (RLS) algorithm [4] that uses a training sequence of 1024 bits which is sufficient for convergence. After this the much more computationally efficient least mean squares (LMS) algorithm [4] is used in a decision directed mode to track the slow drifts that occur due to changes in the coupling and modal distributions as a result of environmental fluctuations.

2. Experimental Results

Firstly, the performance of a single channel system, denoted single input single output (SISO) and shown in fig. 1(a), operating at a bit rate of 20Gb/s was quantified. Here the signal from transmitter one was launched directly from a single mode fiber (core diameter 8 µm) that was butt coupled to the 62.5µm multimode optical fibre using an adjustable offset launch. The output of the MMF was butt coupled directly into the receiver, unlike that of the work presented in refs. 1 and 2 where a single mode fibre was also used to couple to the receiver and hence provide mode filtering. After the direct detection and digitization a single digital equaliser is used to compensate for the modal dispersion. Figure 2(a) shows the measured Q factor in dB as a function of the received optical power when the offset launch condition is optimised. The length of the equaliser required depends on the modal dispersion and hence the length of the fiber as can be seen in fig. 2(b) where the impact of the equaliser length on the signal Q is plotted. The results in fig. 2(a) were processed using an optimum equaliser length of 11 and 19 bit spaced taps for transmission distances of 550m and 1100m respectively. A received power penalty of 2dB and 4dB for transmission distances of 550m and 1100m, respectively, compared to the back-to-back performance at a Q of 9dB is obtained.

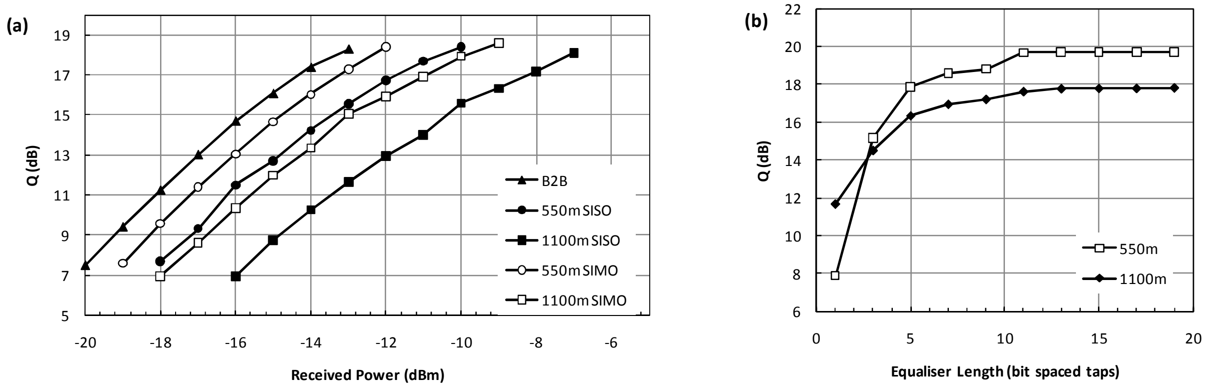

Fig. 2(a) Q as a function of the received power for single channel transmission with (SIMO) and without (SISO) receiver diversity. (b) Impact of equaliser length on system performance.

The performance of the 20Gb/s single channel SISO system can be improved by employing diversity at the receiver using the experimental setup shown in fig. 1(b). At the output of the multimode fibre a commercial 1x2 multimode coupler is used to split the received signal onto two receivers resulting in a 1X2 SIMO system. Here the received power is measured at the input port of the receiver MMC. The MIMO reception and processing results, shown in fig. 2(a), provide a gain in performance of 1dB and 1.8dB in the power penalty for transmission distances of 550m and 1100m, respectively, over that obtained for the SISO system.

To further enhance the capacity the 2x2 MIMO system shown in fig.1(c) is used. Here two 20Gb/s channels are coupled into the MMF using a 2x1 MMC. The data patterns on each channel are decorrelated by quarter of the pattern length. To provide a reference point the performance of the system is characterised when each transmitter is turned on in turn for a transmission distance of 550m. Transmitter 1 which is launched on the through port of the MMC has a receiver sensitivity at Q=9dB of -14dB. Transmitter 2 which is launched on the coupled port of the MMC shows a power penalty of 2dB compared to Transmitter 1, as a result of the increased losses and dispersion that the higher order modes experience. When both transmitters are simultaneously transmitting then for a transmission distance of 550m there is a 1dB penalty at Q=9dB for both channels compared to their respective single channel transmission performance. For a transmission distance of 1100m this penalty increases to 5dB and 4dB for transmitter one and two respectively.

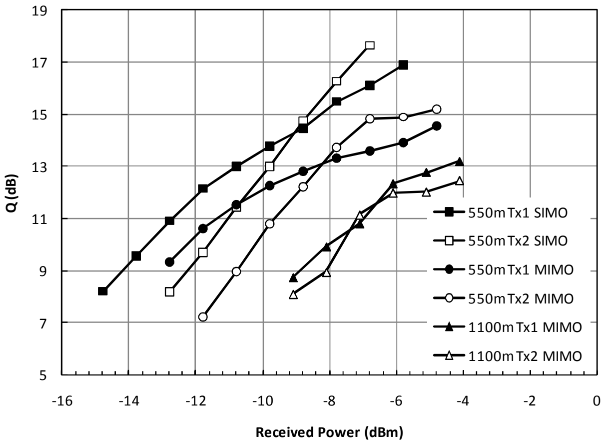

Fig. 3 Q as a function of the received power for multi-channel 2x2 MIMO transmission.

4. Conclusion

42.66 Gb/s data comprising of two 21.33Gb/s baseband intensity modulated NRZ data channels has been experimentally transmitted over 1.1km of 62.5µm multimode optical fibre using direct detection and MIMO signal processing. These results demonstrate the applicability of receiver based MIMO digital signal processing to compensate for modal dispersion and enhance the capacity of multimode fiber links by exploiting the modal diversity that these fibers offer.

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6. References

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