A Novel Modal Dispersion Compensation Method for Multimode Fiber-Optic Links

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Abstract — The multimode fiber (MMF) is a proper choice for short range optical fiber connections. Several applications need cost effective solutions. These connections can apply MMFs, however, the transmission parameters are degraded by the fiber modal dispersion. Therefore any efficient method to compensate modal dispersion is very important. In this paper mode filtering technique is introduced for that purpose. Two types of mode filters are proposed and tested by simulations and measurements. By the application of mode filters significant improvement is achieved in the transmission of QPSK and QPSK-OFDM signals. E.g. in case of a 500m long multimode fiber link transmitting signals with 500Mb/s bit rate the error vector magnitude (EVM) is improved from 40% to 5%.

I. Introduction

The multimode fiber (MMF) is a proper choice for short range optical fiber connections. Several applications need cost effective solutions, for example the distribution of wireless radio signals in mobile cell networks [1]. These connections can apply MMFs. Due to the small attenuation of the fiber, the loss in the distribution network is low. Further advantages are the immunity to the electromagnetic interference and high capacity of the optical fiber.

Recently, the cell size is decreasing, therefore more and more remote antenna units (RAUs) are required. The high amount of RAUs increase the cost of the distribution system, therefore low cost solutions should be developed. The application of MMFs reduces the cost because MMFs with large core diameter make the installation easier and cheaper.

However, the distortions of MMFs are stronger than the distortions of single mode fibers (SMFs) due to its modal dispersion which causes limitations in MMF links. Therefore the compensation of modal dispersion is a relevant problem. Some works discuss the effect of modal filters in multimode fiber connections, for example in [2] the bandwidth of the connection is increased by compensating the modal dispersion.

In a radio over multimode fiber system not only the bandwidth but also the transmission quality of the digital modulated radio signals is important. In this paper the effect of mode filtering technique is described in radio over multimode fiber system, and quality of the modulated signal is improved by the application of proper mode filtering.

As a radio over multimode fiber link is mostly applied as an optical distribution network of radio signals for radio base stations in cellular mobile networks, the most frequently applied wireless modulations should be investigated. These modulations are QPSK with a single subcarrier and with multi-subcarriers, i.e. with OFDM. Therefore QPSK-OFDM modulation is also tested in this paper.

II. System model

The investigated fiber-optic link uses a multimode fiber. The MMF model applies the overfilled launch condition (OFL). When divergence of the light beam is large enough, the light source illuminates the whole fiber core, so all of the fiber modes are generated. The OFL launch condition counts on the generated modes equally. Although it is complicated to get exactly equal modes in a practical multimode fiber connection, OFL can be used as a proper model for simulating the impact of modal dispersion. Furthermore, the overfilled launch condition causes more significant modal dispersion than a real multimode fiber, therefore the simulation based on the OFL provides investigations with a worst-case model .

In a short range RoF application the other distortion effects may be neglected, as the length of the fiber is too short to consider chromatic dispersion, and the optical power is low, thus the nonlinear effects are not significant.

The model of the multimode fiber is based on [3] and [4], where the transfer function and the main parameters of the multimode fiber are described. The applied multimode fiber is a gradient index fiber with 50μm core. The number of mode groups and the group delay of the mode groups were calculated according to [4].

In this paper two types of mode filters are simulated: an air gap mode filter, and single mode fiber patchcord. The model of the air gap mode filter is based on [5], where several mode filters including air gap mode filter are investigated. The model of the single mode fiber patchcord is described in [2]. This model is really simple, because it cuts off all of the higher order modes except one mode.

The simulation model can be seen in Fig. 1. The light of the laser is modulated by an ideal modulator in order to avoid the nonlinear effects of the modulator. The RF modulated signals are detected by a PIN diode.

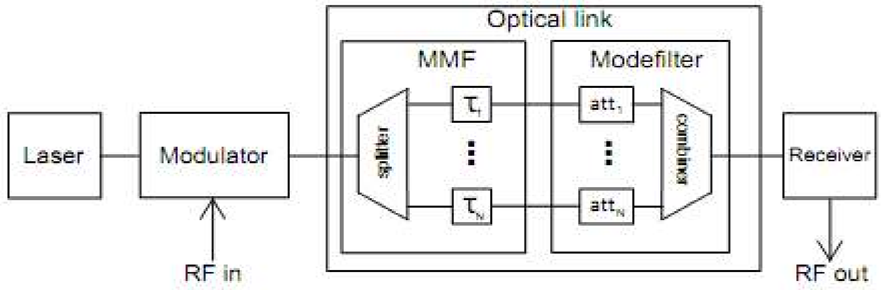

Fig. 1. Block scheme of the simulation model

III. Simulation Results

The simulations were carried out by VPI transmission maker 9.1. The system model is implemented in the simulation software, and modulated RF transmission is simulated. Two types of modulation are investigated, QPSK and QPSK-OFDM. For these RF modulations the Error Vector Magnitude (EVM) is tested. The thermal noise at the detector is set to 10^{-11} A/√Hz, and the shot noise is also considered. The optical power is 1mW, and the modulation depth is set to 100% during the simulations. The carrier frequency of the RF signal is 2GHz. The EVM is simulated on two lengths of MMF: 100m and 500m with three bit rates. These are 125Mb/s, 250Mb/s, and 500Mb/s. The fiber length and the bit rates are relatively small, but that is a typical set up in short range indoor applications.

The results of the first simulation are shown in Fig. 2. As it can be seen the two types of mode filters can reduce the EVM of the connection. The thermal noise is relatively low, thus the modal dispersion is the main distortion effect.

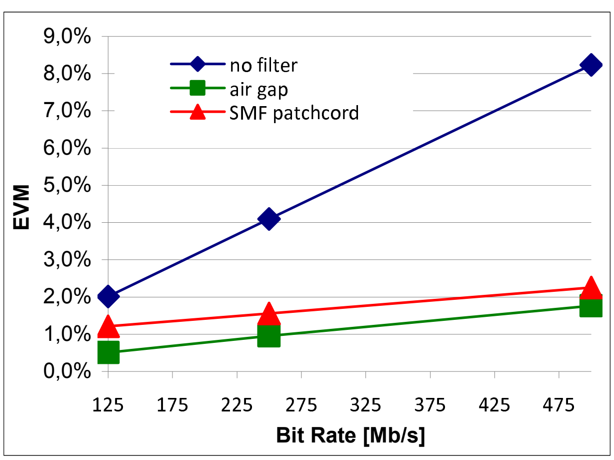

Fig. 2. EVM vs. bit rate for 100m fiber length with QPSK

Without the mode filter the EVM is around 8% for 500Mb/s bit rate. The mode filters can reduce this value to 2%. The air gap mode filter seems to be more efficient than the SMF patchcord filter, because it has less insertion loss than the SMF patchcord.

Then the dispersion compensation effect of the mode filters is investigated on 500m of multimode fiber. In this case the modal dispersion distorts stronger. The EVM results are relatively high without mode filtering. At 250 Mb/s and 500Mb/s the EVM values are higher than 40%. In this case the EVM is not reliable, because the constellation points are overlapped. However, the effect of mode filtering technique is very spectacular, as it reduces the EVM to less than 5% at all of the bit rates. This simulation result shows that mode filtering technique can be a very efficient method to compensate the modal dispersion.

Further QPSK-OFDM modulation is also tested because it is important to test multicarrier modulation over MMF. All of the OFDM subcarriers are modulated by QPSK. The number of subcarriers is 64.

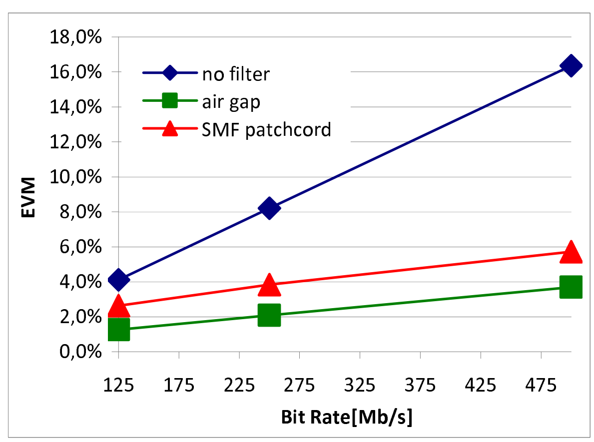

Fig. 3. EVM vs. bit rate for 100m fiber length with QPSK-OFDM

The simulation results of QPSK-OFDM are seen in Fig. 3. The trace of Fig. 3 is similar to Fig.2, where the fiber length is the same, but the EVM values are higher. Although the mode filtering technique can reduce the effect of modal dispersion, the compensated EVM is still around 6%. This difference between the two simulations is due to the different Peak to Average Power Ratio (PAPR). As the PAPR is higher for OFDM signals, the average power is relatively lower compared to QPSK signal and the signal to noise ratio (SNR) is smaller for QPSK-OFDM signals than for QPSK signals.

The maximum magnitude of the QPSK and QPSK-OFDM signals must be the same in order to get 100% intensity modulation depth at the optical modulator. With this modulation depth, the signal amplitude has the largest available value without nonlinear distortion. However, the average power of these signals is different at this modulation depth due to the different PAPR, which causes the different EVM results.

IV. Measurement results

After the simulations, the mode filters are tested with measurements as well. During the experiments the OFL (overfilled launch) condition is difficult to realize for the multimode fiber, therefore the measurements are a little bit different from the simulations. To demonstrate the effect of the mode filters, cut off points of the frequency response have to be found. These frequency cut offs are caused by the modal dispersion, therefore the mode filters can make the frequency response smooth, and these cut off points can disappear.

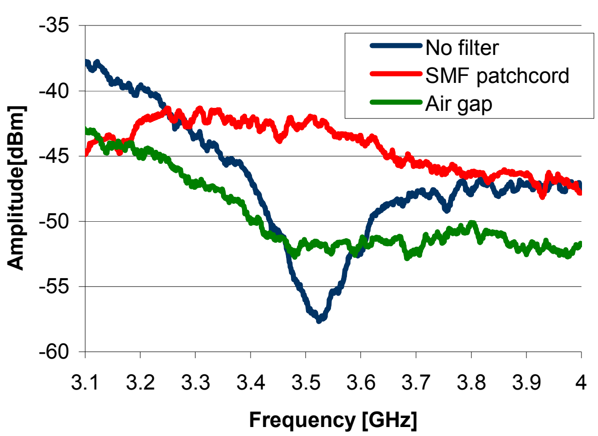

Fig. 4. Transfer function of MMF link with and without mode filters

The measurement results are plotted in Fig. 4. The transfer function of the MMF link has a cut off point around 3.5 GHz. The mode filters can make the transfer function trace smoother, however the air gap filter has less efficiency compared to the SMF patchcord. The mode filters can improve the link, but the experiments show that SMF patchcord has better performance than air gap mode filter. This point is different from the simulations, as the air gap filter was better than SMF patchcord during the simulations. It is due to the difference between the simulation model and the real mode filter. The realization of the air gap mode filter is much more difficult than the realization of SMF patchcord filter, and it leads to differences between the simulation and measurements.

The quality of the QPSK transmission is also investigated. The carrier frequency is set to 3.52 GHz, and the data rates are 100ksps and 1Msps respectively. At 100ksps the EVM of the link without filter is 28%. The air gap filter improves that to 25%, and the SMF patchcord improves that to 8%. At 1Msps the constellation is overlapped without mode filter or with air gap filter, but the SMF patchcord decrease the EVM to 26%.

V. Conclusion

Mode filtering technique has been proposed to compensate for the mode dispersion of multimode optical fiber links. By applying mode filters significant improvement has been achieved in the transmission of QPSK and QPSK-OFDM signals. E.g. in case of a 500m long multimode fiber link transmitting signals with 500Mb/s bit rate the EVM has been improved from 40% to 5%.

References

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