Short Reach Radio over Polymer Fibre Links

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Abstract *Successful transmission of IEEE 802.11g signals at 2.412GHz over 50m of low cost 1mm core graded index PMMA optical fibre is demonstrated.*

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Introduction

Radio-over-Fibre (RoF) systems have been widely employed for in-building distributed antenna systems (DAS) owing to the wide bandwidth offered by optical fibre. Several demonstrations have been carried out with 850 nm VCSELs and silica multimode optical fibre in an attempt to reduce system costs[1]. However, recently interest has been gathering in PMMA polymer optical fibre (POF) for very low cost systems Owing to the much larger core than multimode silica fibre, the alignment tolerances are improved and termination is also much simpler. However, the attenuation (200 dB/km) of PMMA-POF is much higher than that of silica fibre and the distance-bandwidth product (50 MHz.km) is smaller. While these shortcomings restrict the transmission distance which can be achieved, a small scale in-building DAS could be implemented with transmission distances of the order of 50 m. Such a small DAS could be suitable for small office spaces or in the home.

Previously POF has been demonstrated to carry RF signals by optical multiplying or in baseband using resonant cavity light emitting diodes (RCLEDs)[2,3]. These techniques reduce the required bandwidth but additional electronic components are required to up-convert signals back onto an RF carrier, thus increasing the overall system cost. The wideband, service agnostic property of the optical link is also lost. A WLAN distribution system at 2.4 and 5.2 GHz has also been demonstrated using high bandwidth perflourinated (PF)-GI-POF and a vertical electro-absorption transceiver (V-EAT) using 800 nm and 850 nm wavelengths[4]. However there is particular interest in using lower cost, lower bandwidth, non-fluorinated POF.

In this paper therefore, the lower performance of non-fluorinated POF is overcome through the use of a 665 nm VCSEL, to match the attenuation minimum of PMMA, and a silicon avalanche photodiode (APD) which has a high responsivity and gain at this wavelength. This allows the transmission of IEEE 802.11g signals at 2.4 GHz over 50 m of graded index (GI) POF, despite the low bandwidth of the fibre

Experimental Setup

The RoF link setup is shown in Figure 1. A Vector Signal Generator (VSG) is used to directly modulate a 3 GHz bandwidth 665 nm VCSEL. The VCSEL is biased at 4 mA giving -0.5 dBm optical output power. The optical signal from the VCSEL is directly fed into 50 m POF by butt coupling. The GI-PMMA-POF used in this experiment is OM-Giga-DE100 from Chromis with a 1 mm core diameter. Though PF-GI-POF has a higher bandwidth (500 MHz.km) and lower loss, GI-PMMA-POF is a more cost-efficient choice[5]. The 50 m fibre has 18 dB loss at 665 nm. This could be reduced by using a laser operating closer to 650 nm as here the fibre loss is 200 dB/km rather than 300 dB/km at 665 nm.

A free space optical launch is used to couple light from the POF into the Si-APD (Pacific Silicon Sensor AD100-8). Since the APD has only a 100 μm active area to reduce the device capacitance and allow high speed operation, it is difficult to couple light from the much larger diameter POF onto the APD. To overcome this, a telescopic lens configuration is used to reduce the spot size from the fibre by 10x on to the APD. This incurs an approximately 2.2 dB coupling loss. A low noise amplifier with an electrical gain of 29 dB is employed before the vector signal analyzer (VSA) to improve the link gain.

POF Frequency Response and APD Characteristic

The transmission frequency response of the 50 m POF is shown in Figure 2. The S21 response is measured up to 2.5 GHz and is normalized to a back-to-back link without fibre to remove the responses of the APD and laser. During the experiment a free space attenuator is used to compensate for the lack of fibre attenuation in the back to back test. The curve shows a 7 dB relative loss at 2.4 GHz. The 3dB bandwidth of the POF is about 1.2 GHz. However, since the response is relatively flat at 2.4 GHz,

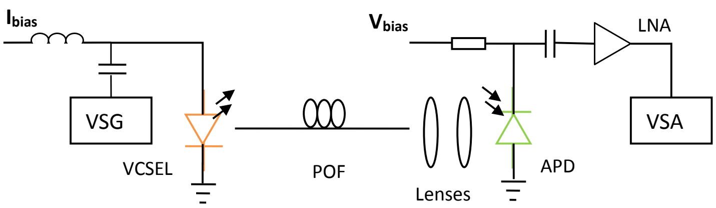

Fig. 1: Experimental setup of the RoF link utilising 50m POF

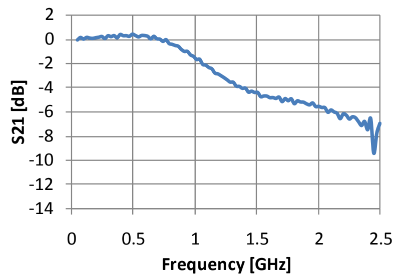

Fig. 2: Normalised frequency response of 50m POF

successful transmission of IEEE WLAN signal can still be anticipated beyond the fibre bandwidth.

IEEE 802.11g Transmission Demonstration

The performance of the link under modulation is measured using an IEEE 802.11g signal at a 2.412 GHz carrier frequency generated by a vector signal generator. The IEEE 802.11g standard is chosen for its complex 64-QAM OFDM modulation format which demands low noise and high linearity from the RoF link.

Plots of the output EVM and burst power as functions of the input RF power are shown in Figure 3. The APD bias voltage is finely tuned and fixed at an optimal value (~135V) to give the best performance.

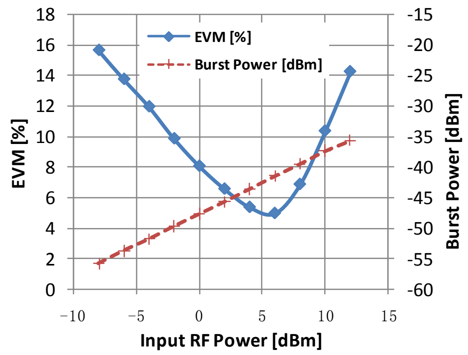

Fig. 3: Transmission of IEEE 802.11g over 50m POF

The best EVM value is measured to be 5.1% for an input RF power of 6 dBm, As the RF power increases, the received burst power increases accordingly with a 1 dB/dB slope as expected. For low RF powers, EVM values are limited by the noise, while for high RF powers, EVM values are limited by the non-linear distortion of the link.

Although there is only a small dynamic range of input powers with an EVM less than 5.6% which is capable of supporting 54 Mbits/s operation, the link is suitable for a downlink. In the uplink the limited dynamic range would severely limit the wireless range. This limitation however can be overcome using automatic gain control (AGC) technology either before the laser or by variation of the APD bias.

The low EVM values indicate good transmission quality. This is verified by real TCP traffic transmission between a Cisco AP and a wireless card. A stable throughput of 20 Mbit/s is achieved. This number is very close to the 21 Mbit/s maximum throughput achieved without the optical link using the same WLAN hardware, and thus can be seen as evidence that the POF RoF link is capable of delivering high quality WLAN service.

Since the link is loss limited, it is thought the dynamic range could be significantly extended by using a laser operating at 650 nm and a ball lens to couple light into the APD. This could reduce the optical losses by as much as 8 dB (2dB coupling losses and 6dB reduction in the fibre attenuation), resulting in a 16 dB enhancement of the RF dynamic range.

Alignment Tolerance

To measure the alignment tolerance of the link the EVM of the IEEE 802.11g signal is measured as the VCSEL is scanned across the facet of the POF. The results are shown in Figure 4. It can be seen that while the performance is not uniform, a region exists with near optimum EVM over a 100 µm width. This is larger than the core diameter of conventional multimode silica fibre and therefore represents a reduction in the required alignment tolerance.

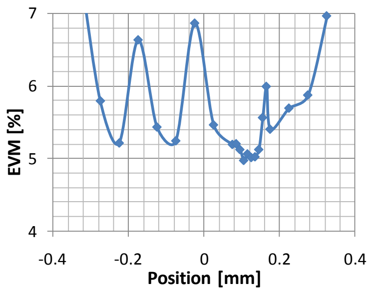

Fig. 4: Variation of EVM with laser – fibre alignment

Conclusions

It has been shown that with the help of a Si-APD, 50m GI-POF can be used in short reach RoF applications for home networks. Despite the high link loss and low fibre bandwidth, successful transmission of IEEE 802.11g signals is demonstrated beyond the fiber bandwidth with an EVM of 5.1%, which is below the 5.6% limit for 54 Mbit/s operation. A throughput of 20 Mbit/s is observed. This performance is achieved with a laser-fibre alignment tolerance of 100 µm.

Acknowledgement

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