



# STEP-INDEX PLASTIC OPTICAL FIBRE (SI-POF) CHANNEL OPTIMISATION: M-PAM AND EQUALIZATION

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## ABSTRACT

Step-Index Plastic Optical Fibre (SI-POF) is gaining popularity in local area network installations due to its characteristics as an inexpensive medium. This research optimized SI-POF channel of two distances (30metres and 60metres) by introduction of equalizer(s) at the output channel signal with M-PAM (PAM-2 and PAM-4) modulation scheme to address bandwidth limitation and inter symbol interference (ISI). The study which was carried out in MATLAB R2019a environment, study employed decision feedback equalizer-DFE (2, 1), (4, 2) and linear equalizer-LE (2, 0) algorithms to train the output channel signal. The study adopted scatter plots, bit error rate (BER) and data rate (DR) as indices to improve the performance of the output signal. The scatter plots of the results show superior performance by enhancing the channels bandwidth signals and addressed inter-symbol interference (ISI). The SI-POF 30m channel with DFE (2, 1) and DFE (4, 2) shows improved data rate of over 400 Mb/s at minimal BER (10<sup>-6</sup>); while SI-POF 60m channel BER lies between 10<sup>-3</sup> and 10<sup>-4</sup> respectively for both DFE (4, 2 / 2, 1). The study exhibit same data rate (DR) of 320 Mb/S for both channel (30m and 60m); while LE (2, 0) appear not a suitable equalizer. The investigation revealed performances of SI-POF channel with equalizer and M-PAM. This shows that the channel could perform better with other multilevel modulation scheme.

**Keywords:** M-PAM, Equalizer, Scatter, BER and DR .

## INTRODUCTION

Step-Index plastic optical fibre (SI-POF) continue to gain popularity as a promising inexpensive medium for indoor networks due to its ease of installation and handling, resistance to electromagnetic interference (EMI) and its lower weight. According to Osahon et al., (2018), SI-POF advantages come at the cost of limited bandwidth-length product (45 MHz × 100 m) and high attenuation (0.15 dB/m at 650nm wavelength). POF is known to its performance on short range transmission and accommodations of trees connection (Ziemann *et. al.*, 2008). This study addressed bandwidth limitation and intersymbol interference (ISI) in the covered channel distance. SI-POF has affinity to withstand rough terrain with minimum attenuation (0.1-0.2 dB/m) using multilevel (M-PAM) transmission modulation techniques, high power optical sources and linear receiver (Noshad and Brandt-Pearce, 2016). Channel equalisation is a technical approach of addressing bandwidth limitation and enhancing signal quality (Burse, *et. al.*; 2010). The study considered M as 2 and 4 for the introduction of equalizer to achieved superior data rate communication system with less noisy data block and distortion. The experiment optimized SI-POF channel (30meters and 60meters) M-PAM output with the introduction of equalizer to compensate bandwidth limitation and address intersymbol interference (ISI) effect. In the experiment, red resonant cavity LED (L10762) and bit pattern generator (BPG) are used as the digital source due to its significant advantages such as high reliability, less sensitivity and robustness to temperature variation as revealed in Figure 1. The photo receiver examined the bit error rate (BER) and data rate (DR) pattern before and after the introduction of equalizer in the communication link

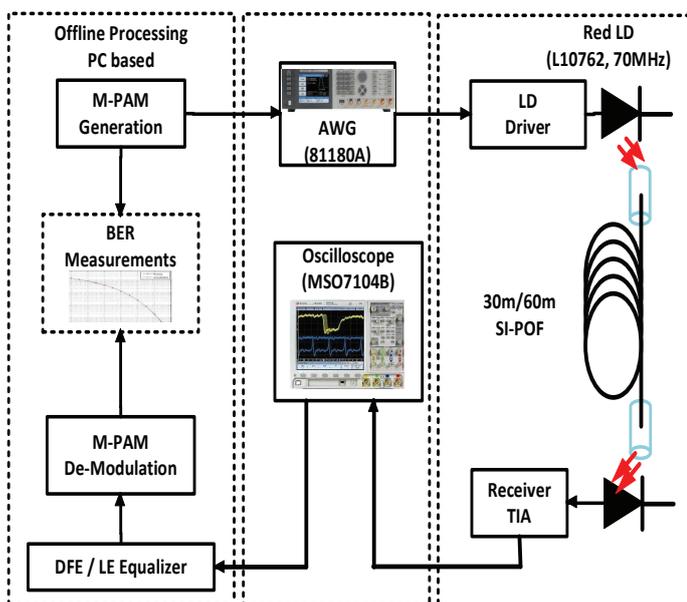


Figure 1: SI-POF Channel Optimisation: M-PAM and Equalization

## MATERIALS AND METHOS

### LED Launch SI-POF System and Receiver Equalization

Red resonant cavity LED (L10762, 70MHz) is deployed in this experiment as a promising light source in SI-POF to mitigate unforeseen factors such temperature challenges, reliable, longer lifetime and embrace eye safety regulations standard. Its performance characteristics enhance multilevel modulation efficacy with combination of receiver equalization to overcome bandwidth limitation and noisy data communication system. The investigation adapted Osahon, *et. al.*, (2018) principle to model the illustrated diagram (Figure 1) using equation 1 MATLAB R2019a environment.

$$I_p(t) = \mathfrak{R}_p \alpha_p (P_{opt}(t) \otimes h_{pch}(t)) + n_p(t), \quad \dots\dots(1)$$

Where  $I_p(t)$  simplified Figure 1 expression communication link's output;  $\mathfrak{R}_p$  denotes the photodiode (PD) responsivity in A/W while  $\alpha_p$  represent the attenuation in the POF channel;  $P_{opt}(t)$  represent the optical signal from the LD;  $h_{pch}(t)$  is the POF channel impulse response; and  $n_p(t)$  is the noise present at the receiver.

### Description of Research Design and Procedures

The study performed 5 experiments per training by transmitting Megabit per second (Mb/s) over short-range (60m and 30m) step-index plastic optical fibre (SI-POF) was implemented with multi-level pulse amplitude modulation (M-PAM) scheme using Red resonant cavity LED (L10762, 70MHz) as the optical source. The study considered SI-POF channel distortion and the non-linear distortion. To allay these distortions under M-PAM levels modulation scheme, the bit error rate (BER) performances and the data rate (DR) of the transversal SI-POF channel, equalizer(s) is introduced and evaluated. The study examined BER and DR performance for the multilevel PAM scheme using two and four levels for the introduction of decision feedback equalizer (DFE) and linear equalizer (LE) respectively. The algorithm employed MATLAB R2019a environment to reduce computational complexity in specified training length.

### Decision Feedback Equalizer (DFE)

Decision feedback equalizer (DFE) is a nonlinear equalizer that employed to reduces intersymbol interference (ISI) in frequency-selective noisy channels (Mathwork, R2019a). DFE adopt tapped delay-weighted sum training techniques in line with stored samples from both input signal and feedback filtered signals as shown in Figure 2.

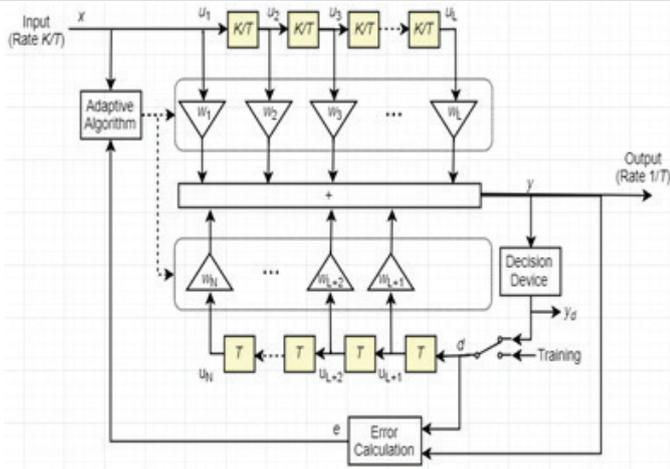


Figure 2: Decision Feedback Equalizer Algorithm (Mathwork, R2019a)

**Linear Equalizer (LE)**

Linear equalizers (LE) aimed to mitigate inter-symbol interference (ISI) as the frequency response of a channel has no null through noise enhancement channel (R2019a). LE algorithm employed tapped delay line stored samples from the input signal through summation of weighted value and update techniques transmission as shown in Figure 3.

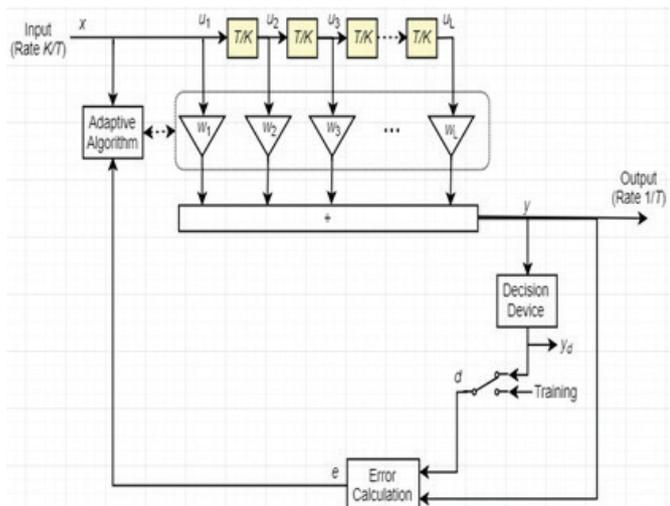


Figure 3: Linear Equalizer (LE) Algorithm (Mathwork, R2019a)

**Procedural Equalizer Parameters**

In summary, the study considered 4 vital parameters for introduction of equalizer into the communication link using M-PAM as follows:

- (i) Algorithm(s) (forgetting factor – 0.999)
- (ii) Number of taps (forward – nft and feedback - nbt)
- (iii) Equalizer delay (D is half taps); and
- (iv) Training length (1000 PAM symbol sampling & 5 experiments)

The computational skill in MATLAB R2019a environment adopted two different types of adaptive equalizer algorithms; (1) linear equalizer - LE and (2) decision feedback equalizer -DFE for comparison purpose and output resolution efficacy. The experiment and computation was grouped according

to the deplored algorithms scenario (a), (b) and (c) as follow:

- (a) no equalizer
- (b) decision feedback equalizer – DFE (2, 1); decision feedback equalizer – DFE (4,2)
- (c) linear equalizer - LE (2,0)

**RESULTS AND DISCUSSION**

In summary, the maximum data rate (DR) at any given M-ary is limited to  $2\log_2(M)$  at bit(s) per second (b/s). The investigation structured four scenarios as follows; channel (30m and 60m) characteristics and where M is considered for 2 and 4.

**30Meters SI-POF Channel Performance**

The study adopted Minakawa, et. al; (2016) principle by employing scatter plot to evaluate the output performance from the channel. Figure 4 revealed a noisy inter-symbol interference (ISI) output channel signal of PAM-2 from 30meters SI-POF channel without equalizer and this shows essentiality for the introduction of equalizer.

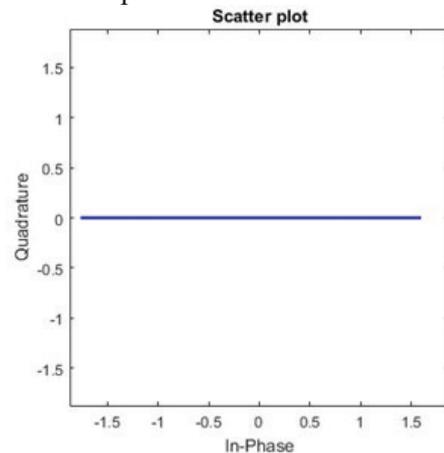


Figure 4: PAM-2 and PAM-4 Output Signals Without Equalizer

Natural SI-POF channel behaviour without equalizer show very high noise (10-1) and distorted signal with low data rate at 360 Mb/s (Figure 4). The study introduced equalizer(s) into the communication link to address bandwidth limitation and ISI, Figure 5(a) revealed the PAM-2 and Figure 5(b) PAM-4 output channel signal respectively.

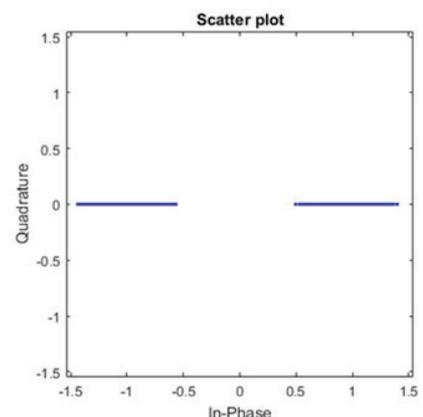


Figure 5(a): PAM-2 Equalized Channel Output Signal

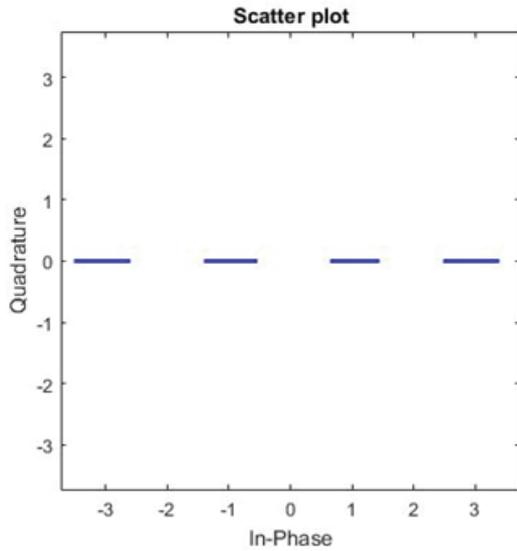


Figure 5(b): PAM-4 Equalized Channel Output Signal

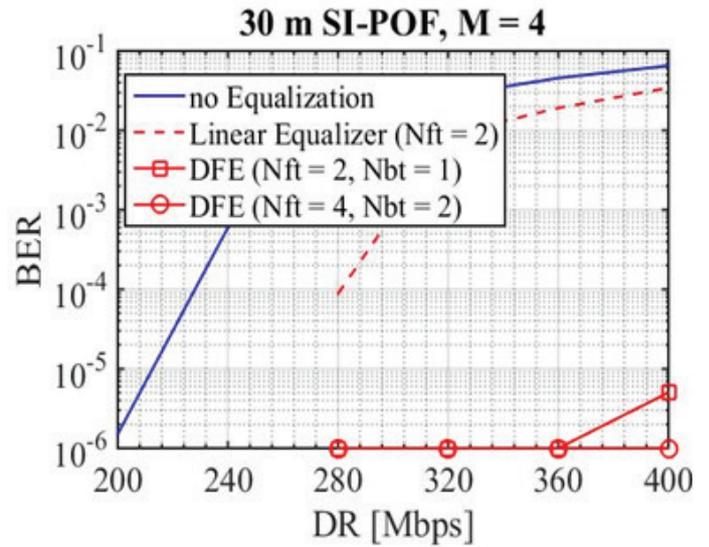


Figure 7: 4Level PAM/30Meters SI-POF

The research further investigated output performance of these equalizers on data rate (DR) and bit error rate (BER). Figure 6 jointly presented SI-POF channel output and the introduction of equalizer(s) for 30M SI-POF PAM-2, this clearly shows progression of BER against DR.

Without equalizer on 30meters/PAM-4 output channel signals appeared distorted and noisy (10<sup>-1</sup> BER) as revealed in Figure 7. Linear equalizer LE (2, 0) applied to the channel but appears not suitable with 10<sup>-2</sup> BER. Both DFE applied in the communication link gives superior data rate (DR) outputs, (4, 2) revealed better performance than (2, 1) as shown in Figure 7. In summary, Table 1 presents overview performance of 30Meter SI-POF channel.

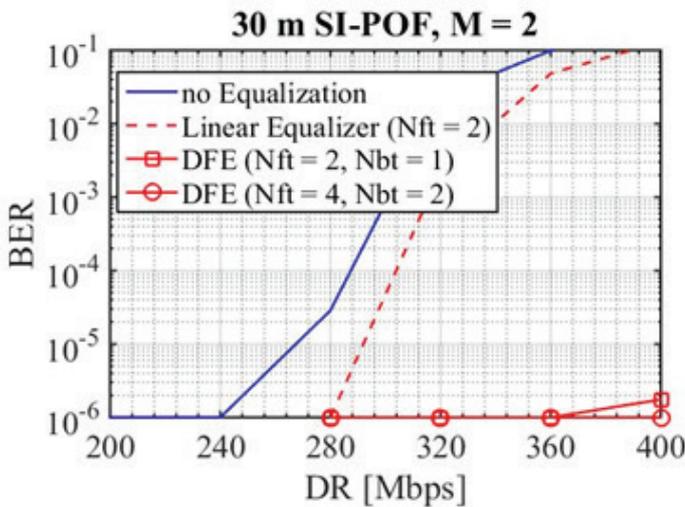


Figure 6: PAM-2 / 30Meters SI-POF Channel

Linear equalizer (2, 0), show better performance of data rate of 380 Mb/S, although it was noisy and distorted like without equalizer. Introductions of DFE (2, 1) and DFE (4, 2) to the communication link, this show superior data rate of over 400 Mb/s. Although, DFE (2, 1) has traces of noise (10<sup>-5</sup>) while DFE (4, 2) shows promising approach to enhances bandwidth and inter symbol interference (ISI) distortion. Figure 7 present four scenarios on introduction of equalizer(s) to 30meters SI-POF channel using PAM-4 modulation scheme.

Table 1: 30Metre SI-POF Summary Performance

DR (Mb/s) Rbvec	M-PAM	Without DFE (BER)	With DFE (4, 2) (BER)
280	2	2.5 x 10 <sup>-5</sup>	2.0 x 10 <sup>-3</sup>
	4	7.3 x 10 <sup>-3</sup>	0.00
320	2	2.3 x 10 <sup>-2</sup>	0.00
	4	2.5 x 10 <sup>-2</sup>	0.00
360	2	1.1 x 10 <sup>-2</sup>	0.00
	4	4.3 x 10 <sup>-2</sup>	0.00
400	2	1.7 x 10 <sup>-2</sup>	0.00
	4	6.9 x 10 <sup>-2</sup>	0.00

**60Meters SI-POF Channel Performance**

The study considered channel characteristics increment with respect to distance from SI-POF 30meters to 60meters. This is to further investigate the output pattern before and after introduction of equalizer(s) to the communication link. Figure 8, (PAM-2, 60meters SI-POF) revealed the studied scenarios of bit error rate (BER) against data rate (DR) in Mb/s.

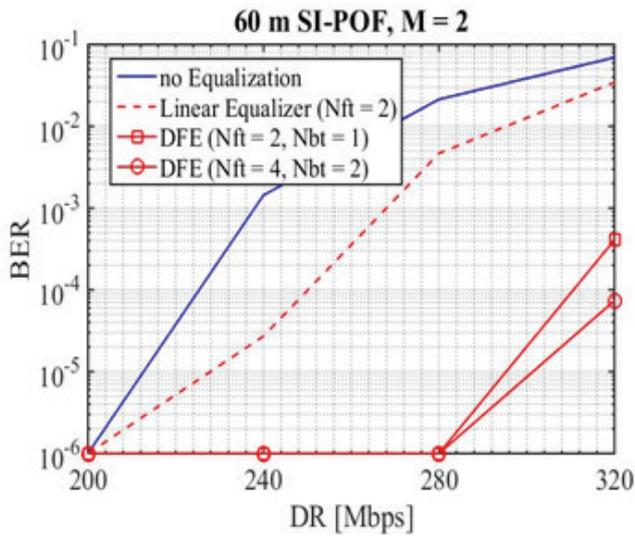


Figure 8: PAM-2 / 60Meters SI-POF

The study shows little difference between no equalization (without equalizer) and LE (2, 0). There is clear disparity between LE and DFE performances, the BER lies between  $10^{-3}$  and  $10^{-4}$  respectively for both DFE (4, 2 / 2, 1) with same data rate (DR) of 320 Mb/S. Although, there difference in data rate is shown in Figure 6, and this account for the chosen delay. Figure 9 present PAM-4 modulation technique over 60meters SI-POF with all the experimental chosen parameters.

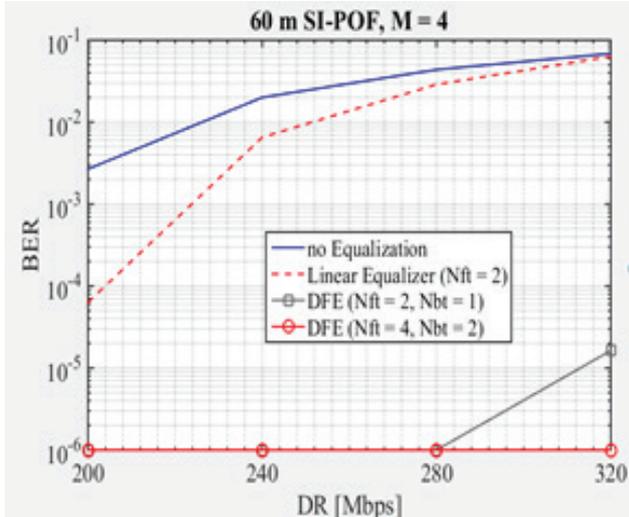


Figure 9: PAM-4 / 60Meters SI-POF

Data rate (DR) performance on LE and without equalizer show little difference but significant in terms of BER. The presence of DFE in the communication link improved bandwidth limitations and reduces the channel ISI as revealed. However, DFE (4, 2) has

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superior performance with BER of  $10^{-6}$  followed by DFE (2, 1) with BER of  $10^{-5}$ . The study shows DFE (4, 2) is a better equalizer for the communication link and posed to have data rate (DR) at infinity. In summary, Table 2 presents overview performance of 30Meter SI-POF channel.

Table 2: 60Metre SI-POF Summary Performance

DR (Mb/s) Rbvec	M-PAM	Without DFE (BER)	With DFE (4, 2) (BER)
160	2	0.00	0.00
	4	$9.4 \times 10^{-6}$	0.00
200	2	0.00	0.00
	4	$1.7 \times 10^{-2}$	0.00
240	2	$1.9 \times 10^{-3}$	0.00
	4	$2.1 \times 10^{-1}$	0.00
280	2	$2.1 \times 10^{-2}$	0.00
	4	$4.1 \times 10^{-2}$	0.00
320	2	$6.9 \times 10^{-2}$	$4.0 \times 10^{-4}$
	4	$6.7 \times 10^{-2}$	$3.6 \times 10^{-5}$

## CONCLUSION

The study has successfully introduced decision feedback equalizer (DFE) and Linear equalizer (LE) to offer better SI-POF communication link to address bandwidth limitation and inter symbol interference (ISI). Considering the experimental scheme above, 30meters channel link appear unsettled and more distorted than 60meter. PAM-4 performs extremely superior with better data rate (DR) and less bit error rate (BER –  $10^{-6}$ ) along SI-POF 60meter with DFE (4, 2) than PAM-2. The experiment established a comparatively study between DFE and LE equalizer for the specific SI-POF channels (30meters and 60meters) and M-PAM scheme(s). The investigation shows that the channel could perform better with other multilevel modulation scheme.

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