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Cost effective optical coupling for enhanced rate polymer optical fiber communication

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ABSTRACT

Recent developments in the short distance communication have made polymer optical fibers (POF) an attractive product in the high speed data communication market. The requirement of a large bandwidth, low cost, light weight and flexibility in installation have placed them over the copper cables especially in applications like home networking and automotives. Since POFs are large core multimoded fibers, their band width is limited by intermodal dispersion. This confines POFs application to low data rate short distance communications. Restrictive mode launchers (RML) and higher order mode strippers placed in the data link helps to reduce the intermodal dispersion. The techniques used to implement these signal conditioners should be simple and cost effective to keep POFs attractive in the short distance communication. In this paper we explore the possibility of integrating the RML and mode stripping elements in the transmitter and receiver package itself. The pre-designed optical signal conditioning elements are projected to get molded in the plastic packages and are fiber plug in modules. This connector less package design, universal to any light source proposes to enhance the data rate and is widely manufacturable at an ease of installation and low cost.

KEY WORDS: - Polymer Optical Fiber, Restrictive mode launching, Encircled flux, Data rate, Bandwidth, Numerical Aperture, package, optical coupling

1. INTRODUCTION

In the rising data rate market, short distance communication requires higher bandwidths and low cost components. One of the potential areas that demands high data rate is premise networks like broadband access network and home automation¹. POFs are being considered as a practical solution for this kind of application. Their major advantages include a very flexible structure, lower connection costs and immunity to electromagnetic interference. The large core structure of POF is advantageous in installation while it allows a large number of modes to propagate through the core. The presence of multimodes limits the bandwidth of POF due to intermodal dispersion. The bandwidth enhancement studies have got foremost interest² to keep POFs attractive in the growing data rate market. The three major component's characteristics, say transmitter, fiber and receiver, decide the bandwidth capacity of a multimode fiber link. Since these networks are implemented in premises and local area networks, over all cost of the components is also of major concern. Even though LED sources are cost effective transmitters, the requirement for higher bandwidths made them less attractive for POF communications. The high power, high data rate, narrow spectral width and smaller spot size compared to LEDs raised low cost 850 nm VCSEL as an alternative solution for such applications. Connector less packages and fiber plug in modules also helped to maintain POF system installation cost lower. There are new generations of POF, which offer a higher bandwidth are manufactured by engineering the core index profile. A graded index (GI) POF can transmit four times higher data rates than a step index POF. But they are offered at higher price than normal POFs.

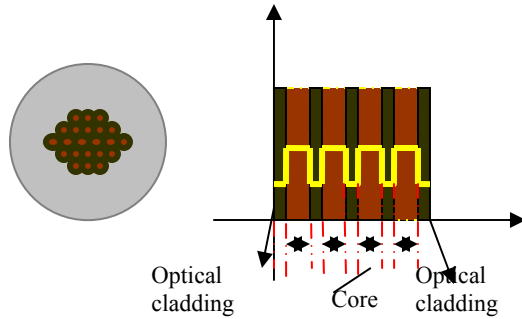


Fig 1. Multi core step index fiber profile

Another alternative to increase the bandwidth of POF is by external coupling mechanisms, which selectively excites either the fundamental modes lying at the centre of the core or higher order modes lying towards the cladding. One of the widely used methods to achieve this condition is attaching a mode conditioning single mode fibers with the multimode fiber. But this will have the additional process of splicing or connecting the SMF to POF.

2. MODAL BANDWIDTH

The bandwidth of a fiber is decided by the aggregate performance of all the modes in the fiber or in other words the modal bandwidth depends on the number of modes excited in the MMF. The optical launch conditions have a greater effect on deciding the number of modes excited. The lower order modes are centred on the core, while a higher order mode finds their paths towards the cladding. Over filled and under filled launches are the two general terms associated with the light propagation through fiber. In the former case the light launched in to the fiber over fills the core of the fiber and hence excites the maximum number of modes possible. In the latter case, the light launched fills only a certain portion of the fiber and excites limited number of modes⁴. Restricting the modal excitation by means of an underfilled launch condition is known as restricted mode launch (RML).

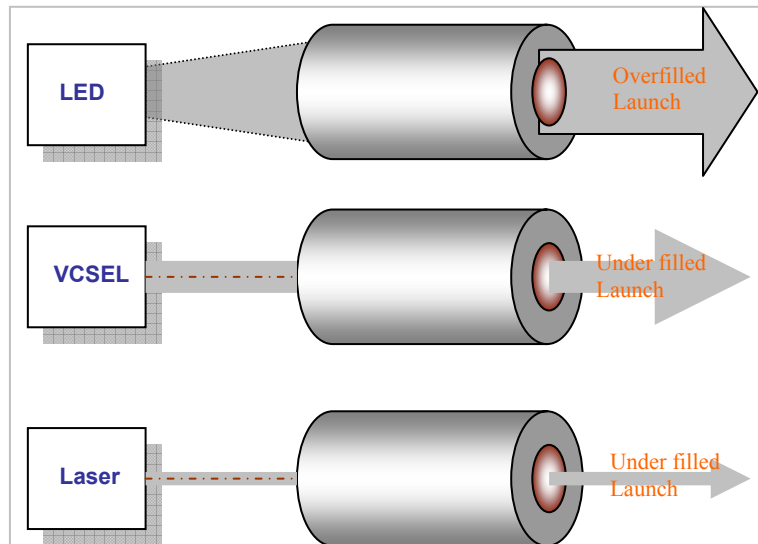


Fig.2 Example of overfilled and under filled launches

The RML can be either centre launch or offset launch. In the center launch, the optical power from a single mode fiber or laser is coupled to the centre of the multimode fiber. This excites the lower order modes, fundamental mode, centered

at the core. Alternatively in the offset launch, the power is launched to an area offset from the centre of the fiber. In this method the power is coupled to the higher order modes having relatively low modal dispersion.

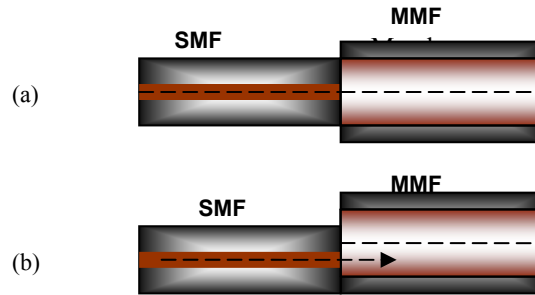


Fig 3. (a) Centre launch (b). Offset launch

Both these methods have proven very effective in increasing the bandwidth of multimode fibers by controlling the number of modes excited. But the fibers having discontinuities in their refractive index profile near the centre badly affects the performance under centre launch scheme. The variation in refractive indices offers different speeds to light and ends up in the phenomena known as Differential Mode Delay (DMD), which considerably reduces the effective bandwidth. In an off set launch, the launch position can be selected to avoid this defective region.

The equilibrium mode distribution (EMD)⁶ and steady state mode distribution are the other two concepts related to light launch conditions. EMD is the mode distribution obtained after going through a system, where the output mode distribution is unaffected by the input mode distribution; independent of launch conditions. This situation is seldom met. Steady state distribution is reached when the mode distribution is no longer changes along the fiber. This depends on launching conditions. The maximum steady state is reached in an over filled launch condition. In the absence of strong mode coupling, restricted launch condition also creates a steady state mode distribution. Once the steady state is reached, the transfer of energy between the modes will stop.

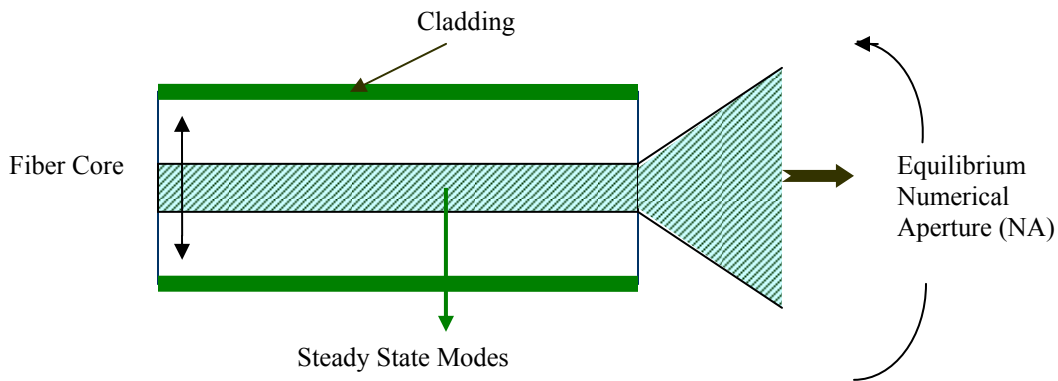


Fig 4. Equilibrium steady state mode propagation

Mode stripping is another method used to reduce the number of higher order modes propagating in a fiber⁵ and there by improving the bandwidth further. They are of two types: core mode filter and cladding mode stripper. In the core mode filter the fiber is wound over a mandrel to reduce the higher order modes in the core. During this process the higher order modes leaks to the cladding and is being lost. This results in an exit numerical aperture less than the material NA of the fiber. A fiber that has reached modal equilibrium, along with the reduced NA, is said to exhibit long-launch conditions. Cladding mode stripper is required in short distance applications since the higher order modes leaked to the cladding

couples back to the detector at the receiver side. It is necessary to remove this mode using a cladding mode stripper. The cladding mode stripper is nothing but a higher refractive index material coated on the fiber cladding. Here the cladding buffer is removed initially and coated with a higher index material.

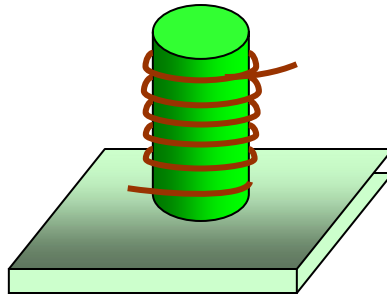


Fig.5. mandrel mode stripper

3. EXPERIMENTAL ANALYSIS

To verify the effects of light source parameters on modal distribution, we set up an experiment to launch the light into POF having a core diameter $980\mu\text{m}$. In the initial experiment, light from a 1310 nm laser diode is launched to the POF using a single mode fiber of core diameter $9\mu\text{m}$ and the near field patterns are captured by a beam analyzer. The second set up replaced the single mode fiber with a multimode fiber of $62.5\mu\text{m}$ to repeat the experiment.

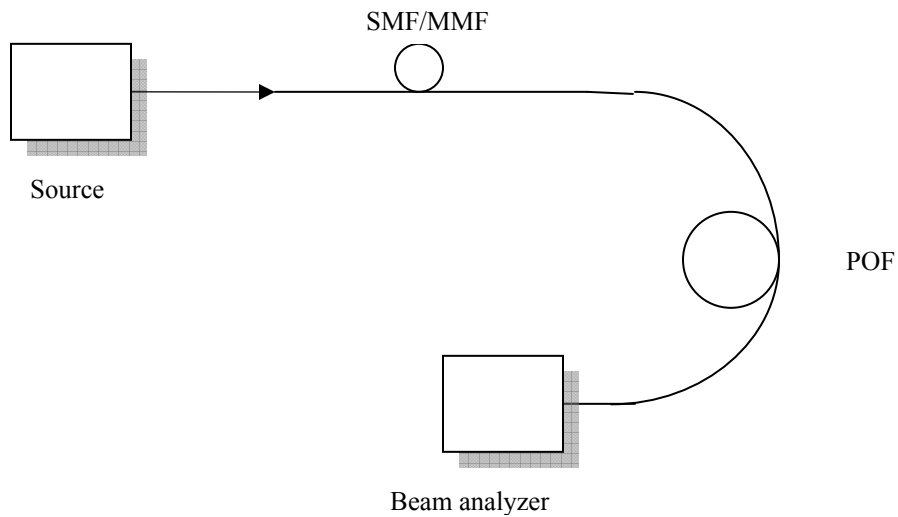


Fig 6. Experimental setup for optimizing the launch conditions

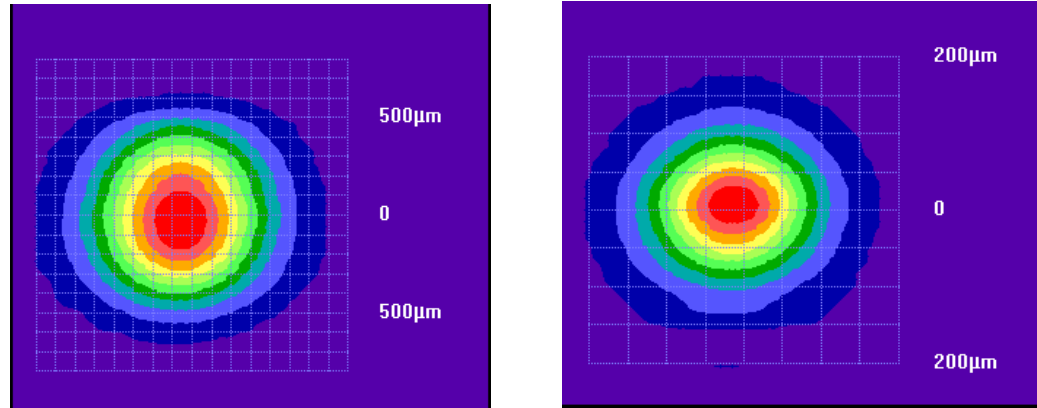


Fig. 7 (a) Near field output pattern of POF, when light launched with MMF (b) launched with an SMF

The design of RML coupling requires the information on encircled flux (EF) of the light source used. The encircled flux is the percentage of the power with in a given radius when light is launched by a transmitter into a multimode fiber. The modal distribution of the fiber depends on the numerical aperture and spot size at the launch end of the fiber. If the spot size is small and its NA is less than the fiber core, the optical power will be concentrated at the centre of the fiber core. The bigger spot size and larger NA, leads to higher order mode excitation. Hence in any optics design for mode control it should take care of a matching spot size and NA of the source and fiber. A steady state equilibrium mode distribution state can be realized by an identical far and near field patterns. The radiation patterns are compressed in the case of RML conditions and enlarged in the case of OFL conditions.

4. INTEGRATED SOLUTION

A conventional POF communication system employs matched beam method and mandrel wrap excitation⁷ methods to enhance the data rate. A typical system looks as in the figure below.

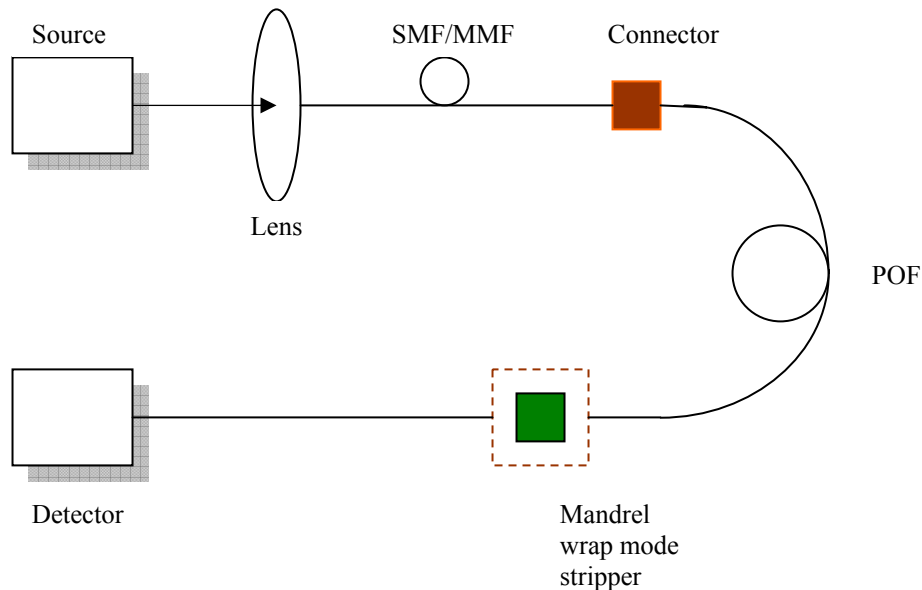


Fig 8. Conventional system

These methods positively improve the bandwidth of the system. But the disadvantage is that the entire system becomes bulky and invites complex process steps like alignment, splicing etc. Also it directly escalates the cost.

Keeping in mind the necessity of a cost effective compact system, we explored the possibility of integrating the signal conditioning elements inside the package. In the proposed design, at the transmitter side the molded plastic package consists of a restricted mode launcher and at the receiver side it involves a mode stripper. Restricted mode launcher, which helps to keep the encircled flux of the source to remain the same irrespective of the light sources used. The design of this element is optimized to generate the same effect of launching as with a single mode fiber of NA 0.1. The signal conditioner at the transmitter side provides center launch with underfilled launching conditions. This helps to excite only the lowest order modes and hence reduces the modal dispersion. The concept of mode stripper is implemented in such a way that it not only helps to radiate the higher order modes excited but also couples the light effectively to the detector. The dimensions of the signal conditioners are optimized based on the optical simulations with a VCSEL source of divergence half angle 16° , SI POF having a core diameter of $980\mu\text{m}$ and a detector radius of $50\mu\text{m}$.

Based on the theoretical calculations, POF of $980\mu\text{m}$ dimensions will support thousands of modes in over filled condition. The design of RML is done to reduce the number of modes excited to a minimum by concentrating the light only to excite the fundamental mode. There by reducing the modal dispersion and increasing the modal bandwidth. The mode stripper at the receiver side is designed to eliminate higher order modes and have efficient coupling to the detector. The mode stripper design is such a way that it will eliminate minimum 10% higher order modes. So with the help of both RML and Mode stripper, the data rate will be enhanced considerably.

The fabrication of this integrated components are proposed to do with plastic molded packages. The transmitter and receiver plastic packages can be fabricated with optimized signal conditioner structure cavities. These cavities are then filled with optically transparent epoxy of suitable index of refraction. Either ultra violet curing or thermal curing can be used for reinforcing the structure. It is better to use an epoxy having $T_g > 95\text{ C}$ having a shrinkage rate less than 2% of the initial volume.

5. CONCLUSION

The various factors to enhance the POF bandwidths are discussed in detail. A novel design with cost effective coupling is explored. The proposed package with the integrated signal conditioners will make the transceiver packages simple and compact. This signal conditioner also helps in effective optical coupling with out the need of any additional light coupling elements, there by avoiding the complex assembly process and cost. Moreover the packages are fiber plugin modules make the system installation much easy. The proposed concept seems to be versatile with better data rate, reasonable coupling losses, easy to fabricate and wide manufacturability. It not only enhances the coupling but also the data rate by reducing the modal dispersion. Above all it is a lower cost method

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