High Bit Rate Polymer Optical Fiber Links: Design and Demonstration

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Abstract: For Perfluorinated Polymer Optical Fiber we show that optical coupling, fiber core size selection and receiver design all can be optimized to realize low-cost, high-speed data links. An example 10 Gbps 200m link is demonstrated.

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1. Introduction

Perfluorinated Polymer Optical Fiber (PF-POF) has high bandwidth arising from excellent Differential Mode Delay (DMD) [1] due in part to strong mode mixing [2,3]. It additionally has good transparency at 850 nm, allowing the design of low-cost, high speed data links using commercial off the shelf (COTS) VCSELs and photodetectors. Here we show that optical coupling, fiber core size selection, and receiver topology choice are all important for realization of low-cost, high-speed data links.

PF-POF links will tend to be loss-limited (~60 dB/km at 850nm) at maximum distance rather than dispersion limited, indicating that efficient coupling from the VCSEL to the fiber and from the fiber to the photodetector, in addition to low receiver noise, are critical to provide maximum reach. Much of the cost advantage of present POF links is due to large core sizes and relaxed alignment tolerance, and the challenge is to maintain alignment tolerance at high speeds in order to realize low cost despite the small size photodetectors needed. Here two approaches are employed simultaneously to address this issue: (1) novel efficient molded nonimaging concentrators are developed to couple from large-core fibers into small detectors while (2) receiver topologies are investigated as a means to allow the use of increased detector sizes. An analysis of the coupling on the transmit and receive side of the link reveals the core size that provides the greatest alignment tolerance for the link. Finally we present a 10 Gbps data link over 200 m of 120 μm core PF-POF using low-cost VCSELs, GaAs p-i-n photodetectors and a custom molded optical insert.

2. Efficient coupling using molded optical inserts

A non-imaging, optical concentrator was designed and optimized for maximum coupling efficiency using commercial optical simulation software, subject to a variety of practical constraints [4]. The final design is low-aspect-ratio with an $f/\# < 1$, and may be diamond turned or injection molded. It has one curved refracting surface and one planar surface to facilitate alignment with and integration of electro-optic devices during chip-on-board (COB) assembly [5]. Figure 1 shows both the prototype and the final injection molded concentrator. This insert has a precision stepped bore for longitudinal and transverse fiber alignment, sized for a slip-fit onto the end of the POF, and is designed to be incorporated into a chip-scale package (CSP) using passive alignment and standard semiconductor packaging process flow, i.e. die pick-and-place technology, die attach, wire bonding, and overmolding [6]. The insert provides stable, efficient optical coupling, even over multiple mate-demate cycles and side-loading with less than 0.3dB variation [7].

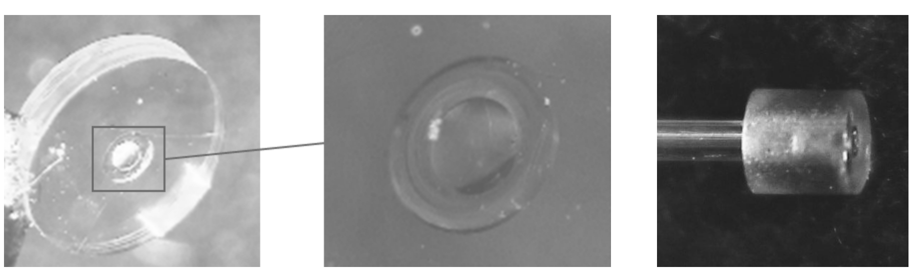

Figure 1. Hemi-aspheric optical concentrator diamond-turned from PEI disc (left) and detail view (center); PEI molded optical insert (right) having integrated concentrator and fiber alignment bore, with POF installed.

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3. Optimum fiber core diameter

It is relatively easy to couple light from a VCSEL source to a large-core fiber (e.g. 120 µm diameter) in the transmitter configuration, for an underfilled spot size. In the receiver configuration, light from the same large-core fiber is collected onto a photodetector with increasing difficulty for the small detectors used at high data rates (30-75 µm diameter). Conversely, small core diameters shift the required mechanical precision toward the transmitter, while relaxing the alignment tolerance of the receiver assembly (all other things being equal).

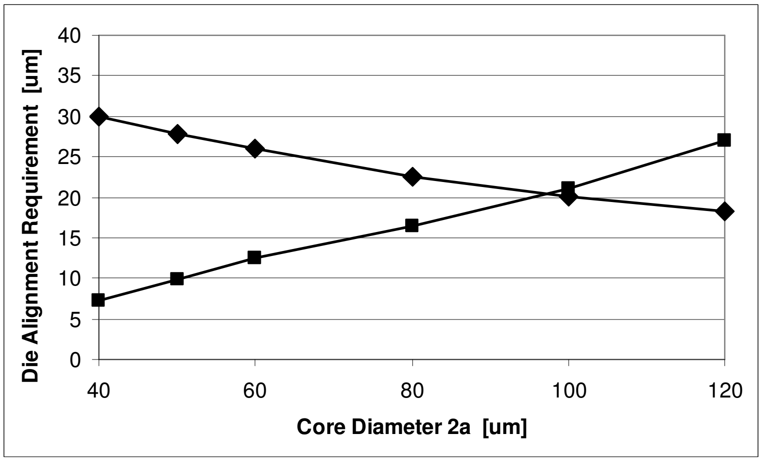

Figure 2. Die-referred alignment requirement to meet a 0.5 dB loss criterion;
(■) Tx with 75% fill factor; (◆) Rx with 80 µm diameter detector.

An example subset of the tradeoff space is explored in Figure 2, which shows, for a 0.5 dB reduction in coupling efficiency, the maximum allowable radial misalignment. For this insert, a core size of ~90 µm apportions the allowable misalignment equally between the Tx and Rx and maximizes system alignment tolerance. Other tradeoffs are explored in this manner, such as die and fiber tilt, fiber offset, and core-to-cladding concentricity.

4. Receiver design for low noise and large area photodetectors

The noise in optical receivers, typically the dominant noise source in an optical link and factor that determines the minimum detectable signal, improves with smaller photodetector capacitances but at the cost of reduced alignment tolerance. Bootstrapping can be used to remove the effect of photodiode capacitance [8] or the input impedance of the TIA can be lowered by the use of a regulated cascode (RGC), thus moving the input pole to high frequency [9]. Here we compare these approaches, as shown in Figure 3, with the commonly used common-emitter with emitter-follower feedback (CE/EF) [10], with regard to their noise performance as a function of input capacitance, which serves here as a proxy for alignment tolerance and, hence, coupling cost. To allow a fair comparison, each design was optimized for lowest noise but constrained to have maximally flat group delay and a bandwidth with 3dB point = 0.7*baud. All circuits were simulated using 0.25µm SiGe BiCMOS (~ 40GHz f_T) and at various bandwidths relative to this f_T to lend some universality to our result and allow scaling to other processes.

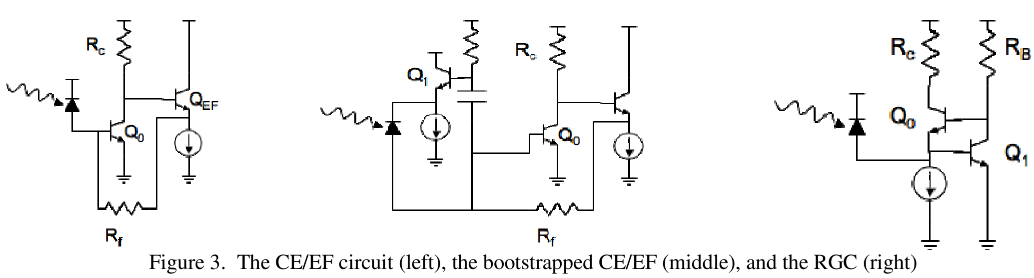

Figure 3. The CE/EF circuit (left), the bootstrapped CE/EF (middle), and the RGC (right)

The results, shown in Figure 4, indicate that the CE/EF has the best noise performance at low bit rates relative to the process f_T for low values of capacitance. Input-referred noise increases with increasing photodiode capacitance due to the reduction in feedback resistance necessary to maintain the input pole at a constant frequency. The bootstrap circuit, while reducing the effective capacitance of the photodiode, also adds the capacitance of the buffer circuit. For low values of photodiode capacitance, the cancellation does not sufficiently offset the additional capacitance added by the buffer. For larger values of photodiode capacitance, the opposite is true and the bootstrap is preferred. The RGC has low input impedance, so the input pole can be placed at very high frequency. Because the input pole is not necessarily dominant, the input-referred noise is less sensitive to the scaling of the input capacitance. However, at low bit rates and for low values of capacitance, the RGC is inherently a noisier circuit. As the process f_T is approached the RGC provides a clear performance improvement over the other topologies.

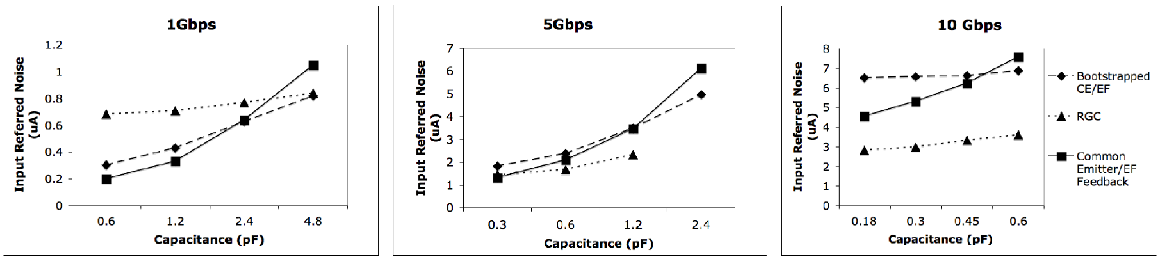

Figure 4. The scaling of input referred noise with photodiode capacitance for the CE/EF (square/solid line), RGC (triangle/dotted line), and bootstrapped CE/EF (diamond/dashed line) for three different bit rates: 1, 5, and 10 Gbps

5. Conclusion

A COB transmitter was assembled from a COTS laser driver IC, an 850 nm VCSEL die, and the insert, encapsulated as shown in Figure 5. A COB receiver was made with another insert, a die-level GaAs p-i-n photodiode, and a COTS transimpedance amplifier die. Standard manual die attach and wire bonding was used.

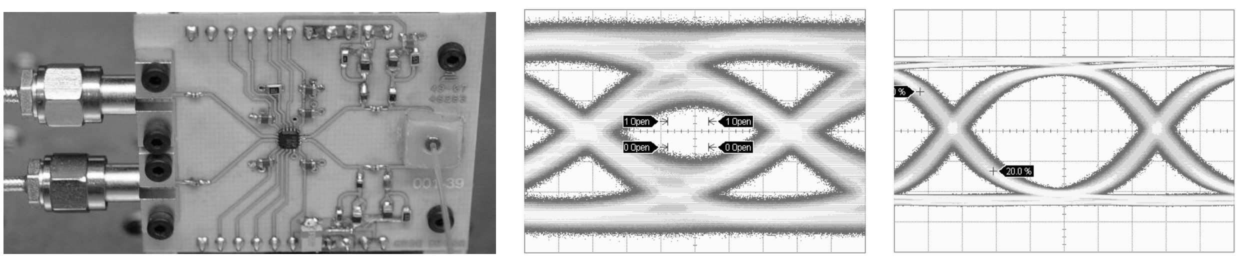

Figure 5. COB transmitter with encapsulated insert (left); Eye diagram for 200 meters of GI-POF (center); Eye diagram for 1 meter (right).

A simplex link was demonstrated at 10 Gigabits/second over 200 meters of Chromis GigaPOF-120 PF-POF, shown in Figure 5 (center) at a received optical power of 140 µW. Back-to-back performance was approximated by a 1 m length of the same POF, and the resultant eye pattern is shown in Figure 5 (right) at a received power of 1.8 mW.

Here we have presented several ways to maximize alignment tolerances to reduce manufacturing costs for high speed PF-POF links using passively aligned, standard semiconductor industry packing process integration flow.

6. References

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