KDPOF: Innovating in communications for large core Polymer Optical Fiber

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I. Company profile

Knowledge Development for POF (KDPOF) is a Spanish company with the mission of developing state of the art silicon for Polymer Optical Fiber (POF) market, providing low cost, low power and out-performing high speed communications over POF.

KDPOF offers a technology to increase the maximum bitrate to more than 1 Gbps in link layer, and increases the reach of the technology to more than 300 m at 100 Mbps.

KDPOF is founded by Carlos Pardo (CEO) and Rubén Pérez-Aranda (CTO). They used to work for DS2 (Power Line Communication Company as R&D Manager and R&D Engineer) and SIDSA (Broadcast Telecommunication IP Vendor Company as CTO and R&D Project Manager).

On the past they had been developing Silicon for RF and cable transmission. They have deep knowledge on telecommunications algorithms and their implementation, as well as in silicon commercialization.

Today KDPOF is a team of highly qualified compromised professionals with the qualities of a good work, ethics, and environmental care as some of their principles.

II. Technology

KDPOF is a high spectral efficiency communication system that exploits the capacity of large core POF (i.e. SI-POF). It is not only a theoretic system, but also it is a fully engineered solution for SI-POF that is implementable with the state of the art of microelectronics. It is a capacity achieving system that automatically adapts the operation to variable conditions as model of fiber, bending, coupling losses, connectors, guiding conditions, etc.

Our point of view is to use techniques commonly implemented in copper and wireless communication systems to approach the capacity limit of the fiber, because POF, as communication channel, is closer to be considered as a copper cable than as a Glass Optical Fiber (GOF).

KDPOF has applied the following advanced telecom techniques to the POF channel:

- Advanced Channel Estimation. The KDPOF communication system continuously monitors the communication channel characteristics, and has an up-to-date and accurate description of the channel. This description has both the channel and noise characteristics
- Advanced Equalization. Based on the channel estimation, the KDPOF system equalizes the transmission and the reception on the signal optimizing the capacity of the link at every moment.
- Advanced Coded Modulation. In order to obtain a performance close to the Shannon capacity of the channel, the KDPOF system applies advanced channel coding. The implemented techniques provide both high performance and low implementation cost and power consumption for very high bit rates.

KDPOF innovates in the methodology for POF communication systems design, applying the most powerful criterium: to approach the Shannon capacity limit as much as possible through the use of tools belonging to the Information Theory.

A deep knowledge of Information Theory allows us to answer several important questions:

- What elements (i.e. optoelectronics, fiber, amplifiers, etc.) compose the POF as communication channel?
- Where is the capacity (Shannon's limit) for this communication channel? How can we calculate the capacity?
- What are the most suitable telecom techniques to minimize the gap to capacity?

Usually the transceivers for optical fibers are designed according to the optimization of the eye-diagram, searching for a tradeoff between bandwidth and SNR (Signal-to-Noise Ratio). In order to achieve higher data-rates, current developments of POF communication systems consider the optimization of digital modulation, light emitters, photodiodes and analogue circuits as isolated problems. This produces as result over-engineered solutions for each problem with excessive costs and without achieving the main goal: to approach capacity.

On the other hand, KDPOF introduces a novel criterium in POF systems design, optimizing in a coupled manner the digital circuit and the analogue transceiver (Trans-Impedance Amplifier, Driver, Light Emitter and Photodiode). This is carried out by accurate models and advanced numerical algorithms that maximize the capacity (i.e. entropy) from the point of view of the Information Theory.

KDPOF is developed with a design flow based on hierarchically structured software patterns, that enable for a coupled optimization of all their parts and for an iterative design based on very detailed simulations. Therefore, the cost and the time-to-market is drastically reduced and the performance is easily forecasted enabling to dynamically adapt the product strategy.

III. Applications

Home networking

The rising performance of broadband connections for residential users will present a new challenge for telecom operators in the short and medium terms: how to deliver the high bit rate digital signals with high quality-of-service to all consumer devices scattered inside the building of final users? We present POF for short-reach and high-capacity optical communications for residential customer premises. This represents the main market to which is directed the KDPOF technology.

The clear POF advantages here are:

1. Simple do-it-yourself (DIY) installation due to plug-less connections. This is the key and most important advantage of POF with respect to (multimode) glass fibre and is a consequence of its much larger core diameter. The standard 1mm diameter makes an easy and low cost DIY installation of the terminals possible, even by non-skilled persons; and makes POF connections extremely tolerant to residual dust on the terminal faces – a major issue, on the contrary, for glass fibre connectors.

2. Therefore, POF is suitable to be installed by any user, and because it does not require special connectors, any cable distance is possible. User only need to cut the cable at distance he/she requires.

3. Compared with Ethernet cable (Cat.5/e), POF is cheaper and much thinner and flexible. See table above.

4. Minimum space consumption and low weight compared to copper solutions.

5. Immunity to external electromagnetic interference (EMI) and compliancy with national safety regulations, enabling parallel installations to power lines in ducts. That means existing copper wiring will not interfere with data passing through POF so it can even be installed next to electrical cabling.

6. No EMI generation, an issue that is gaining increasing attention in relation to health risks connected with high-power wireless solutions.

7. High environmental resilience, allowing the deployment of POF cables in adverse environments such as wet areas or even in water pipelines, sewers and drainage pipes.

8. POF is operating in visible light, so interconnection verification is straight forward.

9. POF, connectors, and optoelectronics are low-cost consumer parts which is ideal for installers who save on cable costs and installation, testing and maintenance time.

Today, commercially available products based on POF provide data connections of 100 Mbps up to 50 meters over standard SI-POF.

The KDPOF goal in this application is thus to provide a broadband-enabling technology that will underpin the home and premises networks of the future. Such networks will be expected to support state-of-the-art multimedia, and storage services such as High Definition Video on Demand and Storage Area Networking. This requires the underlying physical layer to be adequate to support these applications, i.e. the foreseeable future network will have extremely stringent requirements in terms of speed (at least 1Gbps) and QoS to the end user.

Providing data rates around 1 Gbps and assured Quality of Service (QoS) to every device in the home, KDPOF can be considered as a long term solution. Because it is an adaptive system, KDPOF provides a flexible technology, adapting the operation to achieve the highest communication capacity for any kind of amateur or professional installation. We will show that more than 1 Gbps can be provided in the range of 100 meters of standard SI-POF.

Access networks

The ultimate goal of Telcos is to deliver as much bandwidth as possible to any new revenue generating service. Offering hundreds of megabits transport capacity to many homes is a requirement to provide future services such as high definition digital broadcasting.

A full and direct upgrade from copper (i.e. VDSL) to Fiber to the Home (FTTH), based on GOF, might be feasible, but the investment can be prohibitive in many locations due to the high installation costs of the last fiber drop. When GOF is not viable, POF can be offered in a more cost-effective manner providing a long-term solution. This alternative solution consists in using KDPOF for the last drop, up to 200 meters, for rates of more than 400 Mbps, hence reducing the costs, time and complexity of the installation.

The adaptability that provides KDPOF plays a key role, because the same technology can be installed in very different deployment scenarios: residential buildings, hotels, etc. As in home network applications, the multimedia streaming services, like IPTV, impose the hardest requirements to the access networks.

Industrial communications

Industrial Fast Ethernet has been envisaged by many companies in order to merge seamlessly the factory plant field-buses with enterprise intranet. This network operates over POF; the most established fiber medium in the factory automation space.

Today, Industrial Fast Ethernet transceivers operate 100 Mbps on SI-POF links up to 50 meters. Operating on industrial environments, KDPOF will provide a great coverage improvement for Fast Ethernet installations along the factory plant. KDPOF technology will provide Fast Ethernet (100 Mbps) over SI-POF links up to more than 200 meters, with red LED, and 300 meters with green LED. This means a capacity upgrade of industrial buses maintaining the installed low cost infrastructure.

Automotive infotainment networks

Consumer demand for more electronic devices in cars, such as anti-collision cameras, DVD players, and navigation systems, has led to the deployment of POF in automobile networks. Its high bandwidth and ease of use, coupled with its high tolerance to vibrations and external noise sources make POF ideal for in-vehicle embedded multimedia networks.

It is remarkable the development in the last years of Media Oriented Systems Transport (MOST). This is a network optimized for multimedia applications inside the automobile. MOST defines from the physical layer to the application layer of OSI model and it is usually installed following ring topologies. Three versions have been developed, providing from 25 Mbps to 150 Mbps over POF.

MOST has been developed based on a partnership of carmakers, systems architects and key component suppliers. Audi, BMW, Daimler, Harman/Becker and SMSC are the core partners. MOST has been widely used in over 20 million cars for infotainment networks.

KDPOF technology is ready to produce a capacity upgrade to the current status of MOST technology. It can be used in the same ring topologies and with the same fiber and optoelectronic components currently installed in MOST networks. KDPOF could be seen as a new physical layer able to provide 1 Gbps over longer fiber stretches, enabling MOST to be installed in longer vehicles, such as a train or an airplane, and to deliver more multimedia services using the same POF infrastructure.

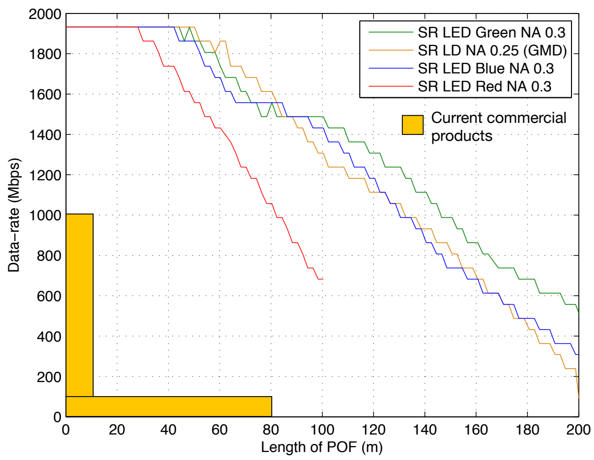

Fig 1: Data-rate (Mbps) vs. length of standard SI-POF (meters) for short reach applications

IV. Performance

Next sections show performance capabilities of KDPOF technology. Since KDPOF design is configurable and scalable it can be updated to be used from short reach to very long reach applications. On one hand the capacity is translated in very high data-rates (> 1 Gbps) over short POF links. On the other hand the capacity is translated in a high coverage (long POF links) working with lower data-rate (hundreds of Mbps). We only present some simulation scenarios that we have considered representatives to show the capabilities of KDPOF technology.

The results are reported for standard SI-POF Mitsubishi Eska Premier GH4001 (1 mm, NA 0.5). Commercial large area photo-diode and operational amplifiers are used to implement the receiver. The tests are performed for a Bit Error Rate (BER) < 10^{-10}, and different light emitters are considered: red, green and blue LEDs with launching UMD numerical aperture NA = 0.3, and a red laser (LD) with launching GMD (Gaussian Mode Distribution) NA = 0.25.

Short reach applications (Home Networks)

The system is configured to work with a symbol-rate of f_S = 250 MHz. The transmitter uses a DAC of 12 bits and the receiver an ADC of 10 bits. It is important to note that both components work at symbol-rate and they are available nowadays in the market. This operation mode is suitable for Home Networks deployed over inexpensive SI-POF.

Figure 1 shows the performance as data-rate vs. standard SI-POF length for the different light emitters. Orange rectangles show capacity covered with current commercial products. As can be seen the low attenuation of green and blue windows increases the data-rate regarding to the red LED in a high spectral efficiency system as is KDPOF. Laser diode (red) causes an improvement of data-rate regarding to red LED due to higher injected power to fiber, higher cut-off frequency and narrower wavelength width. As drawback, LD has more dependency with temperature than LED, and LD is not eye-safe. These facts must be considered for the selection of the light emitter. On the other hand, a huge capacity gap can be observed between the current commercial products and KDPOF technology.

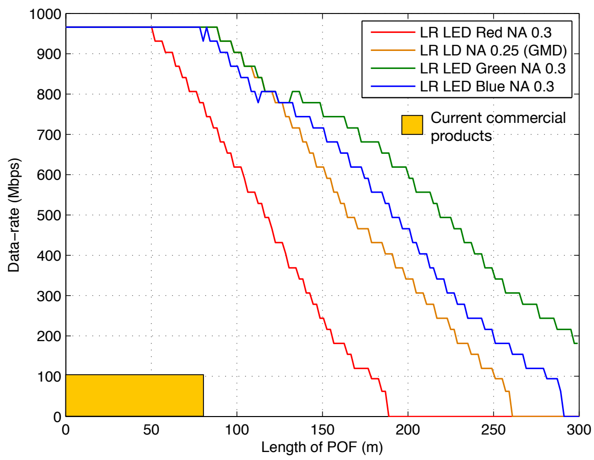

Fig 2: Data-rate (Mbps) vs. length of standard SI-POF (meters) for long reach applications

Long reach applications (Access Networks)

For this case the system is configured to work with a symbol-rate of f_S = 125 MHz. The transmitter uses a DAC of 12 bits and the receiver an ADC of 10 bits, both at symbol-rate. Figure 2 shows the performance as data-rate vs. standard SI-POF length for the different light emitters. This operation mode could be considered for Access Networks.

Very long reach applications (Industrial Communications)

In this case the system is configured to work with a symbol-rate of f_S = 50 MHz. The transmitter uses a DAC of 12 bits and the receiver an ADC of 10 bits, both at symbol-rate. Figure 3 shows the performance for very long reach applications.

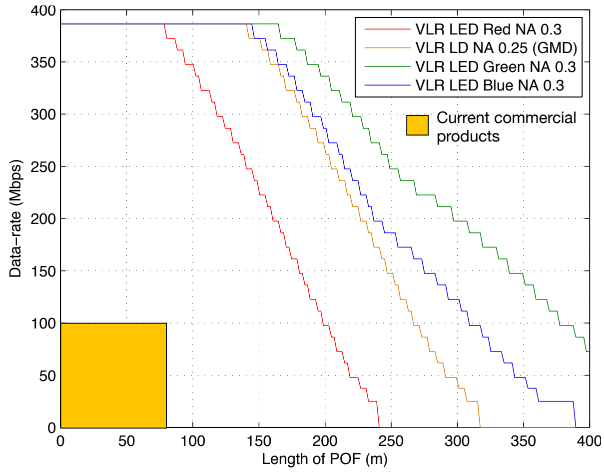

Fig 3: Data-rate (Mbps) vs. length of standard SI-POF (meters) for very long reach applications

Remarkable conclusions about performance

From the presented performance results we conclude that cost-effective LED are enough to achieve rates of more than 1 Gbps over standard SI-POF in short reach applications as Home Networks. Furthermore, long and very long communication links can be implemented over standard SI-POF, delivering more than 400 Mbps at lengths around 200 meters for Access Networks and 100 Mbps at lengths around 300 meters for Industrial Communications. Furthermore, capacity analysis and coupled design of analog and digital front ends show that green is the optimum color for SI-POF.

V. Products

KDPOF technology becomes a product in two different ways: as Application-Specific Integrated Circuit (ASIC) or chip and as Intellectual Property (IP) that can be integrated in third part Systems on Chip (SoC). In order to be specific, the following sub-sections show some examples of how KDPOF products become part of systems that integrate POF connectivity, in applications as home networks, access networks, industrial communications and automotive infotainment systems.

Ethernet transceiver

Figure 4 shows an ASIC that performs the basic Gigabit /Fast Ethernet transceiver functionality for integration in home and access networks as well as industrial communications. KDPOF ASIC interface on the left side with the system, where it is integrated (through commonly used buses as G/R/MII), or it is directly connected to 100/1000TX RJ45 connector or a USB connector.

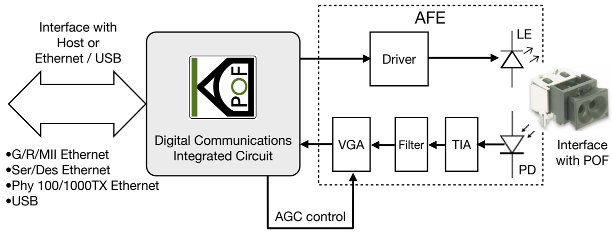

Fig 4: Gigabit/Fast Ethernet transceiver

On the right side, KDPOF ASIC interfaces and controls the Analogue Front End (AFE), which interacts with optoelectronic components - light-emitter (LE) and photo-diode (PD). The transmission path contains a driver circuit that accommodates the signal to be injected in POF by LE. The reception path performs the optical-to-electric conversion through the PD and Trans-Impedance Amplifier (TIA) and filtering to eliminate signal aliasing and adapts the amplitude of the signal through a Variable Gain Amplifier (VGA), so it is suitable to be received by KDPOF ASIC. VGA is controlled by ASIC, which runs the Automatic Gain Control (AGC) task based on internal algorithms designed for optimum signal reception.

This scheme is good for integration of KDPOF in different systems as Costumer Premisses Equipment (CPE) and routers, basement installed head-end (HE) access equipment, Ethernet Network Interface Controller (NIC) for industrial control devices, Ethernet NIC for data storage devices, PC, digital TV, Set-top-Boxes, multimedia hard-drives, etc and Ethernet/USB - POF media converters.

A requirement, that we consider very important, is the backward compatibility of KDPOF silicon with current deployed POF technologies based on 100FX/1000FX physical layer. 100FX has been inherited by POF from 100 Mbps Ethernet connectivity developed for multimode GOF. It is far to be optimum for POF. However, KDPOF silicon will integrate 100FX and a smart detection mechanism to determine if device in the other side of fiber is KDPOF or not. If KDPOF capabilities are detected, the system will start in high performance operation; it KDPOF signal is not detected system will start compatible with 100FX mode.

Ethernet bridge

Other scheme is shown in figure 5, where KDPOF ASIC integrates two POF interfaces with Ethernet bridging capabilities. In this scheme the ASIC controls two AFEs and routes packets among three ports - two POF cables and one bus for connection with the system.

This scheme is very well suited for do-it-yourself home network installations, because it reduces the number of cables along the residence and allows to extend the network in a simple manner - by insertion of a new device between two ones or connecting it to the last device of the network. This scheme can be integrated in all the devices with multimedia capabilities, enabling an easy and reliable POF based home network installation. It can also be integrated implementing Ethernet-POF media converters to provide POF connectivity to devices that have Cat5/6 connection but do not include KDPOF technology.

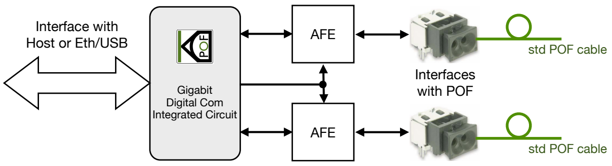

Fig 5: Gigabit/Fast Ethernet bridge with two POF ports and one system port

Another scheme with bridging capabilities is depicted in figure 6, which can be viewed as an upgrade of the above scheme. Here, KDPOF ASIC routes packets among three POF ports. This scheme is well suited to extend the home network following a tree topology. This scheme can be implemented in separate POF repeaters.

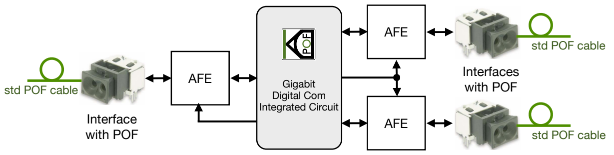

Fig 6: Scheme for Gigabit/Fast Ethernet bridge with three POF ports

Bridged daisy-chain home networks based on KDPOF

Figure 7 shows a bridged home network based on POF, implementing a daisy-chain topology for easy installation and upgrade. The Router integrates a basic Ethernet transceiver, and the Server, Desktop computer and Home Cinema integrates an Ethernet bridge as that explained above. Laptop, commonly used for non multimedia tasks is connected by WiFi for this example. WiFi connectivity could be directly provided by the router, however it could be provided by a pico-cell implemented with a WiFi access node circuit plus a KDPOF Ethernet bridge. Last case represents how the coverage of very high-speed wireless networks could be improved by the use of POF, in high area residences.

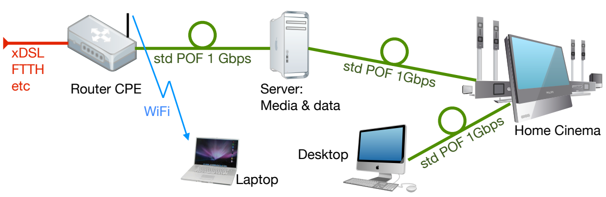

Fig 7: Bridged daisy-chain home network based on KDPOF

Bridged daisy-chain topology provides several advantages compared with usually installed Ethernet Cat.5 start and MOST ring topologies, because it requires fewer cables, reducing the cost. Compared with ring topology, bridged daisy-chain is more reliable. Ring topologies need of the correct operation of every device connected to the network. Furthermore, failure of only one fiber stretch in the ring causes the full failure of the network. On the other hand, only one cable is required for connecting rooms in the home

MOST physical layer

KDPOF technology is able to provide a new physical layer to MOST infotainment systems enabling data-rates around 1 Gbps over longer fiber stretches. We envisage this challenge can be achieved by integration of KDPOF as IP in third part ASICs. The last are in charged to provide the rest of layers (link to application) that MOST standard specifies, as well as the connectivity with the Host Controller.

Figure 8 depicts the scheme for new MOST physical layer IP integration.

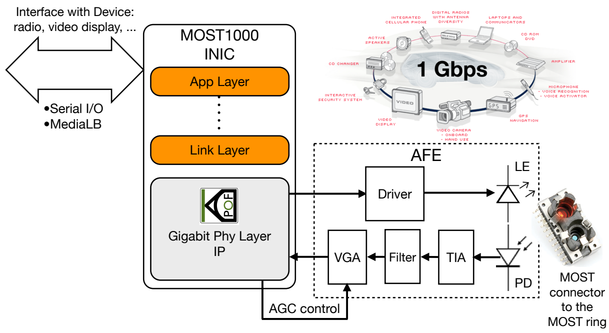

Fig 8: New physical layer for speed and coverage improvements on MOST infotainment systems

Contact

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