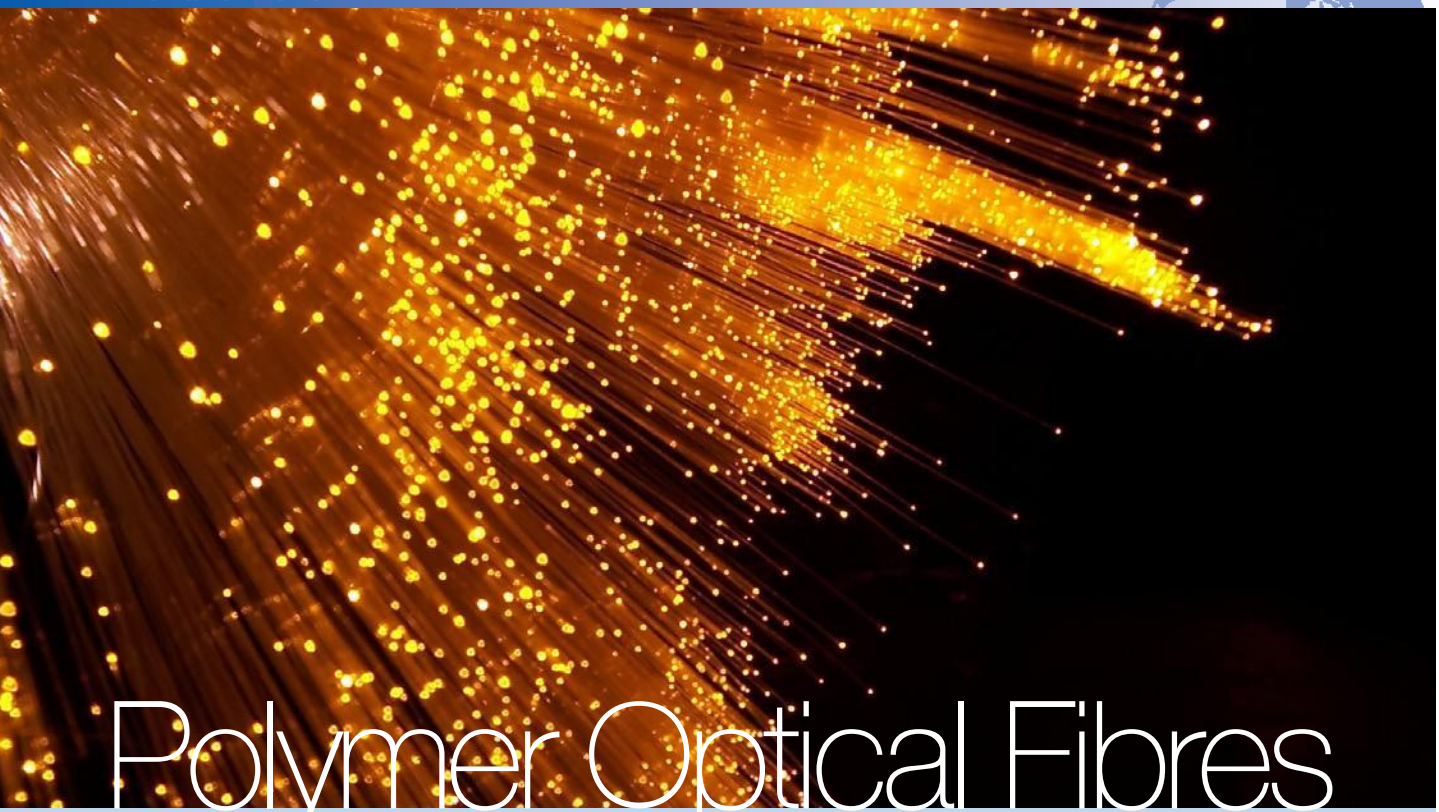

Polymer Optical Fibres

- Most Robust Gigabit Cable for Home Networks

By Olaf Ziemann, Polymer Optical Fibre Application Centre, University of Applied Sciences, Nürnberg

Future television services will be based on two different network philosophies. The first is the distribution over existing analogue networks (coaxial cables, radio). Quality, capacity and flexibility have greatly improved over the last few years. Nevertheless, the capacity of these networks is limited, mainly for switched services. IPTV, on the other hand, offers almost unlimited capacity and flexibility but requires broadband access and in-house networks. This article will describe how Polymer Fibres can fulfil the requirements of these in-house networks at Gigabit speed and with extremely easy installation.

Olaf Ziemann, Polymer Optical Fiber Application Centre, University of Applied Sciences, Nürnberg

(olaf.ziemann@pofac.ohm-university.com)

Olaf Ziemann studies physics at the University of Leipzig. He worked on his Ph.D. between 1990 and 1995 at the Technical University Ilmenau (Thuringia) in the field of optical communication. His working areas have been coherent optical detection and optical code multiplex. He worked at the technology centre at Deutsche Telekom (T Nova) between 1995 and 2001 on hybrid access networks and building networks. Over the last 15 years, he has been Chairman of the Information Technology Society (ITG) Polymer Optical Fibres (POF) subcommittee. Since 2001, he has been a Professor and the scientific director of the POF Application Center at the University of Applied Sciences Nürnberg and a member of the international POF committee. He published the POF handbook in 2007/2008.

In-house architecture for IP-TV

In Europe, most households are connected via DSL (Digital Subscriber Line) or HFC (Hybrid Fibre Coax) lines to the internet. The typical bit-rates are between 6Mbit/s and 25Mbit/s and the capacity is asymmetrical. Such connections can be used perfectly for SDV (Switched Digital Video) applications at standard quality. The typical capacity of HFC connections is 160Mbit/s (5 analogue channels) shared between 100 to 200 connected households.

The network termination, better know as modem or set-top box (STB), is located in the customer's dwelling. It is necessary to distinguish between two different kinds of services. A number of digital TV services do not give direct access to the compressed data stream. The STB is equipped with a TV-specific connector (like HDMI) for the direct connection of the TV set. A real IP-based service uses any available Ethernet link and the customer can store or distribute the content inside his network in any way.

The Polymer Optical Fibre (POF) is one of the options for future in-house networks (which will be Ethernet, in almost all cases). It will be shown in this article why POF offers more advantages in comparison to other solutions.

The Polymer Optical Fibre

The POF is one possible solution for Ethernet links in apartments as well as in MDUs. Figure 1 shows the typical spectral loss of a standard 1mm PMMA-POF (following the international standard IEC 60793-2-40, class A4a.2).

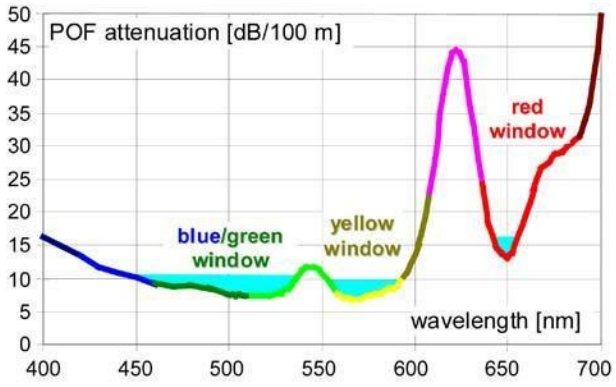

Figure 1: Spectral loss of a PMMA-POF

PMMA-POF operates in the visible part of the spectrum. Most of the present available transmitters use red light (650nm). Blue and green LED offer higher speed, high efficiency and lower loss over the spectrum and will dominate future POF applications.

One advantage of using visible light is that the signal can be detected (seen) without any additional power. The typical required power is less than 1 mW (which is always eye-safe). If we take into account that the best laboratory values for the efficiency of red LED is 50% (Osram 2010, [1]) and for blue LED around 65% ([2]) we can estimate a drive current in the order of 1 or a few milliamps in the near future. In combination with highly integrated drivers and receivers, the power consumption of fast optical POF links will be much lower than that of similar fast radio or power-line interfaces.

Gigabit transmission with POF

The transmission of 100Mbit/s over distances of up to 100m POF is very easy. Simple NRZ modulation can be applied and a large number of commercially available red, green and blue LEDs offer sufficient bandwidth.

Future SDV services in HDTV quality will require higher bit-rates, however. The demand for HDTV is estimated to be between 12 and 20Mbit/s generally. If we assume several users to be in one network, along with the issue of low QoS in home networks and the fact that many other applications in the home will run simultaneously over the same network, a 100Mbit/s connection will not be sufficient. The next hierarchical step is Gigabit Ethernet. As can be seen in Fig. 2, the typical bandwidth of the SI-POF is only about 80MHz.

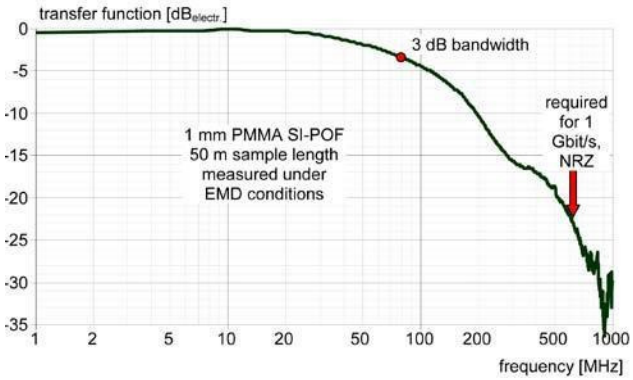

Fig. 2: Frequency response of 50m PMMA-POF

For a pure NRZ modulation at 1250Mbit/s (1Gbit/s incl. 4B5B coding) the required bandwidth is 625MHz, indicated by the arrow. As one can see, this will not work easily.

Nevertheless, the transmission of such bit-rates over distances of up to 100m has been achieved over the last few years. The first publication of a 1Gbit/s transmission over 100m POF was made by Siemens in 2006, [3]. A DMT (Discrete Multi Tone) modulation was used to compensate the limited bandwidth of the POF link.

Other possibilities are passive analogue and digital equalizing. Using a very easy hand-made equalizer filter, the POF-AC achieved an error-free (BER < 10^{-9}) transmission over 100m at a bit-rate of 1390Mbit/s. A digital filtering (DFE: Decision Feedback Equalizer) transmission experiment was possible with a capacity of 2.2Gbit/s over 100m (at a BER < 10^{-9} enabling 2.0Gbit/s at BER < 10^{-9} after error correction, see [4]). The ISMB Toriono presented the transmission of 1.25Gbit/s over 50m with a power margin of 6.5dB in [5]. The specialty in this work was the use of a low cost and eye-safe RC-LED instead of a laser diode.

The Polymer Optical Fibre (POF) is one of the options for future in-house networks.

In combination with highly integrated drivers and receivers, the power consumption of fast optical POF links will be much lower than that of similar fast radio or power-line interfaces.

For practical applications in home networks, the transmission over 50m should be sufficient for almost all possible connections. Figure 3 shows a transmission at 1.25Gbit/s over 50m with our passive equalizing filter. The eye diagram is wide open and there is a wide gap (approx. 1cm) between the connector and the photo detector (please do not try this with your glass fibre at home).

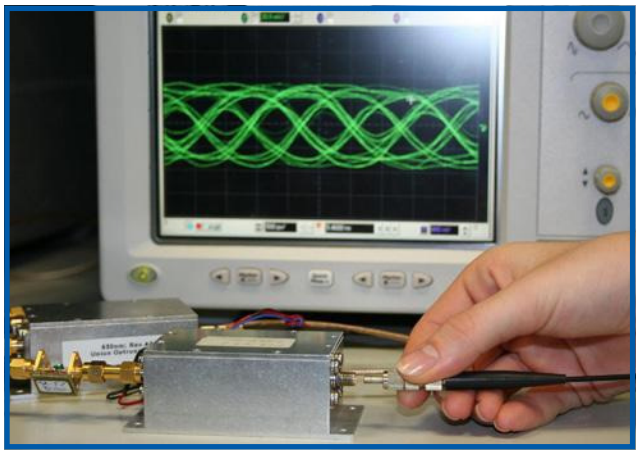

Fig. 3: Gigabit data communication over POF with a huge power margin

A future POF Gigabit standard

The fact that 1Gbit/s transmission over 50m can be achieved with a significant margin makes the SI POF a nice candidate for future home networks. The power budget enables a full temperature range operation (up to +70°C), the use of in-line-connectors and includes ageing, tight bends and poor fibre end faces.

The DKE (German Commission for Electrical, Electronic & Information Technologies of DIN and VDE) started work on a proposal for an optical POF-Gbit-Interface in Oct. 2009 (see **www.dke.de/ak412-7-1** for details). About 30 different institutes and manufacturers of POF components discussed the best options for the transmission scheme, power budget and fibre interface. The current favourite solution is the combination of PAM (Pulse Amplitude Modulation), THP (Tomlinson Harashima Precoding) and MLCC (Multi-Level Coset Coding) error correction. Some advantages of this concept (proposed by KD POF, [6]) are:

- PAM16 modulation requires only about 140MHz link bandwidth.
- It supports the use of bandwidth-limited LEDs as transmitters.
- Bit-rate can be adapted to decreased channel quality.
- Details of this proposal and the work of the DKE group will be presented at the next POF conference in Bilbao in September 2011.

Some installation aspects

The greatest advantage of the POF compared with copper cable is its easy installation. Most of the currently available transceivers do not require connectors. The fibre will be simply cut and fixed in the transceiver using a mechanical clamp. The dimensions of the cable are between 1.5 x 3.0mm to 2.2 x 4.4mm. The German company DieMount offers components for bi-directional transmission (100Mbit/s full duplex) over only 1 POF. This makes the connection as easy as possible. The Italian ISBM Institute published the successful bi-directional transmission of just 1Gbit/s over 75m in 2011 ([7]).

Bending sensitivity is another issue for home installations. So called BIF (Bend Insensitive Glass Fibres) offer a bend radius down to 5mm. However, some new POF offer much lower bend radii down to 2mm. The MC POF (multi-core POF) consists of many single cores, tightly connected. The handling and most of the optical properties are identical to a conventional single-core POF. A photograph of such a MC-POF is shown in Fig. 4. The total core diameter is 1mm and the protection jacket is 1.5mm.

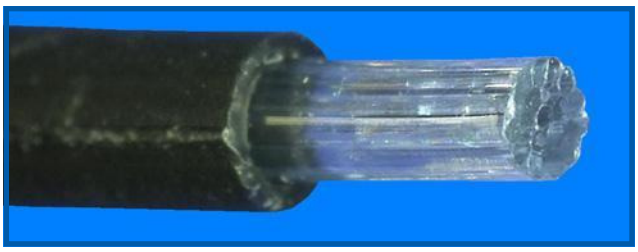

Fig. 4: Multi-core POF with 2mm bend radius

The future development of green lasers (maybe VCSEL) and faster photo detectors (MSM) will enable further improvements of the POF link capacity.

Outlook

The availability of broadband access lines with capacities of »100Mbit/s and the rising number of IP TV services in HDTV quality will create a demand for in-house networks at 1Gbit/s speed in the very near future. Polymer Optical Fibres can offer this speed over a 50m distance with a high power margin. Multi-Core POF enables extremely low bend radii. An international standard for the future POF Gigabit Interface is under preparation, several products at 100Mbit/s, including bi-directional transmission over one fibre, are available.

The development will not end at 1Gbit/s. In the laboratory, the transmission of 10Gbit/s has just been demonstrated (over 25m, [8]). Graded Index POF with the same diameter will enable even higher bit-rates. Applications of these systems will be active optical cables (e.g. thinner HDMI cables) and interconnections. The future development of green lasers (maybe VCSEL) and faster photo detectors (MSM) will enable further improvements of the POF link capacity.

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