KD1000 IC FAMILY:
THE FIRST GIGABIT POF STANDARD IMPLEMENTATION

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Abstract: The first Gigabit POF norm, as contained in the German VDE-DKE standard VDE 0885-763-1 will be reviewed. The new ETSI TS 105 175-1-1, which makes reference to the VDE norm, paving the way for commercial product implementations in the market will be reviewed as well. The paper will present the QUASAR-POF© Alliance for the promotion of the new standard. As a demonstration of the practical implementability of the new norm, the first family of commercial integrated circuits will be presented.

Key words: Gigabit POF, Norm, Integrated Circuit, Standard, Home Networking, FTTH.

1. Introduction

On the past, POF has been used in the home networking market with limited success. The main reasons for that are the limited access speeds which, based on xDSL, were bringing up to 20 Mbps to the home. At the same time PLC and Wi-Fi home networking technologies were already fulfilling the limited demands for bandwidth coming from in house software applications and services.

In Europe, since 2009, and much earlier in Japan, South Korea, and US, the situation is changing. Telecom operators are in a competitive race of bit rates and prices and are using different access technologies as marketing slogans. In parallel with this market push effort the bit rate demand is steadily increasing due to new services like HD-IPTV, Clouding, VPN, and life/work styles (Remote jobs, self-employment, etc.).

This competitive landscape has forced telecom operators to invest on massive FTTH deployment projects as a way of differentiating themselves. As an example, at the end of 2011 there were more than 75 Million FTTH subscribers World Wide. [1]. In the future this trend will only but increase as, for example, the European Commission Digital Agenda states that at 2020, up to 50 % of EU households should have 100 Mbps

The bitrate race has started from 20 (xDSL/Cable) to 50 Mbps, 100 Mbps and 200 Mbps. Rather than price reduction as a differentiation strategy, telecom operators are offering more and more bit-rates supporting new offered services.

To keep up with this trend, a robust, reliable, stable and flexible network topology within the house is needed. The customer needs to be able to use the total provided bit-rate at any point in the house as well as enjoy a remaining extra bandwidth to be used for services like file sharing and local video streaming.

A hybrid mixture of networking technologies comprising a Fixed-Wired-Reliable network along with Wi-Fi Flexible-Mobile-Ubiquos access points is demanded. Tablets, Laptops and smart-phones require a Mobile network. Fixed PCs, Multimedia hard-drives, Game Stations, IPTV set-top-boxes and routers are normally wire connected.

New wires installations may reuse mains conduits within a daisy chain / tree topology. This is the easiest, most affordable and fastest way to introduce a new wiring either in green (new construction) or brown (already constructed) fields. Moreover, wired networks are naturally more "Energy Efficient" than wireless. Energy efficiency is an important topic in the society for two reasons: environmental care arguments are forcing the usage of an Energy Efficient infrastructure; secondly, health reasons are starting to force the limitation in transmitted power in wireless networks, limiting high-speed reliable coverage to a single room [2].

Plastic Optical Fibre based home networks have been deployed for the last few years. POF has a clear value proposition when compared to other "new wires" installations like CAT-5e as it is easier to install. POF installations do not require any connectorization and can be laid down sharing existing main ducts. Several financial studies based on field trials report savings on the order of 15 % to 20 % when comparing with CAT-5e alternatives with savings mainly coming from installation times**.** [3], [4].

A well-established market of device OEMs and installation companies exists in Europe and North America. China is rapidly adopting POF as a cheap and easy way to deploy broadband home networks. Continental associations are already promoting POF among home construction, rehabilitation and Office installation professionals. [5], [6], [7].

All the POF networking equipment so far in the market is using simple NRZ modulation techniques inherited from the Glass Optical Fibre world thus limiting the performance to 100 Mbps for typical home up to 50m. At 2009 a working group within the German standardization body VDE/DKE was created to elaborate a gigabit solution for POF. This group, under the name of VDE/DKE WG 412.7.1, has been working for more than 2 years to develop a physical layer specification for a communication technology optimized for Plastic Optical Fibers (POF). The targeted fibre was the standardized IEC 60793-2:40 A4a.2 POF currently employed in home network installations.

The result is a new Ethernet standard nick named: HS-BASE-P. The official normative document is entitled: *"Physical layer parameters and specification for high speed operation over plastic optical fibres type HS-BASE-P"* with number VDE 0885-763-1. Following suite, the ETSI POF Technical recommendation ETSI TS 105 175-1 has been complemented with the new TS 105 175-1-1 which makes reference to the above mentioned VDE norm paving the way for commercial product implementations in the market.

The best demonstration of the implementability and market suitability is the new family of integrated circuits to be launched into the market by the KDPOF silicon company. This family is aimed towards home networks to complement the new high speed FTTH accesses already being offered by telecom operators.

2. Features

HS-BASE-P is structured and written following the well-known IEEE 802.3 conventions. PCS, PMA, PMD and MDI are completely defined to guarantee interoperability between silicon from different manufacturers. It has been conceived from the beginning to be an OPEN standard, as any of the IEEE 802.3 PHYs.

A summary of the HS-BASE-P main performance highlights follows:

Bitrate: 1 Gbps, MAC Layer compatible with other 1 Gbps full duplex standards in IEEE 802.3.

Adaptive Bit Rate: Specified as optional. It may be supported to guarantee connectivity under extreme conditions.

Jitter / Latency: It is driven by the application. The new standard requires more restricting values for jitter and latency than previous ETSI technical specifications like TS 105 175-1.

Frame Error Rate, Bit Error Rate: Even though TS 105 175-1 requires a BER less than 10-12, the new standard defines a maximum BER of 10-10. The chosen BER level is suitable for compatibility with 1000-BaseT installations and can be reasonably verified.

RFC 2544 compliance: The new standard complies with the standard validation tests required in 1 Gbps connections.

Backwards Compatibility: The new standard warrantees backwards compatibility with already deployed 802.3 100BASE-X devices with PCS and PMA specified under clause 24.

Environmental requirements: Temperature, EMI and Safety levels are driven by the application. The new standard complies with the above mentioned TS 105 175-1 where typical levels are stated.

Several topologies are supported by the new standard mainly Star, the topology of choice for green fields, Daisy Chain ideally suited for brown field deployments allowing the reuse of the mains ducts and Tree which is complementary to Daisy Chain to support branches.

Energy Efficient Ethernet: Low power modes are described as optional in the new standard opening the door for Energy Efficient Ethernet implementations.

3. Structure and performance

Following closely the logical partitioning of IEEE 802.3 sub-clauses, the new standard warrantees interoperability among multi-provider systems:

- Physical Coding Sub layer
- Physical Medium Attachment
- Physical Medium Dependent
- Medium Dependent Interface
- Service primitives and interfaces

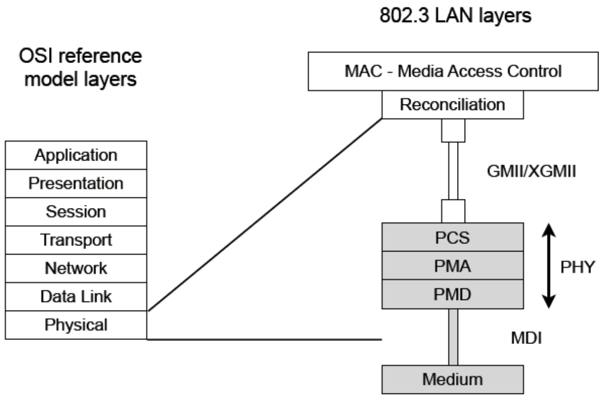

FIGURE 1: 802.3 LAN standard layers

The standard is structured around several annexes defining several speeds and functionalities:

- 1000BASE-P: Fixed bit-rate, full duplex gigabit link.
- 100BASE-P: Fixed bit-rate, full duplex 100Mbps link. (Optional)
- xGBASE-P: Variable bit-rate, full duplex gigabit link. (Optional)
- xFBASE-P: Variable bit-rate, full duplex 100 Mbps link. (Optional)

The **1000BASE-P PHY** annex defines a normative Full Duplex Fixed bit-rate of 1 Gbps link. The achievable performance of this annex is 50 m of SI-POF in a worst-case scenario and 70 m of SI-POF in a typical scenario. Although the standard defines as normative 25 m and optional 50 m, both cases represent worst case scenarios for current optoelectronics and next generation optoelectronics.

The **100BASE-P PHY** is an optional annex for a Full Duplex Fixed bit-rate of 100 Mbps link. The achievable performance of this annex is 100 m of SI-POF in a worst case scenario and 150 m of SI-POF in a typical scenario.

The following table summarizes the main parameters of each annex:

	1000BASE-P	100BASE-P
Coding and Modulation	312,5 Mbaud, 16-PAM, 3.3145 bits/s/Hz/dim	62,5 Mbaud, 4-PAM, 1,8145 bits/s/Hz/dim
Delay constrain	<25us	<90us
BER	$<10^{-10}$	
MTTFPA	$>10^{40}$ years	
Worst case max link	50 m	100 m
Typical max link	70 m	180 m

TABLE 1: Standard annexes main parameters

Finally, the **xGBASE-P** and **xFBASE-P** PHYs are the optional annexes describing the Adaptive Bit Rate (ABR) versions of the 1 Gbps and 100 Mbps annexes. The Adaptive bit rate functionality is based on the quality of the received signal.

The ABR modes are very cost effective solutions especially suited to extend the coverage with bit rates between 100 Mbps and 1 Gbps, ensuring link robustness in distances up to 200 m.

A comparison of bit-rates vs. POF lengths under the ABR behavior is shown in the following figure:

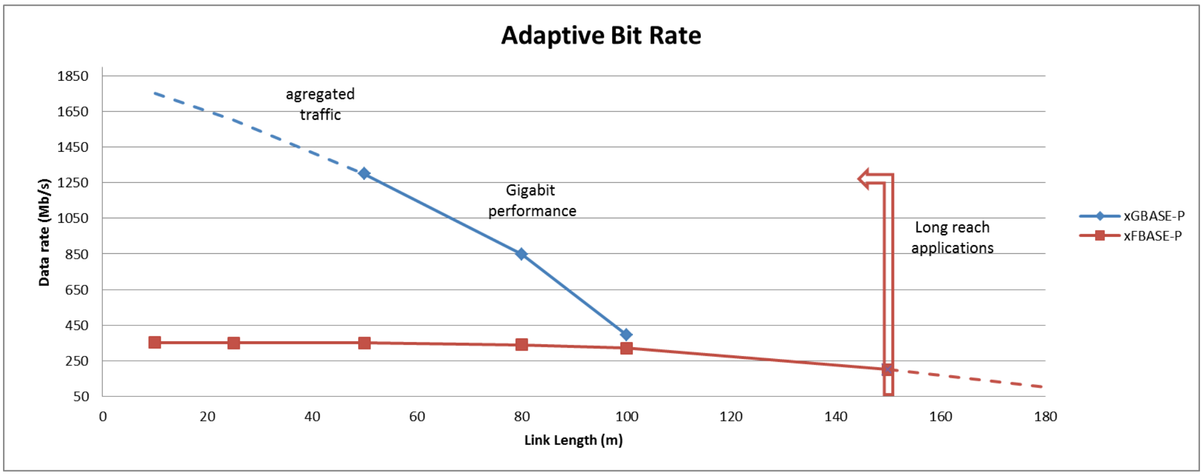

FIGURE 2: Adaptive Bit Rate Performance (Elaborated from 0885-763-1)

It is important to note that the above figure, which has been constructed following the Informative annexes of the standard, tries to represent practical implementation scenarios for future Home and Industrial applications. For example, the transmitted AOP lies on the range of current available red LED sources operated on the safe and reliable range. A typical transmitted AOP for an 80m/850 Mbps POF link (IL of 14.7 dBo) is -3.0 dBm. In the case of the xFBASE-P informative annex a link of 150 m at 200 Mbps (IL of 25 dBo) can be established with the same transmitted AOP. It is obvious that increasing, for example, the transmitted AOP above these levels will increase the link speed-length coverage but at the cost of an unacceptable device life hit or using non-commercial or non-standard optoelectronic devices.

The new standard has proven its practical implementability as a real time prototype. As such, it is already running and providing the expected performance. Independent laboratory testing of prototypes have shown the expected behavior under fast temperature cycles from -40 ºC to +85 ºC. The system is able to monitor in real time the channel distortions and compensate them to achieve the maximum performance.

Simplex cables are also supported with splitter technologies. Performance of the simplex operation will be reported. Extra light power is required to compensate the splitter losses.

4. Technology

The new HS-BASE-P standard is a physical layer developed with the aim to approach Shannon's limit of SISO communication channels like POF. The goal of the new standard is to specify communication systems optimized for limited bandwidth non-linear optical communication media.

The new standard allows affordable silicon implementation reducing the risk to the implementers. The implementers of this Physical layer will find it to be competitive in price and power consumption against current 802.3 1000Base-T physical layers.

The communication system is structured around the following items:

- Channel equalization following the Tomlinson-Harashima Precoding
- Channel coding based on Multilevel Coset Coding (MLCC). Based on low cost binary component codes MLCC provides a high coding gain FEC scheme with low complexity HW implementability for mid and high spectral efficiencies. The MLCC configurable spectral efficiency property preserves constant coding gain.
- Frame structure for continuous adaptation and tracking. It allows a low cost implementation of receivers with timing recovery, non-linear channel estimation & equalization. The designed frame enables very fast and robust link start up.
- Energy Efficient Ethernet based on Low power modes.

The following transmission block diagram summarizes the technology architecture. The PCS / PMA and PMD parts are coded in different colors. Three data paths, Payload, Headers and pilots, are needed for frame building and also shown in the block diagram of the following figure.

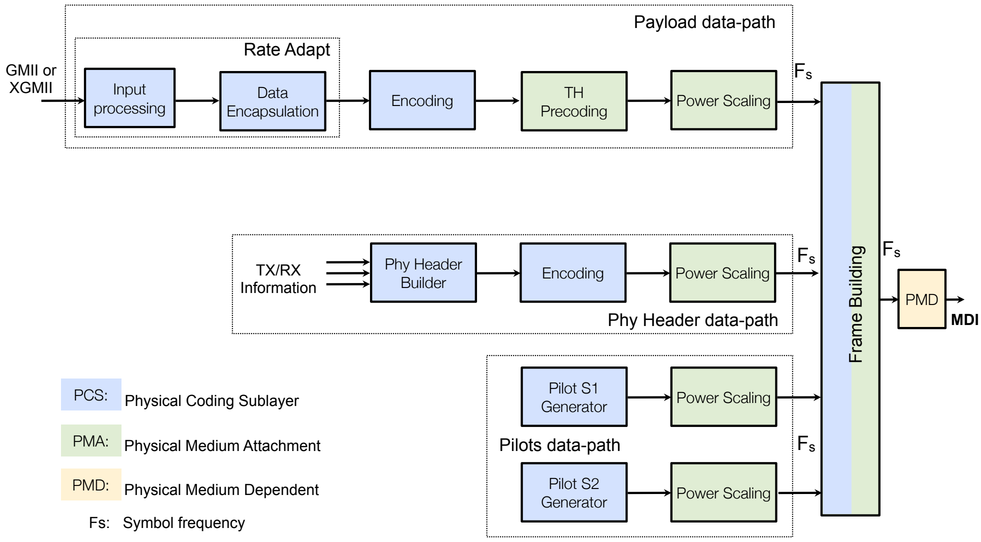

FIGURE 3: Transmitter block diagram (Source VDE 0885-763-1)

As already mentioned, the new standard uses a coding technique called Multi-Level Cosset Coding (MLCC) [8]. MLCC splits the traffic in three streams. Subsequent encoding takes only part on two of the three streams allowing an optimal coding performance. MLCC reduces the cost and power consumption of the alternative encoding of the full data stream at high data bit rates like that of 1 Gbps.

The PMD is coupled to the fibre optic cabling at the MDI. In other words, the MDI is the interface between the PMD and the POF. The standard specifies three types of MDI; a Connectorised duplex receptacle of type LC and two informative ones, a Connector-less duplex receptacle that accepts a bare duplex cable termination and a simplex receptacle that accepts a bare simplex cable termination and includes a splitter that splits up the light of the incoming POF in two, symmetric or asymmetric output branches.

The communication system has been designed from the very beginning with the target in mind to optimize the capacity of the communication channel, which comprises not only the fiber but the optoelectronics as well. Many transmission modes were evaluated combining different modulation schemes with a plethora of symbol rates. A numerical optimization approach based on Information Theory selected a final winning combination of 312.5 MHz symbol rate with 16-PAM modulation levels.

The new standard allows an implementation of EEE (Energy Efficient Ethernet). EEE translates into an optimum performance in terms of power consumption of the overall communication system. The next figure shows a comparison in a typical packet size and arrival statistics condition of the new standard (EE-POF) to the 1000 BASE-T (EEE-1G). HS-BASE-P EEE is clearly superior to its 1G BASE-T alternative.

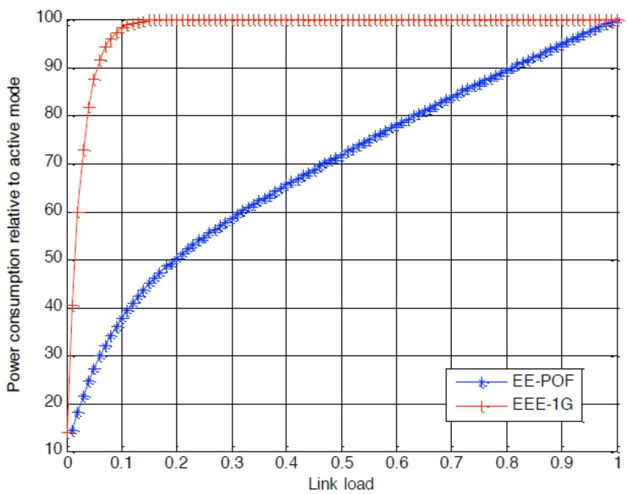

FIGURE 4: Energy Savings comparison for typical 6oo Bytes frame Poison arrivals

5. Market implementation

The market suitability of the new standard is reinforced thanks to the soon to be released ETSI new Technical Specification (preliminary TS 105 175-1-1) entitled *"Access, Terminals, Transmission and Multiplexing (ATTM); Application requirements for physical layer specification for high-speed operation over Plastic Optical Fibres type HS-BASE-P"*. The new ETSI TS provides a compendium of application requirements for home networking infrastructures based in Plastic Optical Fibre (POF) transmission media. The description of the application covers different network topologies as well as different market peculiarities.

This new ETSI Technical specification complements the existing ETSI TS 105 175-1 and paves the way for an easy and successful market deployment of the new Gigabit POF standard.

The completion of a successful Gigabit POF standard has carried along with it the creation of an International Alliance named **QUASAR-POF**. The QUASAR Alliance currently comprises the main leading companies integrating the POF Home Networking supply chain. Telecom Operators like Telefónica, Home networking equipment vendors like Homefibre or Casacom and electro-optical equipment companies like Avago, Mitsubishi, Hamamatsu and Firecomms are already QUASAR members and seek for a successful Gigabit POF standard market deployment. QUASAR membership is open to any interested company.

Leading optoelectronic companies already QUASAR members like AVAGO, FIRECOMMS and HAMAMATSU are finishing the design of new optical transceivers especially suited for the Gigabit POF standard compliant systems. These new transceivers are based on current existing robust MOST light sources with lineal interfaces which follow the new standard requirements and ensure the best performance of the overall system.

Silicon companies like Knowledge Development for POF (KDPOF) will release a full family of Integrated Circuits that will be the first market solution implementing the new standard. Announcement is expected by the end of this year with samples availability by Q1 2013.

The KD1000 family of products has been developed bearing in mind the needs of the home networking market. Following suit families for the Industrial and Automotive markets will be released.

The KD1000 main features are:

- Open & Flexible interfaces: Ethernet *GMII and SerDes. For easy connectivity to an Ethernet MAC or PHY.
- Backwards compatibility: for current 802.3 100 base-FX POF implementations.
- Support: JTAG and TR-069 CPE WAN compatibility
- Packaging: Small QFN
- Sensitivity: Up to -21 dBm (ER>10dB) for 1 Gbps at 50m of standard SI-POF with red LED.
- Technology: 65 nm Low power CMOS.
- Area: Small area for low cost and easy integration.
- Power: <250 mW/port (w/o optoelectronics). Advanced power management. Single supply 3.3 V

The KD1000 family comprises several devices that incorporate different interface configurations like GMII/RGMII and/or SGMII as well as Hub, Phy and MAC functionalities.

OTP configuration is an option for large volumes with I2C EEPROM configuration as a family default.

References

[1] FTTH Europe Council. www.ftthcouncil.eu/documents/Reports/Market_Forecast_December_2011.pdf
[2] Council of Europe. Document 12608 May 6th 2011
[3] www.homefibre.com
[4] http://www.comoss.com/ref/news/1000-Rollins-ATT.pdf
[5] www.pofto.org
[6] www.quasar-pof.com
[7] www.china-pof.org
[8] G. D. Forney et al., *"Sphere-bound achieving coset codes and multilevel coset codes"*, in IEEE Trans. on Information Theory, vol. 46, no. 3, May 2000, pp. 820-850