# COMMERCIAL SILICON FOR GIGABIT COMMUNICATION OVER SI-POF

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**Abstract:** This paper describes KDPOF's commercial portfolio of gigabit silicon for communication systems over SI-POF. The targeted markets are described along with their key performance needs. The gigabit portfolio of products is presented with a sample of typical applications. The paper reviews briefly the technology and performance behind the silicon core, which are common to all KDPOF commercial products, with special emphasis on the standard compliant features.

**Keywords:** Spectrally efficient communication. Gigabit Standard. Commercial Silicon. Commercial products. Integrated circuit. POF.

# 1. Introduction

KDPOF will release to market in Q1 2013 the first Application-Specific Standard Product (ASSP) to comply with the VDE v 0885-763 specification (announced in [1]). This silicon will be the first member of a family of products from KDPOF targeted to key POF markets: commercial (home and SOHO), industrial and automotive.

The needs and projections of key customer segments have been taken into account in developing the product requirements. After thorough market research activities, and thanks to the power and flexibility of the VDE specification, this first ASSP for the commercial market will incorporate key features that will enable product integrators to offer, in addition to reliable and stable true Gigabit data speed, key customer demanded features like reduced power consumption and diversity of data interfaces like RGMII and SGMII, at a competitive price.

KDPOF has developed a family of devices that implement the key features of the VDE specification, with outstanding performance built around the following:

- <u>Channel Equalization</u> following the Tomlinson-Harashima Precoding [4, 5].
- <u>Channel Coding</u> based on Multilevel Coset Coding (MLCC) [3]. Based on low-cost binary component codes, MLCC provides a high coding gain FEC scheme with low complexity hardware implement-ability for mid and high spectral efficiencies. The MLCC configurable spectral efficiency property preserves constant coding gain.
- <u>Frame Structure</u> for continuous adaptation and tracking enables a low-cost implementation in receivers of timing recovery, non-linear channel estimation and equalization. It enables for very fast and robust link start-up.
- Energy Efficient Ethernet based on low-power modes [2].

# 2. Markets

Well known for its high reliability in very harsh environments, Plastic Optical Fiber is widely used in the industrial market for field buses and in the automotive industry for its information and entertainment buses (infotainment). Leveraging success in these markets, POF is being installed in home and small office networks, the youngest and fastest growing markets for POF.

Now, and thanks to the new Gigabit family of ASSP for POF, the KD1000 family, new horizons open up for POF in these markets.

Key features of KD1000 are:

- <u>Open and Flexible Interfaces</u>: Ethernet xGMII and SerDes, for easy connectivity to an Ethernet MAC or PHY
- <u>Backwards Compatibility</u>: For current IEEE 802.3 100BASE-FX based POF implementations

- <u>Packaging</u>: 88-pin QFN
- Sensitivity: Up to -21 dBm for 1 Gbps at 50 m of standard A4a.2 SI-POF with red LED
- Technology: 65 nm, low-power CMOS
- <u>Power:</u> < 1 W/port (including optoelectronics); advanced power management; single supply 3.3 V

The KD1000 family comprises several devices that incorporate different interface configurations like RGMII, RMII, MII and/or SGMII and SerDes 1000BASE-X as well as PHY and MAC functionalities. OTP configuration is an option for large volumes with I2C EEPROM configuration as a family default.

Market	Product	Data Interfaces	Comments		
KD1001		RGMII			
Commercial	KD1002	SGMII, SerDes 1000BASE-X	Optimized for high-density switches and SFPs		
	KD1100	2 x S/RGMII	Switching and bonding capabilities		
KD1011 RGMII, RMII, MII		RGMII, RMII, MII	Industrial grade and temperature range		
Industrial	KD1012	SGMII, SerDes 100BASE-X	Optimized for long reach (100 Mbps, >100 m) applications		
	KD105x	Ethernet (xGMII) P2P video (DVP)	Optimized for automotive quality grade, temper- ature range and EMC		
Automotive			Wake-up capability		
Automotive			Real Time (time stamping, PTP, SyncE) support		
			Full duplex over single POF operation mode ASIL>3 safety grade		

Table 1: KD1000 family of ASSP.

# 2.1. Commercial market

Commercially available products in the market today provide data links of only 200 Mbps up to 50 m over standard SI-POF. The typical application for Gigabit POF within the home is as a backbone for the home network.

Providing data rates of more than 1 Gbps and an assured Quality of Service (QoS) to every device in the home, the new family of ASSP offer a future-proof solution and an excellent alternative for the distribution of present and future multimedia services as well as data sharing within the home or small office. These features are ideally suited for emerging IPTV and digital video services, where the Quality of Experience (QoE) and guaranteed data-rate are the most important factors for a successful deployment.

Members of the KD1000 family for the commercial market include the KD1001 and the KD1002. The difference between the two devices is the data interface offered to the MAC side (RGMII and SGMII, respectively).

The KD1001, a fully integrated Gigabit POF Ethernet transceiver, has a small footprint and is optimized for lowpower. This new transceiver implements the physical layer of the VDE v 0885-763 HS-BASE-P (1000BASE-P and xGBASE-P) to transmit data on standard SI-POF, MC-POF or PCS. It is manufactured using a 65nm CMOS process, which offers the best performance, lowest cost, and lowest power for Gigabit POF solutions.

With its SGMII and SerDes 1000BASE-X Ethernet interface, the KD1002 enables SFP applications implementing Gigabit POF connectivity. Moreover, high-density switches can incorporate Gigabit POF ports thanks to this member of the KD1000 family. With a commercial temperature range and backwards compatibility with legacy IEEE 100BASE-FX installations, the KD1002 is an ideal product for home and SOHO networks.

## 2.2. Industrial

Operating in industrial environments (-40 °C to 85 °C), the ruggedized members of the KD1000 family, the KD1011 and KD1012, provide a greater coverage for Fast Ethernet installations throughout the factory floor. With its native capacity achieving modulations and seamless component optimization, KDPOF technology provides Fast Ethernet (100 Mbps) over SI-POF links of up to more than 150 meters following annex 100BASE-P of the VDE specification and using off-the-shelf red LEDs and connectors. This translates into a true and effective capacity upgrade of the existing industrial buses while maintaining the installed low-cost POF infrastructure.

## 2.3. Automotive

Future KD1000-family automotive products will be able to provide a physical layer of 1 Gbps to networking needs within the car that is fully compatible with the same fiber, connectors and optoelectronics components currently installed in lower speed networks. In addition, due to specific features such as remote wake-up, Precision Time Protocol (IEEE1588) and SyncE, KDPOF's automotive ASSP are suitable for the implementation of ADAS (Advanced Driver Assistance Systems) over any kind of POF cabling topology.

KDPOF technology is compatible with many input interfaces. Its interface-encapsulation feature allows the connection of several automotive input devices, such as MOST, DVP for cameras or native Ethernet. Thanks to the native Ethernet compatibility of the KDPOF technology, it is possible to seamlessly integrate KDPOF's PHY with the proposed OPEN Alliance new automotive bus.

## 3. Applications

The KD1000 family members are tailored for specific target markets and applications. Data interfaces have been carefully chosen to enable compact and low-cost final products. Commercial market applications demand standard Ethernet data interfaces like the parallel RGMII and the serial version, SGMII. Due to the high level of integration of the KD1000 family with internal power supplies, clock generation and amplifiers, external support components are reduced to a few capacitors, resistors and indicating LEDs.

The most common and simple application of the KD1001 is a media converter, which uses its RGMII interface to connect with a Gigabit Ethernet PHY, such as Marvell 88E1310. As shown in Figure 1, a compact, low-power, Gigabit media converter can be implemented with a reduced bill of materials (BOM).



Figure 1: Schematic for a 1 Gbps POF-Ethernet UTP media converter.

In the case of high-density switches, a serial interface like SGMII is required to reduce and simplify the board layout. For these applications, the KD1002 is the ideal choice as it is able to interface with Gigabit Ethernet switches like Marvell 88E6182 with a minimum number of lines resulting in a compact board layout and a minimum BOM. An example of such an application is shown in Figure 2.



Figure 2: Schematic for a 1 Gbps POF switch.

## 4. Performance

## 4.1. Link Budget and Sensitivity

Table 2 shows optical performance with three different fibers (Fiber 1 - GH4002, Fiber 2 - HMCKU1000PW and Fiber 3 - MH4002) under different conditions. AOP stands for Average Optical Power.

Home Networking	25°C			70°C		
25 m @ 1 Gbps	Fiber 1	Fiber 2	Fiber 3	Fiber 1	Fiber 2	Fiber 3
AOP at TX (dBm)	-3.15	-3.15	-3.15	-5	-5	-5
POF attenuation (dBo)	-3.7	-5.7	-5.6	-3.7	-5.7	-5.6
RX lens coupling loss (dBo)	-2	-2	-2	-2	-2	-2
Sensitivity at PD (dBm)	-20.5	-20.7	-21.5	-20.2	-20.4	-21.2
Link budget (dBo)	15.35	15.55	16.35	13.2	13.4	14.2
Link margin (dBo)	11.65	9.85	10.75	9.5	7.7	8.6

Home Networking	25°C			70°C		
50 m @ 1 Gbps	Fiber 1	Fiber 2	Fiber 3	Fiber 1	Fiber 2	Fiber 3
AOP at TX (dBm)	-3.15	-3.15	-3.15	-5	-5	-5
POF attenuation (dBo)	-8.5	-9.6	-11.5	-8.5	-9.6	-11.5
RX lens coupling loss (dBo)	-2	-2	-2	-2	-2	-2
Sensitivity at PD (dBm)	-19	-19.6	-21	-18.7	-19.3	-20.7
Link budget (dBo)	13.85	14.45	15.85	11.7	12.3	13.7
Link margin (dBo)	5.35	4.85	4.35	3.2	2.7	2.2

Industrial (Long Reach)	25°C			85°C		
50 m @ 100 Mbps	Fiber 1	Fiber 2	Fiber 3	Fiber 1	Fiber 2	Fiber 3
AOP at TX (dBm)	-3.15	-3.15	-3.15	-6	-6	-6
POF attenuation (dBo)	-8.5	-9.6	-11.5	-8.5	-9.6	-11.5
RX lens coupling loss (dBo)	-2	-2	-2	-2	-2	-2
Sensitivity at PD (dBm)	-33	-33.1	-33.2	-32.6	-32.7	-32.8
Link budget (dBo)	27.85	27.95	28.05	24.6	24.7	24.8
Link margin (dBo)	19.35	18.35	16.55	16.1	15.1	13.3

Industrial (Long Reach)	25°C			85°C		
100 m @ 100 Mbps	Fiber 1	Fiber 2	Fiber 3	Fiber 1	Fiber 2	Fiber 3
AOP at TX (dBm)	-3.15	-3.15	-3.15	-6	-6	-6
POF attenuation (dBo)	-18.3	-18.1	-20.3	-18.3	-18.1	-20.3
RX lens coupling loss (dBo)	-2	-2	-2	-2	-2	-2
Sensitivity at PD (dBm)	-32.9	-32.8	-33.1	-32.5	-32.4	-32.7
Link budget (dBo)	27.75	27.65	27.95	24.5	24.4	24.7
Link margin (dBo)	9.45	9.55	7.65	6.2	6.3	4.4

Home Net ABR perfor- mance at 25°C (Mbps)	50 m	75 m	100 m	
Fiber 1 - GH4002	1000	850	400	Fiber 1: <b>GH4002</b>
Fiber 2 - HMCKU1000PW	1000	850	550	Fiber 2: HMCKU1000PW
Fiber 3 - MH4002	1000	850	550	Fiber 3: <b>MH4002</b>

Table 2: Link budget, link margin and ABR performance with three commercial POF fibers under different conditions.

#### 4.2. Power supply and consumption

The power supply strategy has been implemented to balance power efficiency with board layout flexibility. The ASSP can be single-supplied with a regulated 3.3V external source. Thanks to the internal regulators (see Figure 3), the needed internal voltages are self-generated (1.2V and 2.5V).

If external power supplies are available, the ASSP can take advantage of the on-board sources and avoid internal voltage generation with the benefit of higher power efficiency and lower dissipation.

Overall, depending on the supply scheme chosen by the board designer, power consumption could range between a minimum of < 500 mW (no internal regulation) and a maximum of < 8 mW (single 3.3V supply).



Figure 3: Internal voltage supply scheme in which all required voltages are generated internally from the single 3.3V supply.

## 5. Optical Transceiver

In combination with KDPOF's KD1000 ASSP, the AVAGO Technologies analog POF transceiver provides the system designer with the ability to implement Gigabit Ethernet over 2.2mm jacketed standard POF.

One of the main features of the analog POF transceiver is the possibility to connect POF cable using a simple insert and lock system which eliminates the need for a connector. This enables a very fast installation and maintenance.

This compact transceiver is lead free and compliant with RoHS. The form factor is similar to the well-known RJ45 connector.

The analog POF transceiver package contains the two optical subassemblies, transmitter and receiver, which are mounted in the housing for bare fiber connection. The metal shield provides excellent immunity to EMI/EMC.

The main features of KDPOF/AVAGO solution are:

- Easy bare fiber termination solution for 2.2mm jacket POF
- EMI/ EMC robust
- Operating temperature range -40°C to 85°C
- Single 3.3V power supply operation
- Integrated optics to efficiently focus light for fiber coupling



Figure 4: Optical transceiver with Avago Technologies analog POF transceiver.

#### 5.1. Transmitter

Two devices compose the transmitter: a linear current silicon driver and a 650nm fast LED. The driver linearly converts a differential input voltage signal into current for proper LED operation. The driver implements a slow automatic Extinction Ratio (ER) and current bias control by sensing the input voltage signal. This control loop ensures the linear operation of the LED in the full range of temperature conditions without optical clipping.

The extinction ratio (ER) and bias control, together with advanced current pre-emphasis circuitry and highly linear wide-band current steering, enable the optical transmitter for advanced linear modulations as required to achieve reliable 1 Gbps over POF in combination with the KDPOF KD1000 ASSP.

The fast LED is the same device already qualified for automotive applications, thus leveraging the robustness required by the automotive market to Gigabit over POF applications. Under the control of KD1000, the transmitter can be set into a power-saving state effectively enabling a Low Power Idle (LPI) mode as defined in VDE v 0885-763.

## 5.2. Receiver

The receiver part of the transceiver is a complete monolithically-integrated linear fiber optical receiver that comprises an integrated pin-photodiode with a diameter of 390  $\mu$ m and the necessary amplifiers and logic. The circuit is completely shielded against stray light and electromagnetic fields. This, along with its high sensitivity, makes it an ideal choice for applications with over-illuminated receivers of large-core fiber transmission systems in harsh environments. The receiver is manufactured in a silicon technology optimized for low-cost high-reliability fiber communication applications.

The receiver features a highly linear transimpedance amplifier for signals with a wide average optical input power range of up to 0 dBm at a wavelength of 670 nm. An integrated automatic gain control circuit ensures optimal and predictable behavior for modulation signals with high crest factors. At the highest transimpedance a bandwidth of 30 MHz is attained.

The optical receiver provides a monitoring current output, which represents the average optical power collected from the photodiode. As in the case of the transmitter, the receiver can be set into a power-saving state by externally forcing this output to a voltage above a threshold, effectively allowing the implementation of Low Power Idle (LPI) modes.

## 6. Evaluation Kit

To enable customers to evaluate the KD1001 product, KDPOF has released the KD-EVK1001-MC Media Converter Evaluation Kit. This kit is a tool to design and evaluate high-speed prototypes using the KD1001 Gigabit Ethernet POF transceiver IC (10 mm x 10 mm, 88-pin QFN plastic package). The Evaluation Kit contains two KD-EVB1001-MC media-converter boards, which interface the free graphical user interface (GUI) tool from KDPOF for PC/MAC/Linux platforms. This flexible and self-contained kit enables easy monitoring and configuration, easy evaluation of performance and real time monitoring.



Figure 5: KD-EVB1001-MC media converter board. The Media Converter Evaluation Kit contains two boards to configure a point-to-point link to evaluate the performance of the KD1001 ASSP.

As shown in Figure 6, the kit allows the installation of a test set-up configured as a point-to-point POF link using two media-converter boards. A single computer can be used to monitor low-level parameters of the link. The connection between the computer and the boards is made using the supplied USB2All box. The kit is easy to use with common lab equipment, without need for additional items. A GUI tool eliminates need for additional BER equipment. This kit enables real-time monitoring of the link, and reporting key performance parameters like: distortion, frequency and time channel response, MLCC constellations, PHY and net rates, SNR at decoding, received average optical power and BER after FEC. Status of the KD1001 is accessed through the GUI, which is run on a computer connected via USB.



Figure 6: Typical test set-up using the components of the kit.

The GUI, shown in Figure 7, includes several panels, which provide complete access to the KD1001 transceiver, link status and parameters. The GUI also includes a BER panel to capture bit error rate at the receiver.



Figure 7: GUI tool which provides reported PHY information in real time.

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