

# GigaCoupler – A scalable Opto-Isolator with Gbps-Data Transmission

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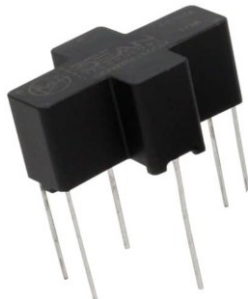
## Abstract

Optocouplers are widely used for signal transmission between galvanically separated circuit parts. For decades, these have been an integral component of electronic modules. The wide selection becomes limited, and costs rise disproportionately for data rates >50 Mbps or isolation voltage exceeds several kV. This is where the GigaCoupler comes in. It is a novel short-range optical transceiver technology. In this paper, we introduce the concept and describe the implementation. Results of initial testing show that a data rate of 1.25 Gbps is achievable with an isolation voltage in the double-digit kV-range and a footprint of only 0.5 cm<sup>2</sup>. Potential applications such as optical probes, isolated A/D or D/A converters; an alternative to circuit boards with embedded waveguides and a rotary usage are in the focus of this contribution.

## 1 Introduction

Optocouplers transfer signals using light waves. The in- and output are electrically isolated. Typically, voltage differences of up to 5 kV are possible between the connecting legs [1]. Usually, uni-directional transmission is supported by off-the-shelf optocouplers. Typically, data rates of around 10 Mbps are already considered as high-speed [2]. The selection is very limited when a data rate above 50 Mbps is required [3].

High voltage isolation requires a large form factor, design restrictions and a limited data rate. Such a component is shown in **Figure 1**.



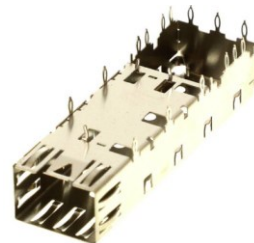
**Figure 1** Specific optocoupler package [4]

If both are of interest: a high insulation and a high data rate, then “SFP” (Small Form Factor Pluggable) modules may be used. They consist of two optical transceiver-modules. In addition, these support bi-directional communication. They were developed for network connections and therefore suitable for low-loss data transmission over longer distances. A specific embodiment in this area is shown in **Figure 2**. It is called “SFP+ AOC (Active Optical Cable)” and has its main area of application for high-speed connections within racks and between neighboring racks [5]. The connection to a printed circuit board (PCB) is established by the required port cages. A sample can be seen in **Figure 3**. The required area for a single SFP module is 8 cm<sup>2</sup>. However, for an opto-coupler application, two of them are required, and the bending radius of the fiber cable should not be neglected. Due to large form factors and high costs, SFP

solutions are only a makeshift for intra- or inter-board connection.



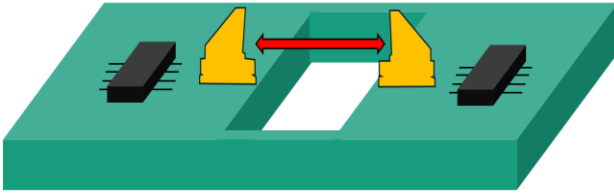
**Figure 2** SFP+ and AOC [5]



**Figure 3** typical SFP cage [6]

Our solution represents a new approach which is called “GigaCoupler”. The transmitter (Tx) and the receiver (Rx) are spatially separated from each other. The GigaCoupler contains a second link for full-duplex functionality. The outward and the return path overlap spatially. This goes along with 2 benefits: it minimizes the required space, and the system becomes rotation capable. In contrast to the SFP solution, no optical fiber is required which reduces form factor, costs and complexity. All that is required is a line of sight between both transceivers. The GigaCoupler enables a surface-mountable assembly. **Figure 4** illustrates the use case of an intra-board link. The system is very robust, hence positioning tolerances are no challenge. Furthermore, the isolation can be tailored by setting the distance between the transceivers. Even with just a few centimeters,

the isolation voltage far exceeds that of conventional opto-couplers. Leakage currents can be effectively kept small by inserting a slot like depicted in **Figure 4**.

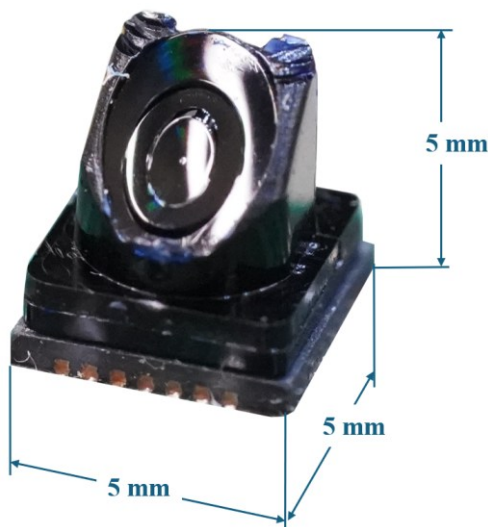


**Figure 4** GigaCoupler integration scheme as intra-board link

The introduction of the GigaCoupler concept and proof of feasibility are part of a previous publication [7]. This article focuses on the analysis of potential applications.

## 2 Implementation of the GigaCoupler concept

The lens is a key component of the transceiver. It was carefully designed to meet the specific requirements of the GigaCoupler application. The lens has been shaped using an ultra-precision molding tool. An easy moldable polymer material was selected for the proof-of-concept phase. **Figure 5** shows the transceiver package consisting of free form lens and QFN (Quad flat no leads) substrate. That QFN-base enables surface mounting.

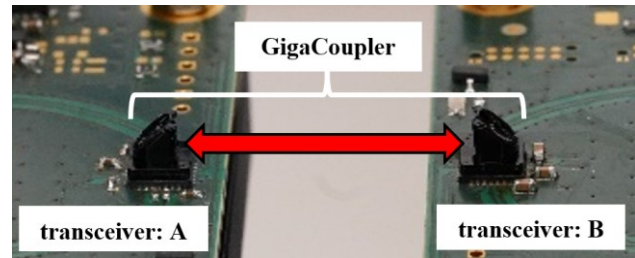


**Figure 5** View of a GigaCoupler transceiver

The transceiver was soldered onto PCB. Two of these are placed in front of each other as shown in **Figure 6**. In order to assess the quality of the transmission link, the occurring bit errors are determined. The test also examines which misalignment between the transceiver-couple can be balanced by these before an increase in bit error rate (BER) is observed.

The data transfer was considered acceptable for a maintained error rate of max. 1 on a billion transferred bits. The acceptable error rate cannot be specified in general terms.

This depends on the application scenario and here especially on the communication protocol and the possible error correction.



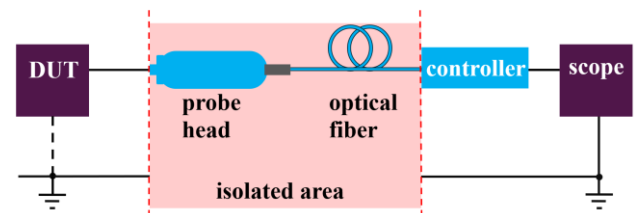
**Figure 6** GigaCoupler integration as inter-board link (distance of transceivers: 23 mm)

## 3 Implementation types and potential application areas

There are many conceivable scenarios for the GigaCoupler. These range from feedback control in high-voltage power supplies, high speed digital in-/ output at peripheral interfaces of computers or isolated interfaces of PLCs (Programmable Logic Controller) to many other application fields. Following, a few areas of application are explained in detail to illustrate potential use cases of this product.

### 3.1 Isolated probing system

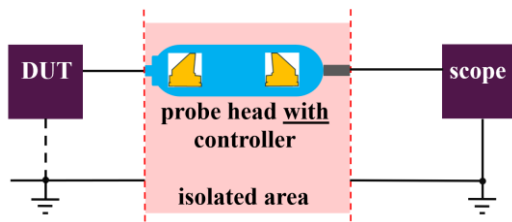
Probes are essential accessories for oscilloscopes, power analyzers, spectrum analyzers a similar equipment. Certain applications require a galvanic isolation of the DUT (Device under Test) from ground and oscilloscope. This may be the case for instance when modern semiconductor components like IGBTs (Insulated Gate Bipolar Transistor) with voltage levels up to 6.5 kV with stately shorter slew rates or motor drives should be characterized. These isolated probes are featured by a high common mode rejection ratio (CMRR). The elimination of electrical return paths gives the chance to keep this value as high as possible. High quality probes allow a CMRR value in the mid 5-digit range at a frequency of 1 GHz [8], enabling the measuring of small signals despite a high voltage and fast switching environment. The RT-ZISO from Rohde & Schwarz is such a high-end probing system [8]. The fiber architecture used for this purpose isolates the DUT from the measuring setup at a frequency of up to 1 GHz. **Figure 7** illustrates the structure of that probing system.



**Figure 7** Isolating using optical fiber – illustration based on [8]

The substitution of optical fiber by GigaCoupler would lead to a more compact and inexpensive probe setup. The

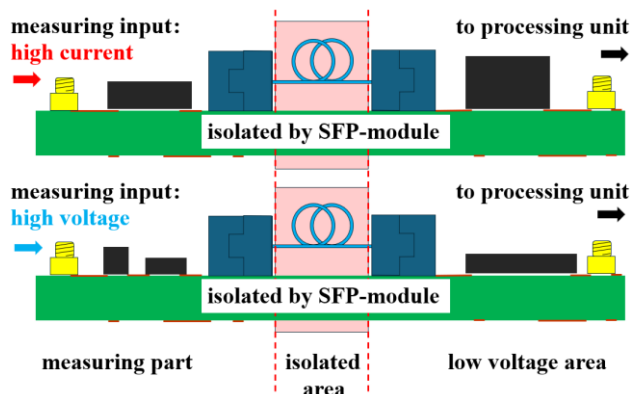
arrangement of controller device and probe head inside of one common unit can save space which is shown in **Figure 8**.



**Figure 8** Probe head with integrated controller unit – isolated by GigaCoupler

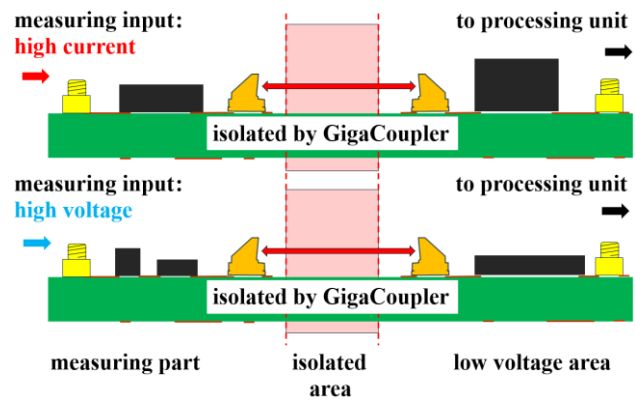
### 3.2 Power analyzer

The precise determination and analysis of power shares is of great importance for the efficient generation of energy and its use. The measurement of active power is performed by the simultaneous measurement of current and voltage. The measuring input must be galvanically separated from the processing unit. A common realization is shown in **Figure 9**. Besides the use of SFP-modules, the galvanic separation can also be performed by capacitively or inductively couplers.



**Figure 9** View of current and voltage measuring channel with isolating fiber

The requirements for power analyzers are constantly increasing. First, there is the rising voltage. The current standard for electrical measuring devices and lab equipment considers voltages up to 1.5 kV (DC) now [9]. Further challenges can be expected in continued development of certain components like WGBs (Wide Bandgap Semiconductors) or at restructuring of the energy nets towards HVDC (High Voltage Direct Current) with the aim of low loss transmission between the producer of energy and consumers [10]. In addition to the required voltage strength, another focus lies on a good synchronization of current and power measurement. For example, the runtime must not exceed a few nanoseconds between the current and the voltage measuring input [11]. In order to satisfy both the required galvanic isolation and a high synchronization, the use of a GigaCoupler holds great potential for improvement. The construction with GigaCoupler can be seen in **Figure 10**.

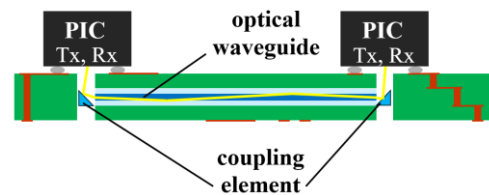


**Figure 10** View of current and voltage measuring channel with GigaCoupler

A total of 4 transceivers is required for both measuring channels. The distance between these depends on the isolation strength. Since this is in the single-digit range, an air gap of 1 cm to 2 cm is sufficient.

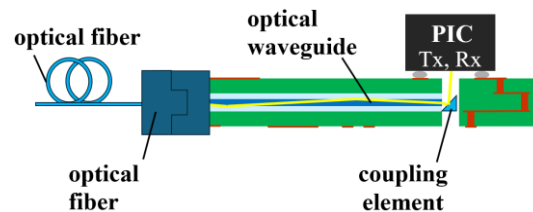
### 3.3 Electro-optical circuit carrier

For three decades now, it has been announced that the optical printed circuit board would be ready to take over the entirely electrical boards as soon as the physical limits of copper have been reached. The principal structure of an electro-optical board is depicted in **Figure 11**.



**Figure 11** Cross-sectional view of a circuit carrier with electrical and optical interconnections

In addition to optical intra-board solution, a transmission of light via optical waveguides is also conceivable from board to backplane or from board to optical fiber and vice versa. This is exemplary indicated in **Figure 12**.



**Figure 12** View of an electro-optical circuit carrier with fiber connection

The optical approach might work but comes with challenges and drawbacks. On the one hand, the limits of the copper tracks were repeatedly raised. On the other hand, the integration of an optical layer in a printed wiring board comes with disadvantages like partially production under clean room conditions, a rather exotic layout process, the necessity of using special chips with optical I/Os (PIC = Photonic Integrated Circuit), additional circuit elements for

beam deflection/ coupling, the thermal mismatch between pure polymer-layers and the conventional multilayer stack and so on.

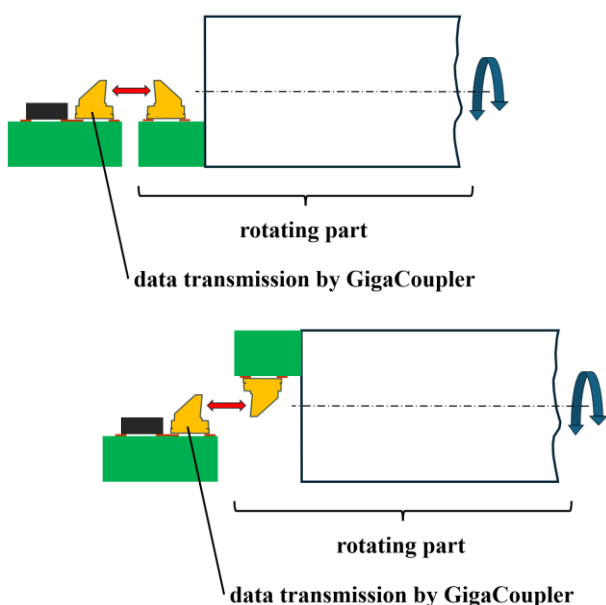
The intended optical paths inside the multilayer structure could be replaced by the GigaCoupler, too. This approach would be able to bypass the above-mentioned drawbacks appropriately. There is a need for higher bandwidths in applications like data center racks with a second focus on low power consumption or flight computers with an optical transmission via plug-in PCBs and backplane [12]. Usually, several optical connections in parallel are required. A slot for graphic cards is typically connected with 16 lanes for example. Although these 16 interconnections could be replaced by 2x 16 transceivers, the approach might be costly. A promising alternative could be multi-channel GigaCoupler transceivers.

### 3.4 Slip ring replacement

Mechanical slip rings are widely used because they are inexpensive, but they are limited in data rate and face wear. The optical rotational transmission via Fiber Optical Rotary Joints (FORJ) is expensive and requires complex modules. The available capacitive type [13] doesn't require optical fibers, but poses other challenges. The small distance between rotating and non-rotating part of slip ring requires a sophisticated assembly and the sensitivity to electromagnetic interference must be viewed critically.

The GigaCoupler can replace the existing contactless solutions. Compared to FORJ, the GigaCoupler would be more cost-effective and in relation to capacitive slip rings the mentioned drawbacks can be eliminated. This gives the end user a simpler integration if only conventional (electrical) connectors are required and a conversion from electrical to optical and back is not needed.

**Figure 13** shows a possible configuration for an on-axis application. The figure shows an arrangement with a rotation of 0° and 180°.



**Figure 13** Example of a GigaCoupler arrangement for rotating application

Requirements for a higher bandwidth can be met by further transceiver couple(s).

## 4 Summary and Outlook

With the implementation of optical transceivers in parallel to a PCB shown here, it is possible to transfer data at a baud rate of 1.25 Gbps and potentially more with the next generations. Optocouplers cannot compete with this. Further advantages of the GigaCoupler lie in tracking resistance and achievable isolating voltage. Due to the separation into two transceivers, these are much higher than what can be obtained from an optocoupler. These benefits and the small form factor will be of interest for applications which have reached their limits here so far. The special lens design and the concept of GigaCoupler are protected by several IP rights.

This works shows that several applications can benefit from the GigaCoupler technology. The substitution of the fiber in optical probes results in a significant reduction in space if controller and probe are merged in a single housing. Power analyzers can benefit from isolation and high bandwidth. Excessive efforts and exotic layer structure and assembly are avoided by eliminating data transmission via embedded waveguides in PCBs. Finally, it is worth highlighting the rotational capability that enables further application fields.

Next steps include an optical characterization and a qualification of GigaCouplers behavior under rough environmental conditions. A data rate of 1 Gbps is not the upper limit. The target is 10 Gbps via an intermediate step with 5 Gbps.

## 5 Acknowledgment

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