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TECHNICAL REPORT

colour inside

Roadmap of optical circuit boards and their related packaging technologies

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ROADMAP OF OPTICAL CIRCUIT BOARDS AND THEIR RELATED PACKAGING TECHNOLOGIES

FOREWORD

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IEC 62658, which is a technical report, has been prepared by IEC technical committee 86: Fibre optics.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86/442/DTR	86/453/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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ROADMAP OF OPTICAL CIRCUIT BOARDS AND THEIR RELATED PACKAGING TECHNOLOGIES

1 Scope

This Technical Report covers the roadmap of optical circuit boards, and its related packaging technologies including optical circuit board connectors and optical modules on boards.

2 General

2.1 Background of optical packaging technology road map

The volume of network traffic is dramatically increasing due to the amount of data being captured, processed, conveyed and stored as digital information. This information is generated from many sources, including critical business applications, email communications, the Internet and multimedia applications which have collectively fuelled an increase in demand for data networking and storage capacity. In addition, the proliferation of media rich applications, such as digital music and video sharing services is fuelling a concurrent increase in data processing in data centres [1][1]. The growth in network traffic attributed to personalized content is 20 % per month, giving rise to a doubling of network traffic every 1,5 years. However, this is out of step with the input/output (I/O) performance or I/O throughput of servers, which doubles every 2 years. Therefore, there is an increasing gap between the performance evolution of network equipment such as servers, and the growth in network traffic (Figure 1) [2].

1 Figures in square brackets refer to the Bibliography.

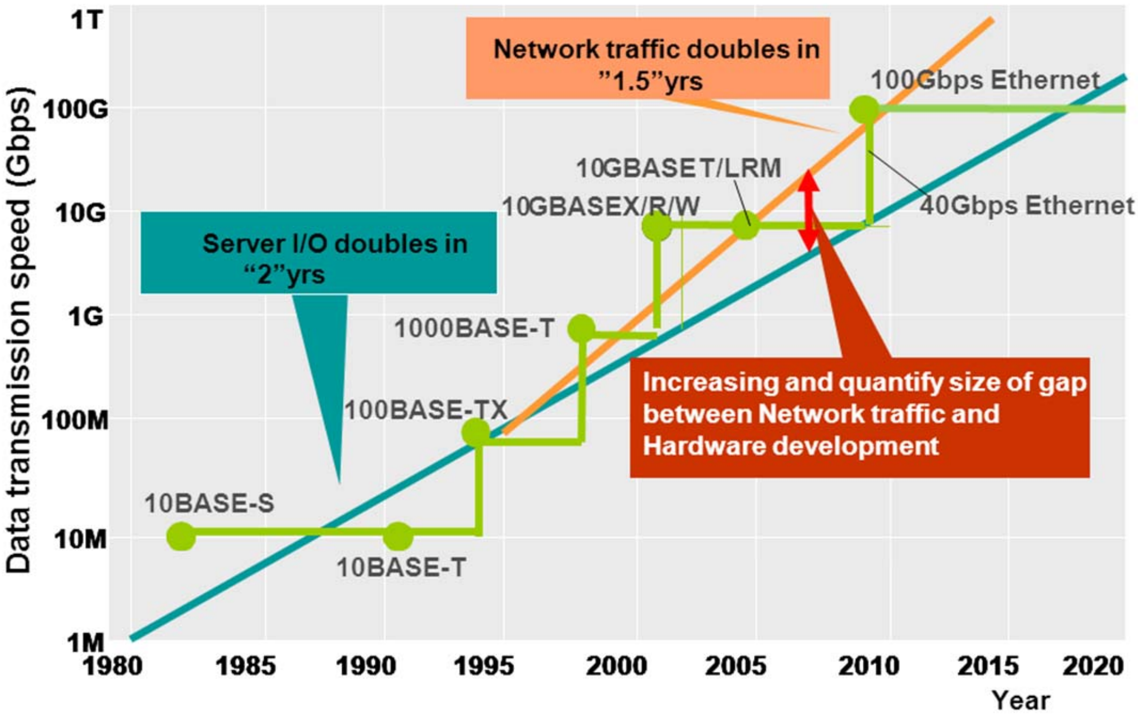

Figure 1 – Data transmission speed and capability trends for network traffic and server systems [2]

In general, system power consumption will increase as the volume of internet traffic expands. By 2020, power consumption in network routers in Japan will reach the gross power generation of Japan in 2005. An energy saving by 3 to 4 orders of magnitude in network router technology is required in 2030 to meet the stipulated targets in the Kyoto protocol [3] (Figure 2).

In addition, the bandwidth and density requirements for interconnects within high-performance computing systems are becoming unmanageable, due to increasing chip speeds, wider buses and larger numbers of processors per system [4]. The increase in system bandwidth and density required to satisfy this demand would impose unmanageable cost and performance burdens on future data networking and storage technologies.

An alternative to the current electrical printed circuit board (PCB) interconnect technology is required across multiple high-speed application spaces to mitigate this common trend. Optical interconnects are expected to bridge the performance gap between network hardware and traffic, and give rise to a reduction in hardware power consumption while increasing bandwidth density by over two orders of magnitude.

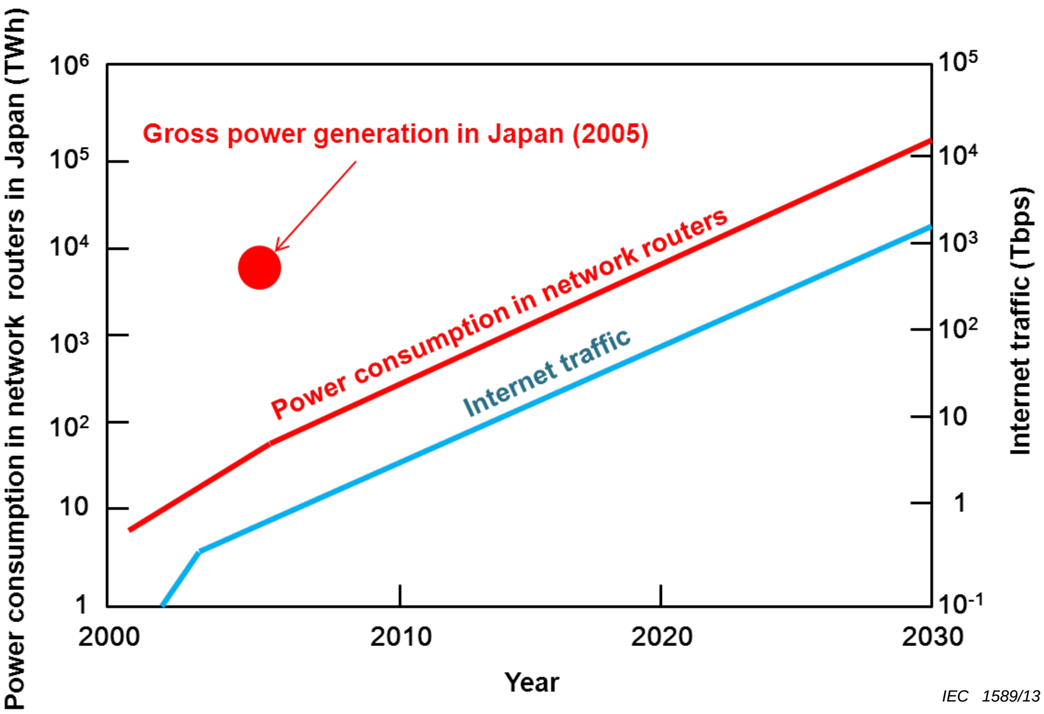

Figure 2 – Internet traffic and router power consumption in Japan [5]

2.2 Advantages of optical interconnects

Optical interconnects will be fundamental in further scaling the performance of networking, server, router, data storage and high performance computing technologies.

The design and development of future higher capacity network hardware will be hindered by high-frequency electronic constraints such as crosstalk, dielectric loss, skin effect, electro-magnetic interference (EMI) and high sensitivity to impedance matching. The maximum permissible density of electronic transmission lines is determined by the crosstalk incurred between electronic channels. The higher the signal frequency, the greater the separation between electronic channels required to keep crosstalk within acceptable levels. For example, the line pitch between adjacent electronic channels required to convey a signal data rate of 10 Gbps is 3 times larger than that required to convey a signal data rate of 3 Gbps. This makes it more difficult to design and manufacture a high-capacity printed circuit board, as the electronic transmission line density must decrease as the signal speeds increase. The adoption of optical interconnects will mitigate these design constraints. Optical waveguides neither produce nor are affected by electro-magnetic interference, and are therefore not constrained by electromagnetic compatibility regulations that impose a severe cost burden on the design of high-speed copper printed circuit boards (PCBs) and supporting interconnect technologies, such as connectors. The layout advantages offered by optical waveguides will give rise to a reduction in the functional area and layer count of the PCB. The level of reduction will strongly depend on the application, with the more I/O intensive applications subject to the greatest potential reduction in PCB volume.

Another advantage of the adoption of embedded optical interconnects in high-capacity networking, server, router, data storage and high performance computing technologies is a reduction in power consumption.

As the network traffic increases, the power consumption of network hardware is expected to increase 5 fold by 2025 and 12 fold by 2050 [6]. For data transmission at speeds greater than 10 Gbps, current electrical interconnects will need to be enhanced by active signal conditioning devices such as pre-emphasis and equaliser circuitry to ensure that the signal distortion or degradation due to the mitigating factors described above remains within acceptable levels. In addition, the power consumption of electronic signal drivers will also increase. As signal frequencies increase, an electronic signal driver will need to ramp up the signal power in order to overcome the fundamental loss mechanisms on a copper transmission line. These loss mechanisms include dielectric loss, skin effect, and the surface roughness of the copper trace, which accentuates skin effect by increasing the effective surface area. Dielectric loss effects can be mitigated to some extent by using specially high frequency printed circuit board laminate materials, however at mounting cost to the system. Long distance optical interconnects such as single mode optical fibres for multi-kilometre data transfer also require adaptive equalisation, but for very short distances, such over a system backplane this is certainly not required (Figure 3).

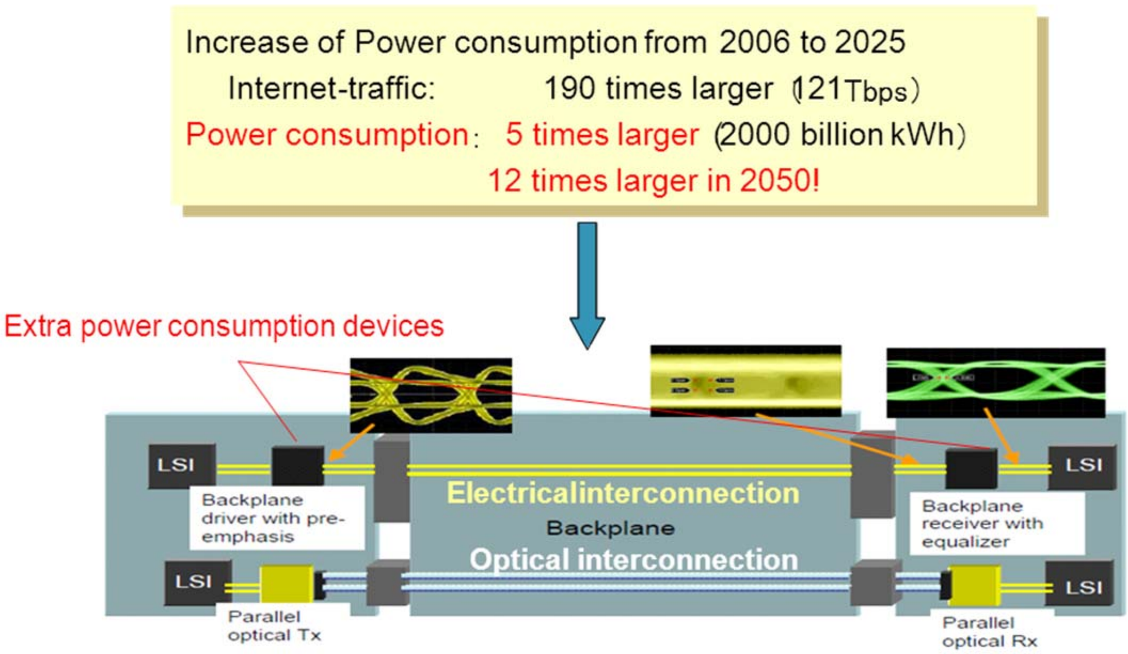

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Figure 3 – Increase of power consumption in future network

Though optical interconnects will require active devices to convert electronic signals to optical signals and vice versa, it is expected that the power consumption due to these conversion technologies will be less than those due to electronic signal driver and signal conditioning technology for interconnects over a given length. Cisco's green story [7] provides a breakdown of power consumption in network technology systems. Among prevailing network technologies, servers are the most power consumptive accounting for 50 % of all power consumption in the network systems space, followed by data storage systems, which account for 35 % [8]. This indicates that the adoption of optical interconnects in network server and storage systems would be an effective path to realizing green information and communication technology [9]. Figure 4 shows the comparative power consumption profiles of a 10 Tbps electrical router and a 10 Tbps optical router, whereby the optical router consumes 20 % less power than the electrical router.

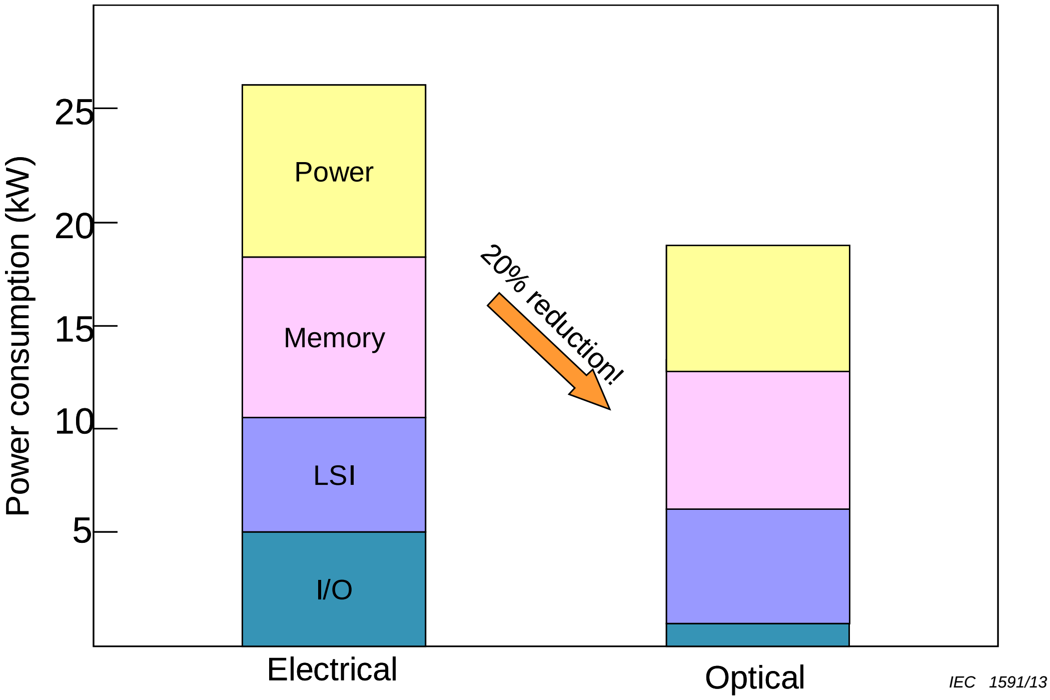

Figure 4 – Comparison of power consumption of 10 Tbps electrical and optical routers

2.3 Planar embedded optical waveguides

It is proposed that the resulting performance bottleneck due to the electrical constraints described above be substantially reduced by conveying high-speed data optically instead of electronically. This requires that optical channels be incorporated into the system at the printed circuit board (PCB) level. While many technology solutions have been put forward and commercially deployed to support embedding conventional optical fibres onto printed circuit boards, there has been a great deal of research and development activity centred in Europe looking at the fabrication and deployment of planar optical waveguide channels on/ in printed circuit board substrates[10] to [18]. The key academic contributors to research into planar optical waveguides include University of Cambridge, University College London, Vrije Universitaet Brussels, University of Ghent, Loughborough University, Heriot-Watt University and Fraunhofer Institute IZM, while the key industrial contributors include IBM Research in Zürich, Xyratex Technology, TTM Technologies, Vario-optics, TE Connectivity, FCI and Dow Corning.

Collectively research and development activities in this field have included a wide range of planar waveguide fabrication techniques, in-plane and out-of-plane waveguide coupling and connector solutions. Though this activity has been mostly centred on polymer waveguides, some research and development has been carried out on embedded planar glass waveguides as well.

3 Standardization of board-level optical packaging

3.1 Role of IEC TC86/JWG9 (with TC91)

Broadband technologies and services using optical networking systems have come into widespread use, not only at the backbone level but also at the access level. As data bandwidths continue to increase, the optical interconnect must be driven even further down, to the system level, which requires the development of suitable opto-electronic packaging and interconnect solutions to accommodate the system environment.

Within the system, packaging and interconnect solutions are being developed to accommodate the multiple levels of system embedded optical interconnect including:

a) System level where daughter cards communicate optically with one another across an optical backplane [19];
b) Board level where individual chip sets or mid-board transceivers communicate optically with one another across an optical PCB [4];
c) Chip level where different components within a chip or multichip module are optically connected to each other;

These technologies naturally shall include optical or electro-optical PCBs, opto-electronic modules (such as mid-board transceivers) and active and passive optical connectors.

To promote the proliferation of these technologies, their interfaces, test and measurement procedures, and performances should be standardized. The standardization of fibre cables, optical network connectors, and fibre interconnecting devices and passive components fall within the purview of the relevant working groups in TC86 subcommittees. No task group had been assigned to look at system-level optical packaging and interconnect technologies until the establishment of the IEC TC86/JWG9 (with TC91) in 2009, which was specifically tasked with the standardization of in-system optical circuit board packaging, including performance and reliability requirements, optical interconnect interfaces, and their test methods as shown in Figure 5.

Supporting technologies such as optical PCB connectors and board-level optoelectronic modules are being considered in other parallel working groups in TC86 with the support of JWG9.

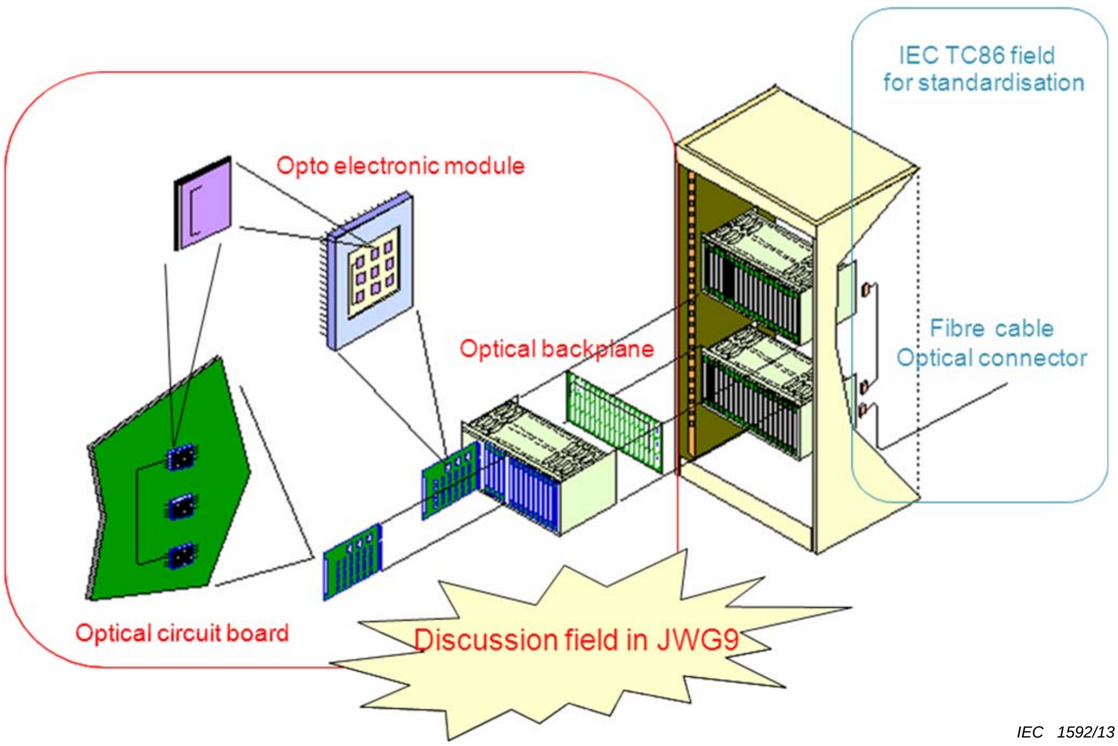

Figure 5 – Discussion field in IEC TC86/JWG9 (with TC91)

3.2 Optical circuit boards [20]

Optical circuit boards have arbitrary optical transmit patterns with straight / crossing / bent / tapered optical channels with input/ output optical ports. The optical channels would comprise optical fibres (glass, polymer) and/or planar optical waveguides (glass [21], polymer [10]). The boards can be categorized as flexible or rigid according to the supporting substrate (Figure 6). Optical boards can also fall into a third category, flexi-rigid, whereby the optical channels are housed on a flexible substrate, part of which is fastened to a rigid substrate and another part of which is free to float. This category of optical board would be suitable for direct passive board-to-board optical connects where one or each of the connecting boards would typically need a compliant section to mitigate board misalignment and vibrations.

The supporting substrate may comprise a single or multilayer printed circuit board in one embodiment. A circuit board consisting of an optical circuit board and electrical circuit board is defined as an electro-optic circuit board (EOCB).

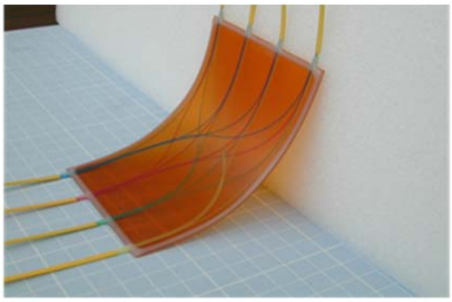

Figure 6a- Flexible optical circuit board using optical fibres

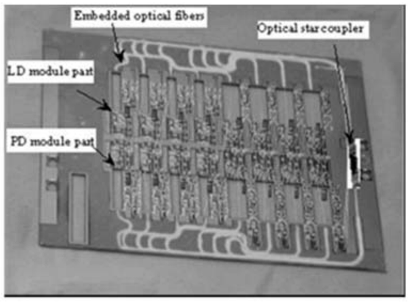

Figure 6b- Rigid optical circuit board using optical fibres

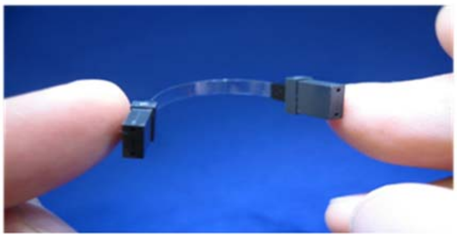

Figure 6c- Flexible optical circuit board using optical waveguides

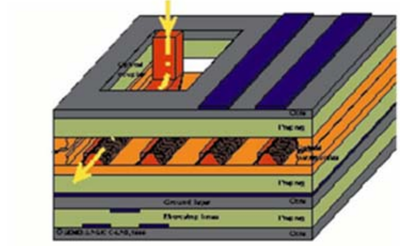

Figure 6d- Rigid optical circuit board using optical waveguides

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Figure 6 – Classification of optical circuit boards

3.3 Optical backplanes [22]

An optical backplane is a circuit board, which supports optical connectors, to which two or more daughter cards can be connected, and optical channels forming an optical pathway or pathways between the at least two daughter cards.

Daughter cards are usually connected orthogonally to the plane of the backplane giving rise to a bookshelf-type board arrangement. Optical backplanes will often include electrical layers to accommodate power distribution, control signals and low-speed communication bus signals along with optical layers to convey high-speed optical signals between the daughter cards attached to the backplane. Optical backplanes could also be typically referred to as optical motherboards or optical midplanes.

Optical backplanes can be divided into four categories based on optical interconnect type, electrical/optical connector topology and daughter card arrangement as shown in Figure 7.

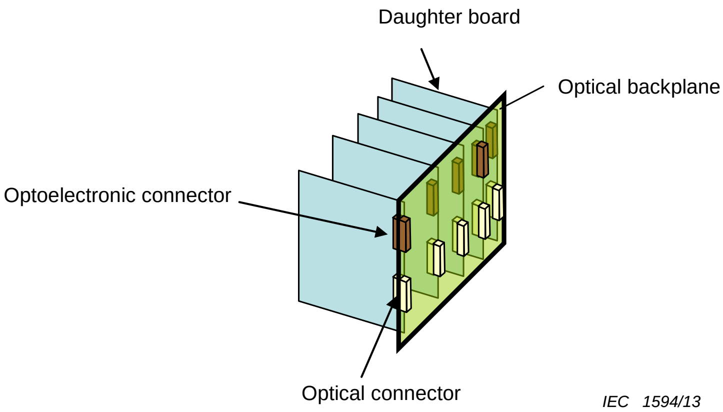

Figure 7a – Type A

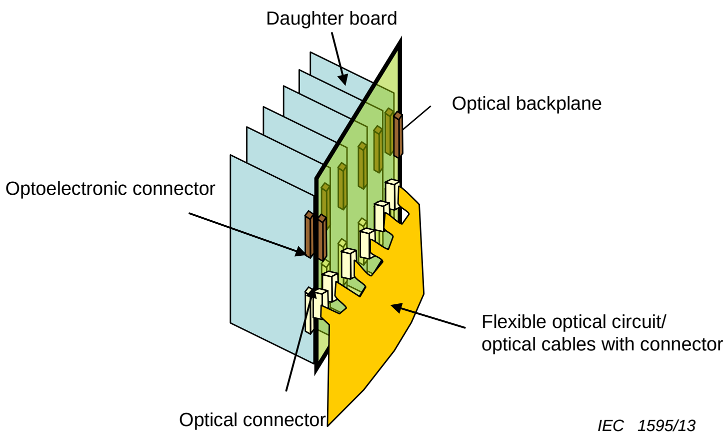

Figure 7b – Type B

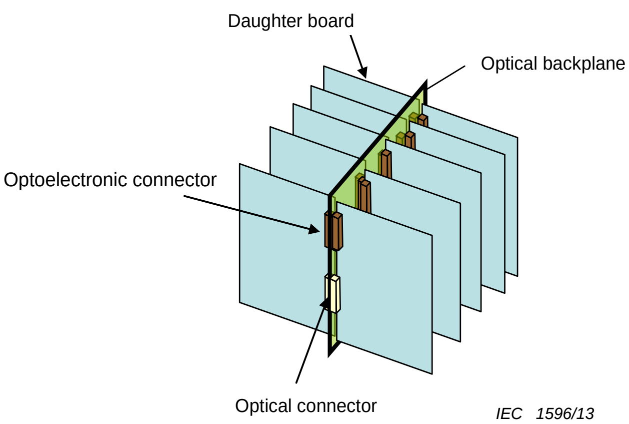

Figure 7c – Type C

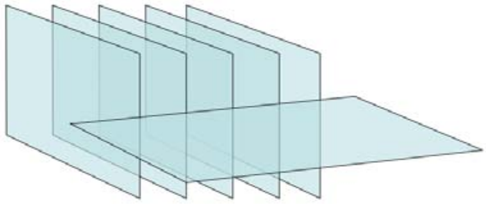

Figure 7d – Type D

Figure 7 – Four types of optical backplane applications

3.4 Optical circuit board connectors [23]

Optical circuit board connectors include board-to-board optical connectors, and module-to-board or module-to-module on board optical connectors (Figure 8). A right-angled optical connector or RAO connector is a multi-channel parallel optical connector, which can connect two optical circuit boards or an optical circuit board and optical ribbon cable orthogonally to each other. The optical connection interface is typically based on or compliant with MT ferrule technology, whereby two MT ferrules incorporating either circular fibres (glass or polymer) or planar waveguides (polymer on a flexible substrate) are connected to each other. Preferably, the same type of optical waveguide is used in both connecting sections in order to minimize optical losses due to numerical aperture or size mismatches. Fibre-based MT parallel optical connectors are well known and commercially available. Waveguide based MT ferrules have been demonstrated [10].

The right-angled bend in the connector can be achieved by an optical fibre or flexible planar waveguide bent by 90°, such that the radius of curvature does not exceed the bend limit of the fibre/waveguide. This technology is commercially available.

In one example, an optical board connector of the type SF (sagged fibre) makes use of the elastic force (or buckling force) of sagged fibre to enable an effectively spring-loaded fibre optic connection between boards or between on-board modules. The bare fibres are typically assembled in a micro-hole or V-groove. The technology is commercially available.

Module-to-module or module-to-board connector type PT (photonic/electronic tied) is a right-angled fibre optic connector, which can be plugged or unplugged from surface emitting/receiving opto-electronic modules mounted on the board.

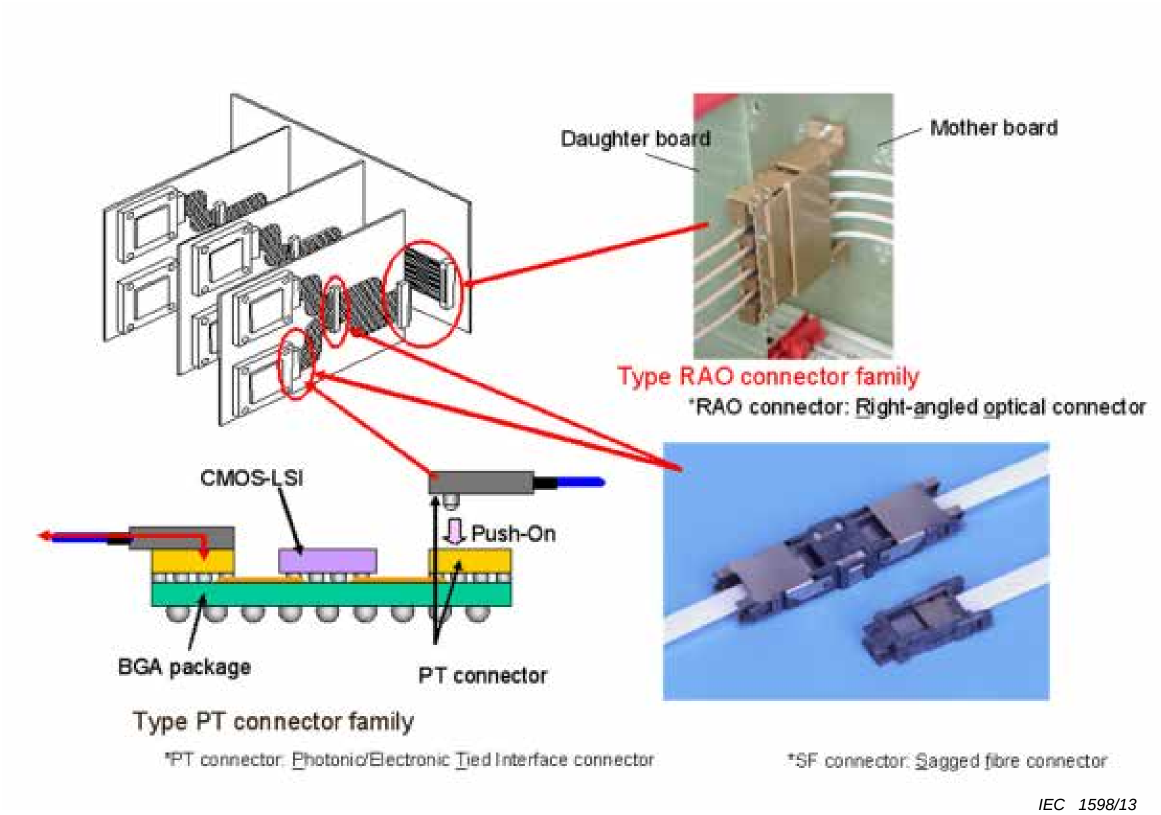

Figure 8 – Classification of optical circuit board connectors

3.5 Opto-electronic modules on boards

Two types of on-board optoelectronic (OE) module are hereby defined (Figure 9).

a) In the first type, the modules can be mounted onto a standard electrical printed circuit board with provision to accept an optical PT type connector.

b) In the second type, the modules are mounted onto an electro-optical circuit board and connected both electrically and optically to the board, whereby optical signals emitted from the module are launched directly into optical channels embedded in the circuit board and vice versa. The optical interface will preferably make use of lenses or other beam shaping devices to mitigate the effects of beam diversion over free space.

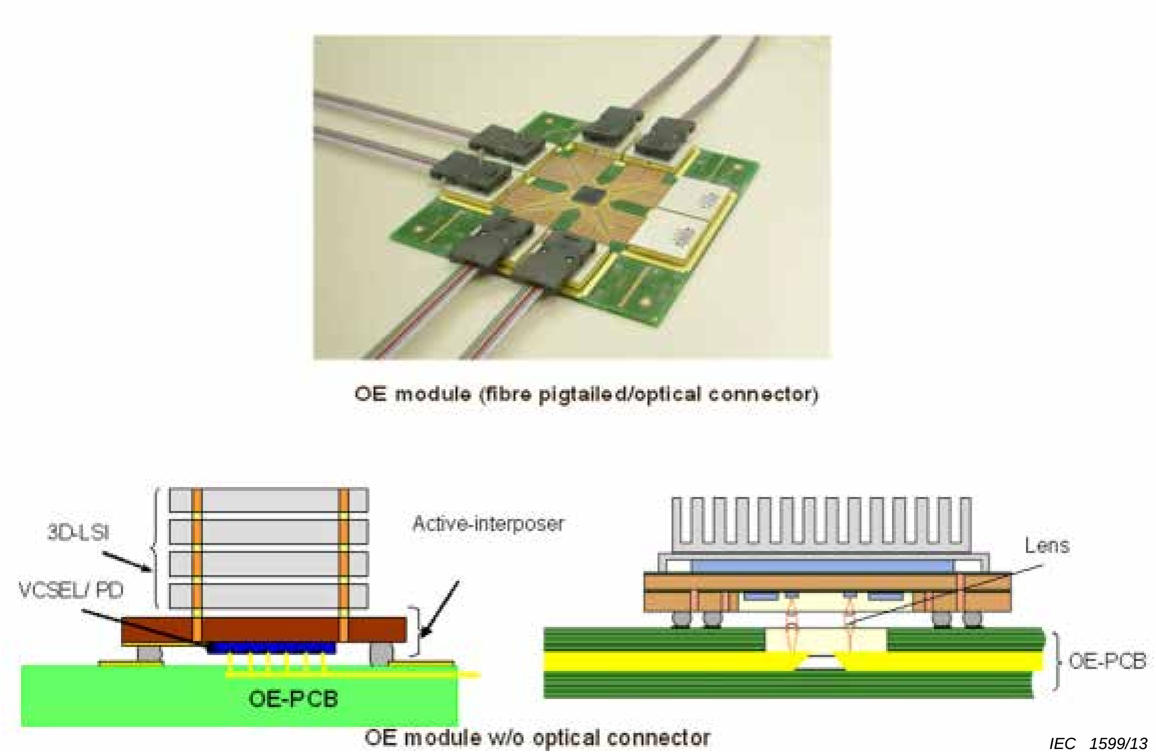

Figure 9 – Classification of optical modules on boards

3.6 Originating standards

In Japan, 22 de-facto standards relating to optical circuit boards, optical backplanes, optical connectors, and optical modules on boards have been published by Japan Electronics Packaging and Circuits Association (Figure 10). Based on these de-facto standards, several IEC standards have been published.

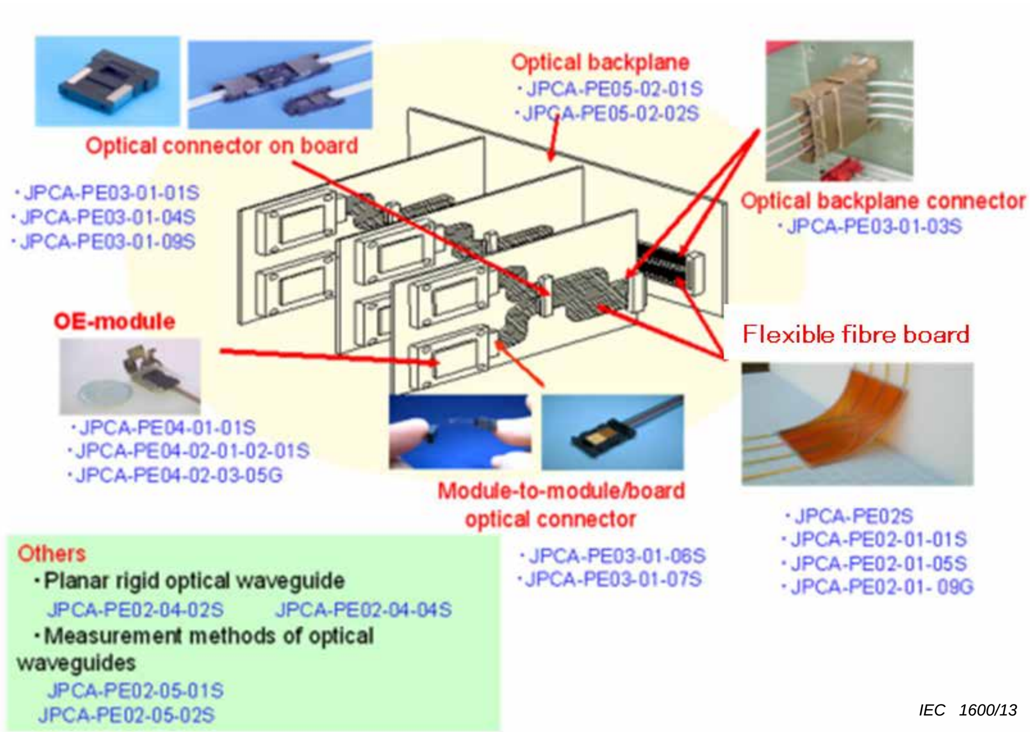

Figure 10 – De facto-standards in Japan [24]

4 Standardization road map

4.1 Performance trends for optical circuit boards

Figure 11 shows projected board capacity trends for optical circuit boards in terms of data rate per optical channel and number of optical channels per board.

Board mounted optical transceiver modules will increase in both channel count and data rate. In 2011, mid-board transceiver modules with 4 duplex or 12 single channels operating at 10 Gbps per channel were commercially available, with array subcomponents such as 4 and 12 channel VCSEL arrays and PIN photodiode arrays operating at up to 25 Gbps and single channel components operating at 40 Gbps available from certain vendors to enable 4 duplex channel 40 Gbps midboard transceivers and beyond.

According to the board capacity trends shown, current 10 Gbps array technologies would typically require 30 optical channels per board, while the introduction of 40 Gbps array technologies in the near future would push this requirement to 100 optical channels per board.

New parallel optical engine developments based on integrated silicon photonics [25] rather than multi-chip module technologies will push I/O data rates and capacities even further to Terabit per second (aggregate) modules.

According to the 40 Gbps and 100 Gbps Ethernet standards published in 2010, the optical channel capacity on a circuit board could be driven to over 1 000 optical channels per board to accommodate the future interconnect requirements.

Therefore, the trend predicted in optical circuit board fabrication will be toward hybrid electro-optical circuit boards with increasing numbers of optical layers.

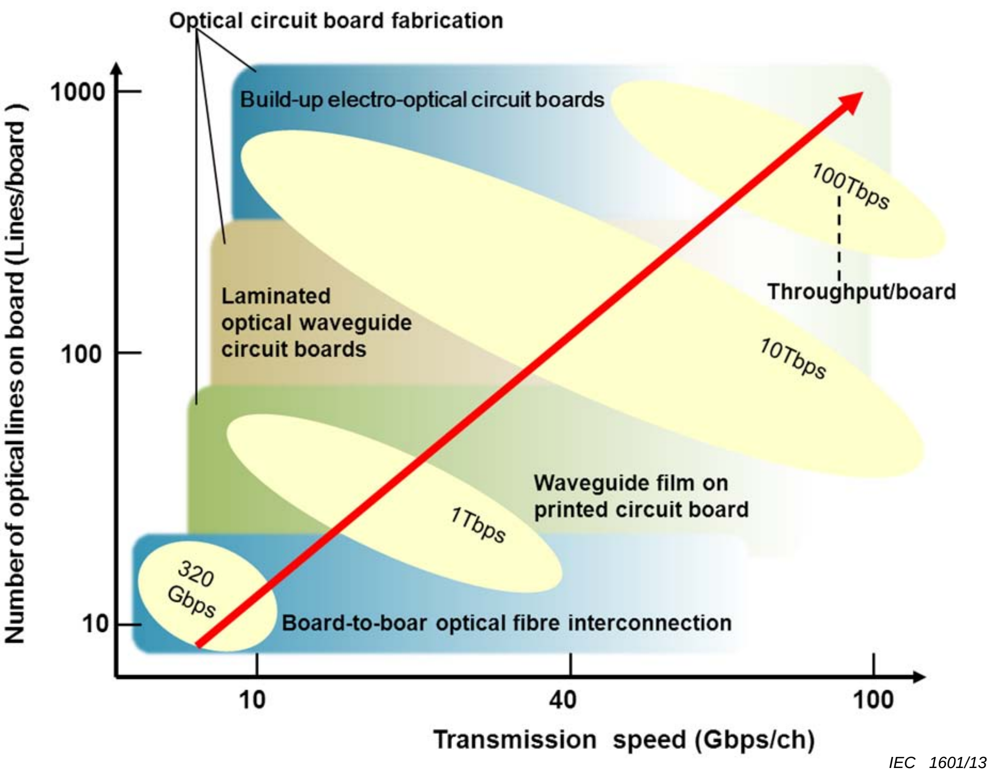

Figure 11 – Performance trends for optical circuit boards

5 Standardization road map of optical circuit boards

Based on the performance and packaging trends shown in Figure 11, a standardization roadmap for optical circuit boards and supporting technologies, was proposed at the IEC TC86/JWG9 (with TC91) Kyoto meeting in October 2008. This roadmap is shown in Figure 12.

General proposals for the performance and measurement of optical circuit boards have been completed submitted by JWG9 to be published as international standards.

A NP describing the special case for an optical backplane was proposed in the IEC TC86/JWG9 (with TC91) Locarno meeting in 2009.

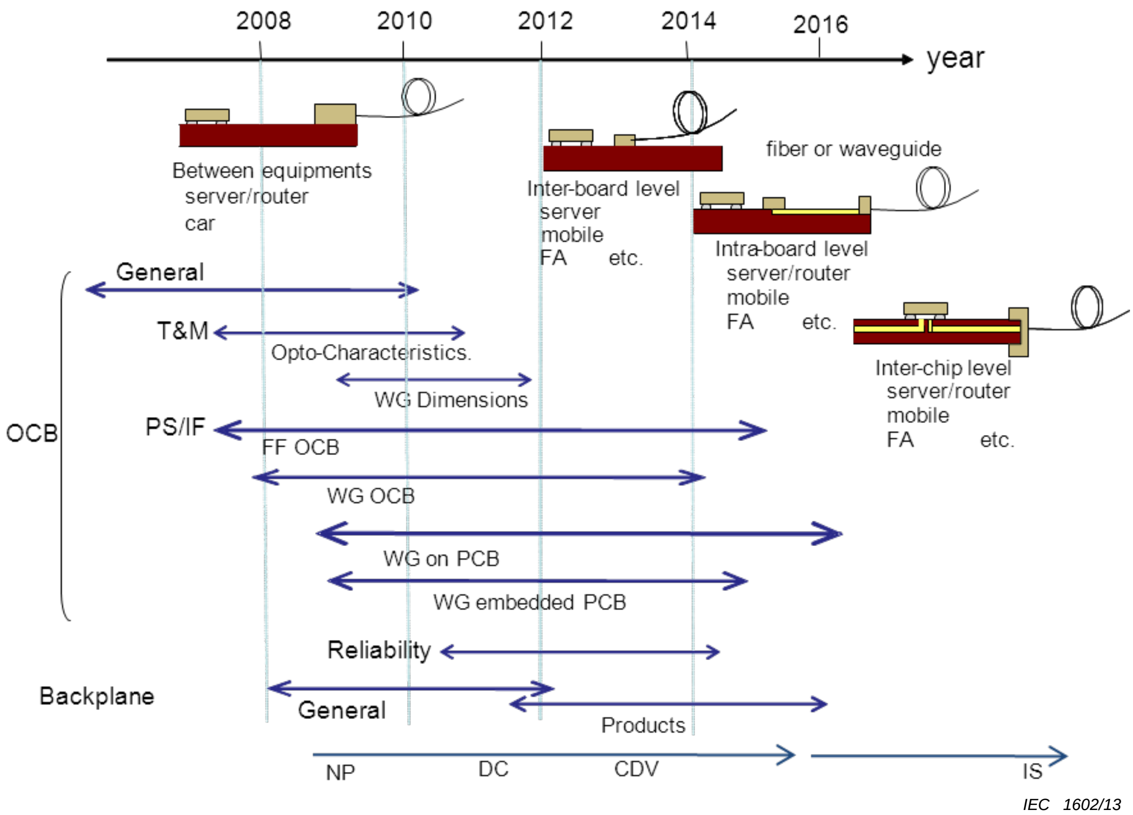

Figure 12 – Standardization roadmap of optical circuit board and its related optical packaging

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