DEVELOPMENT OF PARALLEL OPTICAL INTERCONNECTION MODULE FOR OPTICAL-I/O OF 80-Gbit/s-THROUGHPUT MCM


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Abstract. We have developed new parallel optical interconnection module called "ParaBIT-0M" and applied it to an optical I/O interface of an 80 Gbit/s-throughput ATM switch multichip module (MCM).

Introduction
The continuing exponential growth in telecommunications traffic due to the widespread of multimedia and computer networks is driving the development of Tbit/s-class ATM switching systems. One problem in designing these systems is, interconnecting the high-throughput ATM-switch multichip modules (MCM). These modules are usually interconnected electrically by mounting them on a printed circuit board (PCB). However, an 80 Gbit/s ATM switch MCM, a key component in sub-Tb/s class ATM switching systems, has 256 parallel I/O ports and total throughput of 160 Gbit/s. A PCB is not suitable for interconnecting such high-throughput MCMs because it is difficult to suppress the data skew by controlling the signal-line length and the deviation of the impedance in large area PCB. Parallel optical interconnections are better for high-throughput MCM-to-MCM interconnections because the optical fibers provide wide bandwidth, low loss, light mass, and crosstalk immunity. We proposed Parallel Inter-Board Optical Interconnection Technology, or ParaBIT(1), which enabled to realise high-capacity and low-cost parallel inter-board optical interconnections. We previously developed a prototype ParaBIT module called ParaBIT-OP(3-5). We have now developed a new ParaBIT module, called ParaBIT-0M, to provide small, low-skew, high-capacity MCM-to-MCM optical interconnections and have applied ParaBIT-0Ms to the optical-I/O interface of an 80 Gbit/s ATM-switch MCM. In this paper, we first clarify the role of ParaBIT-0M in an optical I/O interface MCM. We then describe the development of ParaBIT-0M.

Role of ParaBIT in Optical I/O interface MCM
A schematic view of an optical I/O interface MCM is shown in Figure 1. It consists of three main blocks: an 80 Gbit/s-throughput MCM block, an optical I/O interface block (ParaBIT-0Ms), and a metal frame with a liquid cooling jacket. The electrical I/O ports of 80 Gbit/s-throughput MCM are arised from MCM interface LSIs. Each MCM interface LSI has 18 electrical I/O ports (16-data and 2-control signals). Each ParaBIT-0M mounted on the metal frame is connected with two MCM-interface LSIs and operates as a 36-ch-optical-I/O-port of MCM. The maximum data rate of each I/O port and total throughput of each ParaBIT-0M is 625 Mbit/s and 20 Gbit/s, respectively.

Development of ParaBIT-0M and Optical-I/O MCM
The ParaBIT-0M module must meet two requirements to be suitable for an optical-I/O interface of 80 Gbit/s MCM.

1. Its width must be less than 40 mm, and its depth must be less than 38 mm.
2. The data-skew width across the 18 ports connected to each interface LSI must be less than 240 ps.

Figure 1 : Application of ParaBIT-0M to the optical-I/O interface of 80 Gbit/s-throughput MCM

Figure 2 : Photograph of a ParaBIT-0M.

The AlN multi-layer substrate of ParaBIT-0M was designed to reduce the module size. It has a width of 39 mm and a depth of 17 mm. All of the components needed to provide 40-ch and over-25-Gbit/s-throughput E/O or O/E conversion are mounted on this small substrate. A photograph of a ParaBIT-0M is shown in Fig. 2. Both the transmitter (Tx) and receiver (Rx) modules have the same
shape as this photograph, and their volume is only 8.9 cm$^3$
each (39 x 35 x 6.5 mm) as a result of high-density packaging. The electrical I/Os of ParaBIT-OM are 150-$\mu$m-pitch bonding pads formed in a row on the AlN substrate. These pads are wirebonded to the bonding pads formed symmetrically on the MCM. ParaBIT-OM thus meets requirement (1). To reduce the data skew, we use 10-m long low-skew multimode fiber ribbons with a skew widths of less than 5 ps. As a result, the data skew in ParaBIT-OM is dominated by the Tx and Rx skews. The Tx skew is mainly caused by laser-operation delay and signal-pattern jitter. Eye opening diagrams of optical signals from ParaBIT-OM (Tx) are shown in Fig. 3 for two different bias conditions. The bias currents in Fig. 3(a) and (b) are about 70% and 110% of the VCSEL array threshold current, respectively. In both cases, modulation was done using a 700 Mbit/s PRBS-NRZ 2$^{23}$-1 current pulse with a height of 5 mA. A comparison between Fig. 3 (a) and (b) indicates that a bias current above the threshold reduces the Tx skew. However, keeping the bias current above the threshold is difficult when the environment temperature varies, because the Tx ICs of ParaBIT-OM do not have a temperature compensation function, such as an APC, in order to achieve low cost, low power consumption, and small-size packaging. Therefore, it is important to suppress variations in the threshold current due to temperature variations. In conventional 1.3-$\mu$m Fabry-Perot LDs, it is impossible to obtain temperature-insensitive I-L characteristics. However, VCSELs can be designed to have such I-L characteristics by controlling the offset between the wavelength of the cavity mode and the quantum well gain peak. We thus use four 10-ch VCSEL arrays as the optical signal sources in ParaBIT-OM (Tx). The I-L characteristics of these arrays measured at 25 and 70 °C, which corresponds to the operation temperature range of ParaBIT-OM, are shown in Fig. 4. They indicate that the threshold currents of the VCSEL arrays are highly uniform and stable in this temperature range. Using these arrays thus makes it possible to ensure that the bias current remains above the threshold without using temperature compensation. As a result, the Tx skew is reduced to 80 ps. The Rx skew in ParaBIT-OM (Rx) is mainly caused by deviations in the optical signal power, because DC coupled fixed-decision-level receiver ICs are used for low cost and low power consumption. In the output power range (less than 2 mW) corresponding to the operating range of the VCSELs, the slope efficiencies are uniform and stable between 25 and 70 °C (see Fig. 4). The temperature-insensitive VCSEL arrays also make it possible to suppress the deviations in optical-signal power to less than 2 dB, which corresponds to an Rx skew of less than 160 ps. Therefore, the total skew in ParaBIT-OM, i.e., the sum of the Tx and Rx skews, is 240 ps and meets the requirement (2). These results show that the highly uniform and temperature insensitive VCSEL arrays are the key to reducing cost, power consumption, and data skew in parallel optical interconnections. To confirm the performance of ParaBIT-OM, bit error rate (BER) characteristics have been measured by operating the Tx and Rx modules with 5 channels of 625 Mbit/s PRBS NRZ 2$^{23}$-1. BER characteristic of channel 3 under 5-ch operation (channel 1-5) is shown in Fig. 5. The dynamic range of receiver is 5 dB at the bit error rate of 10$^{-12}$. We mounted eight ParaBIT-OMs (2 Rx and 6 Tx) on a metal frame and wire-bonded to an 80-Gb/s MCM. We examined the performance of the optical I/O interface MCM and confirmed that ParaBIT-OMs acted as the optical I/O ports of MCM successfully.

**Summary**

The ParaBIT-OM module we have developed is small enough to be used in an 80-Gbit/s-throughput MCM and has 40 parallel E/O or O/E conversion channels and over 25 Gbit/s throughput. The optical-I/O MCM we fabricated is composed of eight ParaBIT-OMs and an 80 Gbit/s-throughput MCM. Its successful operation indicates that ParaBIT has high potential for inter-MCM as well as inter-board optical interconnections.

**References**

1) R. Kawano et al., Proc. of 49th ECTC, to be published.

**Figure 3** : Eye diagrams of ParaBIT-OM (Tx): 700-Mbit/s PN23 current pulse : (a) $I_b=0.7 \times I_{th}$, (b) $I_b=1.1 \times I_{th}$.

**Figure 4** : I-L Characteristics of a 10-ch VCSEL array.

**Figure 5** : Bit error rate characteristic of ParaBIT-OM.