Completion of Bus-Extender development for sPHENIX INTT

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sPHENIX is a second-generation experiment at Relativistic Heavy-Ion Collider. It is scheduled to start in 2023 to explore the properties of quark-gluon plasma. The INTermediate Tracker, INTT,[1)] is a silicon strip detector placed in a tight and confined space near the beam pipe. INTT measures more than 1000 particles in a collision. Large amount of raw data is sent to the later read-out electronics placed more than 1.1 m away from INTT with a curving path for signal processing at high speed. It is difficult for commercial cables such as flex flat cable and co-ax cable to satisfy all the requirements listed below. We developed a special data cable namely "Bus Extender (BEX)" for INTT based on flexible printed circuits (FPC).

The requirements for BEX are: (1) length of 1.1 m, (2) high-density signal lines (128 lines/5 cm), (3) high-speed data transfer of 200 Mbps by LVDS with 100 Ω differential impedance, (4) flexibility, (5) mechanical reliability, and (6) radiation hardness. We developed BEX for five years to satisfy all the requirements. Instead of the standard polymide, liquid crystal polymer (LCP) was used for the substrate to reduce loss of signals transmitted at high speed. The design of BEX was optimized by the printed circuit simulation. The prototype BEX was made for testing. BEX consists of four metal layers including signal, power, and ground layers laminated by glue. The uniformity of width for signal lines is measured to be 122 ± 2 μm.

Using the prototype BEX, the electrical performance is measured with S-parameters, differential impedance, and eye-diagram and compared with the simulation. Figure 1 shows S-parameter for insertion (SDD21) and return loss (SDD11). The data and simulation are labeled as "meas" and "em," respectively. From the comparison, the simulation successfully reproduced the overall behavior of the data. The eye-diagram is often used to visually inspect the margin of the signal pulse. By comparing the mask (gray hexagonal shape) which represents the minimum requirement of the margin, the measured eye diagram satisfied the requirement as shown in Fig. 2. The differential impedance was estimated as 95 Ω by the time domain reflectometry. The result is slightly lower than the requirement but acceptable.

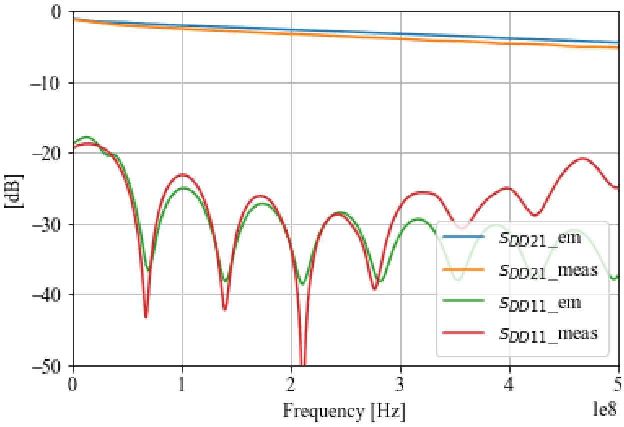

Fig. 1. Insertion and return loss.

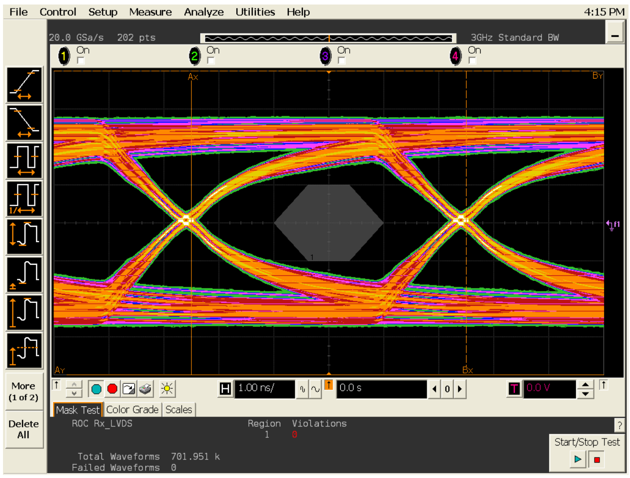

Fig. 2. Eye-diagram.

The mechanical reliability was evaluated by the peeling and the thermal shock test using the FPC samples with the same configuration. The peel strength between the laminated two layers was measured by a tensile tester. The result was more than 16 N/cm and indicates BEX has sufficient strength. We also compared the strength with radiation exposure by 5 k Gy and

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found no change. This indicates that the impedance of BEX was not changed by irradiation. The thermal shock test aimed to check the long-term stability. BEX was exposed with $-15°C$ and $75°C$ for 30 min. with 5 min. interval. The rapid change in temperature puts physical stress with expansion and contraction. The electrical resistance of the signal line is increased if the signal line is damaged. After 1000 thermal cycles that are equivalent to 8 years of use, we found no resistance change. These mechanical performances are detailed in Ref. 2).

After the evaluation of the prototype, we performed the mass production of 130 BEXs. The issue with low yield rate was investigated and the tiny dust caused mis-formation of lines.[3] A visual inspection fixture was also developed to monitor the line formation during production. As a result, the mass production was completed with almost 100% yield. In summer 2022, all the BEX was assembled to the INTT barrel. INTT and BEX are ready for sPHENIX data taking in April 2023.

References
1) Conceptual design report of sPHENIX (2018).
2) T. Kondo *et al.*, Trans. J. Inst. Electron. Packag. **15**, E21 (2022).
3) T. Hachiya *et al.*, RIKEN Accel. Prog. Rep. **55**, 98 (2022).