GBT20, a 20.48 Gbps PAM4 Optical Transmitter Module for Particle Physics Experiments

1. Introduction

High-speed optical links are commonly used in modern high-energy physics experiments to transmit large-volume data from detectors to counting rooms. Optical transmitter modules are essential components of optical links. Future high-energy physics experiments demand optical transmitter modules with even higher bandwidth than those currently available. Based on an ASIC GBS20 [1] we recently developed, a pluggable radiation-tolerant PAM4 optical transmitter module GBT20 is designed.

2. ASIC overview

The block diagram of the GBS20 ASIC is shown in Figure 1. The GBS20 has 16 input data channels, which are split into the Least Signification Bit (LSB) or the Most Significant Bit (MSB) channels. Each input data channel operates at 1.28 Gbps. By employing phase aligners, all the data are always sampled correctly. The input data are scrambled with a 2^7-1 Pseudo-Random Binary Sequence (PRBS) generated in an internal test pattern generator before being fed to two serializers. The output serial bit stream of each serializer has a data rate of 5.12 Gbps or 10.24 Gbps. After through five-stage limiting amplifiers, the output data of the LSB/MSB channels are combined into a PAM4 signal. The combiner drives directly a VCSEL diode. The GBS20 operates at 10.24 or 20.48 Gbps. A low-jitter Phase-Locked Loop (PLL), which is derived from lpGBT [2], generates clocks of different frequency different frequencies. An Inter-Integrated Circuit (I^2C) target block is used to configure GBS20. The power supply of the whole chip is divided into three parts: digital 1.2 V, analog 1.2 V, and analog 2.5 V. The 2.5 V power domain is only used in the PAM4 combiner. The supply voltage of the combiner can be reduced to 1.2 V in a low-power mode.

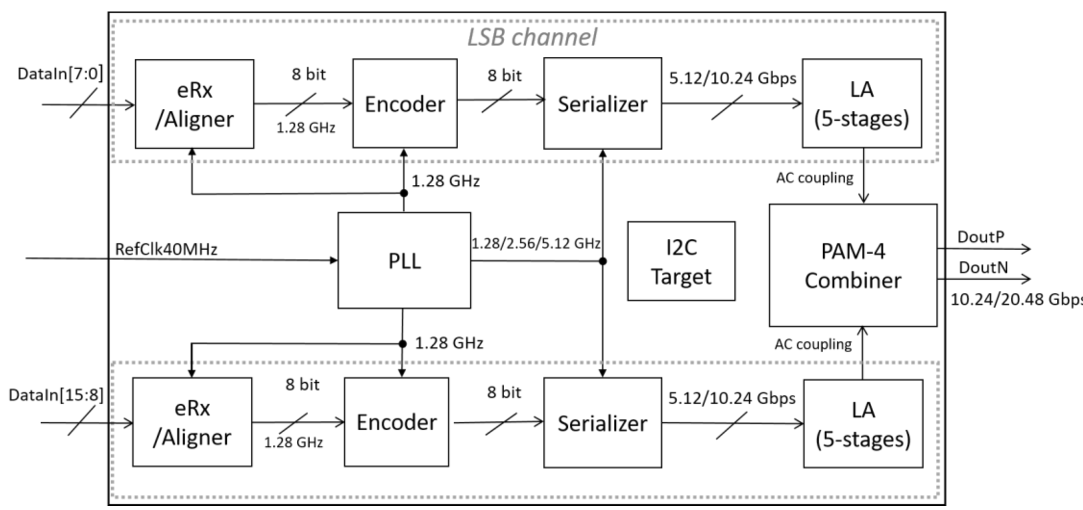

Figure 1. Block diagram of GBS20 ASIC.

3. Module design

The block diagram of the GBT20 module is shown in Figure 2. We adopt two kinds of gold fingers, a 60-pin OSFP, and a 48-pin Firefly, as the electrical signal interface. A GBS20 ASIC die is AC coupled to a

VCSEL diode. The DC bias circuit of the VCSEL diode is implemented on the module. The GBT20 module uses either a die (Part No. APA45001010001 from II-VI Laser Enterprise) or a TOSA (Part No.TTL-1F67-627 from Truelight) of a VCSEL diode. The VCSEL die is directly wire-bonded to the PCB, and an LC lens (Part No. OT002 from Orangetek Corporation) is mounted above the VCSEL die for optical coupling. The TOSA is mounted to the PCB with a flex cable. The LC lens or the TOSA provides the interface to a standard LC connector. A custom latch attaches the LC connector to the LC lens or the TOSA. By employing different electrical interfaces and optical components, GBT20 has four variants (OSFP-TOSA, OSFP-lens, firefly-TOSA, and Firefly-lens).

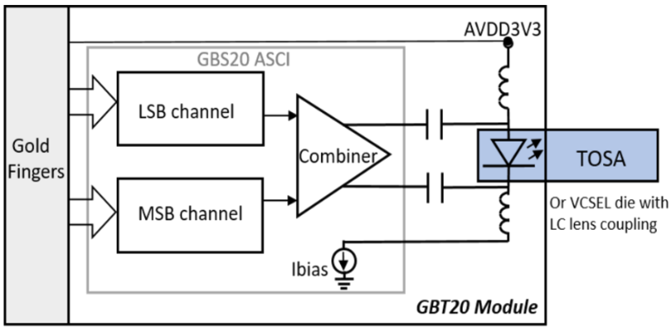

Figure 2. Block diagram of the GBT20 module.

The photographs of the OSFP variants are shown in Figure 3. The GBS20 die was wire bonded to the PCB underneath a protective plastic cover. A 25 Gbps TOSA was soldered to the PCB, as shown in Figure 3(a). An LC lens was mounted above a wire-bonded VCSEL die, as shown in Figure 3(b). An OSFT-TOSA module was attached to an optical fiber with a custom latch, as shown in Figure 3(c). The module size is 40.8 mm (L) x 18.85 mm (W) x 5.75 mm (H). A photograph of an OSF-lens variant is shown in Figure 3(d). The module size is 40.3 mm (L) x 18.85mm (W) x 6.68 mm (H). A photograph of an OSFP-TOSA module mounted on a carrier board is shown in Figure 3€. The height of the OSFP connector is 8.45 mm, resulting in the height of the module being no less than 8.45 mm. The latches shown in the photographs are printed by a 3D printer with composite-x resin. The tensile strength of the latches is –0 - 75 MPa after the latches are UV cured. Two screws fix the module, the motherboard, and the latch together.

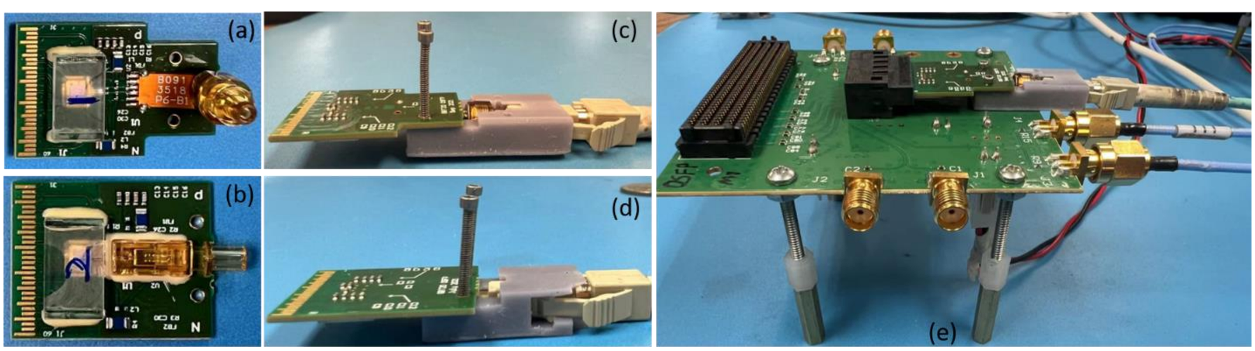

Figure 3. Photographs of OSFP-TOSA (a) and OSFP-lens (b) variants without the latch, OSFP-TOSA (c) and OSFP-lens (d) variants with an optical fiber plugged in, and an OSFP-TOSA variant mounted on the motherboard (e).

The 3D views of the firefly variants and a motherboard are shown in figure 4(a-c). The Firefly connector is lower (3.95 mm) and narrower than the OSFP connector, the firefly variants are smaller than the OSFP variants.

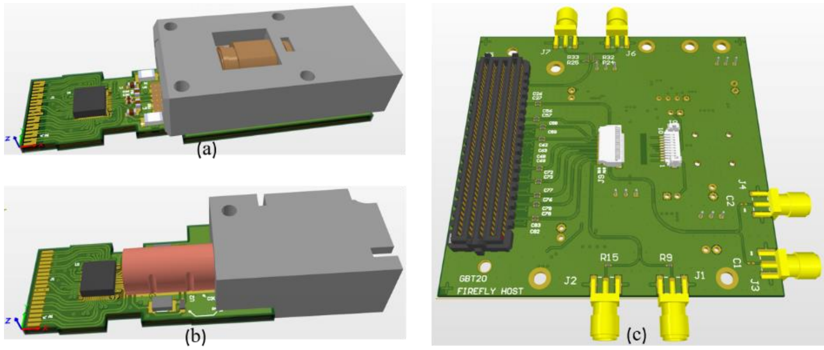

Figure 4. 3D views of firefly-TOSA (a) and firefly-lens variants (b) with a mechanical latch and the motherboard (c).

4. Module test results

The block diagram and a photograph of the test setup are shown in Figures 5(a-b). A Cyclone 10GX FPGA development Kit (DK-DEEV-10CX220-A) generates 16 differential pairs of data. The input data go through an FMC connector and AC coupling capacitors before being fed to the mezzanine board. The output of the GBT20 module is connected to an optical scope for an eye diagram test or a Kintex-7 FPGA evaluation board (Xilinx KC705) for a Bit Error Rate (BER) test. A clock builder board (Silicon Labs Si5338EVB) provides three 40 MHz clocks, one for the FPGA, one for the GBS20 ASIC, and the other one for the oscilloscope. To configure GBT20, an I2C level translator board is employed. The main power supply of the test board is 4 V. Low-dropout regulators provide separated voltages for the chip and the VCSEL.

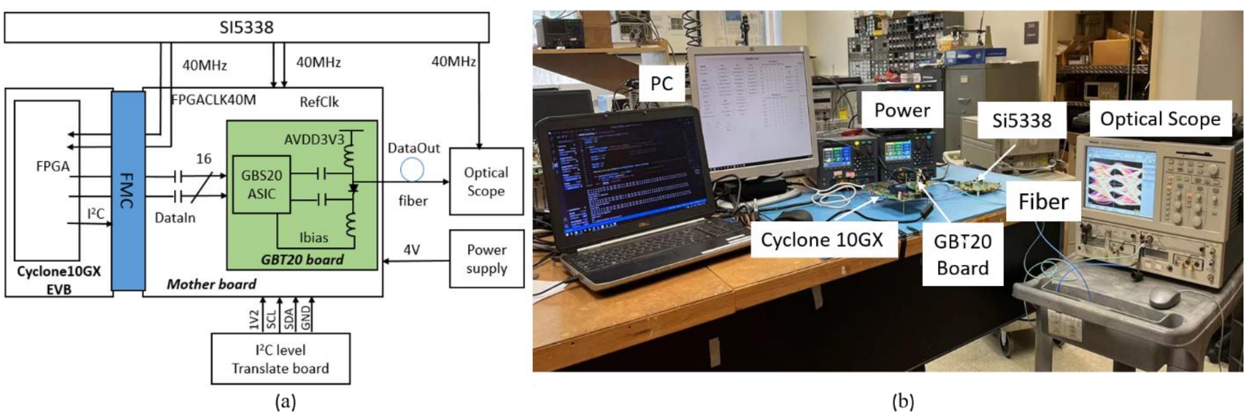

Figure 5. Block diagram (a) and photograph (b) of the test setup.

While the firefly variants are under production, preliminary tests of the OSFP variants have been conducted. The PAM4 optical eye diagrams at 10.24 Gbps or 20.48 Gbps are shown in Figure 6. The module has a clear PAM4 optical eye diagram. The maximum OMA is around 1 mW. The power dissipation of GBT20 is 238 mW and 164 mW in the high or low power modes, respectively.

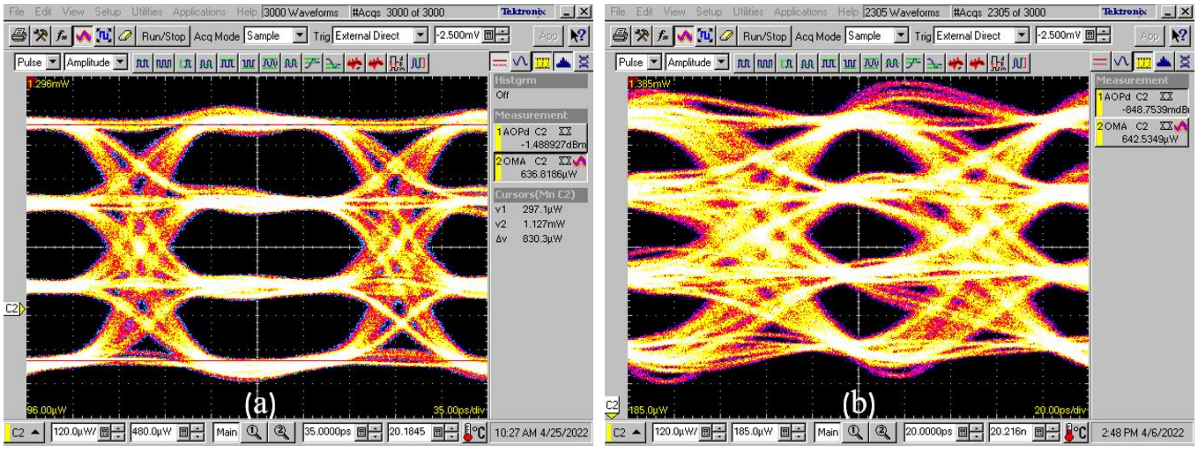

Figure 6. Optical PAM4 eye diagrams of an OSFP-TOSA variant at 10.24 Gbps (a) and 20.48 Gbps (b).

The LSB or MSB channels can be independently turned off to check NRZ eye diagrams. The optical NRZ eye diagrams for the OSFP-lens variant are shown in Figure 7. The lens variant is noisier than the TOSA variant. The difference in the noise performance may come from different VCSELs and light couplings.

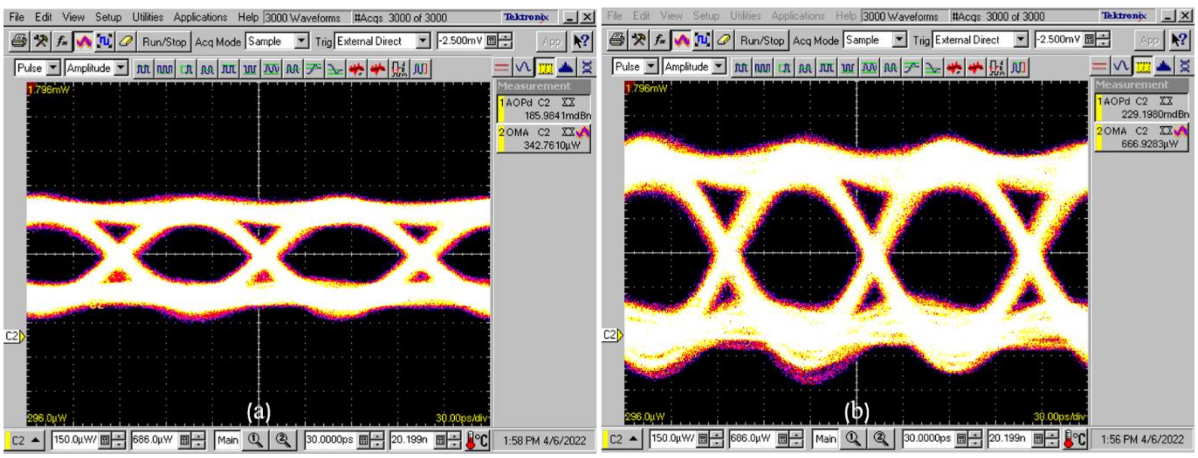

Figure 7. Optical NRZ eye diagrams of the LSB (a) and MSB (b) channels (b) of an OSFP-lens variant at 10.24 Gbps.

We have measured the BER of GBT20. No error was detected during three hours for each input data channel, corresponding to a BER of low than 1 x 10^{-12}.

An irradiation test finds no single-event effect after a fluence of 8.6 x 1013 with a 400 MeV proton beam, and no obvious performance degradation after a total ionizing dose of 35 kGy. The full set of the test results will be presented at the workshop.

Figure 8. Photograph of a GBS20 evaluation board in the box (a) and beam test setup (b).

5. Conclusion

We present the design and test result of the first PAM4 transmitter GBT20 module for particle physics experiments. The OSFP variants achieve our design goals when operating at 10.24 or 20.48 Gbps. More progress and full test results will be presented at the workshop.

Acknowledgments

The work is supported by SMU's Dedman Dean's Research Council Grant and the National Science Council in Taiwan.

References

[1] L. Zhang et al., *A 20 Gbps PAM4 data transmitter ASIC for particle physics experiments [J]*, Journal of Instrumentation 17 (2022) C03011.

[2] P. Moreira et al., *The lpGBT: a radiation tolerant ASIC for data, timing, trigger and control applications in HL-LHC*, presented at *Topical Workshop on Electronics for Particle Physics*, Santiago de Compostela, Spain, 2–6 September 2019 (2019).