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基于柔性电路板单纤双向光纤组件的以太无源光网络单元研制

汪洋,李明维,王东山

(国网电力科学研究院 北京南瑞智芯微电子科技有限公司,北京 102200)

摘　要:随着宽带接入技术的发展,以太无源光网络是光纤到户的一种备选方案.而光网络单元数量众多,其成本成为限制以太无源光网络技术实施的重要影响因素.本文提出了一种低成本以太无源光网络单元实现方式:采用带柔性电路板的单纤双向光纤组件直接安装在光网络单元的电路板上.为了验证弯曲柔性电路板的高速性能没有恶化,采用有限元方法仿真了弯曲柔性电路板的小信号响应.由于该方式没有独立的光收发模块,无法采用比特误码分析仪进行测试,因此提出了采用网络测试仪搭建光网络单元的光信号性能测试系统的方案并实现了对光信号的性能测试.结果表明:对于发射机,在 0℃～70℃的范围内得到了超过 10 dB 的消光比和 1 dBm 的平均发射功率;对于接收机,估算灵敏度为－27 dBm.

关键词:无源光网络; 光网络单元; 单纤双向光学组件; 柔性电路板

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Investigation of Ethernet Passive Optical Network-Optical Network Unit Using Flexible Printed Circust-Bidirectional Optical Sub-Assembly

WANG Yang, LI Ming-wei, WANG Dong-shan

(*State Grid Electric Power Research Institute, Beijing NARI SmartChip Microelectronics Company Limited, Beijing* 102200, *China*)

Abstract: With the development of broadband access network, Ethernet Passive Optical Network (EPON) becomes a candidate for fiber to the home. As the huge amount of Optical Network Units (ONUs), the deployment of EPON is affected by the cost of ONU. A low cost EPON (ONU using Bi-directional Optical Sub-Assembly (BOSA) with Flexible Printed Circuit (FPC) was proposed. The FPC-BOSA is mounted directly to the ONU board. Small signal response of FPC was simulated by Finite Element Method (FEM), the results prove that the high speed performance do not degrade. However, there is no individual transceiver module in this proposal, so bit error tester can not be used to test the optical performance. Measurement system using network tester was set up. For the transmitter, the extinction ratio over 10 dB and the average optical power over 1 dBm were obtained from 0℃ to 70℃. For the receiver, the estimated sensitivity achieves －27 dBm.

Key words: Ethernet Passive Optical Network (EPON); Optical Network Unit (ONU); Bi-directional Optcial Sub-Assembly; Flexible Printed Circuit(FPC)

OCIS Codes: 060.4510; 140.2020; 060.4250

0 Introduction

Passive Optical Network (PON) was considered as an attractive solution for broadband access network[1-5]. The Ethernet PON (EPON) standard was ratified as part of the Ethernet in the first mile project of the IEEE 802.3 in 2004. Due to the convergence of low-cost Ethernet equipment and low-cost fiber

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First author: WANG Yang(1984－), male, lecturer, Ph. D degree, mainly focuses on optical communications. Email: wangyang06@semi.ac.cn

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infrastructure, EPON appears to be a candidate for Fiber to the Home (FTTH). EPON consists of an Optical Line Terminal (OLT) at the service provider's central office and a number of Optical Network Units (ONUs) near end user. As a result of the large amounts of ONUs, the deployment of EPON is affected by the cost of ONU. One of the key factors is the expensive optical transceiver in EPON ONU.

The transceiver consists of a Bidirectional Optical Sub-Assembly (BOSA) with packaged Laser Diode (LD) and Photodiode (PD), a Printed Circuit Board (PCB) with LD driver and PD amplifier chips, a metal shell and connector. To reduce the cost of transceiver, some efforts were made in various ways. A micro BOSA was developed by OKI and SIGMA-LINKS using silicon microlens in packaging[6]. A 2-D optical coupling using Planar Lightwave Circuit (PLC) and surface mount technology was applied by NTT instead of 3-D optical coupling BOSA[7]. OneChip Photonics was introduced a novel type transceiver product using InP-based Photonic Integrated Circuit (PIC) technology[8]. The methods above could change the device package, optical coupling type or device fabrication process, so more complex and precise equipment are needed, which brings investment for production line upgrade and yield problems. In this paper, a BOSA with Flexible Printed Circuit (FPC) directly mounted on the ONU board was proposed to reduce ONU cost while preserving the structure inside BOSA.

1 Analysis of BOSA on board

An easy-manufacturing and low-cost approach is the BOSA-on-board solution, in which the BOSA is directly mounted to the top of the ONU board and the pins are bended down to the board making through-hole connections. However, the long pins of the connection create a significant amount of inductance, which have bad impact on the signal quality at gigabit data rates.

The equivalent circuit of the pin leads could be roughly modeled as a conductive leads and value of the inductance was estimated by equation[9]

$$L=2\mu_s l\left\{\ln\frac{l+\sqrt{l^2+r^2}}{r}-\sqrt{1+\left(\frac{r}{l}\right)^2}+\frac{r}{l}\right\}\times 10^{-7}[\mathrm{H}] \tag{1}$$

where the relative permeability μ_s is unity, l is the length of the lead, r is the radius of the lead. The diameter of the lead is 0.45 mm, so $r=0.225$ mm. In the conventional Small Form Factor (SFF) packaged optical transceiver, l is less than 2 mm so that the inductance should be less than 0.757 5 nH. The relationship between the length of lead and the inductance is shown in Fig. 1.

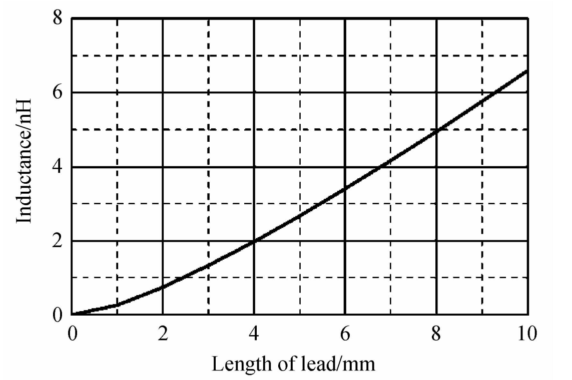

Fig. 1 Inductance of lead

However, the length of lead becomes more than 8mm in the BOSA-on-board solution. The total inductance of the anode and the cathode pin lead outside, the laser diode TO-Can is considered as 10 nH. We have simulated the eye diagrams of laser diode in both SFF transceiver and BOSA-on-board solution.

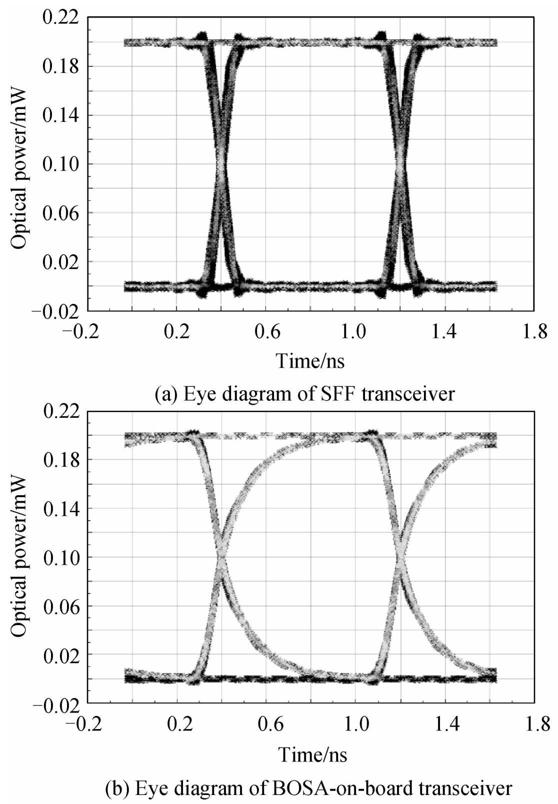

Fig. 2 Simulated transmitter eye diagram of SFF transceiver and BOSA-on-board

The eye rise/fall time is 68 ps in SFF transceiver and 166 ps in BOSA-on-board solution. According to the eye diagram, the long leads result in about 100 ps increase of the rise/fall time. The degeneration of the eye diagram in BOSA-on-board solution would worsen the bit error rate.

2 Solution of FPC-BOSA

A FPC was used in substitution for the long leads in our proposal. FPCs are often used as connectors in various applications where flexibility, space savings, or production constraints limit the serviceability of rigid circuit boards or hand wiring[10-13]. Recently, FPCs become more and more important in high speed link[14-15]. As we known, transmission line with matched impedance on printed circuit is a suitable media for high speed signal. The characteristic impedance of microstrip line could be calculated by the following equation

$$Z_0=\frac{87}{\sqrt{\varepsilon_r+1.41}}\ln\left(\frac{5.98h}{0.8w+t}\right) \qquad (2)$$

where ε_r is the dielectric constant, h is the thickness of the FPC, w is the width of microstrip line, t is the thickness of conductor. The polymer FPC with a dielectric constant of 4.6 and a thickness of 130 μm has been chosen as the substrate. According to the equation, w should be 600 μm for 25 Ω impedance, which is matched with the output of laser driver.

In addition, the bending effect of the FPC has been also considered. The bending angle is 90° and the bending radius is 4 mm as the Fig. 3(a) shows. The bending FPC model was built in Fig. 3 (b) and simulated by the Finite Element Method (FEM) to obtain the electromagnetic properties.

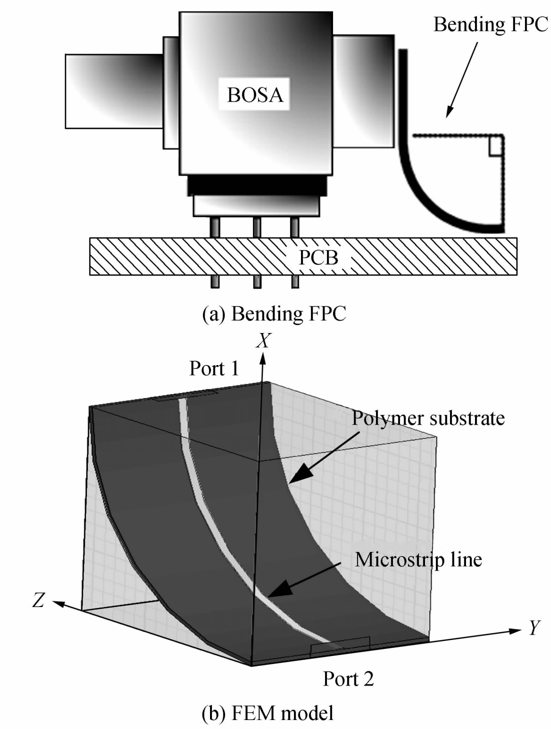

Fig. 3 Schematic figure of bending FPC and FEM simulation model

The simulated results of the small signal response are shown in Fig. 4. The reflection of the bending FPC is less than 30 dB at 1 GHz and the transmission is about −0.05 dB, which represent no effect on the signal integrity at the data speed of 1.25 Gbit/s. Therefore, FPC-BOSA could be the low-cost solution for transceiver without performance degeneration.

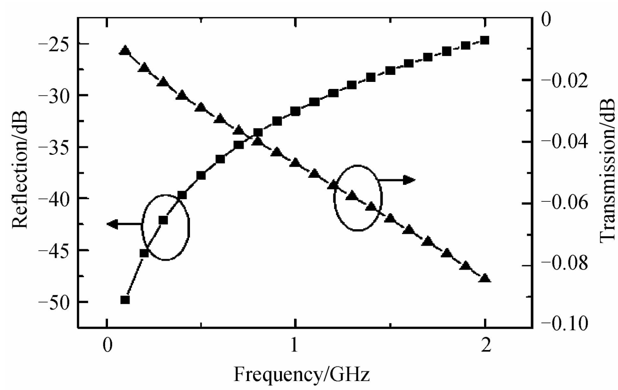

Fig. 4 Small signal response of bending FPC

In Fig. 5, the schematic structure of our ONU DEMO consists of one EPON ONU chip, one fast Ethernet port, one analog IC integrated laser diode driver with limiting amplifier, one BOSA with FPC and one power supply module. The arrows represent data paths and directions.

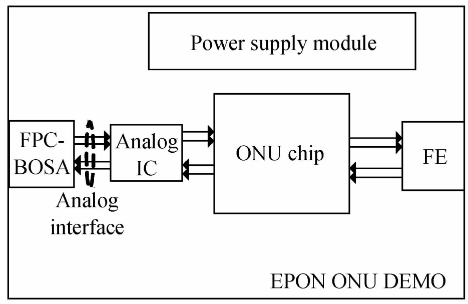

Fig. 5 Schematic structure of EPON ONU DEMO using FPC-BOSA

There are three advantages in the EPON ONUs using FPC-BOSA. Firstly, FPC-BOSA is directly mounted on the ONU board, so the cost is lower compared with a SFF-type transceiver. Secondly, the ONU could be compact as the PCB design components become smaller. Thirdly, FPC-BOSA does not need to bend the lead, so the manufacturing is easy and the high-speed performance does not degrade.

3 Measurement setup and result

Due to the optical transceiver function is achieved by on-board BOSA, the transceiver could not be tested directly by bit error tester. We have demonstrated a measurement method that no pattern generator is required. As the Fig. 6 shows, a single mode fiber links the ONU and an OLT, while the network tester connects the ONU and the OLT by Ethernet cable to make a loop. Ethernet frames with Pseudo-Random Binary Sequence (PRBS) payloads are sending in both clockwise and counterclockwise directions in the loop. In the fiber channel, a tunable attenuator and a PON power meter are used to adjust the received optical power of the ONU. A part of transmitted optical signal is coupled to a high speed photodiode with a fourth-order Bessel-Thomson filter, which connects to an oscilloscope.

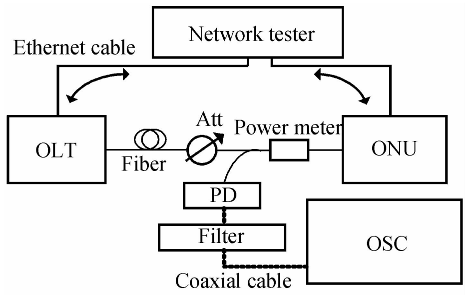

Fig. 6 Measurement system

The optical transmitter performances at various temperatures have been tested by the oscilloscope as the eye diagrams shown in Fig. 7. All the eye diagrams have passed the mask defined in IEEE802. 3ah and 40% mask margin has been achieved. The extinction ratios are over 10 dB and average optical powers are over 1 dBm.

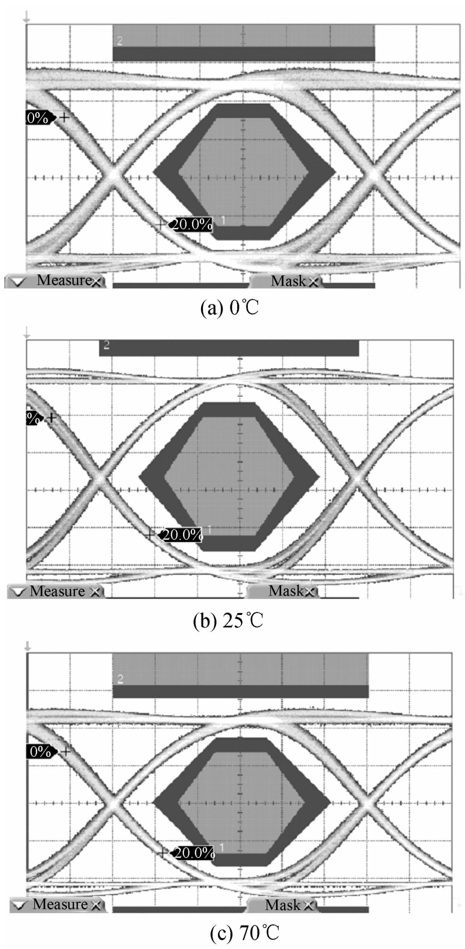

Fig. 7 Transmitter eye diagram

The optical receiver performance has been measured by the network tester. The frame loss rates of the ONU DEMO at various optical attenuations are depicted in Fig. 8. The power penalty is less than 1 dB compared with the reference ONU, in which the optical transceiver is a traditional SFF device. According to the sensitivity of the SFF transceiver is less than −28 dBm, the estimated sensitivity of the ONU DEMO achieves − 27 dBm, which is better than 1000BASE-PX20 defined in IEEE802. 3ah.

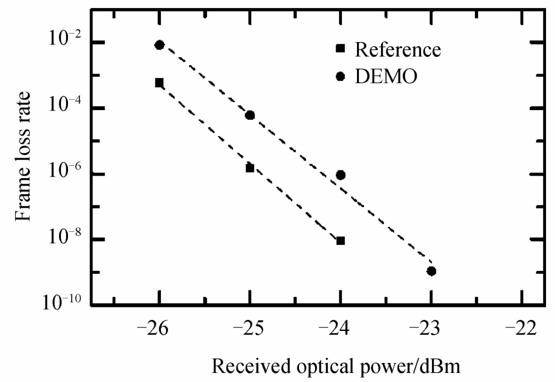

Fig. 8 Frame loss rates for different received optical power

4 Conclusion

We have demonstrated a low cost EPON ONU, which using an on-board BOSA with FPC to substitute traditional SFF transceiver. The measurement system without bit error tester was setup to analyze the transmitter and the receiver performances. The eye diagrams from 0℃ to 70℃ has all passed the mask with the extinction ratio over 10 dB and average optical power over 1dBm. Frame loss rates of the ONU DEMO were compared with a reference with traditional SFF transceiver, and 1 dB power penalty indicates that the receiver sensitivity of the ONU DEMO achieves − 27 dBm.

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