Basic Study of Non-Contact Connector for High-Speed Space Cable Transmission

Space Fibre, Short Paper

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***Abstract*—The data transmission rate required for the earth observation satellites is in the order of Gbps because of the enhanced performance of the observation sensors. However, the data transmission rate is approaching to the capable limits due to the issues of increased loss caused by the connectors or wires connected. In addition, there is another issue of the transmission irruption due to the vibration during the satellite launch. The transmission technology using the non-contact connector which has high vibration tolerance against the lossy wire connection systems is proposed and this paper describes the advantages of the non-contact connector, consisting of Transmission Line Couplers (TLC). With the transmission characteristics analysis of the connector and the design concepts, analysis of actual measurement results reveal that 15 m cables transmission of 2.5Gbps and BER less than 10^{-12} is feasible.**

***Index Terms*—Transmission line coupler, Non-contact connector, WizardLink, Cable, Comparator.**

I. Introduction

Data processing components that are mounted in satellites must be small and light, having high data transfer rates, and high storage capacity [1]. The next generation of earth observation satellites will require data transmission rates to a maximum of 20 Gb/s and at least one terabyte of storage capacity [2]. However, the data transmission rate is approaching to the capable limits due to the issues of increased loss caused by the connectors or wires connected. These connections consequently have the mismatch of impedance and complication of systems ensued by the increase in parts and wires of wired connections. In addition, there is another issue of the transmission irruption due to the vibration during the satellite launch.

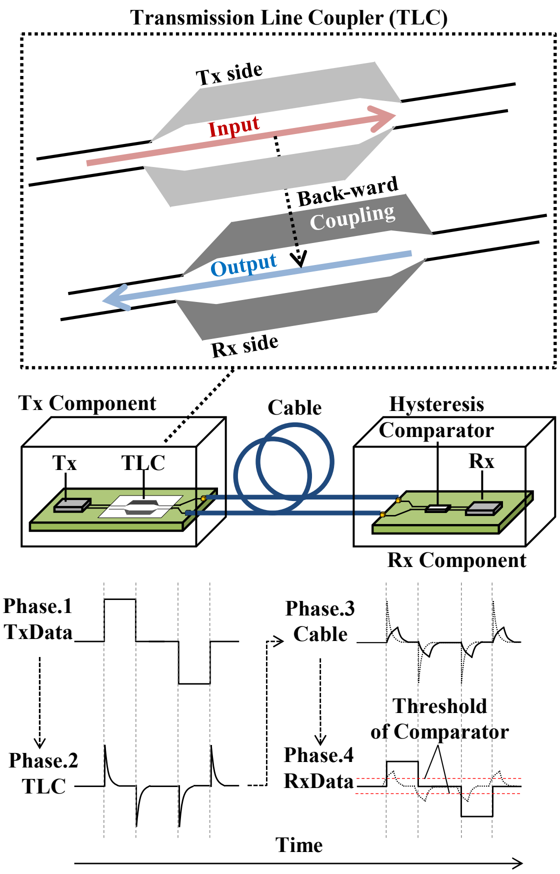


Fig. 1. High-speed space cable transmission system

In order to conquer the above problems, we focused our efforts on the new high-speed data transmission methodology, which is using the non-contact connector, consisting of Transmission Line Couplers (TLC) [3][4][5]. This method has been known to enable high speed transmission up to 12.5Gbps and have high tolerance for vibrations during the satellite launch to the space. Moreover, it is considered that the transmission with the non-contact connector includes the potential to reduce the inter symbol interference (ISI) [4]. Thus our study suggested the transmission technology with non-contact connector for lossy wire connection system and this paper describes the advantages of that. With the 3D EM simulations and measurements with test boards, it could be possible that the proposed system could expand the length of cable transmission system up to 15 m of 2.5 Gbps and BER less than 10^{-12} is feasible with the tolerance for the vibration.

II. Cable Transmission System with Non-Contact Connector

The space cable transmission system with the non-contact connector is described in this chapter, shown in Fig. 1. Using the TLC as the non-contact connector in this system is the most important. Signals sent from the transceiver get into each TLC <phase.1>. After going through the TLC, the signals are shifted differential pulses because the TLC should behave the series capacitance which cuts dc components of the signals <phase.2>, and get into the cable, as lossy transmission line. Due to the conductivity loss of the long cable transmission, the pulses might be attenuated terribly when pulses reach the component where the receiver is mounted on <phase.3>; nevertheless the pulses could be reshaped to rectangle signals by the hysteresis comparator <phase.4>. A hysteresis receiver recovers the original data by retrieving them [5]. The recovered data signals are transferred to the receiver. Therefore, the receiver could get the high integrity data signals depended on the characteristics of the comparator however attenuated pulses might be. In addition, this system must be unrelated to the jitter caused by the ISI if the width of the pulse stays in a unit interval (UI), in principle.

III. Design Concept of Non-Contact Connector

A. Transmission Line Coupler as Non-Contact Connector

The design concept of the TLC as the non-contact connector is described by the view of EM/transient simulations in this section.

When a differential data signal is transmitted from a transceiver to the other module, its shape has to be changed to 1st order differentiated pulse shape in this system [5]. Therefore, it is necessary that the non-contact connector has low-cut characteristics. In order to satisfy the above characteristics, the differential TLC might be suitable and proposed in recent studies [3][4][5]. The TLC is made by use of simple board patterns without any connector components. The coupling range meets a dual constraint: not too long for ISI, and not too short for received amplitudes. The ac coupling is needed to be bilaterally symmetric, so that the signals and I/O circuits in both directions are the same [4]. The coupling distance is supposed that it could be adjusted by the thickness of the spacer whose dielectric constant is close to the substrate's dielectric constant. The TLC has been known to have the strong horizontal offset tolerance, which is about the same as the width of the coupler [5].

B. 3D Electromagnetic(EM) Analysis

3D EM model of the proposed TLCs in this study are shown in Fig. 2. The mixed s-parameters of this model are evaluated. The differential pulse is generally created by the backward coupling between the upper and the lower TLCs. Therefore, the mixed s-parameter from differential port 1 to differential port 2 (SDD21) is the critical parameter for the transmission characteristic of the pulse created by the TLCs.

The coupling gain of the TLC is known to be determined by the ratio of the electrode width (W) and the connection distance (H). The bandwidth and the amplitude are also known to be determined by the electrode length (L). The value of W is fixed to 3 mm, and H is fixed to 1.34 mm, as the typical design. The value of L is shifted from 6 mm to 10 mm by 2 mm steps in this section.

The result of 3D EM analysis is shown in Fig. 3. From the results, each TLC has the low-cut characteristics and broad bandwidth less than 10 GHz. Moreover, it is confirmed that the more L is longer, the lower the frequency at the peak level of the SDD21. These characteristics suggest that the TLC of which L=10 mm which has the largest gain at 1.0 ~ 5.0 GHz could generate a pulse whose shape has the largest amplitude and the pulse width.

C. Transient Analysis

Transient analysis model of the proposed TLCs are shown in Fig. 4. Transceiver's output parameters are set as TLK2711A, in order to compare the waveform of the pulse generated by the TLCs. The TLC model is the mixed s-parameter obtained in the preceding chapter. The data transmission rate is set 2.5Gbps as WizardLink transmission. As shown in Fig.5 (a) ~ (c), it is confirmed the conventional rectangle signals are certainly shifted to the 1st order differential pulses by the TLCs. In particular, it is clear that the pulse amplitude and width are the largest when the value of L is 10 mm. In this study, the TLCs of L=10 mm is accordingly selected from the perspective of the influence of the attenuation in the cable transmission system, and used for measurement works.

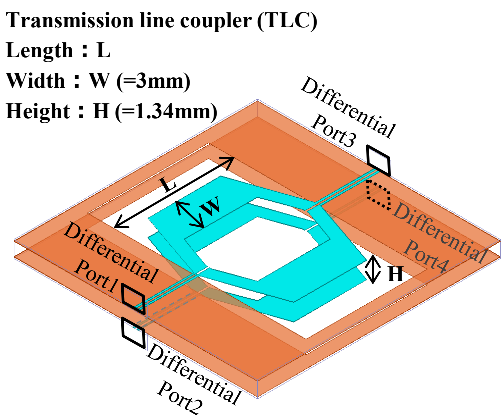


Fig. 2. 3D EM model of TLC

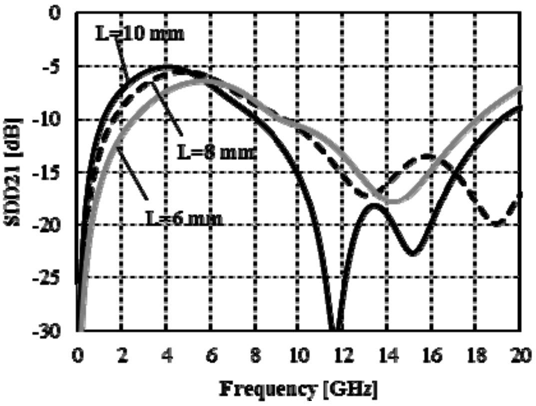


Fig. 3. Transmission characteristics of TLCs

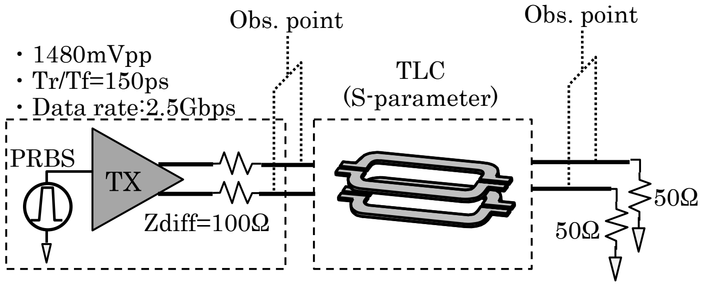


Fig. 4. Transient analysis model of TLC

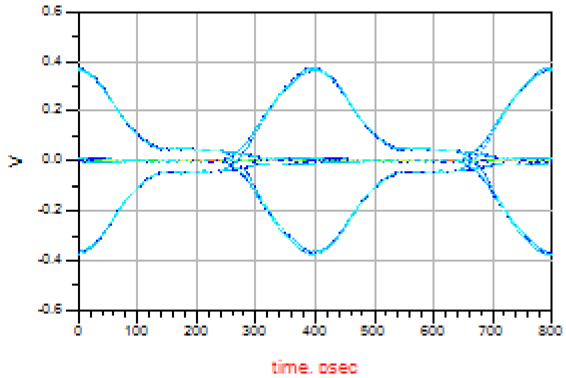
IV. Cable Transmission Measuremet

In order to confirm the availabilities of the proposed transmission system with the TLC, 15 m space cable transmission measurement is evaluated in this section. From the results of measurements, the validations of the design of the TLC and the signal integrity of the proposed system are discussed.

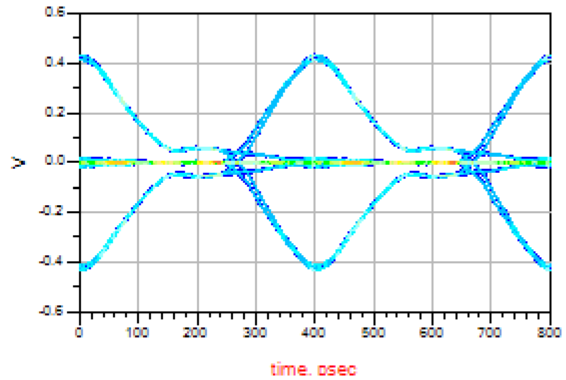
A. Measurement System

There are two measurement systems in this study, shown in Fig. 6. Time domain measurements were made with an Agilent DSO81304A oscilloscope at every probe point. Figure 7 shows the view of the measurement.

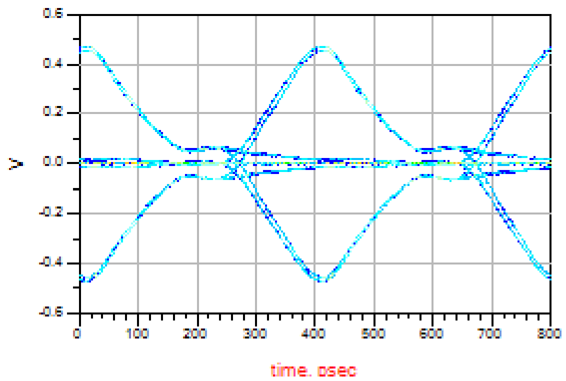
One is the proposed non-contact connector system, shown in Fig 6 (a). The TLC whose *L* is 10 mm was selected for this measurement because of its amplitude superiority for the lossy cable transmission. 1480 $mV_{p\text{-}p}$ signals sent from transceiver, T LK2711A, get into non-contact connector, and are shifted to the differential pulses. The data transmission rate of this system is set 2.5 Gbps as the WizardLink transmission. Tx/Rx components are connected by the space cable whose length is 15 m. This cable called MW311 is made by Junkosha Co. The attenuation of this cable is defined 0.91 dB/m@1GHz. Then, differential pulses are reshaped to rectangle pulses by the hysteresis comparator. The levels of hysteresis thresholds are set ±70 mV, which could be estimated from the gain of the non-contact connector and the quantity of the decrement of the space cable.



(a). *L*=6 mm



(b). *L*=8 mm



(c). *L*=10 mm

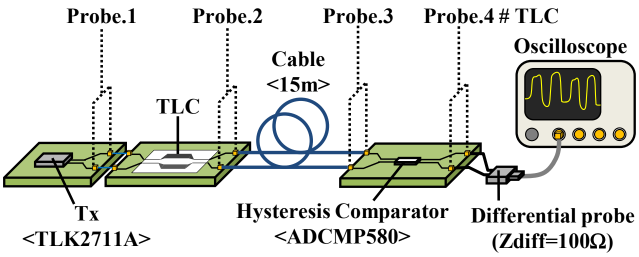
Fig. 5. Calculated waveform of pulse created by TLC

The other is the conventional system without the TLC in order to compare the transmission characteristics, shown in Fig.6 (b). Except the TLC and the comparator, it is the same setup with the non-contact connector system.

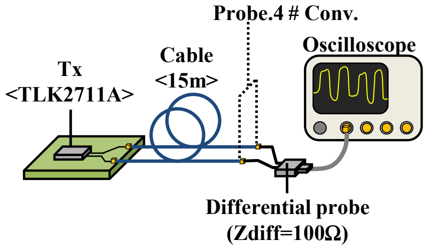
B. Results of Measurement

Fig.8 shows the results of the measurement at each probe point.

Probe.1 shows the eye pattern of the output data signals from TLK2711A. It is indicated that the output signals have approximately 1480 $mV_{p\text{-}p}$ and 80 ps jitter. Thus, it could be said that the tendency of the waveforms of the transceiver model used in the transient analysis should be valid with that in this measurement system.



(a). Non-contact connector system



(b). Conventional system for comparison (without non-contact connector)

Fig. 6. System of evaluation for cable transmission

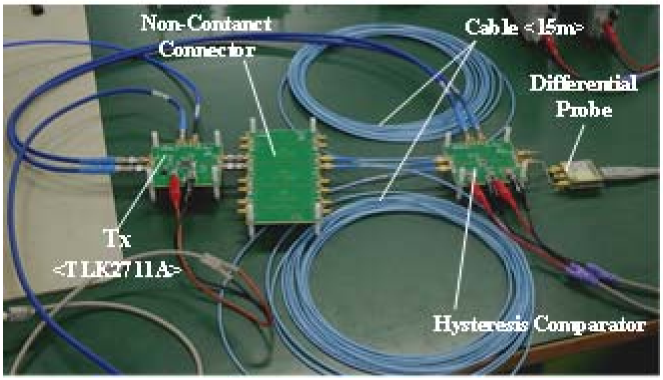
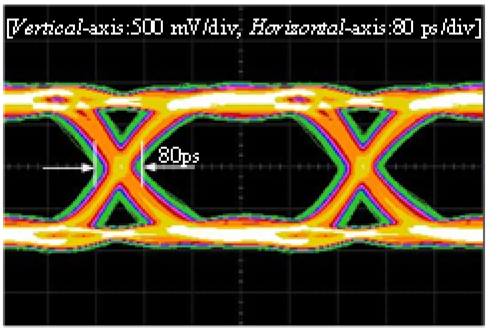


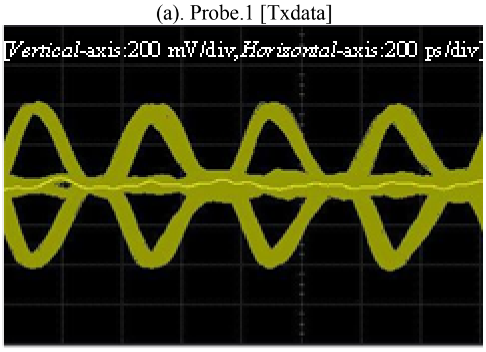
Fig. 7. View of measurement system

Probe.2 is the waveforms of the differential pulses created by non-contact connector. Shown in Probe.2, the differential pulses of about ±400 mV amplitude and less than 250 ps pulse width were obtained by the proposed TLCs. It suggests that the width of obtained pulses could be within less than UI [ps] at 2.5 Gbps.

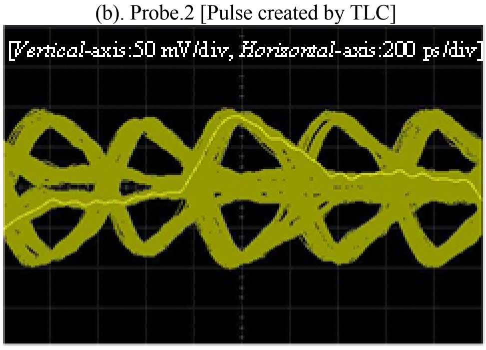
Probe.3 shows the waveforms of the differential pulses after transmitted through the 15 m cable. Due to the loss of the cable, the amplitude of the differential pulses were certainly attenuated by less than ±100 mV. Even though they might be attenuated by the lossy component, it is note that the comparator can reshape them to the rectangle pulse if the thresholds of the comparator are set properly. However, it is obvious that the width of differential pulses was force to be expanded to more than 400 ps because of the increase of the *RC* component of the cable. This width of the differential pulse might be over the UI at 2.45Gbps when it reaches to the comparator. Thus the waveform of Probe.3 seems to be affected by ISI, but it should be too small to cause the transmission irruption.



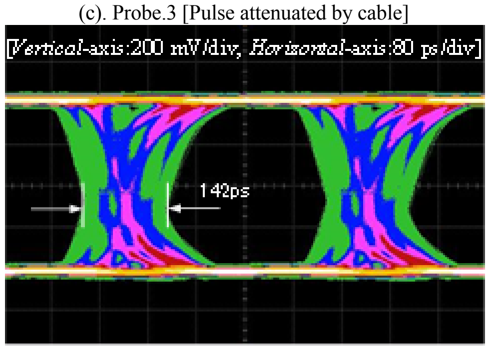
(a). Probe.1 [Txdata]



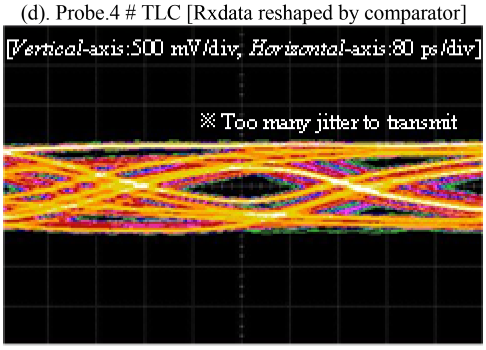
(b). Probe.2 [Pulse created by TLC]



(c). Probe.3 [Pulse attenuated by cable]



(d). Probe.4 # TLC [Rxdata reshaped by comparator]



(e). Probe.4 # Conv. [Rxdata without TLC]

Fig. 8. Measured waveforms

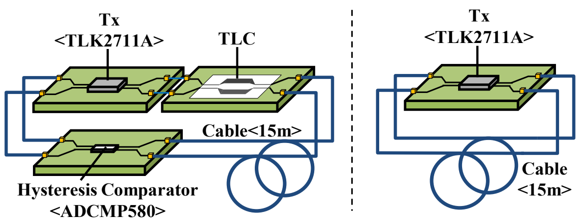
Finally, the eye pattern of the rectangle pulses reshaped by the comparator is shown in Probe.4#TLC. In order to confirm the availabilities of the non-contact connector system, the eye pattern of the conventional system is shown in probe.4#Conv. From these results, in the proposed non-contact connecter system, this clearly shows the differential pulses were reshaped well by the comparator and the signals transmitted at 2.5Gbps to the receiver. It suggests that the parameter of L of the TLCs and the hysteresis thresholds should be set properly taking the amount of attenuation of the cable into consideration. On the other hand, in Probe.4#Conv., it is confirmed that there is too many jitters to achieve the cable transmission in the conventional system. This is because the bulk conductivity and the loss tangent of 15 m cable simply influenced the eye opening.

C. Communication Test

Using embedded test function of TLK2711A, bit error checks were proceeded in order to confirm the integrity for the communications in the proposed system. Fig.9 shows the configurations of this test. The effective data transmission rates, is actually up to 2.0 Gbps, was transmitted. Consequently, It was confirmed that no signal bit failure occurred during the period of launch (1 hour). Therefore, the BER less than 10^{-12} for the WizardLink transmission was confirmed in the proposed system. On the other hand, it was observed that the communication test was end in failure continually in the conventional system. From the above, it could be said that the proposed non-contact connector system could have the availability for extending length of the transmission line, such as space cable, and so on.

V. Conclusion

The cable transmission system at 2.5Gbps with non-contact connector was presented in this paper. The detailed design methodology of the non-contact connector was described at first. The analysis suggests that the parameter of L of the TLCs determines the pulse amplitude and it should be set taking the amount of losses of the cable into consideration. In addition, analysis of actual measurement results reveals that the 15 m cables transmission of 2.5 Gbps and BER less than 10^{-12} is feasible with non-contact connector. It also means that the flexibility in the arrangement of the satellite components could be improved by using the proposed scheme. There is still room for improvement of broad band transmission characteristics for the shape of the differential pulse on the TLCs. Thus the alternative solutions to generate the more edged pulse with larger amplitude are needed, as the further study.



(a). Proposed system (b). Conventional system

Fig. 9. Configurations of Bit error check

Acknowledgment

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