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Fabrication and Reliability Study of Twinax Pairs with Dual Longitudinal Balanced Shields

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Abstract. This manuscript provides a fabrication process of a new type of twinax pairs with dual longitudinal balanced shields and twinax cables comprising this type of twinax pairs, and investigates the environmental and mechanical reliability of the twinax pairs. Single 30 AWG twinax pairs and twinax cables comprising 30AWG twinax pairs are fabricated for research purposes. Signal integration tests are conducted before, during, and after environmental and mechanical conditionings, including temperature cycling, temperature and humidity cycling, flexibility cycling, and static bending. Consistent insertion loss before, during, and after the conditionings indicates that the single twinax pairs and the twinax pairs in the twinax cables fabricated in this work exhibit robust environmental and mechanical reliability.

Keywords: twinax pair, twinax cable, QSFP cable, environmental reliability, mechanical reliability.

1. Introduction

Twinax cables are among the most widely used multiconductor transmission structures, especially for short to medium reach less than 20 meters [1-5]. A twinax cable usually includes a plurality of twinax pairs and a shield wrapping the plurality of twinax pairs. Twinax cables are generally classified into two categories: external cables mainly for rack mounted equipment and internal cables mainly for motherboards on chassis. Typically, an external cable further includes a braid surrounding the shield and a jacket wrapping the braid. An internal cable usually does not include a braid and a jacket, and twinax pairs of an internal cable may be laminated or in bundles.

In various engineering and industrial applications, twinax cables and twinax pairs may experience severe environmental and mechanical conditions, such as temperature, humidity, dynamic and static bending. Furthermore, in modern communication systems, hot plugging/unplugging is often required [6, 7]. In a hot plugging/unplugging process, cables and components may be checked and replaced during operation. For example, in troubleshooting of a data communication system, a motherboard may be checked or replaced when the system is in operation. In this case, twinax cables connected to the motherboard may be mechanically and environmentally challenged. Thus, mechanical and environmental reliability of cables is essential for operation reliability of the system.

Performance of a twinax cable is closely related performance of twinax pairs in the twinax cable. Many efforts have been made in optimizing structures of twinax pairs. However, fabrication and reliability study of twinax pairs are hardly reported.

This work is based on a twinax pair structure with a dual longitudinal balanced shield we proposed [8], and focuses on the fabrication techniques and the environmental and mechanical reliability of the twinax pair structure. The second part of this manuscript discusses the structure and the fabrication of twinax pairs with dual longitudinal balanced shields and twinax cables comprising this type of twinax pairs. The third part of this manuscript reports experimental methods and results of the environmental and mechanical reliability study of the twinax pairs and the twinax cables fabricated in this work. Discussions on performance of the twinax pairs are made in the fourth part. Concluding remarks are given at the end of this manuscript.

2. Twinax Pairs with Dual Longitudinal Balanced Shields

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In this work, twinax pairs with dual longitudinal balanced shields and twinax cables comprising this type of twinax pairs are fabricated, and their signal integrity properties are characterized.

2.1. Basic structure of a twinax pair with dual longitudinal balanced shield

Figure 1 illustrates a twinax pair with a dual longitudinal balanced shield and a quad-small-form-factor-pluggable (QSFP). In the twinax pair shown in Figure 1(a), the dual longitudinal balanced shield includes two narrow shield tapes, providing more uniform and efficient shielding. Each shield tape is independently held with a spiral PET tape for optimal reliability [8]. The twinax pair also includes four layers of adhesive for improved reliability.

As shown in Figure 1(b), the QSFP cable includes eight twinax pairs. For controlling electromagnetic radiation and electromagnetic interference, the twinax pair bundle comprising the eight twinax pairs is wrapped by a shield tape, and the shield tape is further wrapped by a braid. For insulation purposes, the braid is covered by an insulating jacket.

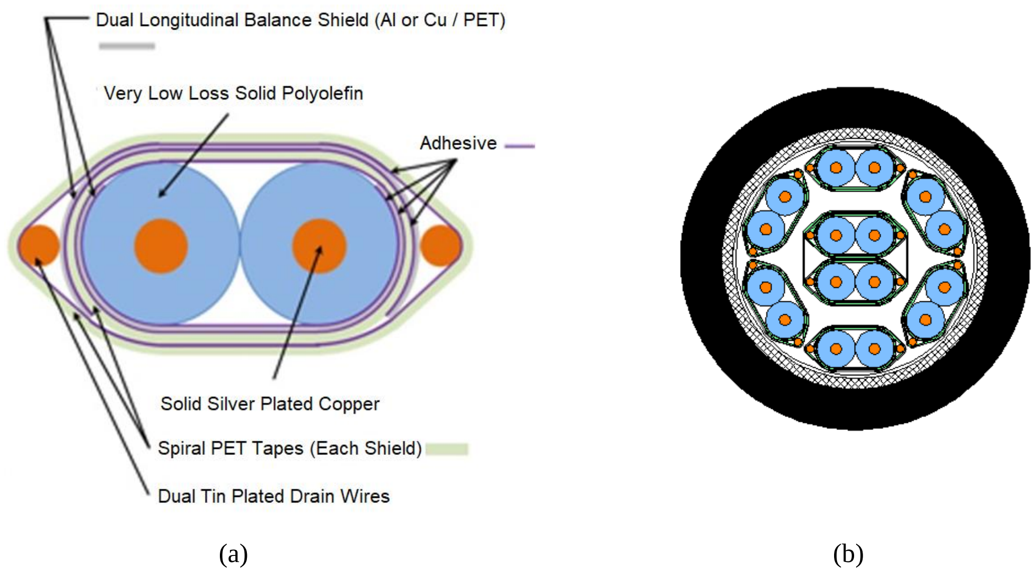


Fig. 1: Basic structures of a twinax pair with a dual longitudinal balanced shield and a QSFP cable comprising twinax pairs with dual longitudinal balanced shields. (a) Cross section of the twinax pair. (b) Cross section of the QSFP cable.

2.2. Fabrication of twinax pairs and twinax cables

As shown in Figure 2, the fabrication process of the twinax pair mainly includes: primary extrusion, taping and cabling, braiding and jacket extrusion. After the jacket extrusion, signal integrity (SI) of the twinax pairs and twinax cables is characterized under various environment and mechanical conditionings to study their environmental and mechanical reliability [9].

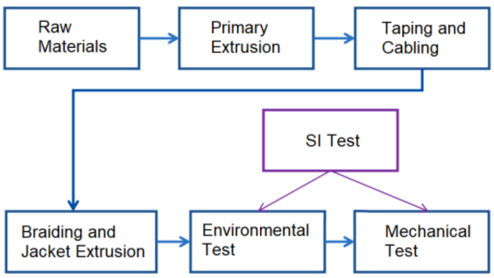


Fig. 2: Flowchart of a fabrication process of a twinax cable.

(1) Primary extrusion

Primary extrusion mainly refers to a process of forming a structure with two high-speed conductors and two ground conductors. Each of the two high-speed conductors is covered with a very low loss insulator, for example, solid polyolefin.

(2) Taping and cabling

Taping mainly refers to applying two narrow shield tapes (Al or Cu) on the structure formed in the primary extrusion, mainly comprising two high-speed conductors and two ground conductors. Each shield tape is independently wrapped by a polyethylene terephthalate (PET) tape in a spiral way to improve shield reliability. A twinax pair is formed after the typing process.

Cabling mainly refers to a process of forming a bulk cable from the twinax pairs formed in the typing process. The bulk cable includes a plurality of twinax pairs, and the bulk cable is covered with a shielding layer (Al or Cu).

(3) Braiding and jacket extrusion

During a braiding and jacket extrusion process, a braid layer is formed wrapping the bulk cable formed in the cabling process, and a jacket is then formed on the braid layer. The braid layer and the jacket may improve the reliability of the twinax pairs and the twinax cable. Figure 3 shows a QSFP cable fabricated in this work for research purposes. Major dimensions of a typical QSFP cable with 30 AWG twinax pairs are listed in Table 1.

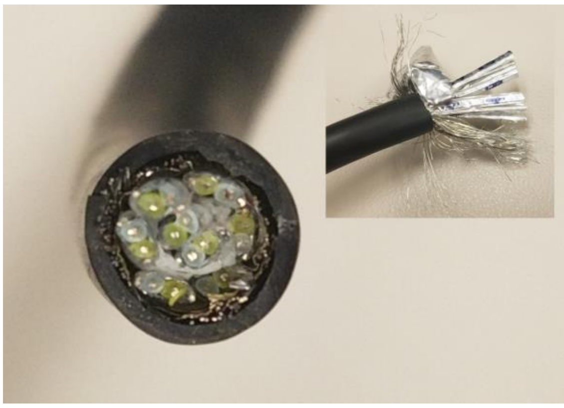


Fig. 3: Cross section of a QSFP cable. The insert shows an image of the cable with the cable shield, braid and jacket peeled.

Table 1: Structural parameters of the twinax pairs

Structural Parameters	Specifications (Unit: mm)
Diameter of high-speed conductor	0.262±0.008
Diameter of ground conductor	0.180±0.008
Diameter of braid conductor	0.080±0.008
Outer diameter of insulator	0.89±0.05
Outer dimension of the twinax pair	Width: 2.35±0.1
	Thickness: 1.08±0.1
Outer diameter of the braid of the QSFP cable	5.9±0.3

3. Study of Environmental and Mechanical Reliability

During a braiding and jacket extrusion process, a braid layer is formed wrapping the bulk cable formed in the cabling process, and a jacket is then formed on the braid layer. The braid layer and the jacket may improve the reliability of the twinax pairs and the twinax cable. Figure 3 shows a QSFP cable fabricated in this work for research purposes. Major dimensions of a typical QSFP cable with 30 AWG twinax pairs are listed in Table 1.

After the twinax pairs and twinax cables are fabricated, their signal integrity (SI) properties are characterized with a microwave network analyzer, and the environmental and mechanical reliability of the twinax pairs is studied, with emphasis laid on the change of differential mode insertion loss SDD21 due to environmental conditioning and mechanical conditionings.

In this work, a Keysight N5224A PNA microwave network analyzer is used for characterization of SI properties. The measurement frequency range is 10 MHz to 26 GHz. Based on IEEE Std 802.3cd 100GBASE-KR2, special attention is paid on 13.28 GHz. The environmental conditioning mainly includes temperature conditioning, and temperature and humidity conditioning. In a cycle of environmental conditioning, a temperature and/or humidity condition is maintained for several hours to achieve a stabilized condition. The mechanical conditioning mainly includes flexibility conditioning, and static bending conditioning.

In this work, for each conditioning, fresh twinax pairs with 30 AWG high-speed conductors are tested. The twinax pairs may be single twinax pairs, or twinax pairs in a twinax cable. Each twinax pair is 3 meters long. At room temperature, the insertion loss of the fresh twinax pairs at 13.28 GHz is in a range of approximately -14.1dB to -14.3dB. The insertion-loss specification of the twinax pairs is -15 dB up to 13.5 GHz.

3.1. Temperature cycling test

Figure 4 shows an experimental setup for temperature and humidity cycling tests. As shown in Figure 4, the twinax pairs under test are placed in a step-controllable high and low temperature testing machine (Model EW2870UWAF, GWS Environmental Equipment Co. Ltd., Guanzhou, China). The temperature and humidity in the machine may be programmed to meet test requirements. In this work, the temperature cycling tests include regular temperature cycling test and extended temperature cycling test.

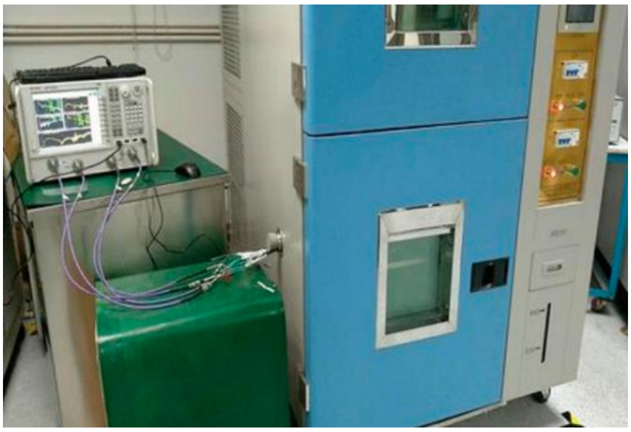


Fig. 4: Experimental setup for temperature and humidity cycling test

(1) Regular temperature cycling test

In a regular temperature cycling test, the twinax pairs are tested at a temperature range in regular engineering and industrial applications. Figure 5 shows a cycle for regular temperature conditioning. As shown in Figure 5, the regular temperature cycle includes four tests - Test1, Test 2, Test 3, and Test 4. Test 1 is conducted at 20℃ (room temperature) at the beginning of the cycle, testing the twinax pairs before conditioning. Test 2 is made at 0℃ and Test 3 is conducted at 45℃. Test 4 is conducted at 20℃ (room temperature) at the end of the cycle, testing the twinax pairs after conditioning. The humidity floats during the entire cycle.

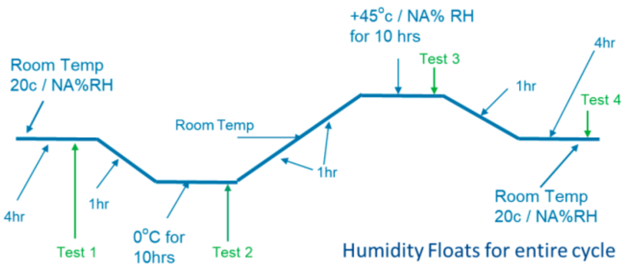
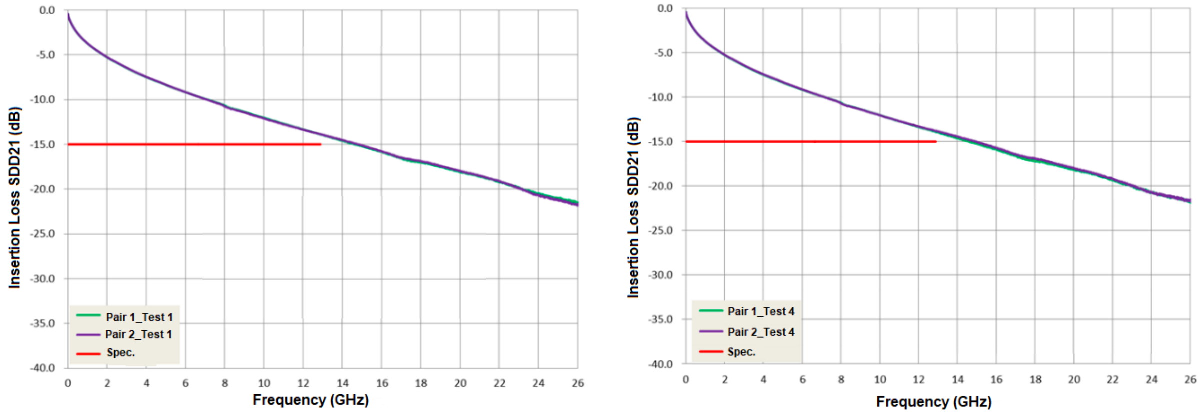


Fig. 5: A cycle for regular temperature conditioning.

Two single twinax pairs (Pair 1 and Pair 2) are tested. Figure 6 compares the insertion loss of the two twinax pairs before and after conditioning. As shown in Figure 6, the insertion loss of the twinax pairs before and after conditioning meet the insertion-loss specification.



(a) (b)

Fig. 6: Insertion loss of two twinax pairs (Pair 1 and Pair2). (a) Before conditioning. (b) After conditioning. The red line indicates the insertion-loss specification (-15dB up to 13.28 GHz).

Changes of the insertion loss (IL) of the twinax pairs in the temperature cycling at 13.28 GHz are listed in Table 2. As shown in Table 2, the insertion loss at 0℃ is lower than the insertion loss at room temperature 20℃. The decrease of the insertion loss is consistent with the increase of the conductivity of metals with the decrease of the temperature. Besides, insertion loss at 45℃ is higher than the insertion loss at room temperature 20℃. The increase of the insertion loss is consistent with the decrease of the conductivity of metals with the increase of the temperature. After the temperature returns to the room temperature, the insertion loss is quite close to the insertion loss before conditioning. As such, the temperature cycling does not have long-term effects on the twinax pairs.

Table 2: Effects of temperature cycling to the insertion loss of the twinax pairs at 13.28 GHz

	Test 1@20°C (Unit: dB/3m)	**Test 2@0°C (Unit: dB/3m)**	**Test 3@45°C (Unit: dB/3m)**	**Test 4@20°C (Unit: dB/3m)**
Pair 1	-14.12	-13.59	-14.75	-14.12
Pair 2	-14.10	-13.57	-14.69	-14.01

(2) Extended temperature cycling test

In an extended temperature cycling test, the twinax pairs are tested at an extreme temperature range to verify their operation safety. Figure 7 shows an extended temperature conditioning cycle. As shown in Figure 7, seven tests are conducted at the extended temperature cycling, including Tests 1-7. Test 1 is conducted at 20℃ (room temperature), Test 2 is conducted at 40℃, Test 3 is conducted at 60℃, Test 4 is conducted at 80℃, Test 5 is conducted at 105℃, Test 6 is conducted at 125℃, and Test 7 is conducted at 20℃. The humidity floats during the entire cycle.

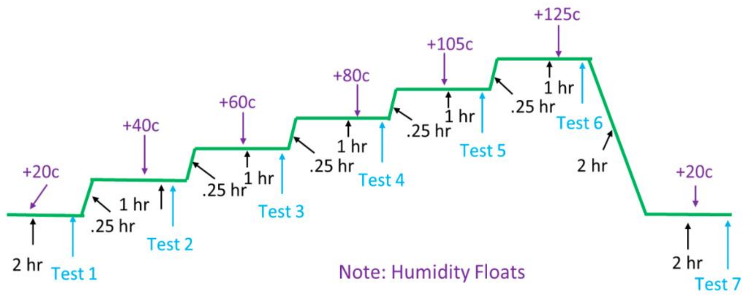


Fig. 7: A cycle for extended temperature conditioning.

Five twinax pairs (Pairs 3-7) in a twinax cable are tested during the extended temperature cycle. The insertion loss values of the five twinax pairs at different temperatures at 13.28 GHz are listed in Table 3. As shown in Table 3, the insertion loss of the twinax pairs increases with the increase of the temperature. After the temperature returns to the room temperature, the insertion loss is quite close to the insertion loss before the conditioning. As such, the extended temperature conditioning does not have long term effect on the twinax pairs. After the extended temperature conditioning, the insertion loss of the five twinax pairs is consistent the insertion loss the five twinax pairs before the conditioning.

Table 3: Insertion loss of twinax pairs at 13.28 GHz at different temperatures

	Test 1 @20°C (dB/3m)	**Test 2 @40°C (dB/3m)**	**Test 3 @60°C (dB/3m)**	**Test 4 @80°C (dB/3m)**	**Test 5 @105°C (dB/3m)**	**Test 6 @125°C (dB/3m)**	**Test 7 @20°C (dB/3m)**
Pair 3	-14.20	-14.62	-15.09	-15.82	-16.55	-17.19	-14.21
Pair 4	-14.11	-14.59	-15.11	-15.75	-16.47	-17.10	-14.16
Pair 5	-14.16	-14.70	-15.20	-15.88	-16.61	-17.26	-14.26
Pair 6	-14.19	-14.72	-15.14	-15.83	-16.51	-17.15	-14.16
Pair 7	-14.20	-14.70	-15.19	-15.83	-16.56	-17.20	-14.19
Average	-14.17	-14.67	-15.13	-15.82	-16.54	-17.18	-14.20

3.2. Temperature and humidity cycling test

Figure 8 shows a temperature and humidity conditioning cycle. In this work, three cycles are performed continuously. As shown in Figure 8, in each cycle, four tests are conducted. Test 1 is conducted at 20℃ (room temperature) and 45% relative humidity (RH) at the beginning of the cycle. Test 2 is conducted at -10℃ with floating humidity, and Test 3 is conducted at 65℃ and 85% RH. Test 4 is conducted at 20℃ (room temperature) and 45% RH at the end of the cycle. The temperatures and humidity values are chosen to mimic the working conditions of twin pairs and twinax cables in a server chassis.

Two twinax pairs (Pair 8 and Pair 9) in a two-pair cable are tested. Figure 9 shows the insertion loss (SDD21) before and after conditioning (three cycles). In Figure 9, 1st_test 1 stands for Test 1 of the first cycle, indicating the state “before conditioning,” and 3rd_test 4 stands for Test 4 of the third cycle, indicating the state “after conditioning.” As shown in Figure 9, the insertion loss of the twinax pairs does not change much after three temperature and humidity conditioning cycles.

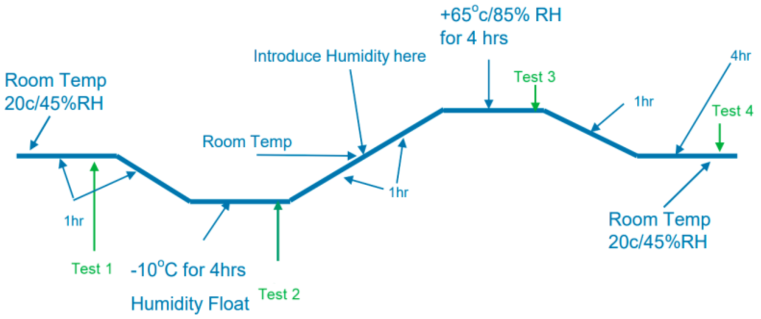
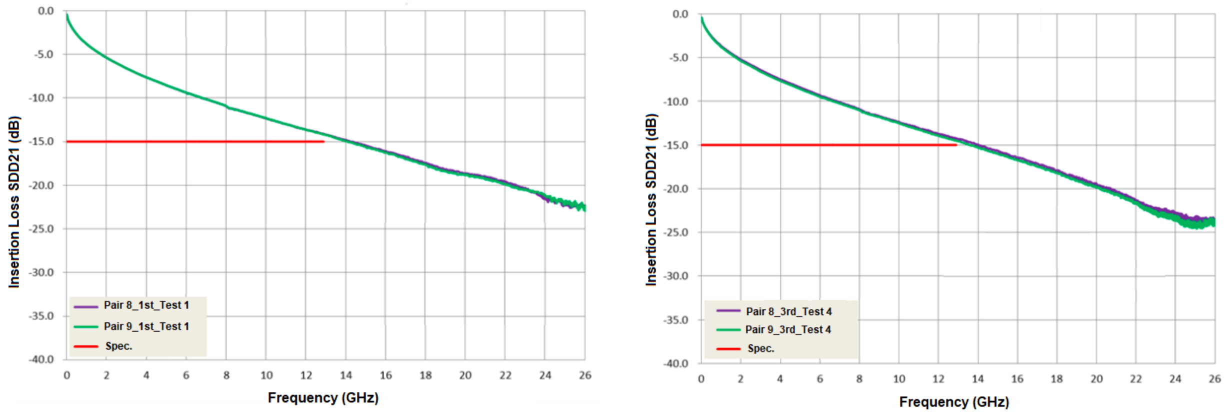


Fig. 8: A cycle for temperature and humidity conditioning.



(a) (b)

Fig. 9: Insertion loss of two twinax pairs (Pair 8 and Pair 9). (a) Before conditioning. (b) After conditioning. The red line indicates the insertion-loss specification (-15dB up to 13.28 GHz).

Changes of insertion loss at 13.28 GHz due to temperature and humidity conditioning are listed in Table 4. In Table 4, the changes of insertion loss are obtained by comparing the insertion loss after conditioning to the insertion loss before the conditioning. As shown in Table 4, the change of insertion loss after each cycle is less than 3%, and the changes of insertion loss of consecutive cycles do not accumulate.

Table 4: Changes of the insertion loss at 13.28 GHz of the twinax pairs due to temperature and humidity conditioning

	Change of insertion loss % After Cycle 1	**Change of insertion loss % After Cycle 2**	**Change of insertion loss % After Cycle 3**
Pair 8	+1.93%	+2.38%	+0.87%
Pair 9	+2.53%	+2.71%	+2.36%

3.3. Temperature and humidity cycling test

In engineering and industrial applications, high-speed cables may be dynamically and/or statically bended. Flexibility refers to the capability of enduring dynamic bending. In this work, a bending tester (Luxshare-ICT, Guangdong, China) is used for testing flexibility of the twinax pairs in a twinax cable. The cable is flexed at a radius of five times of the cable diameter for 1000 cycles. Figure 10 shows the insertion loss of a typical twinax pair (Pair 10) in a QSFP cable. The insertion loss is measured before bending, after 250 dynamic bending cycles, after 500 dynamic bending cycles, after 750 dynamic bending cycles, and after 1000 dynamic bending cycles. As shown in Figure 10, dynamic bending does not change the insertion loss much, especially at frequencies lower than 15 GHz, and the insertion loss meets the insertion-loss specification.

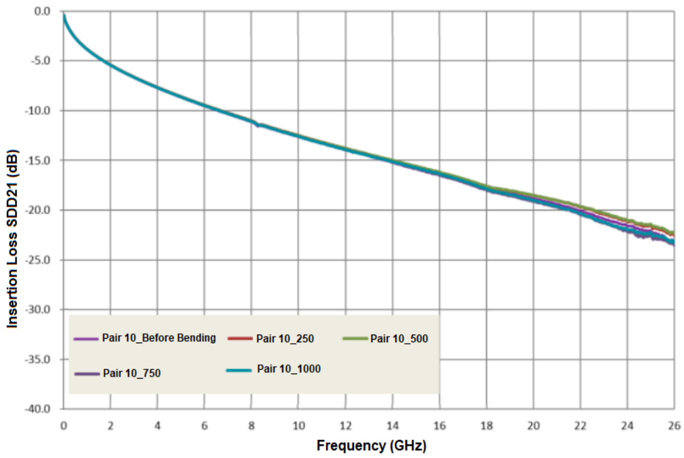


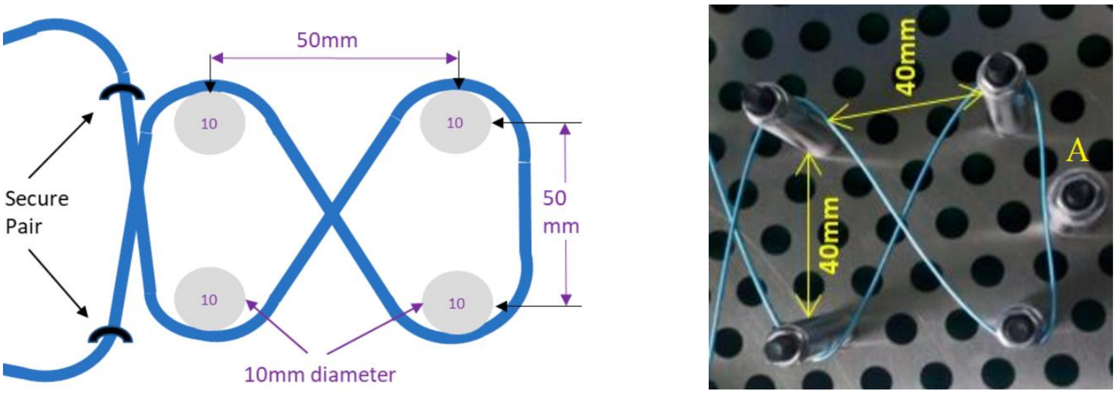
Fig. 10: Insertion loss of a twinax pair (Pair 10) in a QSFP cable measured before bending, after 250 dynamic bending

cycles, after 500 dynamic bending cycles, after 750 dynamic bending cycles, and after 1000 dynamic bending cycles.

In addition, failure test of dynamic bending is conducted on single twinax pairs (Pair 11 and Pair 12). The failure test finds out the number of cycles before the insertion loss of the twin pair at 13.28 GHz is equal to or larger than -15.0 dB. In this work, Pair 11 fails at the 1,215th cycle, and so it survives up 1,214 cycles. Pair 12 survives up to 1,463 cycles. Accordingly, the twinax pairs may endure more than one thousand cycles, meeting the flexibility requirements from engineering and industrial applications.

3.4. Temperature and humidity cycling test

Static bending test is conducted on two single twinax pairs (Pair 13 and Pair 14) at room temperature. Figure 11 shows the experimental setup for the static bending test. As shown in Figure 11, the experimental setup includes four mandrels each with 5 mm radius, which is about 5 times of a minor dimension of the single twinax pairs. As shown in Figure 11(b), an adjustment mandrel A is used to keep the twinax pair between two mandrels straight.



(a) (b)

Fig. 11: Experimental setup for static bending test. (a) A schematic of the setup, and (b) a picture of the setup.

Signal integrity test is performed before, during, and after the static bending. To study the signal integrity during static bending, the twinax pair is tested after the twinax pair has been statically bended for 24 hours continuously. To study the signal integrity after static bending, the twinax pair is tested within 5 minutes after the pair is released from the static bending. Figure 12 and Table 5 show the insertion loss of a twinax pair (Pair 13) before, during and after the static bending. As shown in Figure 12 and Table 5, the insertion-loss values of the twinax pair before, during and after the static bending are quite close, indicating that the static bending has little effects on the insertion loss of the twin pair.

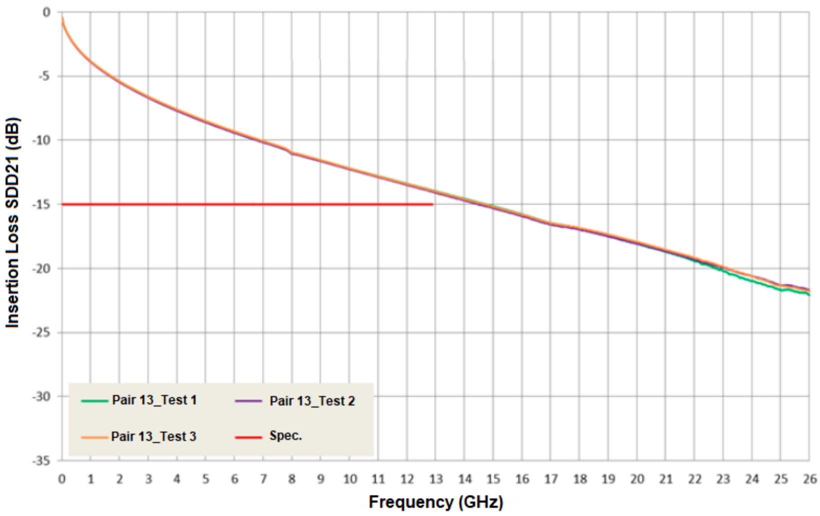


Fig. 12: Insertion loss of a twinax pair (Pair 13) before, during and after static bending. Test 1, Test 2, and Test 3 are conducted before, during, and after the static bending respectively. The red line indicates the insertion-loss specification (-15dB up to 13.28 GHz).

Table 5: Insertion loss before, during and after static bending at 13.28 GHz

	Before Bending (Unit: dB/3m)	**During Bending (Unit: dB/3m)**	**After Bending (Unit: dB/3m)**
Pair 13	14.14	14.25	14.16
Pair 14	14.30	14.38	14.38

4. Discussions

In the fabrication process of twinax pairs with dual longitudinal balanced shields, on-line monitoring techniques are used to monitor important parameters, such as the diameters of the high-speed conductors and ground conductors, to control process variations, and the twinax pairs fabricated exhibit consistent SI properties. In addition, the facilities used in the fabrication process are widely used in engineering and industrial fabrication and can be easily maintained. As such, the fabrication process can be used in large scale production of twinax pairs with dual longitudinal balanced shields.

The robust environmental and mechanical reliability of the twinax pairs is related to the special structure of the twinax pairs. Since the dual longitudinal balanced shield includes two narrow shield tapes, more uniform and efficient shielding may be achieved. Also, since each shield tape is independently held with a spiral PET tape, optimal reliability may be obtained. Moreover, four layers of adhesive in the twinax pair further improve the reliability.

In addition, the experimental results indicate that the insertion loss of the twinax pairs increases with the increase of temperature. The increase of the insertion loss with increase of temperature is consistent with the decrease of conductivity of metals with the increase of temperature. Since other dimensional and electrical parameters do not change much in the temperature range of this work, the change of insertion loss is mainly due to the change of conductivity of the high-speed conductors and the ground conductors in the twinax pairs.

5. Acknowledgements

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