# Thin Flexible Printed Circuit Supporting Transmission Rate from 1 to 10 Gbps

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Due to the increasing demand for high speed communication in electronic equipment, rapid improvement is observed in data transmission rate through interface and wireless communication device. Particularly in the mobile device such as mobile phone and tablet PC, thinner and lighter FPC is required. In such high speed transmission field, flexible printed circuit (FPC) has been applied in place of co-axial cable. From this kind of circumstance we have started the development of high speed FPC. We have verified the transmission performance of the in-house developed FPC supporting USB 3.0 and 4G-antenna by optimizing FPC structure and material, thereby demonstrate the application possibility of the FPC in the high speed transmission field.

Keywords: flexible printed circuits (FPC), high speed transmission, high frequency, low dielectric

## 1. Introduction

Recently, there has been a growing need for high-speed transmission in the field of electronic devices. And the transmission speeds of interface and mobile communication standards have been rapidly increasing.

As shown in **Fig. 1**, the Sumitomo Electric Group has been developing products to meet the need for high-speed communication such as optical fibers, co-axial cables and FFCs. In tablet PCs and mobile phones, the demand for shorter transmission paths and lower profiles is increasing. In some fields, flexible printed circuits (FPCs) are beginning to be used as a means of high-speed wiring.

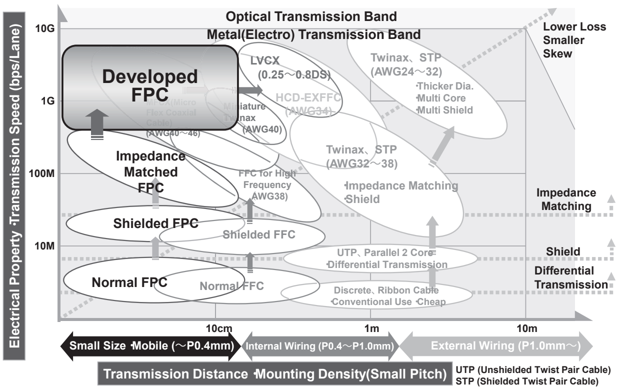


**Fig. 1.** Matrix of the Lengths of Wiring Inside and Outside Devices, and the Transmission Characteristics

We have developed an FPC for antennas that conforms to USB 3.0, one of the high-speed interface standards, and the Fourth-Generation Mobile Communication Standard. The details are described in the following sections.

## 2. Outline of High-Frequency FPCs

**Figure 2** illustrates the layer construction of a general FPC. A conductor circuit is formed on the base material made of insulating film. The created conductor circuit is coated with a material called "a cover lay," which is an insulating film integrated with adhesive to protect the circuit or insulate it from another circuit. In general, an FPC with this configuration uses a polyimide film for the base material, and a polyimide film and epoxy adhesive for the cover lay. In case of a multi-layer circuit board, two FPCs are glued together with inter-layer adhesive (usually epoxy-based).

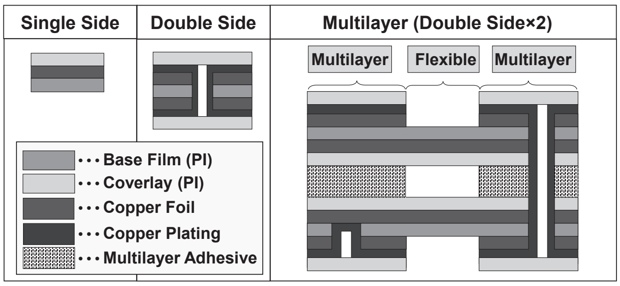


**Fig. 2.** Layer Configurations of General FPCs (One-sided, Double-sided, and Multi-layered)

**Figure 3** shows the dielectric characteristics of different types of insulators. Common polyimide films, having superior dielectric characteristics compared to FR-4, which is used for rigid plates, are suitable for high-frequency applications.

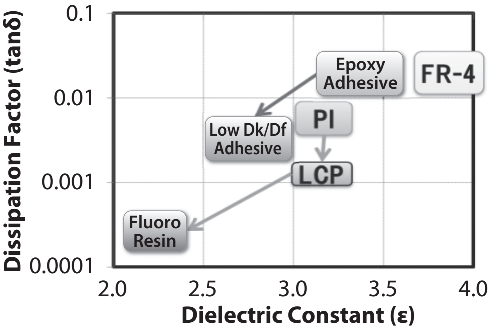


**Fig. 3.** Technological Trends in the Dielectric Characteristics ($\varepsilon$ and tan $\delta$) of Insulating Materials

## 3. FPC Development for High-Speed Interface Applications

Conventionally, a main board and a high-speed interface are connected with a co-axial cable or an optical fiber, except for some applications. However, a long cable is a cause of increased transmission loss.

As shown in **Fig. 4**, USB 3.0 and SATA 3.0, which have been put into practical use, have a transmission rate of 5 to 6 Gbps, which is relatively low for high-speed interfaces. When they are used for wiring inside a device, the wiring length is 30 cm or shorter, to which FPCs are applicable in terms of design. There is also the potential need for integrated wiring with several interfaces and thin wiring mainly for tablet PCs.

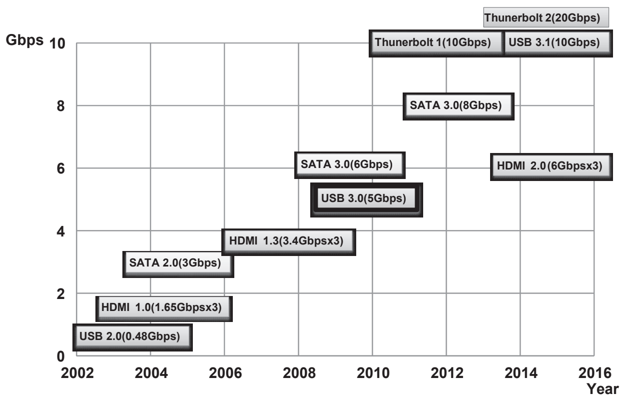


**Fig. 4.** Load Map of the Transmission Rate of High-Speed Interfaces

**Figure 5** shows the outer appearance of a prototype FPC for evaluating the transmission characteristics of the USB 3.0 interface. This FPC has a USB 3.0 connector at one end and Zif connector contacts at the other end for high-speed transmission. The total length is approximately 150 mm. There are cost concerns about extending the length of an FPC. In our double-sided FPC design, the maximum length is around 270 mm, which is a realistic size for actual products.

There are two challenges for realizing a high-speed connection with FPC technology.

(1) Reducing transmission loss (improving insertion and reflection characteristics)
(2) Measures for controlling EMI (electromagnetic wave noise)

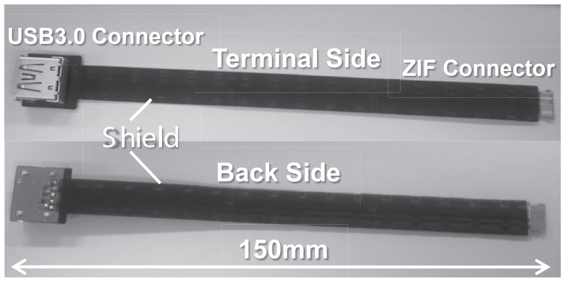


**Fig. 5.** Outer Appearance of a USB 3.0 FPC for Evaluating Transmission Characteristics

### 3-1 Reducing transmission loss

**Figure 6** illustrates the cross section of a USB 3.0 FPC. It has GND wiring at both ends of the differential circuit. There are two types of layout of the GND shield material: one side and both sides of the conductor. In general, expanding the cross sectional area of the core conductor is effective for cutting down on the transmission loss of a cable. Similarly, it is expected that increasing the cross-sectional area of an FPC conductor leads to reducing transmission loss. The width of a conductor was optimized to reduce transmission loss by conducting simulation and loss measurement in VNA. **Figure 7** indicates the insertion loss of an FPC obtained through evaluations for optimization and the results of measuring a 150-mm-long FPC. A 150 mm-long FPC provides the transmission characteristics that sufficiently satisfy the USB 3.0 loss standard for cable wiring. The Eye aperture also provides good results at 5 Gbps.

For further reductions in transmission loss, changing the materials of the insulator and shield, as well as the conductor width was thought to be effective. For the insulator material, polyimide (tan $\delta$ = 0.008, hereinafter referred to as "PI") was replaced with liquid crystalline polymer (tan $\delta$ = 0.002, hereinafter referred

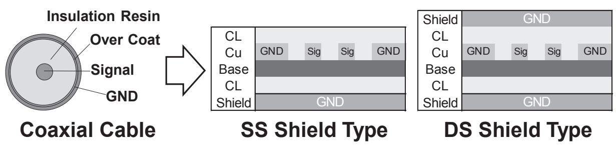


**Fig. 6.** Cross-sectional Structure of a USB 3.0 FPC (Two-sided and one-sided shield types)

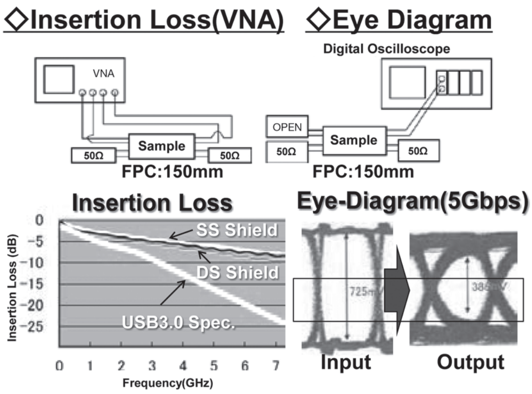


**Fig. 7.** Transmission Loss of a USB 3.0 FPC and Eye Pattern Measurement

to as "LCP") that had superior dielectric characteristics. The shield material was also changed from deposited metal to metal foil of lower resistance. **Figure 8** shows the results of evaluating the transmission characteristics (eye pattern). With the new materials, An FPC with a wiring length of 400 mm indicates an eye opening at 5 Gbps. Then a test at 10 Gbps confirmed signal transmission up to a wiring length of 200 mm with a judgment level of 25% or more attenuation (peak ratio) in the eye opening.

( )Peak Ratio

| | | Input | Output 200mm | Output 400mm |
|---|---|---|---|---|
| PI / Normal Shield | 5G bps | 694mV(100%) | 191mV(28%) | NG(0%) |
| LCP / Low-R Shield | 5G bps | | 405mV(58%) | 199mV(29%) |
| LCP / Low-R Shield | 10G bps | 664mV(100%) | 225mV(34%) | NG(0%) |

**Fig. 8.** Eye Pattern Measurement Results with Different Insulator and Shield Materials

The above results suggest that an FPC of 200 mm range, which is a practical length, has the possibility of supporting high-speed transmission in the next-generation standard, USB 3.1 (10 Gbps), by optimizing the width and material of the wire.

### 3-2 Measures for controlling EMI (Electromagnetic Wave Noise)

Another challenge in using FPCs in high-frequency bands is EMI. A co-axial cable has a core surrounded with a mesh of GND conductor and shielded terminal connectors, which ensures EMI isolation. On the other hand, FPCs have not been used in high-frequency ranges, and EMI measures are therefore essential. For EMI measures on relay cables, shield materials are effective, and that are partly applied to conventional FPCs. The effects of suppressing electromagnetic emission noise by shielding were examined. **Figure 9** shows the results of an evaluation using an EMI tester. They indicate that shielding an FPC controls almost all the noise emitted from the signal lines.

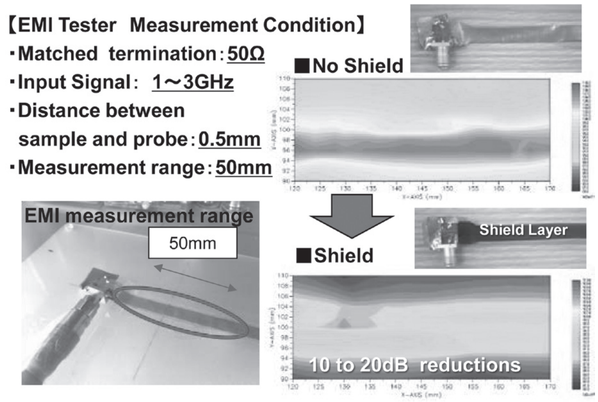


**Fig. 9.** Reductions in Electromagnetic Emission Noise by Shielding an FPC

For the EMI design of connector contacts, the PC and other system manufacturers provide no definite guidelines. Therefore, noise emission from the contacts was examined with a connector manufacturer. **Figure 10** illustrates the comparison of emission noise between a conventional connector and a shielded connector. The conventional connector emits a large amount of noise from around the contacts. In contrast, the shielded connector suppresses electromagnetic noise emitted from the contacts with a metal shield cover. As this type of shielded connector provides impedance matching at the connection, high-frequency support can be expected.

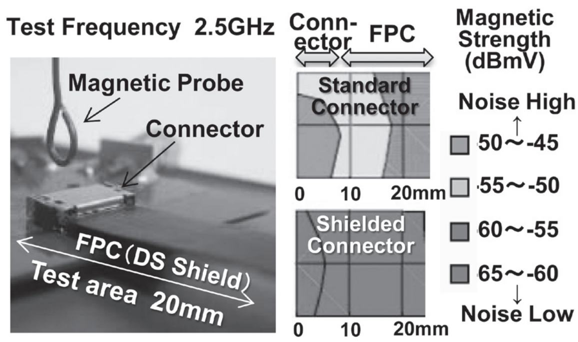


**Fig. 10.** Reductions in Electromagnetic Emission Noise from an FPC with an EMI Shield Connector

## 4. FPCs for Mobile Device Antennas

In the field of mobile devices, the mainstay products have been changing, from flip mobile phones to smartphones in recent years. The communication standard has been progressing to higher speeds from 3rd Generation (3G) to 4th Generation (LTE). Following this trend, there is a growing need for high-frequency, and high-transmission speed supports in electronic components. As smartphones require batteries with larger capacities compared to flip mobile phones, space saving is also required. **Figure 11** summarizes the internal structure of a smartphone. In conventional design, the electromagnetic signal received from the antenna FPC is transmitted to the main board through a co-axial cable. However, in mobile devices, as the length of the transmission to the main board is 15 cm or shorter in most cases, the co-axial cable can be replaced with an FPC safely in terms of design. We have developed an antenna FPC integrated with a multi-layer board FPC that replaces the co-axial cable in order to respond to the need for high-speed transmission and space saving.

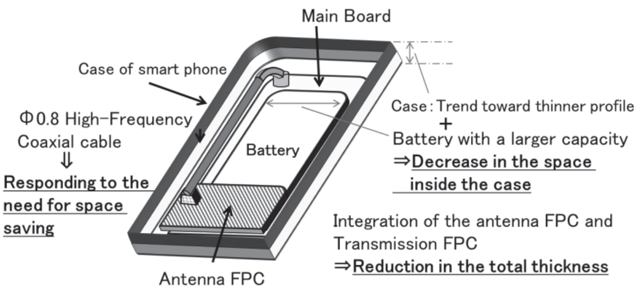


**Fig. 11.** Summary of the Internal Structure of a Smartphone

**Figure 12** shows the cross section of a co-axial cable and an integrated antenna FPC. The co-axial cable has a core, which transmits a signal, is surrounded with a low-dielectric fluoroplastic and an outer layer that serves as a GND conductor. The integrated antenna FPC has a similar structure. The outer layer is a GND conductor and the transmission circuit is at the center, which results in a reduction in thickness by approximately 65%.

Conventional multi-layer FPCs use polyimide or epoxy inter-layer adhesive. However, these materials have large dielectric loss tangents, which is inappropriate for high-speed transmission. Reducing transmission loss has been the biggest challenge for responding to the needs of users. The integrated antenna FPC developed for transmission loss reduction uses low-dielectric materials for the base and inter-layer adhesive to support high transmission speeds. The flexible circuit arrangement, one of the features of an FPC, enables optimization for high-speed transmission with small transmission loss. **Figure 13** compares the transmission loss of a co-axial cable and an integrated antenna FPC made of LCP. The transmission loss of the integrated antenna FPC is -2.0 dB or smaller, which sufficiently supports the communication speed of the 4th Generation, satisfying the requirements of high-speed transmission. The integrated antenna FPC we developed responds to the need for both high transmission speeds and space saving.

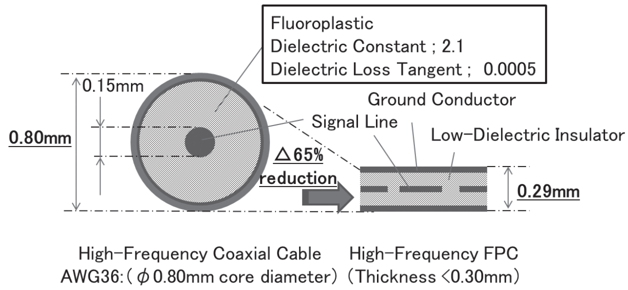


**Fig. 12.** Cross Section of an Integrated Antenna FPC

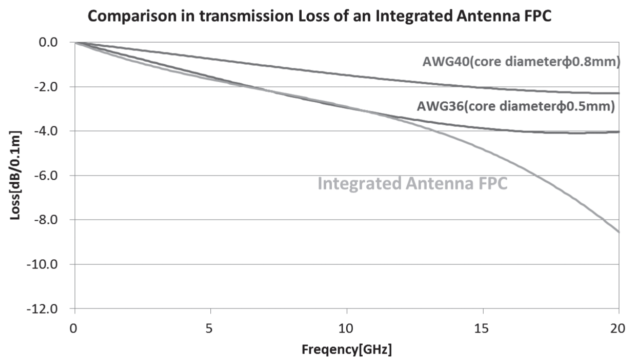


**Fig. 13.** Comparison in Transmission Loss of Co-axial Cables and an Integrated Antenna FPC

## 5. Conclusion

There is a growing requirement for high-speed transmission especially in the field of communication. In-vehicle applications use high-speed devices such as millimeter wave antennas. The potential need for high-frequency boards is starting to expand. Based on the above results, we have started research on next-generation high-speed FPCs and will accelerate technological development with an eye toward horizontal expansion to new fields.

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