A Study of Impedance Control in Flexible Printed Circuit (FPC)

Tomonari Yokoyama[1], *Hirohito* Watanabe[1], *Yukiharu* Sakaguchi[1], *Haruo* Miyazawa[1], *Yoshiharu* Unami[1] and *Nobuyuki* Sadakata[1]

Ordinary, requirements for printed circuits are only to be connected correctly and to have enough electrical current capacity. If signals used inside of equipments are very low frequency, impedance control of circuit is not needed. Impedance control is needed only for long communication cables between equipments.

When electrical circuits with high frequency signal are operated, impedance control is needed for not only communication cables but also printed circuits.

Recently it is not rare that the high frequency signal (several hundreds MHz to several GHz) is used inside of equipment. In this case, the circuit should be considered as distributed constant circuit even if the circuit is very short. Therefore impedance control of circuit is needed on Printed Circuit Board.

Based on the background described above, we have tried to control characteristic impedance of Flexible Printed Circuit (FPC) .

1. Introduction

In the field of electronic circuitry, if necessary wires were properly connected on a printed circuit board and the wiring pattern had a sufficient current capacity relative to the current, no trouble occurred in the operation of the printed circuit board. Along with the recent remarkable increase in the circuit operation speed, however, the above-mentioned conditions are not sufficient for the design of a printed circuit board. One of the required items is the characteristic impedance of a pattern.

So far, for a device using only a low-speed signal of several MHz or less, only the characteristic impedance of telecommunication cables connecting between the devices should be considered. This was because the wavelength of the signal to be used was long enough compared to the size of the device, and the circuit in the device could be regarded as a lumped constant circuit. The cables connecting the devices are not sufficiently short in relation to the wavelength that is to be used, hence it should be regarded as a distributed constant circuit. Therefore, control of the characteristic impedance is required for cables.

Recently, it is not uncommon to use electrical signals with the frequency of several 100 MHz to several GHz in a device. If such a high-speed signal is transmitted, a transmission line should be regarded as a distributed constant circuit even if the transmission line is short and intended for use only in the device. Therefore, the control of the characteristic impedance on the printed circuit board is required.

In light of the above situation, a flexible printed circuit (hereinafter referred to as FPC) is growing in demand. This report describes the challenges in controlling the characteristic impedance on FPC and the present achievements.

1 Circuit Technology Development Division, Electronic and Electrical Development Center

2. Outline

2.1. Characteristic impedance

Characteristic impedance is determined by the square root of the ratio between the induction element and the capacity element of the signal line per unit length.

If the output impedance of the signal output circuit, the load impedance connected to the terminal portion of the signal line, and the characteristic impedance of the transmission line are consistent, no signal reflection occurs on the transmission line. The connection of input/output impedance that is equal to the characteristic impedance is equivalent to an infinitely continual transmission line having a uniform characteristic impedance.

2.2. High-speed signal transmission line

The signals often used for a high-speed data transmission are PECL, LVDS, CML, etc. For these signals, a driver for connecting the load of 50 Ω of impedance is used and the output impedance is adjusted to 50 Ω. On such an interface, the characteristic impedance of the transmission line to be connected needs to be controlled to 50 Ω

2.3. Differential impedance

In such a high-speed signal, differential input and output are generally used to enhance resistance to the common mode noise from the outside.

Input impedance at the termination of the transmission line is also defined by differential impedance, which is 100 Ω. In this case, the characteristic impedance of the transmission line is also defined by the differential impedance, which is 100 Ω, thereby preventing signal reflection between transmission lines.

Generally, differential impedance is not equal to the sum of the characteristic impedances of two signal wirings. The larger the coupling coefficient between two signal wires, the smaller the differential impedance. If there is a large gap between two signal wires so that it may be regarded as no connection of two wires, the differential impedance becomes equal to the sum of the characteristic impedances of two signal wires.

3. Simulation

3.1. Modeling of transmission line

To control the characteristic impedance on the wiring board, a co-planar line, microstrip line, or strip line is generally used.

3.1.1. Co-planar line

A co-planar line has a structure of the type of transmission line that is used for the cables such as a feeder line. It is formed by a parallel wiring so that the gap between the circuit pattern transmitting a signal and the circuit pattern of the ground becomes constant. The weak points in using a co-planar line are that the degree of freedom for wiring becomes low because the impedance is controlled only by the width and the gap, and the noise radiated from the signal line becomes greater than in a microstrip line or a strip line because of the line wiring at the ground.

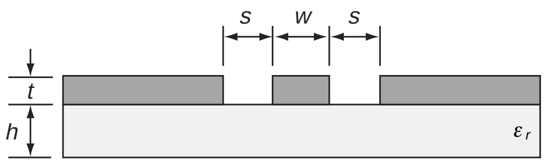
3.1.2. Microstrip wiring

On a microstrip line, signal patterns are arranged to overlap a ground plane. A co-planar line can be made up of a single-sided board, whereas a microstrip line requires a board having at least two-layers. On a microstrip line, the characteristic impedance can be controlled by the distance between the ground plane and the signal pattern and the wiring width of the signal pattern.

This is a transmission line that is relatively easy to connect, can reduce radiant noise, and can be used most frequently on the printed circuit board.

3.1.3. Strip line

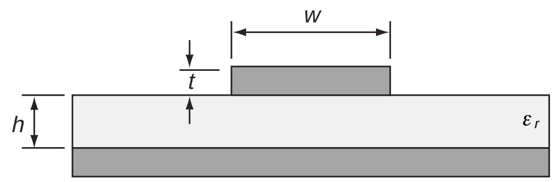
A strip line has a structure where signal patterns are arranged so as to get caught in the ground plane. Therefore, the board must have at least three layers. Similar to a microstrip line, the characteristic impedance can be controlled by the distance between a ground conductor and a signal pattern and the wiring width of the signal pattern. This is a structure that can reduce the largest amount of radiant noise.



(a) Co-planar line

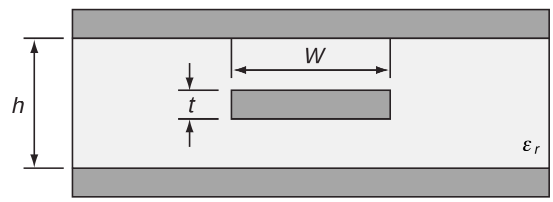
$$Z_0 = \frac{30\pi}{\sqrt{\varepsilon_{re}}} \frac{K\left[\sqrt{1-\{w/(w+2s)\}^2}\right]}{K\{w/(w+2s)\}} \quad {}^{1)}$$

$$\varepsilon_{re} = 1 + \frac{\varepsilon_r - 1}{2} \cdot \frac{K\{w/(w+2s)\}}{K\left[\sqrt{1-\{w/(w+2s)\}^2}\right]} \cdot \frac{K\left[\dfrac{sinh(\pi w/4h)}{sinh\{\pi(w+2s)/4h\}}\right]}{K\left(\sqrt{1-\left[\dfrac{sinh(\pi w/4h)}{sinh\{\pi(w+2s)/4h\}}\right]^2}\right)}$$



(b) Microstrip line

$$Z_0 = \frac{60}{\sqrt{0.475\,\varepsilon_r + 0.67}} \ln\left(\frac{5.98h}{0.8w+t}\right) \quad {}^{2)}$$



(c) Strip line

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{5.98h}{\pi(0.8w+t)}\right) \quad {}^{3)}$$

w : Signal pattern width
s : Distance between ground plane and signal pattern
h : Thickness of dielectric material layer
t : Thickness of conductor layer
ε_r : Permittivity

Fig. 1. Structure of transmission lines.

3.1.4. Differential line

The differential impedance is controlled by the gap between signal patterns, too.

3.2. Conventional analysis method

On these transmission line models, the characteristic impedance of co-planar transmission line, microstrip transmission line, and strip transmission line configured on the FR-4 (glass, epoxy) board has been analyzed. But the characteristic impedance with a rigorous electromagnetic field analysis required a very complicated calculation, and the calculation method using approximate expressions as indicated in Fig.1 was generally used to calculate the characteristic impedance.

These mathematical expressions, however, are approximate expressions derived from the actual measured values of the characteristic impedance. Therefore, the accuracy of the approximate values on induction ratio, board thickness, and signal pattern width that are not usually used on the FR-4 board is low, and these approximate expressions cannot be used for the calculation of the characteristic impedance of FPC.

3.3. Introduction of simulator

Along with remarkable improvement in the operation speed of the electronic circuit, control of characteristic impedance was required. At the same time, along with remarkable improvement in the processing time of the computer, a rigorous electromagnetic field analysis of transmission lines through numerical calculations became possible.

Under the circumstances, the electromagnetic field analysis simulator of transmission lines was introduced. This allowed conducting numerical calculations accurately even on the parameters where the accuracy of the approximate values becomes low if the approximate expressions for the FR-4 board as Fig.2 are used.

3.3.1. Impedance simulator on FPC

Regarding a flexible printed circuit board, it is necessary to consider the point that it is not made up of a single insulation material such as FR-4, but of composite materials such as an adhesive layer and a base material layer. The difference of the contribution ratio to the impedance values of each composition of microstrip line such as layer thickness and width is measured through the simulation. It was found that insulation layer thickness and signal pattern width had the largest effect on the impedance.

4. Feedback by the actual measurement

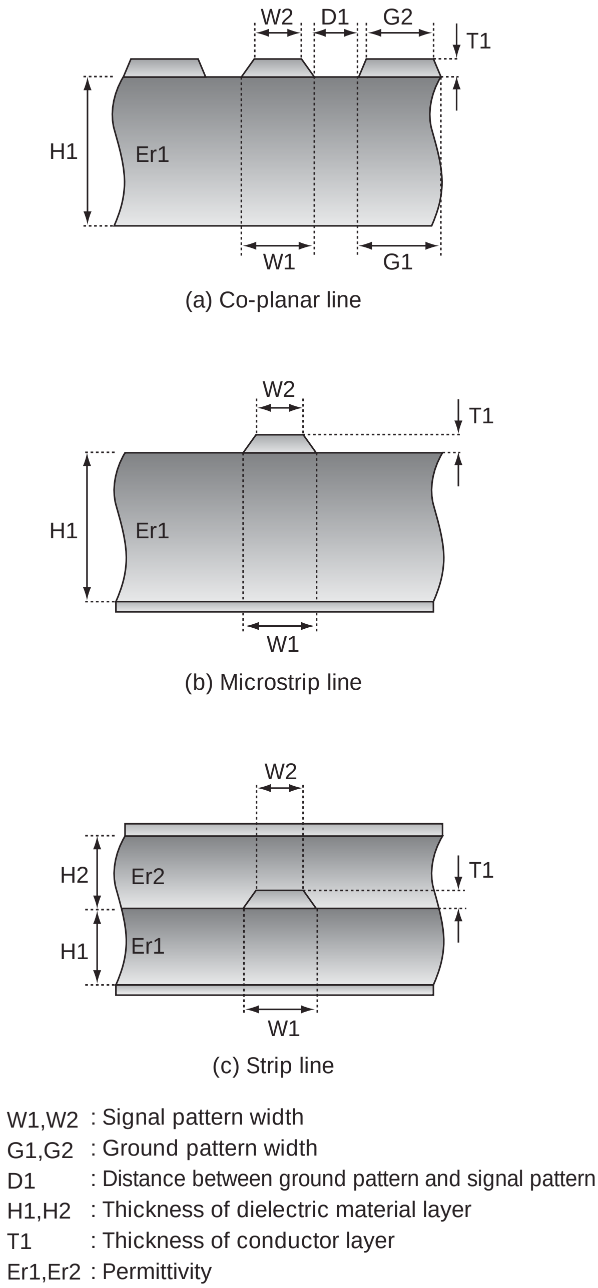


Fig. 2. Structure of transmission line by simulator.

4.1. Actual measurement of characteristic impedance by TDR

To correlate the calculation result through the simulation using the microstrip line model with the characteristic impedance of the actual FPC, we made the samples of components such as copper clad laminates (hereinafter referred to as CCL) and cover lay (hereinafter referred to as CL) using various materials and assigned a signal pattern width and measured the characteristic impedance using TDR.[4)]

4.2. Cross-sectional observation of samples

To give a detailed feedback according to the simulation result, a cross-section observation was conduct-

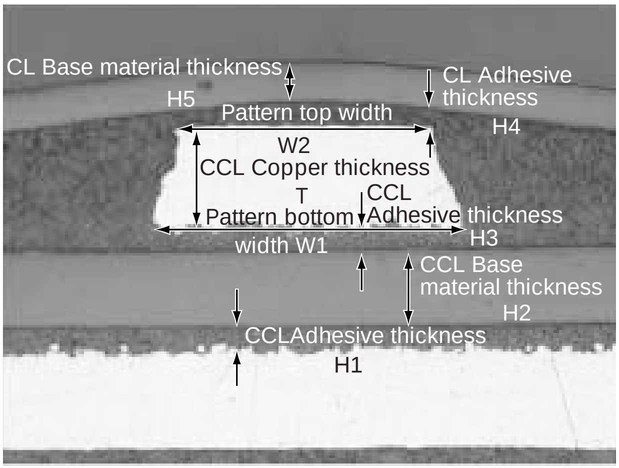


Fig. 3. Cross section view of FPC.

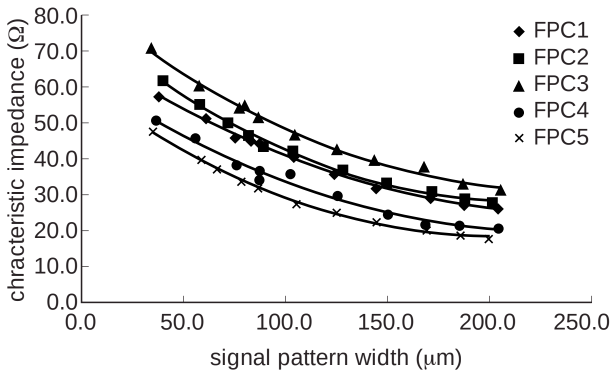


Fig. 4. Calculated characteristic impedance.

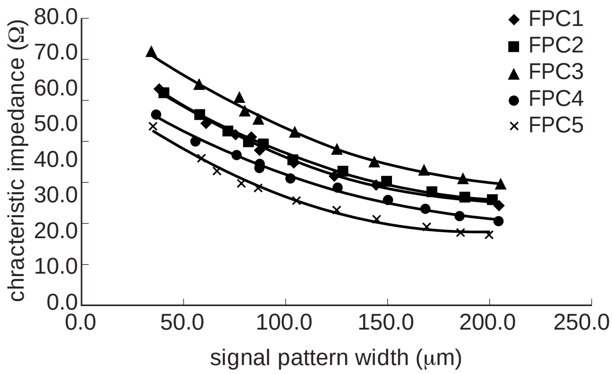


Fig. 5. Measured characteristic impedance.

ed on the FPC where the characteristic impedance was measured. The measured points on the cross-section observation were: (1) CCL base material thickness, (2) CCL adhesive thickness, (3) signal pattern top width, (4) signal pattern bottom width, (5) signal pattern copper foil thickness, (6) CL base material thickness, and (7) CL adhesive thickness. Figure 3 shows the cross-section photo of the FPC.

4.3. Comparison of the results

By comparing the simulation result and the actual measurement of the characteristic impedance based on the actual measured parameters and the actual measured permittivity of the base material, the correlation with the actual circuit was examined to confirm the effectiveness of the simulation.

The result showed that the difference, depending on the kinds of materials (adhesive agents and base materials are different depending on the maker), was small, and that it depended heavily on the structure such as the layer thickness and signal pattern width.

These results corresponded to the estimation through the simulation. With regard to the impedance values too, there was a certain ratio of agreement between the simulation values and the actual measured values. From these facts, it was found that with compensation values, the simulation could be applied to the FPC similarly on the FR-4 board.

Figure 4 shows the characteristic impedance that was calculated using the simulation software, and Figure 5 shows the characteristic impedance that was actually measured.

5. Impedance control in a manufacturing process

Based on the above-mentioned results, we examined the fluctuations of various factors affecting the impedance value in the actual mass-production manufacturing process and evaluated whether impedance could be controlled. Especially we checked the insulation layer thickness and the signal pattern width that were expected to affect the characteristic most significantly.

Concerning the material thickness, the data submitted through the material supplier showed that the fluctuations affected the impedance only at a slight level.

Then it was found that the effects of the signal pattern width on impedance depended on whether the fluctuations in the etching process could be reduced, and in addition, the thickness of the plating and pattern layout affected it.

We made it possible that the characteristic impedance was controlled within ±10% of the target value and the differential impedance was controlled within ±15% in consideration of the fluctuations in materials and manufacturing processes.

6. Conclusion

To control the characteristic impedance of the FPC, we conducted simulations on the transmission line models and made trial models to measure the actual values. The microstrip line structure could realize the target characteristic impedance, and the design values of the pattern width could be calculated. On the FPC, the control of the signal pattern width had the largest effect in various parameters, and it was found that it was important to reduce the fluctuations in width in the layout of the circuit. We made it possible to control the impedance including the fluctuations in materials and signal pattern width in mass-production.

With the promotion of high-density packaging and wiring using the miniaturized and higher-performance portable devices, thin, flexible, and higher-definition wires are required for a flexible circuit board.

It is difficult to meet the impedance specification with a thin material on the conventional structure. So, we are now studying on some methods including the formation of the ground conductor layer of a microstrip line into a mesh.

Finally, to whomsoever it may concern, we thank you for your guidance and cooperation in association with this study.

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4) TDR=Time Domain Reflectmetory