Analysis and Improvement on Propagation Efficiency of High-Speed Asymmetric Differential Transmission System

Ding-Bing Lin¹, Ji-Liang Pan²

¹ Institute of Computer and Communication, National Taipei University of Technology.
No.1, Sec.3, Chung-Hsiao E. Road Taipei, Taiwan, +886-2-27712171 ext. 2274.
dblin@en.ntut.edu.tw

² Graduate Institute of Automation Technology, National Taipei University of Technology.
No.1, Sec.3, Chung-Hsiao E. Road Taipei, Taiwan, +886-2-27712171 ext. 2272.
s1618013@ntut.edu.tw

Abstract

The paper proposes a method for compensating an undesired phase delay caused by unequal-length differential transmission lines. Appropriately disposing a periodic structure on the ground plane of unequal-length differential transmission lines having a bend structure can achieve the signal integrity. The differential transmission lines having a bend structure can get same propagation delays by improving the phase velocity of the shorter transmission line even if they are unequal in length, whereby improving the phase difference of the differential mode output and the quality of output signal.

Key Words: periodic structure, slow-wave, signal integrity (SI).

1. Introduction

With operating frequencies in circuit systems becoming higher and higher in recent years, interferences the circuit systems suffer are relatively more and more serious. The differential circuit is widely used in radio frequency (RF) and microwave circuits since it is not easily affected by the noise interference from common-mode signal, power noise interference, coupling interference from other circuits and external electromagnetic interference.

An unequal-length differential transmission line structure is generally used in a practical circuit layout while circuit integration is becoming a current trend. Accordingly, if the differential output of a differential circuit fails to be appropriately compensated, the phase difference of its differential-mode output will not be equal to ±180° of desired value, which might further cause common-mode signal, undesired signal integrity (SI) and electromagnetic interference. Therefore, the undesired phase difference will become an important factor when the differential circuit operates in high speed transmission.

Accordingly, appropriately compensating the length of the differential transmission lines becomes an important manner to improve above condition. The compensating manner [1] adopted before is to use meander line structure so as to increase the short part of the differential transmission lines, that is, to increase its respective propagation delay. However, since the adjacent meander segment might bring near-field coupling effect, it will make propagation delay exceed ahead and result in reflective wave. Further, since the meander line is a regular circuitous structure in shape, the size of its circuit will relatively be increased. In regard to this disadvantage, we appropriately utilize the slow-wave characteristic of a periodic structure [2] to slow down the phase velocity of the short differential transmission line of a differential circuit, thereby compensating the phase of the differential-mode output without increasing the size of the original circuit.

When the differential circuit operates in high speed for processing a digital signal, a digital circuit designer can get clear information through observing the waveform in time domain and check whether its corresponding output signal quality is reliable and useful through analyzing the opening size and width of an eye diagram. The opening size of the eye diagram represents the signal distortion caused by the discontinuous structure and loss of the circuit, and the width of the eye diagram represents the clock asynchronism and jitter caused by the intersymbol interference (ISI) and dispersion of the circuit.

In this paper, we simulate and make a set of unequal-length differential transmission lines having a bend structure in which a periodic structure is appropriately disposed on the ground plane of the unequal-length differential transmission lines, thereby achieving the signal integrity by utilizing the slow-wave characteristic of the periodic structure.

2. Signal Integrity of the Unequal-Length Differential Transmission Lines

Disposing one reactance cell (load) at every fixed distance (period) on an infinite transmission line or wave guide generally results in three propagation characteristics on spectrum: (1) pass- and stop-band characteristic; (2) leaky-wave characteristic; and (3) slow-wave characteristic. In particular, since the periodic structure has the slow-wave characteristic, it has been widely used for minimizing the circuit size and used in phase shifter and delay line. According to the basic theory of transmission line, it can be understood that the phase constant of a lossless transmission line is \( \beta = \omega \sqrt{LC} \), and the phase velocity is \( v_p = \frac{c}{\beta} = \frac{1}{\sqrt{LC}} \), wherein \( L \) and \( C \) are respectively represent the equivalent parallel capacitance and series inductance per unit length on the
transmission line. Therefore, by analyzing \( v_p \) (or its corresponding phase delay time \( t_p(\text{sec}) = \frac{d(m)}{v_p(m/\text{sec})} \)), it can be understood that increasing the C and L value on transmission line will make the propagation phase velocity on such a loaded structure slower than that on the load-free transmission line (i.e., make the phase delay time increased) so as to achieve the slow-wave effect. In addition, since the periodic structure is formed by serially connecting infinite single units together, the slow-wave characteristic of the periodic structure can be achieved by increasing the equivalent capacitance and inductance of each single unit on the periodic structure. In this paper, we will extend and apply this concept of utilizing the slow-wave characteristic of the periodic structure to the ground plane of a transmission system. With disposing the periodic structure on the ground plane, we can find that the equivalent slow-wave effect on the transmission line can be increased and the transmission characteristics have lower insertion loss (IL) and return loss (RL). Accordingly, we do not need to consider the increase of insertion loss (IL) and return loss (RL) caused by the increasing discontinuous structure formed by disposing the periodic structure on the signal planes. However, since the periodic structure has stop band characteristic, a circuit should be designed to prevent the required operating band from being interfered by the stop band. Therefore, it would be better that the stop band is adjusted and positioned on a higher frequency band.

As shown in Fig. 1, it shows a schematic view of a practical periodic structure of which the slow-wave characteristic is applied to improve the undesired output phase caused by unequal-length differential transmission lines. The periodic structure is appropriately disposed on the ground plane of the unequal-length differential transmission lines and under the shorter transmission line such that the shorter transmission line has the effect of slowing down the phase velocity \( v_p \) (i.e., increasing the phase delay time \( t_p \)). The right side of Fig. 1 further shows a schematic view of UC-PBG [3]–[6] structures having slow-wave characteristic, wherein the net part represents the pattern practically etched on the ground plane of this system structure. We can obtain the corresponding propagation characteristics on different frequency bands through appropriately adjusting the structure size \( (a) \) of each single unit cell and the periodic distance \( (d) \) for periodically arranging the single unit cell in series.

As shown in Fig. 2, when the differential transmission lines have a single bend structure, it will cause an asymmetric structure on the transmission system such that these two transmission lines respectively have different total phase delay times \( (t_d) \). The difference of the phase delay times between these transmission lines is \( 2t_d \), and such a difference provides us with a designing basis for utilizing the periodic structure to compensate the phase delay mismatch caused by the single bend structure, that is, we have to utilize the slow-wave characteristic of the periodic structure to additionally produce a phase delay time, which is approximately equal to the difference, on the shorter transmission line such that these two transmission lines have closer propagation delays, that is, to solve a signal integrity problem caused by the single bend structure.

The mixed-mode S-parameter can provide the convenience of describing the propagation characteristics of the pure differential mode, the pure common mode, the mode conversions between the differential mode and the common mode operated in a differential circuit, and can be obtained by converting the single-ended S-parameter obtained by simulation and measurement. Therefore, the mixed-mode S-parameter is relatively concise and reliable for observing the propagation characteristic of each mode in a differential circuit. The conversion relation [7] between the single-ended S-parameter \( (S_{\text{std}}) \) and the mixed-mode S-parameter \( (S_{\text{mm}}) \) is as following:

\[
S_{\text{mm}} = MS_{\text{std}}M^{-1}
\]

wherein \( M \) represents a transition matrix

\[
M = \frac{1}{\sqrt{2}} \begin{bmatrix}
1 & -1 & 0 & 0 \\
0 & 0 & 1 & -1 \\
1 & 1 & 0 & 0 \\
0 & 0 & 1 & 1
\end{bmatrix}
\]
3. Experiment and Verification

Fig. 3 shows a differential transmission system having a bend structure fabricated on a FR4 substrate (H=1.6 mm, $\varepsilon = 4.4$). Fig. 4 shows two set of series-formed periodic structure (42 unit cells in total) etched on the ground plane of the differential transmission system. The size ($d$) of each unit cell and the periodic distance ($a$) of the periodic structure etched on the ground plane can be designed according to the analysis of the respective propagation delay times of these two transmission lines. According to above concept, the unit cell of the periodic structure has the size of $d=3.62$ mm, $L_1=1.61$ mm, $L_2=1.51$ mm, $L_3=0.99$ mm, $L_4=0.77$ mm, $L_5=0.52$ mm, $L_6=0.79$ mm, $L_7=0.4$ mm, $L_8=3.42$ mm, $L_9=0.89$ mm, $L_{10}=0.4$ mm, $L_{11}=0.67$ mm as shown in Fig. 5. Fig. 6 shows a result of simulating the corresponding propagation delay time ($t_d$) of each transmission line of the differential transmission system. It is desirable that the shorter transmission line (TLB=164.74 mm) and the longer transmission line (TLA=173.32 mm) might provide with closer propagation delay times by the size and periodic distance of the designed UC-PBG periodic structure. In this result, it can be understood that an additional propagation delay time about 1 to 2ns will be provided on the corresponding frequency band after the UC-PBG periodic structure is appropriately etched on the ground plane under the shorter transmission line.

Fig. 5. a schematic view of a unit cell.

Fig. 6. the simulated propagation delay time ($t_d$) of the bend structure.

Fig. 7. the differential-mode transmission coefficient (Sdd21).

Fig. 8. the common-mode reflection coefficient (Scc11).
As shown in Fig. 8 Fig. 9, the operating-mode conversion transmission coefficient (Scd21) before and after compensation will be reduced. That is, when the transmission system is a cascade structure, the noise component caused by multiple cascades, whereby improving the quality of output signal.

Fig. 10 shows the eye diagrams of the differential mode transmission coefficient (Sdd21) before and after compensation and the eye information are made in Table. 1. We can clearly understand, by observing the eye information, that the opening size of the eye diagram.

### 4. Conclusion

In order to improve the compensating manner for different propagation delays caused by differential transmission lines having a bend structure, this paper adopts the slow-wave characteristic of the periodic structure and etches the UC-PBG slow-wave structure on the ground plane of the differential transmission system, whereby compensating the signal integrity of the differential transmission system by changing the phase velocity. Since high-speed transmission is a trend in the future, for example, the transmission rate in circuits will be increased from 1Gbps to 10 Gbps, the signal integrity problem caused by different lengths of differential transmission lines will get higher and higher significance. Therefore, this paper introduces the use of the UC-PBG slow-wave structure for compensating the signal integrity of differential transmission lines, which is believed worth being applied to practice for above problems.

### Reference