

Characteristics of LCTL and Radiated Emission for Differential Type Microstrip Lines with Partial Unbalance

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Abstract: In this paper, LCTL (Longitudinal Conversion Transfer Loss) and a radiated emission characteristics for differential type microstrip lines with a partial unbalance wired on a printed circuit board (PCB) are investigated. As the result, after inserting an unbalance element, it can be seen that a radiated emission increased due to deterioration of LCTL. The calculated results of the LCTL by using 4-terminals network chain matrix agreed with the measured results very well. A common mode current in differential type microstrip lines with a partial unbalance was calculated by using 4-terminals network chain matrix, and used to radiated emissions analysis. The calculated results of the radiated emission also agreed with the measured results.

Key words: differential type microstrip lines, LCTL, 4-terminals network chain matrix, common mode current, radiated emission

1. Introduction

Recently, differential transmission lines are used to high-speed interfaces such as USB2.0 or IEEE1394. They hardly radiate an emission [1]. However, a radiated emission increases when a common mode current generates, and the common mode current changes with LCTL.

An experimental and theoretical studies on LCTL and radiated emission characteristics for a twisted pair cable by using 4-terminals network chain matrix theory have been already reported [2]. A study of a radiated emission from differential type microstrip lines using the method of moment has been already reported [3]. An experimental study on LCTL and a radiated emission for differential type microstrip lines with a partial unbalance by using unbalance elements has reported, but there is not a theoretical study [4].

With this background, in this paper, a balance-unbalance conversion factor LCTL and radiated emissions for the differential type microstrip lines with a partial unbalance were measured up to 650 MHz. In order to analyze the LCTL and radiated emissions, we tried to apply the 4-terminals network chain matrix theory to the differential type microstrip lines with a partial unbalance wired on PCB.

2. Analysis Method

2.1 Balance-Unbalance Conversion Factor

Transmission system using balanced cables can be analyzed by 4-terminals network chain matrix theory [2]. So, we tried to apply the theory to differential type microstrip lines on PCB. This chain matrix integrates the balanced pair lines parts and the ground parts as shown in Figure 1. A distributed constant circuit can be represented by a series circuit of lumped constant circuits. We assumed the balanced pair lines were perfectly balanced, and the unbalance part was modeled by adding a lumped element to one of the balanced pair lines.

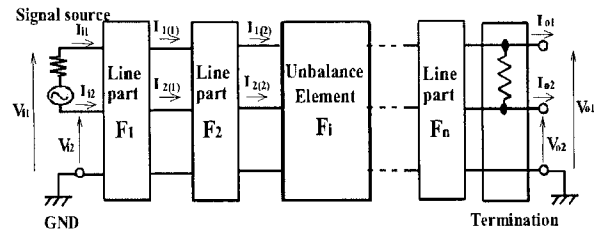


Fig. 1 4-terminals network

The chain matrices representing 1) the perfectly balanced pair lines parts, 2) the termination, and 3) the local unbalanced part are first derived. From the cascade connection of these matrices, the chain matrix M of the differential type microstrip lines with a partial unbalance is obtained, as expressed in Eq. (1). The elements of the chain matrix can be calculated by using the characteristic impedance and effective relative dielectric constant of differential type microstrip lines [4]. LCTL is adopted as the balance-unbalance conversion factor, and given by Eq. (2) as the ratio of the differential mode input voltage and the common mode output voltage. From its definition, LCTL can be expressed by using the

$$\begin{bmatrix} V_{1i} \\ V_{2i} \\ I_{1i} \\ I_{2i} \end{bmatrix} = M \begin{bmatrix} V_{1o} \\ V_{2o} \\ I_{1o} \\ I_{2o} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & B_{11} & B_{12} \\ A_{21} & A_{22} & B_{21} & B_{22} \\ C_{11} & C_{12} & D_{11} & D_{12} \\ C_{21} & C_{22} & D_{21} & D_{22} \end{bmatrix} \begin{bmatrix} V_{1o} \\ V_{2o} \\ I_{1o} \\ I_{2o} \end{bmatrix} \quad (1)$$

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elements of the chain matrix M as shown in Eq.(3)

$$LCTL = 20 \log \left(\frac{1}{2} \frac{V_{1o} + V_{2o}}{V_{1i} - V_{2i}} \right) \quad [\text{dB}] \quad (2)$$

$$LCTL = 20 \log \left[\frac{1}{2} \frac{-(C_{11} + C_{21}) + (C_{12} + C_{22})}{(A_{11} - A_{21})(C_{12} + C_{22}) - (A_{12} - A_{22})(C_{11} + C_{21})} \right] \quad (3)$$

2.2 Radiated Emissions

Radiated emissions from a differential transmission system are dominantly generated by the common mode currents. In order to calculate the radiated emissions, it is necessary to obtain the common mode currents on the differential type microstrip lines with a partial unbalance. The common mode currents in differential type microstrip lines with a partial unbalance were calculated by using 4-terminals network chain matrix.

The output currents I_{o1} , I_{o2} can be zero because the out put terminals are open as shown in Fig. 1. Thus, Eq. (1) becomes Eq. (4). The input currents I_{i1} , I_{i2} can be obtained by the input voltages V_{i1} , V_{i2} and the chain matrix M .

$$V_{i1} = A_{11}V_{o1} + A_{12}V_{o2} \quad (4.a)$$

$$V_{i2} = A_{21}V_{o1} + A_{22}V_{o2} \quad (4.b)$$

$$I_{i1} = C_{11}V_{o1} + C_{12}V_{o2} \quad (4.c)$$

$$I_{i2} = C_{21}V_{o1} + C_{22}V_{o2} \quad (4.d)$$

Fig. 1 shows the currents at each section of chain matrix consisted of n sections. In this network, the relation between the currents and voltages at the output of the k th matrix F_k is given by Eq. (5). If the input voltages V_{i1} , V_{i2} are given, the currents at arbitrary positions can be calculated by using Eq. (4) and Eq. (5). The common mode currents on the differential type microstrip lines with a partial unbalance are obtained as the difference between the currents $I_{1(k)}$ and $I_{2(k)}$ at each section.

$$\begin{bmatrix} V_{1i} \\ V_{2i} \\ I_{1i} \\ I_{2i} \end{bmatrix} = [F_1][F_2] \cdots [F_k] \begin{bmatrix} V_1^{(k)} \\ V_2^{(k)} \\ I_1^{(k)} \\ I_2^{(k)} \end{bmatrix} \quad (5)$$

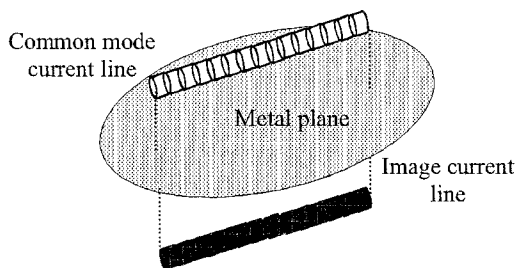


Fig. 2 Model of radiated emission calculation

It is assumed that the radiated emissions from the differential type microstrip lines can be calculated by the common mode current on the single line and its image current as shown in Fig. 2. The radiated emissions from each common mode current and its image current are superposed at the observation point, and the radiated emissions from the entire differential type microstrip lines can be calculated.

3. Method of Experiment

3.1 Printed Circuit Board Configuration

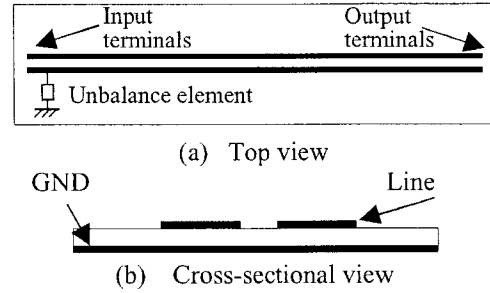


Fig. 3 Structure of differential type microstrip line

The structure of the differential type microstrip lines is shown in Fig.3. The dimensions of the PCB are the dielectric layer thickness of 1.6 mm, the conductor thickness of $35 \mu\text{m}$, the conductor width of 1.7 mm, the conductors spacing of 0.8 mm, and the conductor length of 470 mm. The dielectric material is glass epoxy, and its relative dielectric constant is 4.7. The differential mode characteristic impedance Z_D and the common mode characteristic impedance Z_C of the differential type microstrip lines are 99.2Ω , 39.9Ω respectively. Each mode effective relative dielectric constant $\epsilon_{D,eff}$, $\epsilon_{C,eff}$ are about 2.99, 3.63 respectively. Each mode characteristic impedance and effective relative dielectric constant are calculated by the reference [5].

3.2 Balance-Unbalance Conversion Factor

The LCTL of the PCB was measured by the measurement system as shown in Fig.4. The balanced terminals of the baluns (Balance-Unbalance transformer) were connected to both ends of the lines on PCB. These baluns have not only the terminals for the differential mode but also the port for the common mode. The ratio of the differential mode input voltage V_{Din} to the common mode output voltage V_{Cout} was measured using a network analyzer. Both baluns were grounded to the metal plane of PCB. The impedance of the baluns is $50 \Omega : 100 \Omega$. The frequency range of this measurement is from 1 MHz to 650 MHz, which is the specified bandwidth of the baluns. At the input end of the PCB, a coaxial cable was connected to the unbalanced port of the balun. At the output end of the PCB, another coaxial

cable was connected to the common mode port of the balun. The unused ports of baluns were terminated by $50\ \Omega$. The unbalanced condition was realized by inserting a chip element between one of the balanced pair lines and the ground near the input terminal of PCB.

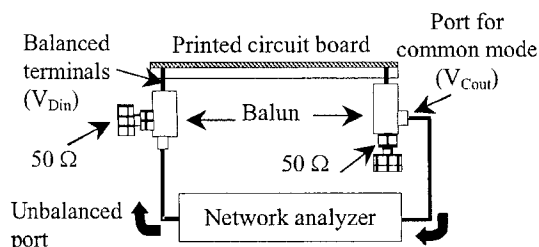


Fig. 4 LCTL measurement system

3.3 Radiated Emission

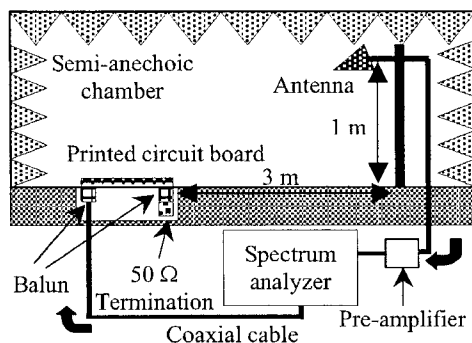


Fig. 5 Radiated emission measurement system

Radiated emissions from the PCB were measured in the electromagnetic semi-anechoic chamber. Fig. 5 shows the measurement system of radiated emissions. The function of a tracking generator is built in the spectrum analyzer. At the input end of the PCB, a coaxial cable was connected to the unbalanced port of the balun. At the output end of the PCB, a balun was connected, and two ports of this balun were terminated by $50\ \Omega$. PCB was set on the site floor, and ground of the PCB was connected to the metal plane of the site. The baluns, a spectrum analyzer, a pre-amplifier and coaxial cables were placed under the metal plane so that radiated emissions from the part other than the differential type microstrip lines might not be measured. A receiving antenna was placed 3 m away from the center of the PCB. The antenna height was 1 m. A biconical antenna was used in the frequency range of 30 MHz to 300 MHz, and a log-periodic antenna was used in the frequency range of 300 MHz to 650 MHz.

4. Results and Discussions

4.1 LCTL Characteristics

LCTL, that is a balance-unbalance conversion factor, changes with the difference of the impedance between each line and the ground. In order to change

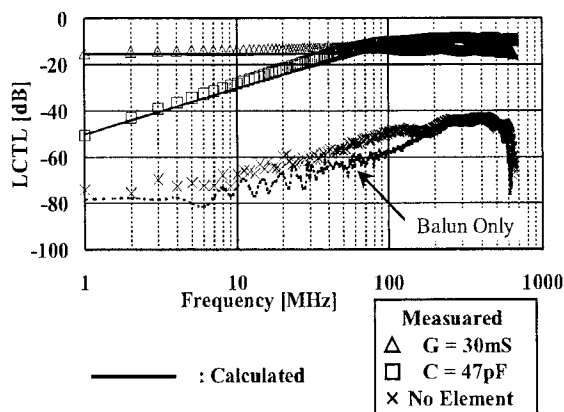


Fig. 6 LCTL characteristics

the impedance between each line and the ground, the unbalance element was inserted in the place of 10 mm from the input end of one line. The kinds of the unbalance elements were a capacitor of 47 pF and a resistor of $33\ \Omega$, of which conductance was about 30 mS. Fig. 6 shows the measured and calculated results for the frequency characteristics of LCTL. For comparing, LCTL without an unbalance element and LCTL of the baluns are also shown in Fig. 6.

As the results, the calculated values by using the 4-terminals network chain matrix theory agreed very well with the measured values. The insertion of an unbalance element caused the deterioration in the LCTL characteristics. As for the unbalance by the insertion of a capacitor of 47 pF, LCTL showed a 20 dB/dec slope until 100 MHz. On the other hand, the frequency characteristic of the LCTL was almost flat until 650 MHz when the resistor of $33\ \Omega$ was inserted. The measured results of the LCTL without an unbalance element were close to the LCTL of the baluns. This shows that there is hardly unbalance factor in the differential type microstrip lines.

4.2 Radiated Emission Characteristics

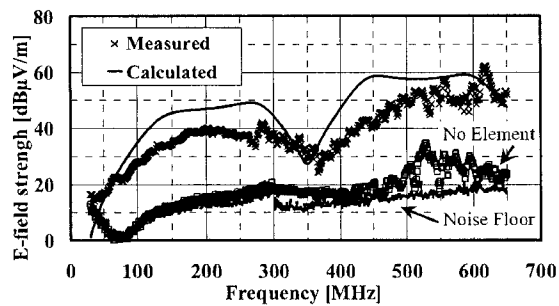
We measured the radiated emissions from the differential type microstrip lines with the partial unbalance. Horizontal polarization electric fields were measured. In the measurement of LCTL and the radiated emissions, the same PCB and the same unbalance elements were used. The output power of the tracking generator was set to 0 dBm. Fig. 7 shows the comparisons of the measured and calculated results. For comparing, radiated emissions without an unbalance element and the noise floor of the measurement system are also shown in Fig. 7.

As the results, the calculated electric field values agreed with the measured values. After inserting an unbalance element, radiated emissions increase compared with PCB without an unbalance element. The length of the differential type microstrip lines becomes equal to a wave length in the transmission line at 370 MHz. The radiated emission decreases at

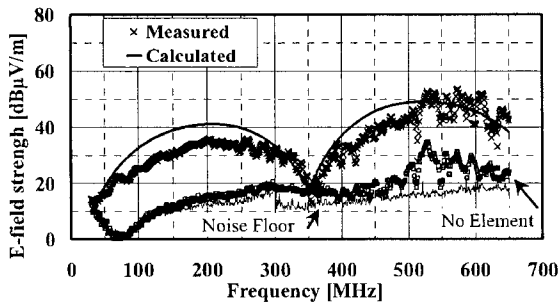
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this frequency because the radiated emissions from each section of the differential type microstrip lines cancel out at the observation point.

Next, the relation between the unbalance elements and the radiated emissions are investigated. Since the adequacy of our calculation method has been shown, the investigation is done by the

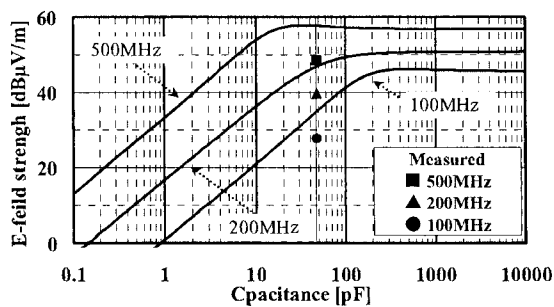


(a) Unbalance element : Capacitor (47 pF)

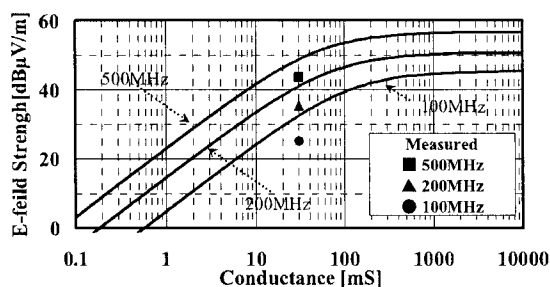


(b) Unbalance element : Resistor (33 Ω)

Fig. 7 Radiated emission characteristics



(a) Effect of capacitance



(b) Effect of conductance

Fig. 8 A relation between unbalance elements and radiated emission

calculation. In Fig. 8, the radiated emissions increase in proportion to the capacitance and conductance, and saturate. When a capacitor of 2 pF is inserted in one of the differential type microstrip lines, the radiated emission from our PCB is over the limit of CISPR 22 at 500MHz.

5. Conclusion

This paper shows the characteristics of the LCTL and the radiated emissions of the differential type microstrip lines with a partial unbalance on PCB.

As the results of inserting the unbalance element, LCTL deteriorated and the increases of radiated emissions were observed. The calculated value of the LCTL and the radiated emissions agreed very well with the measured value. Therefore we confirmed the availability of 4-terminals network chain matrix theory for differential type microstrip lines. The radiated emissions increase in proportion to the capacitance and conductance of the unbalance element. When a capacitor of 2 pF is inserted in one of the differential type microstrip lines, the radiated emission from our PCB is over the limit of CISPR 22 at 500MHz.

As a future issue, we shall establish to measure the LCTL and radiated emission more than 1GHz. Secondly, we shall investigate the improvement of the LCTL and the suppression effect of a radiated emission by using a noise suppression parts such as a common mode choke coil.

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