RADIATION FROM
ELBOW-SHAPED TRANSMISSION LINE

Takuji Yamada †  Kimitoshi Murano ††  Fengchao Xiao †
Yoshio Kami †  James L. Drewniak †††

Department of Information and Communication Engineering, University of Electro-Communications†
Department of Communications Engineering, Tokai University††
Electromagnetic Compatibility Laboratory, University of Missouri-Rolla †††
E-mail: taka-y@ice.ucc.ac.jp

Abstract: Radiation from an elbow-shaped transmission line above a right-angled ground plane are studied. Such transmission-line model is seen as an interconnecting wire appearing on a motherboard and a daughter board used in a desktop-personal computer. The numerical results by FDTD method and the experimental results show that the radiation from the elbow-shaped line is larger than that from an ordinary transmission line.

Key words: Bent line, radiation loss, far field radiation, rotating-EM field.

1 Introduction

Recently, advanced electronic devices and equipment induce complicated electromagnetic environment. Since electronic circuits are mounted with high density, many interconnecting wires or transmission lines are arranged with complicated structure on a printed circuit boards (PCB). Electronic equipment such as a personal computer (PC) has many transmission lines in various configurations, for example, bent line, parallel line, etc. To solve the electromagnetic interference (EMI) problems, radiations from transmission lines of not only straight line but also those in various arrangements should be studied. In [1], the radiation from a bent transmission line was studied numerically and experimentally. Where the transmission line is arranged in parallel to a flat plane. However, transmission lines arranged three-dimensionally exist in actual equipment. For example, it is not rare that an extension board or daughter board, such as a video card and some network interface card is connected to a motherboard of PC. In such cases, since the daughter board is sometimes inserted into the motherboard perpendicularly, traces or transmission lines of the cards are not on the same plane to the transmission lines in the motherboard, that is, the connected transmission line seems to be in an elbow-shaped line. Thus, there is an electromagnetic-discontinuity between traces or transmission lines at a interfacing section of two boards. These discontinuities may cause anxious aggravation of signal integrity (SI), and also increase of radiation from the transmission line.

In this paper, the radiation from the elbow-shaped transmission line on the right-angled ground plane is examined. The transmission line system consists of a thin wire installed on a perfectly conducting ground plane and the wire-line together with the ground plane are bend halfway in a right angle. The wire line is, of course, always in parallel to the ground plane. At first, the radiation loss of such an elbow-shaped line is discussed. Then the radiation characteristics from the elbow-shaped line is measured three dimensionally by using a susceptibility test method which applies electromagnetic (EM) fields with rotating polarization (rotating-EM field) to the transmission line system [2]. Moreover, some experimental results are compared with the numerical results by FDTD.

2 Elbow-shaped Line Model and Radiation Loss

First, in order to clarify the radiation from the elbow-shaped line, the radiation is considered from the transmission coefficients of the line. The elbow-shaped transmission line considered here is shown in Fig. 1. The whole transmission line of length \( \ell = 170 \) mm installed at height \( h = 3 \) mm is arranged on the center of the ground plane. The diameter of wire line is 0.5 mm. The transmission line bends at the position of 70 mm (\( \ell_1 \)) away from an end. The characteristic impedance is approximately 140 \( \Omega \) and the transmission line is terminated with a 50-\( \Omega \) load. The ground plane consists of two plates arranged in right-angle as shown in Fig. 1.

The radiation loss \( L \) can be obtained using the reflection coefficient, \( S_{11} \), and the transmission characteristics, \( S_{21} \), of the transmission line as fol-
1D2-1

Fig. 1 The model of the bent line.

\[
L = 1 - \left( |S_{11}|^2 + |S_{21}|^2 \right). \tag{1}
\]

where \( S_{11} \) and \( S_{21} \) can be expressed as follows,

\[
S_{11} = \frac{Z_{in} - 50}{Z_{in} + 50} \tag{2}
\]

\[
S_{21} = \frac{2Z_{in} \cdot V_L}{(Z_{in} + 50) V_0} \tag{3}
\]

where \( Z_{in} \) is the input impedance of the elbow-shaped line. \( V_L \) and \( V_0 \) are the voltage at the output terminal and input terminal, respectively. The radiation loss can be obtained by calculating these variables using FDTD method. In numerical analysis, the line system is assumed perfect. Figure 2 shows the numerical results of the radiation loss for the elbow-shaped line and the straight line of the same length and height. It is confirmed that the radiation loss has the maximum values at some specific frequencies. When a transmission line is excited with a source of internal resistance different from the characteristics of the line, the excited power can propagate to the terminal load of the maximum magnitude at resonance frequencies. The frequencies correspond to the case when the line length is integer multiple of a half wavelength. In this case currents flowing at terminals or risers are of the maximum value. Therefore, the current flowing at the line terminals vertical to the ground plane causes the maximum radiation. From Fig. 2, the resonance frequencies for the straight and the elbow-shaped lines at about 2.5 GHz are slightly different from each other.

To check the validity of the above consideration, an experiment was conducted. Terms of \( S_{11} \) and \( S_{21} \) characteristics were measured using a vector-network analyzer. The elbow-shaped wire line and the ground plane are made of a thin copper wire and an aluminum plate, respectively, in our experimental set-up. The experimental results of the radiation loss for the elbow-shaped line obtained from (1) are shown in Fig. 3. In addition, for comparison, the straight transmission line was also measured similarly. The data are obtained by converting the measured values in dB into true values so that the obtained results would depend on the accuracy of the measured dB values. The two sets of the results have obtained similar characteristics. From those results, it is confirmed that the radiation loss of the elbow-shaped line is larger than that of the straight line in a high frequency regime. But the level differences between two models are not so much large in frequencies above 2 GHz. We have not found out the reason yet.

The comparison between the numerical and the experimental results of radiation loss for the elbow-shaped line is shown as Fig. 4. It can be seen that the magnitude level is so different, though, the qualitative characteristics are comparatively in good agreement. The resonance frequencies appeared in the experimental and the calculated results are quite different from each other.

Another point is that the transmission line system is assumed lossless in numerical calculation, but the line has conductor loss so that the experimental results of radiation loss contain conductor loss and thus appear larger than the numerical results.

Fig. 2 Numerical results of radiation loss of straight line (real line) and bent line(broken line).

Fig. 3 Experimental results of radiation loss of straight line (real line) and bent line(broken line).

3 Far-field Radiation from the
elbow-shaped Line

To clarify how much the radiation loss of the elbow-shaped line has contributed to the radiation field, the susceptibility measurements of the line were conducted. Three-dimensional (3D) susceptibility characteristics (3D-susceptibility map) can be obtained by applying the susceptibility test method using rotating-EM field [2]. As long as the elbow-shaped line model can be considered to be passive and linear, the reciprocity theorem holds, and the input and the output in the experiments can be interchanged. Therefore, the far-field radiation can be estimated from the experimental results of susceptibility.

The experimental set-up is shown in Fig. 5. The rotating-EM fields generated in an anechoic chamber are applied to the elbow-shaped line system setting at the position 4 m away from the transmitting antenna. Here, an orthogonal log-periodic-dipole-array antenna (orthogonal LPDA) is used as the transmitting antenna. The rotating-EM fields are generated by exciting the orthogonal LPDA by different two double-side-band suppressed-carrier (DSB-SC) signals as shown in Fig. 5. Figure 6 shows the schematic representation of the coordinate system for the elbow-shaped line model.

Figure 7 shows 3D-susceptibility maps of the straight-transmission line and the elbow-shaped line at the frequency of 530 MHz, respectively. For the straight-transmission line, the radiation from a rear side ($\phi = 180^\circ$) is larger than the elbow-shaped line. Moreover, it is shown that the radiation is relatively large at $\theta = 90^\circ$.

Figure 8 shows the comparison with the radiation from the straight-transmission line and the elbow-shaped line at $\phi = 0^\circ$. It seems that the radiation from the elbow-shaped transmission line is a little larger than the straight-transmission line at almost all frequencies. The radiation pattern of the elbow-shaped and the straight transmission lines are shown in Fig. 9. These levels of the radiation patterns are normalized by the maximum radiation value. From these radiation patterns, the angle of the maximum radiation of the straight transmission line is not at $\phi = 0^\circ$, because the transmission line is asymmetrically arranged to the center of a ground. However, the maximum radiation for the elbow-shaped line are in the direction of about $\phi = 0^\circ$ and the beam width of radiation is also narrow.

From these results, it may be considered that the ground plane of the elbow-shaped line works like the reflector of a corner-reflector antenna.

From the experimental results, it is concluded that the radiation from the elbow-shaped line is larger than the straight transmission line.

Fig. 4. Comparison between the numerical (solid line) and the experimental (broken line) results for the radiation loss of elbow-shaped line.

Fig. 5. Experimental setup for the measurement of the radiation.

Fig. 6. Experimental setup for the measurement of radiation; $\theta$ is E-field angle and $\phi$ azimuth of EUT: (a) for over view and (b) for top view.
3 Conclusion

The radiation phenomenon from the elbow-shaped line is discussed with the results of experimental and numerical analysis by FDTD method. It was confirmed that the elbow-shaped transmission line had larger radiation loss than the straight transmission line. These experimental results are in comparatively good agreement with the numerical results. Then, the experimental analysis of the far field radiation is confirmed. From experimental results, the radiation of the elbow-shaped transmission line is similar to a corner-reflector antenna due to the ground of the elbow-shaped line.

In fact, there is a crevice between a mother board and a daughter board and the ground of two cards are connected with thin wires between.

Fig. 7  Experimental result of 3D-map; (a) is for the straight line and (b) for the elbow-shaped line.

Fig. 8  Experimental results of far field radiation at $\phi = 0^\circ$: the straight line (broken line) and the elbow-shaped line (real line).

Fig. 9  Experimental results of radiation pattern: (a) for the straight line and (b) for the elbow-shaped line at $\phi = 90^\circ$.

In order to perform analysis about the model of connects between a mother board and a daughter board, we will perform consideration quantitively about models treated in this paper and the influence of bending is due to be performed in the future.

Acknowledgment

This work was supported in part by the Japan Society for the Promotion of Science (JSPS) under the Research for the Future Program – Reduction of Electromagnetic Noise Levels.

References
