MODELING OF LOAD EFFECT DUE TO FERRITE CORE ATTACHMENT TO PARALLEL TWO-WIRE LINES ABOVE A GROUND PLANE

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1. Introduction

Ferrite cores are widely used to reduce the radiated emissions from electronic information devices and also to improve the system immunity [1], while the effects for the latter case are not fully elucidated. This is due to lack of understanding on the load effect produced by a ferrite core attachment. From this viewpoint, we previously analyzed the load effect caused by attachment of the ferrite cores to a cable or a wire above a ground plane, and proposed equivalent circuits for the load effect [2],[3]. In this paper, the load effect of a ferrite core attachment to a parallel two-wire transmission line above a ground plane was investigated theoretically and experimentally.

2. Theory

Consider a parallel two-wire transmission line being attached by a ferrite core, which is kept a fixed height from a ground plane. Figure 1 shows the geometrical configuration and dimensions. The modes of propagation on the lines consist of a transmission-mode with a return path of the ground and a transmission-mode between the lines. The former is called an unbalanced mode (UM) and the latter is called a balanced-mode (BM). For a lossless transmission line in homogeneous media, it is theoretically well known [4] that both the modes can independently be propagated along the lines. Denote by V_{SM} and I_{SM} (S=U,B) the voltage and current for the SM transmission, respectively. Then the voltage V_k and the current I_k $(k = 1, 2)$ on the line $\#k$ can be expressed [4] as

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 1 & 1/2 \\ 1 & -1/2 \end{bmatrix} \begin{bmatrix} V_{UM} \\ V_{BM} \end{bmatrix}, \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 1/2 & 1 \\ 1/2 & -1 \end{bmatrix} \begin{bmatrix} I_{UM} \\ I_{BM} \end{bmatrix}. \tag{1}$$

Since the voltage and current for each transmission mode should satisfy the transmission-line

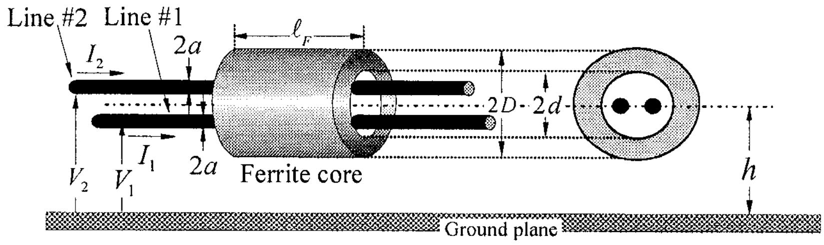

Figure 1 A parallel two-wire transmission lines attached by a ferrite core above a ground plane.

equations peculiar to the mode, they are uniquely determined by the boundary conditions given at the line ends, resulting in that V_k and I_k at any point on the line #k can be calculated directly from (1). Figure 2(a) shows the two-wire line circuit with a ferrite core attachment to be investigated in this paper. The line #1 is driven by the sinusoidal source with a magnitude of E and an internal impedance of Z_{1i}, and is terminated at the receiving end in a load impedance of Z_{1o}. The sending and receiving ends of the line #2 are terminated in load impedances of Z_{2i} and Z_{2o}, respectively. Z'_{1o} is the impedance seen through the transmission line with a length of ℓ_o terminated in the load Z_{1o} at the receiving end of the line #1. Z'_{2i} is the impedance through the line with a length of ℓ_i terminated in the load Z_{2i} at the end of the line #2. The lengths of the parallel lines and the ferrite core are taken as ℓ and ℓ_F, respectively. When we analyze the load effect due to the ferrite core attachment to the parallel two-wire lines above a ground plane, we assume that the core affects the UM transmission, while it gives no effects to the BM transmission. Figure 2(a) can then be replaced by an equivalent circuit as shown in Figure 2(b). Here $V_{UMi,o}$ and $I_{UMi,o}$ are the UM voltages and currents at the sending and receiving ends, respectively. $V_{BMi,o}$ and $I_{BMi,o}$ are the BM voltages and currents at the sending and receiving ends, respectively. $\boldsymbol{F}$ is the four-port matrix describing the operation of the equivalent circuit for the load effect produced by a ferrite core attachment to the UM transmission line, whose parameters can be obtained from [3]. Both $\boldsymbol{A}_{UMi}$ and $\boldsymbol{A}_{UMo}$ are the four-port matrices for the UM transmission line without ferrite core attachment, and $\boldsymbol{A}_{BM}$ is the matrix for the BM transmission line. From Figure 2(b), for example, the voltage and current at the receiving ends

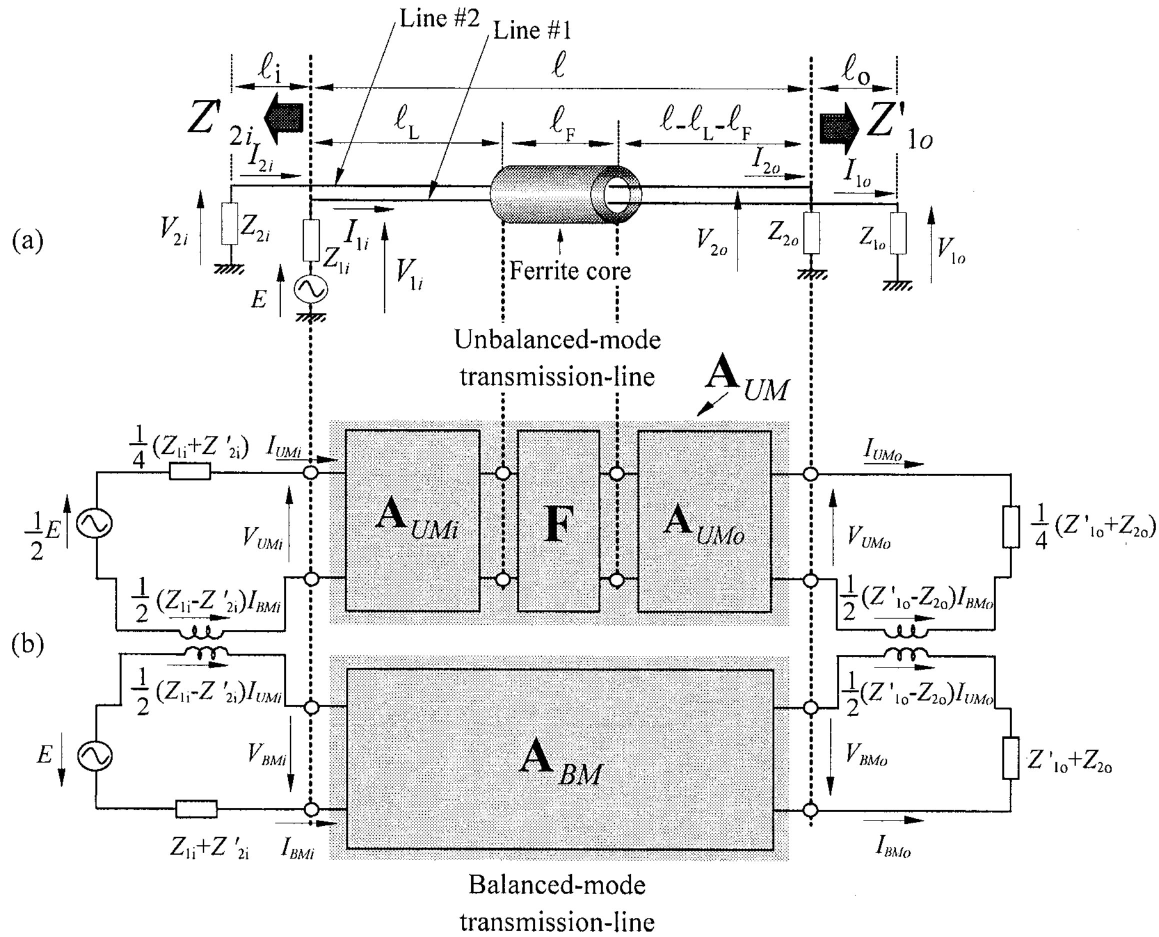

Figure 2 (a) Analysis model of a parallel two-wire lines attached by a ferrite core and (b) its equivalent circuit.

for the UM and BM transmissions can be given by

$$\begin{bmatrix} V_{UMo} \\ I_{UMo} \end{bmatrix} = \left[\boldsymbol{A_{UMi}} \cdot \boldsymbol{F} \cdot \boldsymbol{A_{UMo}} - \boldsymbol{A_i} \cdot \boldsymbol{A_{BM}} \cdot \boldsymbol{A_o}^{-1} \right]^{-1} \begin{bmatrix} -Z'_{2i}/(Z_{1i} - Z'_{2i}) \\ 2/(Z_{1i} - Z'_{2i}) \end{bmatrix} E \quad (2)$$

$$\begin{bmatrix} V_{BMo} \\ I_{BMo} \end{bmatrix} = \boldsymbol{A_o}^{-1} \begin{bmatrix} V_{UMo} \\ I_{UMo} \end{bmatrix} \quad (3)$$

where

$$\boldsymbol{A_{UMi}} = \begin{bmatrix} \cos(\beta_{UM}\ell_L) & jZ_{UM}\sin(\beta_{UM}\ell_L) \\ j\frac{1}{Z_{UM}}\sin(\beta_{UM}\ell_L) & \cos(\beta_{UM}\ell_L) \end{bmatrix}$$

$$\boldsymbol{A_{UMo}} = \begin{bmatrix} \cos\{\beta_{UM}(\ell - \ell_L - \ell_F)\} & jZ_{UM}\sin\{\beta_{UM}(\ell - \ell_L - \ell_F)\} \\ j\frac{1}{Z_{UM}}\sin\{\beta_{UM}(\ell - \ell_L - \ell_F)\} & \cos\{\beta_{UM}(\ell - \ell_L - \ell_F)\} \end{bmatrix}$$

$$\boldsymbol{A_{BM}} = \begin{bmatrix} \cos(\beta_{BM}\ell) & jZ_{BM}\sin(\beta_{BM}\ell) \\ j\frac{1}{Z_{BM}}\sin(\beta_{BM}\ell) & \cos(\beta_{BM}\ell) \end{bmatrix}$$

$$\boldsymbol{A_i} = \begin{bmatrix} \frac{1}{2}\frac{Z_{1i}+Z'_{2i}}{Z_{1i}-Z'_{2i}} & \frac{2Z_{1i}Z'_{2i}}{Z_{1i}-Z'_{2i}} \\ -\frac{2}{Z_{1i}-Z'_{2i}} & -\frac{2(Z_{1i}+Z'_{2i})}{Z_{1i}-Z'_{2i}} \end{bmatrix}, \boldsymbol{A_o} = \begin{bmatrix} \frac{1}{2}\frac{Z'_{1o}+Z_{2o}}{Z'_{1o}-Z_{2o}} & -\frac{2Z'_{1o}Z_{2o}}{Z'_{1o}-Z_{2o}} \\ \frac{2}{Z'_{1o}-Z_{2o}} & -\frac{2(Z'_{1o}+Z_{2o})}{Z'_{1o}-Z_{2o}} \end{bmatrix}.$$

Here β_{SM} and Z_{SM} ($S = U, B$) are the phase constant and characteristic impedance for the SM transmission, respectively. Substituting (2) and (3) into (1) yields the voltage V_{ko} and the current I_{ko} ($k = 1, 2$) at the receiving end on the lines #k shown in Figure 2(a).

3. Experiment

For the parallel two-wire lines as shown in Figure 2(a), near-end and far-end crosstalks occurring on the two-wire lines attached by a ferrite core were measured with a network analyzer. Figure 3 shows an experimental setup and measurement method of the crosstalks. As for the two-wire lines, copper lines having the same circular cross sections with a radius of 0.25 mm were used. They were kept a line space of 2 mm and a height of 10 mm from an aluminum plate with a width of 1 m and a length of 2 m. The line #1 was driven by the sinusoidal voltage in a magnitude of E through a 50Ω coaxial cable, while both ends of the line # 2 was terminated in 50Ω loads. The parallel length of the both lines was 18 cm and the length protruded from the parallel lines was 2 cm. A commercially available ferrite core was used, which was a toroidal type core with a length of 15.93 mm, an external diameter of 11.9 mm and an internal diameter of 8.31 mm. The crosstalks were calculated from the equivalent circuit shown in Figure 2(b). For the load effect due to the ferrite core attachment, under the assumption that the line with a circular cross section was penetrated into the center of the core, whose inductance and capacitance per unit length have the same values as those of the UM transmission of the parallel two-wire lines, the resultant equivalent circuit was derived from [3]. Figure 4 shows the frequency characteristics of far-end and near-end crosstalks, where circles and solid lines represent the experimental and calculated results, respectively. It was found that the calculated values agree with the experimental results in the whole measurement frequency range.

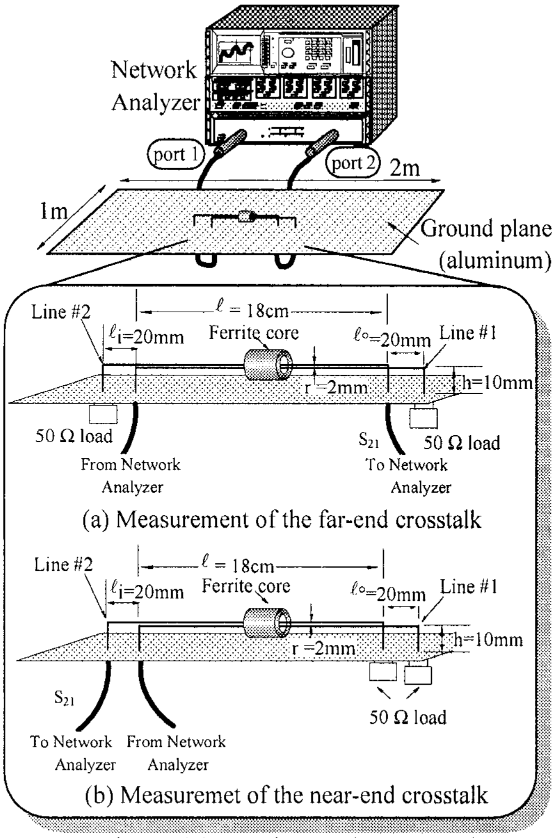

Figure 3 Experimental setup and measurement method for crosstalks.

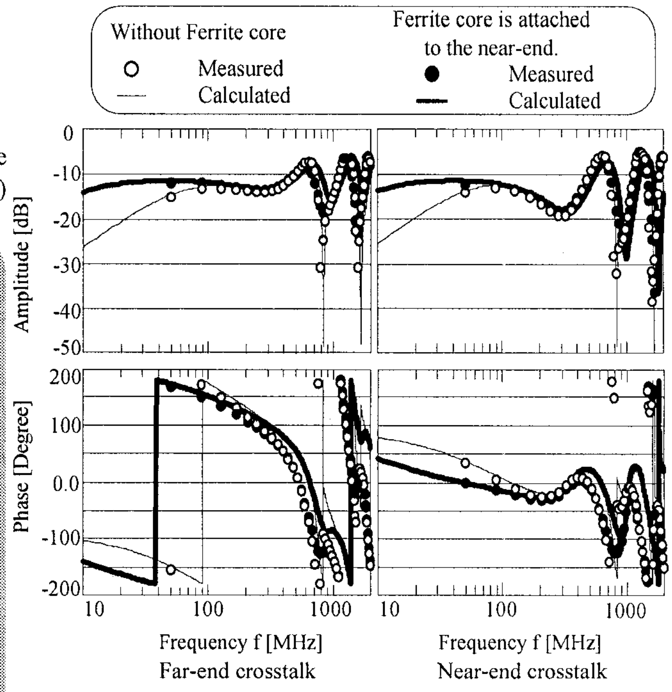

Figure 4 Frequency characteristics of far-end and near-end crosstalks.

4. Conclusion

Based on the fact that the UM and BM can be propagated independently along parallel two-wire lines above a ground plane, the load effect produced by a ferrite core attachment was analyzed under the assumption that the core affects only the UM transmission. This modeling was validated by measuring the crosstalks between parallel two-wire lines above a ground plane. The future subject is to investigate whether or not the modeling presented here is applicable to multi-wire lines above a ground plane.

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