ANALYSES OF THE ELECTROMAGNETIC FIELDS AROUND A TWO-WIRE PARALLEL LINE BASING ON DISTRIBUTED CIRCUIT THEORY

Hiroshi Echigo, Akira Ishikawa
Faculty of Engineering, Tohoku Gakuin University
E-mail: echigo@tjcc.tohoku-gakuin.ac.jp

Abstract: In this paper, analyses of electromagnetic (EM) fields around a two-wire parallel line are given. Basing on the distributed circuit theory, the current distribution on the line is given, that leads to the vector potential $\boldsymbol{A}$(x,y,z) at any point around the line. The EM fields derived by this vector potential $\boldsymbol{A}$(x,y,z) were analyzed.
Key words: two-wire parallel line, standing wave ratio, vector potential, distributed circuit theory.

1. Introduction

A two wire parallel line is one of the basic transmission line for electromagnetic [EM] waves. The transmission line is treated as one that dose not radiate EM waves in the circuit theory. However, this kind structure of metal wires can cause emission of EM energy as an antenna. In this paper, as one of the analysis of EMC problems, unwanted EM wave radiations from a two-wire parallel line are analyzed, basing on the circuit analysis to derive the current distribution on it.

2. Modeling of a Two-Wire Parallel Line

2.1 Dimensions of the Line and the Primary Constants.

The parameters of the line analyzed here are listed in Table 1. Using these parameters, the primary constants of the line are derived as follows.

a = 0.005 Radius of conductor in [m]
b = 0.020 Separation of conductors in [m]

give the capacitance/m and inductance/m as

$$cd = \pi\,\varepsilon_0 \,/\, Log[b/a] \quad \cdots\cdots\cdots\cdots\cdots(1)$$

$$ld = (\mu_0/\pi)\, Log[b/a] \quad \cdots\cdots\cdots\cdots\cdots(2)$$

and the series resistance/m as

$$Rpm = \{1.724\sqrt{f}\,/(2\pi\, a *6.61)\}*10^{-4} \quad \cdots\cdots\cdots\cdots\cdots(3)$$

(Resistance of Cupper)

2.2 Secondary Constants.

The secondary parameters of the line are derived by the primary constants. The characteristic impedance is given by the formula,

$$W = \sqrt{(lld/cdd\,)} \quad \cdots\cdots\cdots\cdots(4)$$

or

$$W = 276\,/\sqrt{\varepsilon_s}\;\; Log_{10}[\,b/a] \qquad [\Omega].$$

The attenuation constant and the phase constant are

$$\alpha = Rpm/2 *(1/W) \quad \cdots\cdots\cdots(5) \quad [\text{Np/m}]$$

$$\beta = \omega\,/\,c_0 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots(6) \quad [\text{radian/m}].$$

Therefore, propagation constant is

$$\gamma = \alpha + j\,\beta \quad \cdots\cdots\cdots\cdots\cdots\cdots(7)\,.$$

Table 1 Parameters of the two-wire parallel line

Radius of the wire	0.5 cm
Separation of the wire centers	2.0 cm
Length	2.0 m
Materials	Cupper
Characteristic impedance	166 Ω

2.3 the Coordinate System.

To assist to understand the analyzed results, let define the coordinate system as in Fig.1. The line end

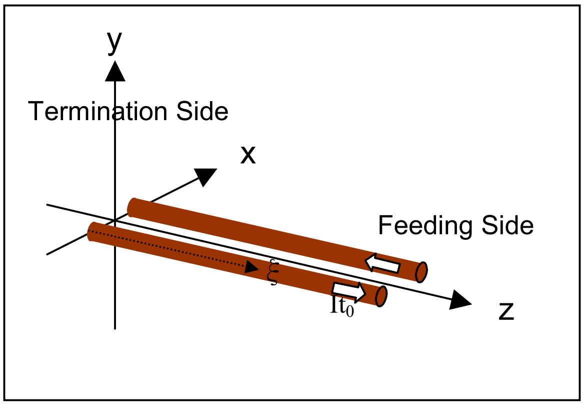

Fig.1 The coordinate system.

or termination position is set to be z = 0. The line is included in the x-z plane.

2.4 Feeding Circuits and Terminations.

Feeding Circuits

The feeding circuit is composed with two voltage sources with the inner resistance Zi and an inductance Lim of the connecting wire. Their values were supposed to be,

$$Zi = 50\ [\Omega],$$
$$Lim = 10.\ {*}10^{-9}\ \ [\text{H}].$$

Supposing that the two source voltages are same but with different sign, the equivalent source is voltage source of Vd with series impedance of 2*Zi+Zim, where

$$Zim = j\ \omega\ Lim$$
$$Vd = V1 - V2 = 2{*}V_0.$$

Termination Circuits

The terminal impedances are supposed to be for open-circuit condition, short-circuit condition and resistive condition, respectively as,

*Open: Cterm = $0.1{*}10^{-12}$ [F];
$Zterm = 1/(j\ \omega\ Cterm)$.
*Short: Lterm = $1.5{*}10^{-9}$ [H];
$Zterm = j\ \omega\ Lterm$.
*Resistive: Rterm = 166.2 [Ω];
$Zterm = Rterm + j\ \omega\ Lterm$.

According to the distributed circuit theory, the reflection coefficient Γ at the line end is give as,

$$\Gamma = (Zterm - W)/(Zterm + W) \cdots\cdots\cdots(8)$$

The other hand, when it is terminated by Zterm, the input impedance of the line at feeding points is to be,

$$Zin = W\frac{(1 + \Gamma\ \ Exp[-2\gamma l])}{(1 - \Gamma\ \ Exp[-2\gamma\ l])} \quad \cdots\cdots\cdots(9)$$

3. Current Distributions on the Line.

Let Vtr be the traveling wave voltage, value of which is at the end of line. The following relations are derived at feeding point.

$$It_0 = \frac{(Vtr\ \ Exp[+\gamma\ l] - Vtr\ \ \Gamma\ \ \ Exp[-\gamma\ \ l])}{W} \quad \cdots\cdots\cdots(10)$$

, where It_0 is the current value on the line at the end of the feeding side as shown in Fig.1. "l" is the line length. Considering that Vd is driving voltage in balanced mode, it relates with It_0 as,

$$Vd = (Zi + Zi + Zim)\ It_0 + Zin\ It_0 \quad \cdots\cdots\cdots(11)$$

Therefore, Vtr can be determined after giving Vd and circuit parameters.

Finally, the current distribution on the line is given as,

$$I[\xi] = \frac{Vtr}{W} \cdot (Exp[+\gamma\ \xi\ ] - \Gamma\ \ Exp[-\gamma\ \xi\ ]) \quad \cdots\cdots\cdots(12)$$

, where ξ is distance from the line end at the termination side.

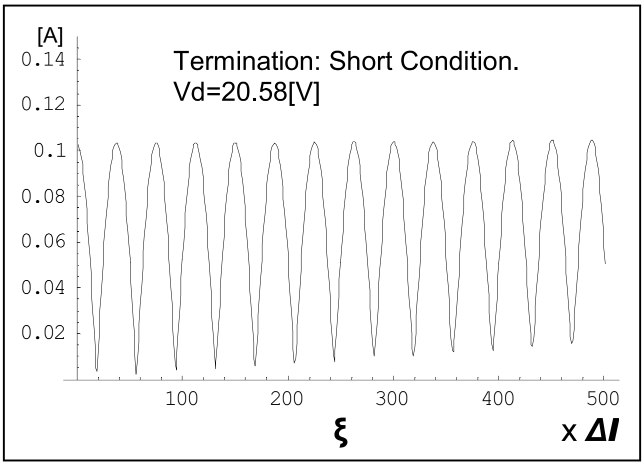

Fig.2 Current distribution on the line.
Δl =0.003992[m]

4. Vector Potentials and Magnetic Fields around a Two-Wire Parallel Line

It is well known that the Vector potential is give as,

$$\mathbf{A} = \iiint \frac{\mu\ \mathbf{i}\ e^{-jk|\mathbf{r}-\mathbf{r}'|}}{4\pi\ |\mathbf{r}-\mathbf{r}'|} dV' \quad \cdots\cdots\cdots(13)$$

Since the current distribution on two wires and feeding and termination circuits are found as above-mentioned manner, the vector potential around the two wire parallel line can be determined. To calculate the field around the line numerically, the current distributions are segmented into a set of small-sized pieces.

After determining the vector potential, magnetic flux density ***B*** is derived as,

$$B = \nabla \times A \quad \cdots\cdots\cdots(14)$$

An example of calculated results is shown in Fig.3 that gives the real part of By around the terminal end at a certain instant. The line edge locates at the center of the figure and the line expands towards right.

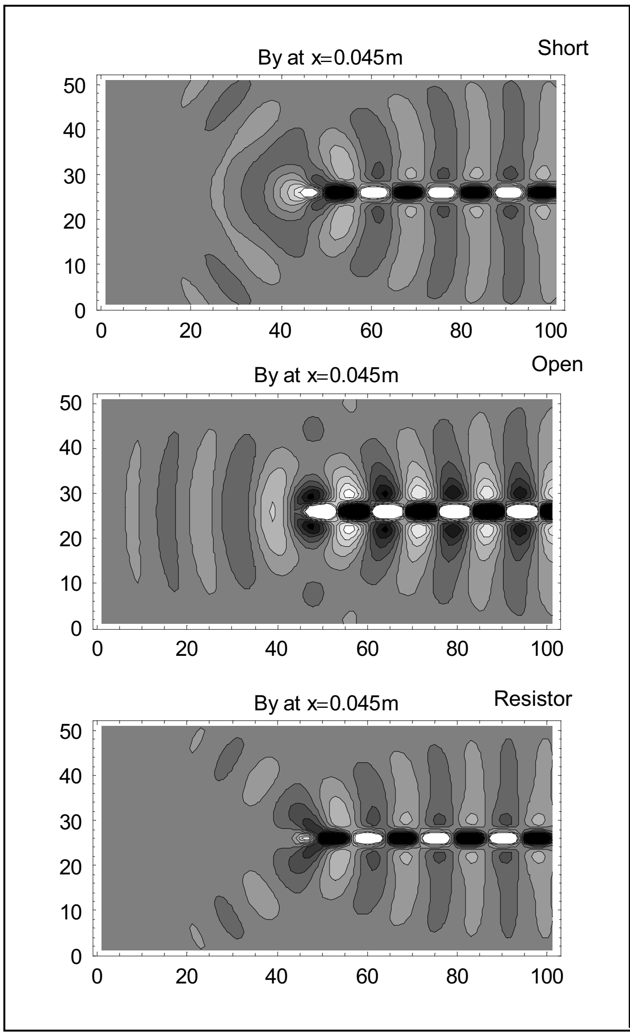

Fig.3 Calculated **By** on the plane x=0.045 m for terminations of SHORT, OPEN & RESISTOR. (y=-0.5~+0.5m, z=-0.9+1.1m)

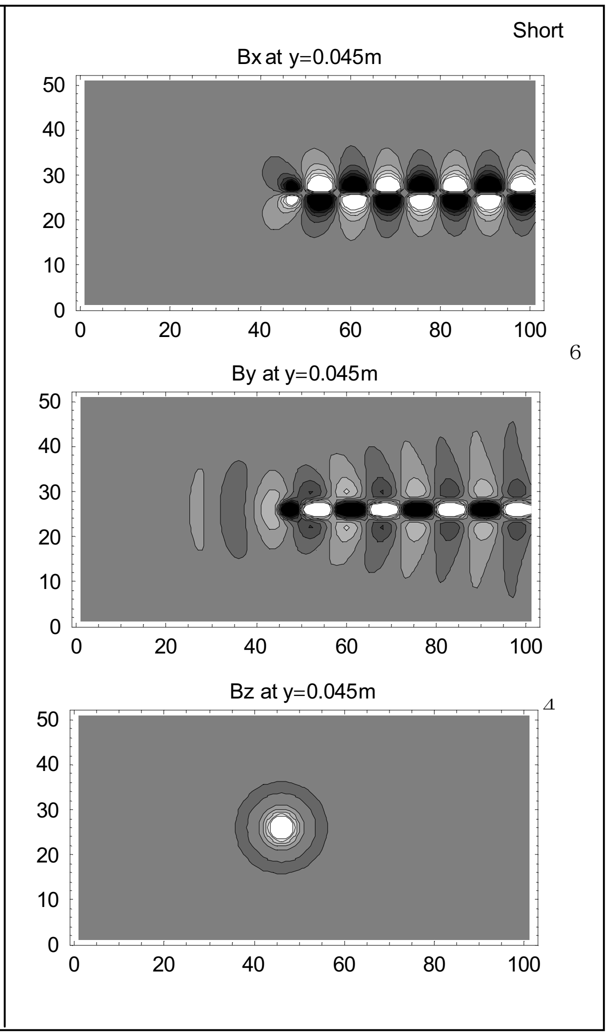

Fig.4 Calculated Bx, By, Bz fields on the plane y=0.045 m. (x=-0.5~+0.5m, z=-0.9+1.1m)

Figure 4 shows B's patterns on the plane y=0.045m for each component Bx, By, Bz.

6. Fields in the Fresnel Region and Their Inverse Projections

Basing on this calculation method, the field pattern in the Fresnel region is obtained. The Bz field pattern as shown in Fig.5 was derived on the plane parallel to the x-z plane. The distance is 1.65m from the plane including the line. Applying the inverse projection of these calculated complex values on to the x-z plane, the locations of suspicious EM radiation source may be found. Figure 6 displays the resultant inverse projection corresponding to Fig.5. The brighter parts are supposed to be the radiating portions. The upper one is just the same position of the feeding end of the line and the lower is for the terminal edge. Fig.7 is the 3-D display of Fig.6. The same result was obtained by using Bx data. They are given in Fig.8, Fig.9, and Fig.10.

7. Conclusion

After derivation of the current distribution on a two wire parallel line basing on the distributed circuit theory, the field patterns of magnetic flux density were calculated. They gave ways to understand the wave propagations on the line and radiations from it.

Adding them, the inverse projection of the field patterns in the Fresnel region gave the radiating portions.

References

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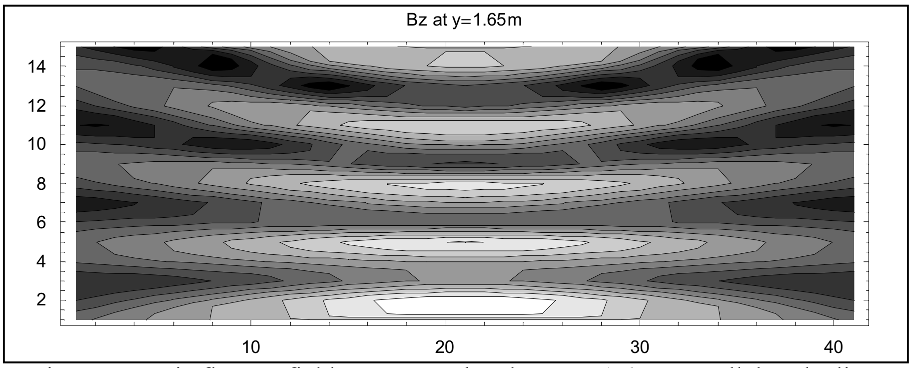

Fig.5 Magnetic flux Bz field pattern on the plane y = 1.65m. parallel to the line.

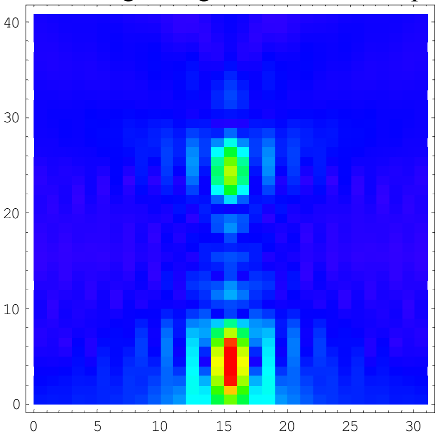

Fig.6 Inverse projected pattern.

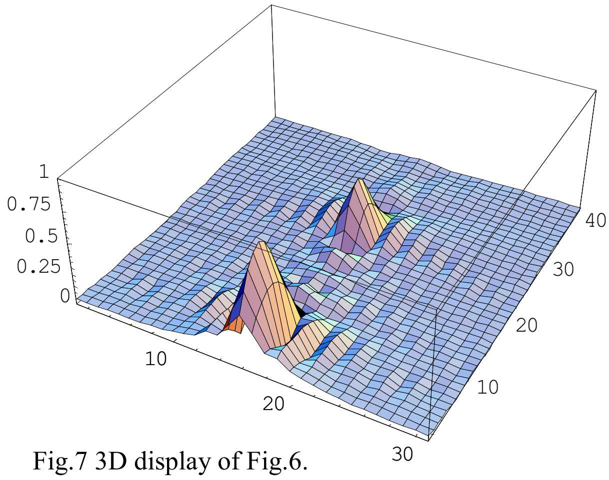

Fig.7 3D display of Fig.6.

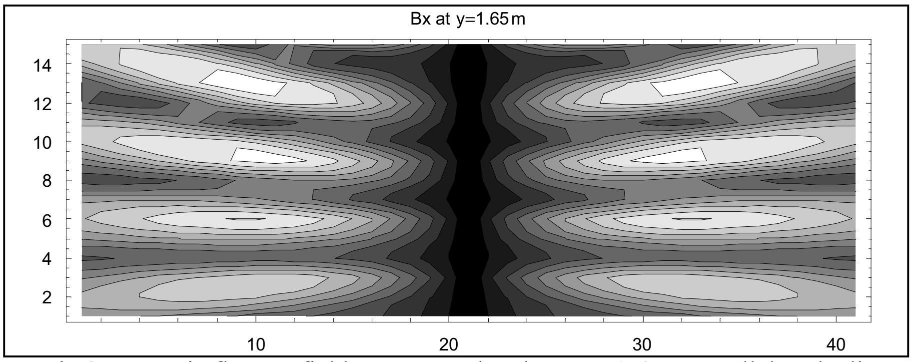

Fig.8 Magnetic flux Bx field pattern on the plane y = 1.65m. parallel to the line.

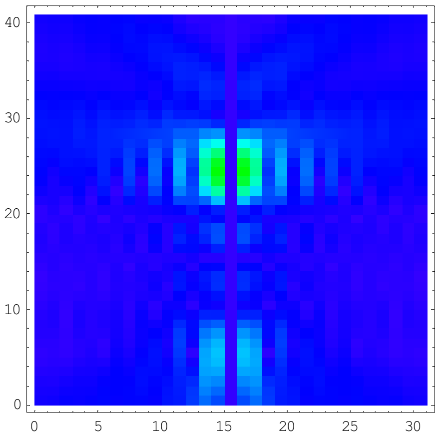

Fig.9 Inverse projected pattern.

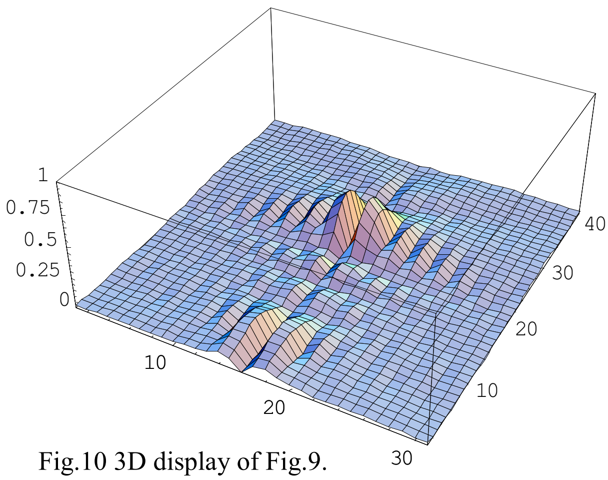

Fig.10 3D display of Fig.9.