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Calculation of Near Field Emitting from Telecommunication Lines

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SUMMARY An analytic expression of electromagnetic near field emitted by a single current flow along a straight wire is derived to obtain the radiated EMI limit from the telecommunication lines connected to the equipment. The validity of the theory is tested in the experiment. Calculations show that the conversion factor between the electric field strength and the terminal voltage is not significantly changed by the wire length. A maximum conversion factor of about -30 dB in the frequency range of 0.1–30 MHz is obtained.

1. Introduction

Recently, importance of studies dealing with the electromagnetic interference (EMI) is growing much more, and several specifications have been standardized for the field strength limits emitted from equipments and the power-line-conducted noise limits for equipments[1]. However, the field strength limits emitted from the telecommunication lines connected to the equipments have not been given. The characteristics of the near field emissions from the telecommunication lines as well as establishment of their measurement method are required to obtain the limits. Although the theoretical analyses of field emitting from the line have been made[2],[3], these analyses have been limited to the Far Field. In this letter, the calculations for near field emission from a telecommunication line is described, along with the measurement results for the model line.

2. Calculation

Figure 1 shows a telecommunication line model for the calculations. Here, (a) represents the Y-Z plane of the model and (b) represents the X-Y plane. As shown in Fig. 1(a), one straight wire representing a telecommunication line is constructed parallel to the earth. Referring to Fig. 1(b), the electric field of the point $P(x, y, z)$ is given by

$$\boldsymbol{E}=\frac{1}{j\psi\pi\omega\varepsilon}\int_{-\frac{l}{2}}^{\frac{l}{2}}\int_0^h\{\nabla(\boldsymbol{J}\cdot\nabla\psi(r_1))+k^2\boldsymbol{J}\psi(r_1)\}+\rho\{\nabla(\boldsymbol{J}\cdot\nabla\psi(r_2))+k^2\boldsymbol{J}\psi(r_2)\}]dydz, \tag{1}$$

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with

$$\psi(r)=\exp(-jkr)/r \quad \text{and} \quad k=\omega\sqrt{\varepsilon\mu}, \tag{2}$$

where the first term represents the electric field directly emitting form the current source J and the second term represents the electric field indirectly emitting from the current source J. When the earth conductivity is infinite, the second term represents the electric field emitting from the image current source. In Eqs. (1) and (2), ω is the angular frequency, ε is the dielectric constant, μ is the magnetic permeability, l is the wire length, h is the height of the wire, r_1 is the direct path distance from the wire to point P, and r_2 is the indirect path distance from the wire to point P via the reflection on the earth. ρ is the reflection coefficient of the earth. For the horizontal electric filed, it is given by[4]

$$\rho=\frac{\cos\alpha-\sqrt{n^2-\sin^2\alpha}}{\cos\alpha+\sqrt{n^2-\sin^2\alpha}}, \tag{3}$$

and for the vertical electric field, it is given by[4]

$$\rho=\frac{n^2\cos\alpha-\sqrt{n^2-\sin^2\alpha}}{n^2\cos\alpha+\sqrt{n^2-\sin^2\alpha}}, \tag{4}$$

with

$$n^2=\varepsilon_r-j\frac{1.8\times10^{10}}{f}\sigma, \tag{5}$$

and

$$\alpha=\mathrm{Tan}^{-1}\left\{\frac{\sqrt{x^2+(z-z_1)^2}}{h+y}\right\}, \tag{6}$$

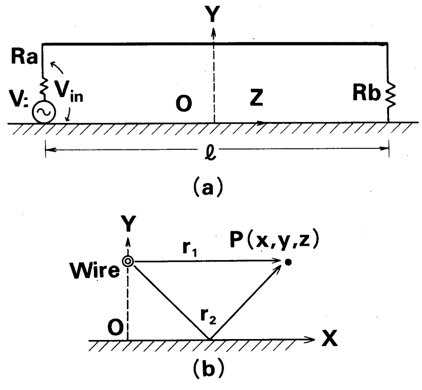

Fig. 1 Transmission line model for the radiated field calculation. (a) Y-Z plane and (b) X-Y plane.

where f is the frequency in hertz, ε_r is the relative dielectric constant of the earth, σ is the conductivity of the earth in siemens per meter, x, y and z are the coordinate of point P, and z_1 is the distance from the midpoint of the line.

In Eq. (1), J is the current on the transmission line consisted by the wire and the earth. It has the J_y and J_z component, where J_y represents the current from $y=0$ to $y=h$ at $z=-l/2$ and $z=l/2$. J_z is calculated by using the wave equation and is given by

$$J_z=\frac{V_i}{z_0-R_a}\cdot\frac{e^{-\gamma(z_1+l/2)}-P_b e^{\gamma(z_1+l/2)}}{e^{\gamma l}-P_a P_b e^{-\gamma l}} \qquad (7)$$

with

$$P_a=\frac{R_a-z_0}{R_a+z_0},\ \text{and}\ P_b=\frac{R_b-z_0}{R_b+z_0}, \qquad (8)$$

where R_a and R_b are the terminating resistances at both ends of the wire, and z_0 and γ are the propagation constants of this transmission line[5]. Under the condition of $l\gg h$, J_y is approximately given by

$$J_y=\begin{cases} J_z\left(-\frac{l}{2}\right), & z=-\frac{l}{2}, \\ J_z\left(\frac{l}{2}\right), & z=\frac{l}{2}. \end{cases} \qquad (9)$$

On the numerical integration of Eq. (1), the trapezoid rule is used.

3. Experiment

In above theory, the current on the line is calculated by using the wave equation. The near field is measured to examine whether the assumption used in the theory is good or not.

Figure 2 shows the telecommunication line model used for the experiment. This refers to the calculation model shown in Fig. 1. In this model, the Cu sheet simulates a perfect-conductive earth and the Cu wire represents the telecommunication line. One end of the line is terminated by a 50 Ω resistance and the other end is connected to the earth. In the experiment, a signal with the frequency of 300 MHz is fed to one end of the line and the X component of the magnetic field is measured using a micro loop antenna whose antenna factor is 36 dB ((μA/m)/μV) in the frequency of 300 MHz.

Figures 3 and 4 show the experimental results. In these figures, solid curves represent values calculated by Eq. (1) and filled circles represent measured values. The vertical axis represents the X component of the magnetic field normalized by the terminal voltage V_{in}, i. e. the voltage between the input terminal of the transmission line and the earth. The horizontal axis denotes the x or z position of the antenna normalized by the wavelength, λ.

Figure 3 shows the magnetic field change when the antenna moves in the direction normal to the line and

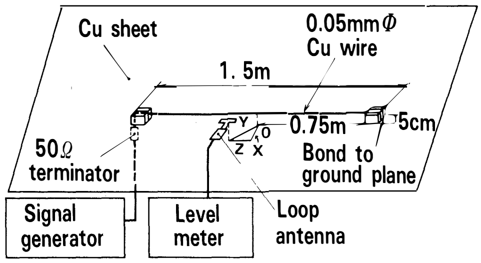

Fig. 2 Transmission line model for the experiment.

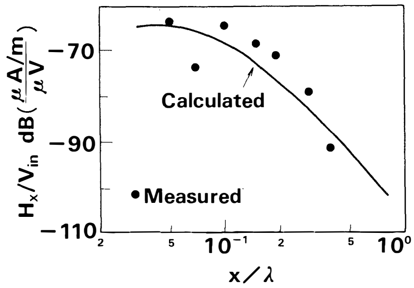

Fig. 3 Magnetic field change when the antenna moves in the direction normal to the line. Parameters are $y=0.05$ m, $z=0$ m, $h=0.05$ m, $l=1.5$ m, $f=300$ MHz, $R_a=50\ \Omega$, and $R_b=0\ \Omega$.

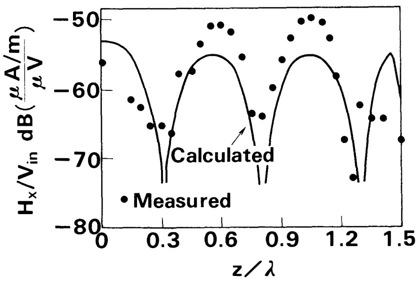

Fig. 4 Magnetic field change when the antenna moves in the direction parallel to the line. Parameters are $x=0.05$ m, $y=0.05$ m, $h=0.05$ m, $l=1.5$ m, $f=300$ MHz, $R_a=50\ \Omega$, and $R_b=0\ \Omega$.

Fig. 4 shows the change when the antenna moves in parallel with the line. It is shown form these figures that the calculated values and the measured values represent a similar tendency and the calculated values are approximately agreement with the measured values. Thus, it is confirmed that Eq. (1) is quite useful for calculating the field emitting tendency from the line.

4. Relation between the Electric Field and the Terminal Voltage

Using Eq. (1), frequency dependence of the conversion factor is calculated, where the conversion factor is defined as the electric field strength E normalized by the terminal voltage V_{in}. The results are shown in Fig. 5 for the line length l of 200 and 2000 m. In the calculation, an earth conductivity of 0.01 s/m, a wire diameter of 0.4 mmϕ and a wire height of 5 m are used. The electric field strength at the points around the cable, where the distance from the earth to the points is 5 m and the

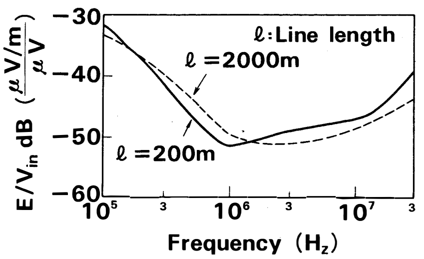

Fig. 5 Frequency dependence of the conversion factor for the case of h=5 m, $R_a=R_b$=1000 Ω, and σ=0.01 s/m.

distance from the cable to the points is 10 m, are calculated. In above conditions, the distance 10 m is used because the limits of radiated interference field strength is specified at a test distance of 10 m for the class B equipment in CISPR[(1)]. The conversion factor is evaluated from the maximum electric field strength normalized by the terminal voltage. It is found from Fig. 5 that the conversion factor is not varied largely against the line length change, and a maximum conversion factor of −30 dB in the frequency range of 0.1−30 MHz is obtained. Using Fig. 5, the electric field strength limits emitted from the telecommunication line are able to be given by the terminal voltage V_{in}.

5. Conclusion

Analytic expressions for near field emissions from a single current flowing along a straight wire were derived. The near field emission from a scale down model was measured and the result shows that the field emitting tendency from the line could be calculated by using Eq. (1). As a result of these calculations, the conversion factor between the electric field strength and the terminal voltage was obtained. It was shown that the conversion factor was varied very little against the line length change, and a maximum conversion factor of about −30 dB in the frequency range of 0.1−30 MHz was obtained. The conversion factor is useful to obtain the field strength limits emitted from the telecommunication line.

In the future, it is need to measure the electric filed emitting from the cable over the earth and to confirm the validity of the theory.

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