Analysis of Radiation from Pulse Wave Antennas

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1. Introduction

In recent years, electronic devices are indispensable as they are familiar and it becomes problem that unnecessary radiation from their circuit boards causes malfunction of other electronic appliance. Transmitting waves on digital circuit boards are pulse waves. In this paper, we treat pulse traveling wave antenna aiming to analyze the radiation from the conductor. The time-domain problem for pulse wave has come to be able to be easily calculated using analysis tools by the FDTD method for instance. However, physical understanding of the mechanism of radiation from pulse wave antenna are not easy by the tools. Therefore, we try to obtain a simple analytical solution of Maxwell's equations in time-domain for traveling wave.

2. Formulation

Suppose a bounded distribution of time-dependent source in free space is as shown in Fig.1. The vector potential **A** at the observation point P and time t are given by

$$\mathbf{A}(\mathbf{r},t) = \frac{\mu_0}{4\pi}\int_{V'} \frac{[\mathbf{J}]}{R}\,dv' \tag{1}$$

where **J** is the current, and $\mathbf{R} = \mathbf{r} - \mathbf{r}'$ is the vector from the source ($\mathbf{r}'$) point to the field point ($\mathbf{r}$). The square brackets indicate that the magnitude inside them must be evaluated at the retarded time $t' = t - R/c$, where c is the velocity of light in free space. That is,

$$[\mathbf{J}] = \mathbf{J}(\mathbf{r}',t') \tag{2}$$

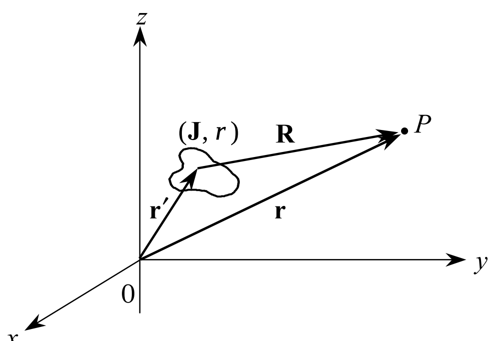


Fig.1 Geometry.

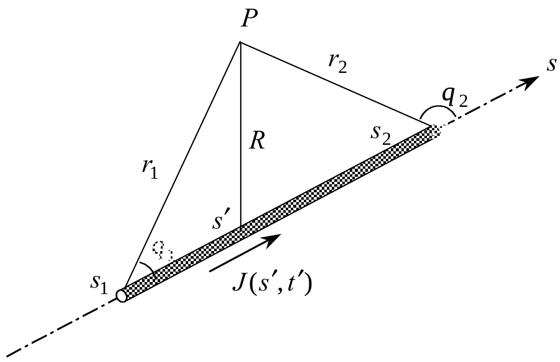


Fig.2 Traveling current **J** and observation point R

Introducing Eq.(1) and (2), the magnetic field **H** is expressed as follows

$$\mathbf{H}(\mathbf{r},t)=\frac{1}{m_0}\nabla\times\mathbf{A}(\mathbf{r},t) \tag{3}$$

Radiation field is proportional to $1/R$ and its vector is orthogonal to $\mathbf{j}_R$, which is the unit vector in the direction of **R**. Hence **H** can be expressed for far field as follows [1]

$$\mathbf{H}(\mathbf{r},t)=\frac{1}{4p}\int_{V'}\left\{\frac{[\mathbf{J}]\times\mathbf{j}_R}{R^2}+\frac{1}{cR}\left[\frac{\partial\mathbf{J}}{\partial t'}\right]\times\mathbf{j}_R\right\}du'\approx\frac{1}{4p}\int_{V'}\frac{1}{cR}\left[\frac{\partial\mathbf{J}}{\partial t'}\right]\times\mathbf{j}_R\,du' \tag{4}$$

Next, we obtain the radiation field when a traveling-wave current is given. Suppose the current $\mathbf{J}(\mathbf{r}',t')$ on a wire conductor shown in Fig.2. The current **J** is a traveling-wave and flows from the starting point s_1 on the conductor to the terminal point s_2. That is,

$$\mathbf{J}(\mathbf{r}',t')=J(s',t')\mathbf{j}_s=J(t'-s'/u)\mathbf{j}_s \tag{5}$$

where u is speed of the traveling-wave and $\mathbf{j}_s$ is the unit vector in the direction of s.

The radiation component may extract only the term in proportion to $1/R$. Therefore we can express **H** as follows

$$\begin{aligned}\mathbf{H}_{rad}(\mathbf{r},t)&=\frac{1}{4pc}\int_{s_1}^{s_2}\frac{\mathbf{j}_s\times\mathbf{j}_R}{R}\frac{\partial J(t)}{\partial t'}ds'\\&=\frac{1}{4pc}\int_{s_1}^{s_2}\frac{\mathbf{j}_s\times\mathbf{j}_R}{R}\left(\frac{\partial s'}{\partial t}\right)\frac{\partial J(t)}{\partial s'}ds'\\&=\frac{1}{4pc}\left[\frac{\mathbf{j}_s\times\mathbf{j}_R}{R}\left(\frac{\partial s'}{\partial t}\right)J(t)\right]_{s_1}^{s_2}+O\left(\frac{1}{R^2}\right)\\&=\frac{1}{4pc}\sum_{i=1}^{2}\frac{(-1)^iJ(t_i)\mathbf{j}_s\times\mathbf{j}_{ri}}{r_i}\left(\frac{\partial s'}{\partial t}\right)_{s'=s_i}\end{aligned} \tag{6}$$

where

$$t=t-\frac{R}{c}-\frac{s'}{u} \tag{7}$$

and R can be shown from Fig.2 as follows

$$R^2=r_i^2+(s'-s_i)^2-2r_i(s'-s_i)\cos q_i \tag{8}$$

Then $\partial t/\partial s'$ can be written by

$$\frac{\partial t}{\partial s'}=-\frac{1}{c}\frac{\partial R}{\partial s'}-\frac{1}{u}=-\frac{1}{c}\left(\frac{c}{u}+\frac{s'-s_i-r_i\cos q_i}{R}\right) \tag{9}$$

We obtain a simple expression of Eq.(6) by substituting Eq.(9) as follows

$$\mathbf{H}_{rad}(\mathbf{r},t)=\frac{1}{4p}\sum_{i=1}^{2}\frac{(-1)^{i-1}J(t_i)}{r_i}\frac{\mathbf{j}_s\times\mathbf{j}_{r_i}}{(c/u)-\mathbf{j}_s\cdot\mathbf{j}_{r_i}} \tag{10}$$

From above, it is evident that the radiation field by the traveling-wave is expressed as a summation of radiation field from generation and vanishing points of current. The radiation field from arbitrary multiple discontinuous points can be expressed by generalizing Eq.(10).

3. Radiation characteristics

The antenna and the pulse wave are shown in Fig.3, where the length of the antenna is *L*, the pulse width is *W*, and the distance from the starting point of the antenna to the observation point is r_1. The pulse is not a complete square but a trapezoidal wave that has the inclination in rising and falling, the width of which is W_S. We consider about the radiation in far field for $L = 90cm$, $W = 100L$, $W_S = L/3$, and $r_1 = 100L$. It is necessary to consider the propagation time of distance r_1 from Eq.(10). This delay time r_1 / c is corrected in Fig.4.

The radiation of the magnetic field begins, when the pulse is emitted in the antenna (Fig.4a-1). To begin with, the magnetic field is radiated for traveling direction of the pulse (Fig.4b-1). As the pulse travels, the radiation disappears while the largest radiant direction is changed from $0°$ to $180°$ (Fig.4c-1, d-1). Then, the radiation disappears, when the rising part of the pulse passes (Fig.4e-1). While there is no change in the current, the magnetic field keeps nonradiation. Then the similar radiation is also repeated in the falling time of the pulse wave.

Next, we consider about the radiation in near field for $r_1 = 1.1L$. As well as in far field, the radiation of the magnetic field begins when the pulse is emitted in the antenna (Fig.4a-2). And it is also radiated for traveling direction of the pulse (Fig.4b-2). However, the change afterwards is complex. The radiation is shown in the synthesis of the decreasing component, which changes the largest radiant direction from $0°$ to $180°$ and the constant component which always exists (Fig.4c-2, d-2). And the magnetic field keeps showing the same waveform when the current does not change (Fig.4e-2). After the falling time of the pulse wave, the magnetic field disappears.

4. Conclusion

The radiation characteristics of the traveling pulse wave antenna has been studied, and the time variation of radiation field has been shown. In far field, it has been shown that the radiation occurs at the rising and falling time of the pulse wave, and does not exist while the current is constant. In near field, however, the field keeps showing a same waveform when the current does not change. It is expected that not only the radiation field but also the induction field is included in the derived magnetic field expression.

This work has been supported in part by Japan Society for the Promotion of Science (JSPS) in research for the future program.

Reference

[1] R.G.Martin, A.R.Bretones, and S.G.Garcia, “Some Thoughts About Transient Radiation by Straight Thin Wires”, IEEE Antennas and Propagation Magazine, vol.41, no.3, pp24-33, June 1999.

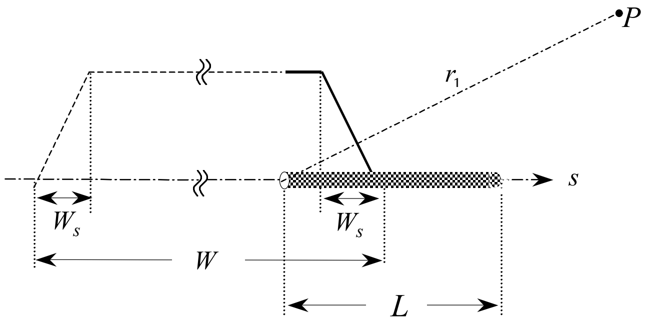
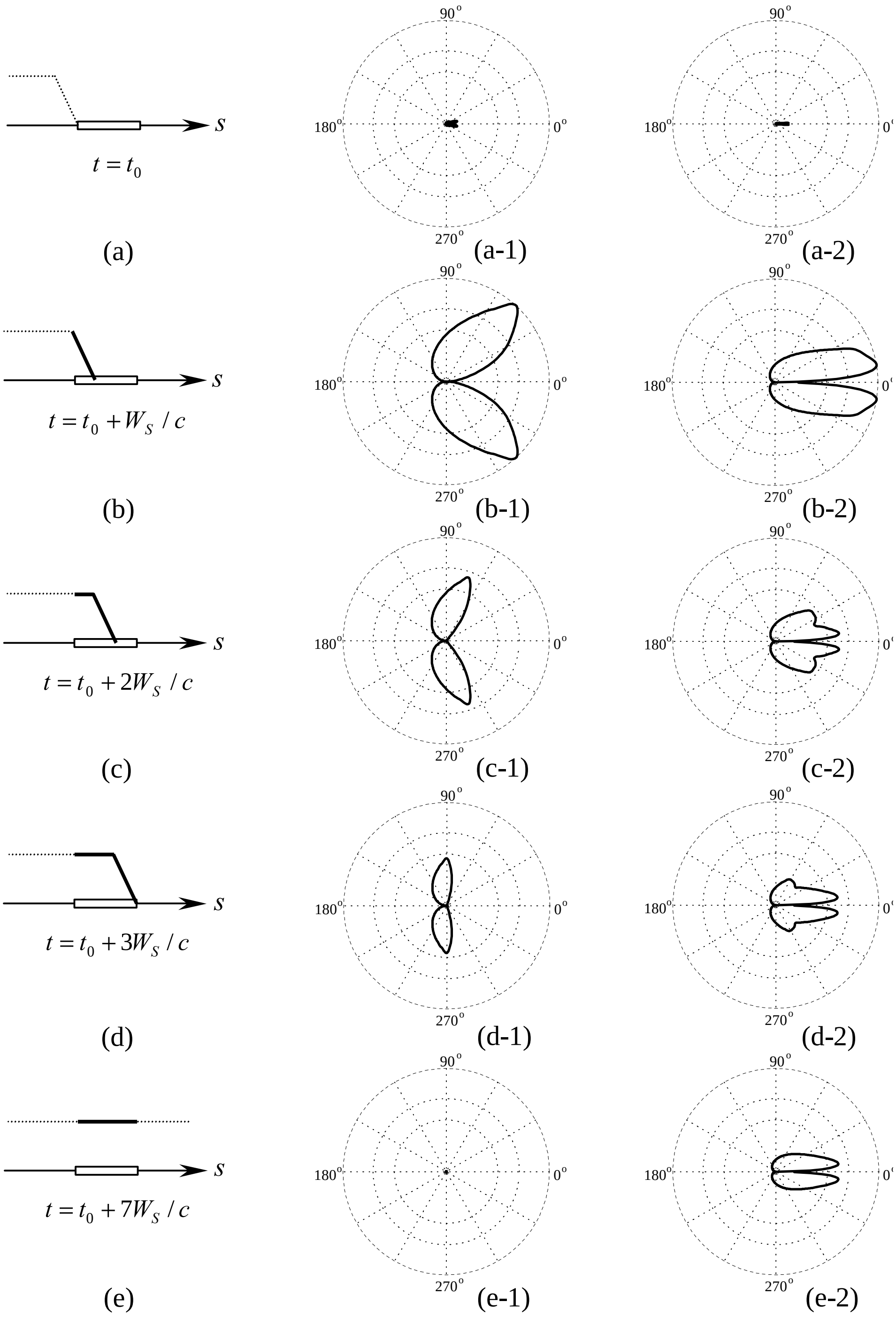


Fig.3 Relation of antenna and pulse wave.



(a-1)~(e-1), $r_1 / L = 100$ (a-2)~(e-2), $r_1 / L = 1.1$

Fig.4 Radiation characteristics. (▬ H_f)