Jong Kweon Park. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 13, Issue 10, October 2023, pp 118-120

RESEARCH ARTICLE OPEN ACCESS

A simple field derivation method for the infinitesimal dipole & loop antennas by arbitrary current distribution

Jong Kweon Park
Department of Mobile Convergence Engineering, Hanbat National University, 125 Dongseo-daero,Yuseong-Gu, Daejeon, 34158, Republic of Korea
Corresponding Author: Jong Kweon Park

ABSTRACT:
In order to analyze the pulse characteristics of infinitesimal dipole & loop antennas, this paper induced the related expressions using the incident wave reconstruction technique (IWRT), and analyzed the derived results. The techniques proposed in this study have the advantage of being able to obtain easily the expressions for the radiated fields & the near-fields that represent the pulse characteristics of the antenna. The derived field expressions valid in all distance will be widely used to study the near-field & far-field characteristics of the antenna for arbitrary input current.

Keywords: infinitesimal dipole antenna, infinitesimal loop antenna, incident wave reconstruction technique, pulse characteristics, near-fields, UWB, EMI/EMC.

Date of Submission: 05-10-2023 Date of acceptance: 19-10-2023

I. Introduction

In general, when the field characteristics of infinitesimal(ultra-small) dipole & loop antennas are studied, they are interpreted in the frequency domain, and the properties are very well known. Field expressions for electric and magnetic fields are also well-interpretably expressed in frequency domains. However, the field characteristics of ultra-small dipole & loop antennas for arbitrary input current in the time domain are shown in several books [1], but the process or results of obtaining those characteristics are very difficult. Also, with the development of UWB technology, it is very important to understand the pulse characteristics of the antennas. Since 2002, with an increased interest in UWB technology, it has become very important to understand the pulse characteristics of several antennas well. In this paper, as is well illustrated in various literature, we would like to obtain the field expression of the infinitesimal dipole & loop antennas by arbitrary input current by using the field expression in the well-known frequency domain. The techniques used are very simple techniques using the incident wave reconstruction technique and k and ω operators [2]. We have already proposed the above technique and utilized for the field derivation of infinitesimal dipole antenna in [3]. The derived field expressions for the antennas valid in all distance can be used for the antenna design and EMI/EMC applications.

II. Basic Idea and Field Derivation (Dipole Antenna)

When an input current $\mathrm{I(t)} = I_0 \cos(\omega t)$ is applied to a ultra-small dipole antenna of length l, the radiation field is expressed as follows [4]. The expression is a field expression obtained when the input current is a time-harmonic function. We would like to use the following expression, which is already well known, to induce fields by arbitrary input current.

$$\vec{E}(\vec{r},t) = \frac{\omega \mu_0 l}{4\pi r} I_0 \sin(kr - \omega t) \sin\theta\, \hat{\theta}$$

where $\mu_0$is the permeability of the free space, c is the speed of light, and k is the wave number. Here, using the relational expression of $k^n = \frac{\omega^n}{c^n}$, $\omega^n = \frac{(-1)^{n+1} d^n}{dt^n} (n = 1, 2, \ldots)$ and using the incident wave reconstruction technique [2], we obtained the following field expression.

$$\vec{E}(\vec{r},t) = \frac{\mu_0 l}{4\pi r} \frac{d}{dt} [I(t - \frac{r}{c})] \sin\theta\, \hat{\theta}$$

It can be seen that the obtained field expression is also consistent with the results given in reference [1, Table 7.1]. In other words, the approach for field derivation is different but the final result is the same. The derivation procedure of [1] is very long and difficult to obtain the final field expression. But the procedure of the proposed technique is very short and simple to obtain the final field expression. Therefore, we can simply obtain the radiation field of the ultra-small dipole antenna by arbitrary input current. If the current distribution is a Gaussian pulse with period T, $\mathrm{I(t)} = I_0 e^{-(t/T)^2}$ such as an input current, it is possible to obtain a radiation field very easily using the above expression.

It is also possible to derive the full electric and magnetic fields at any distance, rather than limiting them to the radiation fields. The induction process is similar to the process of obtaining a radiation field, so it is omitted, and the final results are summarized as follows. The following equations [4] are the fields of the small-dipole antenna in the frequency domain when the current distribution is the time-harmonic function.

$$\vec{H}(\vec{r},t) = -\frac{1}{c}\frac{\omega l}{4\pi r} I_0 \sin(\omega t - kr)\sin\theta\,\hat{\phi} + \frac{l}{4\pi r^2} I_0 \cos(\omega t - kr)\sin\theta\,\hat{\phi}$$

$$\vec{E}(\vec{r},t) = -\frac{\omega\mu_0 l}{4\pi r} I_0 \sin(\omega t - kr)\sin\theta\,\hat{\theta} + \frac{\eta_0 l}{4\pi r^2} I_0 \cos(\omega t - kr)\left(\sin\theta\,\hat{\theta} + 2\cos\theta\,\hat{r}\right) + \frac{1}{\omega\varepsilon_0}\frac{l}{4\pi r^3} I_0 \sin(\omega t - kr)\left(\sin\theta\,\hat{\theta} + 2\cos\theta\,\hat{r}\right)$$

Where η_0 is the intrinsic impedance of the free space and k is the wave number. The next expression indicates the electric and magnetic fields by arbitrary input current at any distance from the antenna.

$$\vec{H}(\vec{r},t) = \frac{1}{\eta_0}\frac{\mu_0 l}{4\pi r}\frac{d}{dt}[I(t - r/c)]\sin\theta\,\hat{\phi} + \frac{l}{4\pi r^2}\,\mathrm{I}(t - r/c)\sin\theta\,\hat{\phi}$$

$$\vec{E}(\vec{r},t) = \frac{\mu_0 l}{4\pi r}\frac{d}{dt}[I(t - r/c)]\sin\theta\,\hat{\theta} + \frac{\eta_0 l}{4\pi r^2} I(t - \frac{r}{c})\left(\sin\theta\,\hat{\theta} + 2\cos\theta\,\hat{r}\right) + \frac{1}{\varepsilon_0}\frac{l}{4\pi r^3}\int I\left(t - \frac{r}{c}\right)dt\left(\sin\theta\,\hat{\theta} + 2\cos\theta\,\hat{r}\right)$$

If it is very close to the antenna, it can be thought of as quasi-static, and from the above expression, this is the third field term of the above electric field. The third field shows that it is an electric field by an electric dipole moment that we know well. We can use the above expression to study the characteristics of electric fields according to the distance from the antenna. And also this field expressions can be used for the study of pulse characteristics by any pulse-like current distribution. The proposed method for the field derivation has an advantage of simplicity using the already well-known fields in the frequency domain.

III. Field Derivation (Loop Antenna)

When an input current $\mathrm{I(t)} = I_0\cos(\omega t)$ is applied to an infinitesimal loop antenna with radius a, the field is calculated using a phasor, especially the radiation field is simply expressed as shown in the following expression [4]. This expression is a field expression obtained when the input current is a time-harmonic cosine function.

$$\vec{E}(\vec{r},t) = \frac{\eta_0 k^2 a^2}{4r} I_0 \cos(kr - \omega t)\sin\theta\,\hat{\phi}$$

where η_0 is the intrinsic impedance of the free space and k is the wave number.

We would like to use this expression to induce an entire field or a radiation field by arbitrary input current. Here, the relational expression of $k^n = \frac{\omega^n}{c^n}$, $\omega^n = \frac{(-1)^{n+1}d^n}{dt^n}$ is used and organized using the incident wave reconstruction technique given in reference [2], which is expressed as follows.

$$\vec{E}(\vec{r},t) = -\frac{1}{c}\frac{\mu_0\pi a^2}{4\pi r}\frac{d^2}{dt^2}\left[I\left(t - \frac{r}{c}\right)\right]\sin\theta\,\hat{\phi}$$

Therefore, we can simply obtain the radiation field of the infinitesimal loop antenna by arbitrary input current. Furthermore, it is possible to apply this technique to the entire electric and magnetic fields at any distance, rather than limiting this technique to the radiation fields. The induction procedure is similar to the procedure of obtaining a radiation field, and the induction procedure is very long and thus omitted here, and the final results are summarized as follows.

$$\vec{E}(\vec{r},t) = -\frac{1}{c}\frac{\mu_0\pi a^2}{4\pi r}\frac{d^2}{dt^2}\left[I\left(t-\frac{r}{c}\right)\right]\sin\theta\,\hat{\phi} - \frac{\mu_0\pi a^2}{4\pi r^2}\frac{d}{dt}\left[I\left(t-\frac{r}{c}\right)\right]\sin\theta\,\hat{\phi}$$

The expression shown above represents an electric field at any distance from the antenna. If the distance is very close to the antenna, the second term expression will be the most important term and if the distance is far from the antenna, the first term will be the most important term. In the antenna applications, the first term is used, but in the EMI/EMC applications (in the near/medium field), the second term is used. We can see that the field characteristics between them have a different function with respect to time. We can use the above expression to study the characteristics of electric fields according to the distance from the antenna.

The expression induced in this paper is meaningful in that fields can be obtained for arbitrary input current. Also, the procedure of obtaining is very simple and easy, so there is a difference from other existing methods of induction [1]. In UWB technology, the pulse characteristics of the used antenna is necessary, thus the derived field expression is used for that study.

IV. Conclusion

In this paper, we have used the incident wave reconstruction technique and k and ω operator for the field derivation. When arbitrary input current distribution is applied to the infinitesimal dipole & loop antennas, its radiation field and the whole field are simply obtained. The obtained field expression could be widely used to study field characteristics for arbitrary input current. The same technique can be used for the full field as well as the radiation field, and the results obtained will be available to study the field characteristics at various distance of the infinitesimal dipole & loop antennas. As a future research project, we would like to conduct a pulse characteristic study on the array of infinitesimal dipole & loop antennas.

References

[1]. G. S. Smith, “An introduction to classical electromagnetic radiation”, Cambridge university press, USA, 1997.

[2]. Y. Zhang and M. E. Geyer, “Analysis of ultra-wideband short pulses for radio communications”, Int. J. Commun. Syst., Vol.15, pp.1-12, Dec. 2001.

[3]. J. K. Park, “A study on the pulse characteristics of infinitesimal dipole antenna”, 2016 radio wave and optical technology conference proceedings(in Korean), Vol. 17, No. 1, pp. 73-74, Nov. 2016

[4]. C. A. Balanis, “Antenna theory : analysis and design”, John Wiley & Sons, Singapore, 1998.