Internal Resistance of Voltage Source by Use of the Finite-Difference Time-Domain Technique

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Abstract—**The introduction of the internal resistance of a voltage source is a very effective method for analyzing the electromagnetic characteristics of antennas and microstrip devices by use of the finite-difference time-domain (FDTD) technique. However, some trial and error may be needed when choosing a resistance value to obtain a stable result. This letter proposes a method to obtain a proper internal resistance of a source voltage in a FDTD code. The key to this method is to choose a resistance value such that the voltage drop due to an internal resistance is less than the amplitude of a voltage source. The reductions of total computation time-steps are shown for various antenna types.**

Index Terms—**Finite-difference time-domain (FDTD) technique, reduction of time-steps, source resistance, voltage drop.**

I. INTRODUCTION

THE finite-difference time-domain (FDTD) technique has been widely applied to analyze the electromagnetic characteristics of antennas and microstrip devices. A transient source excitation such as a Gaussian pulse provides impedance and scattering parameters of a target object in a wide frequency band by applying the fast Fourier transformation (FFT). However, sometimes a strong resonance requires an excessive number of time-steps for transient fields to disappear completely.

Moreover, today's antenna simulations require a relatively large computational space including other environmental objects. Sometimes, it is needed to find out scattering parameters of a handset with a human head model, to design body-mounted devices, or to solve a problem with a very fine grid size to consider the effect of components.

Researchers have tried various approaches to reduce the number of required time-steps that will result in transient field decay. The method of [1] is limited in application, and [2] and [3] require an additional structure such as a coaxial line in a FDTD space. The prediction techniques in [4] and [5] add a complex prediction process.

Luebbers *et al.* [6] proposed a simple and very effective method to reduce time-steps needed for FDTD calculations of resonant devices. It is an extension to the gap feed by use of an internal resistance. They used one resistance value, 50 Ω, to illustrate the advantage of using an internal resistance in the FDTD grid. In this letter, the effects of various internal resistances on reduction of the time-step are investigated, and a simple method to choose an optimum resistance value is proposed.

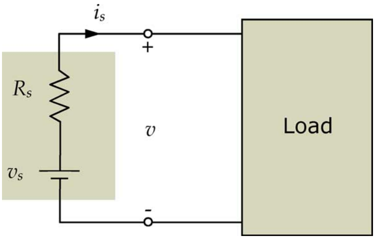

Fig. 1. Voltage source with internal resistance R_s.

II. THE OPTIMUM INTERNAL RESISTANCE OF SOURCE VOLTAGE

Assuming an internal resistance in a voltage source, as shown in Fig. 1, the total voltage just before the target device can be written as

$$v(t) = v_s(t) - R_s \cdot i(t). \tag{1}$$

In a usual calculation using the FDTD technique, the internal resistance of a voltage source R_s is set to zero. The zero-resistance voltage source can require a relatively long period to dissipate the excitation energy or sometimes leads to an unstable result.

This letter proposes an internal resistance value dependent on the structure and dielectric properties at the feeding part in a given device. The proposed method gives a very small number of total time-steps and a stable result with one calculation by including the step to determine the resistance value in a FDTD code.

Fig. 2 shows the proposed flow chart in a FDTD code. The larger R_s provides the shorter calculation time. However, when the voltage drop due to internal resistance R_s becomes larger, exceeding the voltage source V_s^n, it finally results in an unstable time-domain response that does not converge to zero for a pulse input; this will be described in more detail in the next section. Therefore, the internal resistance is calculated at the FDTD time-step when the first nonzero circuital current around the source voltage appears after launching of the source V_s^n. In the case of a Gaussian pulse as a transient source, the source resistance is determined at the first time-step ($\mathrm{n} = 1$). The error due to the one-half offset time between the current and voltage was neglected.

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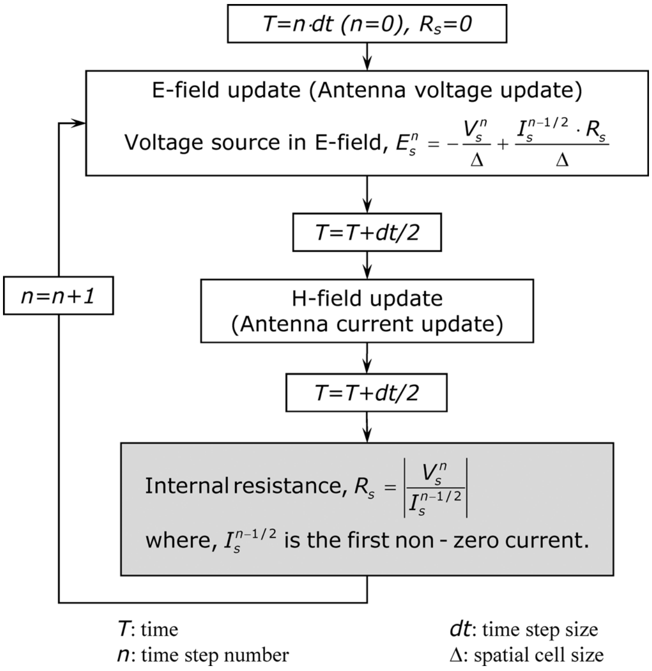


Fig. 2. Program to determine optimum resistance of internal voltage source.

III. INTERNAL RESISTANCE VALUE AND REDUCTION IN FDTD CALCULATION TIME

Fig. 3 shows the electric field-source locations of various antenna types that operate at different frequencies. Fig. 3(a) is a microstrip antenna with a top plate of 12×21 mm^2 on an air substrate. Fig. 3(b) is a dipole antenna coated with a dielectric of $\varepsilon_\mathrm{r} = 4.0$ and $\sigma = 0.0$, and a radius of 0.22 mm was assumed. Fig. 3(c) shows a mock-up handset model comprised of a monopole antenna on a conducting box and fabricated with brass. The length and radius of the monopole are 91 and 1 mm, respectively. A handset model with a helical antenna is shown in Fig. 3(d). The helix structure is 258 mm long, and the rectangular box covering the ground plane has dielectric properties of $\varepsilon_\mathrm{r} = 4.0$ and $\sigma = 0.04$ S/m.

As shown in Fig. 3, all the antennas were fed using the vertical electric field at the feed point given by

$$E_s^n\left(i_s, j_s, k_s\right) = -\frac{V_s^n}{\Delta z} + \frac{I_s^{n-1/2}\cdot R_s}{\Delta z} \tag{2}$$

where $V_s^n = \exp\left[-\alpha(n\cdot dt - \beta\cdot dt)^2\right]$, and

$$I_s^{n-1/2} = \left[H_x^{n-1/2}\left(i_s, j_s-1, k_s\right) - H_x^{n-1/2}\left(i_s, j_s, k_s\right)\right]\cdot\Delta x + \left[H_y^{n-1/2}\left(i_s, j_s, k_s\right) - H_y^{n-1/2}\left(i_s-1, j_s, k_s\right)\right]\cdot\Delta y.$$

For a transient voltage source, a Gaussian pulse with $\alpha = (4/\beta\cdot dt)^2$ and $\beta = 128$ was used. In all the cases considered, a uniform grid size of $1\times 1\times 1$ mm^3 and a time-step size of 1.8 ps were used.

The current time-domain data are compared in Fig. 4 for various resistances of the microstrip and helical antennas of Fig. 3. We can see that the larger internal resistance greatly reduces the number of time-steps needed for convergence. The larger resistance dissipated the transient fields more rapidly.

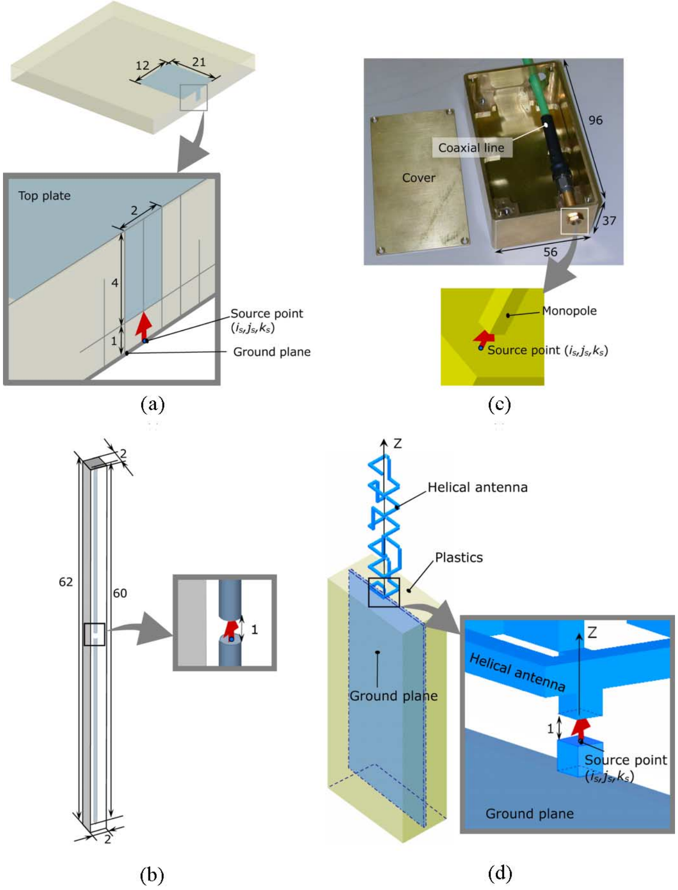


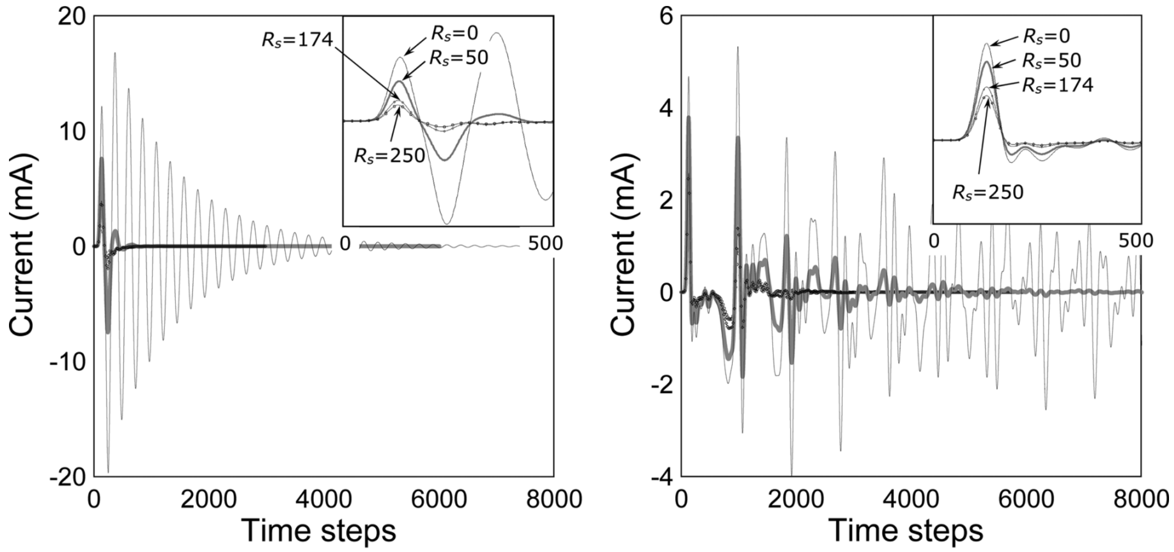
Fig. 3. Antenna structures and feed locations. (a) Microstrip antenna. (b) Dipole antenna. (c) Handset with a monopole antenna. (d) Handset with a helical antenna (all dimensions in millimeters).

A source resistance value of 174 Ω was obtained with the proposed approach of Fig. 2. The extent of convergence between the results using 174 and 250 Ω is small. For the used FDTD cell and time-step sizes, if the excitation function and the electric properties of material around the source point are identical, the source resistance value for the proposed method is constant. For all the cases considered, a resistance of 300 Ω or greater caused the transient fields to diverge.

A nonresistive voltage ($R_s = 0$) for the handset model with a helical antenna required a number of time-steps greater than 60 000 for convergence.

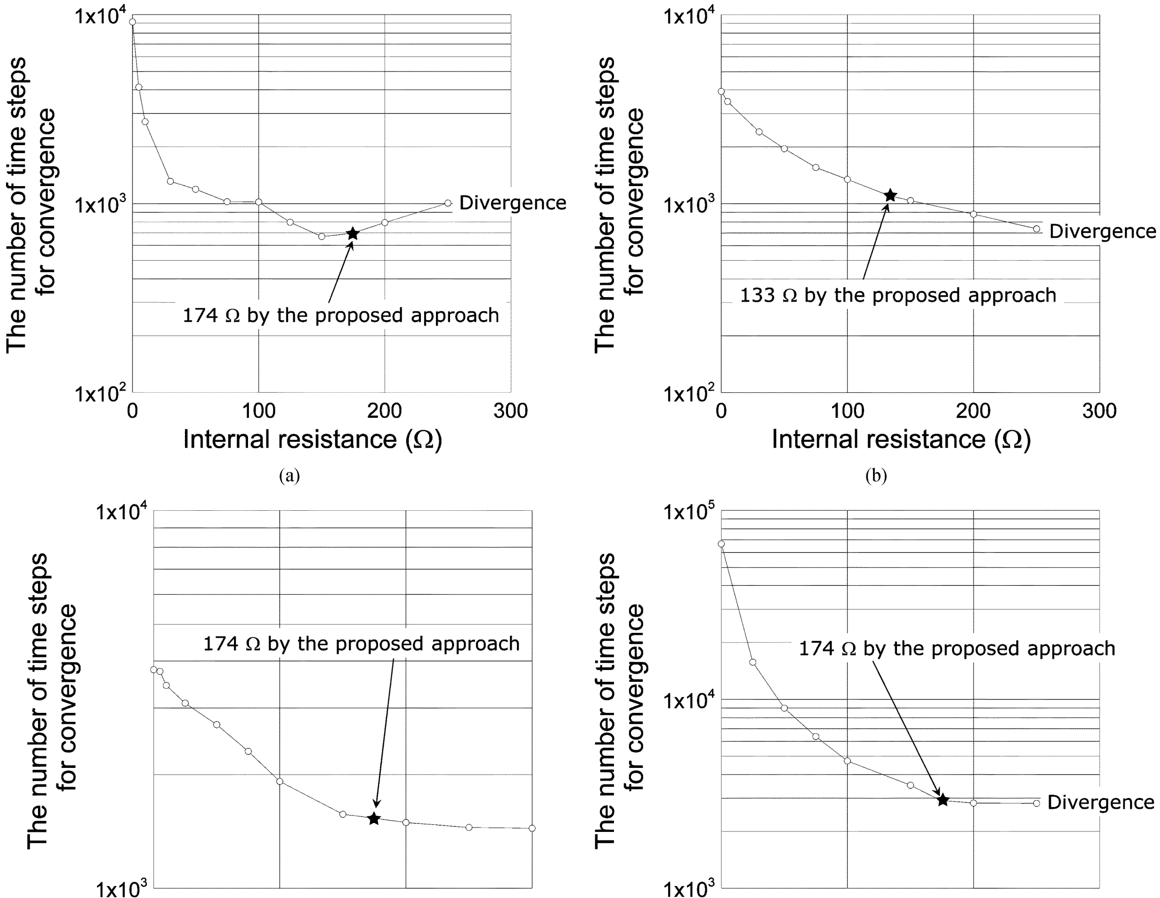
Fig. 5 compares the number of time-steps required for the current to converge to 10^{-5} of the maximum amplitude of the excitation voltage for each antenna. The internal resistance calculated according to the method in Fig. 2 results in dramatic reduction in the number of time-steps as compared to that for the zero-resistance case. In all the cases, when the resistance reaches 300 Ω, it does not drop the source terminal voltage $v(t)$, but amplifies the voltage and current step by step and finally the transient fields diverge.

The input impedances were obtained by applying the complex Fourier transforms to the results in the time domain. Fig. 6 compares the input impedances for the different internal resistances. We can see that the results agree very well with each other for zero resistance and for the resistance obtained with



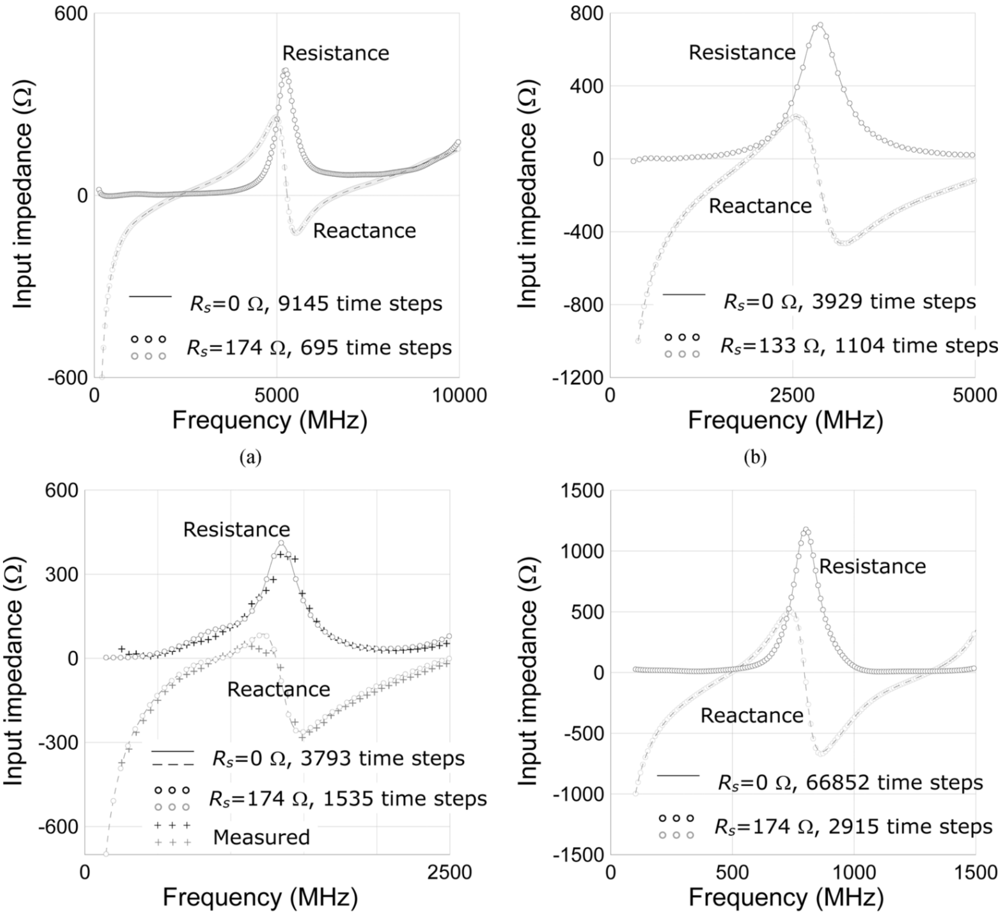
(a) (b)

Fig. 4. Source current $i_s(t)$. (a) Microstrip antenna and (b) handset with a helical antenna.



(c) (d)

Fig. 5. Comparison of the time-steps for convergence for each antenna type. (a) Microstrip antenna. (b) Dipole antenna. (c) Handset with a monopole. (d) Handset with a helical antenna.



(a) (b) (c) (d)

Fig. 6. Comparison of input impedances. (a) Microstrip antenna. (b) Dipole antenna. (c) Handset with a monopole. (d) Handset with a helical antenna.

the proposed approach. For the experimental validation of the FDTD calculation, the input impedance of the manufactured handset model of Fig. 3(c) was measured using a coaxial line connected to the feed point inside the box. It showed a good agreement between the calculation and measurement.

IV. CONCLUSION

The proposed approach to obtain an effective internal resistance of a voltage source in a FDTD calculation provides faster convergence of the transient fields. It does not need to determine an effective resistance value by iterating a FDTD calculation since a simple step for selecting the resistance is within the FDTD code.

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