Perturbation Method for Sinusoidally Excited FDTD Analysis

Olli P. M. Pekonen, Petteri Alinikula, and Keijo I. Nikoskinen

Abstract—**A method for perturbing a sinusoidally excited FD-TD simulation is introduced. In this scheme, desired simulation output data is read after the first steady state is reached. Simulated structure is altered slightly as the simulation runs, and thus a perturbation is created into the steady state. A new steady state emerges faster than the initial one and computational efficiency is gained. The new steady state can be perturbed again with similar efficiency. The method is applicable for fast optimization of various microwave applications in FDTD analysis.**

I. Introduction

THE FDTD method has grown to be one of the most suitable means of analysis in many microwave and millimeter-wave problems. Typically, the scheme is excited with a pulsed source, time development of the pulse is studied, and frequency domain results are extracted with Fourier transform. A somewhat less-used feeding method is to use a continuous sinusoidal excitation. In this case output data is derived directly from wave amplitudes and phases as a steady state is reached. The latter method is especially attractive when information is needed only at one frequency.

In this paper, a perturbation FDTD method is introduced. The key idea of the new method is **not** to start a sinusoidal FDTD simulation from scratch every time something is altered in the computation region. Instead, if the simulated structure changes only slightly, formation of a new steady state is faster than what would be possible to achieve if the simulation had been started all over again. The new scheme takes the FDTD method a step towards microwave circuit design and enables fast optimization of various structures.

II. Numerical Example

The scheme is demonstrated with an example in which we calculate the feeding point impedance Z_{in} of a simple open-ended microstrip line as length of the line varies. This structure is described in Fig. 1. The frequency of interest is $f = 5.5$ GHz. The basic microstrip simulation follows closely guidelines presented in [1]. All computation region boundaries except the ground plane at $z = 0$ are terminated with third order absorbing boundary condition presented in [2].

The line is fed with a resistive matched source [3] having internal resistance of $R_S = 50\,\Omega$. The amplitude of the source

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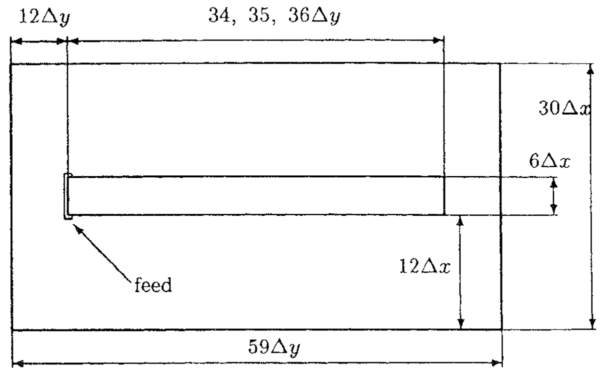

Fig. 1 The studied open-ended microstrip structure seen from above. Cell size: $\Delta x = \Delta y = \Delta z = 0.5$ mm Timestep size: $\Delta t = 0.9627$ ps. Source dimensions $6\Delta x \times 1\Delta y \times 4\Delta z$. Z_0 of the line 50 Ω. Substrate height $h = 4\Delta z$. Simulation domain height $h = 10\Delta z$, $\epsilon_r = 6.023$.

is 1 V. Feeding point impedance Z_{in} is calculated from the feeding point voltage and current simply with

$$Z_{\text{in}} = \frac{V_{\text{in}}}{I_{\text{in}}}, \tag{1}$$

where V_{in} is the voltage at the feed obtained by integrating the electric field along center line of the source, and I_{in} is the current flowing through the feed calculated by loop integrating the magnetic field that surrounds the feeding source at plane $Z = 2\Delta z$.

Two perturbation simulations were run. In the first simulation (perturbation simulation 1) length of the line was increased at iteration loops 1200 and 1800. Original length of the line was 17 mm, increment was 0.5 mm. The whole simulation lasted for 2400 iteration loops equal to 2.31 ns. Time behaviors of source current I_{in} and voltage V_{in} are shown in Figs. 2 and 3, respectively. Perturbation instants are marked with circles ($\circ$).

By visual inspection of V_{in} it is evident that the first steady state is reached after five full cycles of excitation after a considerable overshoot in the feeding point voltage. After loop 1200, the second steady state is reached reasonably well after only three full cycles. The third steady state becomes available after just two full cycles. Computational saving is thus evident.

Fig. 3 shows considerable ripple in the V_{in} waveform after the perturbations. This is due to bad choice of perturbation timing. Optimal way is to create the perturbation when the affected oscillating electric fields are close to zero.

To improve the result a second simulation (perturbation simulation 2) was run in which perturbation times are altered

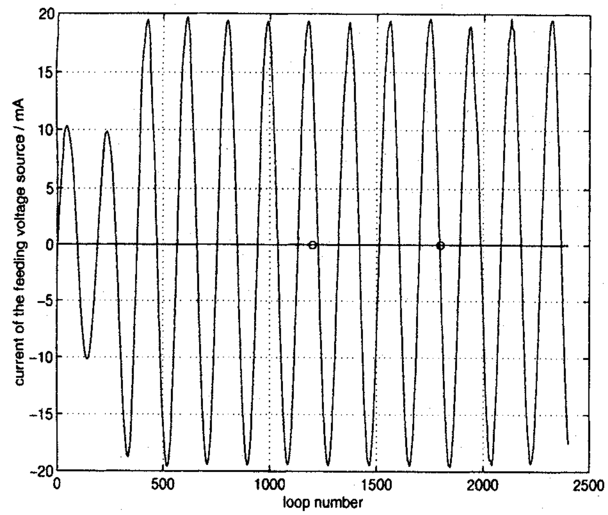

Fig. 2. Time behavior of feeding source current $I_{\rm in}$. In this case the current remains almost identical in both simulations utilizing the perturbation method. Perturbation instants are marked with circles (o).

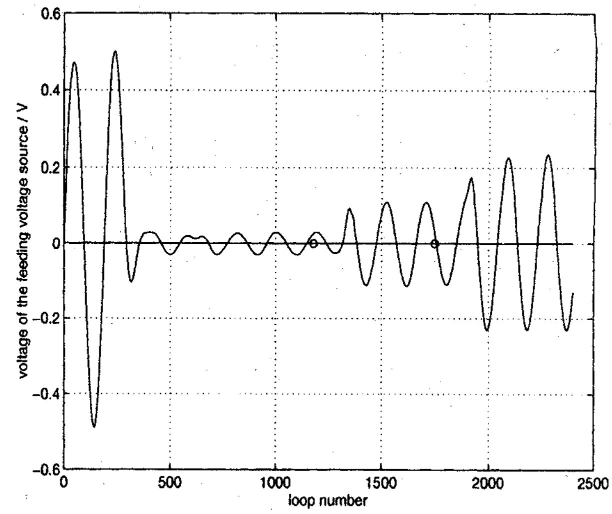

Fig. 4. Time behavior of feeding source voltage $V_{\rm in}$ in the second simulation. Instant of perturbation is chosen to be at electric field zero of the perturbed area. Ripple is almost nonexistent and creation of steady state is fast.

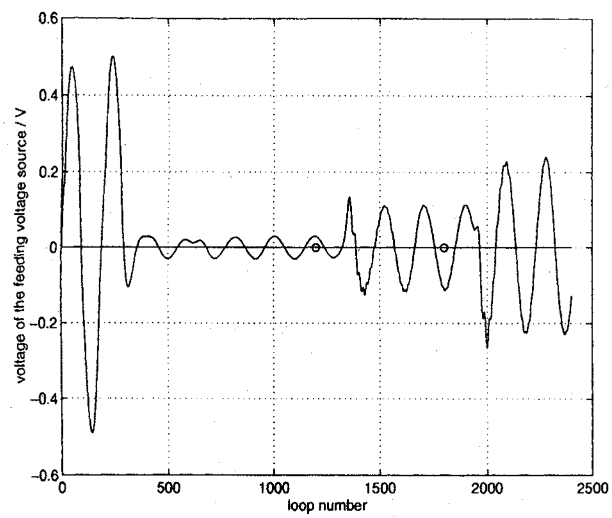

Fig. 3. Time behavior of feeding source voltage $V_{\rm in}$ in the first simulation in which care is not taken when choosing perturbation instants. This produces ripple into otherwise smooth waveforms.

slightly. At the open end of the line tangential electric fields were found to be close to zero at loops 1180 and 1750, which were selected as perturbation instants. Fig. 4 shows the new waveform of $V_{\rm in}$ ($I_{\rm in}$ remained almost identical in this case). The ripple has vanished almost completely and the steady state is reached immediately after the perturbation (making allowance for the time it takes from perturbation to reach the feeding point).

For reference purposes, all three lengths were simulated separately with FDTD for nine full cycles to reach a very reliable steady state. These simulations are denoted as reference simulation 1. To gain additional reference the structure was also simulated with MDS software[1] using simple microstrip models. Open end effects (end capacitance and radiation) are taken into account by methods presented in [4]. An additional 1 mm length (5.9%) was added to the line to account for the inherent inductance of the source that is not present in the ideal MDS models.[2] MDS simulation is denoted as reference simulation 2. The obtained feeding point impedances for the three lengths are shown in Table I.

TABLE I
RESULTS OF THE SIMULATIONS

length	$Z_{\rm in}$(perturbation 1)	$Z_{\rm in}$(perturbation 2)
17.0 mm	$1.39 - j0.73\ \Omega$	$1.39 - j0.73\ \Omega$
17.5 mm	$1.79 + j5.61\ \Omega$	$1.79 + j5.57\ \Omega$
18.0 mm	$2.10 + j12.1\ \Omega$	$1.74 + j11.9\ \Omega$
length	$Z_{\rm in}$(reference 1)	$Z_{\rm in}$(reference 2)
17.0 mm	$1.38 - j0.71\ \Omega$	$0.55 - j2.13\ \Omega$
17.5 mm	$1.39 + j5.46\ \Omega$	$0.55 + j4.51\ \Omega$
18.0 mm	$1.46 + j11.7\ \Omega$	$0.58 + j11.3\ \Omega$

Perturbation simulation 2 exhibits good agreement with both reference simulations. Despite the ripples, the result of perturbation simulation 1 is also in good agreement. This is due to fact that the ripple smooths out relatively quickly. However, the ripples are clearly nonphysical pulses propagating in the computation region and should be avoided when possible.

III. CONCLUSION

A method for steady state perturbation in FDTD was presented by means of a numerical microstrip example. However, the scheme is applicable to any sinusoidally excited simulation including antenna and resonator problems. With the scheme considerable savings can be achieved in the CPU time. Ripples caused by the perturbation can be avoided by selecting the instant of perturbation correctly. The method can be extended

[1]MDS stands for Hewlett-Packard Microwave and RF Design System, Copyright© Hewlett Packard Company 1995.

[2]Since the purpose of this letter is to demonstrate the perturbation FDTD method, closer study of feeding behavior is omitted.

easily to alteration of ϵ_r or σ or any other parameter within a sinusoidally excited FDTD simulation. The method enables especially fast design and optimization of microwave and millimeter wave structures.

REFERENCES

[1] X Zhang and K. Mei, "Time domain finite difference approach to the calculation of the frequency-dependent characteristics of microstrip discontinuities," *IEEE Trans Microwave Theory Tech.*, vol. 36, no 12, pp. 1775–1787, Dec 1988.

[2] P.-Y. Zhao, J. Litva, and K -L. Wu, "A new stable and very dispersive boundary condition for the FD-TD method" in *IEEE MTT-S Int. Microwave Symp. Dig.*, 1994, vol. 1, pp. 35–38

[3] M. Piket-May, A. Taflove, and J. Baron, "FD-TD modeling of digital signal propagation in 3-D circuits with passive and active loads," *IEEE Trans. Microwave Theory Tech.*, vol. 42, no. 8, pp. 1514–1523, Aug. 1994.

[4] R. K. Hoffmann, *Handbook of Microwave Integrated Circuits.* Norwood, MA: Artech House, 1987.