# Fast FDTD Analysis Using OFDM Pulse for Multi-Antenna Systems

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## 1. Introduction

Recently, Multiple-Input Multiple-Output (MIMO) systems [1] attract much attention and the MIMO systems are used widely in many areas of the wireless communication. The MIMO systems can improve the transmission rate without expanding frequency band. In MIMO systems, the transmission performance is greatly affected by the antennas and propagation characteristics. Therefore, it is important that the antennas and propagation characteristics are taken into account in the simulation of the wireless communication.

Finite-Difference Time-Domain (FDTD) method [2] is convenient to analyze complicated structures including the antennas and propagation environments. However, computation time seriously increases in proportion to the number of antennas, since each antenna requires individual simulation.

In this paper we propose a fast FDTD analysis method using simultaneous excitation for multi-antenna systems. In this method, Orthogonal Frequency Division Multiplexing (OFDM) pulse and CI (Carrier Interferometry) [3] method is employed for maintaining the orthogonality among excited signals. The characteristics of the neighbouring antennas can be calculated by assigning different OFDM subcarriers exclusively. The CI enables the simultaneous verification of the antennas distant enough by controlling the length of the pulse. These methods can achieve fast analysis compared with the FDTD method with the conventional pulse. First, we describe the concept of pulse generation and analysis method. Next, the numerical analysis results are shown, and the effectiveness of the proposed method is clarified.

## 2. Basic concept

The OFDM system divides available frequency band into narrow subcarriers and multiplexes them orthogonally. The frequency interval, $\Delta f$, is given by,

$$\Delta f = 1/T \tag{1}$$

where $T$ is length of signal. If the frequency interval does not meet the condition, the subcarriers interfere to other frequency subcarriers. Figure 1 shows the conceptual sketch of the signal arrangement in the frequency domain. The antennas can be analyzed by arranging signals to subcarriers alternately. The signal transformation is given by,

$$s_i(t) = \sum_{n=0}^{N-1} \mathrm{Re}\{Z_i \exp(j2\pi f_n t)\} \tag{2}$$

where $N$ is the number of the subcarriers, $\#i$ is the number of signals, $s_i$ is the signals in the time domain, $Z_i$ is the signals in the frequency domain and $f_n$ is the center frequency of the subcarriers.

Analysis using CI pulse can keep the orthogonality by exploiting the propagation time. In CI technique, the same amplitude value is assigned to all the subcarriers. The signals of the CI method can be expressed as,

$$F = \begin{bmatrix} 1 & e^{-j2\pi\frac{N_t}{N_{sub}}} & \cdots & e^{-j2\pi\frac{N_t(N_{sub}-1)}{N_{sub}}} \end{bmatrix}^T \tag{3}$$

where, $F$ is the signals in frequency domain, $N_{sub}$ is the number of the subcarriers, $N_t$ is liner phase offset in time domain. The frequency domain signals shown in (3) are transformed the into the time domain signals by (2). Figure 2 shows the concept of the signal generation based on CI technique.

The CI method can collect the most of the powers of the signals into the short period of the time. Applying the window function to CI signal can suppress the signal reverberation.Figure3 shows concept of analysis using the CI pulse. In this method, the antennas are placed separately enough and excited together. The incident and arrived signals can be separated by using the temporal orthogonality ascribable to the propagation time.

These two methods are used jointly in the analysis, and can enable the simultaneous evaluation of the multi-antenna characteristics with a single simulation. Figure 4 shows the signal generated by using proposal method. The total length of signals is $1024\Delta t$ but the actual length of signals is about 60% of the symbol length. The signal 1 and signal 2 have similar waveforms, but they have orthogonal frequency components.

## 3. Numerical results

In this section, we analyzed scattering parameter of 2×2 biconical antennas. Figure 5 shows analysis model. The dimension of the analysis region is 4.91m × 0.8m × 0.305m. The length of biconical antennas is 0.105m and four antennas are arranged symmetrically in analysis region. The antennas, #1 and #4, use the signal 1, and the antennas, #2 and #4, use the signal 2 for excitations. The details of the FDTD analysis configurations are summarized in Table 1. For the conventional method, the Gaussian pulse is used and four individual analyses are performed in total. On the other hand, proposed method using OFDM pulse can analyze four antennas at once. Figure 6 shows the frequency characteristics of the scattering parameter. The results simulated by the conventional method are also indicated for a comparison. The results of proposed method shown in Fig. 6 (a) and (b) are in excellent agreement with that of the conventional method. This proves that the proposed method can work effectively for calculating the characteristics of two antennas simultaneously. On the other hand, the slight errors at low-frequency and high-frequency ranges are observed in Fig. 6 (c) and (d). Since the interference from other excitation is comparable to the desired signal in this case, the results are slightly interfered. Though the results of proposed method have discrete frequency points, the proposed method can analyze four antennas concurrently in contrast to the conventional method, that is, the proposed method can calculate antenna characteristics with 1/4 computation time of the conventional one. The degree of the error may depend on the inter-element spacing of antennas, yet the overall results obtained by the proposed method agree very well with that of the conventional method in this simulation.

## 4. Conclusion

The Fast FDTD analysis for multi-antenna systems has been proposed in this paper. This method exploits orthogonalities in both frequency and time domain. The simulated results of the proposed method agree well with the conventional method even with the computation time less than 1/4 of the conventional method. From these results shown in this paper, our proposed analysis method is effective in reducing computation time of the FDTD analysis of the multi-antenna systems.

## References


[1] G. J. Foschini and M. J. Gans, "Capacity when using diversity at transmit and receive sites and the Rayleigh-faded matrix channel is unknown at the transmitter," in Proc. WINLAB Workshop on Wireless Information Network, Mar. 1996.

[2] K. S. Yee, "Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations in Isotropic Media," IEEE Trans. Antennas and Propagation, vol.14, no.4, pp 302-307, 1966.

[3] K. Yokomakura, S. Sampei, H. Harada and N. Morinaga, "A Carrier Interferometry based Channel Estimation Technique for One-Cell Reuse MIMO-OFDM/TDMA Cellular Systems," Proc. IEEE VTC06-Spring, Melbourne, Australia, May 2006.

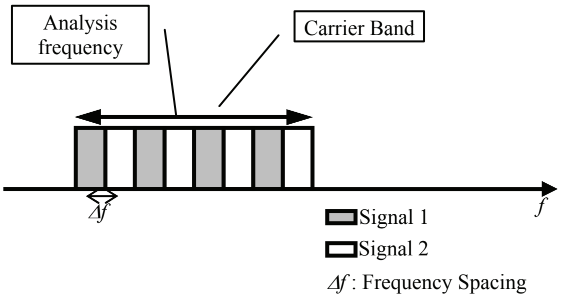



Fig1. Arrangement of signals

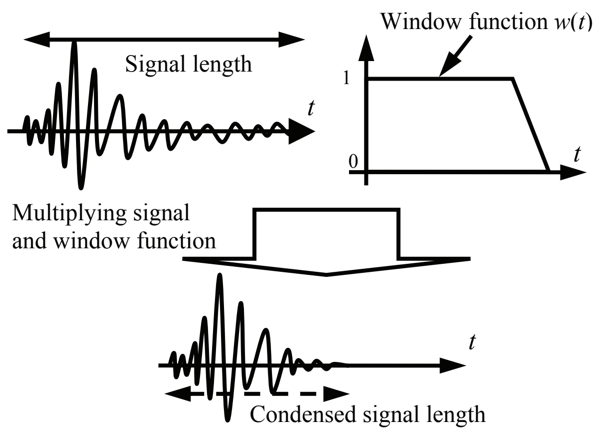



Fig2. Signal applied by window function

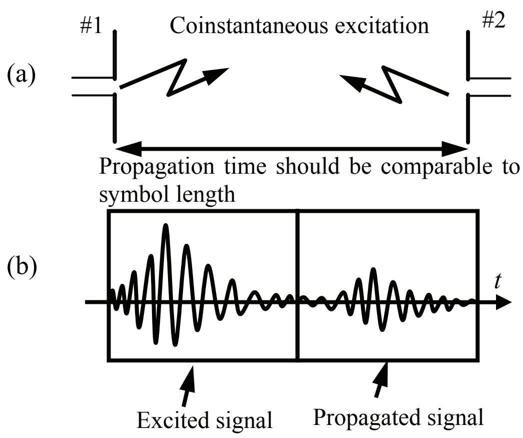
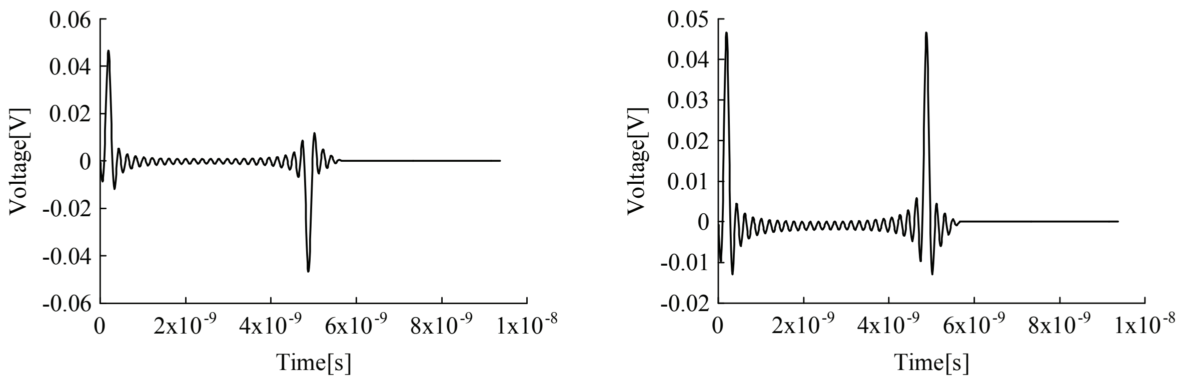



Fig3. Sketch of the antennas and signals in the analysis using CI method: (a) conceptual sketch of the antennas, (b) observed time domain signal.




(a) signal 1

(b) signal 2

Fig4. Generated signals

Table1. Parameters for analysis

| | Conventional | Proposed |
|---|---|---|
| Antenna | Biconical antenna | |
| Exciting pulse | Gaussian pulse | OFDM pulse |
| Feed model | delta-gap feed | |
| Cell size | $\Delta$=5mm | |
| Absorbing B.C. | First-order Mur | |
| Analysis frequency | 0~5GHz | |
| Time step | $9.1477\times10^{-12}$s | |
| Number of time step | $4096\times4$ | $3072\times1$ |

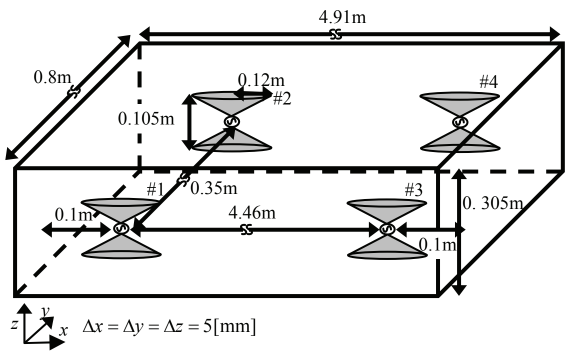
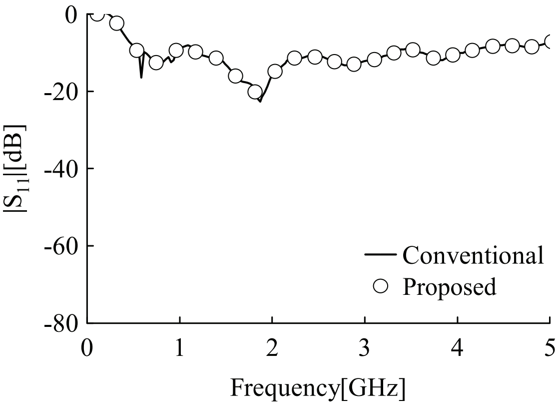
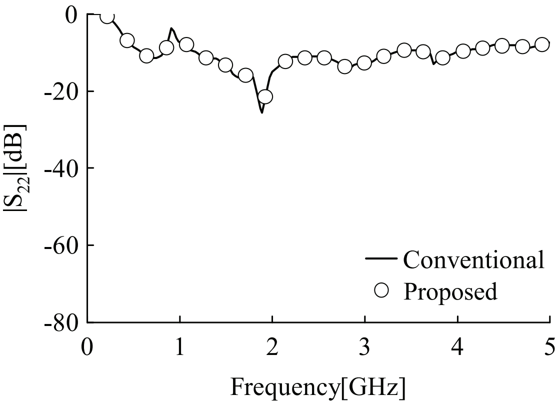


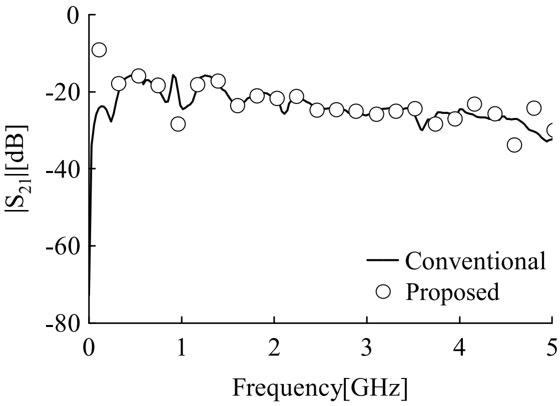

Fig5. Analysis model



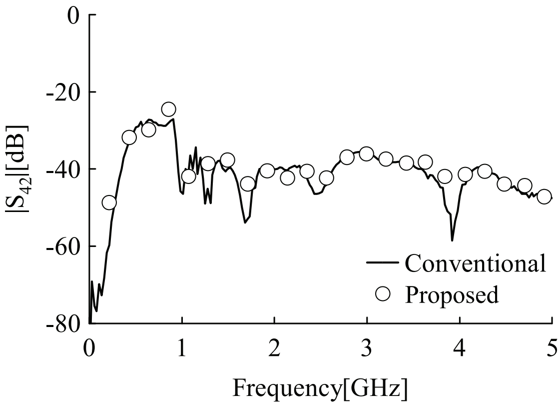

(a) $S_{11}$




(b) $S_{22}$




(c) $S_{21}$




(d) $S_{42}$

Fig6. Comparison of simulated scattering parameter