Dual Polarized Phased Array Antenna Simulation Using Optimized FDTD Method With PBC.

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***Abstract*—In this paper, the progress of developing an accurate and high performance time domain solver for dual polarization phased array antenna is presented. The simulation model is based on finite-difference time-domain method with periodic boundary conditions. The standard Yee model with the wrap around technique is implemented in this full wave electromagnetic solver. The measurement of 64-element array and simulations of 16-element and 64-element arrays are presented to verify the accuracy and performance of the solver. all arrays are populated with single layer dual polarization micro-strip antennas operating in C-band. The measured radiation pattern of 64-element array has been generated using embedded element patterns.**

I. Introduction

Many authors [1] - [6] had investigated the application of finite-difference time-domain (FDTD) simulation with periodic boundary condition (PBC) in electromagnetic structures such as frequency selective surfaces (FSS), electromagnetic band gap (EBG) structures, and phased array antennas. Simulation of infinite phased array antennas can be realized with various techniques. The implementation of PBC for phased array antennas which are periodic in the x and y directions can be categorized into two classes: 1) direct field methods and 2) field transformation methods [8].

Normal incidence case has low complexity and uses lower computational resources. It is capable of gaining wide band simulation results at the cost of losing capability to computing the case with steered beam. The sine-cosine method is using two separate grids to excite with sine and cosine based time depended functions. This method can simulate a array with steered beam at single frequency. Direct field methods need time advanced data for field variable calculation at Periodic boundaries, when the calculation is done for both wide band and beam steering case. In order to eliminate the time gradient across the grid, field transformation methods introduce new set of field variables in FDTD computation. Multispatial grid method and split field method are two techniques that can be categorized as field transformation methods. Even though, the field transformation methods can achieve simulation results in the case of beam steering over a wide frequency band, the methods get complex in order to perform with multi-grid algorithm and smaller time increments. The numerical model used in this study is based on a technique presented in [3] and [1] for periodic boundary condition (PBC) to simulate phased array antenna. The technique used in this work can be categorized into the direct field method class.

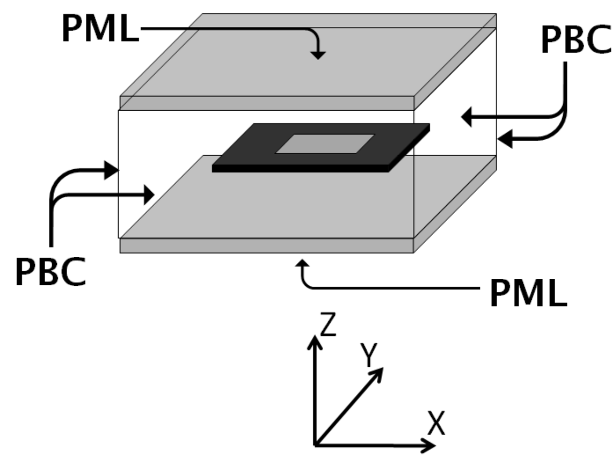

Fig. 1: The model of one unit cell in the phased Array.

II. Theory

FDTD model for unit cell of phased array can be depicted as in figure 1. The number of Yee cells [7] in x and y direction in the mesh will accommodate the only the patch antenna and there will not be any air gap. Yee cells at $x = 0$, $y = 0$, $x = x_p$, and $y = y_p$ are used to form the periodic boundaries. In the $+z$ and $-z$ directions, perfectly match layers (PML) are implemented with proper air gaps to truncate the problem space in finite region. This model can be used to solve the full wave electromagnetic simulation of the infinite phased array antenna [1]

The updating equations, updating coefficients, absorbing boundaries, radiating boundaries, voltage, and current probes/sources can be evaluated using standard FDTD updating equations [9] except at the locations of periodic boundaries. For example, the updating equation for E_y and E_z at the $x = 0$ and $x = x_p$ periodic boundaries can be evaluated in the time marching loop as in equation (1) - (5).

In equation (1) and (2), $E_y^{n+1}(x_p, y, z)$ and $E_z^{n+1}(x_p, y, z)$ are computed using standard FDTD updating equations, but $H_z^{n+\frac{1}{2}}(x_p, y, z)$ and $H_y^{n+\frac{1}{2}}(x_p, y, z)$ are replaced with $H_z^{n+\frac{1}{2}}(\Delta x, y, z)$ and $H_y^{n+\frac{1}{2}}(\Delta x, y, z)$ respectively.

$$\begin{aligned} E_y^{n+1}&(x_p, y, z) = \\ &C_{eye}(x_p, y, z)E_y^n(x_p, y, z) \\ &+C_{eyhx}(x_p, y, z)\left(H_x^{n+\frac{1}{2}}(x_p, y, z+1) - H_x^{n+\frac{1}{2}}(x_p, y, z)\right) \\ &-C_{eyhz}(x_p, y, z)\left(H_z^{n+\frac{1}{2}}(\Delta x, y, z) - H_z^{n+\frac{1}{2}}(x_p, y, z)\right) \end{aligned} \tag{1}$$

$$\begin{aligned} E_z^{n+1}&(x_p, y, z) = \\ &C_{eze}(x_p, y, z)E_z^n(x_p, y, z) \\ &+C_{ezhy}(x_p, y, z)\left(H_y^{n+\frac{1}{2}}(\Delta x, y, z) - H_y^{n+\frac{1}{2}}(x_p, y, z)\right) \\ &+C_{ezhx}(x_p, y, z)\left(H_x^{n+\frac{1}{2}}(x_p, y+1, z) - H_x^{n+\frac{1}{2}}(x_p, y, z)\right) \end{aligned} \tag{2}$$

Updating coefficients $C_{eye}(x_p, y, z)$ and $C_{eze}(x_p, y, z)$ depend on the material properties (ϵ and ρ^e) at (x_p, y, z) location and the time increment (Δt). Updating coefficients $C_{eyhx}(x_p, y, z)$, $C_{eyhz}(x_p, y, z)$, $C_{ezhy}(x_p, y, z)$, and $C_{ezhx}(x_p, y, z)$ depend on the material properties (ϵ and ρ^e), the lattice increment at (x_p, y, z) location, and the time increment (Δt) [9].

$$E_z^{n+1}(0, y, z) = E_z^{n+1}(x_p, y, z) \tag{3}$$

$$E_y^{n+1}(0, y, z) = E_y^{n+1}(x_p, y, z) \tag{4}$$

At the corners ($x = x_p$ and $y = y_p$) of the cell (the FDTD mesh of the patch antenna), E_z has to be updated using (5) equation.

$$\begin{aligned} E_z^{n+1}&(x_p, y_p, z) = \\ &C_{eze}(x_p, y_p, z)E_z^n(x_p, y_p, z) \\ &+C_{ezhy}(x_p, y_p, z)\left(H_y^{n+\frac{1}{2}}(\Delta x, y_p, z) - H_y^{n+\frac{1}{2}}(x_p, y_p, z)\right) \\ &+C_{ezhx}(x_p, y_p, z)\left(H_x^{n+\frac{1}{2}}(x_p, \Delta y, z) - H_x^{n+\frac{1}{2}}(x_p, y_p, z)\right) \end{aligned} \tag{5}$$

The updating equation for E_x and E_z at the $y = 0$ and $y = y_p$ periodic boundaries can be adapted in the same way from the standard FDTD updating equations.

Time marching loop of the FDTD simulation can be implemented as in algorithm 1, which has proper number of time steps, T. The Gaussian pulse excitation is used to excite H channel or V channel. The normalized excitation function can be given as $g(t) = e^{-t^2/\tau^2}$, where $\tau = \sqrt{2.3}/(\pi f_c) \cong n_c \Delta s_{max}/2c$, n_c is the number of cells per wavelength, $t \in 0, \Delta t, 2\Delta t, ..., T\Delta t$, and $\Delta s_{max} = \Delta x = \Delta y = \Delta z$ [8]. Voltage and current are recorded at each ports in order to calculate the s parameters: S_{hh}, S_{vv}, S_{hv}, and S_{vh}.

Algorithm 1 FDTD Time Marching Loop

for $t = [0, \Delta t, 2\Delta t, ..., T\Delta t]$ **do**
  {Update magnetic fields}H_x, H_y, H_z
  {Update magnetic fields in PML}
  {Capture Currents}
  {Update electric fields}E_x, E_y, E_z
  {Update electric fields in PML}
  {Update fields in PBC} E_y^{n+1} and E_z^{n+1} at (x_p, y, z), E_z^{n+1} at (x_p, y_p, z), E_z^{n+1}, E_y^{n+1} at $(0, y, z)$, E_x^{n+1},E_z^{n+1} at (x, y_p, z), E_z^{n+1}, E_y^{n+1} at $(x, 0, z)$.
  {Update sources}
  {Capture voltages}
  {Calculate J and M for radiation}
end for

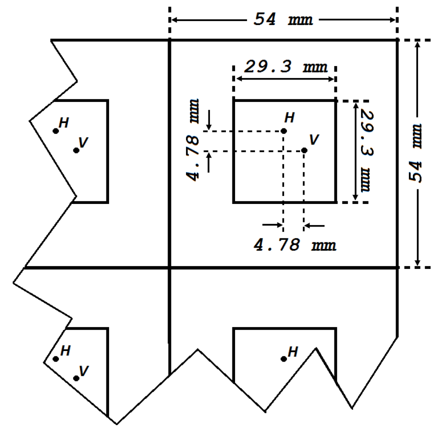

Fig. 2: Specifications of array antenna.

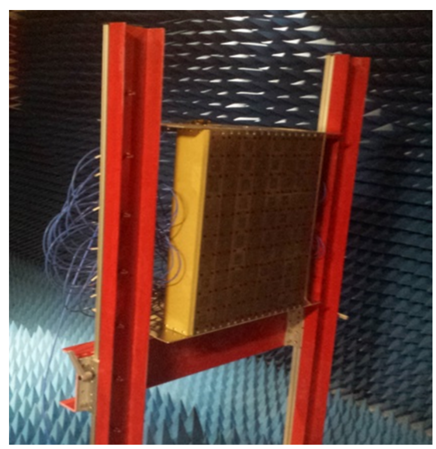

Fig. 3: 64 elements array in NF chamber.

III. Simulation Results and Measurements

Simulations and measurements were done for array of simple micro strip patch antennas fabricated on RT/duroid®5880 with 1.575mm thickness and 1/2 oz copper cladding. The specification of the patch antenna is depicted in figure 2. This creates a C-band micro-strip patch antenna with 1.3741% bandwidth for $VSWR \leq 2$. These elements are used to create

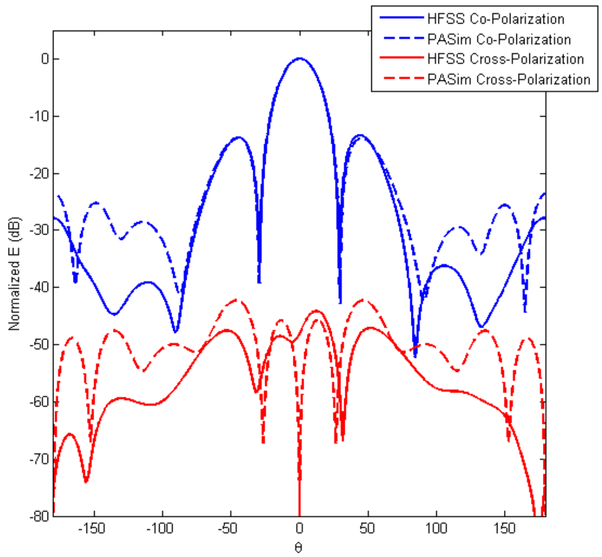

Fig. 4: principal plane cut of 4x4 array simulation by HFSS and PASim Version 1.

4×4 and 8×8 planar array antenna.

A. Simulation

A computer with Intel®Core i7-4770K CPU @ 3.50 GHz and 32GB memory (RAM) is used to perform the simulation with HFSS and PASim. The HFSS simulations of 4×4 array is obtained to verify the results from PASim. The figure 4 shows a principal cut (horizontal plane) of radiation patterns for HFSS and PASim simulations.The figure 5 shows the 3D HFSS and PASim simulations with $U = \sin\theta + \cos\phi$ and $V = \sin\theta + \sin\phi$ coordinates. There is a good agreement between the 4×4 simulation results from HFSS and PASim. The figure 6 shows the simulation and measurements of 8×8 array for the comparison of simulation data with measurements.

The implementation was done using MATLAB, C, and Java. GNU GCC compiler is used to build and optimized the C code. JDK(SE) 8 is used to compile Java program. The C program can be ported to any environment where the ANSI C compliant compiler is available. PASim is relatively small program, which has 3100 lines in C code and 4300 lines in Java code.

B. Measurements

Near-field range measurement of 8×8 array is used to validate the FDTD simulation results. 64-element, dual polarized phased array needs independent phase shift and attenuation control for beam steering and calibration. Since only the broadside patterns are measured and simulated, calibration is the only concern. Then Transmitter/Receiver (TR) modules with phase sifters and attenuates are needed for each channel of the array. In order to avoid the need of 128 TR modules, embedded element patterns of each element are used to generate the measured array pattern. Measurements of embedded element patterns are taken using the near-field range at OU-RIL (figure 3) and the generation of the array patterns with proper calibrations are performed using a MATLAB program.

	A Patch Antenna (Seconds)	4×4 Array of Patches (Seconds)	8×8 Array of Patches (Seconds)
HFSS	277	4016	NP
PASim V1	22468	32684	42431
PASim V2	187	272*	353*
PASim V3	248	361*	468*

TABLE I: Elapsed time and anticipated elapsed time (*) for each simulation. PASim V1,PASim V2, and PASim V3 are written in MATLAB, C, abd Java respectively. NP stands for NOT POSSIBLE

If a single dual polarized patch antenna simulation with T time steps is consuming v CPU time with FDTD algorithm, Simulation of $m \times n$ dual polarization phased array antenna consumes mnv CPU time with the same FDTD algorithm (without PBC). According to the benchmarks given in Table I, the same array antenna was simulated with CPU time $\ll mnv$ and comparable with v.

IV. Conclusion

Full wave electromagnetic simulation of phased array antenna can be fulfilled with commercially available software running on high performance and expensive computer clusters. But those EM solvers are neither customized nor optimized for phased array applications. A fast, accurate, and flexible pattern prediction tool for phased array antenna is indispensable in further research in the field. The benchmarks presented indicate that It is clearly faster than commercially available EM solver and it has a room for improvement by extending the computation to Graphic Processor Unit (GPU). The current version is only for broadside pattern prediction of an array of micro strip patch antenna in a rectangular lattice. Implementing FDTD-PBC technique for cylindrical phased array antenna is the next step in this work. Implementation of the Array scanning method will be an extension to the solver, which will enable it for array pattern prediction with non-periodic excitation. The FDTD model for cylindrical coordinate system will be implemented for dual polarized cylindrical phased array antenna.

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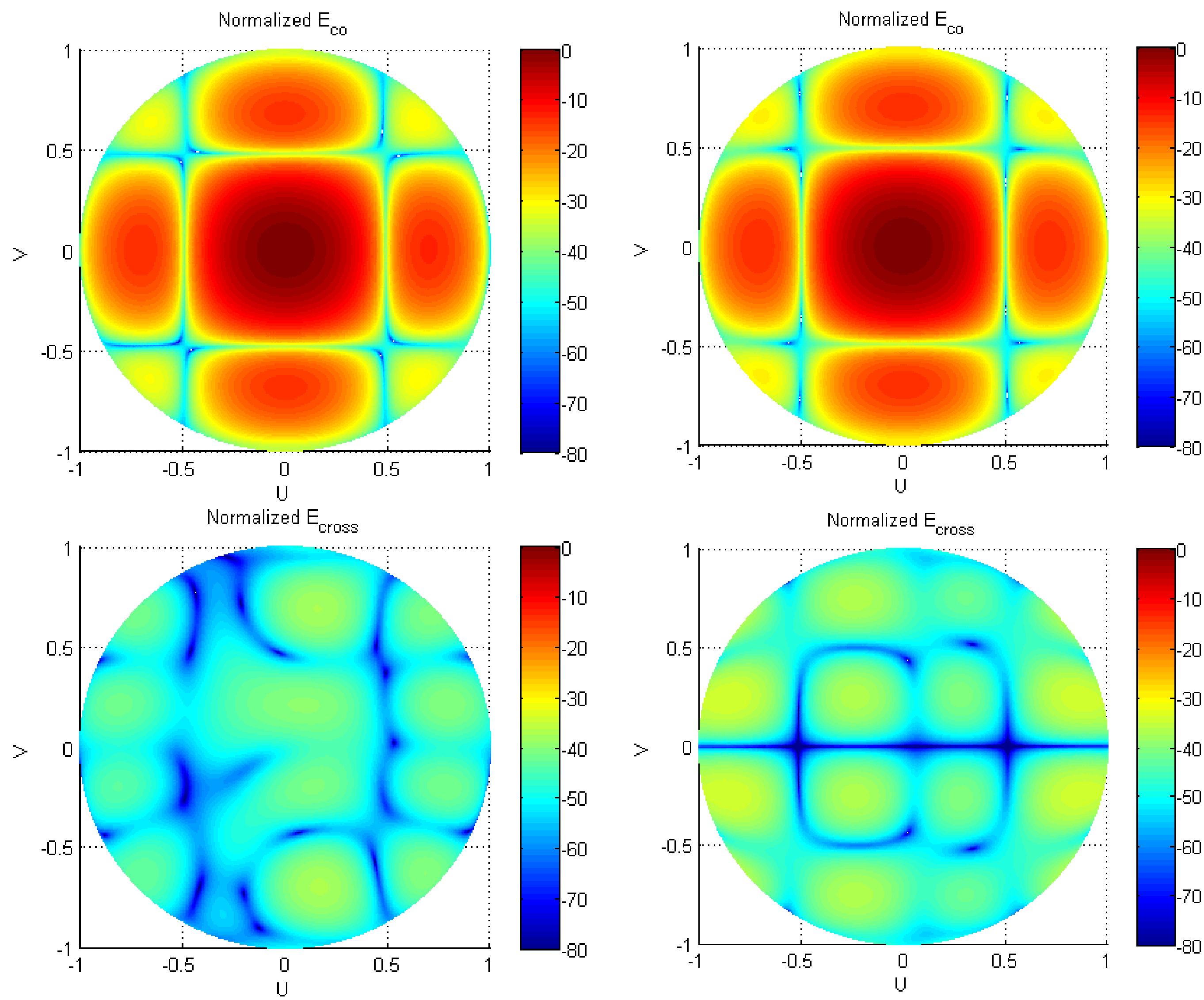

(a) 4×4 Array Simulation by HFSS

(b) 4×4 Array Simulation by PASim

Fig. 5: 4×4 Array Simulation using PASim Version 1 and HFSS

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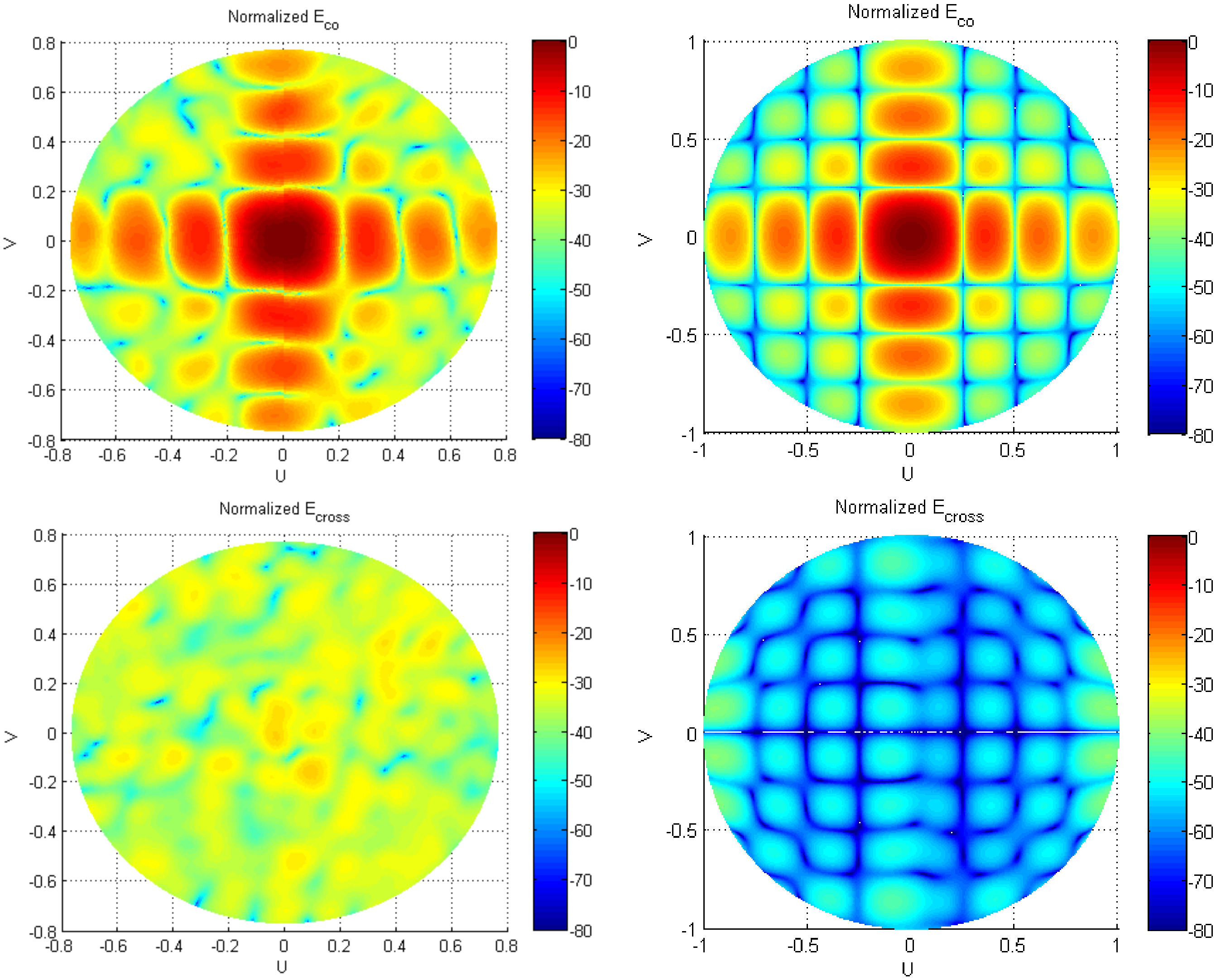

(a) 8×8 Array Measurements

(b) 8×8 Array Simulation by PASim

Fig. 6: 8×8 Array Simulation(PASim Version 1) and Measurement (Near-Field)