Analysis and Design of a Low Sidelobe Level and Wide-band Aperture Coupled Microstrip Antenna Array Using FDTD

P. Loghmannia, M. Kamyab
Department of Electrical Engineering,
K. N. Toosi University of Technology
Tehran, Iran
Loghmannia@gmail.com

M. R. Nickpay
Department of Electrical Engineering,
Islamic Azad University, Shahre_e_Rey Branch
Tehran, Iran
MR_Nickpay@yahoo.com

M. Ranjbar Nikkhah, J. Rashed-Mohassel
Center of Excellence on Applied Electromagnetic systems,
School of ECE, University of Tehran
Tehran, Iran
Ranjbar.Nikkhah@alumni.ut.ac.ir

Abstract—This paper presents a low sidelobe level (SLL) and wide-band 8×8 aperture coupled microstrip antenna array. For rigorous analysis of element characteristics, a single aperture coupled microstrip antenna is analyzed using finite difference time domain (FDTD). Consideration imperfect ground planes in antenna and the finite structure, one finds that FDTD gives more precise results for element designing. To achieve improvement in SLL, Dolf-Chebyshev power distribution is used in the antenna design. Measured results demonstrate that the impedance bandwidth of the proposed antenna is 12% at the center frequency of 5 GHz and average E-plane and H-plane SLL are less than -23 dB. The average gain of the antenna array is 22.5 dB.

I. INTRODUCTION

Microstrip antennas, due to interesting characteristics such as low weight, low-profile and easy manufacturing are being introduced as strong candidates for radar applications [1-3].

Designing a microstrip antenna array with a low SLL is difficult due to mutual coupling among radiating elements and surface wave effect. To overcome this difficulty, aperture coupled microstrip antenna array with a feed network on separate substrate are best candidates [4, 5]. The aperture coupled microstrip antenna was introduced by Pozar in 1985 [6]. In the basic geometry, a patch is printed on a low dielectric constant substrate and is excited by an aperture in the ground plane which in turn is excited by a microstrip line on a separate substrate covering the other side of the ground plane [7, 8]. This structure decreases the surface wave effect on microstrip antennas and leads to reach a low SLL in array designing.

Many attempts have been made to reduce the SLL in microstrip antenna arrays. However, most of the works are either on impedance bandwidth enhancement or improving the SLL of the antenna array, but not both.

This paper presents a corporate-fed 8×8 aperture-coupled microstrip antenna array operating at 4.7-5.3 GHz. A planar aperture coupled microstrip antenna array is introduced leading to a wide impedance bandwidth along with low SLL. For rigorous analysis of element characteristics, a single aperture coupled microstrip antenna is analyzed using FDTD [9]. The uniaxial perfect matched layers (UPML) are used as absorbing boundary conditions [9]. To increase F/B ratio, the reflector surface is placed in back of the aperture coupled antenna.

II. SINGLE ELEMENT APERTURE COUPLED MICROSTRIP ANTENNA

Fig. 1 shows the geometry of a single-element, aperture-coupled microstrip antenna. The microstrip antenna elements are printed on the upper antenna substrate, whereas the feed network is printed on the lower feed substrate. Electrically small, rectangular apertures in the ground plane couple the antenna elements to the feed network. To achieve more rigorous analysis of the aperture coupled element, the FDTD method is used and house code FDTD is developed in MATLAB. Rigorous analysis of the element is essential for array designing. The space steps used in FDTD simulation are \( \Delta x = \Delta y = 0.38 \text{ mm}, \Delta z = 0.254 \text{ mm} \). Six layers UPML absorbing boundary condition are used for termination and four grids between the feed line and UPML are required for a steady solution. The size of the computational domain is 125\( \Delta x \times 125\Delta y \times 57\Delta z \) and the simulation is performed in
5000 time steps. A gaussian pulse type of voltage excitation is used for 50 ohm microstrip input excitation. The reflection coefficient \((S_{11})\) of aperture coupled antenna is defined as 
\[ S_{11}(k\Omega) = \frac{V_{\text{ref}}(k\Omega)}{V_{\text{inc}}(k\Omega)} \]
where \(\Omega = \frac{2\pi}{N\Delta t}\) and \(N\) is the total number of time steps. \(V_{\text{ref}}(k\Omega)\) and \(V_{\text{inc}}(k\Omega)\) are the reflected and incident waves, respectively, at the input. More information about 3D-FDTD simulation is explained in [9].

Using Ampere’s circuital law, i.e., the line integral of magnetic field around the electric field source position, the current through the electric field source is given by [10]:
\[
I_s^{n-1} = \left[ H_x^{n-1}(i_s, j_s - 1, k_s) - H_x^{n-1}(i_s, j_s, k_s) \right] \Delta x \\
+ \left[ H_y^{n-1}(i_s, j_s, k_s) - H_y^{n-1}(i_s - 1, j_s, k_s) \right] \Delta y \\
\]

Using Ohm’s law, the electric source field is [10]:
\[
E_s^x(i_s, j_s, k_s) = \frac{V_s(n\Delta t)}{\Delta z} + I_s^{n-1} R_s / \Delta z \\
\]  

(2)

The simulated reflection coefficient of the aperture coupled microstrip antenna element is shown in Fig. 2. Also, results are verified by HFSS.

III. THE 8×8 MICROSTRIP ANTENNA ARRAY DESIGN

With the design of the single element completed, the 8×8 element array was then designed using a corporate-fed network. The element spacing is 37 mm in x directions and 40 mm in y direction. To achieve improvement in SLL in the two principal planes, Dolph-Chebyshev distribution is used for an appropriate power distribution in x and y direction. To properly designing and checking the Chebyshev distribution factor, the 4×4 aperture coupled microstrip antenna feed network is simulated using Agilent Advanced Design System (ADS). For simulation, the radiating elements are replaced by a 50 ohm termination ports in this simulator. Fig. 3 is a comparison between ADS power distribution and ideal Chebyshev distribution factor. It should be mentioned that the proposed 8×8 microstrip antenna array is full-wave simulated by using of CST Microwave Studio software. A C-band aperture coupled with 8×8 elements is shown in Fig. 4.
IV. RESULTS AND DISCUSSION

In order to validate the analysis, the optimized antenna array was fabricated and measured. The feed network of the array is fabricated on 31 mil Rogers RT 5870/Duriod ($\varepsilon_r = 2.33$, tan $\delta = 0.0012$). Fig. 5 (a) and Fig. 5 (b) are photographs of 8×8 aperture coupled microstrip antenna array fabricated. The return loss of the array was measured using a vector network analyzer. Fig. 6 shows the simulated and measured VSWR of the antenna. Measured results demonstrate that the designed antenna array has a wide bandwidth from 4.7 to 5.3 GHz with VSWR less than 2, covering the frequency range of more than 12%. Measurement and simulation results of radiation patterns at 4.8 GHz, 5.1 GHz, and 5.4 GHz are shown in Fig. 7, Fig. 8, and Fig. 9, respectively.

The proposed antenna has a stable radiation pattern over the entire impedance bandwidth and the average E-plane and H-plane SLL are less than -23 dB. It should be noted that simultaneous increase in impedance bandwidth and improvement in SLL only can be obtained by rigorous analysis of aperture coupled microstrip antenna elements and proper design of corporate-fed networks. It is interesting to point out that measurement results demonstrate that E-plane and H-plane radiation patterns are relatively stable in the entire operating band and SLL does not change significantly with frequency.

The measurement results of the 8×8 aperture coupled microstrip antenna array is illustrated in Table I.

V. CONCLUSION

A low SLL 8×8 aperture coupled microstrip antenna array has been designed, fabricated and measured. For an accurate design, elements of the array are rigorously analyzed by FDTD. Six layers of UPML absorbing boundary condition are used for termination. To achieve further improvement in SLL in the two principal planes, Dolph-Chebyshev distribution is used to appropriate power distribution in x and y directions.
Fig. 9. Full-wave simulated and measured E-plane and H-plane radiation patterns of the low SLL aperture coupled microstrip antenna array at 5.4 GHz.

Table I. Summary of the performance of the antenna array.

<table>
<thead>
<tr>
<th>Freq. (GHz)</th>
<th>Gain (dB)</th>
<th>SLL (dB)</th>
<th>HPBW (deg.)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>H-plane</td>
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<td></td>
<td></td>
<td>E-plane</td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td>21.53</td>
<td>-24.65</td>
<td>13.1</td>
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<tr>
<td>4.9</td>
<td>22.81</td>
<td>-22.04</td>
<td>12.6</td>
</tr>
<tr>
<td>5</td>
<td>23.06</td>
<td>-20.05</td>
<td>12.5</td>
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<tr>
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<td>-21.19</td>
<td>10.7</td>
</tr>
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REFERENCES


