Radiation Pattern Investigation of $n$ Element Microstrip Patch Antenna Array

S. M. Mahfuz Alam, Md. Anwarul Abedin, Utpal Kumar Das and Md. Arifur Rahman

Dept. of Electrical & Electronic Engg, Dhaka University of Engineering & Technology, Gazipur, Bangladesh

E-mail: mahfuz@duet.ac.bd

ABSTRACT

Microstrip patch antenna is widely used in aircraft, spacecraft and other application for small size, low cost and light weight. The fringing field created on patch antenna depends on the dielectric constant of patch element. The desired directivity of the antenna can be achieved by the proper design of the patch antenna array. In this paper the generalized equations of electric and magnetic field for $n$ element patch antenna array are analyzed and effect of dielectric constant of patch element on fringing field are investigated. The results from the derived equations are compared with PCCAD 5.0 software simulation results and results from experiments. The comparison shows that the derived equations can be satisfactorily used for any $n$ element patch antenna array and any phase displacement between two patch elements.

1. INTRODUCTION

In high-performance aircraft, spacecraft, satellite and missile application, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, low profile antennas may be required. Presently there are many other government and commercial applications, such as mobile radio and wireless communications that have similar specifications. To meet this requirements microstrip patch antennas have been studied and researched extensively over the past many years because of its low profile structure, light weight, and low cost in fabrication. They are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. Some of the principal advantages of this type of antennas are low profile in nature, conformability to planar and non planar surfaces, low fabrication costs and compatibility [1].

Antenna array is used to improve performances such as gain, directivity etc. In the case of patch antenna array, it can be used to scan the beam of an antenna system and perform various other functions which would be difficult with any single element. Research has been done on radiation pattern calculation of patch antenna array by improved induced element pattern method (IIEMP) which transforms the large array calculation problem into two small array problems [2]. In this paper, a generalized equations of both electric and magnetic field for an $n$ element patch antenna array are derived considering the phase shift between patch elements without calculating the radiation pattern by transforming large array into two small array and this equation is valid for any number of array element operating at any frequency.

2. BASIC CHARACTERISTICS OF MICROSTRIP PATCH ANTENNA

Microstrip patch antenna consists of very thin metallic strip (patch) placed a fraction wavelength above a ground plane. The patch is so designed that its pattern maximum is normal to the patch. For a rectangular patch, the length $L$ of the element is usually $\lambda/3 < L < \lambda/2$, where $\lambda$ is wavelength. The patch and the ground plane are separated by a dielectric substrate of height $h$ as shown in Fig. 1.

![Fig.1: Microstrip patch antenna](image_url)

There are numerous substrates that can be used for the design of microstrip antennas and their dielectric constants are usually in the range of $2.2 < \varepsilon_r < 12$ [1]. The microstrip line feed is used to feed microstrip patch antenna. The transmission line model of microstrip patch antenna is shown in Fig. 2.
The field distribution is identical to that of a uniform transmission line of characteristic impedance \( Z_0 \) and the phase voltage \( V_{ph} \). The fringing fields associated with edges “01” and “23” of the patch are taken into account by \( Z_0 \) and \( V_{ph} \). The fringing fields associated with edges “02” and “13” are represented by lumped admittances \( Y_e \) (edge conductance) connected at the two ends [3].

Edge admittance is given by,

\[
Y_e = G_e + jB_e
\]  

Where \( B_e = \omega C_e \) and \( G_e, B_e, C_e \) are the edge conductance, edge susceptance and edge capacitance respectively.

The edge conductance accounts for the power radiated at the radiating edges (or open ends). The edge susceptance accounts for the fringing electric field (and hence the fringing capacitance at the open end) [1].

The edge capacitance, \( C_e \) is represented in terms of an equivalent line length extension as shown in Fig. 3.

The transmission-line model gives good physical insight. Basically the transmission line model represents the microstrip patch antenna by two slots, separated by a low impedance (\( Z_0 \)) transmission line of length \( L \) [3].

![Fig. 2: Transmission line model](image)

![Fig. 3: Transmission Line Model, Edge Capacitance](image)

From the theory of open ended transmission line, the edge susceptance of microstrip patch can be expressed as [3]

\[
B_e = Y_0 \tan(\beta \Delta l) \tag{2}
\]

Where \( Y_0, \beta \) and \( \Delta l \) are the characteristic admittance, phase constant and incremental length of the patch due to fringing effect respectively.

If \( \beta \Delta l < 1 \) or \( \Delta l < \lambda \)

Then the edge capacitance can be approximated as

\[
C_e = \frac{\Delta l}{v_p Z_0} \tag{3}
\]

Where, \( v_p = \frac{\omega}{\beta} \) and \( v_p \) is the phase velocity and \( Z_0 \) is the characteristic impedance.

Because of the fringing effect, the effective length of the patch of the microstrip antenna looks greater than its physical dimension as shown in Fig. 2. The dimension of the patch along its length have been extended on each end side by a distance \( \Delta l \), which is a function of dielectric constant, \( \varepsilon_r \) and width to height ration (w/h) and can be expressed as [1]

Normalized length, \(
\frac{\Delta l}{h} = 0.412 \left( \frac{(\varepsilon_r + 0.3)(w + 0.264)}{(\varepsilon_r - 0.258)(h - 0.8)} \right) \tag{4}
\)

The Normalized Length vs. Normalized Width Curve is drawn in Fig. 4 for various values of dielectric constant, \( \varepsilon_r \).

![Fig. 4: Normalized length vs. normalized width](image)
normalized length increases with the increase in normalized width.

3. EXPRESSIONS OF E-FIELD AND H-FIELD OF PATCH ANTENNA

Fig. 5: Patch antenna array

Fig. 5 shows a rectangular patch antenna array of n-elements separated from each other by a distance d. The magnetic field intensity and electric field intensity of a single element patch antenna can be expressed as

\[
E_\Phi = \frac{jk_0 l_n h w}{4\pi r} e^{-j k_0 r} \sin \left( \frac{k_0 w \cos \theta}{2} \right) \frac{\sin \theta}{k_0 w \cos \frac{\theta}{2}}
\]

(5)

\[
H_\theta = \frac{jk_0 l_n h w}{4\pi r \sin \theta} e^{-j k_0 r} \sin \left( \frac{k_0 w \cos \theta}{2} \right) \frac{\sin \theta}{k_0 w \cos \frac{\theta}{2}}
\]

(6)

Where, \( k_0 \) is the phase constant = \( 2\pi/\lambda \) and \( \eta \) is the intrinsic impedance.

For n element patch array the electric field intensity can be expressed as:

Assuming, \( \theta_1 = \theta_2 = \theta \)

\[
E_\Phi = A \left[ e^{-j k_0 r_1} + \frac{e^{-j (k_0 r_1 - \Phi)}}{r_1} + \frac{e^{-j (k_0 r_2 - 2\Phi)}}{r_2} + \cdots \right] \frac{\sin \theta}{k_0 w \cos \frac{\theta}{2}}
\]

(7)

where,

\[
A = \frac{jk_0 l_n h w}{4\pi} \sin \left( \frac{k_0 w \cos \theta}{2} \right) \frac{\sin \theta}{k_0 w \cos \frac{\theta}{2}}
\]

Finally the generalized equation becomes

\[
E_\Phi = A \frac{e^{-j k_0 r}}{r} e^{j (n-1)\psi/2} \sin \left( \frac{\sin \theta}{\sin \frac{\theta}{2}} \right)
\]

(8)

where, \( \psi = k_0 d \sin \theta \sin \Phi + P \)

(9)

P is the total phase shift between two patch elements.

\[
H_\theta = \frac{E_\Phi}{\eta} = (A \frac{e^{-j k_0 r}}{r} e^{j (n-1)\psi/2} \sin \left( \frac{\sin \theta}{\sin \frac{\theta}{2}} \right)) \eta
\]

(10)

Finally the electric field equation for two element array can be written as

\[
E_\Phi = A \frac{e^{-j k_0 r}}{r} e^{j \psi/2} \cos \left( \frac{1}{2} \left( k_0 d \sin \theta \sin \Phi + P \right) \right)
\]

(11)

And the magnetic field equation becomes

\[
H_\theta = (A \frac{e^{-j k_0 r}}{r} e^{j \psi/2} \cos \left( \frac{1}{2} \left( k_0 d \sin \theta \sin \Phi + P \right) \right)) / \eta
\]

(12)

4. RESULT AND DISCUSSION

The electric and magnetic field radiation patterns for single element patch antenna operating at 10 GHz are plotted using MATLAB program in Fig. 6 and Fig. 7 respectively. These results are compared with the experimental results (Fig. 8 and Fig. 9). Fig. 10 shows PCCAD 5.0 software result.
From the above figures, it is clear that the radiation patterns satisfy both the experimental and simulation results.
Fig. 14: H field radiation pattern for two element patch antenna array (PCCAD 5.0)

Fig. 15: E field radiation pattern for $P=\pi/2$

Fig. 16: H field radiation pattern for $P=\pi/2$

Fig. 17: E field radiation pattern for $P=\pi$

Fig. 18: H field radiation pattern for $P=\pi$

Fig. 15, Fig. 16, Fig. 17 and Fig. 18 show the radiation pattern for different values of $P$. So, the proposed equations can be applied successfully for any difference in phase of excitation as well.

5. CONCLUSION

In this paper, the effect of dielectric constant of patch element on fringing field is analyzed. Generalized equations of electric and magnetic field radiation pattern of $n$ element patch array operating at any frequency are proposed. The radiation patterns of both single element and two element patch array, operating at 10 GHz are compared with the experimental results and PCCAD 5.0 software simulation results. The results from the proposed equations are identical to the experimental results and the PCCAD 5.0 software simulation results. The radiation patterns have been observed for different phase shift in excitation between two patch elements. All results
indicate that the proposed generalized equations can be used for any number of patch antenna array operating at any frequency.

REFERENCES


