Microstrip array antenna with and without airgap in plasma environment

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The present paper explores the important characteristics of an array of 4×4-element planar array of circular patch microstrip antenna (CPMA) designed on RT-duroid substrate ($\varepsilon_r = 2.32$) at 1.155 GHz (L-band) for on-board applications in mobile communication through satellite. An airgap is introduced in between the dielectric and the ground plane which improves the bandwidth and maintain the gain of the antenna geometry. This antenna geometry is studied in presence of plasma environment and the effect of generation of electroacoustic waves on the radiation characteristics of the given geometry is determined. For this, a well established linearized hydrodynamic theory and vector wave function technique is used to derive the expression for the field pattern and radiated power by the antenna. The important antenna parameters like radiation conductance, efficiency, directive gain and bandwidth along with radiation patterns are computed and plotted for both plasma as well as for the free space.

1 Introduction

Microstrip antennas have been applied to a variety of systems such as high-flying aeroplanes, satellites, microsatellites and missiles due to their unique properties and easy fabrication techniques. The present paper deals with an analysis of 4×4-element circular patch planar array geometry as an efficient and compact light-weight antenna system for mobile communication through satellite. An airgap is introduced between the ground plane and the substrate of the array geometry in order to enhance the bandwidth, which has considerable importance in many applications.

When mounted on-board space vehicles and mobile satellite systems, these antennas encounter an ionized plasma medium during their travel and re-entry in space, which modifies the overall radiation performance of the radiator. Thus, the objective of the present study is to observe the effect of plasma on radiation properties of geometry under investigation at 1.155 GHz (L-band) of the microwave frequency range.

2 Theory of airgap

In many applications such as in communication intelligence, electronic warfare and radar, wide-band antennas are required. But normal microstrip antennas have disadvantage of narrow bandwidth. The most straightforward way to improve the bandwidth is to increase the separation between the patch and the ground plane by using the thicker substrate. However, it results in the lowering of gain due to dielectric height. Here, an airgap between the substrate and the ground plane has been used. This will not only increase the bandwidth but also maintain the gain. However, an introduction of an airgap rises some disadvantages like poor mechanical properties due to low density of air.

The geometry and airgap configuration of 4×4-element circular patch microstrip antenna are shown in Figs 1 and 2, respectively. It consists of two-layer cavity—the upper layer is the dielectric substrate of thickness $H$ with relative permittivity $\varepsilon_r$ and the lower layer is an airgap of thickness $H_A$ with relative...
permittivity equal to one. These two combined layers together form a single layer structure of total height 

\[ H_T = H + H_A \] 

and an equivalent permittivity, \( \varepsilon_{eq} \), given as

\[ \varepsilon_{eq} = \frac{\varepsilon_r (H + H_A)}{(H + H_A \varepsilon_r)} \] \hspace{2cm} (1)

From Eq. (1), it is obvious that a decrease in the dynamic permittivity (increase of the airgap) results in an upward shift in the resonant frequency.

The input parameters for the present array geometry are taken as follows: thickness of dielectric substrate \( H = 1.59 \text{ mm} \), airgap thickness \( H_A = 1 \text{ mm} \), substrate permittivity \( \varepsilon_r = 2.32 \) (\( \tan \delta = 0.001 \)) and radius of each element \( a = 50 \text{ mm} \). The array elements which are positioned along x-axis are separated by a distance \( d_x \), and those along y-direction are separated by a distance \( d_y \).

The total field of the present array antenna can be expressed by the fields of a single element positioned at the origin multiplied by a factor, which is referred as the array factor. Since the entire array is taken as uniform, the normalized form of array factor \( (AF) \) may be written as

\[ AF = \frac{1}{16} \times \frac{\sin[2(\beta d_x \sin \theta \cos \phi + \beta_\phi)]}{\sin[0.5(\beta d_x \sin \theta \cos \phi + \beta_\phi)]} \times \frac{\sin[2(\beta d_y \sin \theta \cos \phi + \beta_y)]}{\sin[0.5(\beta d_y \sin \theta \cos \phi + \beta_y)]} \] \hspace{2cm} (2)

The subscripts for \( \beta \) are taken as ‘e’ or ‘p’ as the expressions are obtained for electromagnetic and electroacoustic (plasma) mode, respectively.

On neglecting the coupling between the elements, the expressions for far-zone fields, radiation conductance, efficiency, directive gain and bandwidth for 4×4-element planar array of circular patch microstrip antenna are obtained using linearized hydrodynamic theory and vector wave function technique.

The total field patterns are computed for both with and without airgap taking the above-described input parameters along with the element separation \( d_x = d_y = \lambda_c/2 \) and phase shift \( \beta_x = \beta_y = \pi/2 \). The calculated results are plotted for \( A = 0.5 \) (i.e. for plasma) and \( A = 1.0 \) (i.e. for free space) in two different planes, viz. \( \phi = 0 \) and \( \phi = \pi/2 \) plane, respectively, with and without airgap in Figs 3-6. The pattern characteristics of the present array are given in Table 1.

The plasma mode fields are computed for \( A = 0.5 \) in \( \phi = \pi/2 \) plane at 0.5° increments of \( \theta \) in a small
Table 1—Measured values of pattern characteristics of given array geometry

<table>
<thead>
<tr>
<th>Pattern characteristics</th>
<th>( \phi = 0 ) plane</th>
<th>( \phi = \pi/2 ) plane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( A = 1 )</td>
<td>( A = 0.5 )</td>
</tr>
<tr>
<td></td>
<td>( H_A = 0 ) ( **H_A = 1 \text{mm} )</td>
<td>( H_A = 0 ) ( **H_A = 1 \text{mm} )</td>
</tr>
<tr>
<td>Half power beam width</td>
<td>–12° 8° 30° 30°</td>
<td>–15° 15° 25° 27°</td>
</tr>
<tr>
<td>Direction of max. rad.</td>
<td>14° 11° 30° 30°</td>
<td>10° 12° 22° 22°</td>
</tr>
<tr>
<td>First null beamwidth</td>
<td>30° 30° 80° 80°</td>
<td>30° 30° 70° 70°</td>
</tr>
<tr>
<td>Side lobe level (dB)</td>
<td>–3.0 –5.0 – – –</td>
<td>–4.8 –5.1 – – –</td>
</tr>
</tbody>
</table>

Note: * Without airgap
** With airgap

interval of 10°. Assuming that there is no lobe narrower than 0.5°, the normalized values of the P-mode field patterns are plotted between \( \theta \) values of 50° and 60° for both with and without airgap in Fig. 7.

The computed values of radiation conductance for the EM mode (\( G_c \)) as well as for the plasma mode

![Fig. 3](image1.png)  
![Fig. 4](image2.png)  
![Fig. 5](image3.png)  

**Fig. 3**—Variation of radiation \( R(\theta, \phi) \) for \( A=1.0 \) (free space) and \( A=0.5 \) (plasma) for 4x4-element planar array of circular patch microstrip antenna without airgap in \( \phi=0 \) plane and for \( \beta=\pi/2 \)

**Fig. 4**—Variation of radiation \( R(\theta, \phi) \) for \( A=1.0 \) (free space) and \( A=0.5 \) (plasma) for 4x4-element planar array of circular patch microstrip antenna with airgap in \( \phi=0 \) plane and for \( \beta=\pi/2 \)

**Fig. 5**—Variation of radiation \( R(\theta, \phi) \) for \( A=1.0 \) (free space) and \( A=0.5 \) (plasma) for 4x4-element planar array of circular patch microstrip antenna with and without airgap in \( \phi=\pi/2 \) plane and for \( \beta=\pi/2 \)

**Fig. 6**—Variation of radiation \( R(\theta, \phi) \) for \( A=1.0 \) (free space) and \( A=0.5 \) (plasma) for 4x4-element planar array of circular patch microstrip antenna with airgap in \( \phi=\pi/2 \) plane and for \( \beta=\pi/2 \)

**Fig. 7**—Plasma mode field pattern \( |E_{pl}|^2 \) for \( A=0.5 \) for 4x4-element planar array of circular patch microstrip antenna with and without airgap
(G_r), radiation efficiency (η) and directive gain (D_e) are plotted in Figs 8-11, respectively, for different values of plasma parameter (A). These results are also supported and compared in presence of airgap and without airgap.

The bandwidth of the present antenna geometry is calculated theoretically with and without airgap for different values of plasma parameter and are presented in Table 2.

Fig. 8—Variation of radiation conductance, G_r, with plasma parameter A for 4x4-element planar array of circular microstrip antenna with and without airgap.

Fig. 10—Variation of radiation efficiency, η, with plasma parameter A for 4x4-element planar array of circular patch microstrip antenna with and without airgap.

Fig. 9—Variation of radiation conductance, G_r, with plasma parameter A for 4x4-element planar array of circular microstrip antenna with and without airgap.

Fig. 11—Variation of directive gain, D_e, with plasma parameter A for 4x4-element planar array of circular patch microstrip antenna with and without airgap.
Table 2—Bandwidth of 4x4-element circular patch microstrip planar array with and without airgap for different values of plasma parameter (A)

<table>
<thead>
<tr>
<th>Plasma parameter (A)</th>
<th>Without airgap ((H_A = 0))</th>
<th>With airgap ((H_A = 1) mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>29.8</td>
<td>75.8</td>
</tr>
<tr>
<td>0.9</td>
<td>34.0</td>
<td>87.3</td>
</tr>
<tr>
<td>0.8</td>
<td>38.3</td>
<td>98.7</td>
</tr>
<tr>
<td>0.7</td>
<td>39.2</td>
<td>105.7</td>
</tr>
<tr>
<td>0.6</td>
<td>34.2</td>
<td>97.9</td>
</tr>
<tr>
<td>0.5</td>
<td>23.9</td>
<td>69.7</td>
</tr>
<tr>
<td>0.4</td>
<td>13.2</td>
<td>39.4</td>
</tr>
<tr>
<td>0.3</td>
<td>5.1</td>
<td>15.5</td>
</tr>
<tr>
<td>0.2</td>
<td>1.2</td>
<td>3.5</td>
</tr>
<tr>
<td>0.1</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

3 Observations and conclusions

In this paper, a comprehensive analysis of 4x4-element planar array of circular patch microstrip antenna with and without airgap in plasma medium has been presented. The radiation patterns, pattern characteristics, radiation conductances \((G_e\) and \(G_p))\) for electromagnetic and plasma mode, efficiency \((\eta))\), directive gain \((D_e))\) and bandwidth of the array geometry are computed and reported. Some important findings from this study are:

(i) The shape of field patterns has been modified to a great extent and redistribution of the field intensities is observed by creation of an airgap and in presence of plasma medium. The side lobe level (SLL) is degraded for free space \((A = 1.0)\) by 5 dB due to creation of an airgap in both the planes (i.e., \(\phi = 0\) and \(\pi/2\) planes).

(ii) The plasma mode field patterns are oscillatory in nature containing innumerable maxima and minima similar to a discrete ray-like structure. It can be seen that the position of maxima and minima shifted with airgap.

(iii) Radiation conductance and efficiency \((G_e, G_p\) and \(\eta))\) vary with plasma parameter for both with and without airgap. It is clear from Fig. 10 that the efficiency decreases with an increase in plasma to source frequency. However, this antenna geometry is more efficient with an airgap.

(iv) The directive gain \((D_e))\) of the array geometry is maintained and its maximum value is found to be about 10.2 dB, which is slightly better than that of the one without airgap (i.e., about 9.5 dB). A variation of directive gain with plasma parameter \(A\) for this geometry is shown in Fig. 11.

(v) The array geometry has significantly better bandwidth with airgap than without airgap in both the media (Table 2). This enhancement in bandwidth is very much required for such antenna geometries in view of many applications including mobile communication systems through satellite, where broad-band antennas are required.

An experimental verification of these results in the free space as well as in the plasma medium at the designed frequency is required, which may give additional information about the effect of plasma medium and creation of an airgap on the radiation properties of such an array, though simulation of natural plasma in laboratory is a very difficult task.

Acknowledgement

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References