Demonstration of an X-Band Multilayer Yagi-Like Microstrip Patch Antenna With High Directivity and Large Bandwidth

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Abstract

The feasibility of obtaining large bandwidth and high directivity from a multilayer Yagi-like microstrip patch antenna at 10 GHz is investigated. A measured 10-dB bandwidth of ~20 percent and directivity of ~11 dBi is demonstrated through the implementation of a vertically-stacked structure with three parasitic directors, above the driven patch, and a single reflector underneath the driven patch. Simulated and measured results are compared and show fairly close agreement. This antenna offers the advantages of large bandwidth, high directivity and symmetrical broadside patterns, and could be applicable to satellite as well as terrestrial communications.

Introduction

Despite many attractive features like low profile, low cost, and ease of solid state device integration, microstrip patch antennas are limited by their inherently narrow bandwidths and low directivity. Previous attempts to overcome these deficiencies have resulted in substantial success. Larger bandwidths have been achieved through clever use of shorting walls, shaped slots, and electromagnetically coupled patches, while higher directivities have been realized with parasitic patches or high permittivity substrates (refs. 1 to 3). However, most previous attempts were focused on the enhancement of either the bandwidth or directivity. Thus, it would be beneficial to simultaneously improve both of these parameters to increase the versatility of the patch antenna.

Planar Yagi arrays with patch antennas as driven and parasitic elements have been reported earlier (refs. 4 and 5). These antennas produce end-fire radiation and a four-element array of such antennas has been introduced for mobile satellite communications applications (ref. 5). In ground-to-space communications, however, an antenna with a broadside beam is required, and high directivity and large bandwidth are necessary to support high data rate communication. In this paper, a unique multilayer Yagi-like microstrip antenna is presented which simultaneously addresses these aforementioned requirements.

Antenna Design and Optimization

The antenna structure under examination is illustrated in figure 1. Verification that this structure is conceptually similar to a Yagi antenna was performed by varying the number of stacked directors and analyzing its radiation pattern at each increment. As more directors were added, the antenna’s beamwidth narrowed, indicating higher directivity. Simulations performed using Zeland’s IE3D electromagnetic simulator showed that maximum directivity was achieved with three directors and that further stacking had little effect on performance enhancement.
The directors’ size and spacing of approximately 0.8λ and 0.3λ₀, respectively, were baselined from previous designs (ref. 4), where A represents the area of the driven patch, and λ₀ is the free space wavelength. For a copper reflector, baseline size and spacing was determined to be 1.1A and 0.35λ₀, respectively (ref. 4). The investigation presented herein was performed, however, utilizing a lower conductivity material for the reflector (AgHT-8, σ ≈ 5 × 10⁴ S/m). This material was chosen because it was readily available in our laboratory. The multilayer structure was optimized with IE3D based on the AgHT-8 material and 5 and 20 mil thick Duroid® substrates (εᵣ = 2.2). From table 1, it can be observed that changing the conductivity of the reflector in the optimized design results in degradation of bandwidth and/or directivity.

**TABLE 1.—IE3D SIMULATED REFLECTOR CONDUCTIVITY EFFECTS ON ANTENNA PERFORMANCE**

<table>
<thead>
<tr>
<th>Conductivity (S/m)</th>
<th>Resonant Frequency (GHz)</th>
<th>10-dB BW</th>
<th>Directivity (dBi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5x10⁷</td>
<td>10.4</td>
<td>1.4%</td>
<td>12.4</td>
</tr>
<tr>
<td>5x10⁶</td>
<td>10.3</td>
<td>1.9%</td>
<td>12</td>
</tr>
<tr>
<td>5x10⁵</td>
<td>10.3</td>
<td>2.6%</td>
<td>12.2</td>
</tr>
<tr>
<td>1x10⁵</td>
<td>10.2</td>
<td>8.1%</td>
<td>11.95</td>
</tr>
<tr>
<td>5x10⁴</td>
<td>9.8</td>
<td>12.8%</td>
<td>11.8</td>
</tr>
<tr>
<td>2.5x10⁴</td>
<td>9.9</td>
<td>11.6%</td>
<td>11.3</td>
</tr>
<tr>
<td>1x10⁴</td>
<td>10</td>
<td>8.2%</td>
<td>11.6</td>
</tr>
</tbody>
</table>
Antenna Fabrication

The patch antenna was first patterned on a 5 mil thick Rogers Duroid® 5880 (\(\varepsilon_r = 2.2, \frac{1}{2} \text{ oz. copper}\)) substrate. A second 5 mil layer was formed with a rectangular shape cut out and centered below the driven patch for reflector placement. Still a third 20 mil thick layer of the same material, with a ground plane, was placed underneath this reflector patch. The three layers were sandwiched together to form the partially assembled antenna structure (see fig. 1(b)) with total substrate thickness of 30 mils and mounted on a plastic fixture. Separation between the directors, also made from 5 mil thick Rogers Duroid® 5880, and the driven patch were accomplished with 3/8 inch foam spacers (\(\varepsilon_r \approx 1\)). Transparent adhesive was wrapped around the entire structure to keep the multiple layers together. A photograph of the fabricated multilayer patch antenna is shown in figure 2.

Simulated/Measured Results and Discussion

The simulated 10-dB bandwidth was found to be approximately 13 percent with an associated directivity of 11.8 dBi (see fig. 3).

The return loss of the fabricated design was measured using an Agilent 8510C Vector Network Analyzer, and the results are compared with simulation results as shown in figure 3. The measured 10-dB bandwidth was about 20 percent. Discrepancies between measurement and simulation are possibly attributable to slight differences in the actual physical properties of the lossy reflector as compared with those simulated on IE3D.

The antenna’s radiation pattern was measured in NASA Glenn Research Center’s Cylindrical Near Field Range Facility. Comparisons of the simulated and measured radiation pattern for the E-plane and H-plane cuts are shown in figures 4 and 5, respectively. Close agreement between the simulated and measured patterns is observed. The maximum directivity is calculated from equation (1), where \(P(\theta)\) is the power radiated by the antenna, and is found to be 11.3 dBi, which agrees with the simulated value.

\[
D = \frac{1}{\int_{0}^{2\pi/2} \int_{0}^{\pi} P(\theta) \sin(\theta) d\theta d\phi} \quad (1)
\]

Figure 2.—Photo of fabricated multilayer patch antenna.

Figure 3.—Comparison of measured and simulated return loss for multilayer patch antenna.
Conclusions

A directivity- as well as bandwidth-enhancement scheme, based on a vertically-stacked microstrip Yagi-like antenna is demonstrated. The antenna was analyzed via computer simulations and experimental measurements. Simulated as well as measured results show that this structure allows for high bandwidth while simultaneously maintaining a broadside beam of high directivity. Future work on this antenna will focus on design optimization for enhancement of these parameters. Application of this design concept to develop miniaturized antennas at S-band frequencies for surface-to-surface wireless lunar/mars communications is being investigated.

References

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