BROADBAND HIGH GAIN SMALL ARRAY ANTENNA FOR HIGH ALTITUDE PLATFORMS APPLICATIONS

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ABSTRACT
This paper presents a novel design of a high gain multilayer Strip-Slot-Foam-Inverted Patch (SSFIP) antenna working at 30 GHz. The antenna is designed to provide a special radiation pattern, which contributes to the reduction of grating lobes when used as element of array. Sub-arrays of 4 and 16 elements were simulated using a commercial EM simulator. Radiation pattern of 64 and 256 elements array were computed based on the single element radiation pattern and planar array theory. A uniform amplitude and equal phase array of 64 elements was fabricated for testing. Measured radiation patterns are compared with theoretical predictions and they are shown to be in good agreement.

I INTRODUCTION
Today, users of broadband services for home or office are generally dependent upon either cable or satellite technologies to which they are connected. Cable can provide excellent capability, particularly fiber, but has geographic limitation and is only commercially viable in high density usage areas. Satellite provides widespread geographic coverage but has limited capability and changing capacity. Communications via High Altitude Platforms (HAPs) will develop broadband capability from aerial platforms to deliver cost effective solutions providing a viable alternative to cable and satellite, with the potential to reach rural, urban and traveling users as illustrated in Fig. 1.

![Figure 1: HAPs service linked to satellite and wired communication networks.](image)

Examples of HAPs include airships and solar powered aeroplanes operating at altitudes of around 20 km, well above any air traffic. The technology developed aims to support data rates of up to 120 Mbit/s to fixed and mobile users anywhere within a HAP’s 60 km coverage area. In ITU-R [1], frequency band applied to HAPs application is defined to be 27.5-31.3 GHz. The focus of the antenna design is on ground mobile users.

Microstrip antennas are used in a wide range of applications thanks to their thin profile, lightweight, low cost and ease of integration with other RF devices. In array configuration, they can achieve high gain and become an alternative to parabolic reflectors for millimeter wave applications, such as communications via HAPs.

However, microstrip antennas operate only over a narrow bandwidth due to their resonant nature. Future HAPs subscriber antennas require typically 30 dBi gain and a frequency bandwidth of 13% around 29 GHz. Two techniques commonly used to improve the bandwidth are to add parasitic patches which are gap-coupled with the main resonator [2][3][4][5] or to use strip slot coupled multilayer structures [6]. The former reported an achieved operating bandwidth (Voltage Standing Wave Ratio VSWR = 2) up to 14%, while the latter increased the bandwidth to 19.5% with a stripline-fed multilayer antenna.

For applications at high frequency, loss due to dielectric materials becomes important. Cautions need to be taken on low-loss dielectric selection, number of array elements and loss in the feeding network. Practically speaking, the number of elements in a printed array at HAPs frequency band should be limited to minimize the loss. In this work, a strip slot coupled solution has been proposed so that the feeding network is located on a different layer than the patches enabling the routing to be optimized separately. In addition, we considered an array composed of a small number of elements to further reduce feeding network complexity while maintaining the performance required by HAPs application. A high-order mode Strip-Slot-Foam-Inverted Patch (SSFIP) antenna has been designed to provide a specific radiation pattern, which lowers the grating lobe level due to large element spacing. Simulated electrical features of such a high gain broadband element antenna are presented in section II. Section III describes the array performance using high gain element designed in section II. Measurement results on a 8x8 elements array are also compared with theoretical computations in this section.

II HIGH-ORDER MODE SSFIP ANTENNA DESIGN
Features of SSFIP antennas operating at the fundamental resonant frequency have been well documented in [6][7] and [8]. A full-wavelength SSFIP providing two off-axis main lobes at 30° angles with respect to broadside has also been reported [9]. Here we present a novel design of a higher order mode SSFIP with etched patch, which exhibits high directivity in broadside direction.
As presented in Fig. 2, the patch (top-layer) of the high-order mode SSFIP is coupled with the microstrip feed line (bottom-layer) through the slot (mid-layer). The patch is of size $\lambda$ at operating frequency. The patch has been etched in a fractal-like shape to provide a specific radiation pattern as well as broadband impedance matching. The antenna in Fig. 2 has been simulated using commercial electromagnetic Method of Moment (MoM) software [10]. The substrate is Rogers RT/Duroid 5880 with thickness $h = 0.254$ mm and dielectric constant $\varepsilon_r = 2.2$. The overall size of the antenna is $13.8 \text{ mm} \times 16.5 \text{ mm} \times 1.4 \text{ mm}$. The radiation pattern was studied to enhance grating lobe suppression when integrated as an element into an array.

![Figure 2: Different layers of a SSFIP antenna.](image)

Fig. 3 depicts the impedance matching bandwidth obtained by simulation. As it can be observed, the operating frequency for a VSWR = 2 ranges from 27.0 to 33.1 GHz, meaning 20.3% of impedance bandwidth. An example of radiation pattern in the E-plane ($\phi = 90^\circ$) and H-plane ($\phi = 0^\circ$) is presented in Fig. 4.

Table 1 summarizes the gain and half-power beamwidth at four simulated frequencies. The gain flatness remains better than 1 dB in the whole frequency range. The simulated cross-polarization is about 75 dB lower than the co-polarization meaning that the high order mode is properly excited.

<table>
<thead>
<tr>
<th>Frequency [GHz]</th>
<th>Gain [dBi]</th>
<th>E-plane HPBW [°]</th>
<th>H-plane HPBW [°]</th>
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<tr>
<td>27.5</td>
<td>10.1</td>
<td>32.8</td>
<td>30.4</td>
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<td>10.8</td>
<td>30.8</td>
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<td>29.5</td>
<td>10.4</td>
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<td>30.0</td>
</tr>
<tr>
<td>30.5</td>
<td>9.9</td>
<td>27.8</td>
<td>30.8</td>
</tr>
</tbody>
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III ARRAY PERFORMANCE

In a uniform amplitude and phase array, the element spacing should be less than $\lambda$ to prevent unwanted grating lobes in broadside radiation region [11]. With the high-order mode SSFIP of size $\lambda$, it is impossible to satisfy this spacing condition. To minimize the grating lobes, the inter-element spacing of 1.8$\lambda$ is adjusted to place the H- and E-plane grating lobes at the radiation direction where the single element antenna has a null in the radiation pattern. Fig. 5 gives an example of 64-element array with a corporate feeding network.

![Figure 5: 64-element array.](image)
Due to hardware limitations, only 4- and 16-element arrays were simulated using the commercial EM software. In Fig. 6, impedance matching bandwidth (VSWR) versus frequency range of the 16-element array is presented. The broadband behavior of single element remains stable in the array configuration. Simulated cross-polarization is about 23 dB lower than the co-polarization. The theoretical radiation pattern of a general case, e.g. array of $x$-element spaced by distance $d$, has been computed by applying the planar array theory on a simulated single element. The radiation pattern of a 64-element array obtained in such a way is given in Fig. 7.

Measured cross-polarizations are presented in Fig. 11 and Fig. 13. The second lobes of value -11.7 dB at 30.5 GHz are due to the second lobes of the single element at that frequency. The front-to-back ratio is 13 dB for the worst case. This ratio can be further enhanced to 30 dB by absorbing material placed on the backside of the array (Fig. 14).

The gain estimation of the 64-element array has been made by comparing with a commercial broadband Horn antenna of +/- 1 dB uncertainty [12]. The values and comparison with the simulations are summarized in Table 2. The measured gains are 3.5 to 5.8 dB lower than computed values depending on operating frequencies. The main reason is that at high frequency, any uncertainties concerning the dielectric material characteristics or metallic surface conductivity impact the gain predicted by the simulations.

A 64-element prototype (Fig. 8) has been fabricated for verification. The measured impedance matching presented in Fig. 9 exhibits relatively good broadband performance. The theoretical results of a 64-element array are compared with the measured curves in Fig. 10, 11, 12 and 13. Measured radiation patterns show excellent agreement with theoretical prediction in both E- and H-plane. Electrical features of the array remain stable through the whole frequency range. In Fig. 10 it is shown that the E-plane grating lobes are minimized to 15.7 dB lower compared to the main lobe at 27.5 GHz. The grating lobes level for other frequencies can be found both in Fig. 12 and in Table 2. The E- and H-plane cross-polarizations are at about -23 dB compared to the co-polarization within the whole operation frequency range.
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Figure 11: Measured normalized co- and cross-polarization at 27.5 GHz. (a) in E-plane (b) in H-Plane.

Figure 12: Measured and simulated E-plane co-polarization radiation patterns of the 64-element array at (a) 28.5 GHz and (b) 29.5 GHz.

Figure 13: Measured normalized E-plane co- and cross-polarization at (a) 28.5 GHz (b) 29.5 GHz.

Table 2: Performance of 64-element array.

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</tr>
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Figure 14: Enhanced E-plane backward radiation of the 64-element array at 27.5 GHz.

IV CONCLUSION

A broadband high-order mode SSFIP antenna with high directivity in the broadside direction was developed. The highly directive SSFIP antenna enables implementation of an array with a reduced number of elements; thus decreasing feeding network complexity. Sub-arrays of 4, 16 and 64 elements were studied by simulation. A 64-element prototype has been tested and the measured results have been compared with the theoretical computations and shown to be in good agreement.

REFERENCES