APERTURE COUPLED MICROSTRIP SHORT BACKFIRE ANTENNA WITH CORRUGATED RIM

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Abstract

A technique for improving the gain and reduction of the back radiation of the Aperture Coupled Microstrip Short Backfire Antenna is proposed. A modified (corrugated) rim of the antenna is introduced and the influence on its electrical characteristics is investigated. The effect of the dimensions of the rim on the antenna near-field amplitude distribution is presented. The antenna is designed to operate over the Ku-band frequency range from 11.68 GHz to 13.15 GHz.

1. INTRODUCTION

The enhancement of the antenna directivity by using Short Backfire Antennas (SBFAs) has been subject of study in the last 50 years [1], [2] and various designs have been proposed. In the last thirty years the attention has been focused on planar high- gain low-profile structures made of dielectric layers [3], [4], called Microstrip Short Backfire Antennas (MSSBFAs). These structures are mainly formed by a half wavelength leaky cavity resonator between two parallel plane reflectors (a big reflector $R_2$ and a small one $R_1$) and a driven element $F$ (in this case a microstrip patch antenna) which is usually placed close to the big reflector. The cavity between the big reflector and the partially reflective surface (the small reflector) is filled with air or foam material [2], [3], [5]. MSSBFA with high-gain (11 dBi) and dielectric filled cavity but with impedance bandwidth below 1% is proposed in [4].

In [6] it has been shown that the Aperture Coupled Microstrip Short Backfire Antenna (ACMSSBFA) has wide impedance bandwidth (of about 15%) and its maximum gain is approximately equal to 11.5 dBi. A broadening technique using in this design consists in an insertion of two close resonances in the return loss characteristic of the antenna to cover the wide frequency range [7]. The reduction in size is brought by loading the cavity resonator volume with a high permittivity dielectrics. The antenna is very robust and compact with a volume about 4 times less than a MSSBFA with an air cavity. The disadvantage of the antenna is its high level of back radiation ($BRL_{max} = -6$ dB) in the low frequency part of the bandwidth.
This paper is an extended study of [6] and presents ACMSSBFA with a corrugated rim and a lower level of back radiation and a higher gain in comparison with the ACMSSBFA with a conventional rim in our previous work.

2. ANTENNA STRUCTURE AND DESIGN PROCEDURE

2.1. Antenna structure

The electrical characteristics of an ACMSSBFA with a conventional rim (antenna A1) shown on Figure 1 have been improved by changing its rim from a conventional cylinder to a corrugated cylindrical surface. The antenna A1 is the base for comparison in this study. It is known [8] that virtual radiating aperture of the SBFA extends far outside the physical radiating aperture. This indicates that it is possible to increase the antenna directivity and reducing the high back radiation by modifying the rim geometry. Two ACMSSBFA with a corrugated rim and different rim configurations were employed during the investigations in this paper: an ACMSSBFA with one ring (antenna A2) shown in Figure 2 and an ACMSSBFA with two rings (antenna A3) shown in Figure 3.

The ACMSSBFA with corrugated rim are based on the optimized reference antenna structure A1. Its optimized basic geometrical antenna parameters obtained by computer simulation are listed in Table 1. The antennas consist of two main parts (Figures 2 and 3): feeding part and radiating part. Each part of the antenna structure can be optimized independently (due to the suitable choice of the antenna feed – the
Figure 3. Aperture coupled microstrip short backfire antenna with two rings (antenna A3)

Table 1. Dimensions of the investigated antennas

<table>
<thead>
<tr>
<th>Description</th>
<th>Dimensions, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Antenna A1</td>
</tr>
<tr>
<td>$D_2$</td>
<td>24</td>
</tr>
<tr>
<td>$L_1$</td>
<td>7.6</td>
</tr>
<tr>
<td>$w$</td>
<td>6.1</td>
</tr>
<tr>
<td>$L_p$</td>
<td>2.2</td>
</tr>
<tr>
<td>$W_a$</td>
<td>0.38</td>
</tr>
<tr>
<td>$l$</td>
<td>12</td>
</tr>
<tr>
<td>$L_s$</td>
<td>0.7</td>
</tr>
<tr>
<td>$D_s$</td>
<td>24</td>
</tr>
<tr>
<td>$t_w$</td>
<td>1.0</td>
</tr>
</tbody>
</table>

aperture coupling feed), thus facilitating and speeding up the complete antenna design.

In all antenna configurations five substrates are used: an additional substrate Taconic TLX 7, $\varepsilon_{rt} = 2.6$, $\tan\delta_r = 0.0019$, $h_t = 1.575$ mm; a small reflector substrate Arlon AD 410, $\varepsilon_{rq} = 4.1$, $\tan\delta_q = 0.003$, $h_q = 3.175$ mm (two layers); a patch substrate Arlon AD 600, $\varepsilon_{rp} = 6.15$, $\tan\delta_p = 0.003$, $h_p = 1.27$ mm; a feed substrate Arlon AD
The goal of this research is to reduce the back radiation level of the investigated antennas. Two ACMSSBFA with corrugated rim are considered in this paper. The first analyzed antenna construction antenna A2 shown in Figure 2 has only one horizontal ring (with width \( w_1 \)) and possesses a higher directivity (Figure 4a) but this does not affect the back radiation as shown in Figure 4b. The geometrical parameters of the proposed antenna are as follows: \( W_f = 0.98 \) mm, \( t_1 = 0.5 \) mm, \( t_r = 0.5 \) mm, \( u = 1 \) mm, \( w_1 = 2.5 \) mm, \( h_1 = 0.4 \) mm.

The classic technique to reduce the back radiation level is the use of a large conducting screen placed behind the antenna [9], but the waves reflected from more distant zones produce in part out-of-phase contributions and this degrades the directivity. Furthermore this method is not feasible for many applications.

The ACMSSBFA with two horizontal rings (with width \( w_1 \) and \( w_2 \)) shown in Figure 3 has the highest directivity and the lowest back radiation level in comparison with both previously described antenna constructions. The optimized basic geometrical parameters are given in Table 1 and all other non-mentioned dimensions are as follows: \( W_f = 0.98 \) mm, \( h_1 = 0 \) mm, \( h_2 = 0 \) mm, \( t_1 = t_2 = 0.5 \) mm, \( w_1 = 2.5 \) mm, \( w_2 = 2 \) mm.

**2.2. Design procedure**

The first step of the antenna design is carried out according to [10] reducing all dimensions approximately \( n = \sqrt{e_r} \) times, where \( e_r \) is the dielectric constant of the corresponding substrate. Other approaches used in this design are as follows: 1) An aperture coupled feed is chosen because it allows independent optimization of the feed and radiating parts of the antenna. The ratio of slot width (\( W_a \)) to slot length (\( L_a \)) is chosen \( K_a = W_a/L_a = 1/10 \). 2) It was established that the arrangement of the substrates in the radiating part of the antenna must satisfy the following condition

\[
n_p > n_q > n_i > 1,
\]

where \( n_p \), \( n_q \), \( n_i \) are the indices of refraction of the patch, small reflector and additional substrate, respectively, while 1 is the free-space indice of refraction; 3) For a low level of the cross-polarization in the case of linear polarization a rectangular shape of the patch and small reflector is chosen and the values of the patch ratio \( K_p = W_p/L_p \) and
a small reflector ratio $K_1 = W_1 / L_4$ are fixed to 0.8125; 4) The big reflector diameter is

\[ D_2 \approx 2\lambda_{\text{beff}} = 2\lambda_{0b}/n_{\text{beff}} \]  

(2)

where $\lambda_{\text{beff}}$ and $\lambda_{0b}$ are the wavelengths in the radiating part of the antenna and in the free space, respectively, corresponding to the backfire resonant frequency $f_{0b}$, and $n_{\text{beff}}$ is the effective indice of refraction of the backfire cavity; 5) The backfire resonant distance is determinate by the cavity length $h_b$ between both metal reflectors by

\[ h_b = 0.5\lambda_{\text{beff}} \]  

(3)

The backfire resonant distance is also related with the phase $\psi$ of the reflection coefficient $R_e^{i\psi_1}$ of the partially reflecting surface (a small reflector plane) and the reflection coefficient $R_e^{i\psi_2}$ of the big reflector plane [11]. With ray-optics analysis [1], [11] was derived that a maximum broadside radiation is obtained when

\[ \psi_1 - \pi - (4\pi h_b / \lambda_{\text{beff}}) = 0 \]  

(4)

An equation (4) shows that for a given frequency the length of the backfire cavity is determinate by the phases of the two reflectors and the equation (3) is a partial case of (4) when both reflectors are perfectly reflecting. From (4) in general case the backfire resonant distance is given by

\[ \psi_1 + \psi_2 - 2k_{\text{beff}} h_b = -2\pi N \]  

(5)

where $k_{\text{beff}} = 2\pi / \lambda_{\text{beff}}$ is the wave number and $N = 0, 1, 2 \ldots$ is zero or an integer.

The value of the antenna cavity length was obtained using (3) then specified using a full-wave simulation of the entire antenna with computer software HFSS.

### 3. COMPUTED ANTENNA PERFORMANCES

Parametric studies have been carried out to determine the impedance and radiation characteristics of the designed antennas. As criteria in the optimization the back radiation level and the gain are chosen.

Figure 4 shows the influence of the ring width $w_1$ on the gain and back radiation of the antenna A2. It is seen from the figure that the ring width $w_1$ has a strong influence on the gain, with maximum at $w_1=2.5$ mm (Figure 4a) but it does not affect on the back radiation level as shown in Figure 4b.

The computed gain and back radiation for the ACMSSBFA with two rings are shown in Figure 5 for three different widths of the second ring $w_2$. It can be seen in Figure 5b that the back radiation level in this case is reduced significantly. The gain is
relatively insensitive to small variations in the ring width \( w_2 \) but it changes considerably for larger ring width variations. The results shown in Figure 5 illustrate how the antenna can be designed to achieve a maximum gain and low back radiation.

![Graph](image1)

**Figure 4.** Broadside gain (a) and back radiation (b) of an antenna A2 for various ring widths \( w_1 \)

![Graph](image2)

**Figure 5.** Broadside gain (a) and back radiation (b) of an antenna A3 for various ring widths \( w_2 \)

It is known that by suitable choice of ground plane dimensions the antenna gain and back radiation can be improved [9]. It can be seen from computed data in Figure 6 that the gain actually increases when the ground plane diameter increases to the optimum diameter value \( D_5 = 36 \text{ mm} \) and then starts to decrease. The back radiation level is in accordance with [9] and decreases when the ground plane increases but the disadvantage of this technique is obvious. The difference between the back radiation of the reference antenna A1 with screen diameter \( D_5 = 36 \text{ mm} \) and maximum gain and the back radiation of the same antenna with \( D_5 = 24 \text{ mm} \) is about 5 dB.

It is seen from Figure 7b a significant decrease in back radiation of the ACMSSBFA with two rings (antenna A3) in comparison with the antennas A1 and A2.
and the reference antenna with large screen (Figure 6b). The impedance bandwidth is reduced mainly in the lower frequencies within the bandwidth of the antenna.

![Figure 6](image1.png)

Figure 6. Broadside gain (a) and back radiation (b) of an antenna A1 for various screen sizes $D_S$

![Figure 7](image2.png)

Figure 7. Computed reflection coefficient (a) and back radiation (b) of the investigated antennas:
dashed line - A1; solid line with ring markers – A2; solid line – A3

Figure 8 shows the E- and H-plane radiation patterns of the ACMSSBFA with two rings at central frequency 12.4 GHz calculated by means of two differential numerical methods - Finite Element Method and Finite Difference Time Domain method implemented in the software simulators HFSS and Microwave studio. A good agreement is observed between both computed results.

The computed E- and H- plane near-field amplitude distributions of antennas A1 and A3 are shown in Figure 9. It is seen from the figure that the more uniform amplitude distribution in E-plane of an antenna A3 assures better radiation pattern in comparison with an antenna A1. The equal amplitude distributions in both planes for antenna A3 lead to approximately equal E- and H-plane beam widths of the antenna.
Figure 8. Normalized radiation patterns of an antenna A3: HFSS - solid line; MWS – dashed line; (a) E – plane; (b) H – plane, \( f = 2.4 \, \text{GHz} \)

Figure 9. Computed near-field amplitude distribution of antennas A1 and A3: (a) E-plane; (b) H-plane; dashed line - A1; solid line with ring markers – A1 with screen \( D_s = 36 \, \text{mm} \); solid line – A3

4. NUMERICAL RESULTS AND DISCUSSION

The basic electrical characteristics of ACMSSBFA with corrugated rim obtained by numerical simulation are summarized and compared with the same characteristics of the reference antenna in Table 2. The antenna operational frequency bandwidth is defined at a level of -10 dB of the characteristic \( |S_{11}(f)| \), and 3 dB less than the maximum values of the characteristics \( D(f) \) and \( G(f) \).

The ACMSSBFA with two rings studied here offers an improved back radiation and gain compared with an ACMSSBFA with conventional rim.

The primary advantage of this antenna is its low level (below – 20 dB) of back radiation in 44 % of the operational bandwidth. This is a very good result compared to the antenna A1 with a minimum back radiation level of – 17.5 dB. The maximum gain increases with about 1 dBi to 12.4 dBi compared to the reference antenna with \( G_{\text{max}} = \)}
11.5 dBi. In both planes the half-power beam widths are approximately equal \(2\theta_{3dB} \approx 43^\circ\). It is evident from the near-field amplitude distribution shown in Figure 9 that this type of an amplitude depression is due to the small reflector blocking of the antenna aperture center [9].

### Table 2. Basic computed parameters of the investigated antennas

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Antenna A1</th>
<th>Antenna A2</th>
<th>Antenna A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum frequency (f_{\text{min}}), GHz</td>
<td>11.47</td>
<td>11.90</td>
<td>11.68</td>
<td></td>
</tr>
<tr>
<td>Maximum frequency (f_{\text{max}}), GHz</td>
<td>13.28</td>
<td>13.30</td>
<td>13.15</td>
<td></td>
</tr>
<tr>
<td>Central frequency (f_0), GHz</td>
<td>12.375</td>
<td>12.60</td>
<td>12.415</td>
<td></td>
</tr>
<tr>
<td>Fractional bandwidth (bw), %</td>
<td>14.63</td>
<td>11.11</td>
<td>11.84</td>
<td></td>
</tr>
<tr>
<td>Maximum directivity (D_{\text{max}}), dBi</td>
<td>12.10</td>
<td>&gt; 10.60</td>
<td>&gt; 10.70</td>
<td></td>
</tr>
<tr>
<td>Directivity in the bandwidth (D), dBi</td>
<td>&gt; 9.10</td>
<td>&gt; 10.50</td>
<td>&gt; 10.50</td>
<td></td>
</tr>
<tr>
<td>Maximum gain (G_{\text{max}}), dBi</td>
<td>11.50</td>
<td>12.60</td>
<td>12.40</td>
<td></td>
</tr>
<tr>
<td>Gain within the bandwidth (G), dBi</td>
<td>&gt; 9</td>
<td>&gt; 10.50</td>
<td>&gt; 10.50</td>
<td></td>
</tr>
<tr>
<td>Maximum E - plane cross-polarization level (XPL_{\text{EMax}}), dB</td>
<td>-25</td>
<td>-25</td>
<td>-30</td>
<td></td>
</tr>
<tr>
<td>Maximum H - plane cross-polarization level (XPL_{\text{HMax}}), dB</td>
<td>-44</td>
<td>-37</td>
<td>-43</td>
<td></td>
</tr>
<tr>
<td>Minimum back radiation level (BRL_{\text{min}}) within the bandwidth, dB</td>
<td>-16.40</td>
<td>-23</td>
<td>-44</td>
<td></td>
</tr>
<tr>
<td>Max. back radiation level (BRL_{\text{max}}) within the bandwidth, dB</td>
<td>-6</td>
<td>-10.20</td>
<td>-10.10</td>
<td></td>
</tr>
</tbody>
</table>

A partial disadvantage of the investigated antenna is that the overall antenna diameter increases with 20 % and the operational frequency bandwidth decreases by 2.8 % compared to the reference antenna.

### 5. CONCLUSION

This paper is mainly focused on compact and robust Aperture Coupled Microstrip Short Backfire Antenna with improved electrical characteristics. The corrugated rim of the antenna was introduced, which effectively enhances its performance especially the back radiation level and the directivity. The aperture near-field amplitude distribution dependence on the rim configurations and its influence on the gain and the back radiation level are also presented. This design achieves an operational bandwidth of 11.84 % (from 11.68 to 13.15 GHz), with stable radiation patterns, a high gain from 10.5 to 12.4 dBi, and a back radiation level under –20 dB in 44 % of the operation bandwidth. Consequently, due to its very good performances the antenna may become
one of the most competitive candidates for use in mobile and satellite communications.

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REFERENCES