Wideband low-profile null-filled monopole antenna for aircraft flush-mount applications

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A wideband low-profile null-filled monopole antenna for aircraft flush-mount applications is presented. The antenna consists of a semicircular monopole and a direct-fed dual loop in a flanged cylindrical cavity. The zenith null in the monopole radiation pattern is filled by horizontal currents of the dual loop. Measurement shows that the proposed antenna has a reflection coefficient of $<-10$ dB over 4.53–7.43 GHz, 6.45 dB maximum gain, $-0.8$ dB null filled null depth and a $-3.7$ dB minimum horizontal gain at 6 GHz.

**Introduction:** In aircraft communication, the blade antenna has been widely employed since they offer good horizontal gain with uniform vertical polarisation [1]. The blade antenna protrudes from the aircraft surface, increasing the radar cross-section (RCS). Conventional monopole antennas have a deep null of $-30$ to $-20$ dB. For unimpaired communication in all hemispherical directions, the monopole’s null needs to be filled so that the zenith gain is greater than a minimum value, say, $-5$ dB.

The spiral and patch antennas have no nulls in the upper half space but their gain rapidly rolls off in the horizon. To fill the zenith null of a monopole, a horizontal element has been added, resulting in the inverted-L antenna [2] and the inverted-F antenna [3]. The inverted-L antenna can be arrayed to obtain null-filled hemispherical circularly polarised radiation [4].

In this Letter, we present a new type of a wideband low-profile null-filled monopole antenna suitable for flush-mount installation on aircraft surfaces. In the following, the design, simulation and measurement of the proposed antenna are described.

**Antenna structure:** Fig. 1a is a conceptual diagram illustrating the installation of the proposed antenna on an aircraft surface. The radiating element is placed in a radome-covered cavity, which is flush-mounted for reduced RCS. The antenna’s top plane can be made conformal to curved surfaces by suitable shape modification.

**Fig. 1 Proposed antenna**

- **a** Installation on aircraft surface
- **b** Construction

Fig. 1b shows the construction of the proposed antenna. A cylindrical cavity $C$ with a metal flange $F$ is employed for flush-mounting the radiating element $E$ and for providing a uniform and stable ground plane. The radome $R$ covering the cavity is made of the same substrate as that for the semicircular monopole described below.

**Fig. 2 Radiating element**

- **a** Detailed view of monopole and dual loop
- **b** Current on dual loop

Fig. 2 shows the design parameters of the proposed antenna. The antenna is designed in the following steps. First, the height and radius of the semicircular monopole are determined on a large ground plane. The monopole is realised on a $1$ mm-thick Taconic RF-35™ substrate ($P$) with a dielectric constant of 3.5 and loss tangent of 0.0018. Next, the monopole is placed in a flanged cylindrical cavity of $1.0 \lambda_0$ (at the centre frequency) diameter and of the same height as the monopole. The cavity has little effect on the monopole’s bandwidth though it shifts the centre frequency. The impedance matching is achieved by adjusting the gap between the monopole and the cavity surface.

**Fig. 3 Design parameters of antenna**

The dual-loop dimensions are optimised for good impedance matching and null-filling performance over a wide bandwidth. The null-filling principle of the dual loop can be seen in Fig. 4 which shows the patterns of the principal polarisation components of the monopole alone and those of the dual loop alone. The combined radiation is polarised mostly perpendicular to the substrate ($P$) plane in the zenith and vertically polarised in the horizon. The monopole-dual-loop combination has no deep null in the upper hemisphere and its horizontal gain is comparable with that of the monopole alone. The variation of the principal polarisation components with the angle of wave propagation can be overcome by using a circularly polarised antenna in one of communication terminals, say, a ground station.

**Fig. 4 Gain patterns of monopole and dual loop**

- **a** In elevation plane
- **b** In horizontal plane

Solid line: monopole; dashed line: dual loop

Use of a dual loop – two loops connected by a conducting wire $S$ – solves the problem. The use of directly or parasitically fed elements such as a dual dipole, a dual patch and a helical wire have been investigated but their null-filling performances were not satisfactory.
Table 1 shows the performance of the proposed antenna at 5, 6 and 7 GHz. The antenna has a filled null depth of −1.2 to 0.7 dB, and a minimum horizontal gain of −4.5 to −4.1 dBi. The dimensions of the proposed antenna are as follows: \( D_{\text{mm}} = 96.0 \text{ mm}, D_{\text{mm}} = 50.0 \text{ mm}, D_{\text{g}} = 15.0 \text{ mm}, L_f = 19.0 \text{ mm}, t_f = 2.0 \text{ mm}, t_{\text{g}} = 1.0 \text{ mm}, \tau = 3.79 \text{ mm}, g = 2.4 \text{ mm}, h_1 = 2.2 \text{ mm}, h_2 = 3.5 \text{ mm}, h_3 = 1.2 \text{ mm}, w_V = 14.8 \text{ mm}, w_\text{p} = 2.5 \text{ mm}, \alpha = 1.1 \text{ mm} \) and the probe diameter is 1.2 mm. The height and diameter of the cavity are 6.9 and 50.0 mm, respectively, corresponding to 0.14 \( \lambda_0 \) and 1.0 \( \lambda_0 \) at the centre frequency, respectively. For narrower bandwidths, the diameters of the cavity and the flange can be reduced, requiring a smaller space for installation. The widely used commercial software, Microwave Studio\textsuperscript{TM} v.2012 by CST, has been employed in the design of the proposed antenna.

**Fabrication and measurement:** Fig. 5 shows the fabricated antenna. The reflection coefficient and gain patterns of the fabricated antenna were measured by using the HP 8720C network analyser and a three-dimensional antenna pattern measurement facility.

![Fabricated antenna](image)

*Fig. 5 Fabricated antenna*  
*a* Radiating element and cavity  
*b* Side-view of assembled antenna

**Table 1:** Simulated performance of proposed antenna

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Maximum gain (dBi)</th>
<th>Filled null depth (dBi)</th>
<th>Minimum horizontal gain (dBi)</th>
<th>Average gain in upper hemisphere (dBi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6.0</td>
<td>−1.3</td>
<td>−4.5</td>
<td>1.6</td>
</tr>
<tr>
<td>6</td>
<td>7.7</td>
<td>0.7</td>
<td>−4.1</td>
<td>2.5</td>
</tr>
<tr>
<td>7</td>
<td>6.2</td>
<td>−1.0</td>
<td>−4.5</td>
<td>2.4</td>
</tr>
</tbody>
</table>

**Fig. 6** Reflection coefficient of fabricated antenna

**Fig. 7** Gain patterns at 6 GHz of fabricated antenna  
*a* In vertical plane  
*b* In horizontal plane  
Solid line: simulation, dashed line: measurement

In this Letter, we present a new wideband low-profile null-filled monopole antenna suitable for flush-mount installation on aircraft surfaces. The zenith null of a semicircular monopole is filled by employing a dual loop. The monopole-dual-loop radiating element is placed in a flanged cavity. Measurements have shown that the proposed antenna has a filled null depth of −0.8 dB, maximum gain of 6.45 dBi and minimum horizontal gain of −3.7 dBi at 6 GHz. The proposed antenna concept can be utilised for reliable communication in aircraft-to-ground links.

**References**