TE-monopole radiation pattern DRA for UAVs

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1. Introduction

Monopole whip antennas are commonly used on small Unmanned Aerial Vehicles (UAVs) for telemetry and command signals. Disadvantages of these antennas are high aerodynamic drag and a high degree of electromagnetic coupling to the fuselage. The latter problem is the result of the monopole having a Transverse Magnetic polarisation (TM) with respect to the surface of the vehicle causing standing waves to be induced on the surface. For a metal fuselage, the induced standing waves will adversely affect the radiation pattern shape by introducing nulls which reduce UAV operating range and safety. To some degree, this problem can be designed around by using modern simulators such as FEKO™ to determine optimal placement on the fuselage. This is somewhat undermined by the increased use of composite materials in fuselage construction. Composite materials such as Carbon Fibre Reinforced Plastic (CFRP) are composed of conductive fibres embedded in a plastic substrate and consequently form lossy polarising surfaces. As these composite material fuselage parts are laid up by hand, the exact electromagnetic effect of each individual part is unique. This unpredictability of fuselage electrical properties and the general desire to reduce antenna fuselage interaction are motivators to investigate Transverse Electric polarised (TE) monopoles for use on small UAVs.

Although relatively uncommon, TE-polarised monopoles have been developed in the past [1]. Good results were obtained with peak gains of 5dBi and 2.5% bandwidth for $S_{11} \leq -10$dB, for both 1.9GHz and 5.3GHz versions. These characteristics are more than satisfactory to cover the new ITU-R 5GHz UAV band which has 2% bandwidth. However, the antenna is not suitable for placement on a conductive surface, construction was complex and the height of $0.4\lambda$ would cause aerodynamic drag. Thus, there is some motivation to reduce the height and structural complexity of the antenna, as well as adapting it for installation on a conductive surface. As an alternative, it has been noted in the past that the TE$_{011+\delta}$ mode should be one of the lower order modes of a low profile Dielectric Resonator Antenna (DRA) [2]. The aims of this work were to experimentally demonstrate the TE$_{011+\delta}$ mode of a DRA and to then demonstrate a practical design which will later be trialled on a CFRP surface.

2. Identification of the TE$_{011+\delta}$ mode in a cylindrical DRA

Most prior work on DRAs has been on the broadside radiating HE$_{11+\delta}$ mode, which is comparable to a microstrip patch antenna, and the electric monopole TM$_{01\delta}$ mode has been investigated for automotive application [2], Figure 1. The magnetic monopole TE$_{011+\delta}$ mode should produce a TE-polarised monopole radiation pattern according to the electric and magnetic fields within the DRA, Figure 1. However, the existence of this mode has not been confirmed other than in simulation [2].

Cylindrical samples of Type A ($\varepsilon_r=12.6$) having a diameter of 30mm and height of 20mm were purchased from NGK Technical Ceramics. The most straight forward way of detecting the TE$_{011+\delta}$ mode was to move the DRA around a 50$\Omega$ characteristic impedance microstrip line on 1.6mm thick FR-4 substrate, Figure 2. A resonance in the $S_{11}$ when the DRA was centred on the microstrip line was presumed to be the HE$_{11\delta}$ mode, while a resonance at a slightly higher frequency when the DRA was asymmetrically placed was presumed to be the TE$_{011+\delta}$ mode. Having experimentally found probable resonant frequencies and optimal positions for both modes, simulations were run in FEKO™ using the Surface Equivalence Principle (SEP) to represent the finite FR-4 microstrip board and the DRA. A reasonable level of agreement was found between eigenmodes, and experiment and simulation for $S_{11}$, Table 1 and Figure 3. The simulated radiation...
patterns were as expected; a monopole radiation pattern shape but radiating $E_\phi$ as opposed to $E_\theta$ as with a $\lambda/4$ monopole.

### Table 1: Eigenmodes of the DRA

<table>
<thead>
<tr>
<th>mode</th>
<th>DRA installed on:</th>
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<tbody>
<tr>
<td></td>
<td>1.6mm FR-4 (GHz)</td>
</tr>
<tr>
<td>HE$_{11}$</td>
<td>2.25</td>
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<tr>
<td>TE$_{011+\delta}$</td>
<td>2.78</td>
</tr>
</tbody>
</table>

The best coupling to the TE$_{011+\delta}$ mode was for an offset of 10mm from the centred position, Figures 2 and 3. With $S_{11}=-7.4$dB, the straight 50Ω microstrip line evidently did not couple to the TE$_{011+\delta}$ mode very effectively, and considering that a microstrip line would be difficult to install on the exterior of a UAV fuselage was not desirable, a better cable-probe fed configuration was sort.

### 3. Inverted L-probe feed to a TE$_{011+\delta}$ mode in a DRA

Given that the TE$_{011+\delta}$ mode has a horizontal electric field vector which is similar to the current distribution on an inverted-L wire antenna, an SMA fed inverted-L antenna wrapped around the surface of the DRA was trialled as a feed, Figures 1 and 4. A parametric study of this structure in FEKO™ yielded optimal L-probe height and arc angle of (60º, 6.25mm), Figure 4.

The optimal TE$_{011+\delta}$ mode DRA design was then simulated at the centre of a circular ground plane of radii 0.6 to 2.1λ, and compared to $\lambda/4$ monopoles as per [3], Figure 5. The $S_{11}$ (not shown), peak directivity and peak angle of the TE$_{011+\delta}$ mode DRA showed none of the oscillations suffered by the $\lambda/4$ monopole with increasing ground plane radii, demonstrating that the TE$_{011+\delta}$ mode DRA does not couple strongly to the ground plane and consequently will not require retuning or redesign when installed on a UAV fuselage.

The directivity of the TE$_{011+\delta}$ mode DRA was comparable to the prior TE antenna [1] and peak values of a $\lambda/4$ monopole, Figure 5. Likewise, the radiation pattern shape was satisfactory on a 2.1λ radius ground plane, Figure 6. The $S_{11} \leq -10$dB bandwidth was 1.4%, Figure 6, which should be doubled or tripled for the UAV telemetry and command application.

### 5. Conclusions and Future Work

The existence of the TE$_{011+\delta}$ mode in a low profile cylindrical DRA was confirmed experimentally, and the $S_{11}$ and radiation pattern characteristics were found to be stable with changes in ground plane radii. A distinct advantage was that the height was 0.2λ, been half that of the prior TE mode antenna [1]. Future work will consider increasing the $S_{11} \leq -10$dB bandwidth to cover the UAV 5GHz band, testing on CFRP panels, and low cost manufacture by injection moulding using ceramic powder and polyphenylene sulphide [4].

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### References

Figure 1: Three lower order modes of a low profile cylindrical DRA.

Figure 2: Photograph of experimental setup for parametric study for optimal placement DRA for microstrip excitation of $\text{TE}_{011+\delta}$ mode; “offset= 0mm” position been when the DRA was centred on the 50Ω microstrip line on 1.6mm thick FR-4 board.

Figure 3: Return loss from parametric study for optimal placement of DRA for microstrip excitation of $\text{TE}_{011+\delta}$ mode; “10mm” offset as per photograph above.
Figure 4: Geometry and 2.85GHz return loss of parametric study of L-probe feed dimensions; optimum vertical height 6.25mm and optimal arc angle 60º, from FEKO™.

Figure 5: Peak directivity and angle variation with ground plane radius of L-probe fed TE_{011+δ} mode DRA and λ/4 monopole; comparable to Figures 6 and 7 of [3], at 2.85GHz from FEKO™.

Figure 6: Return loss and 2.85GHz radiation pattern of the TE_{011+δ} mode DRA with optimal L-probe feed on 1λ₀ radius ground plane, from FEKO™.