A Biomimetic Antenna in the Shape of a Bat's Ear

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***Abstract*—This letter presents a novel antenna that physically resembles the ear of a bat. The device consists of a circular ground plane with a central monopole element. An equilateral triangular conducting plate is curved around the ground so that the base of the triangle is electrically connected to the perimeter of the circle and is of the same length. The input characteristic is similar to the monopole above ground, providing there are a sufficient number of modes in the triangular plate at the frequency of interest. Certain frequencies yield a high gain and a radiation pattern with low side lobes.**

***Index Terms*—Biomimetic antenna, monopole, triangular patch.**

I. Introduction

THE ears or *pinnae* of bats are structures which have attracted the interest of both the acoustics and the electromagnetics research communities [1]–[3]. There are over 1000 species of bat known to science and there is a corresponding diversity in ear shapes which researchers are just beginning to understand. One of the primary interests in the acoustics area is to produce a compact, lightweight ultrasonic beam former for use in airborne robotics. This interest is inspired by the highly efficient and accurate target localization capability observed in some bat species [2]. It is therefore a fascinating prospect to study the viability of a similar shape in the electromagnetics domain. In this letter, an antenna shape will be presented which attempts to exploit the basic characteristics of these naturally evolved structures. In contrast to many conventional antennas, bat ears often have a highly complex geometrical shape and consequently numerical modeling techniques are the only feasible methods of analysis [3].

So far there is only limited knowledge of the operating modes and there have been few attempts to produce a viable device in the electromagnetic domain. In this letter, a simple geometry is presented which takes the first steps toward mimicking the shape of a bat's ear in a transmitting/receiving structure.

The proposed device is formed by connecting a conducting equilateral triangular plate to a circular ground plane and feeding with a monopole. This simple structure, depicted in Fig. 1, can be parameterized using just the side length of the triangular plate, a, and the length of the feeding monopole, b. When assembled, one side of the triangular plate is curved around the ground plane in such a way to leave the plate conformal to a cylinder with diameter a/π. This geometry is in contrast to that proposed by Wong and Fang [4] which also involved wrapping a triangular planar conductor around a cylinder; however, the present letter does not involve a cylindrical ground plane and is not a microstrip antenna.

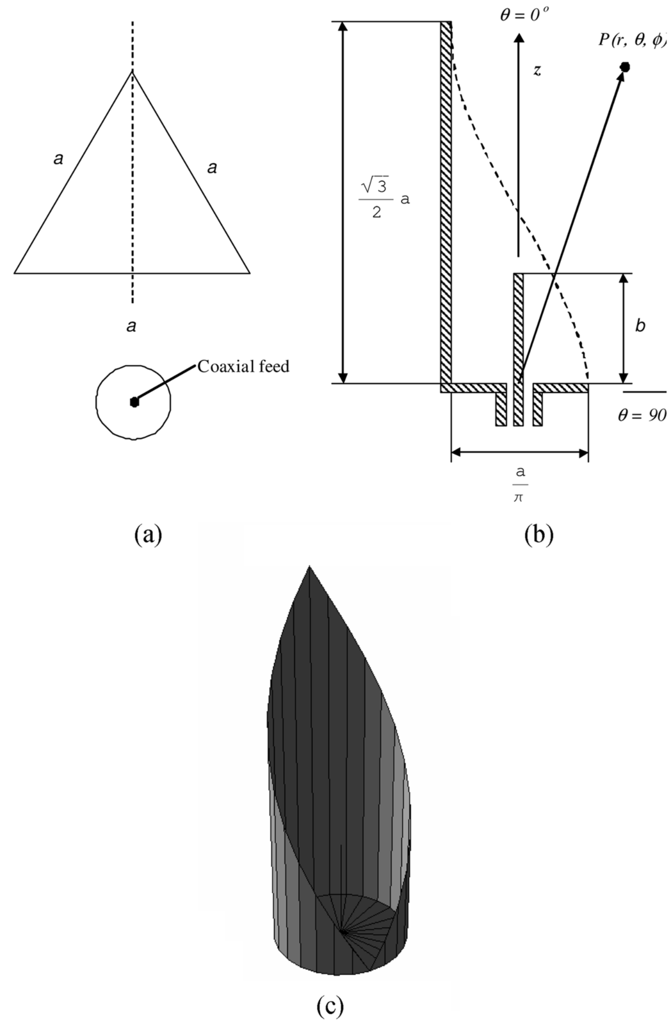

Fig. 1. (a) Flat components of the bat ear antenna. (b) Cutaway view. (c) 3-D projection.

A monopole element above a circular ground plane has been considered by a number of authors including Weiner [5], and the proposed design can be viewed as a further development of this case. It is demonstrated in this letter that while the characteristic TM modes of the triangular plate only marginally affect the resonance of the monopole above ground, the radiation characteristics do change substantially yielding a high gain.

II. Theory

The input impedance seen at the terminals of the antenna would be expected to be broadly similar to that of the equivalent monopole above ground, however some of the radiating modes of the monopole will interact more strongly with the plate than

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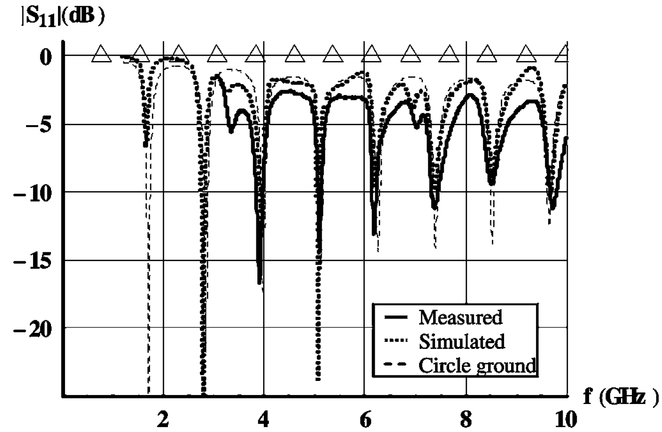

Fig. 2. Measured and simulated return loss at the antenna input for $b/a = 0.50$.

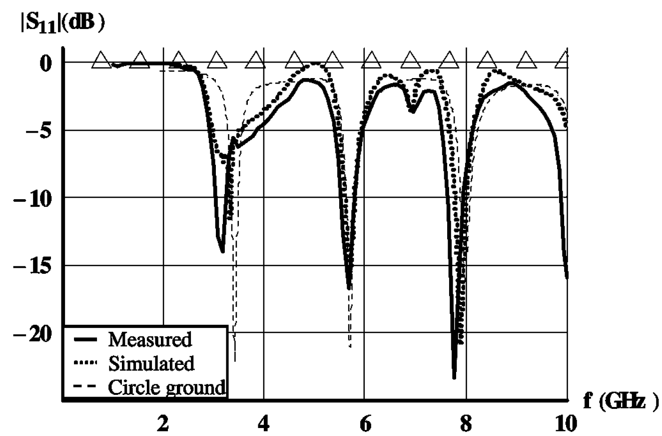

Fig. 3. Measured and simulated return loss at the antenna input for $b/a = 0.25$.

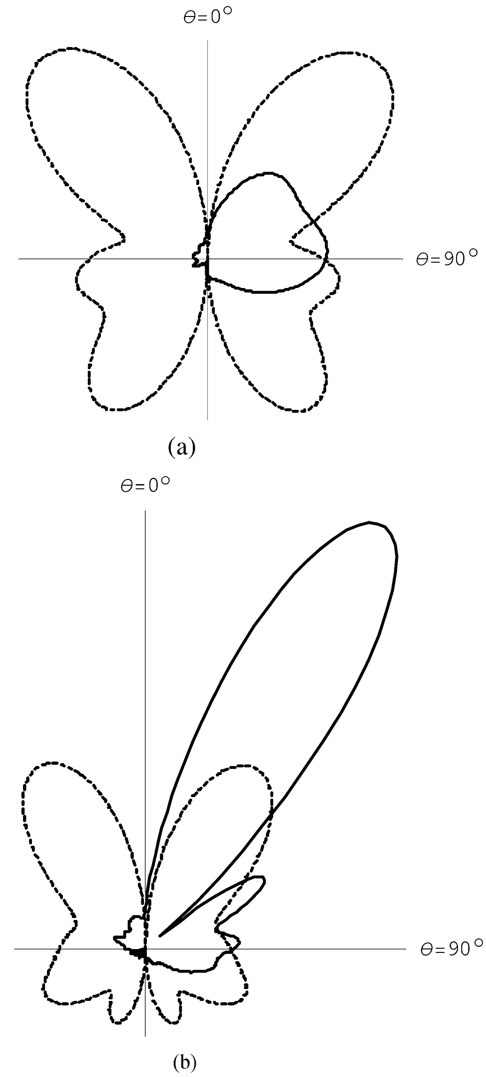

Fig. 4. (a) Copolar radiation at P shown on a linear scale for $b/a = 0.50$ at 2.8 GHz with plate (solid line) and without plate (dashed line). (b) Copolar radiation at P shown on a linear scale for $b/a = 0.25$ at 5.7 GHz with plate (solid line) and without plate (dashed line).

others. It is therefore beneficial to examine the modes of the plate by observing the similarity of the field component orientations within a triangular microstrip patch. The triangular patch has been studied by a number of authors as a resonant cavity having magnetic walls around the perimeter (e.g., [6], [7]). This approach yields a modes where the sum of the mode indices $l + m + n = 0$. The resonant frequencies have been previously confirmed both theoretically and experimentally as

$$f_{mnl} = \frac{2c}{3a}(m^2 + mn + n^2)^{1/2} \qquad (1)$$

where c is the speed of light $\approx 3 \times 10^8$ and all other parameters are as previously defined. The origin of this expression and a detailed derivation of the eigenstructure of an equilateral triangle has been given by McCartin [8]. The current letter considers an indirectly excited structure, rather than the direct (usually coaxial probe) excitation commonly applied. Nevertheless there are similarities between the field vector orientation in the patch and the structure under discussion which is brought about by the central placement of the driving monopole. In particular, the radiated H field of the monopole will successfully excite these TM modes. Another consequence of the excitation method is that triangle modes which are symmetric about the center line (shown dotted in Fig. 1(a) are most liable to be present in the plate.

III. Simulated and Measured Results

Measurements and numerical simulations were carried out in order to determine the input characteristics and to assess the directivity. A computer model employing the TLM method [9] was used to carry out a full study on parameters a and b. A time domain TLM method was selected as it is able to simulate a very wide frequency band, has high spectral resolution, and is able to account for the effects of diffraction.

A physical prototype was fabricated to validate the model for $a = 260$ mm and investigated with different values of b for the range $0 < b/a \leq \sqrt{3}/2$. Note that $b/a = \sqrt{3}/2$ corresponds to the case where the monopole length is equal to the height of the triangle with side length a. In the computer model, both the monopole and the triangular plate were considered as thin structures and wherever possible thin flexible conductive materials were used to manufacture the actual device.

For the cases $b/a = 0.5$ and $b/a = 0.25$ the return loss obtained at the antenna terminals is shown in Figs. 2 and 3. In each case the measured result from the device is compared with a TLM simulation, and also with a simulation of the circular ground plane by itself. Also given in the graphs are the $\mathrm{TM}_{\mathrm{m},0,l}$ triangle mode frequencies calculated from (1) (shown marked on the axes as triangular points). The plots indicate a good agreement between measurements and simulations, and in addition demonstrate that the return loss and the resonant frequencies are only marginally altered by the presence of the triangular plate, except at low frequency. Certain modes of the triangle are also clearly evident, with some being apparent even when the monopole is away from one of its natural resonances.

The computed directive gain patterns for two typical modes are shown in Fig. 4. The dashed lines show the equivalent directivity of a monopole above a ground plane with circumference a for comparison. In Fig. 4(a) the pattern is constrained by the presence of the triangular plate, but the directivity is only increased from 4.2 to 7.4 dBi. However in the case of Fig. 4(b) the radiation pattern has a much higher directivity, 14.7 dBi when compared to 5.5 dBi without the triangle. The main beam in this latter case is inclined at an angle of approximately $\theta = 30$ and the side lobe level is approximately -11 dB. In the equivalent monopole over circular ground, the largest sidelobes are -5.5 dB relative to the main lobe.

It is therefore evident that for certain modes there is a substantial improvement in gain and sidelobe performance over the equivalent circular ground mounted monopole and that a good match can be retained at the coaxial input.

IV. Conclusion

This letter has described a novel antenna shape inspired by the ear of a bat. Results indicate that the device can be designed with a unidirectional radiation pattern and has better side lobe performance when compared with the equivalent monopole over ground. The input characteristics are similar to the monopole except at low frequency where there are fewer TM modes which can be driven in the triangular plate.

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