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Multi-band conical and inverted conical printed quadrifilar helical antennas with compact feed networks

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ABSTRACT

Comparison between radiation patterns of quadrifilar helical antennas with three shapes of cylindrical, conical and inverted conical is provided in this paper. Multi-folded printed lines are used as the arms of quadrifilar helical antennas and the heights of them with their supports are fixed at 35 cm to make a valid comparison. These antennas have multiple resonance frequencies and they can be used for multi-band applications. Radiation patterns of the three shapes are compared at three resonance frequencies, 435 MHz, 620 MHz and 755 MHz. It is indicated that the conical antenna has a wider beam-width and the inverted conical antenna has higher gain at broadside. In addition, three compact feed networks based on miniaturized single layer Wilkinson power dividers for three frequency bands of the antennas are designed and their parameters are reported. Furthermore, the conical antenna and the feed networks are fabricated and simulation results are validated by the measurement results.

1. Introduction

Miniaturized-satellites require compact antennas with circular polarization and uniform pattern to have proper coverage on the hemisphere. A typical solution with compact structure is the resonant quadrifilar helical antenna (QHA), that is extensively improved so far [1–4]. In addition, the ability of constructing the antenna from a printed layout accelerated the developments on this area. QHAs with straight printed arms are studied and optimized in the past [5–9]. The arms of these antennas are printed on a thin substrate that should be rolled to form the printed QHA. Therefore the arms of these QHAs can have arbitrary shapes. For example, straight printed lines are replaced by folded lines in [10–12] to reduce the total size of the antenna. In addition meandered lines and sinusoidal profiles are used in [13–16] for a similar purpose. Also for more size reduction multiple folded lines are used in [17] to form an oblique spiral on the cylindrical surface. On the other hand, the conical printed quadrifilar helical antenna is applied for the satellite application in [18], which has wide beam-width in a relatively large frequency band.

Consequently, the effect of conical shape on the performance of the multi-folded antenna is studied in this paper. It is indicated that the QHA with conical shape has wider beam-width from the cylindrical antenna. In addition, the inverted conical shape is also investigated and higher gain at the broadside is achieved in some frequencies. For example the maximum gain is improved from 5.5 dB of the cylindrical shape to 7 dB in the inverted conical shape at the third resonance frequency.

The feed network of QHAs should have four outputs with similar amplitudes and 90° phase differences between adjacent outputs. The feed network for each frequency band is separately designed and the layout is similar with the one in [19] that consists of three Wilkinson power-dividers, a half-wave line and two quarter-wave lines, while the size of network is reduced from about $0.7\lambda \times 0.5\lambda$ to less than $0.15\lambda \times 0.15\lambda$. However there exist smaller feed networks than [19] for QHA such as the feed networks in [20,21] and [12] those sizes are about $0.27\lambda \times 0.27\lambda$ and $0.25\lambda \times 0.25\lambda$ respectively. The feed networks in [20,21] and [12] use multilayer circuits. Therefore the proposed feed network is the most compact one with single layer circuit and it has the ability of being even more compact if required.

Following previous reports [17,22] and multiple simulations we conclude that changing the form of printed lines does not improve the radiation pattern and beam-width is actually dependent on the total size and shape of QHA. Whereas, it can be observed in [17,22] that the beam-width of the reduced size structure is narrower. It should be noted that this does not mean that one can increase the beam-width by increasing the height of an arbitrary QHA. This concept is only correct for the compact structures that

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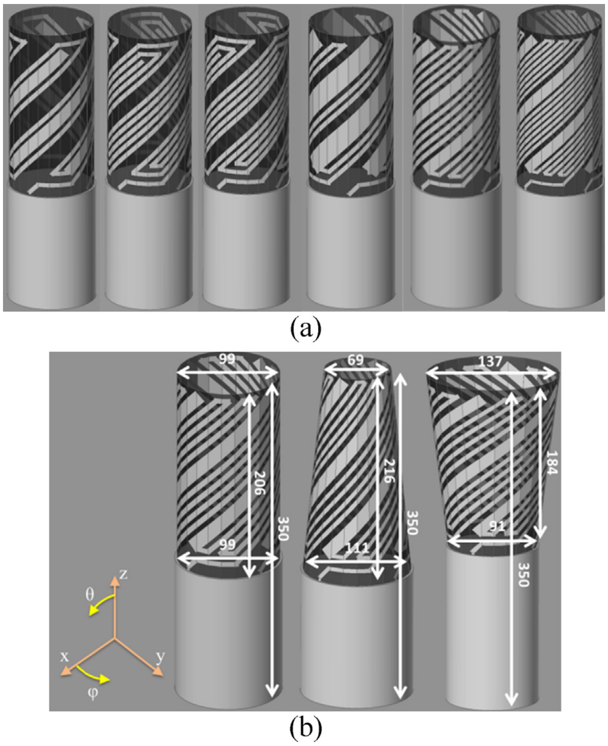

Fig. 1. (a) Schematics of some cylindrical QHAs with different forms of arms and (b) three shapes of cylindrical, conical and inverted conical for the QHA with multi-folded arms, all distances are in millimeters.

have been reached to the threshold of minimization and then the height reduction will bring about the beam-width reduction.

The major problem to achieve the desired beam-width is the restricted height of antenna which is due to the limited space of satellites. Therefore, reforming the cylindrical helix to conical one is studied to obtain wider beam-width without changing the height of structure. In next section, radiation patterns of the printed QHAs with three shapes of cylindrical, conical and inverted conical are compared at three resonance frequencies. Compact feed networks for the three frequency bands of QHAs are presented in Section 3. Also the simulated and measured results of compact Wilkinson power divider of the feed network for 755 MHz are provided in this section. Finally, some measured parameters of the fabricated conical antenna and the feed networks are presented in Section 4.

2. Cylindrical and conical antennas configurations

The effects of changing the form of printed lines as the arms of the QHA are not studied in this paper, since they have been studied in previous papers such as [17]. Presently, some practical forms for the arms of the QHA are shown in Fig. 1(a). The first antenna from the left side is similar to the one in [17] with oblique spirals on a cylinder. The second one has spirals with more number of turns. The third one has similar spirals in reverse direction. The spirals of the first antenna are replaced by folded lines in the fourth antenna and more folded lines are added in the fifth and the last antennas.

The lengths of arms on these structures are different and therefore all resonance frequencies are not similar. Nevertheless, one can control the resonance frequency by changing the lengths of the arms or the number of folds. However, these forms do not vary the radiation parameters such as beam-width and gain significantly, while they depend on total shape and size of the antenna including the underneath conductive support and screen. For example it is obvious that the first resonance frequency of the sixth antenna

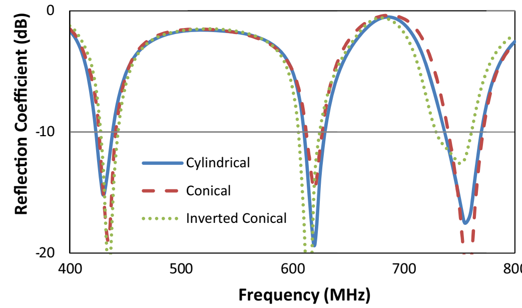

Fig. 2. Simulated reflection coefficients of three antennas.

is lower than the fifth one since it has longer arms. Also if they have one identical resonance frequency, the sixth antenna has more number of lower resonance frequencies than the fifth one while the beam-widths of antennas at this frequency are almost similar. Hence the lengths of arms of QHAs in Fig. 1(a) are adjusted to have a resonance frequency at 435 MHz with similar heights to make a comparison between beam-widths of higher than 3 dB gain, ARs at broadside and the maximum gains of these structures. It can be observed in Table 1 that the QHAs do not have significant distinctions on these parameters at 435 MHz. Therefore the effect of changing total shape of a QHA on the radiation pattern is studied here. In particular, the fifth antenna that has multi-folded printed lines is chosen and three shapes of cylindrical, conical and inverted conical are indicated in Fig. 1(b) for this antenna.

The sizes of antennas are adjusted in order to obtain same resonance frequencies, while the total length of multi-folded line is fixed at 1.27 m for each of them. The heights of the cylinders under the antennas are tuned to make the total heights of antennas equal. Also, the conductive screen under the antenna is assumed to be square and have 35 cm sides and similar Rogers substrate with $h = 0.254$ mm and $\epsilon_r = 202$ is used for all the antennas. The resonance frequencies for three designs are 435 MHz, 620 MHz and 755 MHz as shown in Fig. 2 and thus the total length of multi-folded line is equal to $1.85\lambda_1$, $2.63\lambda_2$ and $3.2\lambda_3$, while λ_i is the corresponding wavelength of the ith resonance frequency. It should be noted that the first resonance frequency is allocated to amateurs' satellite [23].

Radiation patterns of each antenna for the three frequencies at $\phi = 0$ are shown in Fig. 3. It can be observed that the main radiation has left handed circular polarization (LHCP) and the backward radiation has right handed circular polarization (RHCP). Comparison between these patterns concludes the beam-width for conical, cylindrical and inverted conical antennas reduces respectively and the backward RHCP gain reduces in reverse order. A remarkable point for the inverted conical antenna is the high gain in broadside at 755 MHz which reduces the beam-width as shown in Fig. 3(c). Nevertheless, the 2D LHCP patterns for the antennas provide better comparison as shown in Fig. 4 using HFSS, since the region with higher than 3 dB gain is larger for the conical antenna in almost all frequencies. Furthermore, the beam-width of higher than 3 dB gain, AR at broadside and the maximum gain are shown in Table 2, for the three antennas. The AR is less than 1 dB for all three antennas at broadside. For other directions AR can be obtained by comparing LHCP and RHCP radiation patterns of the antennas in Fig. 3.

3. Feed networks

Feed network of the QHA should divide the input power into four equal parts with 90° phase difference between each two adjacent outputs. Simple Wilkinson power dividers and transmission lines can be used for power division and 90° phase shifting respectively. Employing meandered lines can reduce the size of feed network, while compressed structures are preferred for satellite application.