Circular Loop Antenna for Pattern Steerable Applications

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Abstract: A circular loop antenna with feed points on the loop is proposed. This antenna is envisaged to be useful for some beam steering applications. An example of this antenna with 8 feed points is analyzed. The eight feed points are placed symmetrically on the loop, which when excited one at a time steer the beam in eight different directions at steps of 45°. Apart from the direction of the beam, the return-loss, polarization and all other antenna parameters stays the same if the antenna is excited through any of the eight feeds. For the antenna analysed, at the resonating (operating) frequency of 4.4 GHz, the antenna has a directivity of 9.1 dBi with polarization dominance in the E_θ direction.

Introduction: Single element beam steerable antennas are increasingly becoming popular for providing beam steering capabilities without utilizing antenna arrays and associated phase shifters and complex feeding mechanism. The beam steering properties of single element antennas depend upon the antenna geometry. Thus, by changing the antenna geometry electronically the antenna beam can also be maneuvered in space. Single element beam steerable antennas are very useful in different kind of wireless applications such as for 3G, 4G, WiMAX and vehicular applications. The common forms of single element steerable antennas include spiral, square and star antennas. In [1]-[3], the single element spiral antenna with multiple switches is analyzed for pattern reconfigurable properties. The use of switches varies the current distribution along the spiral arm which modifies the current and hence changes the radiation pattern. However, in that antenna, the current distribution variation also introduces the polarization variation (polarization randomness) which is an undesirable effect in some applications. To control the change of polarization behavior, square loop antenna and double square loop antenna were recently introduced in [4] and [5]. Unlike the spiral antenna which is asymmetrical in shape, the square and double square loop antenna structures possess a symmetric geometry and, hence, are able to provide multiple beams in space with the same characteristics for all the radiation patterns. For the square loop antenna [4], the fixed beam steering of 90° steps was achieved using four feeds whereas for double square loop antenna [5], the fixed beam steering in 45° steps was reported using eight feeds. However, both of these antennas steer the beam in fixed steps of either 90° or 45°, thus limiting their usability for some practical applications.

In this paper, the fixed steering step limitation is removed by introducing the single circular loop antenna. By exciting this antenna at an arbitrary point on the loop a tilted beam is generated and can be steered in many (theoretically infinite) specific directions in the space if the feed is moved along the loop. The main advantage of this antenna is that the dimension of the loop can be optimized for a specific beam width for achieving an application specific beam switching step. By benefiting from symmetry, the circular loop antenna is free from polarization randomness and thus exhibits the same properties for each excitation point chosen on the loop.

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The circular loop antenna presented in this work makes use of 8 equally spaced feeds. The eight feeds are chosen to accommodate 8 non-overlapping 3 dB beams (each 3dB beam covering 45° of space) and thus covering the full 360° space azimuthally. Upon activating one feed at a time, the beam can be steered from one point to another thus realizing a steerable antenna.

Antenna configuration: Fig. 1 shows the circular loop antenna which is composed of a conductor strip loop of inner radius r = 19.09 mm whose strip width is w = 1.5 mm. The loop is etched on top of a dielectric substrate of thickness h = 12 mm having a permittivity of $\varepsilon_r = 3.45$ and is backed by a metal ground plane. The antenna is fed at 8 feeding points F_1, F_2, F_3, F_4, F_5, F_6, F_7 and F_8 which are placed symmetrically over the circular loop with an angular spacing of 45°. Due to the symmetrical shape of the antenna, except for the directions of the beam, the performance of antenna is the same for all the feed locations. Thus, only one feed configuration, $F_{1,}$ is analyzed and all other configurations are assumed to yield the same results. The simulations are performed using Agilent ADS Momentum 2008^{TM} software and as this is a planar solver, the ground plane and substrate are assumed to extend to infinity

Results: The antenna is analyzed for configuration F_1 and its return-loss for 50Ω input impedance is shown in Fig. 2. The antenna resonates at a frequency of f_0 = 4.4 GHz. As shown in Fig. 2, antenna shows a -10 dB bandwidth of 550 MHz range from 4.2 GHz to 4.75 GHz. Analyzing the radiation patterns at the test frequency, f_0, it is observed that the antenna generates a tilted beam at $\theta_{max} = 45°$ and $\phi_{max} = 0°$ (Fig. 3). Hence, for F_1 configuration the tilted beam points away from the feeding point. This property of the antenna is the key to obtaining the beam steering of the tilted beam in various quadrants. Fig. 3 (a) reveals that the antenna beamwidth is approximately 45°. Fig. 4 shows the -3 dB beam width patterns for all the eight feeding configurations. Since the feeds are equally spaced apart by 45°, upon switching from one feed to another the beam will also steer in space by 45°, generating a uniform beam switching. It is found that the average directivity of the beams is 9.1dBi and the beams are linearly polarized in the direction of E_θ. It should be noted that by changing the number of excitation points, the antenna beam width can be varied for achieving a desired 3 dB switching steps.

Practical implementation and future work: The results shown in this paper are obtained through simulation. For the practical implementation of the antenna it is very important to negate the effects of inactive feeds on the antenna performance. One method is to shorten the passive feeds to ground as demonstrated in [6]. Another method is by using metamaterials replacing the ground plane. The latter method also reduces the thickness of the antenna. The future work will aim to reduce the cross-polarization component of the tilted beam.

Conclusions: A circular loop antenna with feeds positioned along the loop was introduced for beam steering application. An example of this antenna with eight symmetrical feed points was simulated and analysed. When the feeding points are excited one by one the antenna generates eight tilted beams of identical characteristics covering the space in front of antenna. Since the antenna benefits from symmetry, the return-loss, polarization and all other antenna parameters stays the same for all the eight feeding configurations. The directivity of the antenna for each of the feed configuration was 9.1 dBi with polarization dominance in the E_θ direction.

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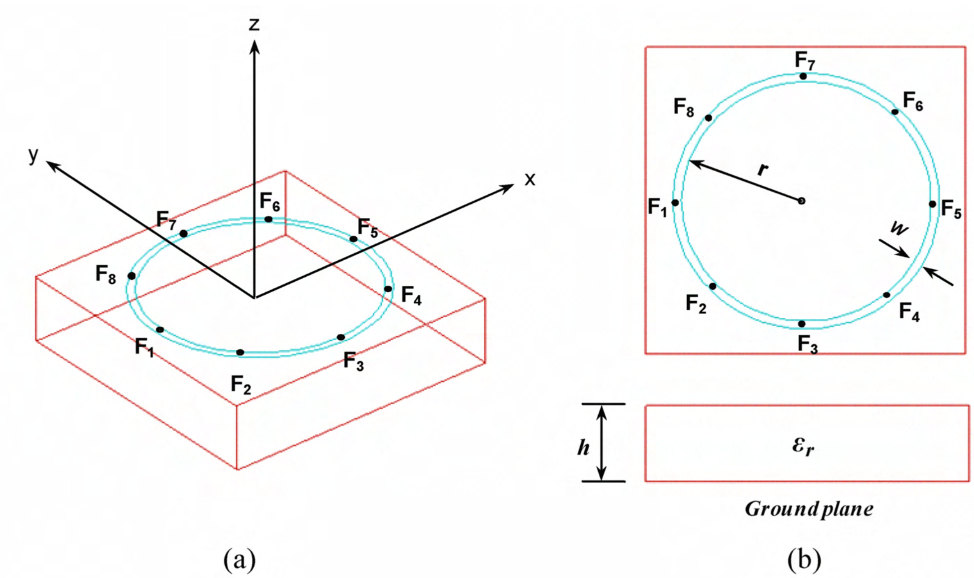

Fig. 1. Circular loop antenna with 8 feeds: (a) Perspective view and (b) Top and side view.

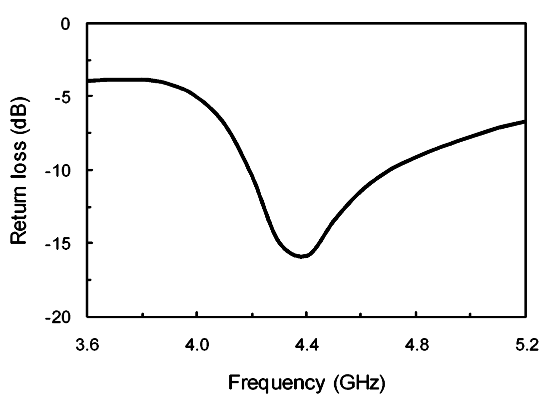

Fig. 2. Return-loss.

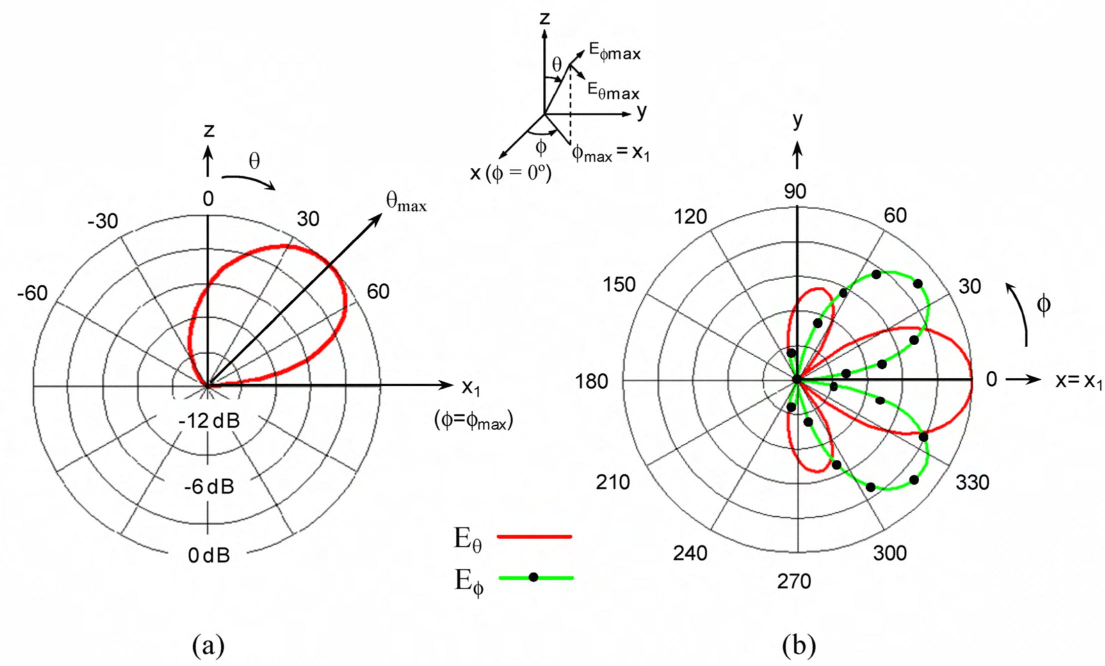

Fig. 3. Normalized Radiation patterns for the feed at F_1 at 4.4 GHz: (a) Elevation cut at $\phi_{max} = 0°$ and (b) Azimuth cut at $\theta_{max} = 45°$.

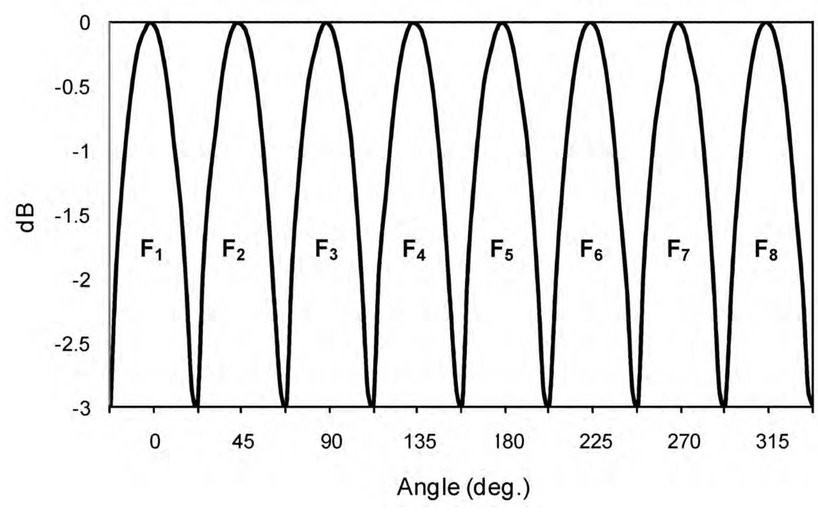

Fig. 4. 3-dB radiation bandwidth at 4.4 GHz for all the eight feeds.