Novel Dual-Polarized Spiral Antenna

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Abstract—A novel multi-arm (N-arm) spiral antenna that provides flexible in control of the radiation pattern and polarization state is described. The antenna has two sets of spiral arms with one set printed on the top side and the other spiral set printed on the bottom side of a planar PCB. These two sets have opposite senses of handedness. The proposed antenna extends the low end frequency of operation as compared to a similar size sinuous antenna. It also provides functionality for radiation pattern control using non-integer excitation modes and reactive loading of spiral arms. The combination of these two control methods offers a capability of steering the radiation pattern null away from the antenna boresight.

Index Terms—spiral arm, multi-arm, spiral array, active region, Archimedean spiral, Sinuous antenna, nulls in circularly polarized patterns, reactive loading, dual-polarized spiral antenna.

I. INTRODUCTION

There is a growing need for re-configurable antennas that allow change of various radiation parameters. These antennas must be simple and small in size in order to be easily integrated with ever-shrinking compact electronic systems. This need is driven by an explosive growth of numerous terrestrial and satellite wireless communication and positioning systems. In the case of some satellite and military systems an antenna must be able to switch its polarization state from left-hand circularly polarized (LHCP) pattern to right-hand circular polarized (RHCP) pattern to a linear pattern [5]. One such antenna with polarization diversity and wideband operation was developed by R. DuHamel in 1987 and is known as the sinuous spiral antenna [1]. The main purpose of the sinuous antenna is to simultaneously respond to opposite senses of polarization, in contrast with the circularly polarized two-arm Archimedes and logarithmic spiral antennas which are blind to orthogonally polarized waves. Compact multi-octave bandwidth two-port dual-RHCP and LHCP and dual-linearly polarized sinuous antennas are commercially available with an integrated quadrature hybrid and absorbing cavity backing [2].

The need exists for pattern re-configurability to create sharp nulls towards interfering RF signals or orient beams toward desired directions for enhanced signal communication and/or detection. The rest of this paper will be focused on a circularly polarized re-configurable wideband spiral antenna that can provide narrow and deep angular nulls in otherwise omnidirectional radiation pattern. The new type of spiral antenna developed and reported in this paper is referred to as a dual-spiral antenna.

The sinuous antenna does not provide sufficient flexibility required for reconfigurable pattern applications. The best performance of the sinuous antenna is achieved when its arms are excited from the inside spiral arm ends rather than the outside spiral arm ends. The space between inside arms is very limited; hence it is difficult to implement a feed structure and/or reactive loads for multi-arm (4 or more arms) sinuous antennas. The proposed new dual-spiral antenna (described in the next section) provides the ability of moving excitation and reactive ports to the outside while maintaining polarization diversity. The increased space between feeding and reactive ports reduces mutual coupling between them and improves polarization purity (reduced Axial Ratio).

The addition of reactive ports to spiral arms allows for pattern control whereby a deep narrow null can be created in the otherwise omnidirectional hemispherical pattern. Satellite based communication/location systems have many benefits (i.e. global reach); they are however susceptible to RF jamming, and interference. The presence of a deep null in the antenna radiation pattern (30-50 dB) can significantly reduce the level of the interfering signal and prevent receiver front-end saturation.

II. PROPOSED NOVEL DUAL-SPIRAL ANTENNA

The dual-polarized spiral antenna design is compared to a typical sinuous antenna of the same size. Various simulations with FEKO electromagnetic commercial software were conducted to determine the radiation patterns, polarization purity and bandwidth performance.

A. Sinuous Antenna Example

A sinuous antenna is simulated using FEKO. The generating function for the sinuous curve in polar coordinates is given by:

\[
\phi(r) = (-1)^p \cdot \alpha \cdot \sin \left( \frac{\pi ln(r/R_p)}{ln \tau} \right) + \delta \tag{1}
\]

where \( p = 1 \cdots P, \ R_{p+1} \leq r \leq R_p, \ R_{p+1} = \tau R_p, \ 0 < \tau < 1 \)

The spiral curve swings back and forth between the polar angles of \( \phi = \pm \alpha \) as the radius increases in value from its minimum \( r_{min} = R_1 \) to its maximum value. The angle \( \delta \) is the sweeping angle of the sinuous curve, see Fig. 1.
The simulated antenna structure is based on the DuHamel’s recommended values of $\alpha = 45^\circ$ and $\delta = 22.5^\circ$. The intended antenna frequency of operation is from 0.8-5.0 GHz. The starting radius is 6mm and ending radius is 60 mm. The antenna is backed by a shallow cavity (15 mm) with an overall cavity radius of 75 mm. A shallow metallic backing cavity is used to provide an unidirectional beam above the antenna aperture. The antenna is simulated in both feed configurations (outside and inside excitation). Fig. 2 shows that the sinuous antenna bandwidth is smaller when fed from the outside. The radiation pattern of the sinuous antenna using outside excitation is quite distorted at frequencies of 2 GHz or higher when compared to a sinuous antenna that uses the inside excitation method.

The degraded performance of sinuous antenna with outside excitation at higher frequencies is due to a significant undesired radiation from the outside perimeter of spiral antenna aperture. Using the phased array terminology, we can think in terms of “grating lobes” that come into visible space when the $\lambda/2$ condition is violated. The closest distance between any pair of adjacent excitation ports is $\lambda/1.77$ at 2 GHz. Refer to Fig. 4 for the current distribution at 2 GHz. One can see a significant radiation occurring at the outside perimeter (left image) for the sinuous antenna excited from outside.

**B. Proposed Dual-Polarized Spiral Antenna**

The proposed dual-polarized spiral antenna allows the current to flow in the second spiral structure that is a mirror image of the first structure. Both spiral structures are parallel to each other (printed on opposite sides of the PCB) and the inner spiral arm ends are joined together as shown in Fig. 5 using vertical vias. This configuration supports multiple polarization radiation patterns similar to the sinuous antenna. The difference is in the fact that the sinuous antenna is an
equiangular type while this is an Archimedean type and provides lots of space for the placement of multiple signal feeding ports. In our case we have eight available ports on the outside perimeter of the dual-spiral antenna. The antenna occupies the same area as the sinuous antenna and is placed above the same shallow metal cavity.

The second spiral structure supports the same circular handedness (right and left) of the radiated signal. In any spiral structure, the reflected waves from the spiral ends travel in the spiral structure in the opposite direction and hence contribute to radiation of cross-pol components of the radiated wave. In the case of the proposed antenna, the handedness is reversed so the current flowing back towards the excitation area and will contribute to the co-pol component of the radiated wave.

In addition, the extended length of the antenna should theoretically extend the bandwidth of the antenna towards lower frequencies (for the same antenna gain). The simulated structure of the proposed antenna is shown in Fig. 6.

III. SIMULATION RESULTS

The main design focus was on a planar four-arm Archimedean type spiral topology with tight winding (spacing of 1 mm and trace width of 0.5mm) and 15 turns. An eight-arm spiral structure was also simulated at limited frequencies.

A quick comparison of Fig. 7 and Fig. 2 shows that the dual-spiral antenna has an increased current intensity in the vicinity of its “active region” as opposed to the outside region. This translates to better radiation patterns as shown in the next Figs. 8 to 10.

The improved performance at low frequency is confirmed in Fig. 8. This is an expected outcome, since the dual-spiral antenna is electrically much longer than the sinuous antenna. The simulated peak gain on antenna boresight at 0.7 GHz is 5-
7 dB higher for the dual-spiral antennas when compared to the sinuous antenna peak gain off boresight.

### IV. NULL FORMING CAPABILITIES

An example of the capability of null forming is demonstrated for the case when the spiral arms are excited with Mode 1 phase gradient normally associated with 8-arm spiral antenna, see Fig. 11.

Changing the sign of the phase gradient between successive feeding ports, changes, as expected, the polarization handedness of the radiation pattern. The null at theta=25° is present for both cases of antenna excitation. Steering the null in the azimuth plane (phi) in increments of 2π/N is achieved by means of sequential rotation of excited ports located on the primary spiral structure while additional “fine” steering can be obtained by reactive loading of the outside spiral ends attached to the secondary spiral structure [3].

A combination of various phase gradients between excited ports of the upper spiral structure and reactive termination of lower spiral structure is presented in Fig. 12. The null theta angle was moved from 25° down to approximately 60°. A 2.0 dB drop in peak gain is also observed for this case, however this is a small price for an ability to reduce an interfering signal by 30 dB before it is amplified by the RF front end.

Figs. 9 and 10 confirm that the dual-spiral antennas produces vertical patterns comparable to the sinuous antenna, while being excited from the outside ends of the spiral s of the antenna structure.
Spiral antennas have a natural ability to excite various modes of operation which translates into a diversity of radiation patterns. It was demonstrated that the new antenna extends the operating bandwidth towards lower frequencies (or provides more gain at the same frequency) as compared to a sinuous type antenna.

The new design allows the excitation of the antenna using outside ports while doubling the number of available excitation points (located at the spiral arm outside ends). The increased degree of freedom offers various mechanisms for pattern control to be applied. One method of pattern control is implemented by a combination of the varying phase gradient between successive excitation ports and various reactive loads at parasitic ports (non-excitation ports).

The simulated peak antenna gain is on average between +7 to +10 dBiC. In normal spiral configurations, the average antenna peak gain is about 5-6 dBiC for the sinuous antenna type. The simulated increase in gain or antenna efficiency by 3 dB is likely due to two spiral antennas working together in cascade. A capability to create nulls with depth of 35-40 dB below the peak gain was also demonstrated.

The efficiency and peak gain of the antenna drops when nulls are present in the radiation pattern. This is mainly due to the unbalanced type of feeding mechanism applied in order to generate a null in radiation pattern.

A prototype antenna is being designed and constructed for experimental verification of these simulation results.

REFERENCES