A Novel Radiation Pattern and Frequency Reconfigurable Single Turn Square Spiral Microstrip Antenna

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***Abstract*—This paper presents a novel pattern and frequency reconfigurable microstrip antenna that uses switched connections. The basic antenna operates with linear polarization around 3.7 GHz. One set of connections provides a re-directed radiation pattern while maintaining a common operating impedance bandwidth with the baseline configuration. The second set of connections results in operation at a higher frequency band at 6 GHz with broadside patterns. Measured results of the three antenna configurations are provided. Potential applications of this reconfigurability and directions for future work are discussed.**

***Index Terms*—Microstrip antenna, reconfigurable antenna.**

I. Introduction

RECONFIGURABLE antennas have the potential to add substantial degrees of freedom and functionality to mobile communication applications and phased array systems. Most reconfigurable systems concentrate on changing operating frequency while maintaining radiation characteristics (e.g., [1]–[3]). However, changing radiation patterns while maintaining operating frequency and bandwidth could greatly enhance system performance. Manipulation of an antenna's radiation pattern can be used to avoid noise sources or intentional jamming, improve security by directing signals only toward intended users, serve as a switched diversity system, and expand the beamsteering capabilities of large phased arrays.

This work introduces a reconfigurable single turn square spiral microstrip antenna capable of both pattern and frequency reconfigurability. Using a two-switch design, a 45°-main beam tilt from boresight over a shared S-band 2 : 1 VSWR bandwidth with the basic configuration as well as a frequency shift to C-band can be obtained. In this study, switching elements are hard-wired for proof of concept, but scaling in frequency will allow the use of MEMS switches in the future. The following section details the reconfigurable antenna design. Section III provides frequency and radiation patterns of all three configurations. Finally, Section IV discusses potential applications of this reconfigurability and directions for future work.

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II. Reconfigurable Antenna Design

The basic antenna is a single turn square microstrip spiral, geometrically similar to the monofilar spiral [4]. While this structure is also related to the curl antenna [5], [6] in many respects, one major difference to note is that this antenna is a standing wave structure on a very thin substrate as opposed to the curl antenna, which is a traveling wave structure on a relatively thick substrate [5], [6]. Antenna dimensions along with switching elements are shown in Fig. 1. The total length of the spiral is 80 mm, and is determined by approximately one wavelength around the desired operational frequency [4], [5]. The coaxial probe feed is located as close as possible to the edge of the innermost end of the spiral conductor. The gap between the first and last linear spiral sections is 1.0 mm. The antenna is centered above a lateral substrate/ground plane area of 34 by 36 mm. The first configuration of the proposed reconfigurable antenna is that of the base geometry where no tuning elements are added. Hence, moving counterclockwise from the top-left corner, the first tuning element is N, no ground, and the second tuning element is S, an in-line short, creating the NS configuration.

A. Pattern Reconfigurability

The original antenna configuration with no tuning elements is approximately one wavelength long. To reconfigure the pattern, two tuning elements are required. The first tuning element is a short to ground, G, that has a shorting pin diameter, d_{short}, equal to 1.23 mm. This grounding pin is positioned at about one quarter wavelength from the feed position. The second element is an open, O, that has a spacing width, w_{open}, of 1.0 mm. With the shorting pin and the in-line open present (the GO configuration), the antenna behaves more as a shorted quarter-wavelength resonator with a parasitic element that helps to maintain the impedance match and create the shifted radiation pattern.

B. Frequency Reconfigurability

To change the operating frequency of the antenna, only one of the tuning elements, the in-line open, is activated. In this mode, the antenna (in the NO configuration) acts as an open-circuited one-wavelength resonator, resulting in a shift in the operating frequency band. At this higher frequency, the coupling to the parasitic arm formed by the in-line open is reduced, resulting in a good impedance match with broadside radiation patterns.

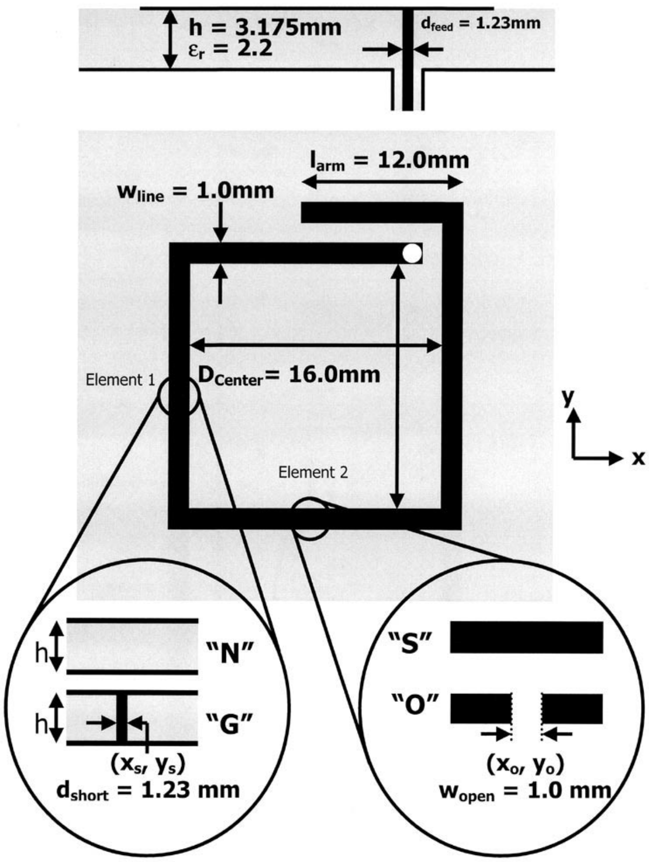

Fig. 1. Antenna geometry showing switches necessary for reconfiguration.

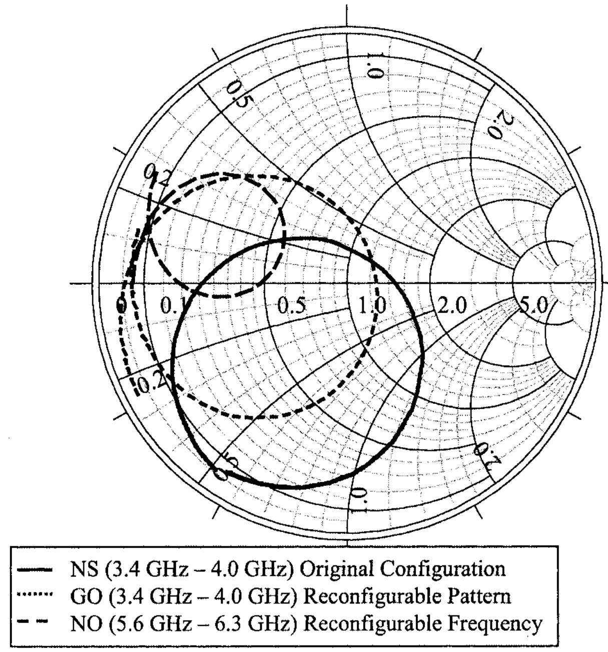

Fig. 2. Measured input impedance of the original configuration (NS), the reconfigured radiation pattern (GO), and the reconfigured frequency (NO).

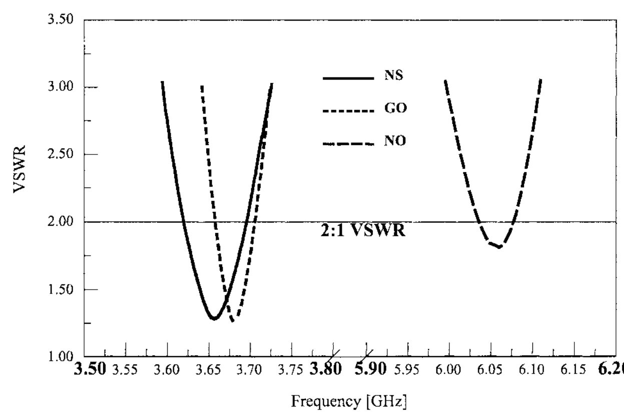

Fig. 3. Measured VSWR values corresponding to the measurements of Fig. 2 that illustrate the common bandwidth of the original (NS) and the radiation reconfigured (GO) antennas.

III. Results

Measurements of impedance and VSWR for the three configurations of the spiral antenna are shown in Figs. 2 and 3 respectively. Fig. 3 illustrates the shared 2 : 1 VSWR between the first configuration, NS, and second configuration, GO, around 3.68 GHz. Fig. 3 also shows the frequency difference between the first configuration, NS, and third configuration, NO, which operates at 6.02 GHz. The measured and simulated gain patterns for all three configurations in the E- and H-planes are depicted in Fig. 4. Simulations were performed using IE3D [8]. The E-plane is designated as the x–z plane (with $+90^\circ$ designated as the positive x axis) and the H-plane is designated as the y–z plane (with $+90$ degrees designated as the positive y axis). The observed changes in antenna behavior with hard-wired connections for the switching elements show very little variation with the dimensions of either the shorting pin radius or in-line open gap. The agreement between measurement and simulation is very good for all configurations except for the magnitude of the plots in the GO case. In this case, the simulation package may not adequately model the effects of the shorting pin to ground, resulting in an impedance mismatch and lower gain than is actually the case.

The pattern reconfigurable NS and GO pair is discussed first. The configurations share a 50 MHz 2 : 1 VSWR bandwidth. Over this shared bandwidth, the measured patterns and gains of each antenna remain essentially constant. The maximum directive gain of each antenna is about 4 dBi. The first configuration (NS) exhibits a well-behaved broadside pattern with linear polarization along the diagonal since the x-directed and y-directed polarizations are in phase. The 3-dB beamwidths are approximately 90° in both planes. The second configuration (GO) undergoes a significant 45°-shift in direction while maintaining linear polarization. The 3 dB beamwidths for this configuration in the E- and H-plane are 125 and 75 degrees, respectively.

The frequency reconfigurable pair (NS and NO) is now compared. With the change in operating frequency, the radiation patterns maintain broadside linear polarization with a rotation to a purely co-polar direction rather than the diagonally oriented polarization demonstrated by the NS configuration. The NO configuration exhibits higher maximum gain (~5.6 dBi) and correspondingly more narrow 3-dB beamwidths (84° and 65° in the E- and H-planes, respectively) than the NS configuration.

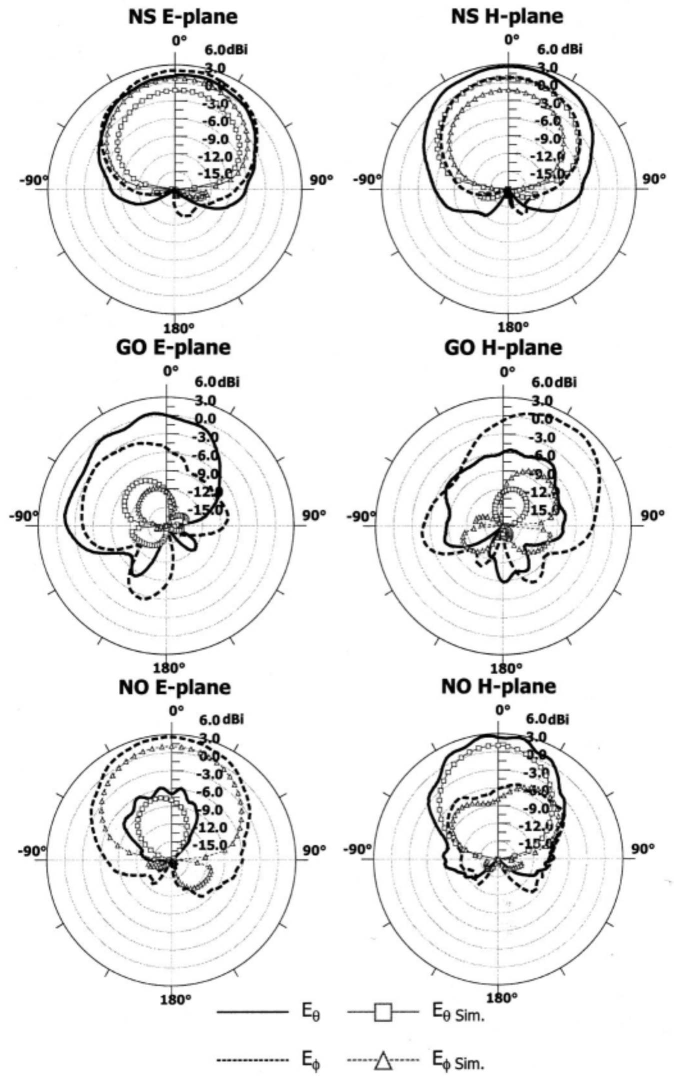

Fig. 4. Measured and simulated gain [dBi] in the E-plane and H-planes for the three configurations.

IV. Discussion and Conclusion

A pattern and frequency reconfigurable single turn square spiral microstrip antenna has been presented. The antenna provides useful frequency and radiation characteristics with a small number of switches. Implementation of pin diodes and MEMS switches into scaled versions of this antenna is underway.

This device represents a new paradigm in individual antenna element design that can be used to greatly expand the capabilities of both portable wireless devices and large phased arrays by providing additional degrees of freedom in element pattern and frequency to achieve new levels of performance. Future work includes the broadening of the operating frequency bands with the addition of spiral turns and the creation of other frequency-stable radiation patterns with the inclusion of more switching elements.

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