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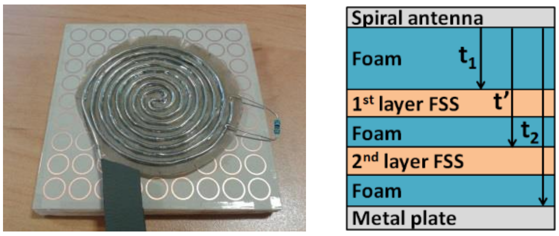
Performance of an Archimedean spiral antenna backed by a FSS reflector

S. Mohamad, R. Cahill, and V. Fusco

This letter investigates the use of a backing cavity composed of a frequency selective surface (FSS) above a metal plate as a means to supress the backlobe radiation and increase the gain of an Archimedean spiral antenna which operates from 3 to 10 GHz. The FSS is designed to reflect signals in the upper band (7 – 10 GHz) with a loss <0.25 dB, and allow transmission in the lower band (3 – 6 GHz). Good impedance match and bidirectional to unidirectional beam transformation is obtained when the FSS and metal plate are inserted a distance λ/4 below the spiral at the centre of the upper and lower bands respectively. Simulated and measured radiation patterns are employed to show the performance enhancement which is attributed to the FSS reflector.

Introduction: The Archimedean spiral is a class of frequency independent antennas which generate circularly polarised bidirectional radiation with equal power in the upper and lower hemisphere [1]. Significant pattern distortion is often observed when low gain antennas strongly illuminate the platform on which they are mounted [2], therefore suppression of backlobe energy is desirable for applications that require unidirectional coverage. For planar spirals this is normally obtained by backing the antenna with a cavity containing an electromagnetic absorber. However a major disadvantage of this classical arrangement is that 50% of the radiated energy is dissipated in the load. A more efficient method, which can increase the antenna gain by 3 dB, is to insert a flat metal plate λ/4 distance below the radiating aperture. However this technique is only suitable for narrow band operation, therefore a wideband spiral would require the deployment of a more advanced ground plane architecture to reduce performance degradation in terms of impedance mismatch and high crosspolarisation [3] at low frequencies, and beam distortion at high frequencies [4]. In [5] the authors reported on a structure composed of eight unequal size metal rings placed one quarter wavelength below the corresponding active regions of an Archimedean spiral. Although the antenna was shown to work from 3 to 10 GHz, the 3D metal step arrangement used to suppress the backlobe radiation was complicated to manufacture and difficult to position precisely below the discrete active regions.

In this paper we report on a much simpler cavity design which consists of a FSS that reflects strongly between 7 – 10 GHz (upper band) and simultaneously allows transmission between 3 – 6 GHz (lower band). The FSS and metal plate are inserted λ/4 (at 8.5 GHz and 4.5 GHz respectively) distance below the antenna, thus forming a cavity which effectively presents two stacked ground planes, one for each band. Unidirectional operation of the new configuration is demonstrated by comparing the predicted VSWR, gain, front-to-back (F/B) ratio, axial ratio and measured radiation patterns at the edges of the two bands, to the performance obtained from an identical unbacked spiral antenna.



a *b*

Fig. 1 *(a) Photograph of spiral antenna on FSS array, and (b) side view of cavity (2-layer FSS and metal plate) -backed spiral antenna with* $t_1 = \lambda/4$ *at 8.5 GHz (8.8 mm), t' = 13.1 mm,* $t_2 = \lambda/4$ *at 4.5 GHz (16.7 mm)*

Antenna and FSS Design: The electromagnetic performance of the two-arm, four-turn Archimedean spiral antenna was simulated using CST MICROWAVE STUDIO software. The antenna was designed to generate predominantly RHCP signals and operate in the frequency range of 3 to 10 GHz with an inner and outer diameter of 4 mm and 60 mm respectively (Fig. 1(a)). The width and spacing between the conductors are both set to 1.65 mm to realize a constant 188 Ω input impedance self-complementary structure [5] and is center fed in anti-phase with equal amplitude signals at two excitation ports separated by a distance of 0.5 mm. For this application the FSS is required to separate the closely spaced upper (reflection) and lower (transmission) frequency bands with low loss as shown in Fig. 2 (ideal case). Two identical periodic screens were employed in the design to achieve a fast transmission roll off below resonance [6]. In this way the phase response of the individual arrays can be controlled so as to generate a transmission peak very close to the edge of the reflection band at 6 GHz [7]. Each doubly periodic FSS is composed of a 78 × 78 mm^2 array of conductive rings arranged on a square lattice with mean diameter 7.7 mm and periodicity 8.7 mm. In the numerical simulator the rings are placed on a 0.28 mm thick low loss high permittivity substrate ($\varepsilon_r = 10$) in order to reduce the physical size of the unit cells. The individual screens were designed to resonate strongly at 8.5 GHz and as shown in Fig. 2 a satisfactory performance is obtained across the upper band (7 – 10 GHz) where the minimum reflectivity is 95%, however very high transmission loss is observed at the upper edge of the lower band, ~ 80% at 6 GHz. A significant improvement is predicted when the two FSS layers are stacked using a 4 mm thick foam spacer (Fig. 1(b)). For this arrangement the transmission loss is reduced to 4.5% (0.2 dB) at 6 GHz and higher reflectivity is obtained at all frequencies in the upper band.

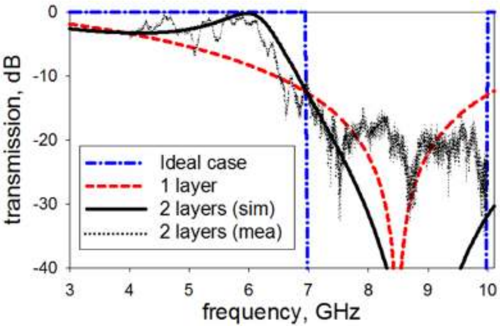


Fig. 2 *Simulated transmission coefficients,* S_{21} *(dB) of FSS; ideal case, 1-layer and (measured) 2-layer structure*

Simulated results: Fig. 3(a) shows that the predicted VSWR (referenced to 188 Ω) of the antenna in free space is flat and < 1.3 above 2 GHz, however the cavity backed spiral is less well matched in the lower band where in regions the VSWR exceeds 2:1. For the latter arrangement the increase in the computed gain is typically 3 dB between 3 – 10 GHz.

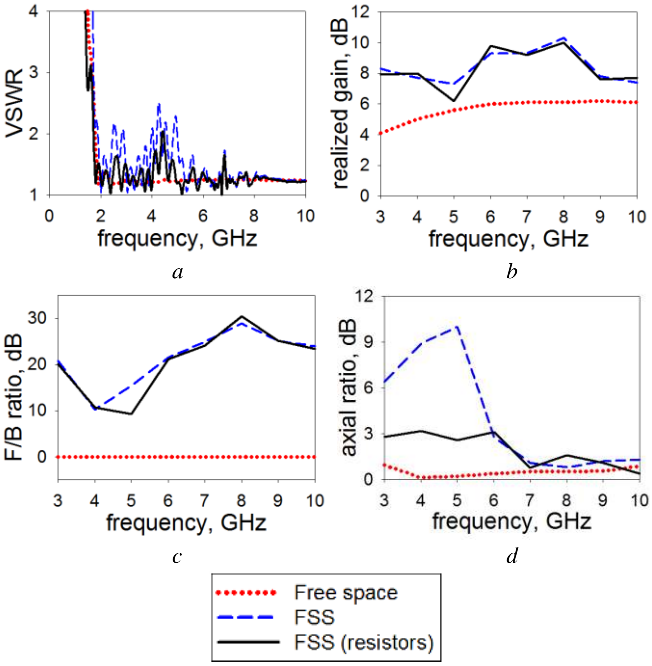


Fig. 3 *Simulated performance of free space and 2-layer FSS and metal backed spiral antenna, with and without 560 Ω termination resistors; (a) VSWR (ref: 188 Ω system), (b) realized gain, (c) front-to-back (F/B) ratio, and (d) boresight axial ratio*

As a general observation the gain variation shown in Fig. 3(b) is attributed to changes in the beam shape and pattern symmetry which generally degrades when a ground plane is inserted below a spiral antenna [5]. The suppression of the dominant cross-polar backlobe is quantified in Fig. 3(c) where the front- (RHCP) to-back (LHCP) ratio of the FSS backed antenna is between 10 and 29 dB higher than a free space spiral, however the boresight axial ratio (Fig. 3(d)) of the unidirectional beam antenna is much higher in the lower band. At these frequencies the active region is close to the truncated edge of the spiral, therefore the predicted increase in the crosspolar energy [5] and degradation of the impedance match (Fig. 3(a)), is probably caused by residual current reflected from the open end of the two conductors. To confirm this hypothesis, in the computer model we inserted 560 Ω resistors at the end of the two arms to suppress the reflected current. The results plotted in Fig. 3 show that this modification significantly improves the VSWR and axial ratio in the lower band without causing a major reduction in the gain and F/B.

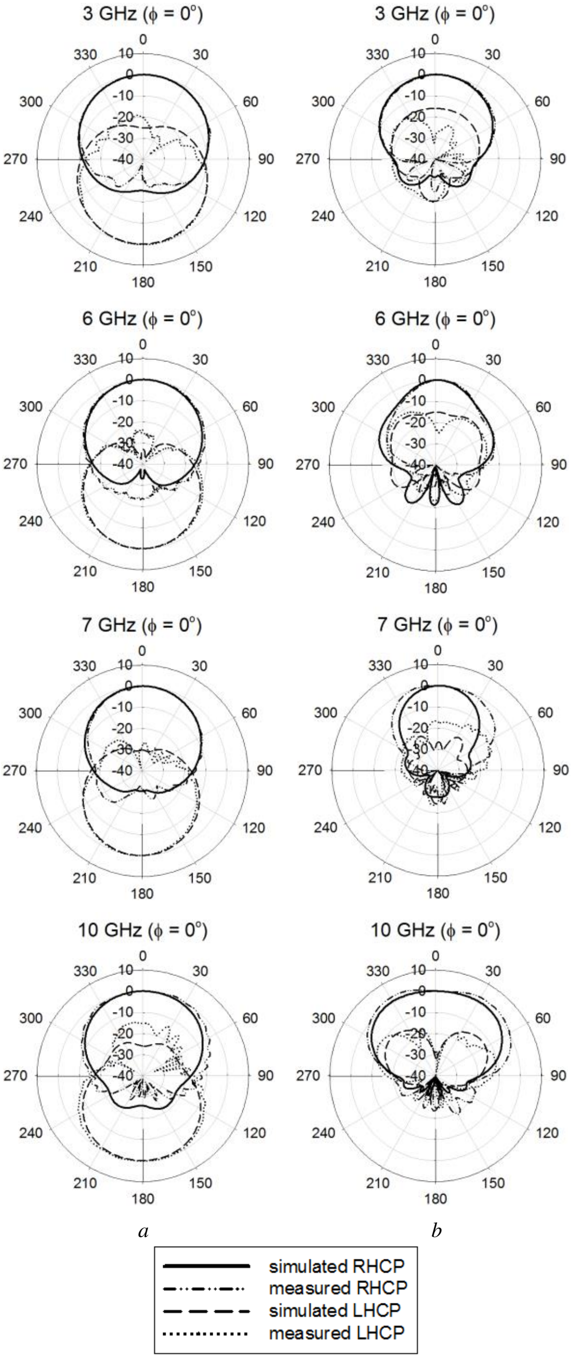


Fig. 4 *Normalized predicted and measured co-polar (RHCP) and cross-polar (LHCP) beams generated by the spiral antenna at frequencies 3, 6, 7 and 10 GHz (a) in free space, and (b) with 560 Ω resistors and FSS reflector*

Fabrication and measured results: The spiral was printed on 0.13 mm thick Taconic TLY-5 substrate (ε_r = 2.2 and tanδ = 0.0009), and soldered to a 1.1 mm diameter 50 Ω semi-rigid cable which was formed to replicate the geometry of the two arms (Fig. 1(a)). An infinite balun was used to excite the antenna at the center feed points spaced 0.5 mm apart. This simple feed arrangement permits the radiation patterns to be measured without the need to deploy a transformer to match the spiral impedance to 50 Ω. The two FSS sheets were each patterned on a 0.28 mm thick, 78 × 78 mm^2 sheet of Taconic CER-10 material (ε_r = 10, tanδ = 0.0035). Construction of the cavity backed antenna was completed by bonding Rhoacell low density foam spacers (ε_r = 1.05) to the surface of the FSS layers, the metal ground plane, and the spiral antenna to form the sandwich structure illustrated in Fig. 1(b). Fig. 2 shows reasonably good agreement between the simulated (assumed to be an infinite size array) and the measured transmission response of the physically small FSS which exhibits ripples that are attributed to truncation effects. Fig. 4 depicts the normalized predicted and measured co-polar (RHCP) and cross-polar (LHCP) radiation patterns for the antenna in free space and placed above the FSS backed spiral with 560 Ω resistor soldered to the open end of one arm and a thin strip of microwave absorber placed on the other. The radiation patterns are plotted at the edges of the two bands (3, 6 and 7, 10 GHz) and only in the ϕ=0º plane for brevity. Fig. 4(a) shows that the antenna in free space exhibits bidirectional radiation at all frequencies with equal gain and opposite polarizations in the forward and back hemisphere. The backlobe suppression obtained by placing the spiral above the FSS is illustrated in Fig. 4(b), and for both arrangements the agreement between the measurements and simulations is generally quite good.

Conclusion: Experimental and numerical results have been used to study the increase in gain and front-to-back ratio which is obtained when an Archimedean spiral is backed by a carefully designed metal backed two layer FSS. The cavity backed spiral antenna operates without the need for mechanical repositioning of the reflector at each frequency and is a much simpler arrangement with fewer layers compared to previously published solutions [5].

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S. Mohamad, R. Cahill and V. Fusco *(The Institute of Electronics, Communications and Information Technology (ECIT), Queen's University Belfast, Northern Ireland Science Park, Queen's Road, Queen's Island, Belfast BT3 9DT, Northern Ireland, UK)*
E-mail: r.cahill@qub.ac.uk

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