A New Trapezium FSS Superstrate for Antenna Gain Enhancement

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Abstract—In this paper, a new frequency selective surface (FSS) for antenna gain enhancement is proposed. The antenna and FSS have an isosceles trapezium geometry. Three different versions of an antenna are created. For each version, the S-parameters S11 and S21 were simulated with the software CST Microwave Studio®. Then, one of the three trapezoid antennas is simulated with an FSS. These two devices, antenna and FSS, were manufactured and had the S11 and S21 parameters measured at the laboratory. The resonance frequency obtained for the trapezium FSS was equal to 2.27 GHz for $\alpha$ equal to 0°, 2.70 GHz for $\alpha$ equal to 15° and 3.12 GHz for $\alpha$ equal to 30°. The simulated antenna gain increased when the FSS is used as superstrate. Without the presence of the FSS, a maximum gain of approximately 1.50 db occurs at 2.20 GHz, when using the FSS as superstrate, the gain increases to approximately 5.25 db. The measured results agree with the simulated results.

Keywords—Antenna; Frequency Selective Surface (FSS); Gain Enhancement.

I. INTRODUCTION

Until the 1930s, antennas were wire-based devices. Since then, other types of antennas have been developed resulting in successive bandwidth increase. Another important factor improving antennas is the microstrip antenna emergence, in the 70’s. These devices are lightweight, discrete, low-cost and surface-moldable [1].

An FSS can be defined as a periodic arrangement of conductors or apertures, capable of filtering certain frequencies [2]. Recently, FSS is being used to modify the microstrip antennas parameters, such as the gain and radiation pattern. In [3], an FSS is used as reflector of a high gain UWB (ultra-wide-band) microstrip circular monopole antenna.

An FSS formed by double rectangular ring elements is used to improve the bandwidth and gain of V-shaped microstrip antennas as shown in [4]. FSS devices can be composed of two different dielectric plates with properties and thicknesses of different materials, both highly reflective and capable of improving the gain and the directivity of a planar antenna [5].

Several types of UWB antennas can also present an increase in their gain through an FSS, without compromising their bandwidth; as can be seen in [6], where an FSS is used in a horizontally polarized slit antenna for high-gain UWB applications.

Two reflective FSS resonating at 5.5 GHz were placed at an angle of 90° and maintained at a specific distance from a monopole antenna. The reflector improved the bandwidth (at -10 dB) of the antenna between 20% and 44%, as well as its gain, leading to a higher directive radiation at 5.5 GHz, maintaining the omnidirectional radiation at around 3 GHz [7].

This work describes the simulated and experimental results of an antenna using an FSS as superstrate, operating at S-band (2.0 to 4.0 GHz). The antenna and the FSS have the geometry of an isosceles trapezium.

The use of the ISM (Industrial Scientific and Medical) band at 2.4 GHz is becoming more important in terms of wireless communications and wireless sensor networks. In addition, a large number of applications based on these technologies is possible in the future, and the development of appropriate antenna designs is of vital importance in this process [8].

II. TRAPEZOID ANTENNA AND TRAPEZIUM FSS

Fig. 1 shows the geometry of the trapezium FSS and Fig. 2 shows the geometry of the trapezoid antenna. For both figures, the yellow region represents the FR-4 substrate with relative electrical permittivity $\varepsilon_r$ of 4.3, tangent loss of 0.025 and thickness of 1.6 mm, while the green region represents the copper material. Table I shows the trapezoid antenna and the FSS parameters. A CPW transmission line powers the antenna. A characteristic impedance of 50 $\Omega$ is used, corresponding to CPW gap and width of $j = 0.3$ mm and $w = 3.0$ mm, respectively.

The angle $\alpha$ in the Fig. 2 varies between 0° and 55.40° reaching its maximum value ($\alpha_{max}$) when the smaller base becomes only one point. In this case, a triangle is formed instead of a trapezoid.

The trapezoid antenna is simulated by placing the FSS as a superstrate at a distance of 22 mm, as shown in Fig. 3. The FSS is a 3 x 3 matrix of unit cells with $\alpha$ equal to 30°. The gain values of the antenna are simulated with and without FSS.

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Fig. 1. Trapezium FSS dimensions.

Fig. 2. Trapezoid antenna dimensions.

Fig. 3. Antenna and FSS as a superstrate (arrangement for simulation).

Fig. 4. Measurement setup.

TABLE I.

| Parameter   | a   | b   | c   | d   | e   | f   | g   | h   | i   | j   |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| FSS         | 9.7 | 9.7 | 3.0 | 1.2 | 2.8 | -   | -   | -   | -   | -   |
| Antenna     | -   | -   | -   | -   | -   | 9.7 | 4.4 | 0.3 | 4.5 | 0.3 |

A. Measurement

The trapezium FSS and the trapezoid antenna with $\alpha$ equal to $30^\circ$ are fabricated with the dimensions provided in Table I. The FSS is placed 22 mm apart from the trapezoid antenna with the use of an acrylic piece as support (see Fig. 4). The S11 and S21 plots are obtained for this configuration using an Agilent Technologies E5071B Vector Network Analyzer that had one of its ports connected to the antenna through a coaxial cable and SMA connector.

The behavior of the antenna and FSS set is analyzed for different angles of antenna and FSS mismatch. Results of simulation and measurements are obtained considering that the FSS in Fig. 4 is $0^\circ$ lagged with respect to the antenna.

III. RESULTS AND DISCUSSIONS

Antenna and FSS simulations with three values of $\alpha$ ($0^\circ$, $15^\circ$ and $30^\circ$) resulted in the antenna return loss shown in Fig. 5, the transmission coefficient S21 of the FSS is shown in Fig. 6. In Fig. 5, the resonance frequency of the trapezoid antenna is 2.45 GHz for the three $\alpha$ values. The reflection coefficient decreased when increasing the angle, which results in S11 of approximately -15 dB when $\alpha$ is equal to $30^\circ$.

In Fig. 6, the resonance frequency obtained for the trapezium FSS is equal to 2.27 GHz for $\alpha$ equal to $0^\circ$; 2.70 GHz for $\alpha$ equal to $15^\circ$ and 3.12 GHz for $\alpha$ equal to $30^\circ$. This is due to the fact that with the increase of $\alpha$ angle, the FSS decreases its perimeter, starting to resonate at higher frequencies.

Simulated gain curves with and without the presence of the FSS superstrate can be visualized in Fig. 7. Without the presence of the FSS, a maximum gain of approximately 1.50 dB occurs at 2.20 GHz. When the FSS is used as a superstrate, the gain increases to about 5.25 dB. Thus, an increase in antenna gain at 2.20 GHz of approximately 4.00 dB is obtained. In the entire frequency range (1.70 to 3.00 GHz), shown in Fig. 7, the simulated gain curve with the FSS as superstrate presented higher values, when compared to having only the antenna element.

The measurements described in Fig. 4 resulted in the curves of S11 in Fig. 8. These graphs are practically identical for all four positions where the FSS is tested.

The return loss of the trapezoid antenna is shown in Fig. 5. The simulated S11 value is approximately -14 dB at 2.50 GHz.
while the measured value is -20 dB at 2.65 GHz. Thus, the measured S11 presents a better result compared to simulations, taking into account a frequency shift of 150 MHz.

Fig. 5. Simulated return loss for the trapezoid antenna with $\alpha = 0^\circ$, 15° and 30°.

Fig. 6. Simulated transmission coefficient for the trapezium FSS with $\alpha = 0^\circ$, 15° and 30°.

Fig. 7. Simulated antenna gain with and without FSS as a superstrate.

IV. CONCLUSION

This work proposes the use of an FSS of unprecedented geometry to increase the gain of a trapezoid antenna. The design is demonstrated by analyzing S11 and S21 curves of the antenna and simulated antenna gain.

The antenna is simulated with and without the trapezium FSS. The presence of the FSS increased the antenna gain, besides shifting its resonance frequency. These two devices, antenna and FSS, are manufactured, where S11 and S21 parameters are measured in the laboratory. The simulated and measured values show good agreement.

The use of the FSS as antenna superstrate improved the gain of the latter in up to 3.5 dB at some frequencies.

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