Design of a broadband and high gain antenna with an inhomogeneous and uni-period structure for Ku-band applications

Jui-Hung Chen, Chun-Yih Wu, Ta-Chun Pu and Hung-Hsuan Lin
Industrial Technology Research Institute
Information & Communications Research Laboratories
M400, Bldg. 14, 195 Sec. 4, Chung Hsing Rd., Chutung, Hsinchu 310, Taiwan
Email: rhchen@itri.org.tw

1. Introduction

In past few decades, lots of researchers investigated the high gain antenna designs for high data rate and point-to-point RF-transmission applications. In order to achieve higher gain for a planar antenna, multi-source or array approach is usually applied [1]. It could achieve uniform current distribution and get good aperture efficiency by dedicatedly adjusting the feeding network to control the phase and amplitude of each antenna element of the array. However, the upper limitation of antenna array is bounded due to the ohmic and dielectric losses of the complex feeding network [2]. To reduce the feeding network loss, Fabry-Pérot structure based on quasi-optical theory is used to enhance antenna performance [3-4]. Those works use a FSS (frequency selective surface) as a semi-transparent layer at desired operating band to cover on a large reflective ground surface with a single feeding element, which could be a patch-type or dipole-type antenna.

Theoretically, higher the quality factor of Fabry-Pérot cavity was deigned, narrower impedance bandwidth will be. Recently, several complex FSS structures are proposed to control the filed distribution in the Fabry-Pérot cavity such as multi-layer FSS structure [5] and multi-resonator FSS structure [6-7] to improve the operation bandwidth. In this paper, a novel dual-resonator FSS structure composed by the unit cell structure of metallic square patches and loops was proposed and studied. It could be observed that broader impedance bandwidth and antenna radiation performance was achieved. In addition, owing to the inhomogeneous and uni-period cell arrangement of this design, it's very promising for antenna optimization and industrial manufacturing.

2. Antenna Design

Geometry of the proposed antenna with a 15×15 array unit cell structure is shown in Fig. 1. A patch antenna is printed on a Rogers RO4003 board (ε_r = 3.55, thickness = 0.508 mm) of overall dimensions 128 mm × 128 mm (approximately $7\lambda_0 \times 7\lambda_0$, which corresponds to about 16.5 GHz). Dimensions of the feeding patch antenna are adjusted to obtain an optimal impedance matching in the proposed FSS structure. Therefore, optimal length of the patch antenna is 4 mm or 0.22λg with respect to the operation frequency. Distance between the ground plane and FSS-cover is about 1/2 wavelength, which could satisfy the resonance condition of the Fabry-Pérot cavity. In order to enlarge the radiation bandwidth, 5×5 metallic square loop unit cell structure is used to replace the metallic patch as shown in Fig. 2 (a). Detailed configuration of each hollow square unit cell structure is described in Fig. 2 (b). Side length of the outer square patch is 8 mm (w_2). As for the inner square loop, the side length is 3 mm (w_3). Compared metallic patch unit cell with metallic square loop unit cell both operated at same operation frequency of 16.5 GHz and in the same period of 8.25 mm (w_1), reflectivity of metallic patch unit cell is much higher.

3. Simulation and Experiential Result

The time domain software simulator, Simulation platform for Electro Magnetic Compatibility, Antenna Design and Dosimetry (SEMCAD) is used in order to enhance the simulation efficiency while tuning overall impedance bandwidth performance of the proposed structure. Both dielectric loss and metallic loss are taken into consideration in the simulation model for more accurate results. The parameters of FSS have been adjusted to get a slower change of reflection phase in desired operating frequency band. Antenna structure and performance is shown and also estimated in Fig. 3. The impedance bandwidth of the proposed structure is about 2.5% or 420 MHz (16.24－16.66 GHz, defined by 2:1 VSWR), which can meet the speculation of Ku-band radar system application. It should be noted that the frequency bandwidth is somewhat different due to the loading effect of the FSS structure. Because we adopt patch antenna as a feeding source, its application become more limited. Furthermore, the possibility to mitigate impact of this limitation and to improve the overall antenna performance could be expected by using another feeding source in our future researches.

In Fig. 3 (b), as expected, the maximal gain of the proposed structure is enhanced to 23.4 dBi at FSS resonance condition of 16.5 GHz. Obviously, the frequency verse antenna gain response of the proposed structure (blue line) is not only much higher approximate 2.3 dB than that of uniform FSS structure (dotted red line), but also wider the radiation bandwidth. Azimuth plane demonstration of the electric field distribution of the proposed structure as shown in fig. 4 can describe the phenomenon. In fig. 4(b), it shows that the electric field distribution is more uniform and less sharp in the proposed FSS structure than (a) when using the same scale of electric field strength. The red colour represents the strongest strength and the blue one represents the weakest in this scale. What is more, the radiation characteristics of the proposed antenna with the proposed FSS structure are also studied in fig. 5. Good broadside radiation patterns are obtained at 16.5 GHz and the side-lobe level is better than -24 dB and -31 dB for E and H plane respectively.

4. Conclusions

This paper presents a novel broadband high gain Fabry-Pérot radiation structure that is formed by a patch antenna and a single layer of uni-period FSS layer fabricated with 5 × 5 metallic ring array surrounded by 15 × 15 metallic patch array fabricated on the Rogers RO4003 substrate. The metallic ring arrays are at the central portion of the FSS layer and the metallic patches are at the outer region. Simulation results show that the maximum antenna gain reached to 23.4 dBi and the impedance bandwidth of the proposed radiation structure is about 420 MHz (16.24-16.66 GHz) by applying 2:1 VSWR definition. This high gain structure is only 128 mm × 128 mm × 9.5 mm which is suitable for high data rate and point-to-point applications. Furthermore, the extraordinary advantage of the proposed FSS structure is its flexible property of design while performing the optimum of antenna operating bandwidth.

5. Figures and Tables

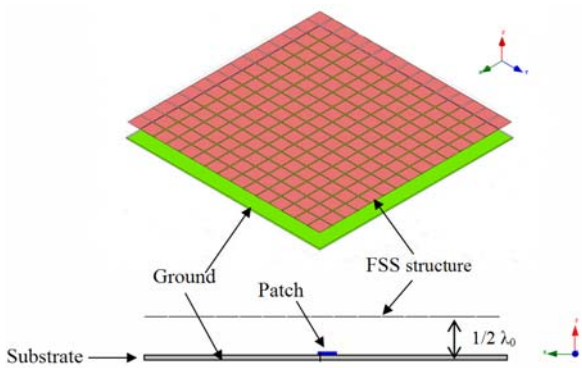

Fig. 1 Configuration of the proposed structure

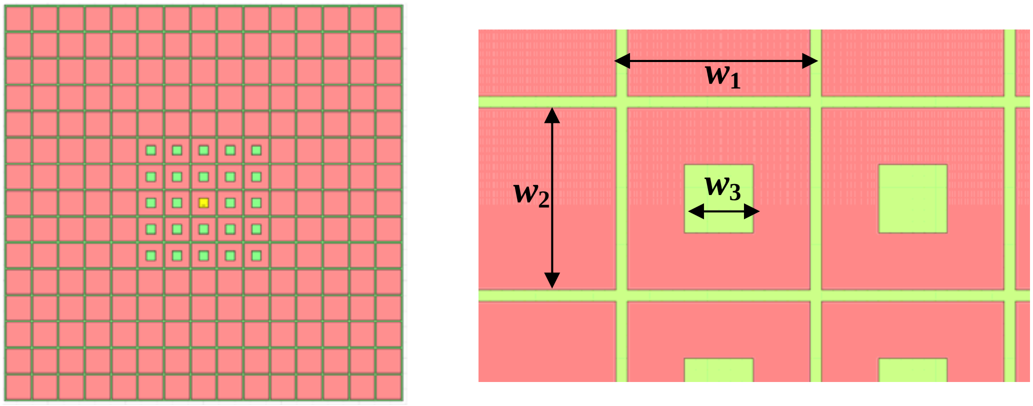

Fig. 2 Structure of FSS cover (a) proposed FSS (b) Unit cell of the structure

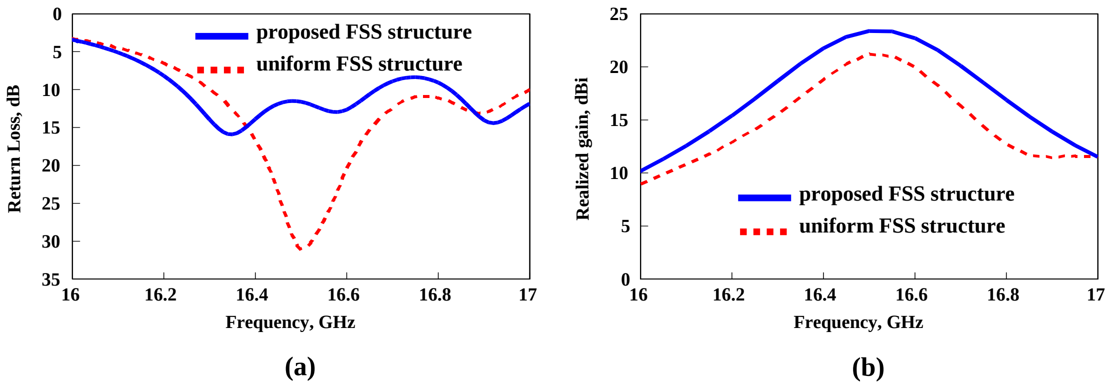

Fig. 3 Comparative simulation results of proposed and uniform FSS structure
(a) Return loss (b) antenna gain

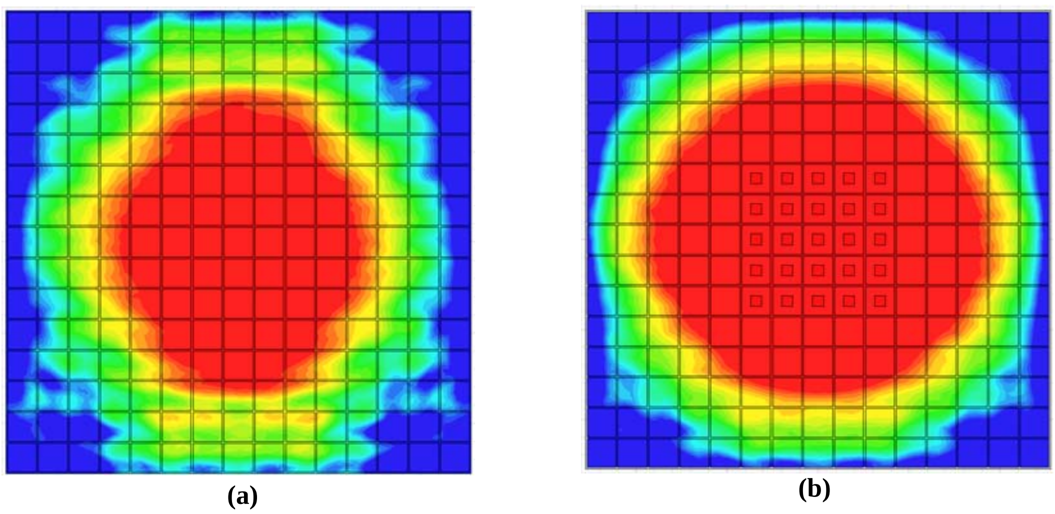

Fig. 4 Electric field distributions in the unit cell (a) uniform FSS (b) proposed FSS

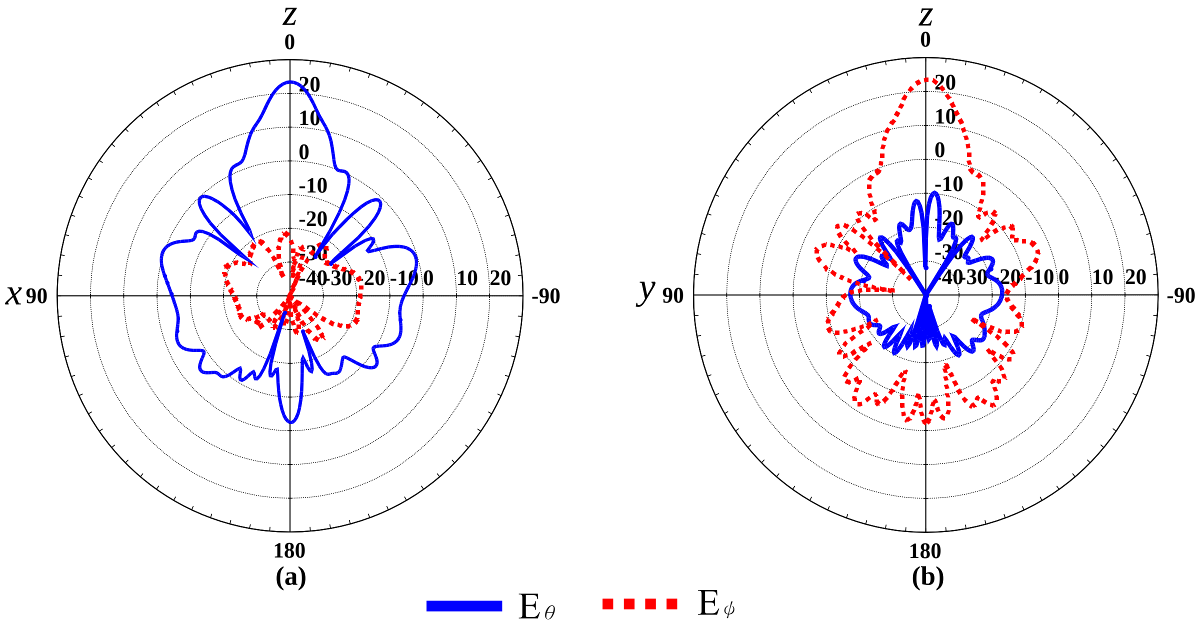

Fig. 5 Simulated radiation patterns of the proposed FSS structure
(a) x-z plane (b) y-z plane

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