A More Practical Patch Used in Microstrip Antenna at Ku-band

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Abstract— In this paper, a Ku-band microstrip antenna is analyzed and will be designed. The characteristics of the patch are analyzed and optimized with Ansoft HFSS. A different patch is evolution of the classic rectangular patch. It has a square loop outside the rectangular patch. We can call it window-patch. The construction of the antenna is resulted from considering efficiency of the spillover efficiency (η_s) and the illumination efficiency (η_i).

Once the unit element has been fully characterized and a reflectarray designed, an important aspect in the reflectarray analysis is the computation of the radiation patterns. In this literature, a method of Array Element Factor is used to calculate it. For the reflectarray antenna, the ideal range of phase shift should realize $0 \sim 360°$, but sometimes things go contrary. It would be discussed the effects brought by the lack of the phase shift and electromagnetic wave incident angle.

1. INTRODUCTION

In the last decade, there is an increasing interest in reflectarray antennas for the following advantage: high gain, light weight, low cost, low profile, flexibility, ease of installation and so on.

Due to reflectarray antennas have quasi-periodic structure, infinite periodic unit model is the mainstream approach to analysis the phase shift of patch. In this study, the characteristics of the patch are analyzed and optimized with Ansoft HFSS. It adopts Floquet port and Master-Slave boundary approach. The aperture efficiency (η) is used to design the construction of the reflectarray, which contains the spillover efficiency (η_s) and the illumination efficiency (η_i).

Radiation pattern and Gain is the most important parts of antennas. Array Element Factor is used to calculate the radiation pattern and it would use commercial software FEKO for the analysis of reflectarrays.

2. ELEMENT EFFECTS

The element characterization is the most important part and critical step of the reflectarray design. If the element design is not optimized, the reflectarray will not scatter the signal from the feed effectively to form an efficient far-field beam. Different from conventional waveguide simulation, in order to account for the coupling effect among the elements, infinite periodic unit model is used to mimic an infinite array environment. In this article, the master-slaver conditions and floquet port in HFSS are used to perform the simulation for a single unit as show in Fig. 1.

In this article the antenna works at 12.5 GHz and the side length of the square arrangement lattice is 12 mm. The phase shift is achieved by changing one or more of the geometrical parameter of the patch. Five cases are going to compared, where the substrates of square patch with 0.5 mm, 1 mm, 1.5 mm, 2 mm thickness, the window patch with 3 mm thickness and 2.2 relative permittivity. The results of simulation show in Fig. 2.

As illustrated in Fig. 2(a), the thickness of the substrate has a big impact on the achievable phase range. Generally, the thicker the substrate, the smaller phase range for square patch. The window patch has a larger phase range than the square patch when the substrate thickness is

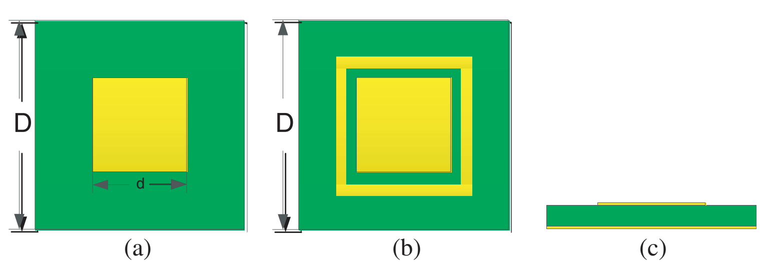


Figure 1: (a) Top view of the square patch. (b) Top view of the window patch. (c) Side view of the patch. The yellow color represents metal patch and the green color for substrate.

greater than 0.5 mm. Fig. 2(b) shows the slope of phase curve, it conclude that the window patch has a smaller slope than the square patch with the substrate thickness smaller than 2 mm except point 3.1 mm. In spite of point 3.1 mm of a larger slope, that is the very thing wants. For the antenna unit periodic changes from the center to the edge, when it reaches $-\pi$, next one is $+\pi$. So the element is not much difference from the former one. The return loss of the window patch has two peaks, the square patch has one peak. An ideal broadband reflectarray element should provide phase curves at different frequencies parallel to each other [1]. From the Fig. 2(d), it knows the reflectarray antenna would have a broadband.

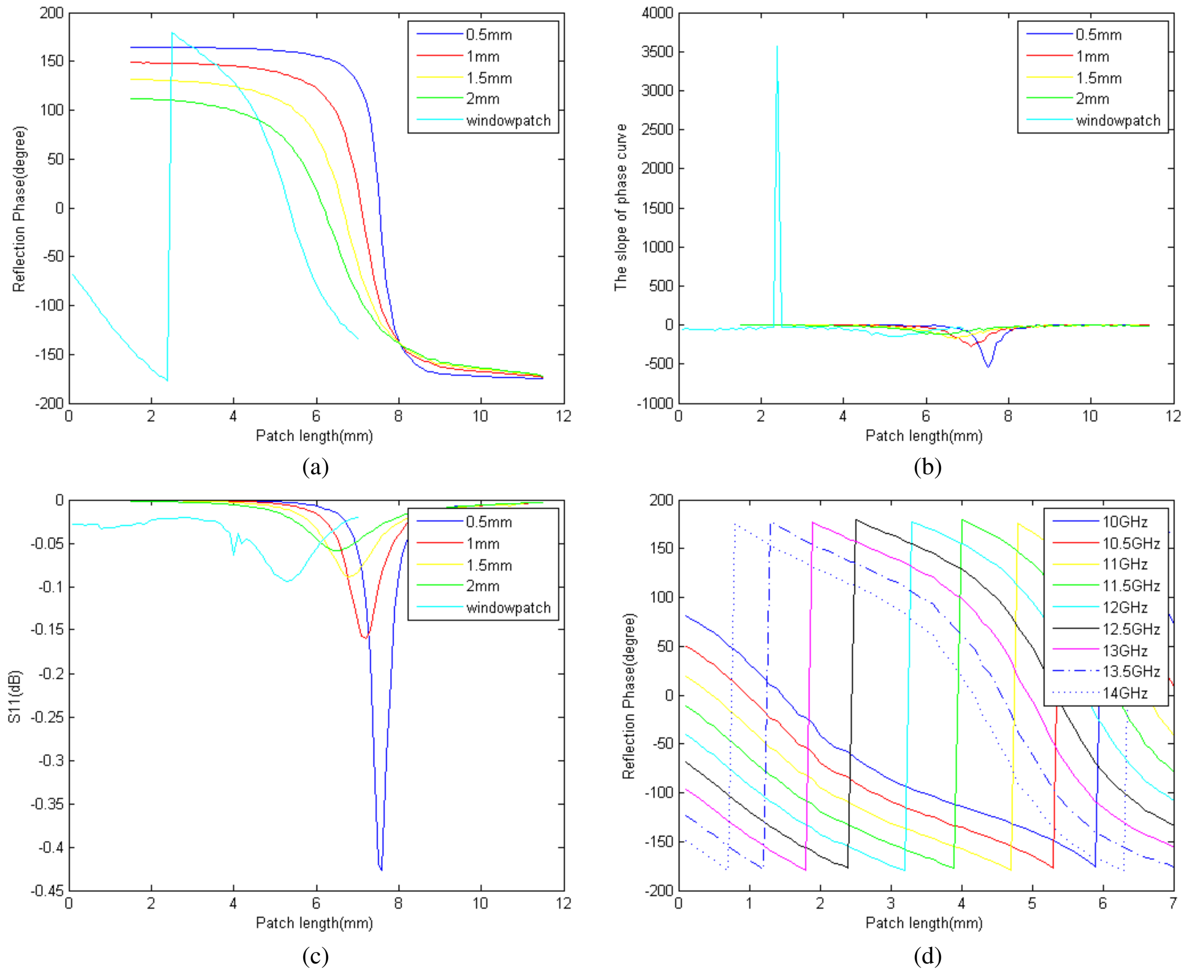


Figure 2: (a) Phase curves obtained with different substrate thickness. (b) The slope of the phase curves. (c) Return loss with different substrate thickness. (d) Phase curves with different frequency.

Table 1: Square patch vs. window patch.

Type of patch	Phase (min)	Phase (max)	slope	S_{11} (dB)
Square patch (0.5 mm)	$-175.3°$	$164.6°$	$-535.3°$/mm	-0.4265
Square patch (1 mm)	$-173.4°$	$148.7°$	$-271.4°$/mm	-0.1604
Square patch (1.5 mm)	$-172.5°$	$131.4°$	$-169.8°$/mm	-0.08926
Square patch (2 mm)	$-172.5°$	$112.1°$	$-119.7°$/mm	-0.05888
Window patch	$-177.5°$	$179.5°$	$-156.6°$/mm (3571)	-0.09358

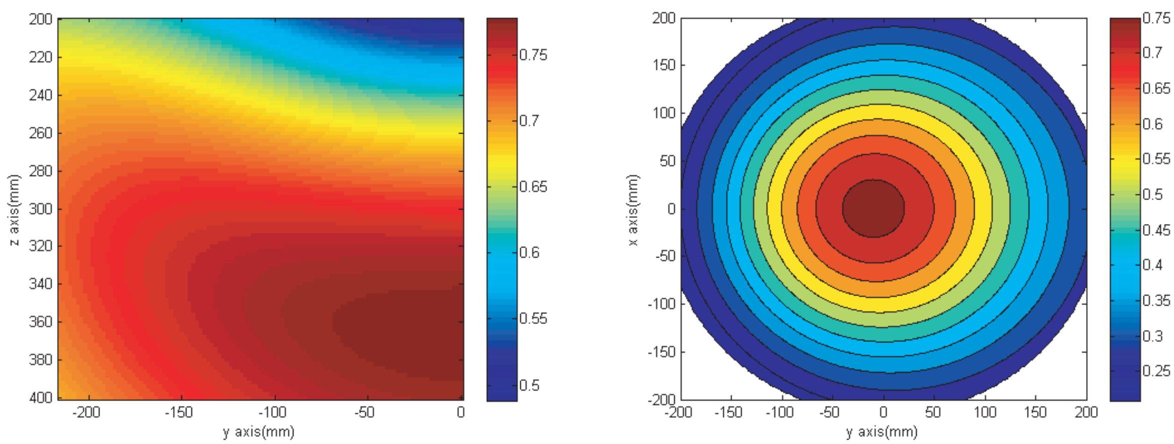
3. EFFICIENCY AND CONSTRUCTION

The antenna gain is determined by the aperture directivity and the aperture efficiency. In this paper, two major efficiency of the spillover efficiency (η_s) and the illumination efficiency (η_i) are considered, which defined as [2]:

$$\eta_s = \frac{2q+1}{2\pi}\int_0^{2\pi}\int_0^{D/2}\frac{H}{r^3}\left(\frac{r_0^2+r^2-s^2}{2r_0 r}\right)^{2q}\rho d\rho d\varphi \tag{1}$$

$$\eta_i = \frac{1}{A_a}\frac{\left|\iint\limits_A I(x,y)dA\right|^2}{\iint\limits_A |I(x,y)|^2\, dA} \tag{2}$$

where q is the value of the feed horn, D is the diameter of reflectarray aperture, r_0 is the distance from the feed horn to the center of aperture, r is the distance from the feed horn to the element, s is the distance from the center of aperture to the element. The feed source is located at yoz plane. The efficiency of the reflectarray is shown in Fig. 3.



(a) (b)

Figure 3: (a) Efficiency vs. the feed location. (b) Efficiency vs. feed orientation with $q = 7$ and $D = 432$ mm.

4. RADIATION PATTERN AND GAIN

Array Element Factor (AEF) is used to calculate the radiation pattern. Both the feed horn and element pattern are approximated by a cosine q model. The calculation of radiation pattern for each observation point could be simplified as:

$$E(\theta,\varphi) = \cos^{qe}\theta\sum_{n=1}^{N}\sum_{m=1}^{M}\frac{cos^{q_f}\theta_{fmn}(m,n)\cdot\cos^{q_e}\theta_{emn}(m,n)\cdot|\Gamma_{mn}|}{r_{fmn}}\cdot e^{j\Phi_{mn}}\cdot e^{j\beta(\hat{r}\cdot\vec{r}_{mn})} \tag{3}$$

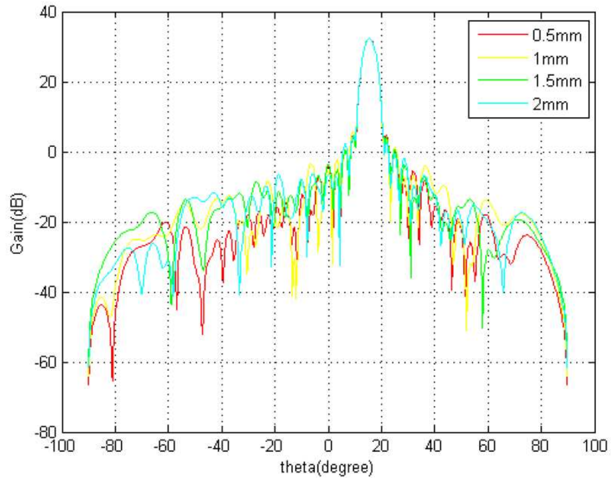
where q_f is the q factor of the feed pattern, q_e is the q factor of the element pattern which is 1 unless otherwise specified, and $|\Gamma_{mn}|$ is the magnitude of reflection coefficient for each element. The antenna directivity is defined though the well-known equation:

$$D_0 = \frac{4\pi\,|E(\theta_m,\varphi_m)|^2}{\int_0^{2\pi}\int_0^{\pi/2}|E(\theta,\varphi)|^2\sin\theta d\theta d\varphi} \tag{4}$$

When the directivity and efficiency are ensured, the gain is calculated as:

$$G_0 = D_0 \times \eta \tag{5}$$

Reflectarray with different thickness of substrate has different phase range as the second part shows. In the Fig. 4, it illuminates four curves of the antenna gain at 0.5 mm, 1 mm, 1.5 mm, 2 mm thickness of the substrate with $D = 432$ mm.



(a) (b)

Figure 4: (a) Gain vs. different thickness. (b) Simulation vs. calculate at 0.5 mm thickness.

As shown in Fig. 4(a) the gain values have little change for different thickness. Array Element Factor (AEF) is a good method to calculate the gain as depicted in Fig. 4(b). The red curve is the result of calculating by AEF. The blue one works out by FEKO. They have the same beam direction.

5. CONCLUSION

In this paper, a more practical patch is introduced in detail and the efficiency, the gain of reflectarray is calculated. In the Fig. 4(b) the gain and beam direction of simulation result is very good agreement with the calculation result. The window patch has more advantages against with the square patch: (a) A greater range of phase shift (b) the smaller the slope of phase shift curve (c) the smaller range of the patch change (d) a larger bandwidth as shown in Fig. 2.

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