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# A Compact and Wideband Flat Lens Antenna based on Aperture Coupled Patches for X-Band Applications

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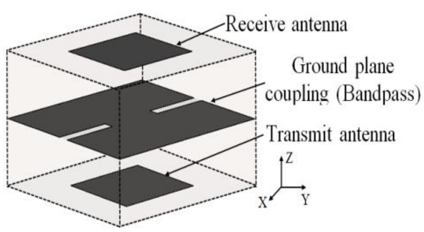
**Graphical abstract**




**Abstract**

This paper presents a wideband and compact flat lens antenna for X-band applications. An 8×8 array of this antenna is designed and realized by using aperture coupled patches from the multilayer Frequency Selective Surface concept. The basic antenna element configuration of this design consists of two back-to-back printed patches with a common ground plane coupling. A pair of identical slots is embedded on the ground plane to provide the necessary phase error compensation between receive and transmit apertures. The lengths of the two slots are varied simultaneously to investigate how much phase shift range can be achieved with this simple design structure. The antenna elements are simulated using the electromagnetic simulation software CST Microwave Studio. A 209° transmission phase range was achieved with transmission coefficient variations of better than -2.25 dB. The gain of the feeding horn antenna used is 9 dB at 10 GHz. Upon the implementations of the lens structure, the gain of the overall antenna system has increased to 16 dB. Our simulation shows a 3-dB transmission bandwidth of around 33% could be achieved for the unit cell. Radiation pattern simulation of the antenna system shows a good symmetry between E and H-plane with a half-power beamwidth of 19.2° and 19.0° in E-plane and H-plane respectively. The gain is greater than 9 dB from 8 to 12 GHz with maximum gain of 16 dB is achieved at 10 GHz. The proposed antenna design uses a simple and less fabrication complexity mechanism for phase error correction.

*Keywords*: Compact lens; phase shift; x-band; wideband



## 1.0 INTRODUCTION

A flat lens antenna is a high gain, light weight and cost effective solution to the bulky and high cost conventional dielectric lenses. Although there are several existing design approaches of flat lens antenna, a typical design structure composes of an array of receive and transmit antennas which are coupled by phase correcting mechanism. A feed antenna usually horn, patch, open ended waveguide or arrays of antenna elements are used to illuminate one side of the array lens to create a space-fed antenna system [1]. The basic conceptual operation of flat lens antenna can be divided into three processes. First, an incident spherical wave-front radiated from the feeding source is received by the reception interface of the array. Secondly, the received signal is collimated or converted into a planar wave-front by the phase-error correction mechanism. And finally, the processed signal with the desired wave-front properties is transmitted by the transmit patches of the lens antenna [2].

Recently, researchers have shown a strong interest and widely studied the performance improvement and manufacturing complexity reduction of this type of lens antenna. Basically, the major difference among flat lens antenna design configurations in the literature is the phase correcting mechanisms used to change the spherical wave from the feed into a flat plane wave. Most of the design efforts reported consist of coupled or joined patch antenna array using microstrip delay lines [2], element patch rotation [3], multi-resonance behavior [4] and slot coupled structures [5]-[9] to achieve the desired phase compensations. However, making a compromise between design complexity and performance is yet to be reached.

The aim of this paper is to design a compact and simple structure of planar lens antenna using a multilayer aperture coupled Frequency Selective Surface elements. Generally, the basic operation of flat lens antenna elements is to convert the spherical incident waves from the feeding source into a planar radiated wave. Therefore, to design a phase controlling technique which is less complex and easier to manufacture for flat lens antenna elements while obtaining the required phase shift range of up to 360° is very significant.

The paper is organized as follows: The antenna unit cell design and analysisare presented in section 2.0, followed by full array antenna simulations in section 3.0. The feeding horn antenna and lens antenna gain simulations comparisonis also discussed in section 3.0. Lastly, the conclusion of the work is drawn in section 4.0.

## 2.0 ELEMENT DESIGN AND ANALYSIS

The basic geometry of the flat lens antenna unit cell structure of this design consists of two back-to-back patches with a common ground plane coupling as shown in Figure 1. This design configuration is originated from an FSS design structure using aperture coupled microstrip patches which is been reported in [5]. Generally, Frequency Selective Surfaces (FSS) are planar periodic structures using identical elements of periodically repeated patches and it behaves like filters to electromagnetic energy [10]. However, in the flat lens antenna case, the length of the coupling apertures should be adjusted to compensate the phase error caused by the spherical wave radiated from the feeding source and to create a focused beam.

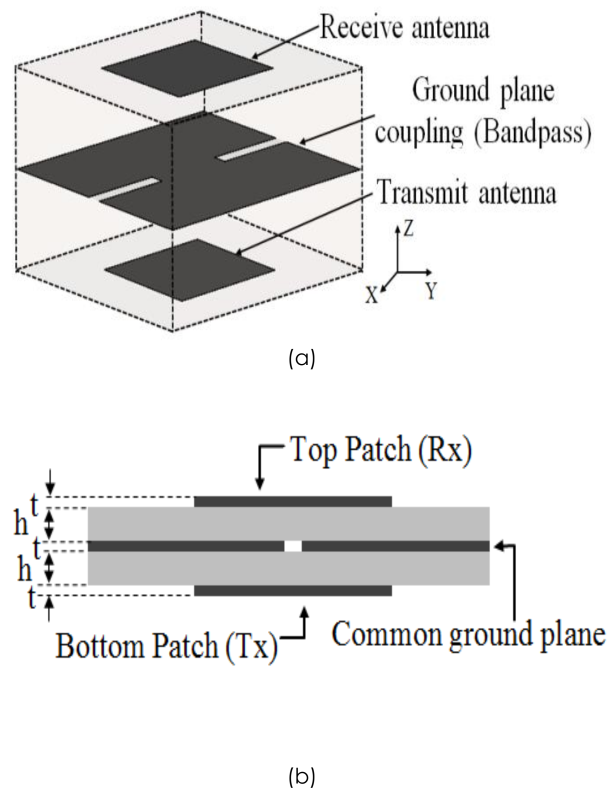
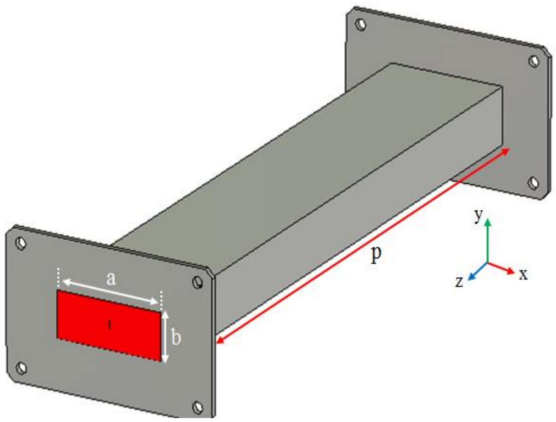
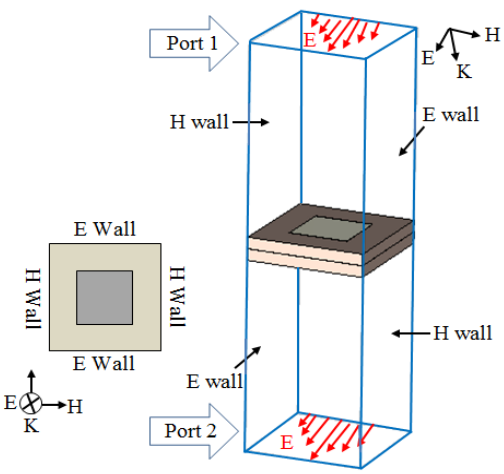


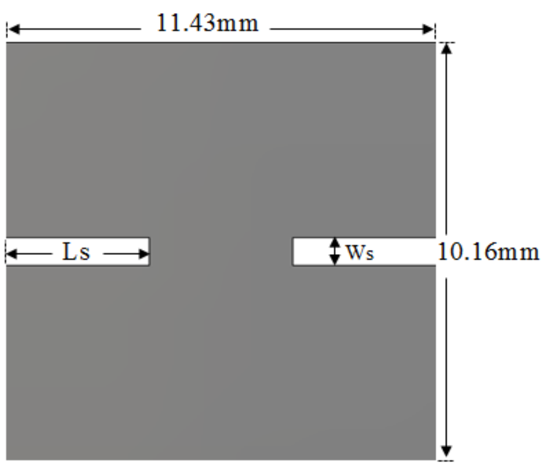

**Figure 1** Geometry of the proposed lens antenna element (a) Exploded unit cell diagram (b) Layer structure (side view)

Several flat lens antenna unit cells are designed at X-band frequency of 10 GHz. The antenna elements are implemented using commercially available Computer Simulated Technology Microwave Studio (CST MWS). The geometry of the unit cell periodicity has been chosen to be based on that of the existing X-band rectangular standard waveguide dimensions [11] as shown in Figure 2(a). Rectangular patches printed on standard FR4 epoxy substrate having relative permittivity ($\varepsilon r$) of 4.3, dielectric loss tangent (tan $\delta$) of 0.02 and physical thickness of 1.6 mm is used to design the antenna elements. As the standard rectangular waveguide (WR 90) dimensions are a = 22.86 mm, b = 10.16 mm and p = 120 mm and since there is a limitation of the antenna physical size a suitable unit cell dimensions of $l$ = 11.43 mm and w = 10.16 mm are employed as illustrated in Figure 2(c). To achieve a maximum coupling through both sides of the aperture an identical size and shape rectangular patches are used. The copper patch size is 5.715× 5.08 mm2 (l/2×w/2) at 10 GHz.




(b)

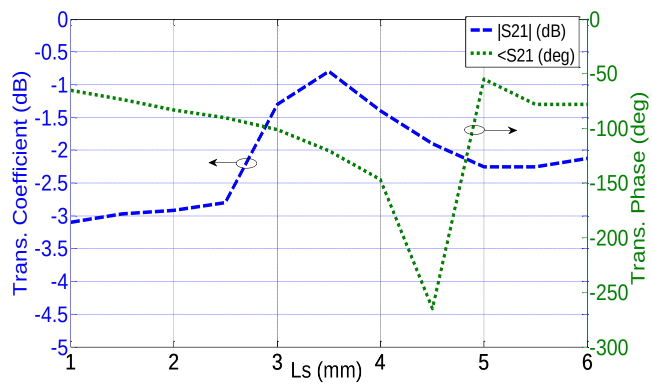



(c)

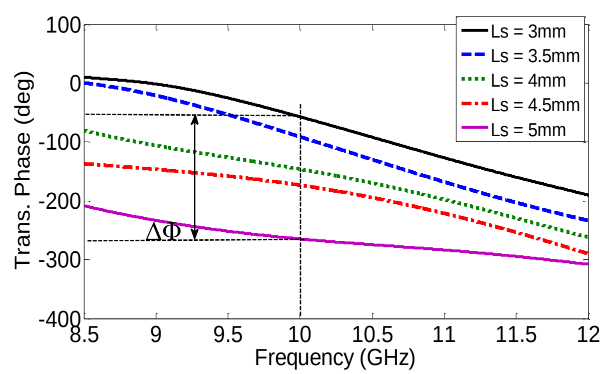
**Figure 2(a)** Standard rectangular waveguide (WR 90) **(b)** A unit cell in waveguide simulator **(c)** The dimensions of the common ground plane coupling

Two identical slots are imbedded in the non-resonant common ground plane with an equal separation distance from the center of the structure as depicted in Figure 2(c). The slots have dimensions of Ls and Ws in which the slot length (Ls) controls the amount of coupling or decides the phase compensation capability of the structure, while the slot width (Ws) has a much lesser affect.

In this paper, the phase range response of the flat lens antenna unit cells were investigated using the two identical slots loaded in the ground plane. A systematic variation of slot lengths (Ls) from 3 mm to 5 mm and a constant slot width (Ws) of 1.5 mm are carried out to study how much phase shift range can be achieved with this simple design structure. The transmission coefficient magnitude and phase response versus the slot length (Ls) are shown in Figure 3 (a).




(a)




(b)

**Figure 3(a)** Transmission phase and magnitude against the varied slot length (Ls) **(b)** Unwrapped transmission phase variations of five different size slot configurations

A phase shift range of 209° (-55° to -264°) is achieved at 10 GHz while maintaining transmission coefficient variations of better than -2.25 dB. This means that the element realizes a limited phase range, but it is acceptable for small antenna structures given the condition that there must be a reasonable F/D ratio (focal length to diameter ratio) [3]. In addition, increasing the slot length up to 3.5 mm gives the highest transmission coefficient while further increase causes the transmission magnitude to drop. Careful optimization of this parameter will improve the performance of the elements and demonstrate the potential of using this unit cell design in flat lens antenna designs.

It is observed that the slot length below 2.5 mm gives one resonance frequency response with a much transmission power loss of or worse than -3 dB. And of course there is no power transmission or coupling while the slot length equals to zero. It is also found that if the slot length is greater than 3 mm until 5.25 mm creates a second resonance frequency response and produces a 2-pole bandpass filter as shown in Figure 4. From this value it is observed that the first resonance frequency is created by the patches whereas the second resonance is generated by the pair of slots in the common ground plane.

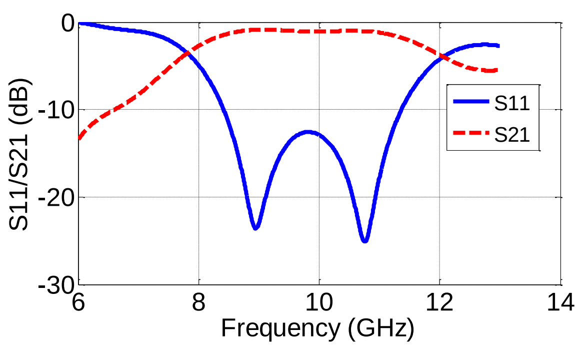


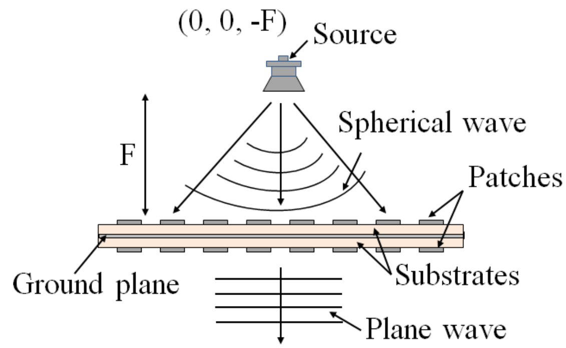

**Figure 4** Simulated transmission and reflection coefficient responses of the unit cell (Ls = 3.5 mm, Ws = 1.5 mm)

## 3.0 FLAT LENS ANTENNA SIMULATIONS

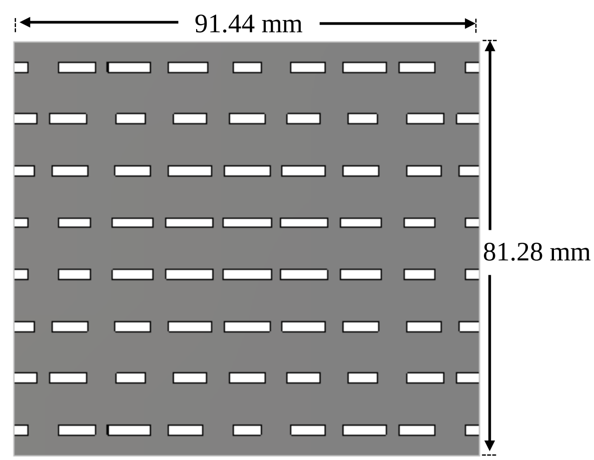
In order to realize the flat lens antenna, an 8×8 array which comprises of the proposed slot coupled elements is designed at 10 GHz as shown in Figure 5. The antenna was simulated using CST software. The antenna aperture size is 91.44 × 81.28 mm². And a small horn antenna is used as a feed antenna for the lens at a focal distance of 70 mm, marking the F/D to be 0.86 as sketched in Figure 5 (a). The required phase error correction of the antenna elements (*m*thcell) can be determined by using the following equation [7].

$$\Phi_m = \frac{2\pi}{\lambda_0}\left[F - \sqrt{x_m^2 + y_m^2 + F^2}\right] - \Phi_o(x_m, y_m) \quad (1)$$

Where $\Phi_m$ is the required phase of an individual cell (*m*th), $\lambda_0$ is the free space wavelength at the design frequency, F is the focal distance and $\Phi_o$ is the phase of the central element on the array while $x_m$ and $y_m$ are the co-ordinate points of *m*th cell on the lens array surface.

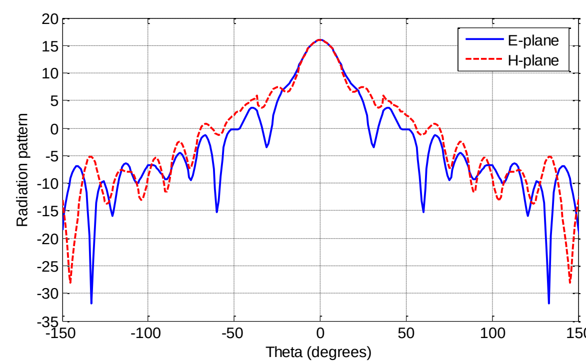



(a)

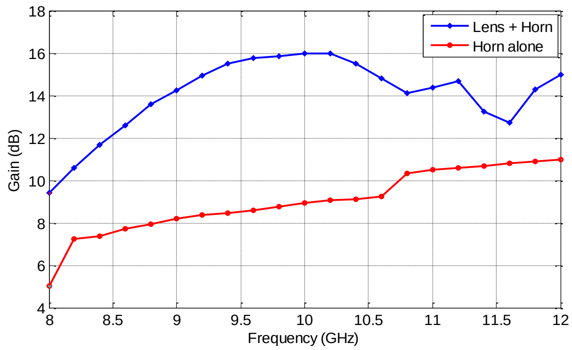



(b)

**Figure 5(a)** Lens antenna structure **(b)** Slotted common ground plane.




(a)




(b)

**Figure 6(a)** Radiation pattern of 8 × 8 array simulation results at 10 GHz **(b)** Simulated lens antenna gain and feeding horn antenna gain.

Figure 6(a) shows the simulated radiation pattern of the lens antenna and the obtained results validate that the lens structure can focus the beam of the transmitted signal as well as enhance its gain. The gain of the feeding horn antenna used is 9 dB at 10 GHz. Moreover, an increase of feed antenna gain as high as 7 dB was experienced after realizing the lens antenna structure as shown in Figure 6 (b).The phase shift technique employed in this design converts the spherical incident wave into a planar radiated wave. Hence, a high directivity beam was achieved at the back of the aperture. This lens antenna design will be fabricated and measured soon for further analysis.

## 4.0 CONCLUSION

A wideband and compact flat lens antenna with a less manufacturing complexity mechanism for phase error correction have been designed. The necessary transmission phase compensation of the elements is adjusted by using a pair of identical variable length slots. An acceptable transmission phase performance with a low insertion loss has been achieved. The proposed antenna design has shown a very good gain enhancement of 16 dB and a radiated high directive beam.

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