A Compact Flat Lens Antenna with Aperture-Coupled Patch Elements

A. A. Awaleh[1], S. H. Dahlan[2], M. Z. M. Jenu[3]

Research Center for Applied Electromagnetics
Universiti Tun Hussein Onn Malaysia
Johor, Malaysia
[1]samad.awaleh@gmail.com, [2]samsulh@uthm.edu.my, [3]zarar@uthm.edu.my

***Abstract*—A compact 7 x 7 flat lens antenna design for X-band applications is presented in this paper. A new design with aperture-coupled E-shaped patch elements at 10 GHz is simulated and analyzed. This antenna design is realized by using two back-to-back printed patches with slotted common ground plane and feed horn antenna. The transmission loss obtained of 2.2 dB is sufficiently low. A 320º transmission phase range for the E-shaped patch unit cell is achieved with less than 1.5 dB of deviation in the transmission loss level.The proposed design uses a simple technique and less manufacturing complexity for transmission phase control.**

Keywords—aperture-coupled; lens antenna; transmission phase; X-band;

I. INTRODUCTION

A flat lens antenna is a low profile, light weight and cost effective solution to conventional and curved dielectric lenses. Regardless of the several existing design approaches, a typical flat lens antenna configuration consists of an array of microstrip patches which are coupled or joined together by phase shifters [1]. A feed antenna usually horn or patch is used to illuminate one side of the array, and for passive flat lenses, either side of the array can be a transmitter or a receiver (or vise versa). In addition tothese characteristics flat lenses have narrow beamwidth and high gain which made them an attractive choice for the applications of the ongoing development of wireless communications and digital radar system for remote sensing.

For the last decade, a considerable effort has been made in developing high performance flat lens antennas. The major difference among the designs of the antennas is the phase correction technique used to compensate the incoming wavefront errors. Most of the designs consist of coupled-patch antennas, using element rotation [2, 3], multi-resonance behavior [4, 5] and microstrip delay lines [6]-[8] to realize phase shift and stacked patches to increase bandwidth. However, the most challenging task is to place the phase delay line inside the structure or between the radiating patches, because of the limited space available [9, 10]. The use of metallic vias to connect the two radiating interfaces or placing an air gap between the microstrip patches also adds another complexity to the design and creates construction limitations.

The organization of the paper is as follows: The unit cell element design and analysis are presented in section II, followed by the results for lens antenna in section III. Lastly, the conclusion of the work is given in section IV.

II. ELEMENT DESIGN STRUCTURE

The basic theory of operation of discrete lens antenna unit cell is to collimate the feed spherical electromagnetic incident wave into planar wavefront at the back of the aperture [6, 11]. Therefore, the unit cell element is designed to establish the needed phase adjustment. The required phase compensation value of the unit cell depends on the incident wave angle and its location on the surface of the array. The significant point of designing a unit cell for discrete lens antenna is to obtain the essential requirement phase shift range of up to 360º.
Hence, the required phase error correction of an individual unit cell element can be determined using the following equation [12]:

$$\varphi_i = \frac{2\pi}{\lambda 0}(R_i - F) \pm 2\pi N + \varphi_0 \qquad \textbf{(1)}$$

Where φ_i is the required phase of an individual cell, λ_0 is the free-space wavelength and φ_0 is the phase of central element on the array. R_i is the distance between phase center of the feed source and *i*'th cell on the array surface. *F* is the focal distance while *N* is an integer number which satisfies $0<\varphi i \leq 2\pi$.

In this antenna design, the essential transmission phase adjustment of the element is controlled by varying the length of the loaded slots on both sides of the structure [13]. The desired transmission phase of each unit cell can be achieved by varying the patch slot length of the elements. This phase control mechanism of the antenna elements is due to modification of the patch surface current density (J) created by the loaded slots. This is because; the effective area of the patch (conducting material) is reduced due to the slots and

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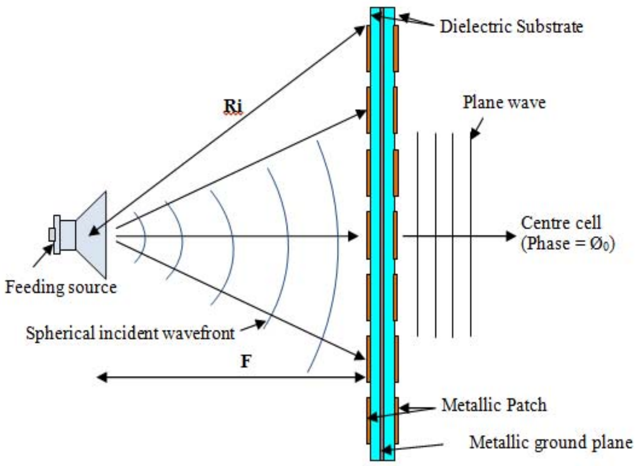
hence, decreases the surface current density (J) as a result. This surface current density alteration of the patch furthermore decreases the electric field intensity of the element and as a result increases the electrical dimensions of the patch. Therefore, this reduces the resonant frequency of the unit cell and makes the transmission phase of the incoming wavefront to be adjustable.

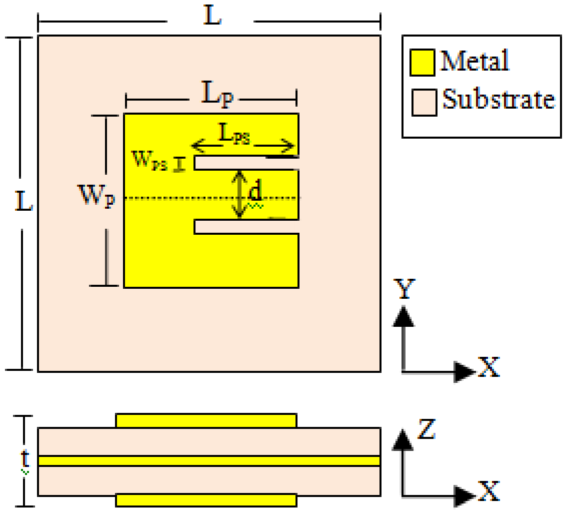
A. The Proposed Element Design

Employing E–shaped patch unit cell makes the antenna structure to be compact and less manufacturing complexity with the feasibility of enhanced performance as will be discussed in section II (B). This unit cell design has several adjustable parameters that need to be considered. Careful optimisation of these parameters will enhance the performance of the unit cell and demonstrate the potential of using E-shaped patch unit cell in discrete lens antennna for transmission phase control, bandwidth enhancement, sidelobe reduction and polarisation conversion purposes[13].

The basic flat lens antenna and feed configuration are depicted in Fig.1 (a). The slot loaded unit cell patch dimensions based on the operation frequency are presented in Fig.1 (b). The system consists of a back-to-back conducting microstrip patch array and slotted ground plane coupling. Similarly, each patch is embedded in parallel and symmetrical slots for transmission phase controlling purposes. The unit cell physical parameters and main features are summarized in Table I.



(a)



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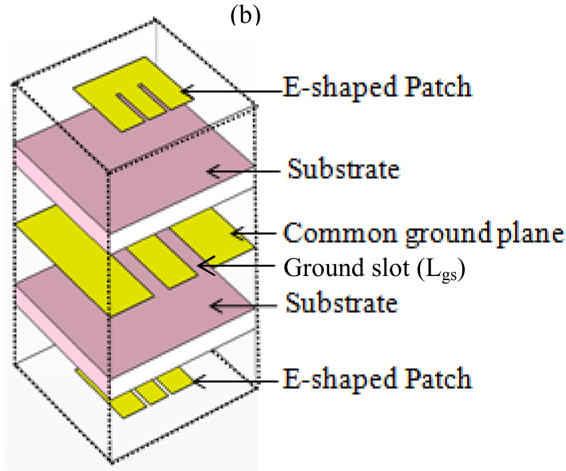


(c)

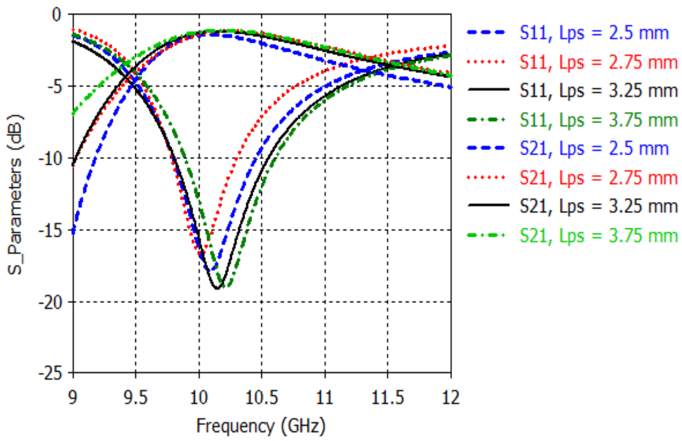
Fig.1. Geometry of the proposed unit cell element. (a) Lens antenna configuration. (b) Slot loaded unit cell structure (c) Exploded unit cell diagram

Table I. Important parameters of the unit cell

Parameter	Value
Design frequency	10 GHz
Unit cell size	15mm x 15 mm
Patch size	L_p = 7 mm, W_p = 7.5 mm
Thickness of the antenna	t = 3.305 mm
Substrate	FR4: ε_r = 4.3, h = 1.6 mm, tan δ = 0.02
Slot dimensions	Adjustable

B. E-shaped Patch Element

In order to realize the required phase compensation of the unit cell, E-shaped patches are proposed and used where the pair of parallel slots is close to the right edge of the radiating patch. The key parameter used to control the phase shift is the adjustable slot length. As mentioned before, a systematic method of varying slot length is employed. The patch slot lengths from 1 mm to 4 mm are used to tune the required phase correction of each element. The ground slot length is also adjusted from 5 mm to 12 mm but with a proper ratio to that of patch slot changes (L_{ps}/L_{gs}). Except from the 0.4 dimension configuration ratio, all the other ratio arrangements are below the required phase correction. A phase range of 320° (-8° to -328°) is achieved for patch slot length of between 1 mm to 4 mm. Fig. 2 depicts the s-parameters of the unit cell for several slot length variations. Both transmission loss and transmission phase results in Fig.2 show the feasibility of good unit cell performance.



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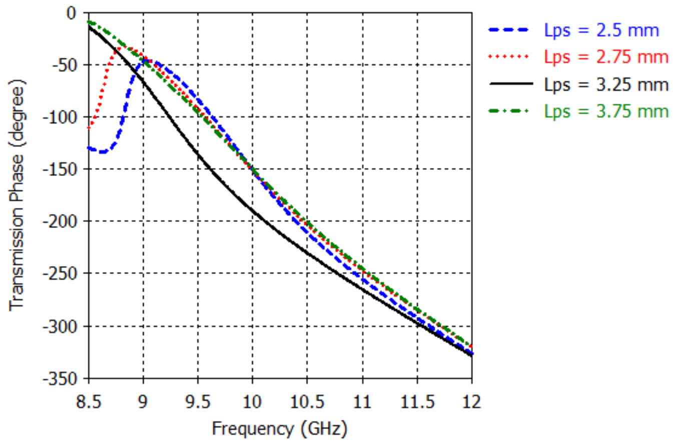


(b)

Fig.2. (a) S_{11} and S_{21} of the unit cell. (b) Transmission phase variations

III. SIMULATION RESULTS FOR LENS ANTENNA

A 7 x 7 flat lens antenna array which consists of the proposed E-shaped patch unit cell is designed to realize the lens antenna at 10 GHz. The antenna structure is illustrated in Fig. 3, and were designed on a standard FR4 epoxy substrate having relative permittivity (ε_r) of 4.3, dielectric loss tangent (tan δ) of 0.02 and total physical thickness of 1.6 mm.

The focal distance *F* which is depicted in Fig. 1(a) is 80 mm and antenna aperture size is 105 mm x 105 mm. And this gives to an F/D ratio of 0.76. The required phase error correction of the antenna unit cell elements can be determined by using equation (1).

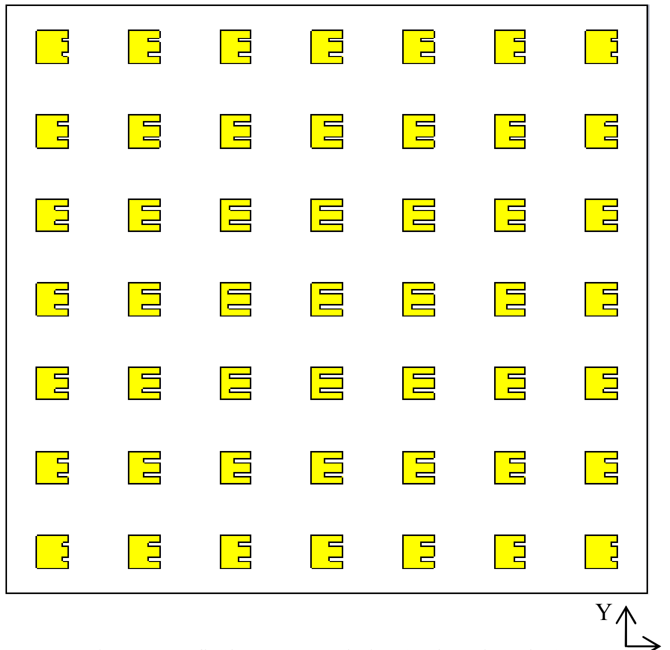
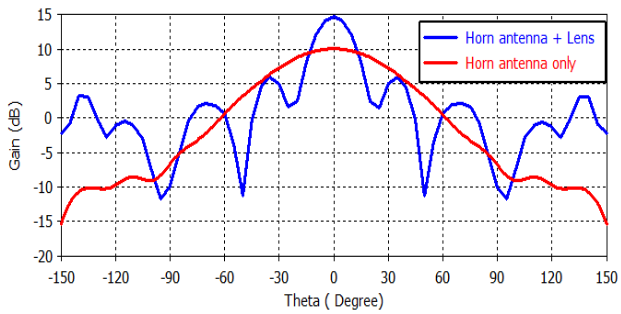
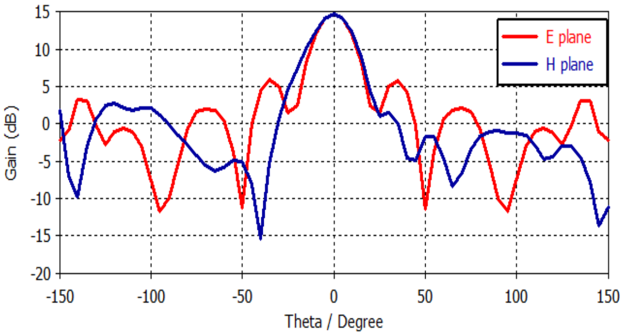


Fig.3: 7 x 7 flat lens antenna design (E-shaped patches).

The gain of small horn antenna used as a feeding source was 10 dB. After employing the full lens structure, the gain is increased to 14.8 dB. The simulation results validated that the flat lens antenna can focus the radiation pattern from feed antenna and enhance its gain as well as shape the beam of the transmitted signal. The simulation result also indicates that the spherical wave front is converted into planar wave front, because the directivity is improved. Fig.4 shows the radiation pattern of the simulated lens antenna. This lens antenna design will be fabricated and measured soon for further analysis.



(a)



(b)

Fig. 4. Radiation pattern of full array simulation results at 10 GHz

IV. CONCULUSION

A compact and less manufacturing complexity of flat lens antenna which is based on aperture coupled microstrip patches have been designed. The transmission phase of the elements of the antenna is controlled by using variable length slots. The obtained results show that the proposed antenna unit cell has very good performance in transmission phase (range of 320^0) and an enhanced gain performance was achieved after employing full array lens structure. Besides, the presented design has compact and small size, which makes the antenna attractive for wide variety of X-band applications. More detailed simulation and measurement results will be analyzed in the presentation.

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