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Measurement of Flat Lens Antenna Unit Cell using Waveguide Simulators

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***Abstract*—This paper addresses the measurement of compact flat lens antenna unit cell in the X-band frequency range using waveguides. A set of sample unit cells based on aperture-coupled concept were fabricated and measured. Two standard WR-90 waveguides and vector network analyzer are used to measure the fabricated elements. The transmission and reflection loss performances of the measured sample unit cells are demonstrated and validated with CST software simulations. The experimental results obtained are promising and indorses that waveguide simulators are precise and cost-effective method of measuring the scattering parameters of flat lens antenna unit cells.**

Keywords—Waveguide simulators; lens antenna; aperture-coupled; scattering parameters; X-band.

I. INTRODUCTION

The continuing development of wireless communication networks and digital radar for remote sensing create a demand of developing high performance flat lens antennas. A flat lens antenna (also called discrete lens) is a light weight, highly deployable and cost effective solution to conventional and curved dielectric lenses. A typical flat lens antenna configuration consists of an array of microstrip patches which are coupled or joined together by phase shifters [1].

In this study, a unit cell approach which is a quick and easy way of designing and analyzing lens antenna arrays is employed. The basic operation of an individual lens array element is to collimate the feed spherical electromagnetic incident wave into planar wavefront at the back of the aperture [2]. Therefore, the unit cell element should be designed to establish the needed phase adjustment. Experimental analysis of the unit cells are crucial to observe and validate the behavior of scattering parameters. Hence, waveguide simulators are convenient way of assessing the performance of lens array unit cells [3]. The background theory of flat lens antenna unit cell is presented in section II, followed by measurement setup in section III. The results and comparisons are discussed in section IV. Lastly, the conclusion of the work is given in section V.

II. THEORETICAL BACKGROUND

In order to understand the background theory of flat lens antenna unit cell, the possible design structures and operation of unit cell element are discussed here. Regardless of the several existing design approaches, a flat lens antenna unit cell consists of two microstrip patches (transmission and reception surfaces) which are coupled or joined together by phase shifters.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 [4], multi-resonance behavior [5] and microstrip delay lines [1, 2] to realize phase shift and stacked patches to increase bandwidth. The flat lens antenna unit cell operation overview is shown in Fig.1.

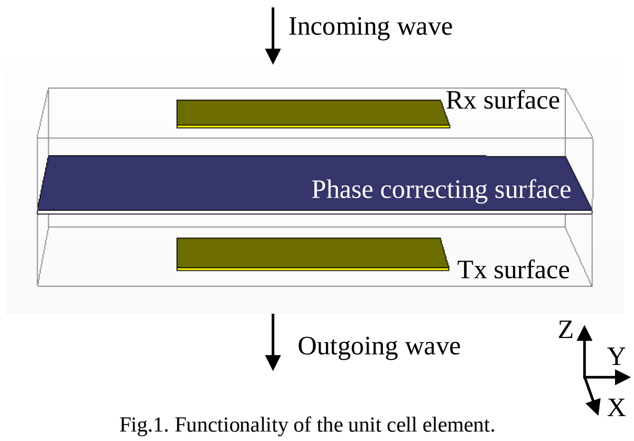


Fig.1. Functionality of the unit cell element.

The unit cell element should be 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.

Therefore, the required phase error correction of an individual unit cell element can be determined using the following equation [6]:

$$\varphi_i = (2\pi/\lambda_0)(R_i - F) \pm 2\pi N + \varphi_0 . \quad (1)$$

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

To evaluate the performance of the unit cell, the reflection and transmission coefficients as well as the phase of the transmitted signal should be measured. Rectangular waveguides are simple and reliable technique to predict the scattering parameters of the fabricated unit cells. Using the infinite periodic boundary of the fields, the reflection coefficient can be calculated as the ratio between the reflected and incident fields. Transmission coefficient can also be expressed as the ratio between the transmitted and incident fields.

In rectangular waveguide, if the dominant mode (TE_{10}) is the only propagating mode and the incoming wave from port 1 is E_1^+ the scattering parameters can be achieved from the following relations:

$$\text{Reflection } (S_{11}) = (E_1^-/E_1^+) \quad (2)$$

$$\text{Transmission } (S_{21}) = (E_2^-/E_1^+) \quad (3)$$

The above scattering parameters relations can be illustrated in Fig.2.

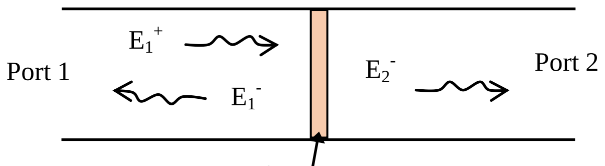


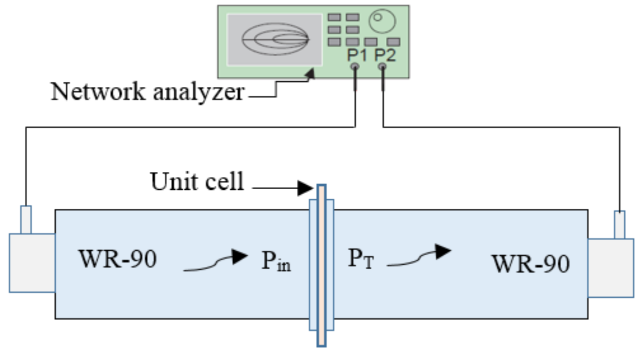
Fig.2. Electric field waves in waveguides

For some flat lens antenna unit cell designs using waveguides to evaluate the performance of the elements would probably be the most precise and cost effective solution compared to full array measurements. However, the most shortcomings may occur if the element under test is not compact in structure or if the unit cell is unfit in the waveguide flanges.

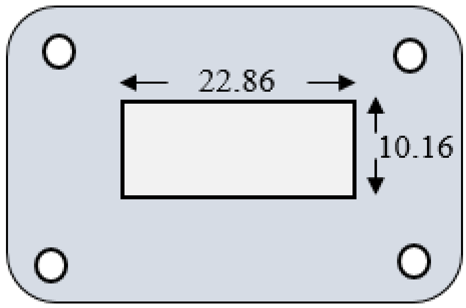
III. Unit Cell Measurement Setup

A set of sample unit cells have been fabricated and measured. Two waveguide simulators were used to measure the performance of the unit cells. The waveguide simulators represent the symmetry of the elements and replicate the characteristics of an infinity array of the unit cells [3]. The rectangular walls of the waveguide simulators act like an infinite periodic boundary condition (PEC) that are around the edges of the unit cell.

A pair of standard rectangular WR-90 waveguides of dimensions 22.86 x 10.16 mm^2 are used and were setup as shown in Fig 3 (a).



(a)



(b)

Fig.3. (a) waveguide simulators with network analyzer setup and (b) Waveguide flange dimensions.

There is a possibility of simulating several incident wave angles employing higher order TE and TM propagation modes. However, in this experiment, only the fundamental TE_{10} dominant mode is measured.The scan angle of the incident wave cannot be easily identified as the element under measurement is covered by the waveguide flanges on both sides.Theoretically, at 10 GHz, the dominant mode (TE_{10}) of the WR-90 waveguide simulator can scan an incident wave angle of 41° [7, 8].

The inner cavity structure of these rectangular waveguides is shown in Fig.4. As the incident wave is propagating on Z-direction, the electric fields are aligned with the Y-direction while the magnetic fields are excited in the X-direction.

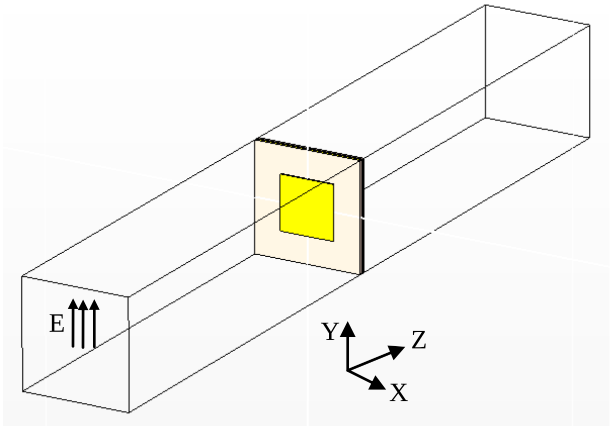


Fig.4. Inner cavity structure of the waveguides.

In order to measure the scattering parameters of the fabricated unit cell samples, a ZVB-14 vector network analyzer are used. Two WR-90 waveguide to coaxial adapters are used to connect the waveguide simulators to the vector network analyzer. The element under test was inserted in between the apertures of the two waveguide simulators as shown in Fig. 5.

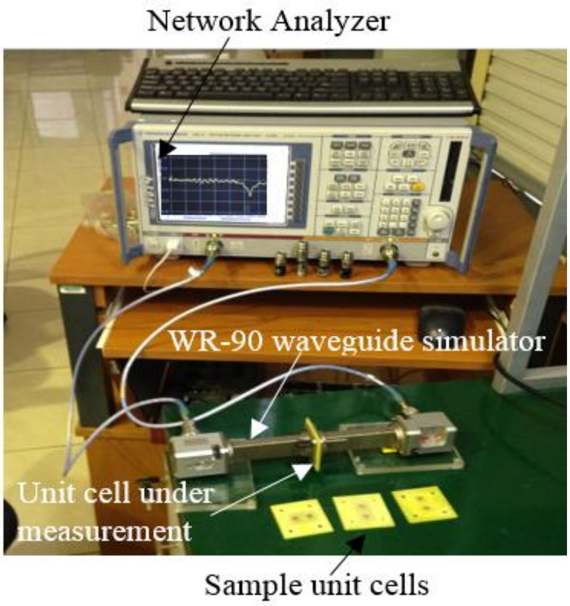
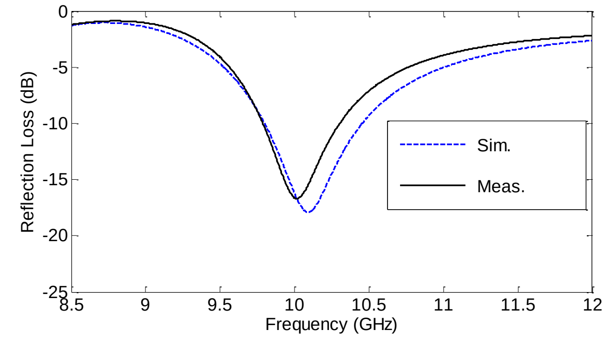


Fig.5. Complete measurement setup.

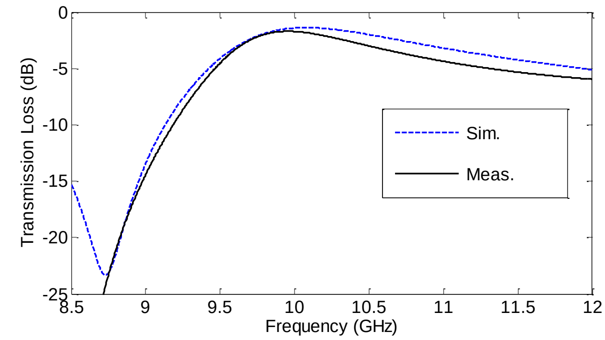
IV. Results

Several unit cell samples with different patch slot lengths for phase error correction have been fabricated and measured to investigate the performance of each element. The transmission loss, reflection loss and transmission phase of the designed unit cells were measured and compared with CST Microwave studio simulations. The scattering parameters measurements and simulations of one unit cell sample are compared as shown in Fig.6.

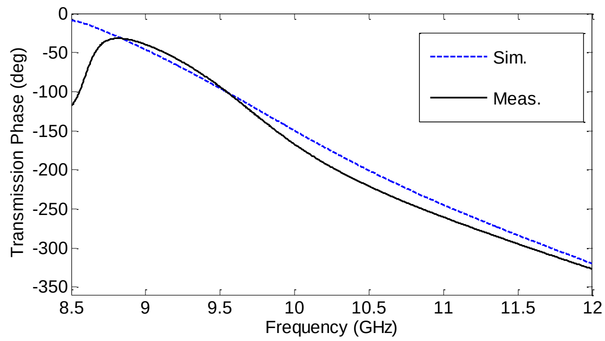
The resonant frequency can be observed to vary from 9.90 GHz to 10.15 GHz, representing a frequency shift of 250 MHz on either side of the operating frequency as illustrated in Fig. 6a. There are some slight differences between simulation and measurement results and these are due to fabrication or experimental tolerances and the glue applied to join the unit cell layers together. Relatively, the simulated and measured results are in good agreement.



(a)



(b)



(c)

Fig. 6. S-parameters of the unit cell: (a) Reflection Loss, (b) Transmission Loss, (c) Transmission Phase.

V. Conclusion

A unit cell measurement technique of compact flat lens antenna in X-band is presented in this paper. A set of unit cell samples have been fabricated and measured in WR-90 waveguides. To confirm the accuracy and reliability of the measurement, CST Microwave studio simulations have been compared with the obtained results. The acquired experimental results validate that waveguides are precise and cost-effective method of measuring the scattering parameters of flat lens antenna unit cells.

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