Analysis of Variable Dielectric Substrate Thickness of X-Band Square Patch Reflectarray Antenna

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Abstract

The analysis of square patch reflectarray antenna with different thicknesses of dielectric substrate is presented. The substrate thickness is varied from 1.41 λ_g to 1.46 λ_g in order to investigate the effect of scattering parameter behavior on the reflection loss and reflection phase of reflectarray antenna design. It has been observed that by increasing the thickness of dielectric substrate, the improvement of bandwidth performance from 126.5 MHz to 635.4 MHz is achieved. The reflection loss is also reduced from 1.322dB to 0.144dB when the different thickness of dielectric substrate is varied from 0.381mm to 1.570mm. The maximum bandwidth performance of the different thicknesses used is obtained by using 1.570mm which offers the highest bandwidth of 635.4 MHz with the lowest reflection loss of 0.144dB. By increasing the thickness of dielectric substrate, 509 MHz improvement in the bandwidth performance is obtained. The performance of the antenna design based on the characteristics of reflection loss, reflection phase and Figure of Merit (FoM) for different thicknesses of dielectric material are discussed in this paper.

Keywords: Reflectarray antenna, variable thicknesses of dielectric substrate, enhanced bandwidth

1. INTRODUCTION

Reflectarray antenna has been developed over 20 years ago which provides a mature technology for communication engineering particularly. The flat reflecting structure of the reflectarray also lends itself for flush mounting onto an existing flat structure without adding significant amount of mass and volume to the overall system structure [1]. The reflectarray antenna manufactured on a planar substrate printed circuit technology and offers the possibility of beam steering as phased arrays [2]. The reflection loss depends on the material properties of the dielectric material employed for the design as well as the thickness of the dielectric material. The feed antenna bandwidth and element spacing also limit the bandwidth of reflectarrays but these two are not serious concerns if the bandwidth requirement is less than 15% [2].The purpose of this paper is to present the analysis reflectarray antenna by using variable dielectric substrate thickness with bandwidth improvements.

2. LITERATURE REVIEW

The use of the printed reflectarray antenna technology with significant innovative features allows possible solutions for mobile ground station antenna which is able to satisfy not only the radiation requirements but also reduced volume (especially when folded) with ease of deployments [3]. It has been reported recently that compact antenna structures with broadband techniques and multiple functionalities have become more important in antenna designs [4]. Despite of many advantages the reflectarray antenna has limited use due to the possibility of higher loss and narrow bandwidth performance. The possibility of high loss is due to the dielectric loss, conductor loss and scattered loss which is introduced by surface wave excitation while the bandwidth performance of reflectarray antenna was mainly limited due to the differential spatial phase delays and its element [5]. Therefore the two factor of loss is conductor and the dielectric materials are much more significant. The reflection loss of the reflectarray antenna is primarily limited to dielectric absorption in the dielectric layer. The conductor loss depends upon the conductivity of conducting material for the patch element [6]. The configuration of absorption in the dielectric layer of reflectarray antenna is shown in Fig. 1.

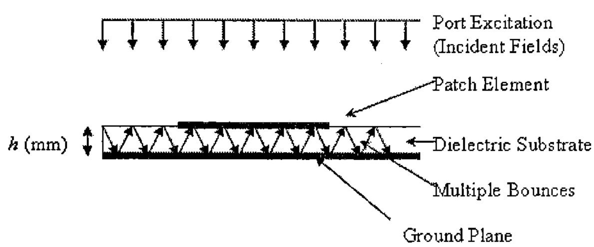

Fig. 1 Dielectric absorption in dielectric layer of reflectarray

As depicted in Fig.1, it is shown that the incident fields which is consumed from microwave energy of reflectarray antenna and the losses due to electromagnetic energy absorption caused by the multiple bounces in the dielectric substrate [7]. For thin dielectric substrate, multiple bounces will occur in the dielectric substrate which contributes the high loss and narrow bandwidth performance. The absorption energy can be reduced by increasing thickness of dielectric substrate (h) hence decrease the number of bounces in the substrate region. By decreasing number of bounces in the region, the absorption of electromagnetic as well as the reflection loss can be reduced. The reflected field from microwave energy consists of scattered energy from the patch element and reflected energy from the ground plane [8]. Maximum electric fields in reflectarray antenna are required to obtain maximum reflected signal. The reflection loss (RL) can be given by equation (1).

$$RL \simeq \alpha_d + \alpha_c \qquad (1)$$

Where, α_d and α_c are the attenuation due to dielectric substrate and conductor loss respectively. The attenuation in dielectric substrate depends on the material properties [8]. The ideal value of reflection loss for reflectarray antenna is 0 dB at resonant frequency.

3. METHODOLOGY

A. *DESIGN OF SQUARE PATCH REFLECTARRAY ANTENNA*

In order to study the effect of different thicknesses of dielectric substrate, an X band square patch reflectarray antenna was designed to operate at 10 GHz. The configuration of the square patch reflectarray antenna is shown in Fig.2.

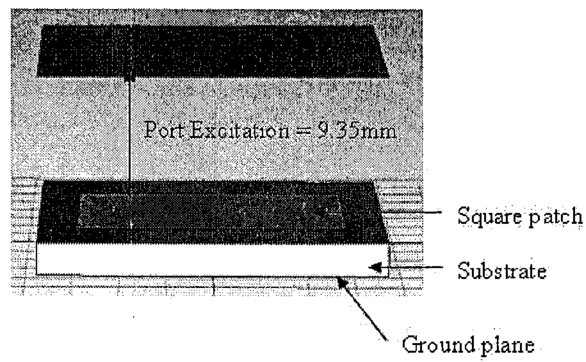

Fig. 2 Configuration of square patch element reflectarray antenna

In this work, commercially available CST computer model has been used to model a unit cell element with proper boundary conditions. Square patch reflectarray antenna was constructed from dielectric substrate (h), ground plane, patch element (L=11 mm x W=11 mm) with port distance excitation (t). In this investigation, the thicknesses of dielectric substrate have been varied from 0.381 mm to 1.570 mm. The dimension of substrate for this square patch (d= 15 mm x 15 mm) has been calculated by using equation (2).

$$d \leq \frac{\lambda_o}{2} \qquad (2)$$

Where λ_o is free space wavelength and V_o is speed of light in free space, 3 x 10^8 ms^{-1}. The width (W) and Length (L) of patch have been calculated by using equations (3) and (4).

$$W = \frac{V_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (3)$$

$$L = \frac{V_o}{2f_r\sqrt{\varepsilon_r}} \qquad (4)$$

Where f_r is resonant frequency which is designed at 10 GHz and ε_r is dielectric constant, ε_r =2.2 has been used in this work. The port excitation was kept at a distance (t) of 9.35mm from the patch element. The calculation of port excitation distance (t) to patch element is based on equation (5).

$$t = \frac{\lambda_g}{4} + h + 0.035 \qquad (5)$$

The distance of port excitation from microwave energy to patch element can be calculated by using equation (6).

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_{reff}}} \qquad (6)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \qquad (7)$$

Where h can be defined as thickness of substrate and w is width of substrate.

B. BANDWIDTH PERFORMANCE

Generally the bandwidth performance of reflectarray antenna can be analyzed by the reflection loss and reflection phase curves. Bandwidth of reflectarray antenna can be measured by using the reflection loss curves. The 10 % and 20 % bandwidth are measured by moving 10 % and 20 % above the reflection loss at 10 GHz. The bandwidth performance of the reflectarray can also be observed by the reflection phase curve [9]. The bandwidth is calculated based on the slope of the phase curve which can be represented by using Figure of Merit (FoM) and static linear phase range. Figure of merit can be calculated by using equation (8).

$$FoM = \frac{\Delta\phi}{\Delta f} \ (^0/\text{MHz}) \qquad (8)$$

Where $\Delta\phi$ is the change in the reflection phase in degrees and Δf is the change in the resonant frequency in MHz of the reflectarray antenna. FoM is calculated in ^{0}/MHz.

4. RESULTS AND ANALYSIS

A simulation model of square patch reflectarray antenna was designed by using commercially available computer software CST MWS. In this study the reflection phase curve for variable thickness dielectric substrate has been plotted in Fig. 3.

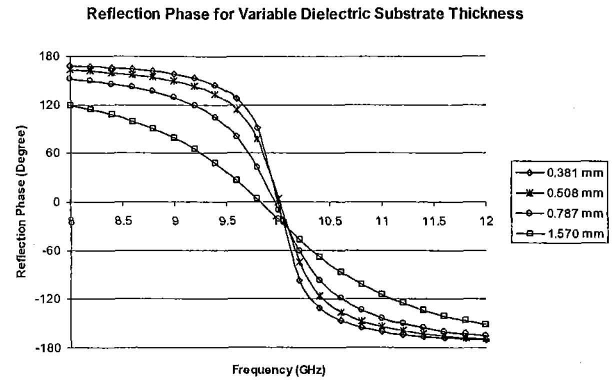

Fig. 3 Reflection phase for different thickness of dielectric substrate

As depicted in Fig. 3, the 1.570 mm thickness dielectric substrate (h) is gentler compared to the others thicknesses of substrate. The reflection phase curve is shown to be much gentler as the thickness of dielectric substrate was increased from 0.381 mm to 1.570 mm. Figure of Merit (FoM) has been calculated and the result is shown in Table 1.

Table 1: Results of figure of merit

Thickness, h (mm)	Figure of Merit (^{0}/MHz)
0.381	0.374
0.508	0.315
0.787	0.235
1.570	0.110

Table 1 shows the Figure of Merit (FoM) with varying thickness of substrate. From the Table 1, it can be seen that the 0.381 mm of dielectric substrate offers of 0.374 ^{0}/MHz FoM compared with 1.570 mm dielectric substrate which offers of 0.110 ^{0}/MHz FoM. The lowest value of FoM is shown offered the highest bandwidth performance in reflectarray antenna.

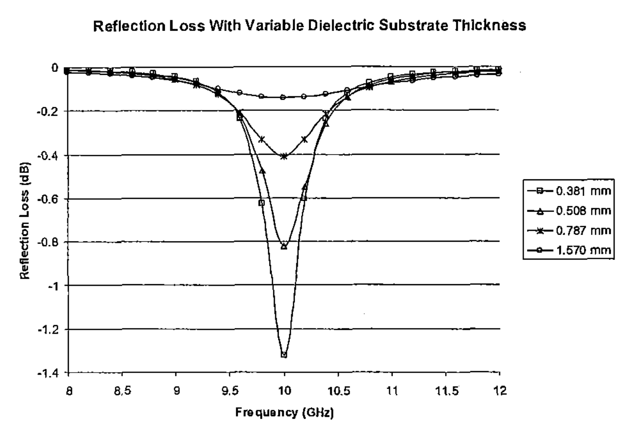

Fig. 4 Reflection loss of different thicknesses of dielectric substrate

Fig. 4 shows the reflection loss curve for variable thickness of dielectric substrate from 0.381 mm to 1.570 mm. It can be seen that the 0.381 mm of dielectric substrate (h) gives the highest loss of 1.322 dB compared with 1.570 mm dielectric substrate (h) which only offers 0.144 dB of reflection loss. From these results, it is proven that the thickest substrate of dielectric material offers low of reflection loss performance.

Table 2: Results of reflection loss and bandwidth performance

Thickness, h (mm)	Reflection Loss (dB)	10 % Bandwidth (MHz)	20 % Bandwidth (MHz)
0.381	-1.322	126.4	186.7
0.508	-0.825	171.5	256.3
0.787	-0.411	277.4	416.8
1.570	-0.144	635.4	952.8

Table 2 shows the results of reflection loss and bandwidth performance. It can be seen that for thickness of dielectric substrate (h) 0.381 mm, 10 % of bandwidth only offers 126.4 MHz while the 1.570 mm offers broader bandwidth performance of 635.4 MHz. It can be observed that the bandwidth performance of 509MHz is achieved. The relationship between variable thicknesses of dielectric substrate and bandwidth performance is shown in Fig. 5.

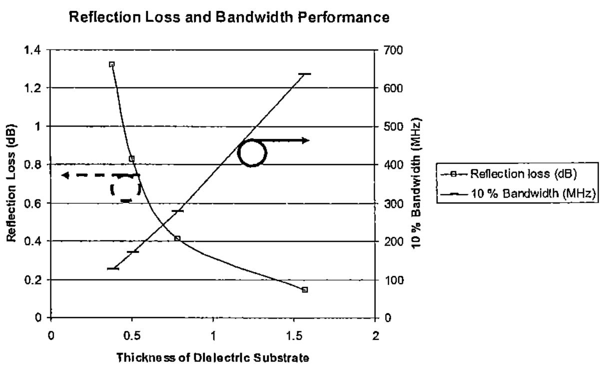

Fig. 5 Relationship between bandwidth for different thickness of dielectric substrate

Fig. 5 shows the relationship between reflection loss and bandwidth performance. By increasing thickness of dielectric substrate, the bandwidth is shown to be increased from 126.4 MHz to 635.4 MHz whereas reflection loss is observed to decrease gradually from 1.322 dB to 0.144 dB. The reflection loss has been reducing by increasing thickness of dielectric substrate. It is because of the thickness of dielectric substrate which reduces the energy absorption in dielectric layer. From Fig. 5, it can be observed that the reflection loss is inversely proportional to the bandwidth performance. From this result, it is shown that the thickness of dielectric material can be used to achieve lowest reflection loss with enhance bandwidth performance.

5. CONCLUSION

The results obtained in this work demonstrate that the dielectric substrate plays a crucial role in determining the bandwidth performance of reflectarray antenna. The effects of substrate thicknesses on the reflectarray antenna performance have been demonstrated for substrate thickness ranging from 0.381mm to 1.570mm. Further investigations are required to be done particularly the experimental verifications in order to validate the simulated results from CST computer model.

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