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# A Technique of Scan Blindness Elimination for Planar Phased Array Antenna using Miniaturized EBG

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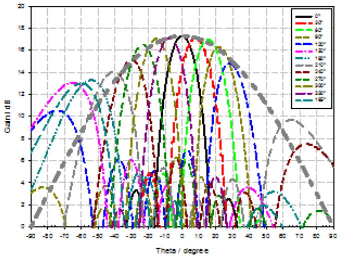
**Graphical abstract**



**Abstract**

In this paper, the planar phased array antenna scan blindness characteristic has been analyzed and a novel technique of eliminating the scan blindness for the phased array antenna has been introduced. The scan blindness of the center element has been used to present the entire phased array characteristic. The array scan blindness characteristics have been simulated and analyzed using CST Microwave Studio (CST MWS). The 5×3 planar phased array antenna radiation patterns against the pattern elevation angle direction has been simulated and compiled. The array's scan blindness has been determined at the angle of approximately $47^0$. The miniaturized capacitive loaded Electromagnetic Band Gap (EBG) has been developed and introduced between the array elements to eliminate the problem. Based on the simulated results, it is shown that the use of a miniaturized EBG is effective in reducing the surface wave effects and eliminates the scan blindness in the array radiation pattern. This novel finding is very useful to improve the antenna directive efficiency for the directional radar and satellite application.

*Keywords*: Miniaturized EBG; phased array antenna; surface wave; directive antenna

## ■1.0 INTRODUCTION

In recent wireless technology, the radar system has been used in a variety of applications such as airborne, military and automotive [1, 2]. In advanced radar systems, planar phased array antenna (PAA) has been used as an essential component [3, 4]. The received signal enables the system to estimate the azimuth and elevation angles of the target. There are two major conflict requirements on designing the PAA using printed antenna technology, one is the requirement to obtain a compact design which utilizes a high permittivity dielectric substrate, and the other is on the high radiation efficiency, which utilizes a substrate with low dielectric constant. The main drawback using the higher dielectric substrate is the enhancement of the surface wave's propagation, whereas for the lower dielectric is the larger structure.

In microstrip antenna design, thicker substrates with higher permittivity have been broadly used in order to attain a compact wideband antenna. The main problem of a phased array using printed technology, such as microstrip patch antennas, is the mutual coupling among elements due to the excitation of surface waves in the structure. This effect limits the angular scanning sector since it causes impedance and pattern anomalies, and in some extreme cases is allied with the scan blindness [5, 6].

Array scan blindness can be described as the condition whereby no real power is coupled from or to the array at certain direction angles. The phenomenon is due to the energy being stored by the surface waves, which bound to the finite array surface. The popular method of suppressing the surface waves is by integrating an EBG structure within the array elements. There are diverse forms of EBG designs that focus on the array applications [7, 8].

The investigations on microstrip phased array antennas have been realized in the compact design on a high dielectric by suppressing the surface wave excitation using EBG structures. The EBG structure is very effective to reduce the mutual coupling within the array elements, which improves the radiation efficiency [4, 9, 10]. In this paper, the capacitive loaded miniaturized EBG has been developed and analyzed for the application of reducing mutual coupling within phased array elements. The effectiveness of the surface structure to suppress the surface wave within the antenna elements and eliminating the radiation scan blindness has been presented.

## ■2.0 ANALYSIS OF SCAN BLINDNESS FOR PLANAR PHASED ARRAY ANTENNA

Scan blindness for the phased array can happen to the large elements of arrays with wide beam width such as the dipole or patch antenna with larger number of elements. At certain angles of scanning, the array mutual coupling can increase the reflection coefficient of the individual elements to near unity [11, 12]. As a result, the array fails to radiate and form a pattern null which is known as scan blindness.

The blindness phenomenon is normally associated with the surface wave on the array elements and the surface wave that is supported by the structure itself, such as dielectric loaded arrays. The existence of an array blind spot usually exists at an array spacing of more than half wavelength, and at a scan angle, which is less than that at which the grating lobe first enters the visible space. Hence the phased array antenna maximum scan blindness angle can be estimated as in the following equation [11]:

$$[cos\theta_{gr}] = \frac{\lambda_0}{d} - 1 \qquad (1)$$

where, $\lambda_0$ is the free space wavelength, $d$ is the distance between the elements in the E-plane, and $\theta_{gr}$ is the angle at which the grating lobes enter the real space, which can be the maximum angle for the scanning blindness to occur.

The scan blindness phenomenon for the planar microstrip phased array antennas as shown on Figure 1 has been simulated and analyzed. The period within the array elements has been set to 68mm ($0.5\lambda_{2.2GHz}$) and 82 mm ($0.6\lambda_{2.2GHz}$) in the *E*-plane direction (*x*-axis), *dx* and fixed to $0.5\lambda_{2.2GHz}$ in *H*-plane direction, *dy*.

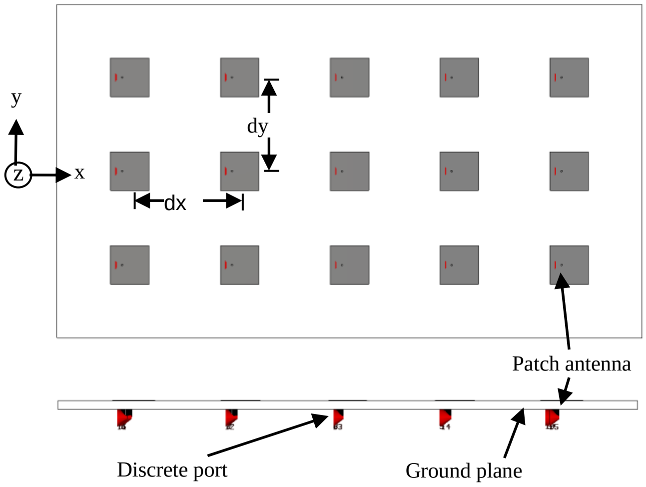


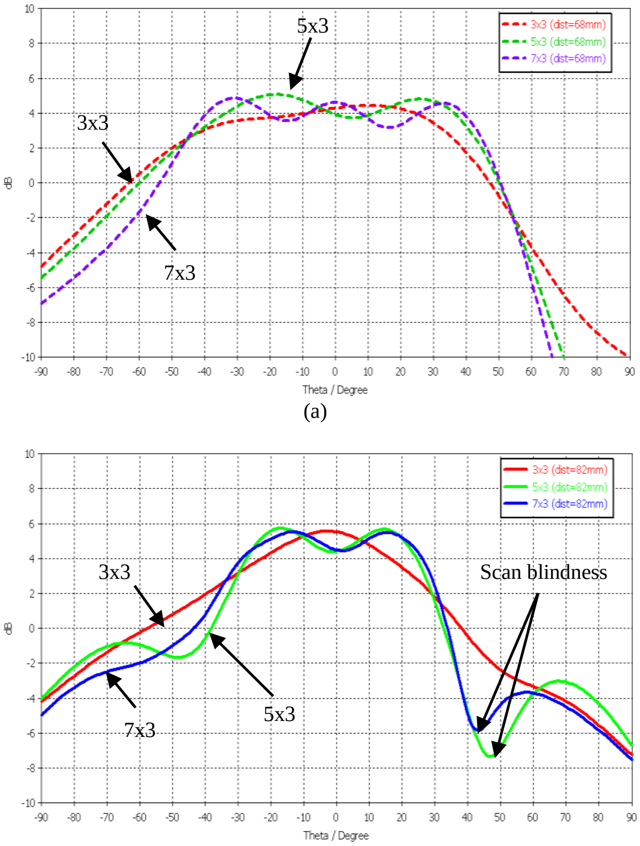
**Figure 1** 5×3 planar microstrip array antennas

The configuration of the array elements has been arranged as 3×3, 5×3 and 7×3 elements, which could be sufficient for analyzing the scan blindness for an array with an infinite number of elements. The phase gradient within the array elements has been gradually increased from 0° to 360° along the *x*-axis in order to achieve a scanning radiation pattern from 0° to ±90°. The phase gradient between the elements has been kept constant for the elements along *x*-axis, which is similar to the case of the linear array.

The simulated active radiation patterns for array's center element monitored at 2.2 GHz are illustrated in Figure 2(a) and Figure 2(b) for the *E*-plane and *H*-plane, respectively. The *E*-plane radiation demonstrates that the scan blindness problem has been observed for planar arrays with 5×3 and 7×3 elements with a period of 0.6λ. On the other hand, the scan blindness has not been observed for a small number of elements (3×3) and for the array period of 0.5λ. These results elucidate that the scan blindness will happen for the phase array antenna with larger number of elements in phased gradient direction and with larger spacing of more than half wavelength.

For the comparison, the *E*-plane scan blindness angle can be predicted using Equation (1). The calculated grating lobe angle is closely related to the period within the element and has not been influenced by the number of elements; hence the grating lobe or maximum scan blindness angle has been calculated as 0° and 49° for the 68 mm (0.5λ) and 82 mm (0.6λ) period within arrays, respectively.

The E-plane simulated result as in Figure 2(b) demonstrates the scan blindness for the phased array with 0.6λ period. The scan blindness for 5×3 and 7x3 phased arrays have shown good relation with the estimation value as the angle of approximately 47° and 43° respectively have been observed. The scan blindness angle for larger number of array is slightly lower with compared to smaller number of array due to more severe mutual coupling effect to the center element from the other elements in the array of larger number of elements.



(a)

(b)

**Figure 2** *E*-plane active radiation patterns for planar phased array center element when the period within elements has been chosen as (a) 68 mm ($0.5\lambda_{2.2GHz}$), (b) 82 mm ($0.6\lambda_{2.2GHz}$)

## ■3.0 DEVELOPMENT OF MINIATURIZED CAPACITIVE LOADED EBG

The capacitive loaded miniature EBG structure with the overall period, *p* and loaded with lumped capacitors has been developed as shown in Figure 3. The structure has been developed using double sided FR4 substrate with dielectric constant, $\varepsilon_r$, of 4.3 and thickness, *t* of 6.4 mm. The miniaturized EBG composed of PEC copper plate with switchable pin vias. The surface mount capacitors are connected within each adjacent EBG patches which act as connection for the current path within the cells.

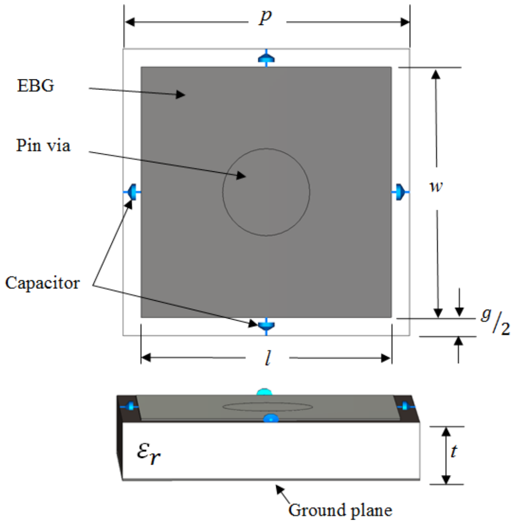


**Figure 3** A miniaturized EBG loaded with lumped capacitors

The miniaturized EBG structure design has been optimized by analyzing the structure surface transmission using 50Ω microstrip transmission line as shown in Figure 4. At the both transmission line edges, the discrete ports have been connected in order to simulate the EBG surface transmission. The EBG dimension has been tuned for the optimized parameter of the miniaturized EBG with the band gap frequency range which covers the antenna operation frequency of 2.2 GHz. The optimized dimensions for the miniaturized EBG structure have been determined as: *p*=3.8 mm; *l*=*w*=3.3 mm; with *g* and $C_L$ of 0.5 mm and 0.5pF respectively. The structure has been simulated using an FR4 material substrate with a dielectric constant, $\varepsilon_r$ of 4.3 and a thickness of 6.4 mm.

The EBG surface transmission loss for the case of all the pin via inserted and the characteristic when removing pin vias as reference are displayed in Figure 5. The EBG surface structure using optimized dimension shows band gap characteristic within the frequency of 1.9 GHz and 2.5 GHz with transmission loss of less than -20 dB. Result also dictates that the switching pin vias in and out has alternately switched the EBG characteristic from suppressing to propagating the surface wave, which denoted by the reduction and increment in EBG surface transmission values respectively. Hence, the EBG surface is suitable to be integrated with the antenna which designed at 2.2 GHz for utilizing its band gap characteristic.

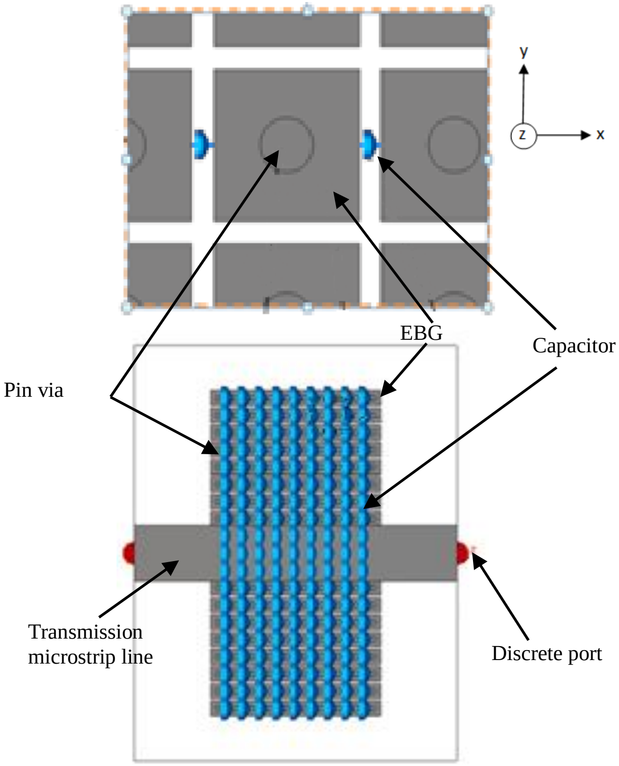


**Figure 4** Miniaturized EBG structure with microstrip transmission line across the surface

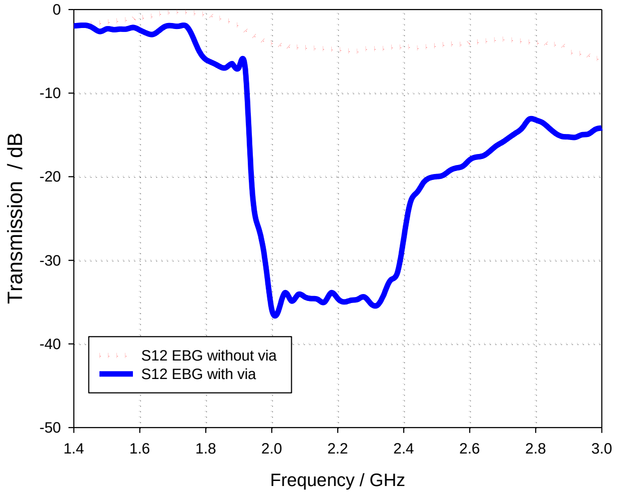


**Figure 5** Surface transmission los for miniaturized EBG structure for EBG inserted with pin via and without pin via

## ■4.0 MICROSTRIP PHASED ARRAY SCAN BLINDNESS ELIMINATION USING MINIATURIZED EBG

The performance for the large array is mainly characterized using two main parameters: the active element pattern and impedance [8]. The parameters are dependent on the mutual coupling from all elements in the array to the element under investigation. However, the mutual coupling is inversely proportional to the element distance; hence only closer neighboring elements have significant impact on the results.

In this section, a 5×3 elements microstrip phased array is considered. The radiation pattern scan blindness characteristics have been studied using separation distances of $0.6\lambda_{2.2\text{GHz}}$ and $0.5\lambda_{2.2\text{GHz}}$ have been chosen along the *x*-axis and *y*-axis, respectively. A technique of eliminating the scan blindness problems is introduced. The technique and results achieved in this section are expected to be relevant for other planar array configurations, and for infinite larger phased array antenna applications.

Figure 6 shows the array radiation pattern for the 5×3 planar phased array antennas. The array has demonstrated a very high gain of 17 dBi at broadside. However, due to the strong excitation of surface waves, it can be observed that the radiation scan blindness exists at the angle of approximately 47°. This introduces scan difficulties for the array and significant power losses at that angle. Additionally, the gain at the scan angle has been reduced which caused losses of data or signal at the direction. The losses might cause drop or losses of important data or signal especially for the active scanning applications, such as for radar and satellite receiver applications.

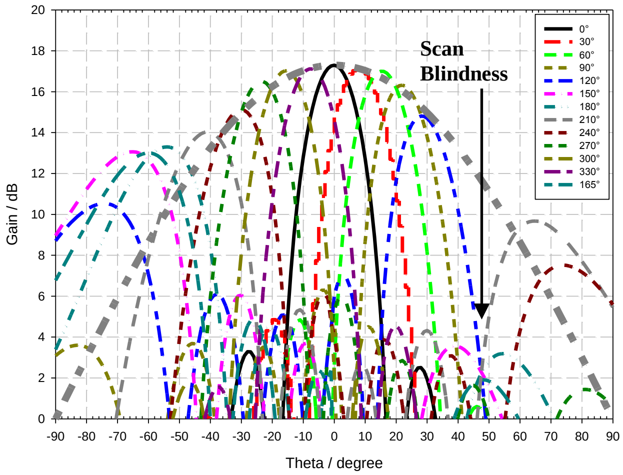


**Figure 6** 5×3 planar phased array antenna radiation patterns against the pattern elevation angle direction, *theta* (*xz*-plane)

From the results in section-2, the array center elements radiation patterns have demonstrated that surface wave excitation is significantly higher in the *E*-plane (*x*-axis) compared to *H*-plane (*y*-axis). In order to eliminate the scan blindness and improve gain, the suppression of surface wave is only essential along the *x*-axis. Hence the miniaturized EBG, which has been developed in section-3 has been utilized to suppress the surface waves. The EBG has been placed between the array elements in *E*-plane direction as exposed on Figure 7. The miniaturized EBG with 3.8 mm period and with 0.5 mm gap within elements has been used. The lumped capacitance element with the value of 0.5 pF has been connected within the EBG. The dimensions and the lumped elements value optimized the EBG band gap bandwidth frequency which covers the antenna operation frequency of 2.2 GHz.

The combination of the array return loss for the antenna at the operating frequency of 2.2 GHz has been simulated for the overall array at each directions of theta. This has been done by varying the feed phase gradient within the array either in *E*-direction or *H*-direction respectively. These have realized the phased array scan characteristic in *E*-plane and *H*-plane respectively.

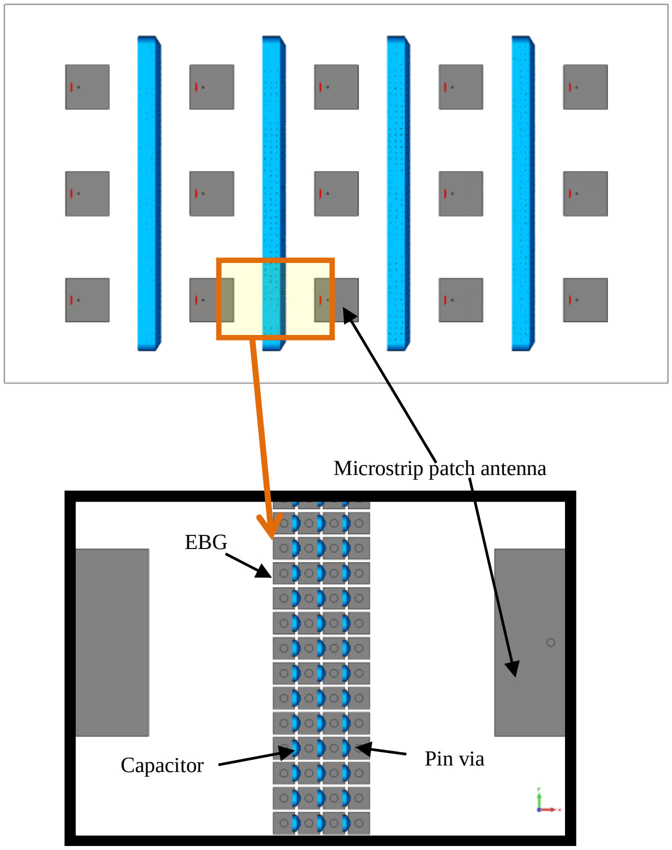


**Figure 7** 5×3 phased array antenna integrated with miniaturized capacitive loaded EBG

The scan characteristics of the array are demonstrated in Figure 8 for the *E*-plane and *H*-plane directions. Originally, scan blindness occurs at about 47° in the *E*-plane with the magnitude of return loss is almost 0 dB, which indicates the mismatching of the array antenna at 2.2 GHz. Employing an EBG shows that the scan blindness has been eliminated as no mismatch occurs in the scan visual range. However, the *H*-plane return loss has illustrated no variation in value for the cases of with and without EBG which demonstrate no severe surface wave effect to the array along the *H*-plane direction.

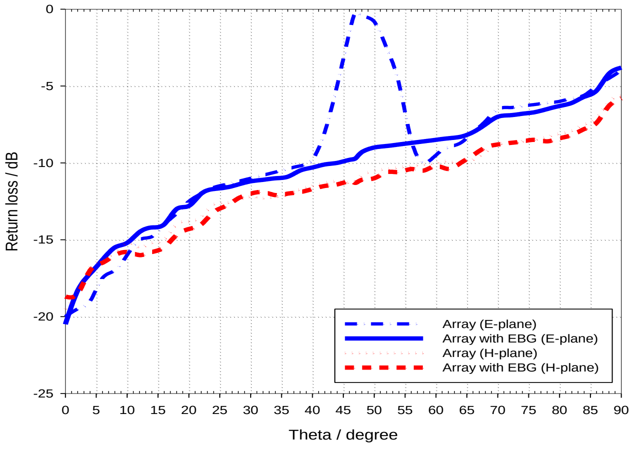


**Figure 8** Scan characteristics for the array without EBG and with EBG in *E*-plane and *H*-plane

The gain of a fully excited array with EBG has been computed with variable phase gradient between the elements as shown in Figure 9. The results illustrate that the beam peaks follow the element pattern nicely without any defected element pattern compared to the case of the array without EBG in Figure 3. The phased array scan blindness has Been completely eliminated due to the suppression of surface wave within the array elements when miniaturized EBG was applied within the array elements.

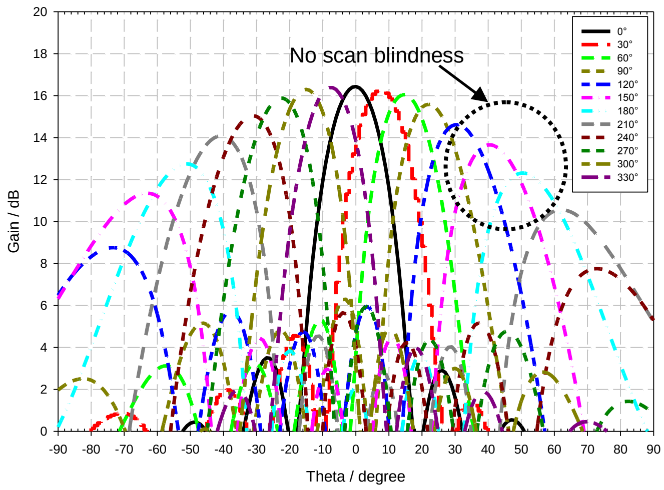


**Figure 9** Gain pattern of the fully excited array in *E*-plane (phi=0°) for the array with EBG

## ■5.0 CONSLUSION

In this paper, the performances of linear and planar phased arrays have been analyzed to determine the condition of scan blindness existence. The results have shown that scan blindness happens to the large number of arrays as the blindness has been observed for 5×3 and 7×3 arrays but not to the smaller array of 3×3. Additionally, it occurs when the array period is more than half wavelength.

The results have illustrated that adding a miniaturized EBG surface between the elements in *E*-plane direction, has effectively eliminated the array scan blindness. The close to zero return loss at the scan blindness angle has been improved when an EBG is integrated with the array which illustrates the suppression of surface wave. Hence, it can be concluded that the novel miniaturized capacitive loaded EBG is proven to be effective in reducing the mutual coupling between the array elements, which results in the elimination of the scan blindness. The novel finding will be very useful to improve the efficiency of phased array antenna in direction finding and detection application such as for the radar and satellite applications.

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