Edge Diffractions Impact on the Cross Polarization Performance of Active Phased Array Antennas

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***Abstract*—This paper examines the impact of diffracted fields on the cross-polarization performance of finite array antennas. The investigation included the calculation, simulation and measurement of several antenna prototypes with different element positions and different ground planes sizes. Characterization of the induced cross-polarization in a finite array with discontinuities in the ground plane was also performed. Excellent agreement between simulations and the actual measurements of eight antenna prototypes were obtained. The results demonstrated that the cross-polarization of the antenna elements in the array can be significantly impacted by the diffracted fields of the external and internal edges or discontinuities.**

***Index Terms*—array antennas, subarray, edge diffractions, co polarization, cross polarization.**

I. Introduction

Recent developments in dual-polarized phased array antennas have proven that current RF technologies are affordable and can be used for the development of phased array antennas for civil applications. Fast scanning updates, adaptive beam forming, and high reliability performance are some of the most important features that make phased array technology an ideal candidate platform for atmospheric radar applications [1]. However, the biggest limitation of phased array antennas is the high polarization requirements necessary to perform sectorial 2D electronic scanning [1]. Dual-polarization radars require a match between co-polar patterns < 0.1 dB and cross polarization better than -20 dB for alternate transmit and receive (ATAR) and greater than -40 dB for simultaneous transmit and simultaneous receive (STSR) [2], [3]. To achieve a high isolation, better than -40 dB for the overall scanning range, the phased array design requires consideration of all possible factors that may affect the cross-polarization isolation. It is common practice in the design of antennas with high cross-polarization, to take into account the performance of the radiating element, wide scanning impedance, small surface waves, mutual coupling, high symmetry in the element and array antenna, and mitigation of possible spurious radiation. These design criteria are effective for achieving cross-polarization isolations not greater than -25 dB across the scanning range. However, for values better than -40 dB, the design criteria must take into consideration other potential mechanisms, such as reflections and diffractions that might be produced in the discontinuities of the finite arrays due to the limitation of the current printed circuit board process that limits the size of the array antenna to 18x18 inches.

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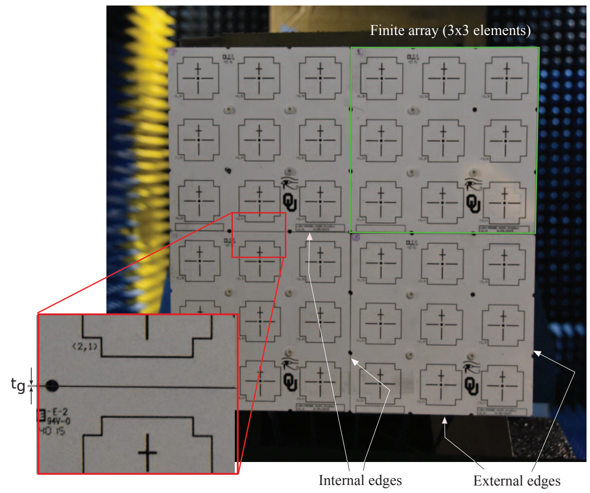

Fig. 1. Photo of a tileable finite array of 6x6 microstrip patch antenna elements, conformed by 4 sub-arrays of 3x3 elements each. Illustration of internal and external edges of a finite array antenna

To minimize the diffracted fields at the external edges of the antenna array, two or three terminated elements are recommended. This technique is effective in minimizing the impact of the diffracted fields induced at the external edges of the array, which commonly produce antenna element distortion (gain reduction, pattern asymmetry, and impedance change). One limitation of this technique occurs when the antenna array presents internal edges. Internal discontinuities or small gaps in the ground plane may not produce a significant degradation in the co-polar antenna patterns of each element near the edges. However, in case of high performance dual-polarized arrays that require values better than -40 dB, the diffracted fields in internal gaps may induce significant degradation in cross-polar patterns.

This investigation was conducted to evaluate the adverse effects of diffracted fields produced in external and internal edges in the cross-polarization of finite array antennas. In the past, the study of diffracted fields at the external edges of an array and their impacts on antenna patterns made use of the Geometrical Optic (GO) and Theory of Geometric Diffraction (GTD) techniques. These techniques have been discussed extensively in the literature [6], [7]. However, no references in the literature to investigations into the diffracted fields produced by the internal discontinuities in finite arrays

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were found.

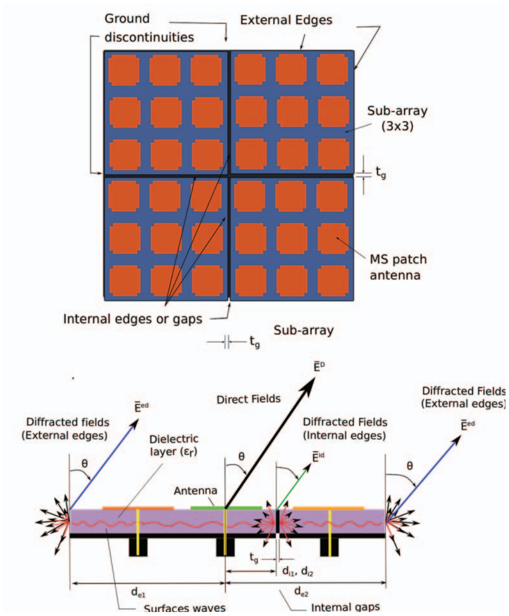

Fig. 2. Representation of tileable finite array of 6x6 elements, conformed by 4 sub-array of 3x3 elements each (top). Diffraction mechanism on the external and internal edges of a finite array antenna (bottom).

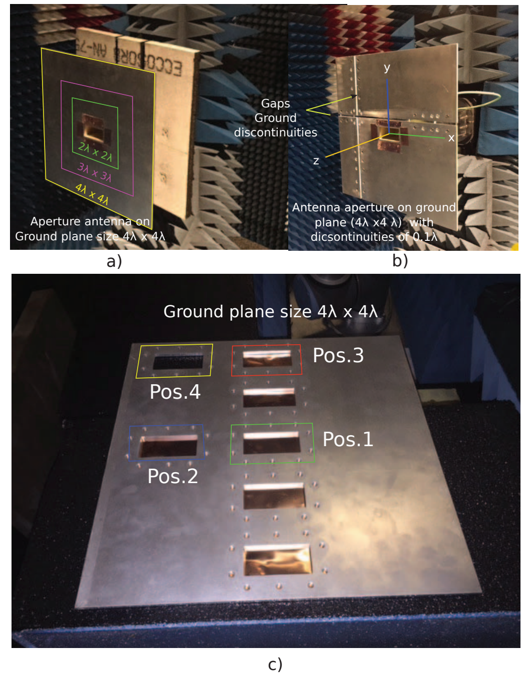

Fig. 3. Setup of antenna measurements in the ARRC anechoic chamber. a) Photo of a rectangular slot aperture on ground plane with different sizes (2λ, 3λ, and 4λ). b) Photo of rectangular slot apertures with different positions on 4λ ground plane. c) Photo of slot aperture on 4λ ground plane with internal gaps.

II. Background and Theory

The amplitude and phased patterns of the radiating element on a finite ground plane can be modified considerably by the effects of the edges, especially in regions of very low field intensity, such as backward radiation. These diffracted fields from the edges and corners of the array, constructively or destructively interfere with the direct radiated fields from the antenna with an infinite ground plane, causing scalloped patterns. Edge diffractions of the finite ground plane can affect the antenna performance in two ways. They may distort the symmetry of the antenna patterns, especially in the back-lobe radiation, and affect the cross polarization in the plane where the fields are stronger. Most large arrays are constructed using subarrays due to the limitations of fabrication processes. Depending on the frequency, array tiles of 4x4, 8x8, or 16x16 elements are commonly used, according to standard PCB fabrication processes. Internal discontinuities happen between the array tiles and they must be considered as an additional contributor in cross-polarization degradation, especially in PAR for weather applications, when the cross-polarization isolation is required to be below -40 dB [2], [3].

One of the most versatile and useful ray-based, high-frequency, techniques is Geometrical Optics (GO). The GO ray field consists of direct, refracted, and reflected rays. It is well known that electromagnetic waves are physically continuous in the time and space domains, both in magnitude and phase. However, limitations occur in situations when the GO yields fields that are discontinuous across the shadow boundaries created by the geometry of the problem. Inherent inaccuracies in GO, make it insufficient to completely describe the scattered field in practical applications near the shadow boundaries and in the shadow zones [6].

A representation of the radiation mechanism for the diffracted fields, which includes the external and internal discontinuities, is illustrated in Fig 2. At the top of Fig 2 is an illustration of a typical finite array composed of 6 x 6 elements, conformed by four sub-arrays, each one containing 3x3 elements. At the bottom of Fig. 2 is a cross-section view of the array which shows surface waves and diffracted fields at the internal and external edges. The superposition of the radiated fields of the antenna elements and the radiated diffracted fields induced in the external and internal edges can be represented by the equation (1).

$$\overline{E}^{\,t} = \overline{E}^{\,D} + \overline{E}^{\,de} + \overline{E}^{\,di} \tag{1}$$

The geometric optic (GO) technique can bee used to calculate the direct fields ($\overline{E}^{D}$) and UTD is used to represents the external and internal diffracted fields ($\overline{E}^{de}$, $\overline{E}^{di}$). By summing vectorially the GO and UTD fields, the total field ($\overline{E}^{t}$) can be computed at a given observation point [6].

$$\overline{E}^{\,d} = \overline{E}^{\,i}(Q_d).\overline{\overline{D}}.A(\rho_c, s).e^{-jks} \tag{2}$$

where $\overline{E}^{\,i}(Q_d)$ is the electric field incident at a point Q_d on the edge, $\overline{\overline{D}}$ is the dyadic diffraction coefficient can be obtained from [6].

III. Results

In this section, the impact of the diffraction mechanism over the antenna patterns of eight rectangular slot aperture antennas (see Figure 3) are discussed. Different ground planes

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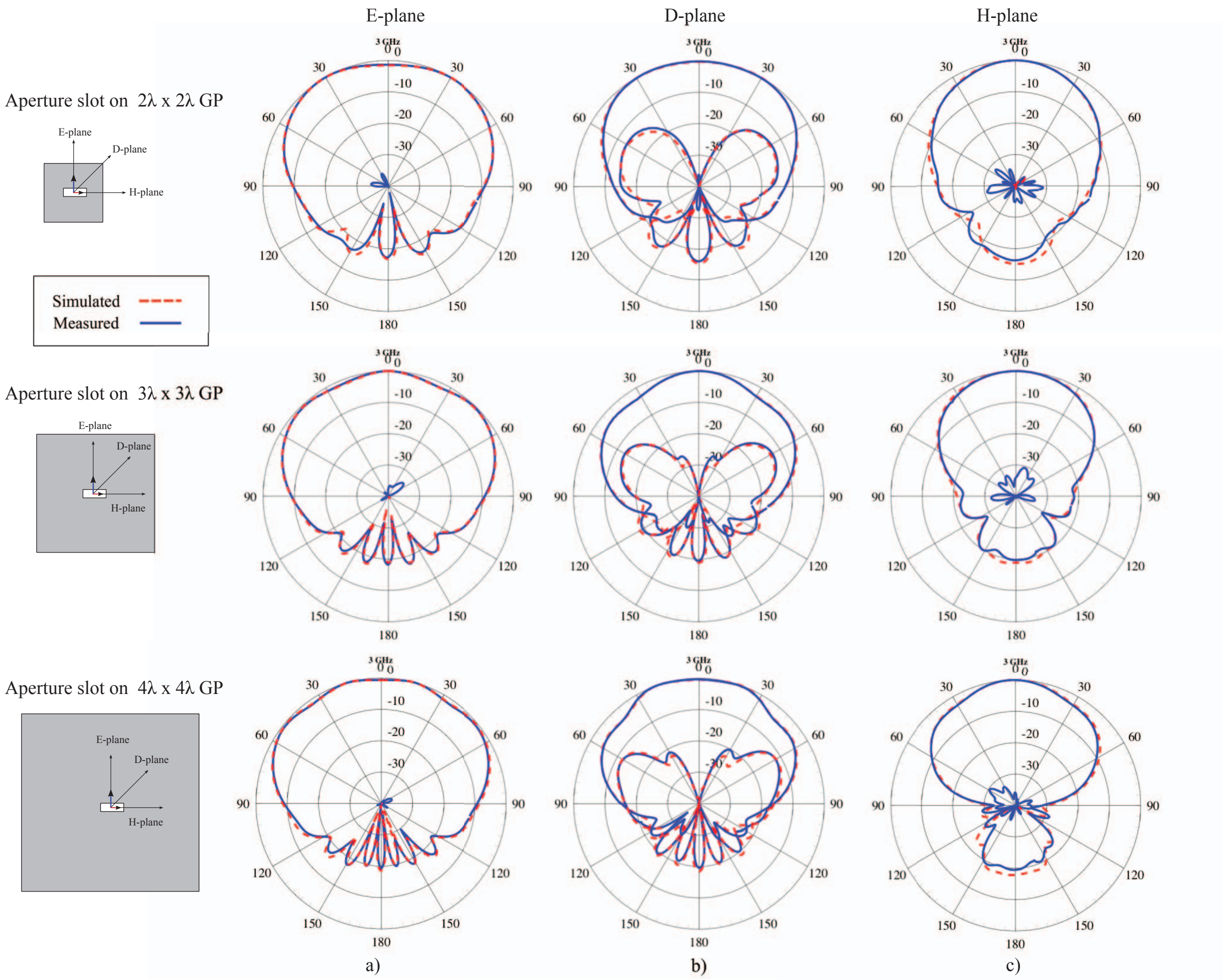

Fig. 4. Aperture slot antenna patterns on three different ground planes (2λ, 3λ, and 4λ) for a) E-plane, b) D-plane, and c) H-plane.

sizes and different element positions in the ground planes are considered. For all the cases, the aperture antenna lies on the x-y plane so the elevation angle (θ) is defined with respect to the z-axis and azimuth (ϕ) angle with respect to the x-axis. Since the equivalent sources of the slot aperture can be represented by an electric current (in x-axis) and magnetic current (in y-axis), the third definition of Ludwig (L3) is used to represent the dual-polarized antenna patterns [5].

The antenna patterns were measured in the ARRC far-field anechoic chamber at the University of Oklahoma. For each case, the measured results were overlapped with the results obtained from numerical simulations performed using HFSS. For all cases, the comparison shows excellent agreement between measured and simulated results.

A. Impact of diffracted fields versus ground plane sizes

Figure 4 shows the results of the diffraction mechanism at the external edges of the ground plane in the antenna patterns (for E-, D- and H-planes) of the slot, when the antenna has different ground plane sizes (2λ, 3λ, and 4λ). The impact of the diffracted fields affects the shape of the co- and cross-polar patterns. The number of ripples in the co-polar patterns are proportional to the size of the ground plane. The amplitude (peak-to-peak) is reduced as the ground plane is increased. The number of ripples in the back-lobe radiation are twice the number of ripples in the front radiation, minus one. In terms of the cross-polarization, the diffracted fields significantly affect the shape of the cross-polarization. This effect can be observed in all of the panes. However, in the E- and H-planes the cross-polarization changes significantly.

B. Impact of diffracted fields versus element position

A rectangular slot aperture was placed in different positions in a square ground plane of 4λ. The objective of this case is to demonstrate the impact of the diffracted fields in the antenna patterns when the elements have different positions. Figure 5, shows the measured antenna patterns overlapped with simulated results in HFSS for the E-, D- and H-planes. In general, the co- and cross-polar antenna pattern shapes show significant changes, especially in positions where the incident electric field of the aperture is stronger. This is the case of the antenna patterns in the E-plane. In comparison with the center position, when the element is placed close to the top edge of the ground plane (second row in Figure 5) the co-polar antenna pattern presents significant asymmetry in the E-plane. This is due to the fact that the incident electric field in these

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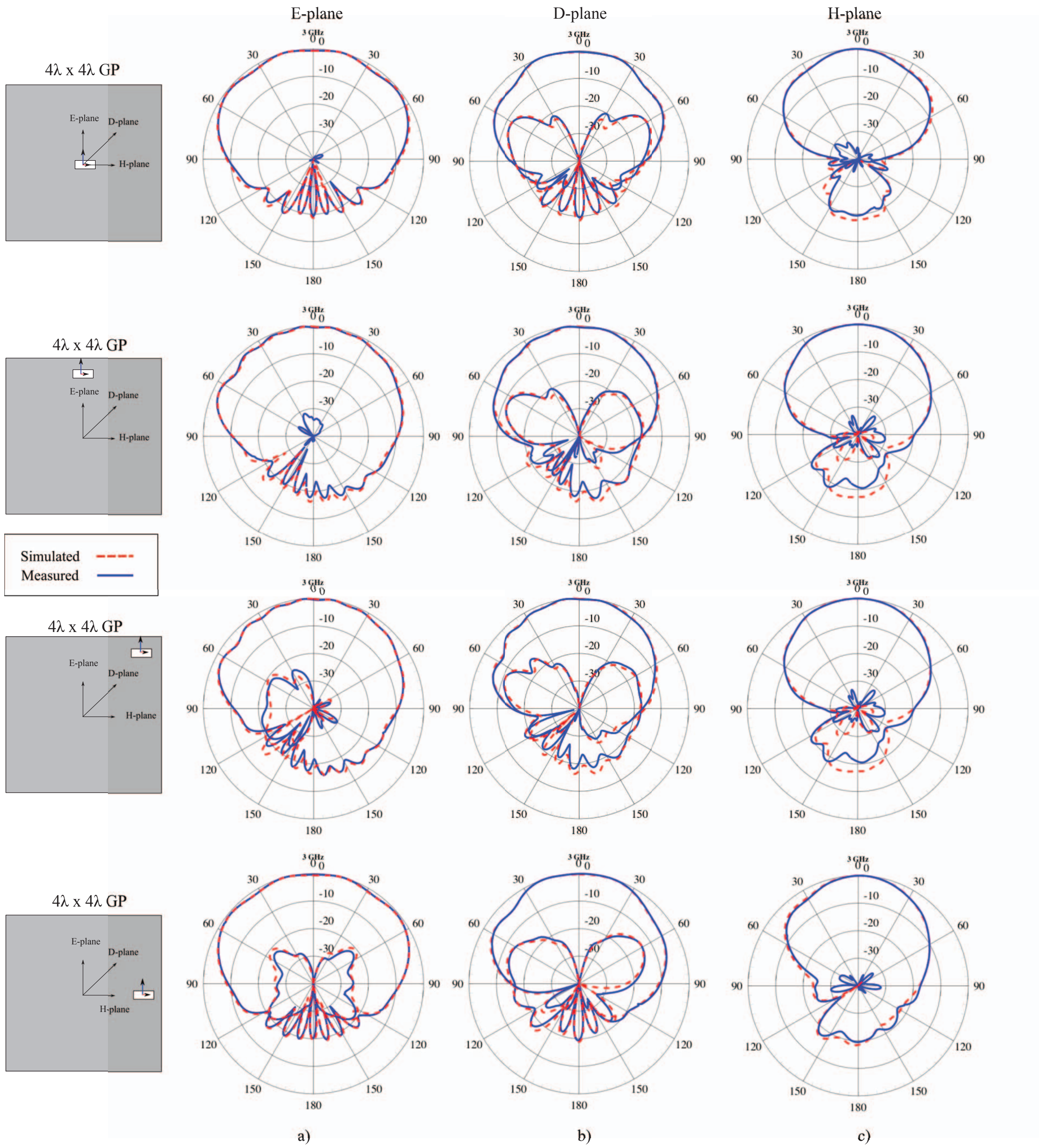

Fig. 5. Aperture slot antenna patterns on four different positions on 4λx4λ ground plane for a) E-plane, b) D-plane and, c) H-plane.

edges are stronger, generating significant diffracted fields in antenna patterns for the E-plane. The antenna patterns in the D-plane are slightly affected by the electric field coupled in this plane. Small effects of the diffracted fields can be observed in the patterns in the H-plane. This is expected, since the magnitude of the incident fields in these edges (H-plane) are smaller. In the E-plane, the cross-polarization patterns increase in magnitude in comparison with the center position. The shape of the antenna patterns is also asymmetric due to the fact that incident fields from the antenna to edges of the panel are different. This effect can be observed more clearly in the D-plane patterns.

In the third row, the element is positioned in the corner of the ground plane. In this case, the distance difference between the center element, with respect to the edges, induces significant phase differences that cause a large impact in the cross-polarization degradation. This effect can be observed in the patterns presented in the E-plane (Fig. 5). Cross-polarization levels from -37 dB increase to -20 dB when the position is in the corner, with respect to the center position. The same asymmetry levels are also obtained for the H- and D-planes with respect to the previous position. Moving down the element position to the center of the E-plane (fourth row in Fig. 5), the patterns present full symmetry in co- and

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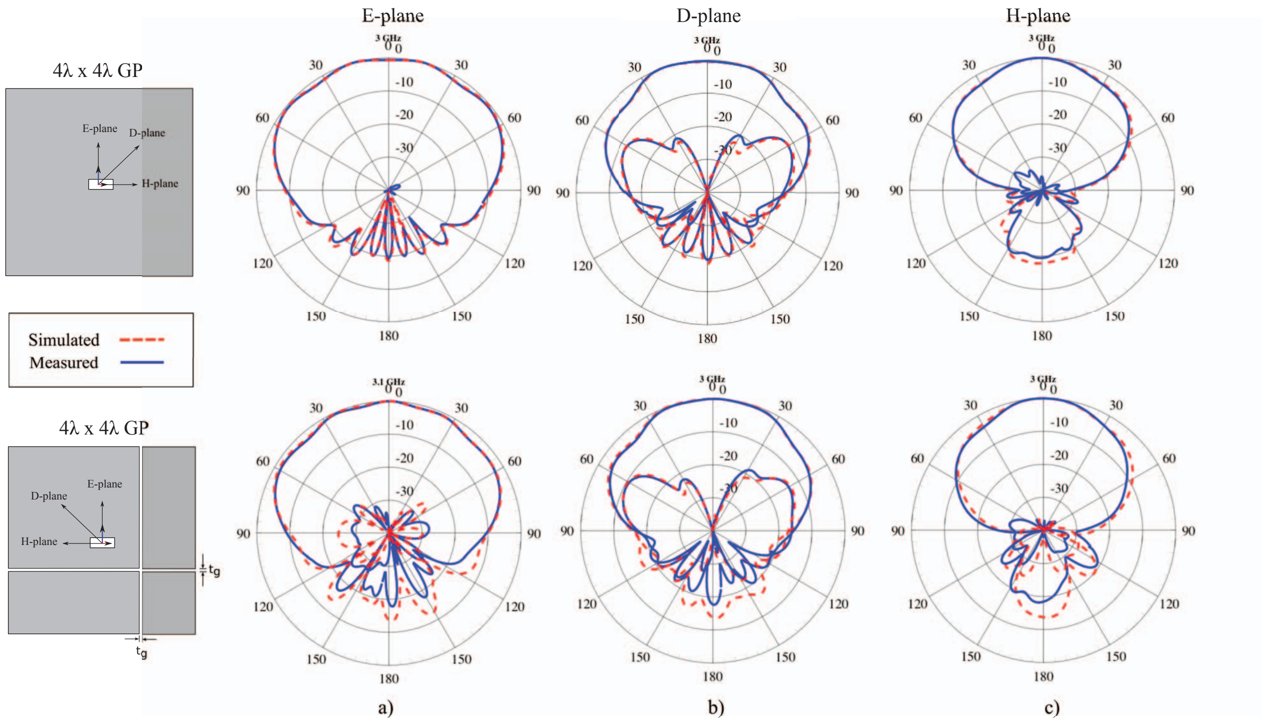

Fig. 6. Aperture slot antenna patterns with and without gaps on 4λx4λ ground plane for a) E-plane, b) D-plane and, c) H-plane

cross-polarization patterns in this plane. However, the cross-polarization levels increase substantially in this particular position.

C. Impact diffracted fields due to internal gaps

Taking into consideration that a large phased array antenna cannot be constructed with a single ground plane, most of the large arrays are constructed using sub-arrays. This physical limitation introduces internal discontinuities in the array that require the investigation of the impact of diffracted fields in the antenna patterns. In this section, the results of the antenna patterns in presence of internal ground discontinuities is discussed. To illustrate the impact of diffracted fields caused by the internal edges, we introduce internal gaps that corresponds to 0.1λ at 3 GHz (See Fig. 3b). Figure 6 presents the measured results compared with simulation results in HFSS for an aperture slot placed in the center of a ground plane without (top in Fig. 6) and with internal edges (bottom in Fig. 6). As is illustrated in Figure 6, the results show an unusual number of ripples and nulls in the E-plane. This can be attributed to coupling between the diffracted fields in the internal and external edges of the ground plane. In this particular case the cross-polarization in the E-plane increases from -37 dB to to -25 dB.

IV. Conclusions

This paper presented the impact of elements positioning in a finite ground plane on the cross-polarization performance of finite antenna arrays. An overview of the diffracted field mechanism using GO and UTD theory is presented. Numerical simulations, compared with far-field measured results of eight antenna prototypes presents excellent agreement. The results illustrate the impact of the edge effects of a finite ground plane on the cross-polarization patterns of a finite array. It is demonstrated that the discontinuities of finite ground planes have a significant impact on antenna patterns, especially in antenna arrays that require high cross-polarization isolation.

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