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Planar Wide-Scan Wideband Phased Arrays with Improved Polarization Purity

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***Abstract*—One of the common requirements for wideband wide-scanning arrays in multifunctional platforms is the polarization agility. Cross-polarization levels should be kept low within the entire field of view and frequency band of operation. However, good polarization purity is hard to achieve especially for arrays that are designed to operate over multi-octave bandwidth. Planar wideband array often use dielectric slabs above the antenna aperture to improve the matching while scanning and increase the front-to-back ratio. However, dielectric superstrate deteriorate the polarization performance on the diagonal planes. The characteristic cross-polarization of a connected slot array in the presence of artificial dielectric layers superstrates is analyzed. An approach to reduce the cross-polarization is then investigated, consisting of localizing the artificial dielectric only in specific regions of the unit cell, rather than on the entire area.**

***Index Terms*–Artificial dielectric layers, connected arrays, cross-polarization, wideband arrays, wide-scanning arrays.**

I. Introduction

Wideband wide-scanning antenna arrays gained popularity in the last decade because of their capability to support multiple functions within a single shared radiating aperture. To reduce the cost and complexity of this type of arrays, it is preferable to target planar designs, where only a single multi-layer printed circuit board is employed for implementing the array [1]–[4]. Polarization purity becomes an important requirement when the array is used for communication services, for which polarization agility is at premium. However, achieving low cross-polarization (X-pol) levels over a large operational bandwidth is not an easy task.

Planar designs often utilizes dielectric slabs above the antenna (superstrates) to improve the matching performance and the scanning capability. To avoid surface waves and scan blindness, the works in [3]–[6] proposed to use artificial dielectric layers (ADLs) in place of real dielectrics. Due to the anisotropic characteristics of such materials, the permittivity decreases with the angle of propagation of a plane wave traveling in the artificial medium, thus surface waves are hardly supported.

Despite the ADL slab can improve the matching and scanning performance, it often causes an increase of X-pol for scanning in the diagonal planes [7]. This undesired behavior is mainly due to the fact that the superstrate does not exhibit the same equivalent electrical properties and transmission characteristics for transverse electric (TE) and transverse magnetic (TM) field components. Therefore, since the radiated field has both TE and TM components when scanning in the diagonal plane, the amplitudes of the two modes change after propagating through the ADLs, yielding higher X-pol.

In this work, a connected array of slots radiating in the presence of an ADL superstrate is considered. First, the X-pol performance is shown for ADLs distributed over the entire unit cell. Subsequently, this unit cell is compared with the case when the ADLs are localized in a smaller region of the unit cell, showing reduced X-pol levels. The final configuration realizes a metal distribution similar to the sliced Vivaldi element proposed in [8], but maintaining the low-profile and planar implementation.

II. Standard Artificial Dielectric Superstrate

The array concept considered here consists of connected slots with ADLs [3], [4]. Connected slots are antenna arrays composed of slots that are electrically connected to each other, to achieve broadband properties. In standard resonant slot arrays, the electric field distribution on the slots is sinusoidal and frequency dependent, thus narrowband. Contrarily, when connecting the slots, the array is no longer composed by separated resonant elements, but can be considered as a single antenna periodically fed. The resulting structure achieves wideband performance, because the electric field distribution on the slots remains nearly constant with frequency.

Artificial dielectrics consist of periodic metallic patches, small with respect to the wavelength, embedded in a host material to realize an equivalent material with modified properties. The equivalent electromagnetic parameters of the artificial material can be engineered by properly designing the metallic inclusions.

As an example, the unit cell in Fig. 1 is considered. The connected slot element is located at a distance of 3mm from the backing reflector and is fed by a delta gap of 5mm size. The slot is 1.1m wide and the material between the slot plane and the backing reflector is assumed to have relative permittivity of 1.4. This value is typical of planar connected array designs [3], [4] and can be practically implemented with a perforated dielectric slab. The ADLs are modeled with the aim to realize a tapered transformer between the free space impedance and 80Ω at the feed. The simulated matching performance is shown in Fig. 2. It can be observed that the active voltage standing wave ratio (VSWR) is lower than 2.6 over a bandwidth of about 4:1, for scanning up to 45°.

Despite the large bandwidth, the simulated X-pol level for scanning to 45° in the diagonal plane, presented in Fig. 3,

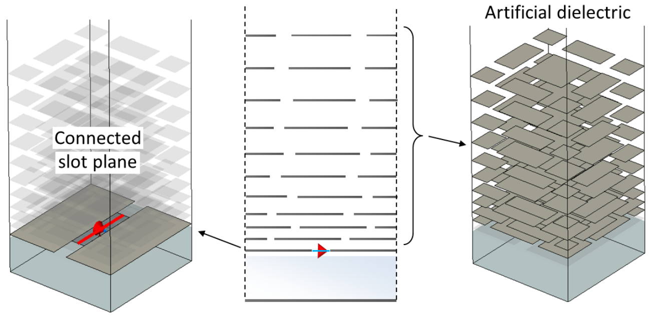

Fig. 1. Unit cell of a linearly polarized connected slot array with artificial dielectric superstrate.

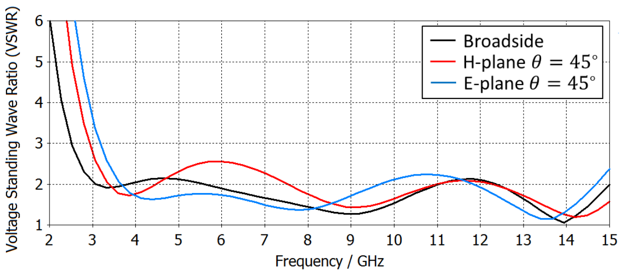

Fig. 2. Active voltage standing wave ratio of the unit cell in Fig. 1, for broadside and scanning in the main planes to 45°.

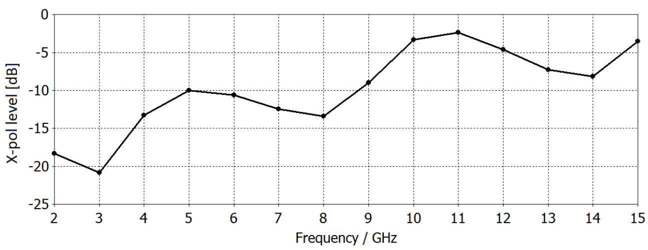

Fig. 3. Simulated X-pol level of the unit cell in Fig. 1, when scanning to 45° in the diagonal plane.

largely varies within the bandwidth and reaches levels up to −2.5 dB.

III. Artificial Dielectric with Reduced Cross-Polarization

To improve the polarization performance, a different unit cell is proposed. The same connected slot element is now loaded with and ADL slab that is not uniformly distributed over the entire unit cell region, but only over one fourth of the volume. The resulting structure is depicted in Fig. 4. To achieve the same matching performance, the density of the metal in the ADLs is increased, since the total effective permittivity is now averaged with the air-filled volume. The active VSWR in Fig. 5 exhibit comparable frequency response as the uniform ADL. On the other hand, the X-pol levels in Fig. 6 are now reduced to values lower than −10 dB.

An explanation of this effect can be highlighted by observing in Fig. 7 the electric field vector lines on a plane located in the proximity of the top artificial dielectric layer. The frequency of calculation is assumed to be 15GHz. It can be noted that, for the uniform ADL, the field has high values over a large portion of the unit cell and several vector lines are rotated compared to the ideal feed polarization. In the non-uniform ADL case, the field is more concentrated in the region when the ADL is located and consequently its orientation remains closer to the impressed field polarization.

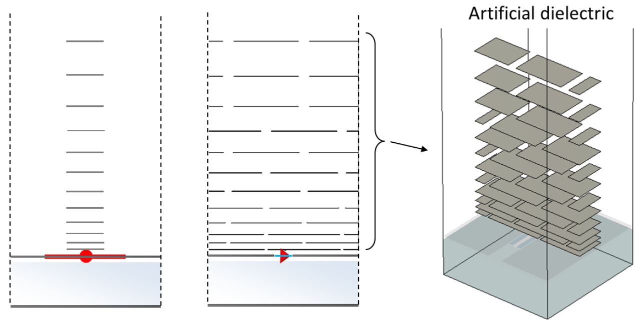

Fig. 4. Unit cell of a linearly polarized connected slot array with non-uniform artificial dielectric superstrate.

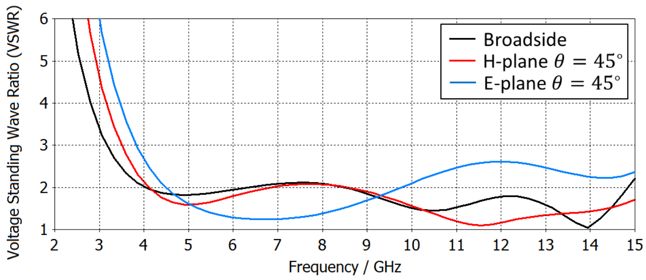

Fig. 5. Active voltage standing wave ratio of the unit cell in Fig. 4, for broadside and scanning in the main planes to 45°.

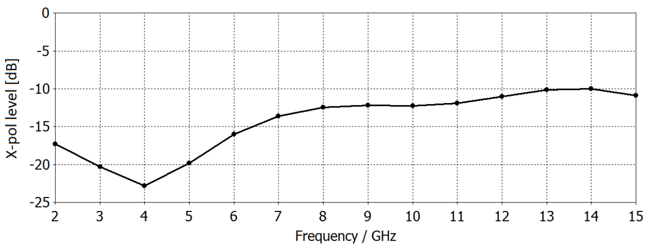

Fig. 6. Simulated X-pol level of the unit cell in Fig. 1, when scanning to 45° in the diagonal plane.

IV. Conclusion

Real and artificial dielectric superstrates are commonly used to improve matching and scanning performance of phased array, but they also worsen the polarization purity in the diagonal plane. It was shown that restricting the volume filled with artificial dielectric to a thinner region aligned with

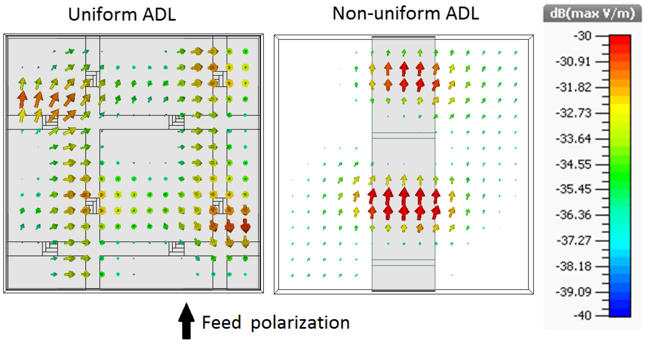

Fig. 7. Comparison of the two considered unit cells, in terms of vector electric field lines on plane above the ADL superstrate. The calculation frequency is 15 GHz.

the slot feed can have beneficial effects in reducing the X-pol levels, without sensible degradation of the impedance matching properties.

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