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Design of Wideband Wide-Scanning Dual-Polarized Phased Array Covering Simultaneously Both the Ku- and the Ka-Satcom Bands

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***Abstract*—We present the unit cell design of a wideband wide-scanning phased array operating in both Ku- and Ka-bands, for satellite communication applications. The radiating elements are dual-polarized connected slots loaded with an artificial dielectric superstrate, acting as a wide angle impedance matching (WAIM) structure. The design of the multi-layer artificial dielectric is based on analytical formulas describing the equivalent reactance of each layer, valid for geometries that are not periodic in the vertical direction. This allows to minimize the total number of metal layers composing the artificial dielectric. The predicted matching performance is investigated by means of simulations based on infinite array approximation.**

***Index Terms*—artificial dielectrics, connected arrays, satcom phased arrays, wideband wide scanning arrays.**

I. INTRODUCTION

In satellite communication (satcom) applications, the need of terminal antennas able to scan to larger and larger angles is emerging, to guarantee agile connections to different satellites. However, conventional planar phased array antennas exhibit limitations when steering a pencil beam in a large field of view, due the increase of the antenna active reflection coefficient when scanning. Moreover, another problem of terminal antennas, especially on mobile platforms, is the limited space allocated to cover multiple required bands. In this regard, it is beneficial to use a wideband array covering simultaneously multiple bands, to provide significant reduction of the overall cost and volume of the system.

For example, a tunable phased array terminal working in both Ku- and Ka-band can yield reduced footprint, size and weight of the system, with consequent decrease of operational costs, including fuel costs created by the weight and drag from the antenna. Such a wideband phased array solution can switch between different types of satellites and between the Ku- and Ka-bands, thus allowing to access most of the existing and future GEO and non-GEO satellites. In aeronautical scenarios, these characteristics offer the possibility of the on-board terminal to roam between different networks and select the optimal one depending on the flight conditions or the availability of capacity in certain regions.

Several solutions to realize wideband wide-scanning arrays have been proposed, including tapered slot antennas [1]–[3], metal flared-notch elements [4], [5], long-slot arrays [6], [7] and tightly-coupled or connected dipole arrays [8]–[12]. However, a typical trend in these designs is that broader matching bandwidths are achieved at the cost of increased cross-polarization (X-pol) levels, reduced scan range or decreased total efficiency. Moreover, in most of the above mentioned designs, the radiating elements and the feed lines are printed on vertical printed circuit boards (PCBs), which leads to costly and complex assembly.

A planar wideband array concept with reduced cost and complexity was presented in [13], [14] and consists of connected slot arrays with artificial dielectric layers (ADLs). These are antenna arrays composed of slots that are electrically connected to each other, intentionally increasing mutual coupling to provide wideband operation. The array is loaded with one or multiple ADL slabs that, by enhancing the upward radiation, reduce the resonance effects of the ground plane. ADLs are periodic arrangements of metallic patches, small with respect to the wavelength, embedded in a host material to synthesize certain desired equivalent electromagnetic parameters. The main advantage of an artificial dielectric compared to a real dielectric is the anisotropy, which is a key property to avoid the excitation of surface waves, even for very large scan angles.

A prototype demonstrator based on the described concept was recently presented in [14] and achieved a bandwidth of 6 to 15 GHz, scanning to at least 60° in all azimuthal planes. In this work we present a new improved unit cell design, where the effort is to scale the operation to higher frequency, to cover simultaneously the Ku- and Ka- bands. This scaling requires novel approaches to the design of the ADL, such that standard PCB manufacturing is still possible. More specifically, the ADL slabs in [14] were based on sets of identical layers and comprised 8 metal layers in total. Here, we drop the restriction of identical layers along the vertical direction, using the theory developed in [15]. This allows attaining similar bandwidth with only 4 metal layers. The steps of the unit cell design are presented and the performance is investigated with infinite array simulations.

II. UNIT CELL DESIGN

The structure under investigation is shown in Fig. 1, which illustrates the schematic side view of the unit cell. This includes the slot plane at distance h from a backing reflector. Above the slot, N artificial dielectric layers are considered.

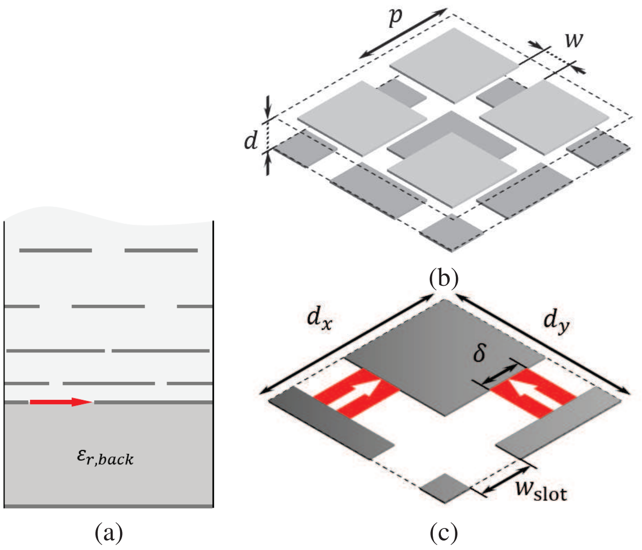


Fig. 1. Illustration of (a) a side view of the unit cell, (b) a layer of the ADL matching structure with geometrical parameters and (c) the dual-polarized slot unit cell.

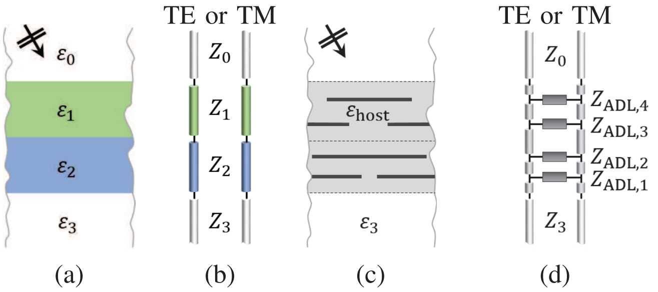


Fig. 2. Illustration of (a) a two-layer dielectric stratification and (b) its transmission line model, as well as (c) a two-layer ADL stratification and (d) its transmission line model.

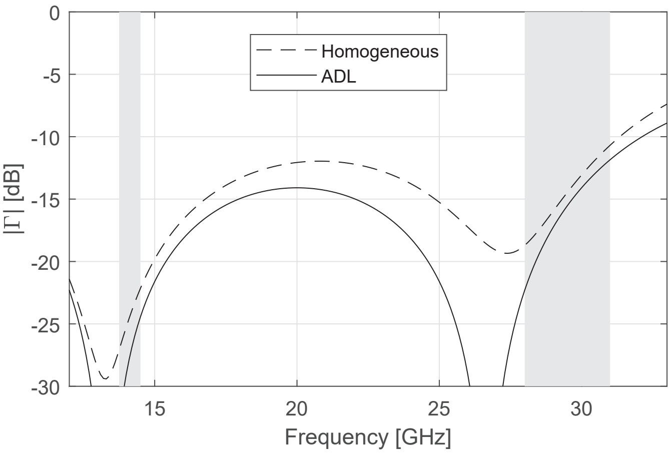


Fig. 3. Reflection coefficient of a plane wave for normal incidence on a two-section Chebyshev transformer. A comparison between homogeneous and artificial dielectric is shown.

The geometrical parameters of the artificial dielectric are assumed to be different for each layer. The resulting geometry can be analyzed by means of the closed-form solution previously derived by the authors in [15]. The application of non-identical layers allows minimization of the total number of metal layers in the ADL slab, given a target operational bandwidth.

In this work, the aim is to design a connected array that simultaneously covers the Ku- and Ka-transmit bands for satellite communication. The two bands are 13.75 to 14.5 GHz (for Ku) and 28 to 31 GHz (for Ka). Therefore, the array design targets an impedance bandwidth from 13.75 to 31 GHz.

A. *Artificial Dielectric Design*

To design the artificial dielectric, we first consider the structure under plane-wave incidence. The propagation of the plane wave through real or artificial dielectric stratification can be represented with equivalent transmission lines for the transverse electric (TE) and the transverse magnetic (TM) modes. Fig. 2 shows the equivalent transmission line for a set of homogeneous dielectric slabs under plane-wave incidence, as well as the transmission line model for a set of artificial dielectric slabs. The values of the shunt impedances $Z_{\text{ADL},n}$ in the model for the ADL are defined by the expressions given in [15], which account for the higher order Floquet wave interaction between adjacent layers.

The artificial dielectric is designed to realize an impedance matching structure that transforms the free space impedance of 377 Ω to a lower impedance at the slot plane ($Z_3 = 120\Omega$). A two-section Chebyshev transformer is considered, since it provides sufficient bandwidth for the application at hand. The first step of the design is to define the two relative permittivities of the two homogeneous slabs that implement the desired Chebyshev response. Once these permittivity values are chosen, a synthesis procedure is applied to determine the required geometrical parameters of an ADL such that it provides the same effective dielectric constants for normal incidence. Figure 3 shows the reflection coefficient of a plane wave incident on the two-section stratification, for both homogeneous and artificial dielectrics. The reflection coefficient of the incident plane wave is below -10 dB in the two bands of interest, highlighted in gray.

The effective permittivity and permeability tensors of the ADLs are obtained from the plane wave S-parameters using the methods described in [16]. The effective refractive index decreases monotonically as the width of the gap between the patches in the ADL increases. This enables the use of simple error minimization techniques such as Newton-Raphson for the design of the ADLs. The analytical expressions used to simulate each section allow the interaction with neighboring sections to be taken into account in the design process. This is important to avoid errors that would arise if each section were designed in isolation.

The resulting designed ADL consists of four metal layers, for which the reflection coefficient for normal plane-wave incidence is shown in Fig. 3 to be similar to that of the ideal Chebyshev transformer.

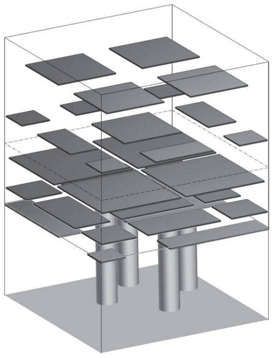
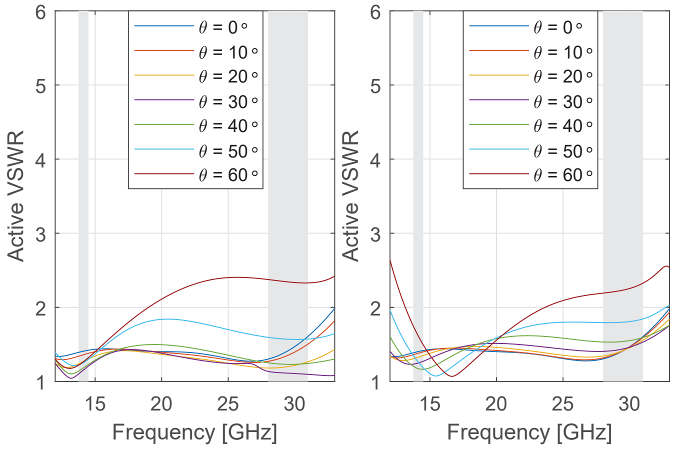


Fig. 4. Schematic representation of the unit cell.



(a) (b)

Fig. 5. Active VSWR for scanning up to 60° on the (a) E- and (b) H-plane.

B. *Connected Slot Element with Artificial Dielectric*

The designed ADL impedance matching structure is combined with a dual-polarized slot array. The input impedance of the combination of ADLs, slot, and backing reflector is determined using the analytical expressions shown in [13]. The geometrical parameters of the slot array are chosen such that the array is optimally matched to the impedance of the feed (120 Ω) for broadside and when scanning up to 60°.

The resulting unit cell is shown in Fig. 4, where the four layers of ADL, the slot plane, the backing reflector and four vias are shown. The vias are used to suppress parallel plate waveguide modes that can propagate between the slot plane and the backing reflector. The voltage standing wave ratio (VSWR) of this unit cell is simulated in CST and shown in Fig. 5. The VSWR is below 2.4 over the target 13.75 to 31 GHz band for broadside and for scanning up to 60° in the principal planes.

III. CONCLUSIONS

We presented a unit cell design of a connected array loaded with artificial dielectrics that covers both the Ku- and Ka-transmit band for satellite communication. By exploiting an artificial dielectric with non-periodic characteristics along the vertical direction, a bandwidth exceeding an octave could be achieved with only four metal layers. The design of the unit cell is based on analytical solutions for the connected array and the ADLs. Simulations of a dual-polarized unit cell showed VSWR below 2.4 for scanning up to 60° in all azimuthal planes.

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