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A Novel Printed-Circuit-Board Feeding Structure for Common-Mode Rejection in Wide-Scanning Connected Arrays of Dipoles

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Abstract— **A novel Printed-Circuit-Board (PCB) solution to avoid common-mode resonances in connected arrays is proposed in this paper. It consists in a loop-shaped circuit that rejects common-mode current propagation over more than an octave bandwidth. The use of such common-mode rejection loop allows the design of linear and dual polarized array of connected dipoles, with cross-polarization levels lower than –17 dBs for elevation angles in the range ±45° and for all azimuths, over more than 30 % relative bandwidth. Full-wave simulations are presented to validate the design.**

I. INTRODUCTION

Wide-band, wide-scanning phased arrays with low cross-polarization across the entire bandwidth are increasingly desired for many applications. Although tapered slot antennas have very broad bandwidth, they are known to radiate strong cross-polarized fields, especially in the diagonal plane ($\varphi = 45^o$), [1]. On the other hand, conventional phased array based on printed resonant elements can achieve only moderate bandwidths (~25%), [2-4].

A novel trend emerging is the use of planar arrays of long dipoles or slots periodically fed at Nyquist intervals which can guarantee both the broad band and the low cross polarization: connected arrays. This concept was originally proposed by Hansen, [5], and further theoretically developed in [6]. The first practical demonstration of a planar connected array antenna was given in [7]. This consisted in a connected array of slots in the UHF band, with good performance observed for broadside radiation. In [8], scanning performance of connected array was investigated for the first time and a theoretical design of a connected dipole array was presented, with 40% relative bandwidth and wide scan capability, up to 45 degrees in all the azimuth planes.

Despite the potentials, the practical implementation of the feeding network in a connected array of dipoles is a difficult problem. As for all wideband phased arrays differentially fed, also for connected arrays the balanced transmission lines used to feed the elements can support both differential and common-mode propagation [9-11]. This latter is undesired, since it can give rise to resonances that ruin the array performance, especially in terms of polarization purity.

Due to electrical connection between the array elements, standard baluns or common-mode rejection circuits, typically used in array of resonant dipoles, are not effective for connected arrays [12]. Therefore, this paper proposes a novel Printed Circuit Board (PCB) solution to avoid common-mode resonances, without resorting to active components or Monolithic Microwave Integrated Circuit (MMIC) technology. It consists in a loop-shaped circuit that constitutes an open circuit for the common mode, while representing a small impedance change for the differential mode. The use of such common-mode rejection loop allows the design of arrays of connected dipoles with X-pol levels lower than -17 dBs over about a 30% relative bandwidth, for both linearly and dual-polarized configurations. All simulation results presented have been obtained via the full-wave commercial electromagnetic CAD tool Ansoft HFSS, for a frequency band observation the spans from 10.5 GHz to 14.5 GHz.

II. COMMON-MODE RESONANCES IN CONNECTED ARRAYS

Let us consider the array geometry depicted in Fig. 1. The array is composed of an infinite number of long dipoles, oriented along x, each fed at periodic locations. A metallic ground plane is included as backing reflector at a distance of $0.28\lambda_0$, with λ_0 being the wavelength at 15 GHz. The periodicities along x and y are equal to $0.43\lambda_0$. Each element has two gaps in order to adjust the reactive energy (capacitance) stored at the feeding point. This double gap configuration, as shown in [8], can be exploited to partially compensate for the frequency dependence introduced by the backing reflector, improving matching performance for wide-scanning operation.

Fig. 2 reports the active reflection coefficient and the X-pol level associated with two unit cell configurations: in the first case the array element is fed at the dipole level (continuous curves), while in the second case the same dipole element includes vertical feeding lines, in order to reach the ground plane level, where the feed is located (dashed curves). The array is assumed to scan toward 45 degrees in the diagonal plane. It can be noted that, when vertical lines are included, even if the antenna is still well matched, the X-pol level in the diagonal plane can be very much degraded, due to common-mode current propagation.

A practical implementation of this array can be obtained by printing the dipoles on vertical Printed Circuit Boards (PCBs) made of a thin dielectric substrate and realizing the vertical lines via co-planar strip (CPS) lines.

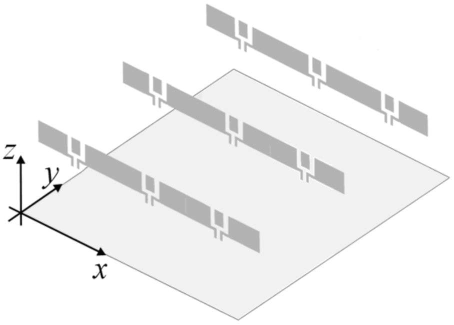


Fig. 1 Array geometry: distance from the backing reflector is $0.28\lambda_0$, while periodicities along x and y are 0.43 λ_0, with λ_0 being the wavelength at 15 GHz

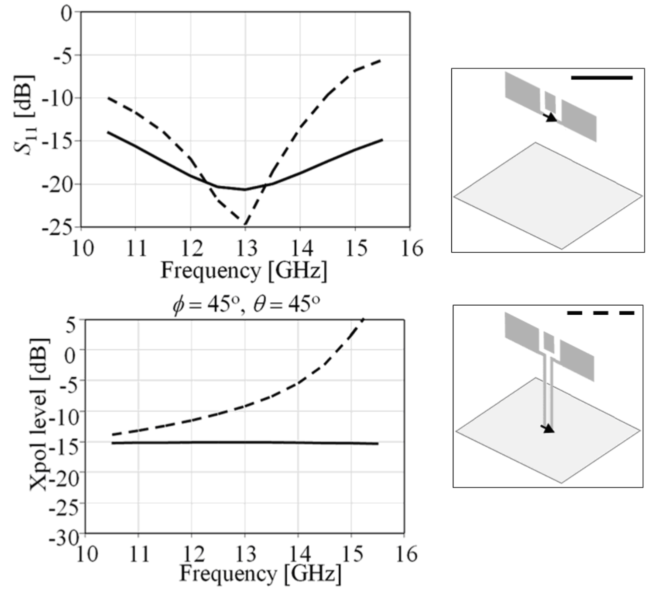


Fig. 2 Active reflection coefficient and X-pol level of an array with and without vertical feeding lines, for $\theta = 45^{\circ}$, = 45°

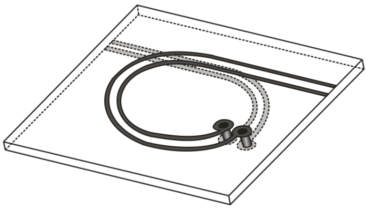


Fig. 2 Geometry of the loop-shaped common-mode rejection loop

III. COMMON-MODE REJECTION LOOP

A. Principle of operation

A loop-shaped circuit realized with CPS lines is proposed to avoid common-mode resonances in connected arrays of dipoles. The geometry of the loop is depicted in Fig. 2. At low frequencies, the currents flowing in the loop are equal in phase, thus the loop only behaves as a small series inductance for the common mode. As the frequency gets higher, different portions of the loops are flown by currents with different phases (see Fig. 3). Figs. 4(*a*) and 4(*b*) show the magnetic field, calculated via Ansoft HFSS, in a cross section of the loop at 7 and 15 GHz, respectively. The loop radius is 1.06 mm radius, and the permittivity dielectric substrate is 2.2. The first configuration corresponds to the case in which most electric currents in the loop are in phase, generating coherent adding magnetic fields which in turn produce a magnetic field circuitation with high contributions in the centre of the selected cross section. The second configuration, at 15 GHz, corresponds to the case in which the electric currents in the loop are essentially divided in two parts with opposite phases, generating cancelling magnetic fields, which in turn produce a magnetic field circuitation with close to zero contributions in the centre of the selected cross section.

As a consequence, at frequencies higher than a certain threshold, the average distributed inductance of the loop becomes lower as the magnetic fields do not add up coherently any more. In a frequency range of more than an octave, the characteristic inductance will tend to very low values, creating a strong impedance discontinuity. The mismatch is such that almost no common-mode propagation is allowed through the component.

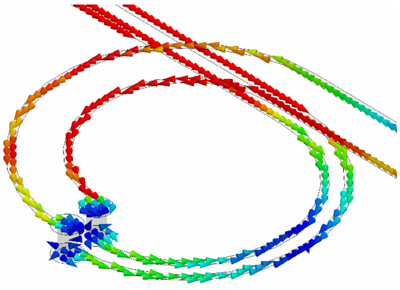
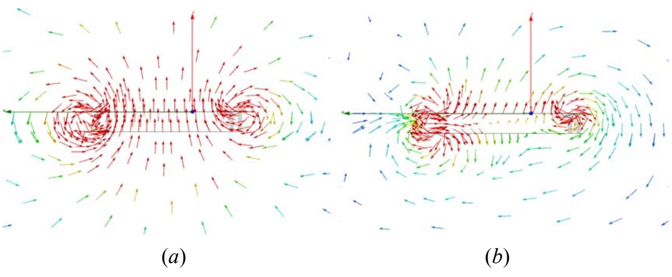


Fig. 3 Magnetic field distribution on a cross section of the loop at 7 GHz (*a*) and 15 GHz (*b*)



(*a*) (*b*)

Fig. 4 Magnetic field distribution on a cross section of the loop at 7 GHz (*a*) and 15 GHz (*b*)

B. Performance

The loop performance is quantified in Fig. 5, which shows the S-parameters pertinent to differential (Fig. 5(*a*)) and common mode (Fig. 5(*b*)). A –10 dBs common-mode rejection is observed over more than an octave bandwidth, from about 9 to 22 GHz, while no important obstacle is observed by the differential mode up to 16 GHz.

IV. ARRAY DESIGN

A. Linear Polarization

The common-mode rejection loop described in the previous section can be added in the vertical feeding line of a connected array of dipoles to avoid the common mode resonance observed in Fig. 2. Fig. 6 shows the array performance in terms of active reflection coefficient and X-pol level when the loop is included and the port is located at the ground plane level. The array is assumed to scan towards 45^o on the diagonal plane. The X-pol level is about –17 dB's, which is the theoretical limit for a perfect linearly polarized radiator for $\theta = 45^\circ$, $= 45^\circ$ observation. A better than -10 dBs matching has been observed over a 40% relative bandwidth, even if not reported here for sake of brevity.

In order to feed the array element with a coaxial connector, a CPS to Microstrip (MS) transition has been designed. A simple transition as the one depicted in Fig. 7 still give rise to unbalanced current propagation in the lower part of the feeding lines (between the loop and the ground plane), with a consequent increasing of the X-pol levels. For this reason, a sleeve balun has been added to perform the CPS to MS transition. As shown in Fig. 8, the joint use of loop and sleeve balun allows the X-pol field to be at least 17 dBs lower than the co-pol field within the operational band. Active reflection coefficients are also reported for broadside and for scanning to 45^o on the main planes, with a matching lower than -10 dBs within the observed band in all three cases.

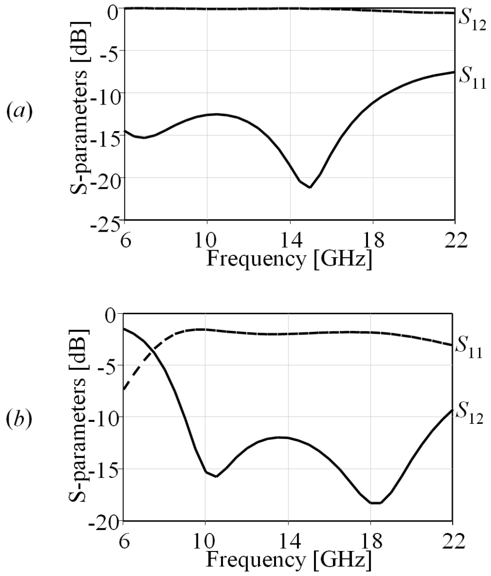


Fig. 5 S-parameters of the loop in Fig. 2 for differential (*a*) and common mode (*b*)

B. Dual Polarization

The dipole element designed for linearly polarized arrays can be adjusted to be used in a dual polarized array. The elements can be arranged in an egg-crate configuration, as depicted in Fig. 9. The simulated active reflection coefficient is below -10 dBs for broadside and scanning to 45^o on the main planes over more than 30 % relative bandwidth, while the X-pol level is lower than -19 dBs over the operative band.

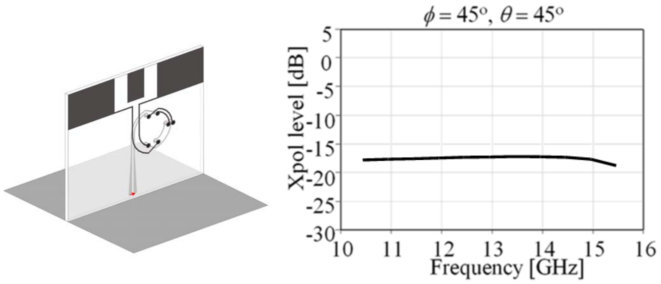


Fig 6 X-pol levels at $\theta = 45^\circ$, $= 45^\circ$ for an array with loop included in the vertical feeding line. Results are obtained via HFSS, in infinite array analysis.

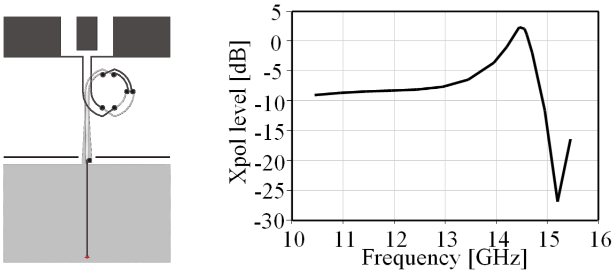


Fig 7 X-pol levels at $\theta = 45^\circ$, $= 45^\circ$ for an array with loop and CPS to MS transition

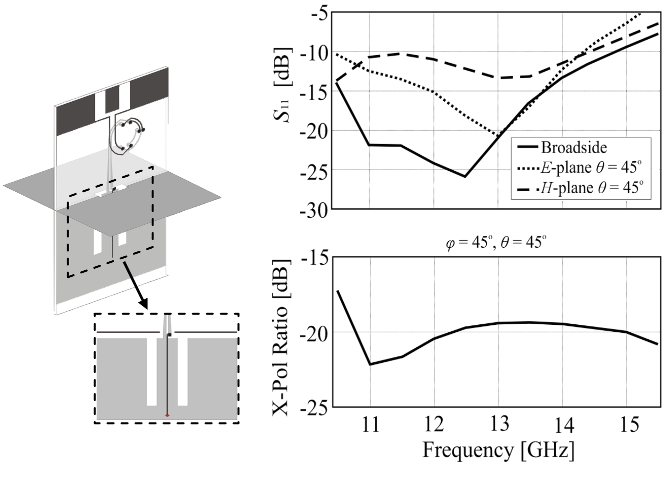


Fig. 8 Active reflection coefficient for broadside and scanning to 45^o on the main planes, and X-pol levels at $\theta = 45^\circ$, $= 45^\circ$ for a linear polarized array including loop and sleeve balun

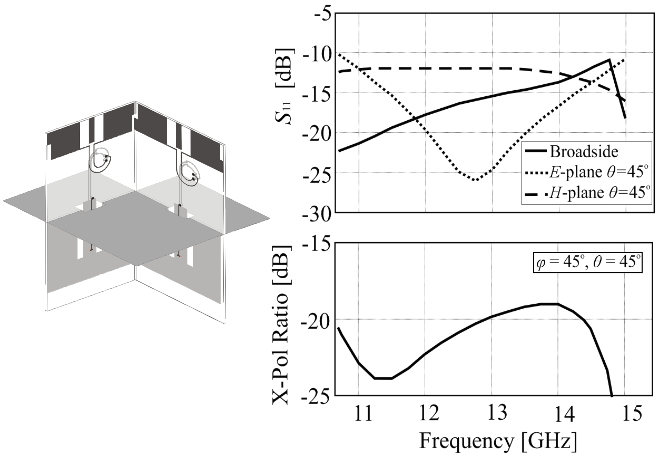


Fig. 9 Active reflection coefficient for broadside and scanning to 45° on the main planes, and X-pol levels at θ = 45°,   = 45° for a dual polarized array including loop and sleeve balun

V. CONCLUSIONS

A PCB-based common-mode rejection loop has been presented. The aim of such microwave component is to choke common-mode propagation and consequently avoid resonances that ruin polarization purity, especially when scanning on the diagonal plane. These issues related to common-mode resonances are typical of all very broadband phased array. However, this work has focused on connected array of dipoles.

The performances of linear and dual polarized connected arrays of dipoles when using the common-mode rejection loop have been investigated, via full-wave simulations within infinite array approximation. The simulated results have shown a significant improvement in terms of polarization purity, obtaining X-pol levels below the -15 dBs, which is a recurrent requirement in many radar or communication applications. A relative bandwidth exceeding 30% has also been obtained for wide scanning up to θ = 45° for all azimuths. Hopefully, by the time of the conference, the measurements will be available from a prototype demonstrator that is being currently manufactured.

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