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CLOVER ARRAY — POLARISATION DIVERSITY SOLUTION FOR ULTRA WIDEBAND SYSTEMS

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Abstract—In this paper, we present an innovative method of cross-polarisation suppression by forming the antennas in a so called Clover Array (CA). Such structure enables usage of polarisation diversity even for UWB systems. The simplified theoretical model of operation is presented as well as exemplary results of crosspolarisation patterns. The theory was verified for CA of planar Volcano-Smoke antennas. For fabricated array the cross-polarisation in main beam is below -14 dBi in the whole FCC-UWB frequency range (3.1 GHz–10.6 GHz).

1. INTRODUCTION

In modern radar application there is a need for polarisation diversity usage [1, 2]. However, due to the cross-polarisation and interference between polarisation channels, construction of suitable antennas is complicated. Furthermore phase-centre should be independent on

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frequency and polarisation [1], since it is preferred for short time-domain pulses.

In this paper, we propose the antenna structure that enables a cross-polarisation suppression and radiation in two polarisation channels with common phase centre. In the initial part of paper the structure of array is described, basic assumptions and the principle of the operation are formulated. Next the theoretical cross-polarisation is calculated by means of magnetic vector potential method. Finally we present the measurement results for clover array of planar Volcano-Smoke antennas.

2. PRINCIPLE OF OPERATION

Proposed CA configuration consists of four antennas: two polarised vertically and two horizontally (see Fig. 1(a)).

All the antennas are located around a common phase centre, however (in opposite to [3]) no point reflection symmetry is applied, but a mirror symmetry. In the following we investigate the structure as two sub-arrays: the first one with horizontal (antennas B and D on Fig. 1(a)) and the second one with vertical polarisation (antennas A and C). The following conditions are imposed for antennas in each sub-array:

- The elements are arranged symmetrically (with respect to XX' or YY' axis)
- The phase shift 180° between the antennas in each sub-array is

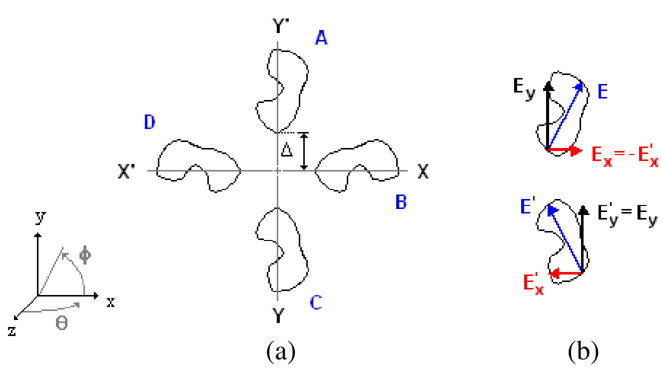

Figure 1. (a) Structure of clover array in coordinate system; (b) Electric field vectors (E and E') radiated from single elements of sub-array and their decompositions in x and y components.

applied in the whole considered frequency range (this means the current phases $\varphi = 0°$ for antennas A and B, and the current phases $\varphi = 180°$ for antennas C and D).

No assumptions are imposed neither on the antenna's shape nor on the bandwidth of operation. If the mutual coupling between the antennas is neglected, one may observe that the antennas A and C radiate y component of electric field in-phase and x component out-of-phase (see Fig. 1(b)). According to Ludwig's third definition of polarisation [4], such behaviour is expected to eliminate completely the cross polarisation in XX' plane and suppress it elsewhere. By analogy second sub-array (antennas B and D) should result with no cross-polarisation in YY' plane.

3. THEORETICAL MODEL

Let us consider structure of CA consisting of the metallic planar radiators as shown in Fig. 1. Vector potential of 4-element antenna array in far field zone may be calculated by the following formula:

$$\vec{A} = \frac{\mu}{4\pi} \sum_{\alpha=1}^{4} \vec{J}_\alpha \frac{e^{-jk|\vec{r}|} e^{jk|\vec{r}\,'|\cos\Psi}}{|\,\vec{r}\,|} \tag{1}$$

where k represents wavenumber, $\vec{r}$ field vector, $\vec{r}\,'$ source vector and Ψ is angle between $\vec{r}$ and $\vec{r}\,'$ vectors. We shall discuss only sub-array with vertical polarisation (antennas A and C), as for other sub-array calculations are equivalent. Therefore antenna's current can be assumed as $\vec{J}_A = \frac{J_0}{\sqrt{2}}(\vec{a}_y + \vec{a}_x)$ for antenna A and $\vec{J}_C = \frac{J_0}{\sqrt{2}}(\vec{a}_y - \vec{a}_x)$ for antenna C. This correspond to single antenna rotated by 45° to the reference plane, that in fact is the worst case scenario from the point of view of polarisation.

After rearrangements the Equation (1) for vertically polarised sub-array yields:

$$\vec{A} = 2A_0\left(\vec{a}_x \mathrm{Im}(\Phi) + \vec{a}_y \mathrm{Re}(\Phi)\right) \tag{2}$$

where

$$A_0 = \frac{\mu}{4\pi} J_0 \sqrt{2} \frac{e^{-jk|\vec{r}|}}{|\,\vec{r}\,|} \tag{3}$$

and

$$\Phi = e^{jk\Delta \sin(\theta)\cos(\phi)} \tag{4}$$

Respectively for horizontally polarised sub-array calculations yield with:

$$\vec{A}_H = 2A_0\left(\vec{a}_x \mathrm{Re}(\Phi) + \vec{a}_y \mathrm{Im}(\Phi)\right) \tag{5}$$

One can clearly see that amplitudes of signals provided by both sub-arrays for the same polarisation are always orthogonal to each other, independent on the frequency and the direction. This orthogonality does not fully correspond to the orthogonality of polarisation, as one may see applying Ludwig's third definition of polarisation [4]. Inaccuracies occur however for angles far away from the main beam, which are of the secondary importance.

Ludwig's third definition of polarisation [4] describes contribution of x and y source current components for co- and cross-polarisation. For example: according to Table 1 in [4] source current in x direction (in presented coordinate system) should impact vertical polarisation component with factor $1 - \cos^2\phi(1 - \cos\theta)$. Please note, that if $\theta = 0$ this factor is also 0. This corresponds to the property, that close to the main beam only y component contributes to the vertical polarisation.

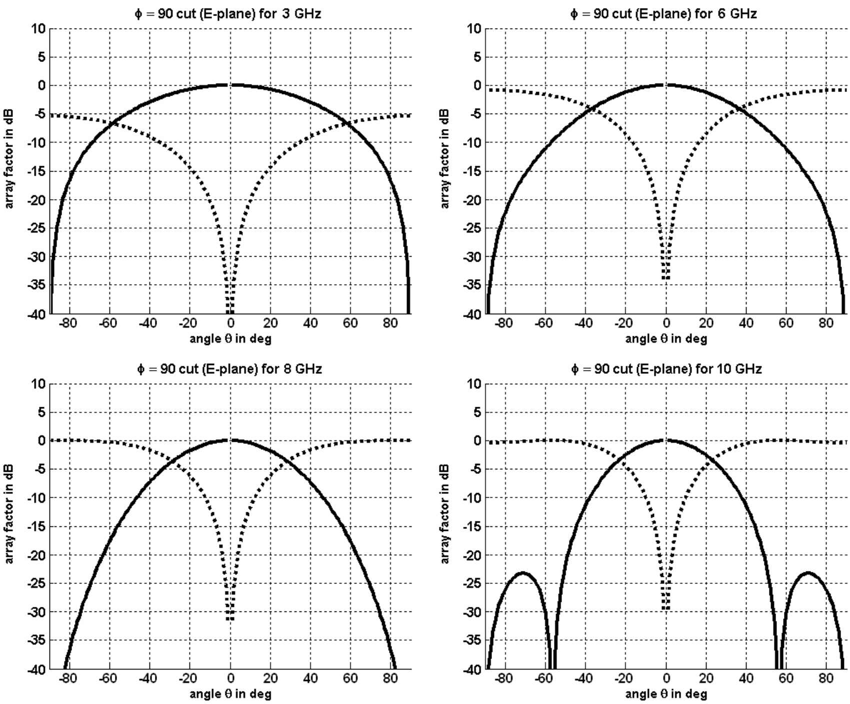

Figure 2. Theoretical array factor of the clover array for different frequencies. Solid line: co-polarisation, dotted: cross-polarisation.

Coefficients from [4] were applied to Equations. (2)–(5) in order to calculate array factor for co- and cross-polarisation, both for CA structure and single radiator. Fig. 2 shows so calculated co- and cross-polarisation of CA for exemplary cut $\phi = 90°$ (E-plane). Fig. 3 compares cross-polarisation of CA and single radiator for cut $\phi = 45°$. Both presented results are in the frequency range from 3 GHz to 10 GHz. Distance between antennas in sub-array is $2\Delta = 18$ mm.

From Fig. 2 one may observe very low cross-polarisation for main beam of CA. In the co-polarized pattern the side lobes are observed for higher frequencies, which emerge due to the increased electric distance between antennas. This is a drawback in every wide-band antenna array, not only of the presented type [2]. Therefore it is preferable to decrease the distance Δ between the antennas as much as possible. This stays however in contradiction with no-interference assumption, which makes a need for a compromise between these two demands.

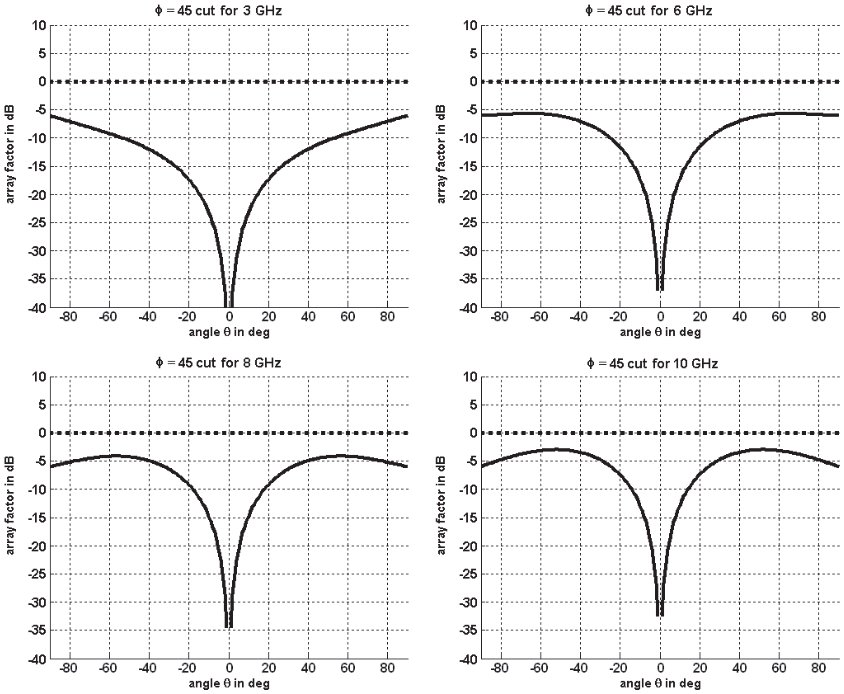

Figure 3. Comparison of theoretical cross-polarisation pattern of single antenna (dotted) and CA with the same source current (solid). The cut is made for $\phi = 45°$.

4. MEASUREMENTS

Presented method was used to design and construct dual-polarised planar UWB antenna for radar applications. Planar Volcano-Smoke antenna [5–7] — which was used for this example — is a wide-band antenna, formed by two slots in conducting plane. Edges of each slot are given by ellipses. Outer slot acts as a actual radiator, whereas inner slot serves as a impedance match. This structure was optimized for UWB-band with parameters described at Fig. 5. Please note, that single antenna of this type has very strong cross-polarisation level, as reported in [7]. Proposed solution allows its suppression with factors demonstrated at Fig. 2.

The geometry of the manufactured CA is shown in Fig. 4. Such configuration allows for a minimization of the mutual coupling between the elements. Required 180° wide band phase shift was realised by the change of hot and cold wires on one end of feeding network, as presented in [8]. The measured radiation pattern for co- and cross-polarisation is shown on Fig. 5. As can be noticed the polarization decoupling in the main beam direction is approx. 20 dB for a wide frequency range.

We also observe that the high cross-polarisation level of single radiator (as observed in [7]) is successfully suppressed by the arrangement in the CA. This confirms the theoretical calculations presented in Section 3.

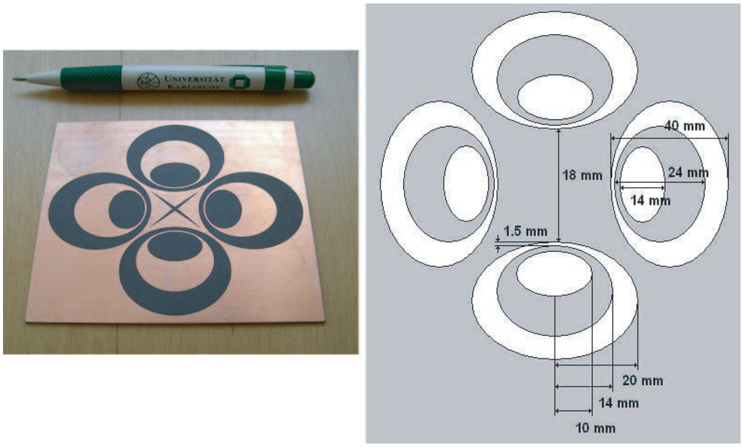

Figure 4. Implemented structure of CA consisting of planar Volcano-Smoke antennas. Photo (left) and structure with characteristic dimensions (right). Grey area indicates metallization.

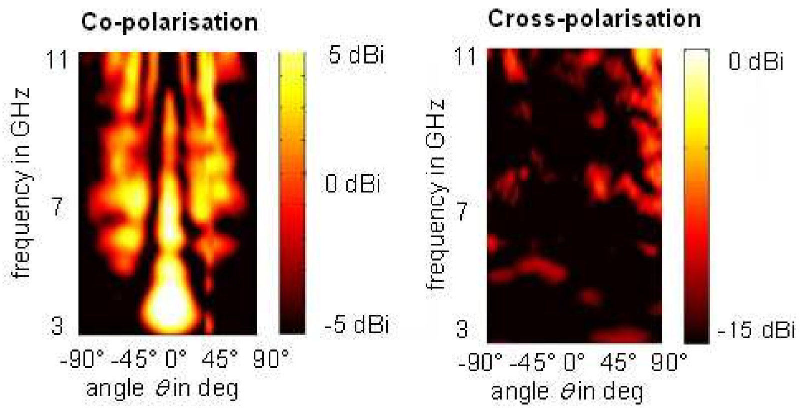

Figure 5. Measured gain of the CA displayed as a function of frequency (vertical axis) and angle (horizontal axis). Lighter region corresponds to the stronger signal, as indicated in the scales on the right. Results are presented for co-polarisation (left) and cross-polarisation (right) in E-plane ($\phi = 90°$). One may notice, that strongest co-polarisation signal (main beam) occurs from around $-40°$ to $+40°$ for 3–5 GHz and gets narrower for higher frequencies. For the same parameters cross-polarisation signal is 20 dB below main beam of co-polarisation.

5. CONCLUSION

The clover array configuration of the radiators is proposed in the paper and the effects of cross-polarisation suppression are explained by an electromagnetic field analysis. The principle of operation is independent of the frequency and thus can be applied for almost any application, especially where a large operation bandwidth is desired.

The prototype of CA is presented and the measurement results confirmed the theoretical assumptions, in particular the broadband suppression of cross-polarisation. The clover array may be used in wide range of applications, from polarimetric radar to telecommunication diversity systems. The further studies should lead to the choice of optimal structure of planar radiator with respect to the level of cross-polarisation and useful radiation pattern.

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