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Dual circularly polarized broadside beam antenna based on metasurfaces

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Abstract. Design details of a Ku band metasurface (MTS) antenna with dual circularly polarized (CP) broadside radiation is shown in this work. By means of the surface impedance tensor modulation, synchronized propagation of two transversal magnetic (TM) and transverse electric (TE) surface waves (SWs) is ensured in the structure, which contribute to the radiation in broadside direction by the generation of a CP leaky wave. The structure is implemented by elliptical subwavelength metallic elements with a cross-shaped aperture in the center, printed on top of a thin substrate with high permittivity (AD1000 with a thickness of $\lambda_0/17$). For the experimental validation, the MTS prototype has been excited employing an orthomode transducer composed by a metallic stepped septum inside an air-filled waveguide. Two orthogonal TE_{11} modes excited with ±90° phase shift in the feed couple with the TM and TE SWs supported by the MTS and generate RHCP or LHCP broadside beam. Experimental results are compared with the simulation predictions. Finally, conclusions are drawn.

Introduction

In last years, MTS antennas became established as ultrathin, light and easily manufacturable alternative solutions able to meet the restrictive space applications requirements [1-6]. MTS antennas, which are composed by a dense layer of metallic subwavelength elements on top of a grounded dielectric, can be analyzed in terms of the equivalent surface impedance tensor. Its modulation controls the propagation characteristics of a transverse magnetic mode and the generation of a leaky wave with given radiation properties [1]. Isotropic [2] or anisotropic [3-6] structures have been presented in the literature, capable to provide broadside [3], isoflux-shaped [4] or more complex radiation patterns [5] with control on the CP of the field.

Nevertheless, all the structures found in literature provide a single CP radiated field. In [6], the authors presented for the first time the theoretical operating principle of a MTS antenna able to provide RHCP or LHCP broadside beam with a single configuration. This structure deals with the propagation of two SWs of TM and TE nature.

Operating principle

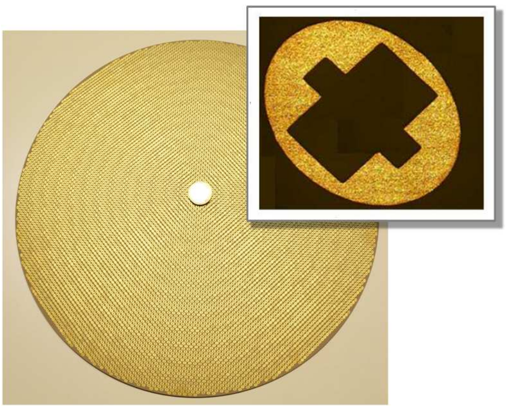
As presented in [6], the electric and magnetic tangential fields at each point of a rotationally symmetric MTS supporting the propagation of TM and TE SWs can be related by means of a diagonal surface impedance tensor in cylindrical coordinates, i.e. $\underline{\underline{\mathbf{X}}} = X_{\rho\rho}\hat{\boldsymbol{\rho}}\hat{\boldsymbol{\rho}} + X_{\varphi\varphi}\hat{\boldsymbol{\varphi}}\hat{\boldsymbol{\varphi}}$. The radial ($X_{\rho\rho}$) and azimuthal ($X_{\varphi\varphi}$) tensor components are modulated following a sinusoidal function in radial direction defined by three parameters: the average value (η_{TM}, η_{TE}) normalized with the free space impedance ($\xi = 120\pi$), the modulation index (m_{TM}, m_{TE}) and periodicity (d_{TM}, d_{TE}) related with each mode:

$$\begin{aligned} X_{\rho\rho} &= \zeta\eta_{TM}\left[1 + m_{TM}\cos(2\pi\rho / d_{TM})\right] \\ X_{\varphi\varphi} &= \zeta\eta_{TE}\ \left[1 + m_{TE}\cos(2\pi\rho / d_{TE})\right] \end{aligned} \quad (1)$$

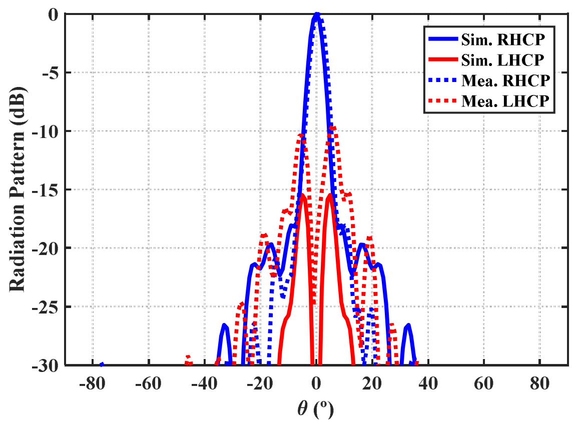
Both modes propagate on the structure balanced in amplitude and synchronized in phase, thus $\eta_{TM}\eta_{TE} = -1$ [6]. Broadside radiation of the generated leaky wave is ensured when the modulation periodicities agree with the surface wave wavelength. Besides, modulation indexes can be appropriately adjusted to ensure balanced contribution to the radiated field. A structure working at 13.5GHz has been implemented with the following parameters: $\eta_{TM} = 1.31$, $m_{TM} = 0.18$, $d_{TM} = 0.6\lambda_0$ related with the TM mode and $\eta_{TE} = -0.76$, $m_{TE} = 0.32$, $d_{TE} = 0.58\lambda_0$ for the TE mode.

Experimental validation

The manufactured MTS antenna is shown in figure 1a. It is composed by a dense layer of subwavelength elliptical metallic patches with a cross-shaped aperture in the centre, printed on top of an Arlon AD1000 grounded substrate with a permittivity of 10.2 and thickness of 1.27mm. At each position of the antenna the patches geometry characteristics and rotation have been selected to provide the surface impedance distribution required for both TM and TE SWs. The structure has been excited with an orthomode transducer composed by a metallic stepped septum inside an air-filled waveguide and a transition from the waveguide to the MTS antenna input port filled with AD1000 dielectric. Two orthogonal TE_{11} modes excited with ±90° phase shift in the feed, couple with the TM and TE SWs supported by the MTS. Depending on the phase shift sign of the excited modes, the generated beam in broadside direction is RHCP or LHCP.



(a)



(b)

Figure 1. (a) Manufactured MTS antenna prototype and details of a subwavelength metallic element. (b) Comparison of simulated (continuous lines) and measured (dotted lines) normalized radiation pattern (φ=45°, θ=0°cut) at 13.5GHz: LHCP (red lines) and RHCP (blue lines). The structure has a radius of $8\lambda_0$.

Measured radiation pattern at 13.5GHz is compared with simulation predictions in figure 1b. As it can be seen, the structure provides RHCP broadside been at working frequency. Due to the rotational symmetry of the MTS structure, the same behavior is obtained when the feed is excited with 90° phase shift (LHCP).

Conclusions

A MTS antenna with RHCP or LHCP broadside beam radiation at Ku band has been presented. The structure has been implemented by elliptical shaped metallic elements printed on top of a grounded AD1000-based dielectric. Good agreement between the simulation predictions and measurements obtained with the manufactured prototype is observed. More details of the design and manufacturing of the proposed MTS antenna solution and the required feeding system will be presented in the workshop.

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