Circularly Polarized Metasurfing Antenna

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Abstract

In this paper we present a planar circularly polarized antenna based on transformation of a surface wave into a leaky wave. The antenna is designed by using the concept of modulation of surface reactance. Such a modulation is obtained by printing a dense texture of square sub wavelength metal patches on a grounded dielectric slab. The final device is a planar thin antenna with a simple feeding constituted by single vertical monopole. Numerical results are presented and discussed. Experimental results are announced for the oral session.

1. Introduction

The antenna we are going to illustrate is a planar circularly polarized leaky wave (LW) antenna excited by a single-point feed. The basic structure we are dealing with is constituted by variable, spiral-shaped modulated surface impedance realized on a grounded dielectric slab with a small vertical dipole used as a feeder. A cylindrical surface wave (SW) excites the surface which converts the SW into a circularly polarized LW.

The design process is based on describing the local interaction between an elemental angular wave front of cylindrical SW and the corresponding elemental angular sector of the spiral. The interaction is faced by means of a 2D canonical problem of a sinusoidal reactance excited by a planar SW. The latter is treated by means of the Oliner-Hessel method described in [1]. This local interaction can also be interpreted as the holographic principle illustrated in [2]. This interpretation is given in [3].

This paper is structured as follow. In section II the local canonical problem is presented as a basis step for the design of antennas based on modulation of surface reactance. Also, the interaction of the exciting surface wave with a spiral impedance surface is introduced, providing an interpretation of the produced circularly polarized radiation. Section III presents the procedure and the main design guidelines to reconstruct the modulated surface reactance by using printed patches on a grounded dielectric slab. Numerical results for a prototype that is going to be realized are also present and discussed. The final conclusions in Section IV discuss the main features of this class of antennas.

2. SW interaction with a spiral shaped sinusoidally modulated reactance.

The canonical problem of a surface wave propagating on a modulated surface reactance is illustrated in [1]. The surface is assumed infinite and invariant along the y direction and is excited by a TM_0 surface wave (see Fig. 1a). In the canonical problem the surface wave is assumed to propagate along the x direction, impinging with normal incidence, thus allowing a TM-TE modal decomposition. The presence of the periodic medium affects more or less quantitatively the wave number of the SW, depend-

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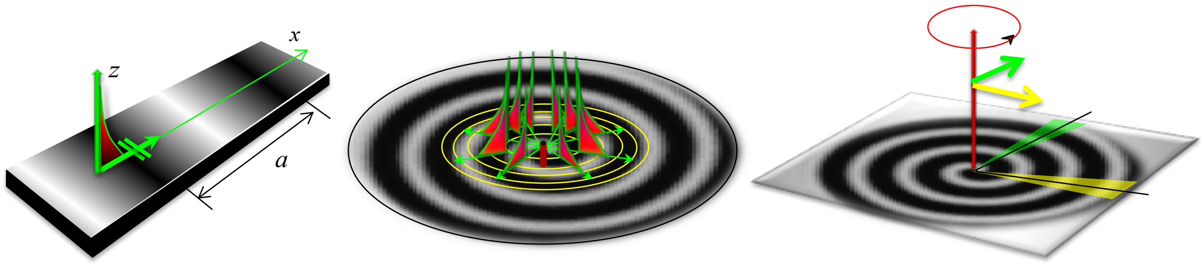
ing on the characteristics of the impedance modulation. Let β_{sw} be the value of the phase constant for the SW propagating in the unperturbed medium. The modulation of the surface reactance changes the value of the phase constant into $\tilde{\beta}_{sw} = \beta_{sw} + \beta_{\Delta}$. If the relative amplitude of the modulation is low, namely the modulation index *m*, the value of β_{sw} is negligible. That is the SW propagates with a phase constant almost similar to the one associated to the mean value of reactance.



(a) (b) (c)

Fig. 1**:** (a) Geometry for the local canonical problem, (b) Surface wave exciting the Archimedean spiral surface impedance and (c) orthogonal sectors excited by the SW with quadrature phase giving rise to a circularly polarized broadside radiation.

Let us now consider a circular surface which possesses an Archimedean spiral reactance sinusoidally modulated along the radial direction. The analytical description of such a surface is the following:

$$X(\rho,\varphi) = X_s\left[1 + m\sin\left(\beta_{SW}\rho - \varphi\right)\right] \tag{1.1}$$

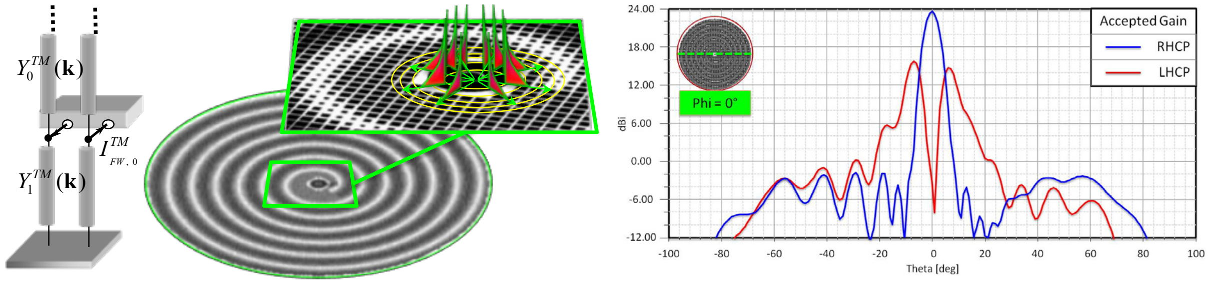
The surface is excited by a SW launched by a feeder (for example a small vertical dipole) located in the centre of the structure (see Fig. 1b). In this case, a rigorous formulation should consider that the SW impinges on the periodic layer not exactly with normal incidence, but with a certain angle. Anyway, if the angle between the local propagation direction vector and the vector normal to the periodic modulation is small, it is reasonable to assume a weak coupling between TM and TE modes (small hybridization). Therefore, in a first approximation, TM and TE modes can still be treated independently and the theory developed in [1] is still suitable for our purposes. Also, such assumption is more reasonable if an initial settlement not modulated zone is added.

The produced broadside circular polarization can be briefly justify as follow. In the assumption $\tilde{\beta}_{SW} \approx \beta_{SW}$, the modulation periodicity along each ray is equal to λ_{SW}, and the difference between the interception with the spiral of two rays separated by 90° is $\lambda_{SW}/4$. Therefore, the dominant Bragg radiation associated to any elemental sector of spiral is directed broadside. Furthermore, any pair of elemental sectors separated by 90° gives rise at broadside to orthogonal and quadrature-phased components respectively, thus justifying the circular polarization. Fig. 1c illustrates the previous concept.

3. Design procedure and numerical results

The surface impedance is synthesized by printing a dense texture of square metal patches on a grounded slab with constant period and variable sizes. Each patch has different size slowly varying from a patch to the adjacent one. Thus, to analyse the coupling of a single patch with the rest of the structure, we assume it as embedded in a locally periodic FSS- like lattice. We identify the local texture in a point with a local periodic printed structure that matches adiabatically the local geometry. Thus, for each local periodic structure, a TM mode (with reference to the normal to the antenna surface) transmission-lines is defined as associated with the dominant Floquet mode (Fig. 2a). Due to the square shape of the patch, rigorously a small TM/TE hybridization with oblique incidence should be considered. Anyway we decided to neglect it for simplicity, since the small area of the chosen patches determines an unimportant cross-polarization effect. By using the Foster reactance properties of the

FSS-network, the pole-zero matching method [4] is applied to find an analytical approximation of the FSS admittance matrix.



(a) (b) (c)

Fig. 2: (a) equivalent transmission line model for the TM dominant SW, (b) Layout for the simulated patch lens antenna, (c) Numerical results of the gain for the both co-polar and cross-polar components.

The layout of the antenna is shown in Fig. 2b. It is realized on Roger RO4350B substrate with a thickness of 1.905 mm and relative dielectric constant equal to 3.66 . Square patches are printed on a regular lattice which elementary cell has a square shape with 1.8 mm of side length. The variation of the impedance is realized by varying the side of the patch between 1.7 mm and 0.5 mm. The final structure has a radius of 5.9 λ at 17 GHz and involves 10556 patches. The aperture field is sampled with 8 patches every surface wavelength. Fig. 2c shows the numerical results for the accepted gain of the co-polar and cross-polar components.

4. Conclusion

This paper leaky wave broadside circularly polarized antennas based on surface impedance modulation were presented. The impedance surface has an Archimedean spiral profile excited by a TM_0 surface wave. To modulate the surface impedance of a grounded dielectric slab a dense texture of printed metal sub wavelength patches were used. The exciting SW is provided by a small vertical probe located at the centre of the structure. Numerical result were provided for a prototype that is going to be constructed showing the performances of such antennas. The final layout results in a simple thin flat devices with good polarization properties in the broadside direction and with a simple feeding. Experimental measurement will be discussed during the oral session.

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