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Single-Layer Dual-Band Leaky Wave Antennas Design Methodology with Directivity Control

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***Abstract*—A new design methodology for dual band leaky-wave antennas is presented in the paper. The proposed methodology is based on the use of a single partial reflective surface (PRS) made with a Frequency Selective Surface (FSS) that fulfills the resonant condition at two different frequencies. This allows the design of a dual band leaky wave antenna including the control on the directivity at each one of the frequencies. Two examples of the application of this method (one with identical directivities at the two frequencies and the other one with different directivities) are presented.**

I. Introduction

A solution for directivity enhancement in two frequency bands is presented, by designing a leaky wave antenna, based on a PRS with a FSS [1]. While a very popular method of designing a dual band FSS is by cascading different layers of FSS that resonate in the desired frequencies, [2], [3], the presented design consists of only one layer, and contrary to other FSSs that have one layer but with printed elements at both sides [4], the periodic metalization occupies only one side of the dielectric. Dual band metasurfaces, of one layer have been implemented previously using complex unit cells [5], [6]. The proposed unit cell in our case is simple, and consists of a double square loop (see the inset of Fig. 2).

The dual band performance is achieved by designing the FSS to have inductive impedance for one of the desired bands and capacitive impedance for the other band. The selected unit cell in Fig. 2 has an impedance with the desired inductive behavior at low frequencies and capacitive at high frequencies. The use of the FSS impedance combined with its distance to the feed (the "height") has been proposed in [7], [8], but never combined to achieve a dual band antenna. The proposed design methodology offers a satisfying band separation and medium directivity levels. The originality of the present work is found in the simplicity and flexibility of the design.

II. Design Methodology

The fundamental hypothesis of the present work is that there can be an equivalence between the performance of a dielectric superstrate based Fabry-Pérot antenna, and one using a FSS. The equivalent FSS can be calculated to be inductive or capacitive, and its impedance is described in [7] as :

$$Z^{i,c} = j\eta_0 \left(\frac{-1 \pm \sqrt{1 + 4\pi^2(\epsilon_r - 1)}}{2\pi(\epsilon_r - 1)} \right) \tag{1}$$

where η_0 is the free space impedance, ϵ_r is the permittivity of the dielectric superlayer, and the inductive corresponds to the + sign whilst the - sign corresponds to the capacitive equivalent. For the equivalence, the height of the cavity defined by the feed antenna and the FSS has to be changed correspondingly as:

$$h^{i,c} = h_0 \frac{\epsilon_r |Z^{i,c}|^2}{\eta_0^2 + |Z^{i,c}|^2} \tag{2}$$

with $h_0 = \lambda_0/2$ being the height of the cavity of the equivalent leaky wave antenna at a frequency f_0, ϵ_r is the permittivity of the reference dielectric superstrate.

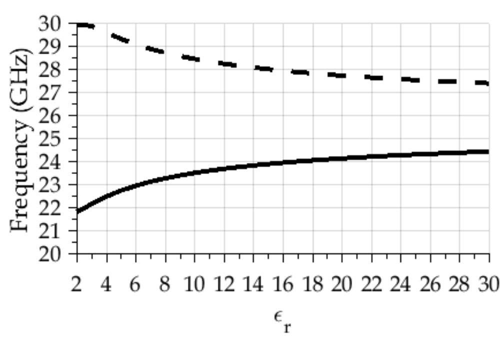

Fig. 1. (a) Frequency variation as a function of the dielectric permittivity for the common solutions of (2), for the inductive (solid line) and capacitive equivalences (dashed line) for h_0= 5.79 mm.

Observing these equivalences, we can understand that it is possible, to define a single cavity height, where both inductive and capacitive criteria are met at two different frequencies, by solving the system of (1)&(2) for a given permittivity. For the given height, he cavity reacts as inductive at lower frequency, and as capacitive at higher frequency.

Fig. 1 shows the frequencies f_1, f_2 of the dual band operation obtained for a fixed cavity height here taken as h_0= 5.79 mm, as a function of the permittivity ϵ_r of the equivalent superlayer. As a first example, we chose f_1=23

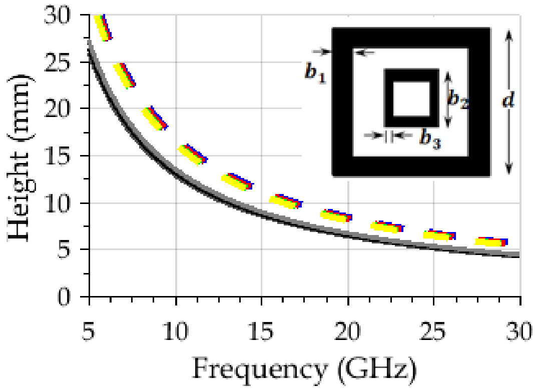

Fig. 2. Solutions for the cavity height as a function of the frequency, for different values of permittivity($e_r = 4, 6, 8, 10, 12$) for the inductive (solid lines) and the capacitive (dashed lines). The FSS unit cell is also presented.

GHz, f_2= 29 GHz and ϵ_r= 6, that lead us to a frequency ratio of $f_2/f_1 = 1.26$. Considering ϵ_r= 6 in eq. 1 the calculated required impedances for the FSS are Z_i= 157Ω and Z_c= -181Ω. These are the values that the impedance of designed the unit cell should reach at f_1 and f_2 respectively.

By properly adjusting the parameters of the unit cell shown in Fig. 2, the desired impedances can be achieved. After simulations of the unit cell by using CST *Microwave Studio*, at the frequencies of interest it reaches the theoretically calculated values when d=8.8 mm, b_1=2.38 mm b_2=3.01 mm b_3=1.41 mm. The central frequency f_0, between the two types of responses is used to calculate the height of the cavity as half wavelength giving h_0= 5.73 mm.

From Fig. 1 we can observe that the achievable separation between frequencies decreases as ϵ_r increases. This means that there is a trade-off between permittivity (that directly determines the maximum directivity) and the separation between the two desired frequency bands.

We present a second design for the same frequencies $f_1 =$ 23GHz and $f_2 =$ 29GHz using two different permittivities. As shown in Fig. 2 for these frequencies, and selecting $\epsilon_{r1} = 6$, $\epsilon_{r2} = 10$ a common solution for the cavity height can be obtained. Using a higher permittivity for the upper band allows a better use of the antenna aperture (higher directivity) at f_2 .

For these permittivities, the impedances are calculated as $Z_i = 157\Omega$ and $Z_c = -132\Omega$ for f_1=23GHz and f_2=29GHz respectively. The synthesized FSS unit cell has dimensions d=8.95 mm b_1=2.51 mm b_2=3.13 mm b_3=1.45 mm whilst the cavity height is h_0=5.8 mm.

III. Results

A leaky wave antenna has been simulated using CST *Microwave Studio*. The antenna is composed of a feed and the designed FSSs (with a size of 9λ for f_1) as superlayer. The superlayer is located at a distance h_0 of the feed.

In the black line of Fig.3 the directivity for the first case is presented (both frequencies with the same permittivity). A maximum directivity of approximately 15 dB is achieved at the two desired frequencies (23 GHz and 29 GHz).

The results for the second case (higher permittivity at the higher frequency) is represented in the grey line of Fig.3. In this case a directivity of 15 dB is obtained in 23 GHz whilst for 29 GHz the directivity is 16.6 dB. These directivities have been also calculated with the spectral Green function analysis with a result of 15 dB for $\epsilon_r = 6$ and 17dB for $\epsilon_r = 10$. The CST full wave results fully validate the expected values of these two presented designs.

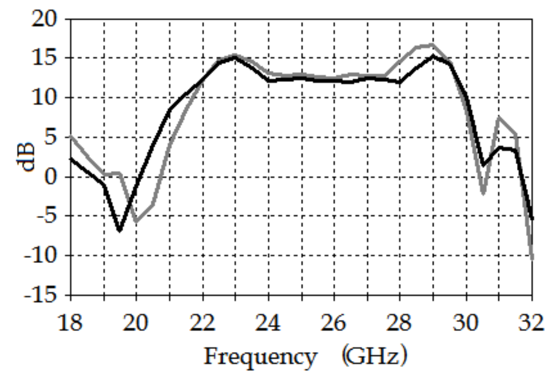

Fig. 3. Directivity of the simulated leaky wave antenna with the FSS designed for identical permittivity $\epsilon_{r1,2} = 6$ (black line) and for two permittivities $\epsilon_{r1} = 6$, $\epsilon_{r2} = 10$ (grey line).

The simulation results prove the goodness of the proposed design methodology.

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