Scattering of a Width-Modulated Microstrip Line for an Arbitrary Angle of Incidence

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Abstract

A parametric study of the scattering of an electromagnetic wave from a recently introduced, periodic, width-modulated microstrip line for arbitrary, i.e. normal and oblique, incidence is presented. The relationship between the analytically known dispersion characteristics (for grazing incidence) and the reflectivity of the structure is investigated for different values of the modulation constant and the incidence angle. The present study, carried out around the first stop band of the surface wave propagation, mainly aims to demonstrate the possibility of reduced virtual prototyping time of the geometry, when it's designed as a reflectarray element.

1. Introduction

Periodic structures have attracted considerable attention because of the interesting features they exhibit, based on the selectivity of their frequency response. The latter is expressed for an excitation from any direction, and based on this distinction, for the 2D case, different aspects have been outlined in the literature. When the excitation is in the plane of the periodic arrangement, pass- and stop-bands for the surface waves are defined [1]. When incidence on the surface from other directions occurs, the study regards reflection/transmission properties and usually such configuration is named as Frequency Selective Surface (FSS) [2]. Reflectarrays are special cases of FSSs, since the grounded structure fully reflects the incident electromagnetic energy, and in this case the crucial parameter is the phase of the reflected wave [3]. The local variation of the phase is obtained by point-wisely changing the geometry of each cell, explicitly meaning that the periodic arrangement evolves to a quasi-periodic one.
The combination of the interactions between the longitudinal and transverse propagation give rise to the holography phenomena [3]. Recently this term has been more and more considered in the field of antennas both for planar and conformal realization [5]. The quasi-periodicity of the geometry represents a challenging field of investigation since the increased number of degrees of freedom allows obtaining a large variety of solutions.
Any of the aforementioned applications require the definition of a unit cell, which is then investigated for the given excitation. In the literatures many kinds of structures have been proposed and optimized: here we consider the recently introduced width-modulated microstrip line geometry [6]. The analytical solution describing the propagation of the surface waves allows time-efficient prototyping. A detailed method for the design of such a unit cell has been presented in [6], while the scope for quasi-periodic arrangements has been discussed in [6]. Because of the electrical continuity between adjacent unit cells provided by the presence of the microstrip line, the junction between unit cells with different characteristics requires special attention. Some aspects on this issue have been considered in [8].

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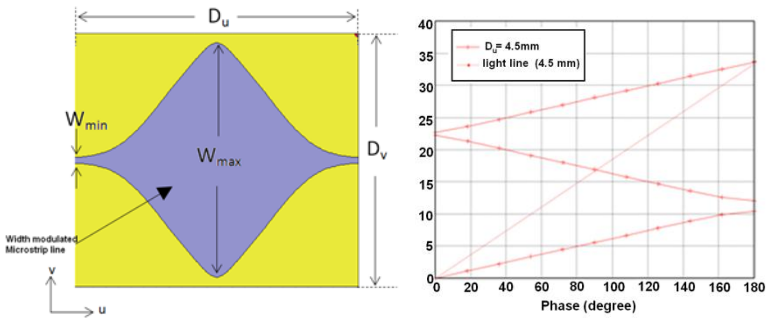
A parametric study on the reflectivity of such a unit cell is presented in this paper, and its equivalence with the band-gap response is investigated.

2. Design of unit-cell and initial study

An example of unit cell configuration with maximum modulated microstrip line width is shown in Fig. 1. The modulated line is printed on a substrate with permittivity ε_r, with the unit cell dimensions (D_u, D_v). The width of the line is varied between w_{min} and w_{max} that in turn controls the effective dielectric constant and, as a result of the periodic variation, EBGs appear. The structure is completely printable on the substrates and no vias are required. A sinusoidal modulation of the effective dielectric constant around an average value of ε_{avg}, with an amplitude of M_u, has been considered, according to

$$\varepsilon_{eff}(u) = \varepsilon_{avg}\left[1 + M_u \sin\left(2\pi \frac{u}{D_u}\right)\right]$$

because this profile has an analytic solution for the dispersion diagram (DD) [1]. The period of the modulation equals the dimension of the unit cell in the longitudinal direction u; M_u and ε_{avg} are called the modulation parameters. Fig. 1(b) shows the DD of the modulated microstrip line presented in Fig. 1 (a), with ε_r=10.2, (D_u, D_v) = (4.5, 4) mm, w_{min}=0.4 mm and w_{max}=3.9 mm. The reported DD for the TE polarisation has been computed by the method described in [7]. The DD in Fig. 1(b) shows the first bandgap around 10 GHz and a second one around 23 GHz. In the bandgaps the propagation constant k is purely imaginary. Because of this, the surface impedance is also purely imaginary; hence the incident field will be completely reflected making the structure suitable for reflectarray type of applications. As frequency goes higher and the dispersion curve crosses the light line (where phase difference corresponds to the propagation along the length of unit cell with a velocity equalling the speed of light), fields are less bounded and propagation of surface wave occurs. Control of the radiation of surface waves by the shape of the microstrip line allows implementation of holographic antennas. In this paper we have concentrated and confined our studies at the first bandgap mainly to investigate the effect of the geometry on the reflectivity. In the second bandgap, once again full reflection of the incident wave is expected, but the determination of the phase of the reflected wave requires a special attention.



(a) (b)

Fig. 1 Unit cell of modulated microstrip line with maximum value of M_u (b) Corresponding dispersion diagram.

3. Results and Discussion

Different values of the modulation parameter M_u from 0 to the maximum M_{max}=0.186 have been considered with an increment of 0.02, and a complete study for normal and oblique incidence on the unit-cell has been simulated with HFSS 12.0. Some results, presented in Fig. 2, highlights that the effect of M_u is very significant: the "in-phase reflection" frequency shifts from 14.8 GHz for zero modulation to 9.93 GHz for maximum modulation. The same behaviour has been observed for the bandwidth as discussed also below.

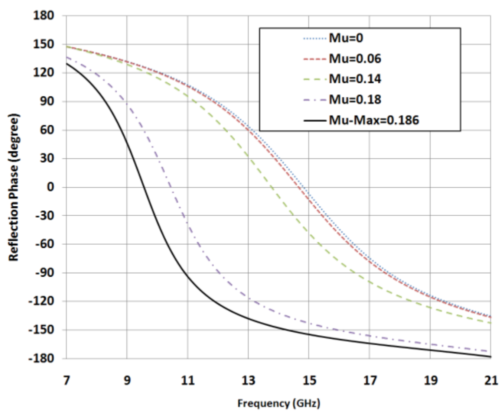
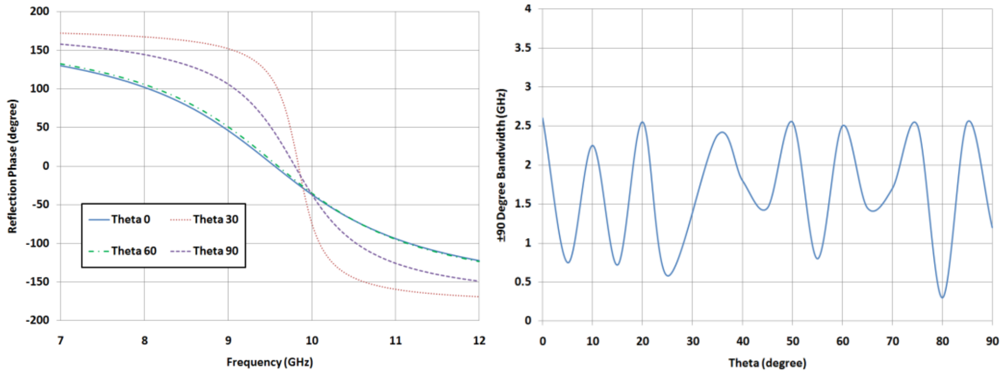


Fig. 2: Variation of the reflection phase for different values of M_u (normal incidence)

A second set of simulations has targeted the variation of the reflection phase for given M_u but different angles of incidence. In particular M_{max} has been considered, and the incidence angle has been varied from 0^o (normal) to 90^o. Results for $\theta=0^o$, 30^o, 60^o and 90^o are indicated in Fig. 3a. Since variation in the slope has been observed, in Fig. 3b the $\pm 90^o$ bandwidth is reported for a finer scan with a step of 5^o. A strong variation of the bandwidth can be observed. However, the bandwidth should be sufficient for most applications.



(a) (b)

Fig.3: (a) Frequency variation of reflection phase for different angles of incidence for M_u=M_{max}, (b) Variation of bandwidth with different angle of incidence

4. Conclusion

The preliminary results targeting possible employment of the proposed unit cell geometry as reflectarray element indicate that the relatively wideband (20%) reflection response is widely influenced by the modulation parameter M_u. On-going research considers this unit cell for reflector array applications and extending the concept to holographic surfaces.

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