The idea of using partially reflecting sheets (PRSs) was introduced in [1] to enhance the planar antennas gain. Later, it was shown that using a high-permittivity superstrate, one can also increase a planar antenna gain [2]. In either method a highly reflecting surface is placed above the source antenna to introduce a resonance (multiple reflections) between the ground plane and the high-reflecting surface. Through this phenomenon, the wave partially leaks from the superstrate and coherent wave leakage makes the antenna structure high-gain [1]. General formulas for 2-D leaky wave antennas have been introduced in [3]. On the other hand, it has been recently shown that, using artificial magnetic conductors (AMCs) [4] as the ground plane of a microstrip antenna with PRS cover, the antenna size can be reduced, while keeping its gain high. However, the radiation characteristics of the reduced size antenna with an AMC ground plane have not been compared against the original planar antenna, with a typical PEC ground plane.

In this paper, first, the idea of using reactive impedance surfaces (RISs) [5] as the ground plane of such leaky wave antennas is proposed and studied through a few examples. Next, the effect of a typical source antenna position on the directivity is investigated through a parametric study. Then, the radiation characteristics of these different antennas are determined and compared. Finally, the conclusion is drawn.

II. RIS as the Ground Plane

The side view of a general 2-D periodic leaky-wave antenna is shown in Fig. 1(a). The resonance condition for the antenna structure in order to radiate efficiently at the boresight angle ($\theta=0$ in this study) and an operating frequency $f$ can be obtained as:

$$l = \frac{N\lambda}{2} + \frac{\lambda}{4\pi} (\Psi_{\Gamma}(f) + \Phi_{\Gamma}(f))$$

where $N$ is an integer number, $l$ is the distance between the ground plane and the PRS, $\Psi_{\Gamma}$ and $\Phi_{\Gamma}$ are the reflection phases of the PRS and the ground plane, respectively. The transverse equivalent network (TEN) model is shown in Fig. 1(b). This model is different from the one introduced in [3], by the fact that the short-circuit representing the PEC ground plane in [3], has been replaced by a reactive impedance which simulates an arbitrary RIS. This configuration is more general, since any kind of impenetrable surface can be employed as the ground plane. As special cases, the electric field distributions of two different antennas are shown in Fig. 2, using their corresponding TEN models. In both cases, it is assumed that the PRS is a high-permittivity dielectric superstrate ($\Psi_{\Gamma} = \pi$), PEC ($\Phi_{\Gamma} = \pi$) and PMC ($\Phi_{\Gamma} = 0$) have been used as the ground plane in Fig. 2(a) and (b), respectively. As can be seen, the distance $l$ is reduced to half when PMC is employed.
Whether using PMC or any other kind of RISs, a minimum quarter wavelength is needed for \( l \), in order to produce the resonance in the antenna structure.

### III. 2-D Truncated Periodic Leaky-Wave Antenna Structure

The side view of the antenna structure is shown in Fig. 1(a). The ground plane is assumed to be infinite in size. In this paper, the radiation characteristics are studied for impenetrable ground plane surfaces with three different reflection coefficient phases of 0, \( \pi/2 \), and \( \pi \). The PRS is a truncated periodic structure with 10-by-10 unit cells of free-standing square patches. Each patch has the dimension of 9.5\( \times \)9.5 mm\(^2\). The unit cell size is 10\( \times \)10 mm\(^2\). The operating frequency is 9.43 GHz. The reflection coefficient magnitude and phase for an infinitely repeated periodic structure of this unit cell, at the operating frequency, are -1.53 dB and -147°, respectively, when it is subjected to the normal incidence. The source antenna is a half-wavelength dipole.

Corresponding directivities versus air-gap height \( l \) are plotted in Fig. 3(a), for the three above-mentioned antennas. In all cases, the antenna height \( h \) is \( 0.375(\lambda_o/4) \). As can be seen, resonances for each ground plane repeat every half-wavelength. The antenna structure provides a directivity of 17 to 20 dBi at these resonances. As shown, the size reduction has been accomplished at the expense of directivity loss.

The effect of the source antenna position on the directivity is investigated through a parametric study at the first resonance for different RIS ground planes. Paying attention to the air-gap heights, as shown in Fig. 3(a), it is evident that the source antenna position has the most and least moving ranges when the ground plane is PEC or PMC, respectively. As illustrated in Fig. 3(b), as long as the source antenna is not placed in the vicinity of the PRS, the high gain can be achieved. In the case of a ground plane with \( \Phi_{\Gamma}=\pi/2 \), attaining the high directivity is also affected by placing the source antenna very close to the ground plane. Therefore, placing the source antenna close to the middle of the air-gap is a good solution in general.

Corresponding radiation patterns for the three above-mentioned cases are shown in Fig. 4. The lowest sidelobe level and the lowest cross-polarizations are related to the first resonance of the structure with the PEC ground plane. Therefore, although using the RIS makes the antenna size small, it may reduce the quality of the radiation characteristics in comparison to a conventional PEC ground plane. However, it may still be useful for applications requiring high-gains at the boresight.

All above-mentioned results have been obtained using Ansoft HFSS software package.

### IV. Conclusions

The idea of high-gain antennas with PRS superstrates and PEC ground planes was extended to any impenetrable ground plane surface. Ideal RISs were used throughout this paper. Radiation characteristics of a few antennas which use these ideal RISs as the ground planes were studied. The effect of the source antenna position on directivity was investigated, as well. The application of this antenna can be in the reconfigurable high-gain antennas, where for a fixed air-gap height, one can obtain high-gains by changing the reflection coefficient phase of the ground plane surface.
Fig. 1. (a) Side view of a general 2-D periodic LWA. (b) TEN model of the LWA.

Fig. 2. TEN model of the antenna with high-permittivity dielectric used as its PRS with (a) PEC and (b) PMC ground plane.

Fig. 3. (a) Directivity vs. air-gap height for three different impenetrable surfaces as the ground planes. (b) Directivity vs. source antenna position at the first resonance for three aforementioned antenna structures.

References:


Fig. 4. (a), (c) and (e) are co-polarization radiation patterns and (b), (d) and (f) are cross-polarization radiation patterns of the high-gain antennas introduced in this paper when the reflection coefficient of the RIS ground planes are $\Gamma=\pi$ (PEC), $\Gamma=0$ (PMC) and $\Gamma=\pi/2$, respectively.