1-D broadside-radiating leaky-wave antenna based on a numerically synthesized impedance surface

1-D Broadside-Radiating Leaky-Wave Antenna Based on a Numerically Synthesized Impedance Surface

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***Abstract*—A newly-developed deterministic numerical technique for the automated design of metasurface antennas is applied here for the first time to the design of a 1-D printed Leaky-Wave Antenna (LWA) for broadside radiation. The surface impedance synthesis process does not require any a priori knowledge on the impedance pattern, and starts from a mask constraint on the desired far-field and practical bounds on the unit cell impedance values. The designed reactance surface for broadside radiation exhibits a non conventional patterning; this highlights the merit of using an automated design process for a design well known to be challenging for analytical methods. The antenna is physically implemented with an array of metal strips with varying gap widths and simulation results show very good agreement with the predicted performance.**

***Index Terms*—Leaky-wave antenna (LWA), numerical synthesis, impedance surface.**

I. Introduction

Leaky-Wave Antennas (LWAs) possess several qualities, mainly being very low-profile and having a simple feeding mechanism [1]. A well-known way of realizing LWAs is by employing Sinusoidally-Modulated Reactance Surfaces (SMRSs) [2], [3]; in these structures, a sinusoidal modulation of the surface impedance enables the radiation of the $n = -1$ Floquet harmonic, and the radiation angle and the leakage constant of the wave depend on the average surface reactance and the modulation amplitude, respectively.

However, printed LWAs based on SMRSs generally suffer from intrinsic problems. Sidelobe level is difficult to control for all scan angles, which can however be mitigated relaxing the uniform modulation scheme [4]. A much harder problem is the appearance of an open stopband [1] for broadside radiation; it impacts on most feeding mechanisms, as it generates a nearly-total reflection loss of the guided wave.

In this work, a deterministic numerical technique for the synthesis of metasurface antennas [5] is applied to the design of a 1-D LWA; this procedure yields the spatial distribution of the surface impedance starting from mask-type constraints on the far-field pattern, without the need of any a priori knowledge or assumptions. The procedure also allows to constrain the impedance to lie withing upper and lower bounds, which is crucial for practical realizability with a given unit cell. In particular, the antenna described in this paper is designed imposing broadside radiation and low sidelobe level, in order to test the numerical technique against some of the harshest requirements. In fact, as recalled above, broadside radiation is a well-known challenge for analytical-based designs. It is noted that the employed process allows design for any pointing angle.

The numerically synthesized impedance surface presents an unconventional impedance pattern, that does not correspond to a sinusoidal modulation. Such impedance surface is implemented using a very simple geometry and full-wave simulations of the whole antenna confirm the predicted radiation properties and further proves the efficiency of the adopted numerical technique.

II. Antenna Design

The adopted design process consists of the steps listed below.

In this specific design case we have considered the following parameters:

- Working frequency: $f = 10$ GHz
- Dielectric substrate permittivity: $\varepsilon_r = 6.15$
- Substrate thickness: $h = 2.54$ mm
- Length of the antenna: $L = 7.5\lambda$
- Realizability constraint on the synthesizable impedance: $X \in [X_L, X_U]$, $X_L = -800\Omega$, $X_U = -100\Omega$
- Mask-type constraints: broadside radiation, $SLL = -20$ dB.

These are the input of the automated deterministic design algorithm. An important feature of the employed impedance synthesis procedure is that it maximizes the gain in the desired radiation direction for a given *incident power*; this inherently minimizes reflection from the metasurface, thereby allowing to avoid stopband problems in the broadside design.

The output of the design procedure is the impedance pattern shown in Fig. 1. It is characterized by a quasi-periodic profile: empty areas, that represent open circuits, i.e. absence of printed metalizations on the dielectric substrate, alternate with regions which contains sharp variations of reactance values. This also points at the importance of limiting the minimum

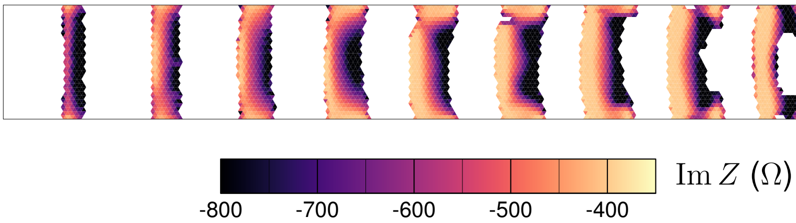

Fig. 1. Impedance pattern along the length of the antenna synthesized with the numerical method. The longitudinal direction is the x axis, while the transverse direction is the y axis.

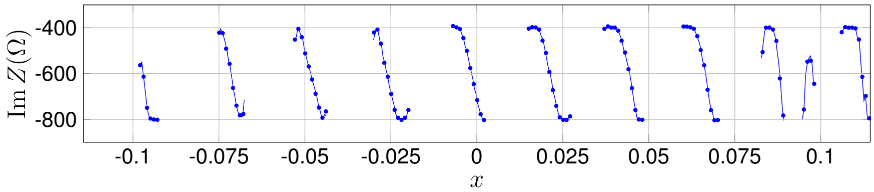

Fig. 2. Impedance profile along the length of the antenna, sampled with a $\lambda/10$ step.

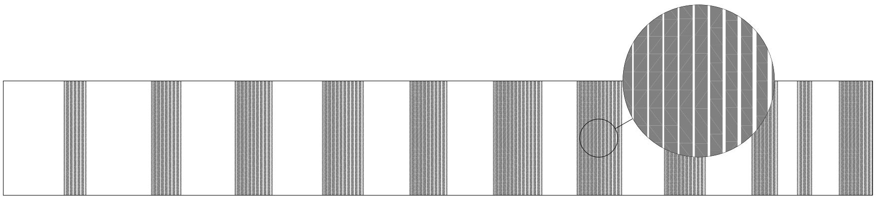

Fig. 3. Array of metal strips separated by gaps of varying width that implements the impedance pattern of Fig. 2.

and maximum reactance for practical realizability.

It can be seen that the synthesized impedance varies not only along the antenna length, but also in the transverse direction; this is mainly due to the fact that the process is inherently 3D and considers a full 2D variation of impedance; also, it is probably linked to the fact that in this preliminary application to 1D antennas the incident wave is a cylindrical one (surface wave excited by a vertical pin in the dielectric). These 2D variations have been averaged out in the present application, to allow for the use of a simple and more conventional unit cell. The reactance profile is then sampled with a $\lambda/10$ step along the x axis (Fig. 2).

The chosen geometry for the physical implementation of the synthesized impedance surface is the well-known array of metal strips separated by gaps of varying width [3]. The mapping between sheet impedance and gap width is obtained by performing normal-incidence scattering simulations of the constitutive unit cell, printed on the selected dielectric substrate, with a periodicity equal to $\lambda/10$ [3]. The resulting array of metal strips is shown in Fig. 3.

III. Results

In order to validate the proposed design, full-wave simulations of the complete structure are performed. To this aim, a in-house solver based on the Method of Moments is employed. Fig. 4 shows the current density distribution on the array of strips, while Fig. 5 compares the far-field calculated using the optimized impedance profile shown in Fig. 1 vs the far-field obtained by full-wave simulations of the array of metal strips shown in Fig. 3, i.e. the one related to the physical implementation of the antenna which ignored the impedance profile variation along the y axis. Results show that there is a very good match between the two patterns, although some discrepancies can be noticed; mainly, the simulated antenna radiates at $\theta = -4°$ instead of broadside and the side lobe level is slightly higher than expected. This is well within the approximations in the prototypical application of the synthesis method to 1D antennas, and notably the source term and the deletion of transverse variation of the impedance; these will be amended in the refined version currently under way. However, it should be noted that the side lobes are still very low compared to other solutions based on SMRSs [3].

IV. Conclusions

This work shows the first application of a newly-developed deterministic numerical technique for the synthesis of metasurfaces to the design of a 1-D LWA. In particular, we addressed the synthesize an antenna radiating at broadside with low side lobe level, which is a notoriously difficult condition to achieve with this kind of structures. The numerically retrieved impedance pattern is physically implemented via an array of strips separated by gaps of varying width and the resulting structure is simulated with good results. While more tests are needed to effectivley specialize this technique to 1D

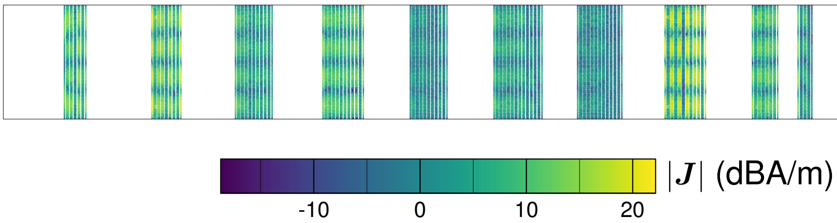

Fig. 4. Current density distribution on the array of strips.

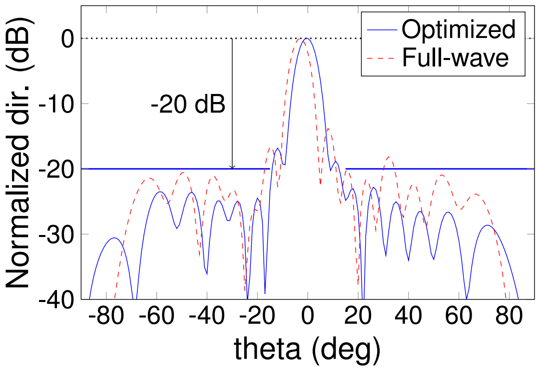

Fig. 5. Far-field pattern calculated using the optimized impedance profile shown in Fig. 1 and far-field pattern obtained by full-wave simulations of the array of metal strips shown in Fig. 3.

leaky-wave antenna design, this initial attempt demonstrates the possibility to overcome the limitations of conventional sinusoidal modulation design approaches. More generally this shows that the underlying synthesis method allows to achieve a design in conditions where analytical approaches do not exist.

ACKNOWLEDGEMENT

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