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All-Metal THz Leaky-Wave Antennas

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Summary

Half-annular and full-annular corrugated leaky-wave antenna, based on asymmetric unit cells, are under study. The structure is constituted by metal only and it is designed to exhibit a suppressed open stop-band. To this aim an asymmetry is realized leveraging on the design of a unit cell with two non-identical perturbations of the metallic profile (i.e., of the groove), or with a single perturbation asymmetric with respect to the propagation of the leaky mode. An efficient in-house method-of-moments, implemented and optimized to study the dispersion behavior of the leaky modes, is applied. Radiative performance are also analyzed through full-wave simulations, which validate the scanning behavior predicted by leaky-wave theory. The numerical results show that, thanks to the one-sided configuration and to the presence of a quasi-flat nonzero attenuation constant, a linear scanning behavior and almost constant gain through broadside can be achieved at terahertz frequencies, with an all-metal and compact structure. Similarly, the corresponding full-annular structure shows a pencil beam with persistent broadside radiation over relatively large frequency bandwidth in the THz region. Experimental validations of the two prototypes are in progress at the Tsinghua University, Beijing National Research Center for Information Science and Technology.

1 Introduction

All-metal leaky-wave antennas (LWAs) represent a class of compact devices offering high-gain with low profile, relatively simple manufacturing, and reduced losses at microwave frequencies and beyond. Corrugated all-metal antennas have been proposed and tested [1], [2], [3]. The structure and the corresponding corrugation can be made radially periodic and can support a fast backward/forward spatial harmonic (i.e., a leaky modes). High-gain pencil beam scanning across broadside, or high-gain beams with persistent (and possibly wideband) radiation at broadside, can be supported by these type of designs.

An open stop-band (OSB) is present in periodic LWAs (see, e.g., [4]): It occurs when the phase constant of the relevant leaky mode approaches to zero, where the attenuation constant typically experiences a quick drop, resulting in a deterioration of the radiation pattern and of the input matching of the antenna. Various approaches have been applied to reduce or eliminate the OSB in LWAs (see, e.g., [5], [6], [7], and refs. therein). Due to the radial periodicity of annular and half-annular structures, new solutions are needed to suppress the OSB. We consider here an asymmetric perturbation within the unit cell of the periodic structure, which can be profitably adapted to the design of annular and half-annular devices, based on or on all-metal structures. On this basis two different LWAs, one annular and one half annular are designed, simulated, and tested.

2 Antenna Design

We are investigating and validating the design of two corrugated metallic periodic LWAs constituted by asymmetric unit cells, operating in the low-THz range, where all-metal designs are particularly attractive due to their reduced losses. Two different configurations of the unit cell are studied to suppress the OSB effects, and their capability of supporting high-gain beams with no gain drop is numerically validated. We consider an unit cell constituted by two non-identical grooves and one based on a trapezoidal groove (i.e., asymmetric with respect to the propgation of the leaky mode). Accurate dispersive analyses are performed for the corresponding linearized structure (approach enforced by the lack of translation invariance in annular geometries) using an in-house accurate and optimized numerical code, which demonstrates the possibility of suppressing the OSB by properly optimizing the shape of the asymmetries.

A one-sided LWA prototype is designed performing full-wave simulations with a state-of-art commercial tool. Preliminary results (that will be presented at the conference) show that the OSB can be completely suppressed and a linear scanning behavior through broadside of an high-gain pencil beam can be obtained with an all-metal leaky-wave antenna operating at terahertz frequencies.

The normalized phase and attenuation constants of the leaky modes supported by the structures under consideration are obtained with a an accurate and optimized in-house method-of-moment (MoM) code [8], which employs a rapidly convergent Ewald representation for the relevant two-dimensional periodic Green's function. Dispersive results using the MoM can be achieved as a function of frequency for the $n = -1$ radiating space harmonic (associated to a TM leaky mode), and can also be validate studying the radation features of the anenna by means of full-wave simulations and/or by conventionally exploiting reciprocity.

The all-metal antennas can be fed with simple and compact waveguide designed to properly coupling the injected energy with the supported leaky modes, which allows for enabling broadisde radiation when the full-annular configuration is considered. Two prototypes working at THz frequencies have been manufactured and are now under study at the Tsinghua University. The proposed LWAs can be particularly suitable for applications requiring a scanning beam with a compact antenna at 60-100 GHz and beyond, such as tracking radars [9], gas detection spectroscopy [10], and link discovery [11].

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