SIW based Dirac Leaky-Wave Antenna

Sina Rezaee
Dept. Electrical Engineering
Sharif University of Technology
Tehran, Iran

Mohammad Memarian
Dept. Electrical Engineering
Sharif University of Technology
Tehran, Iran
nmemarian@sharif.edu

George V. Eleftheriades
Dept Electrical Engineering
University of Toronto
Toronto, ON, Canada

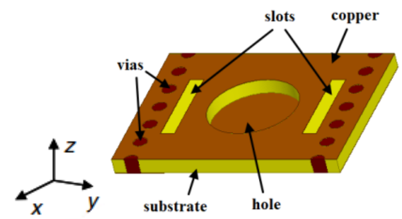
***Abstract*—Dirac leaky-wave antennas (DLWAs) provide interesting features such as radiating through broadside, beam scanning, and ease in fabrication, suggesting them as a favorable solution for radar and communication systems at upper microwave frequencies. In this paper, it is shown that a Dirac photonic crystal can be realized in Substrate Integrated Waveguide (SIW) technology composed of air columns inside a host SIW waveguide, exhibiting a closed and linear dispersion around broadside. The structure is made to radiate acting as a SIW based DLWA. The directive beam scans a wide range of angles, with high efficiency, and is well matched around 28GHz, using a RO4003 substrate. The proposed SIW DLWA is well suited for emerging 5G and IoT applications that require reliable directive beaming and scanning.**

Keywords—Dirac leaky wave antenna; broadside radiation, SIW, 5G applications, IoT

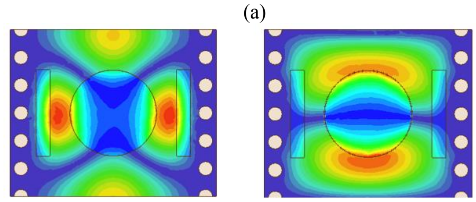
I. Introduction

Leaky-wave antennas (LWAs) provide high gain beams with a relatively simple design which are also scannable with frequency. Continuous beam scanning through broadside from LWAs is, however, a challenging task. Different LWA structures have been introduced thus far, but typically suffer from the so-called open stopband issue around the broadside direction of radiation. The unit cells of periodic LWAs can be modeled with two lossy resonators (shunt and series). The equal resonance frequency of shunt and series resonators is a necessary condition to eliminate the open stopband (frequency balancing). Also, both resonators are specified by their quality factors which correspond to the radiated and dissipated powers in each respective resonator. Balancing the quality factors of these resonators provides a smooth leakage constant and perfect impedance matching (Q balancing).

The conditions to close the stopband in one-dimensional (1D) LWAs at microwaves and terahertz frequency have been described in [1] and [2], using the so-called Dirac photonic crystal and transmission-line metamaterials, respectively. The Dirac photonic crystal (PC) concept is especially useful at higher frequencies up to terahertz and optical ones, with feasible dimensions ($=\lambda_g$) and lower losses, while metamaterial designs are mainly applicable at lower microwave frequencies due to the small unit-cell required ($<<\lambda_g$). The larger unit cell size of the Dirac PCs has the benefit that at higher frequencies, subwavelength features of metamaterial cells are difficult to manufacture or are infeasible. Furthermore, the larger unit cell dimension provides slower beam scanning in antenna application, which is an attractive feature for frequency scanning applications, where a signal with a finite bandwidth is required to be transmitted. The unit cell of the Dirac LWA [1], was composed of two types of dielectrics, (high permittivity rods inside a host waveguide filled with low permittivity).



(a)



(b)

Fig. 1. (a) One-dimensional SIW based Dirac PC. (b) E-field magnitude in the *x–y* plane for the two eigenmodes.

In microwave and millimeter-wave applications, waveguide devices have an important advantage over microstrip devices from the aspects of high Q-factor and higher power capacity. However, waveguide fabrication process is difficult and costly. The substrate integrated waveguide (SIW) technology has remarkable advantages combining the best of both worlds, leading to devices that are lightweight, low cost, low loss and with simple integration with planar circuits [3].

II. The Leaky 1D Dirac PC in SIW

Fig. 1a shows the geometry of the proposed leaky Dirac photonic crystal in SIW. The design is aimed at 5G communication bands in the millimeter-wave range centered around 28 GHz. All dimensions of the proposed structure are designed and then optimized using full-wave solvers. The unit cell of the SIW DLWA has a period of a = 6.115 mm (in the x-direction), a substrate height of 0.508 mm (in the z-direction) and a waveguide width of 6.712 mm (center-to-center separation between the vias in the y-direction).

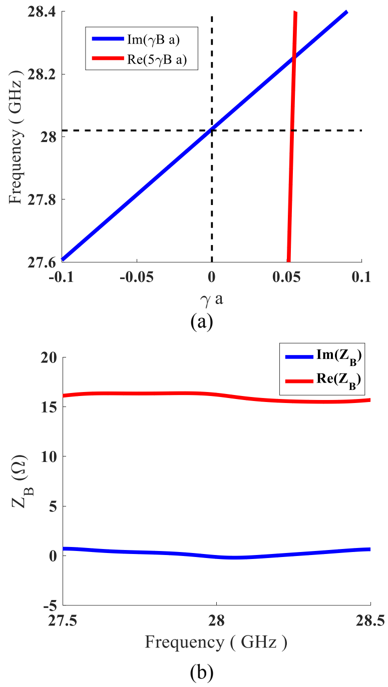


Fig. 2. (a) Bloch propagation constant. (b) Bloch impedance.

The substrate used is based on parameters of a Rogers RO4003 board with dielectric constant ε_r = 3.78, and tanδ = 0.0027. Thickness and conductivity of copper-cladding are 18µm and 19.33e6 S/m respectively. Air columns are placed at the center of each cell and have a circular cross-section with radius 1.58 mm, and the backside of the hole is covered with ground. Additional rectangular perforations in the top metal of the guide are slots with dimensions 0.5x3.177 mm (parallel to the *x*-axis). The radius and center-to-center separation in the *x*-direction of the vias are 0.25 mm and 1.019 mm, respectively. The hole in the unit cell and slots provide leakage for the antisymmetric and symmetric Bloch modes respectively. The sizes of the perforations are designed so that the two conditions (frequency-balancing and Q-balancing) are satisfied to overcome the broadside radiation issue.

The two Bloch modes of the 1D leaky case are shown in Fig. 1b, where they are both degenerate at the Dirac frequency (f_D=28.02 GHz). A 1D Dirac-type dispersion can be seen in the dispersion of the structure in Fig. 2a. The dispersion curve has a linear trend and no stopband. Moreover, the attenuation (leakage) constant does not around close to the γ=0 range, contrary to typical LWAs which exhibit a stopband. The Bloch impedance (Z_B) around the broadside is shown in Fig. 2b. The Bloch impedance is also quite constant enabling the proper matching of the antenna.

The SIW DLWA is shown in Fig. 3a. This antenna is made directly from cascading the unit cells described previously. The antenna has N=25 cells, enough to radiate most of incident power. The 25-cell antenna has a total length of 155.8 mm. Transitions are designed to excite the antenna with 50Ω microstrip transmission lines.

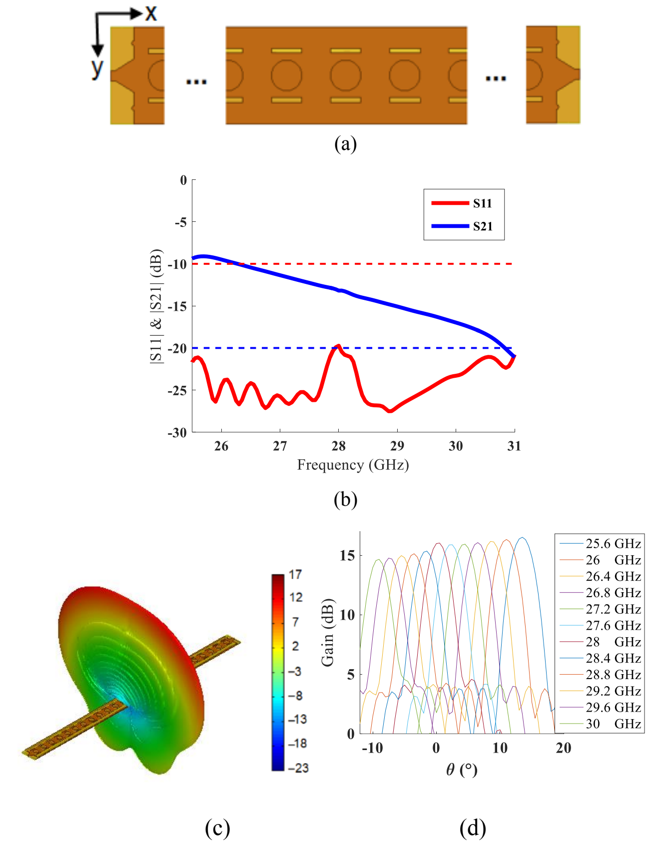


Fig. 3. (a) Top view of the SIW DLWA. (b) S-parameters of a 25 cell design. (c) Three-dimensional radiation pattern. (d) Frequency scanning range.

The S-parameters of the DLWA are reported in Fig. 3b, showing perfect matching ($|S_{11}|$<-20 dB) over a wide bandwidth. The radiation pattern of the DLWA is reported in Fig. 3c, showing a directive fan beam at broadside. The continuous scanning of the DLWA can be seen in Fig. 3d. As can be seen, the DLWA has a wide scan range from -15˚ to 20˚. Losses were included and a 76% efficiency is seen.

III. Conclusions

An SIW based Dirac LWA is proposed and demonstrated at 28 GHz, radiating a directive fan beam continuously scanning a wide range of angles, with perfect matching, and high efficiency. The design is well suited for mm-wave 5G and IoT applications.

References

[1] M. Memarian and G. V. Eleftheriades, “Dirac leaky-wave antennas for continuous beam scanning from photonic crystals,” Nature communications, vol. 6, 2015.

[2] C. A. Allen, C. Caloz, and T. Itoh, “Leaky-waves in a metamaterialbased two-dimensional structure for a conical beam antenna application,” in Microwave Symposium Digest, 2004 IEEE MTT-S International, vol. 1, pp. 305–308, June 2004.

[3] M. Bozzi, A. Georgiadis, K. Wu, “Review of substrate-integrated waveguide circuits and antennas,” IET Microw. Antennas Propag., vol. 5, no.8, pp. 909-920, June. 2011.