Improved Gain Graphene Based Leaky Wave Antenna Loaded by Dielectric Slab in THz Regime

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***Abstract*—A sinusoidally modulated graphene microstrip line based leaky wave antenna that operates in the THz regime is presented. The dispersion diagram of the unit cell of the antenna is obtained by numerical simulation with commercial software. As a second step, the radiation pattern of the designed leaky wave antenna is calculated: the main beam angle scans with the operating frequency according to the dispersion diagram. To increase the gain, the antenna is loaded with a dielectric slab on top of it acting as a partially reflecting surface. By optimizing the height and distance of the slab, increase in the gain is achieved as it is demonstrated by numerical simulations.**

***Index Terms*—gain, graphene, leaky wave antenna.**

I. Introduction

Recently, leaky wave antennas have attracted much interests as high gain and low profile radiating structures which are capable to be integrated into various devices [1]. They have unique ability to scan radiation beam with the operating frequency [2], even if in some cases this characteristic is seen as a drawback, because, for example, of the distortion of the beam, or narrow band. Extensive studies have been performed about the radiation performance of this type of antenna [3]-[5]. During time, different configurations have been considered to limit the aforementioned drawbacks, e.g., [6], [7]. Among them, sinusoidally-modulated surface impedance was introduced in [8] for increase the gain. This idea was developed later to control leaky wave radiation [9], [10].

On the other hand, graphene is a single layer atom of carbon which has attracted significant researher's interests especially in the THz and optical frequency ranges. The main reason of this attention is its unique property: its surface impedance can be tuned by changing the chemical potential (of the graphene) via adjusting the applied voltage. Exploiting this peculiarity, a high number of tunable and reconfigurable applications have been investigated using graphene [11]-[14].

In this paper, our goal is to increase the gain of a sinusoidally modulated graphene based leaky wave antenna. We achieve it by loading the designed antenna with a dielectric slab on top of it at an optimized distance.

The design procedure is presented in Section II. A unit cell as building block of the proposed leaky wave antenna is introduced and the dispersion diagram is plotted based on the scattering parameters of the element. Moreover, radiation pattern of the antenna is obtained. In Section III, a dielectric slab is used to load the proposed leaky wave antenna to achieve a higher gain. The gain of the leaky wave antenna with and without the slab is compared. Section IV concludes the paper.

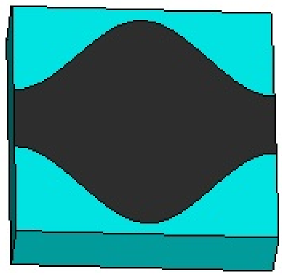

Fig. 1. Unit cell of the leaky wave antenna.

II. Design Procedure

Starting from the desired centre frequency and main beam angle, and exploiting the relation between phase constant β of the propagating wave along the antenna and the lobe angle θ_0, one can optimize the unit cell of the proposed antenna. Equation (1) indicates the main beam angle of a leaky wave antenna [15]:

$$\theta_0 = \cos^{-1}(\beta/k_0) \quad (1)$$

where k_0 is the wave number in air. Equation (1) illustrates that for operating the antenna as a leaky one, phase constant of the wave along the structure should be smaller than air wave number, otherwise the wave propagates as a guiding mode instead of leaky mode [16].

Figure 1 shows the unit cell of the proposed leaky wave antenna which consists of a graphene based width modulated microstrip line on a grounded dielectric substrate with relative permittivity of $\varepsilon_r = 3.8$. The period of the unit cell is considered as p = 80 μm. Dimension of the microstrip line and height of the substrate and characteristics of graphene are optimized to achieve main beam in broadside at the centre frequency of 2.55 THz. The optimized value for the height

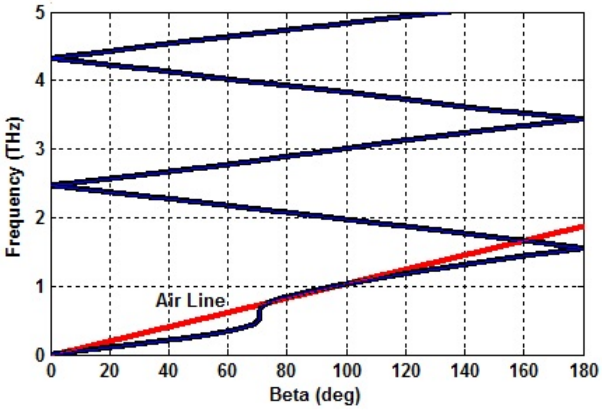

Fig. 2. Dispersion diagram of the leaky wave antenna.

of the structure is h = 20 μm and the characteristics of the graphene are obtained as follows: temperature T = 300 K, relaxation time $\tau = 0.1$ ps and chemical potential $\mu_c = 0.5$ e.V corresponding to Z_s = (169.95 + j 272.38) Ω surface impedance of the graphene, using the closed form expression for the surface conductivity of graphene [17].

By simulating the single unit cell we have obtained its scattering parameters (S_{ij}). From this, using the following expression [18]:

$$\beta = Im[\frac{\cosh^{-1}(\frac{S_{12}S_{21}+((1+S_{11})(1-S_{22}))}{2S_{21}})}{p}] \qquad (2)$$

we have calculated the dispersion diagram of the proposed unit cell as reported in Fig. 2.

As we expected, the dispersion diagram at our design frequency is above the air-line representing leaky wave region. Furthermore, it is observed that at 2.55 THz, β is zero, meaning broadside direction of the main beam. Figure 3.a) shows the structure of the designed leaky wave antenna and Fig. 3.b) reports its radiation pattern which is obtained using HFSS [19]. At 2.55 THz the main beam is directed to the broadside as we anticipated.

III. Loading the Dielectric Slab to the Antenna

In the next step, we load the proposed leaky wave antenna by a dielectric slab with the same relative permittivity as of the substrate. The height of the slab h_2 and its distance to the dielectric substrate d were optimized to achieve the maximum gain of the designed leaky wave antenna as follows: h_2 = 10 μm and d = 20 μm. Figure 4 compares the electric field distribution of the leaky wave antenna with and without the slab. It can be seen that in the structure with the slab shown in Fig. 4b, the electromagnetic wave propagates to a longer distance along the surface of the antenna than in the unloaded case. This is because when the wave radiates into the air, the outgoing wave hits the slab and some part of it will reflect toward the antenna. This part again propagates along the surface and radiates and again some part of it reflects after meeting the slab. This procedure continues resulting to

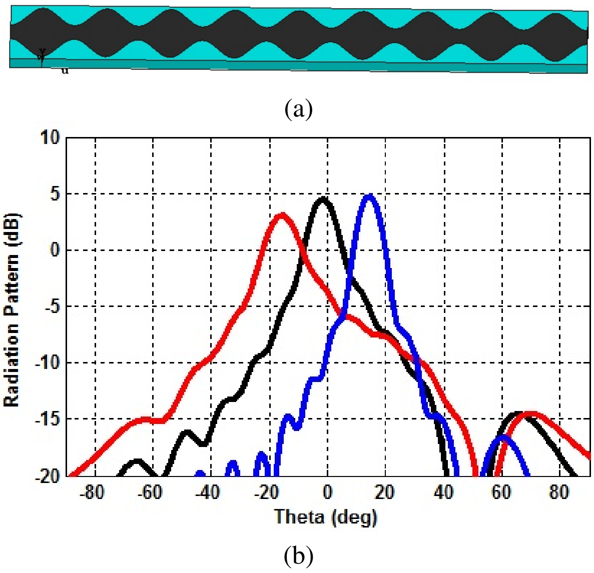

Fig. 3. a) Structure of the designed leaky wave antenna. b) Radiation pattern of the antenna. black: 2.55 THz, red: 2.3 THz, blue: 2.9 THz.

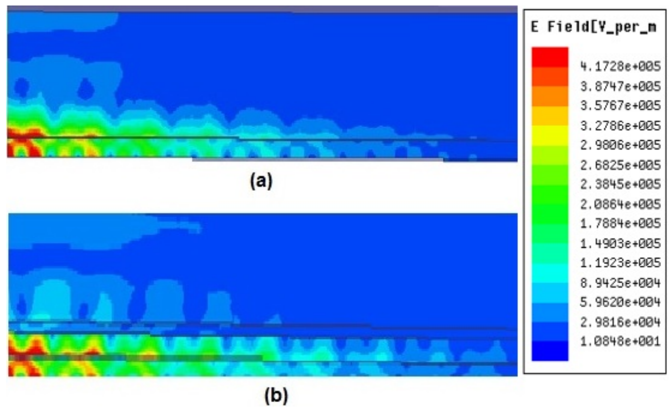

Fig. 4. Electric field distribution of the leaky wave antenna from the side view. a) without slab. b) with slab.

trap the wave between the dielectric substrate and slab. In this way, larger part of the leaky wave antenna contributes to the radiation process compared to the origin antenna causing improvement in aperture efficiency and therefore in gain of the antenna. This is the same mechanism used in employing partially reflecting surfaces, e.g., [20].

Radiation pattern of the leaky wave antenna with presence of the slab at 2.55 THz associated to the broadside directed main beam is shown in Fig. 5. By comparing the figure with Fig. 3.b, one can comprehend the gain improvement. Figure 6 illustrates the gain of the original leaky wave antenna and the one loaded with dielectric slab for different frequencies. It shows gain improvement in frequency range from 2.2 THz to 3 THz. Maximum gain improvement (2.7 dB) happens at 2.7 THz with the beam angle of 5.3 degree. The gain increase in broadside direction is 2.5 dB. The frequencies related to the near broadside main lobe direction show more gain increase

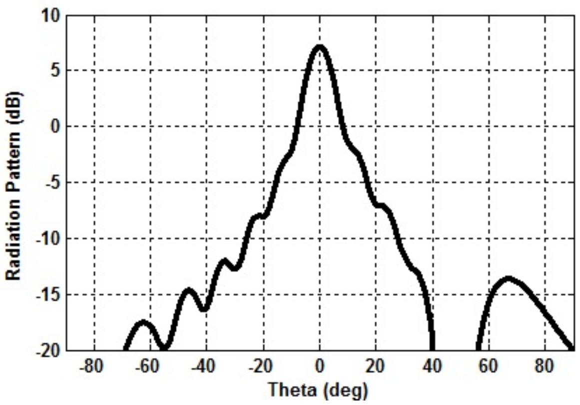

Fig. 5. Radiation pattern of the leaky wave antenna loaded with dielectric slab.

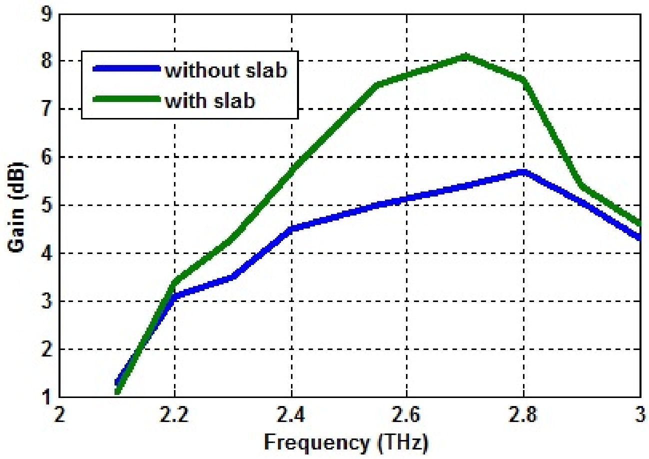

Fig. 6. Gain of the leaky wave antenna with and without the dielectric slab.

because of more interaction of the radiated wave with the slab.

IV. Conclusion

A leaky wave antenna based on graphene sinusoidally modulated microstrip line was investigated in this paper. The dispersion diagram of the antenna was obtained by simulating the unit cell which is building block of the proposed leaky wave antenna. Radiation pattern of the designed antenna was obtained which scans with the operating frequency. The considered antenna was loaded by a dielectric slab with optimized height and distance to the substrate to achieve a higher gain. As the wave radiates into the air, it reflects after impinging on the slab and reflects to the antenna. It propagate along the surface of the antenna again so the wave propagates in larger distance resulting in gain improvement.

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