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Research paper

A new design and simulation of cylindrical-gold horn Nano-antenna at terahertz region for energy harvesting application

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Abstract

In this paper, the design and simulate a new horn nanoantenna at terahertz frequencies by using the CST Microwave studio 2018. The proposed design be composed of an Au–Air–Au symmetric transmission line flared horn at the end, where the arranged of cylindrical gold pillars have been considered in the geometrical lattice. The Numerical simulation have been done in this work with taking in the consideration the losses of the material and the desperation. The horn nanoantenna shown with numerical results (wide bandwidth) and the directivity is greater than 10 dB from the results, the horn nanoantenna could be used in different applications such as energy harvesting, telecommunication and different technical ranging from smart lighting to optical wireless communication.

Keywords: *Nanoantenna; Horn; Gain, Directivity; Terahertz.*

1. Introduction

The importance element in wireless networking which operate at radio and microwave frequencies is an antenna [1], [2]. Nanoantennas, optical devices that can concentrate between free space radiation and localized energy, therefore, become important subject in recent years [3]. Their interesting properties, which allow us to manipulate light at the nano scale dimensions which have a dramatic impact on a variety of fields by controlling the far field emission, such as nano scale optical circuitry[4–8]., photo detection and photoemission [9–13], metasurfaces [14], [15] sensing [16], [17], nonlinear optics [18], [19] and spectroscopy [20], [21].
Actually, incorrect to define the Terahertz (THz) band as part of the electromagnetic spectrum because it is between the infrared and microwaves bands [22]. In addition, the works numbers, innovations, and advanced techniques enhancements in Terahertz (THz) band developed very slowly compared with technologies in microwaves and optical domain of the electromagnetic spectrum [23].
The wide range of applications of Terahertz (THz) band such as wireless nano-links, photo-detection, photoemission, and nonlinear plasmonic, to name a few are interested researcher to discover this filed [24]. This wide range of applications results of unparalleled radiation properties, which shown below briefly [25]:

1) Breakthrough: The waves in THz can push through the different materials with different level of the attenuation.
2) Accuracy: the resolution in the THz wave is better than that of the microwave.
3) Spectroscopy: THz band can be used for the detection.
4) Non-ionization: low power levels in THz band lead to decrease the ionization effect on the biological tissues.
5) Propagation: The proportionality between wavelength and propagation is inverse, where wavelength is low in the THz band in comparison to the light wave.
6) Intensity: The signal directivity in the THz band is easier comparing with microwave.

However, there are some drawbacks against the THz spectrum for examples lack of reliability, compact, temperature insensitivity, and efficient power transmitter antenna and a receiver antenna. These problems becomes as keywords for research in these frequencies bands [26]. Unfortunately, the radiation of THz band was incoherent, so, it was difficult to detect.That problem solved by using coherent photon technology and making the use of THz part in the scientific and commercial applications possible [2].
Several papers introduced in THz band in different fields for example, Davide Ramaccia and at.al presented horn nanoantenna composed of Ag-Sio_2-Ag transmission line flared at the end as style of microwave horn antenna at 1500nm wavelength. The transmission line supported qusi –TEM, used silver for cladding and silicon for waveguide (core) working at near infrared region. The results obtained reflection coefficient amplitude less than -15dB and average gain around 9dB within the bandwidth of operation (85THz). One of interesting options for such antenna used as element planner in antenna array for some application such as energy harvesting. In real time, this beam could be scanned for tunable nano circuits [27]. In addition, Adeel Afridi and Sukrtu Ekin Kocabas studied plasmonic horn nanoantenna, it pleased on metal backed substrate. The thickness of substrate effected on the beam sterling of horn antenna. Use the impedance matching technique to accurately predict factors to reduce reflections impedance matching by more than 61% and the input power delivered around 99.75% to the antenna [28].

Yuanqing Yang et. al. have studied the Broadband nanophotonic wireless links and networks using on chip integrated optical nono-antennas. Where they have used optical horn nanoantennas, which are adapted and utilized as basic building blocks, since they can be readily fabricated and naturally impedance-matched to the feeding waveguides. Thus, optical horn nanoantennas can used as point-to-point optical wireless nanolink which shows a significantly superior performance (100-fold enhancement in power transfer at telecommunication wavelengths and a much wider bandwidth) to that using dipole nano-antennas[29].

In this paper, a new design of cylindrical-gold horn nanoantenna at by using the CST Microwave studio 2018 for energy harvesting and wireless communication applications. The proposed design be composed of an Au–Air–Au symmetric transmission line flared horn at the end, where the arranged of cylindrical gold pillars have been considered in the geometrical lattice.

2. Nanoantenna transmission line configuration

The first step in a new design of Cylindrical-Gold Horn Nanoantenna (C-GHNA) is determined a transmission line. that is utilized to feed the horn nanoantenna. In proposed design, we have considered the Au-Air-Au symmetric transmission line. Figure1 show the diagram of transmission line.

The plasmonic antenna behavior of gold at optical frequencies let to obtain the required series inductance behavior along the transmission line, while the dielectric (air) returns the shunt capacitance. Therefore, such a configuration supports a fundamental forward mode restricted between the two metal layers [30], [31].

Gold considered the complex permittivity model that is presenting in a Drude model with damping and plasma frequencies set to 4.35 THz and 2175THz, while the dielectric (air) considered permittivity function model. According to these models, the dispersion and material losses take into account during implementation design by CST Studio Suite.

To have propagation in terahertz frequencies, the thicknesses of gold and air layers have been set to 50 nm and 400nm, respectively. Waveguide port has used to excite transmission line and the expected forward propagation of the fundamental mode has been correctly obtained at the design frequency.

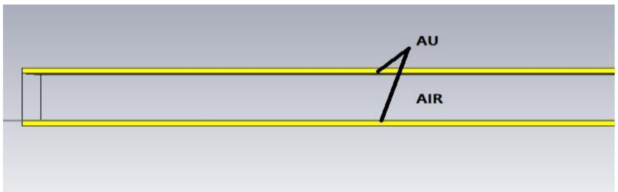

Fig. 1: Transverse Section of Transmission Line.

3. Cylindrical -gold horn Nano antenna design and results

Antenna is done transform electromagnetic waves to alternating currents and vice versa. Horn antenna is the most commonly and simplest used microwave antennas [32].the shape of horn antenna is consisted of metallic waveguide such a way to increase the physical aperture thus, the antenna gain and progressively the impedance matching of the waveguide to one free-space.

In this work, the design process is performed by using CST Microwave studio 2018 in radio frequency and microwave section, optical application, plasmonic and then nanoantenna at Time Domain method. the horn nanoantenna is excited by transmission line, as mention above. The horn antenna consist of two gold layers at one-end of the waveguide, as shown in Figure 2.

The lengths of the horn (ℓhorn) is 1500 nm and the lengths of waveguide (ℓ wg) is 4000 nm. The out vertical aperture (h) is set to1300nm, the smoothness parameter of loft function is used to define the radius of curvature from taper the transmission line into the horn aperture by the numerical simulator CST Studio suite. This parameter is specified 0.35 finally, the overall dimensions of C-GHNA is shown in Table 1

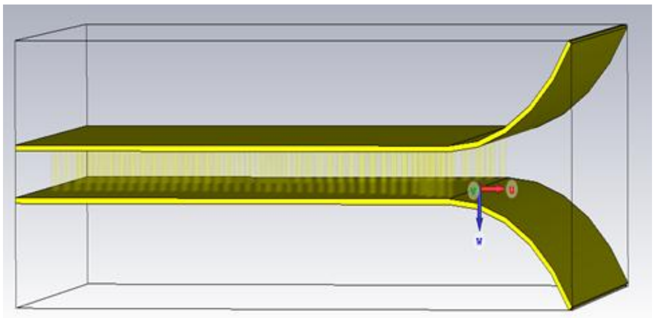

Fig. 2: Horn Nanoantenna Only Two Layers of Gold.

In addition, The arranged of cylindrical gold pillars have considered in the geometrical lattice as shown in Figure 3 to get a lateral confinement of the filed during the waveguide, as mention previously, the transmission line of nanoantenna supports forward mode at terahertz frequencies, where this mode has gradually transformed into a radiating mode by the C-GHNA shape.

Fig. 3: Cylindrical Gold Pillars Have Shaped in This Geometrical Lattice.

Table1: Dimensions of C-GHNA

NO.	Parameters	Values (nm)
1	Wave of waveguide W_{wg}	1500
2	Length of waveguide, L_{wg}	4000
3	Length of horn ,L_{horn}	1500
4	High, h	1300
5	Pitch ,p	50
6	Diameter of cylindrical ,d	45

The distribution of electric field amplitude at the wavelength of 1200 nm has shown in Figure 4. This Figure describe the similarities behavior between a microwave horn antenna and the proposed C-GHNA, where the regular microwave horn antenna given by the amplitude of the reflection coefficient.

The variation of the reflection coefficient (scattering parameter S_{11}) with terahertz (THz) frequencies band has shown in Figure5. The results noted that the horn nanoantenna is effectively matched with a scattering parameter (S_{11}) better than −15 dB in terahertz frequencies. Therefore, the radiation signal is effectively leave the waveguide port and propagate along the transmission line.

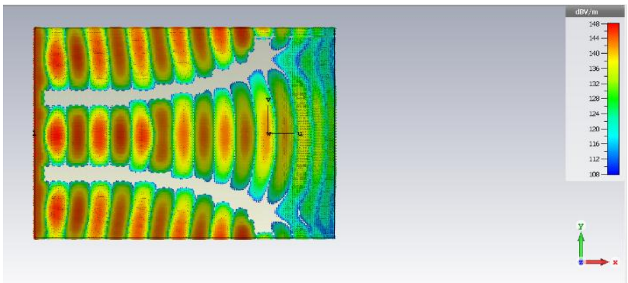

Fig. 4: Current Distribution.

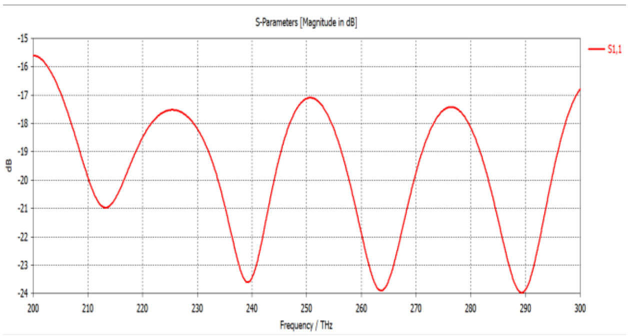

Fig. 5: Amplitude of the Reflection Coefficient (I.E., Scattering Parameter S_{11}) at the Input Port of the Horn Nanoantenna.

The evaluation performance of C-GHNA show a good result for the directivity, where directivity is very important parameter because it measures the power density of the C-GHNA radiates in the direction of its strongest power radiation density.
Figures 6,7and 8 has shown the directivity of C-GHNA at the resonant frequencies 240THz, 263THz and 290 THz respectively. Where the first resonant frequency 240THz with corresponding scattering parameter -23 dB, while the second resonant frequency 264 THz with corresponding scattering parameter -24 dB and third resonant frequency 290 THz with corresponding scattering parameter -24dBi . In additional the values of directivity at 9.84 dB, 10.1 and 10.6 respectively frequencies.

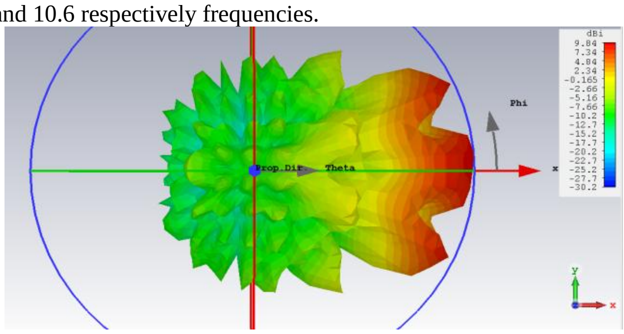

Fig. 6: Directivity of 240 THz (3D Fairfield).

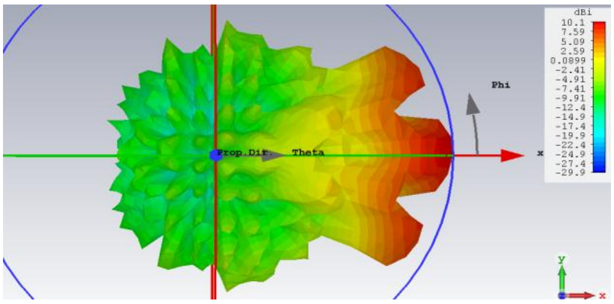

Fig. 7: Directivity of 264THz (3D Fairfield).

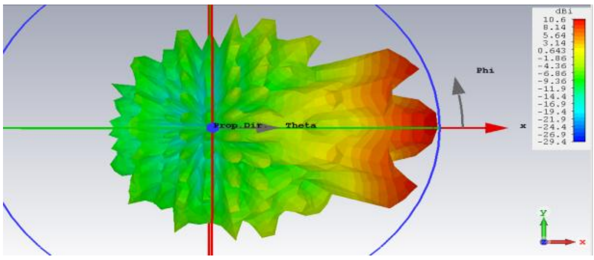

Fig. 8: Directivity of 290THz (3D Fairfield).

By observation the polar plotting in Figures 9, 10 and 11. These appear the components of E-field and H-field at resonant frequency 240 THz having main lobe direction at 66°, and angular width (3 dB) 68.6°. In addition at other resonant frequency 264THz the component of Electric field having main lobe direction at 115°, and angular beam width (3 dB) 109.2° and the last frequency of band 290THz the component of Electric field having main lobe direction at 109°, and angular beam width (3 dB) 58.6°.

The last frequency achieved a good directivity. As well as, The Voltage Standing Wave Ratio (VSWR) of the proposed C-GHNA has been shown in Figure12, which shows that the VSWR lies under the minimum acceptable value of 2. The results of C-GHNA (Resonant Frequency, Bandwidth, scattering parameter S11, Directivity, Half Power Beamwidth) have shown in Table 2.

The used of the spectral region of THz for different application such as energy harvesting devices, smart lighting, optical wireless communication links and spectroscopy for imaging applications since the spectroscopy with a high spectral resolution of the electromagnetic spectrum at Terahertz frequencies regime (THz) is a powerful analytical tool for investigating the structure and energy levels of molecules and atoms.

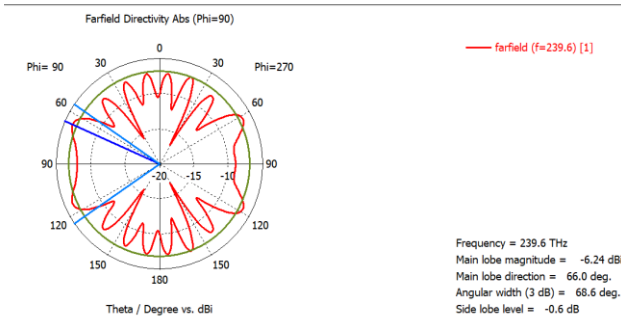

Fig. 9: Polar Plot of the Frequency 240 THz.

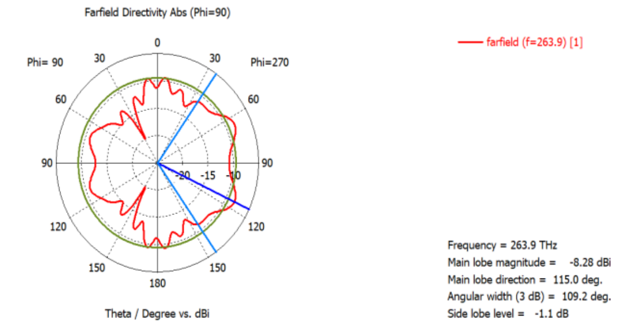

Fig. 10: Polar Plot of the Frequency 264 THz.

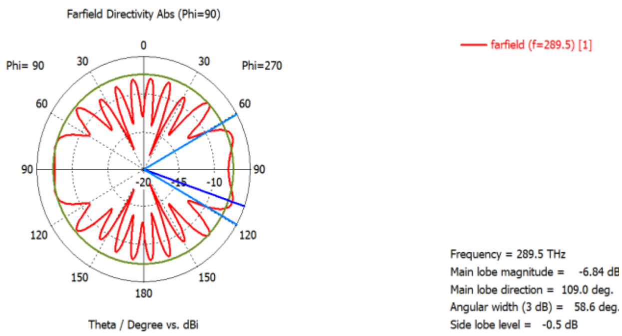

Fig. 11: Polar Plot of the Frequency 290 THz.

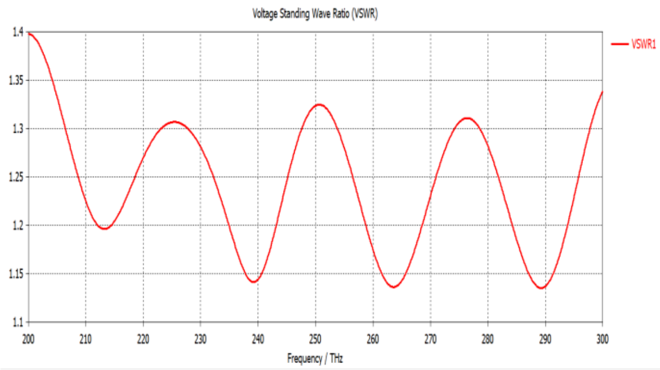

Fig. 12: Voltage Standing Wave Ratio (VSWR) Under Two Value.

Table 2: Results of C-GHNA

NO.	Parameters	Values
1	First Resonant Frequency	240THz
2	Second Resonant Frequency	264THz
3	Third Resonant Frequency	290 THz
4	Bandwidth of 1st band	70THz
5	Return loss to 1st Frequency	-23 dB
6	Return loss to the 2nd Frequency	-24 dB
7	Return loss to the 3th Frequency	-24 dB
8	Directivity of 1st Frequency	9.84 dB
9	Directivity of 2nd Frequency	10.1 dB
10	Directivity of 3th Frequency	10.6 dB
11	Gain of 1st Frequency	8.3 dB
12	Gain of 2nd Frequency	8.38 dB
13	Gain of 3th Frequency	9 dB

In the end, to valuate that the proposed design, we will this work to compare with another researchers implemented for the purpose of horn nanoantenna applications as shown in the following table 3.

Table 3: Comparison between C-GHNA and Other References

Name	S_{11} (dB)	F (THz)	G (dB)	D (dB)	Eff. %	BW (THz)	Side lobe (dB)
[27]	-18	185	7.12	-	-	85	-
	-34	200	8.11				
	-16	230	9.31				
[26]	-64	275	-	14.2	66.93	100	-10
C-GHNA	-23	240	8.3	9.84	84.34	100	-0.6
	-24	263	8.38	10.1	82.9		-1.1
	-24	290	9	10.6	84.9		-0.5

4. Conclusion

In this work, we have presented the new design of a cylindrical-gold horn nanoantenna C-GHNA consisting of an Au-air-Au with symmetric transmission line at one of the end horn, where the arranged of cylindrical gold pillars have been considered in the special geometric shape of C-GHNA. The Cylindrical-Gold Horn Nanoantenna has designed to work at terahertz frequencies. According to the results, the largest value of directivity of band is 10.6 dBi that is considered a good directivity. As well as, the results of the impedance bandwidth for scattering parameter better that -15 dBi with higher gain value 9 dBi within the bandwidth more than 100THz of operation are promising and open the door to the possible implementation of such horn nanoantennas in future wireless communication, smart lighting, harvesting energy and spectroscopy for imaging applications.

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