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Research paper

A new design of Microstrip hash-shape nanoantenna & Microstrip hash-shape slot nanoantenna at THz spectroscopy for imaging application

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Abstract

The terahertz (THz) lies between electronics and optics frequency range, and THz frequencies are the lowest frequencies in which free space conventional optics can still be used before microwave components take over. The development of Terahertz technology systems led to focus of researchers on this technology field. In this paper, the CST Microwave studio 2018 is used to design and simulate a new Microstrip Hash-shape Nanoantenna (MHNA) & Microstrip Hash-shape Slot Nanoantenna (MHSNA). Gain, Directivity, Half Power Beamwidth, Return loss and Bandwidth are computed. The results of work achieved a frequencies in Terahertz in the case of Nano size. The first design and the second design operating in the range of (125.3 THz to 133.4 THz) and (126.4 THz to 133 THz) respectively. Where utilize a Gold in the patch and Ground plane, while, the Silicon material is utilize as substrate which having dielectric material (εr=11.9). Therefore the utilized of these bands of THz frequencies that referred to the millimeter, micrometer for spectroscopy for imaging applications.

Keywords: *Nanoantenna; Microstrip; Gain; Directivity; Terahertz.*

1. Introduction

Optical Nanoantennas Are The Antennas Which Have Resonating Frequency In The Visible Spectrum Regions Of Electromagnetic Wave, Therefor, The Size Of These Optical Nanoantennas Should Be In The Range Of 100–400 Nm [1]. Because The Growing Demand Of High Data Rate And High Speed Communication System, Therefore, It Need The Higher Operating Frequency Lying In The Millimeter And Micrometer Range Of The Electromagnetic Spectrum [2]. In Any Case, To Expand The Working Recurrence And To Set Up A Correspondence Interface In The Thz Area, There Are A Few Structure Issues Which Should Be Addressed Carefully. The Antenna Assumes The Critical Job In The Remote Correspondence Which Needs The Due Thought At The Thz Recurrence. The Gain Of The Antenna Is A Critical Factor To Upgrade The General Communication Link [3].

Tuning The Scattering Response Of The Optical Nanoantennas Using Graphene Have Proposed By B. Mehta And M. E. Zaghloul In 2014. They Proposed The Tuning Of The Dipole Nanoantenna By Transferring Monolayer Of Graphene Technique. This Technique Is Relatively Simple Process And Does Not Require Any Complex Fabrication. The Verifying Of Experimental Results Has Been Proved By Fdtd Simulation [1]. Experimental And Numerical Demonstration Of Stand-Alone Three-Dimensional Optical Tweezers Based On Fibred Bowtie Nanoantenna Have Conducted In 2014. Fibred Nanotweezers Based On A Bowtie Nanoaperture Antenna (Bna) Which Is Carve On The Surface Of A Bowtie At The Tip Apex Of A Metal Coated Near-Field Optical Microscope Probe. This Type Of Bowtie Nanoaperture Provides Standalone Optical Nanosource Directly Excited With In-Fiber Illumination. This Means That There Is No Direct Coupling Between The Fibers Guided Mode And The Free Propagating Field Issued From The Tip. Therefore, The Bna Exhibits High Electromagnetic Field Confinement Together With Electric Intensity Enhancement In Its Gap Zone [4-6].

Metallic Nano-Dipole Antennas Are Modeled And Analyzed For Wireless Optical Communication Application. Firstly Developed A Unified Mathematical Framework To Investigate The Performance In Transmission And Reception Of These Nanoantennas. The Mathematical Framework Takes Into Account The Metal Properties Such As Its Dynamic Complex Conductivity And Permittivity; The Propagation Properties Of Spp Waves On The Nanoantennas, I.E., Their Confinement Factor And Propagation Length; And The Antenna Geometry, I.E., Length And Radius. Finally, To Validate The Model, The Researchers Have Conduct Extensive Simulations With Comsol Multi-Physics And Numerically Investigate To Compare Between Them [7]. The Development Of A New Computational Method In The Spectral Domain For A Full Wave Analysis Of Periodic Plasmonic Nanoantennas On Iso/Anisotropic Substrates Has Presented By Mahdieh Bozorgi, And Zahra Atlasbaf. However, The Use Of Method Of Moments (Mom) For Analysis Planar Periodic Structures Is An Accuracy For This Analysis. By Comparing The Method Of Moments (Mom) Results With Those Results Which Are Obtained By The Commercial High Frequency Structural Simulator (Hfss), Based On Finite-Element Method (Fem), It Is Shown That The Method Of Moments (Mom) Is An Accurate Computational Technique [8].

The Inherent Potential Of Researchers Of Using Terahertz Technology Led To A Rapid Development Of Terahertz Technology Systems. So, For Many Years The Researchers Have Been An Interest In The Use Of The Spectral Region That Has Been Referred As The Millimeter, Micrometer And Sub-Micrometer, Far-Ir, Or Terahertz Region For Imaging Because This Spectral Region Represents A Useful Compromise Between Atmospheric Penetration And Image Resolution [9].

In 2004 The Performance Of Bi-Periodic Arrays Of Gold Nanoantennas For Molecular Sensing Applications Has Studied Using The Fourier Modal Method (Fmm) By Stefan Enoch Et. Al. The Results Shows That The Coupling Between The Particles Of Nanoantennas Of Electromagnetic Can Be Optimized To Increase Their Sensitivity To A Weak Change Of The Shallow Dielectric Environment. Especially, Arrays Whose Elementary Cell Consists Of A Dimer Of Two Closely Packed Particles Are Found To Be At Least Three Times More Sensitive Than Single Particle Arrays [10]. Because Of The Unique Capability Of Nanoantennas And Nano Plasmonic Light Concentrators That Led To Utilize It In Photoconductive Terahertz Sources And Detectors. These Nanoantennas And Nano Plasmonic Has Proven To Offer Higher Terahertz Radiation Powers And Detection Sensitivities By Enhancing Photoconductor Quantum Efficiency While Maintaining Its Ultrafast Operation [11].

For Optical Telecommunication Applications, Plasmonic Waveguides Provide A Much Smaller Footprint Compared To Dielectric Optics Devices Because These Plasmonic Suffer From High Metallic Losses Which Led To A Short Propagation Length [12]. To Solve This Problem, Wireless Optical Communication Can Be Adopted By Using Nanoantennas System As Transmitters/Receivers To Replace The Loss Plasmonic Waveguide Links [12–14]. Depending On The Manipulating Structures, The Concentration Of Photo-Generated Carriers Within The Device Active Area, Allowing A Larger Number Of Photo Carriers To Efficiently Contribute To Terahertz Radiation And Detection. So, The Terahertz Optoelectronic Devices Through Use Of Various Types Of Nanoantennas And Nano Plasmonic Light Concentrators Has Presented By Many Researchers. [12–14]. It Is Very Important To Show That For Optical Wireless Communications, Directive Nanoantennas Have A Better Link Capability Compared To Non-Directive Nanoantennas. This Is Because To The Fact That Point To Point Communication That Targets A Specific Direction Requires Less Power If Compared With Its Point To Many Points Counterpart That Needs More Power Due To The Uniform Power Distribution Over All Directions [11].

Mai O. Sallam Et. Al. In 2017 Have Studied A New Circularly Polarized Wire Grid Nanoantenna Array Designed For Optical Telecommunication Applications. The Array Consists Of Two Groups Of Radiators Which Are Orthogonal To Each Other. Each Group Consists Of Six Aligned Radiators Connected Via Non-Radiating Connectors. A 90° Phase Shift Is Achieved By Inserting a Gap between the Feeding Coupling Rods and the Inner Radiators of One of the Two Antenna Groups. The Antenna is characterized by It's A Wide Axial Ratio Bandwidth Which Covers The Range From 188.2 Thz To 197.8 Thz. The Radiation Efficiency Of The Antenna Is 82.75% At 193.55 Thz With Very Small Variations Along Its Operating Bandwidth. Such Good Radiation Characteristics Are Very Attractive For Optical Communication Applications, As Well As The Spectroscopic Imaging System Is Capable Of Analyzing And Revealing Various Biological And Chemical Conditions. Since A Nanoantenna- Metamaterial Based Thz-Time Domain Spectroscopy System Have A Highly Sensitive And Selective Detection Method For Residual Pesticide Molecules [15-16].

There Are Numerous Number Of Applications At Terahertz Frequency Regime That Gained High Attention. The Design And Analysis Of Terahertz Microstrip Patch Antenna For Detection Of Plastic Explosive Semtex By Deploying Fr4 Material As Substrate With Dielectric Constant Of 4.4 Whereas The Radiating Patch And Ground Plane Are Made Up Of Copper Material Having High Conductivity And Low Resistivity Has Proposed By Payal Kalra Et. Al. In 2017. The Results Have Shown That The An Input Impedance Of 49.15 Ω Which Resonates At 4.32 Thz Frequency With Return Loss Of -52.10 Db And With A Gain Of 5.88 Db And Directivity Of 5.75 Dbi Which Makes It Highly Suitable For Detection Of Plastic Explosive Semtex [17].

To The Best Of Our Knowledge We Proposed A New Design Of Microstrip Hash-Shape Nanoantenna (Mhna) & Microstrip Hash-Shape Slot Nanoantenna (Mhsna). In This Work, Mhna & Mhsna Are Composed Of Ground Plane, Silicon Material As Dielectric Substrate And Patch Antenna. The Ground And Patch Made Of Gold Nanoparticles Materials. We Used Gold Material Because It Has High Conductivity Without Changing The Properties. In Our Proposed Design The Size Of Patch Is Half Wavelength From The Size Of Substrate. The Results Show Good Gain And Directivity Because We Got Close Bands In Both Designs At Terahertz Region For Thz Spectroscopy Imaging Applications, Since The Electromagnetic Wave At This Frequency Can Penetrate Ambiguous Materials And Preparation And Synthesis Materials, So The Thz Spectroscopy Imaging Revealed Fingerprint Like Spectrum Similar To Ir Bands.

2. Nanoantenna design configuration

Optical Nanoantennas, With Typical Dimensions Of A Hundred Nanometers, Have Several Important Optical Applications Because Of An Ability To Achieve High Electromagnetic Field Values Localized In Subwavelength “Hotspots”. In New Proposed Design Of Optical Nanoantenna Which Is Called Microstrip Hash-Shape Nanoantenna (Mhna) & Microstrip Hash-Shape Slot Nanoantenna (Mhsna) As Shown In Figure 1 And Figure 2 Respectively. That Is Illustrate The Overall View Are Consist Of Three Layer: Ground, Substrate And Hash-Shape Patch. The Patch Nanoantenna & Patch Slot Nanoantenna Are Composed Of Gold Metal. The Dimension Of Hash-Shape Patch Nanoantenna & Patch Slot Nanoantenna Are 500 Nm For Width (Wp) And Length (Lp) Is 500 Nm With Thickness (T) 20 Nm, While, The Cut Off Region In The Four Corner Of Patch Mhna & Mhsna Were 100 X 100 Nm.

The Purpose Of These Cut Off Of New Design Mhna & Mhsna Are To Change The Current Distribution On The Patch That Lead To Enhancement Of Radiation Pattern Of Mhna & Mhsna. Moreover, In Order To Get The Best And A Good Solution For Both Far-Field And Return Loss S11 We Utilized Waveguide Excitation Port. The Substrate Layer Made Up Dielectric Material (Silicon) With Thickness (H) 50 Nm And A Dimension Is 900, 900 Nm W, L Respectively, Where The Dielectric Constant Of Silicon Is (Ɛ) 11.9. The Ground Layer Consist Of Gold With Dimension 900 X 900 Nm Meanwhile The Thickness Was 20 Nm. Over All Parameters Of Mhna & Mhsna Have Shown In Table 1.

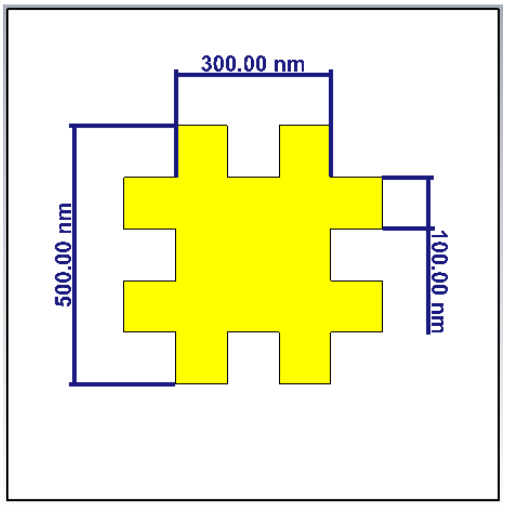


Fig. 1: Overall View of MHNA

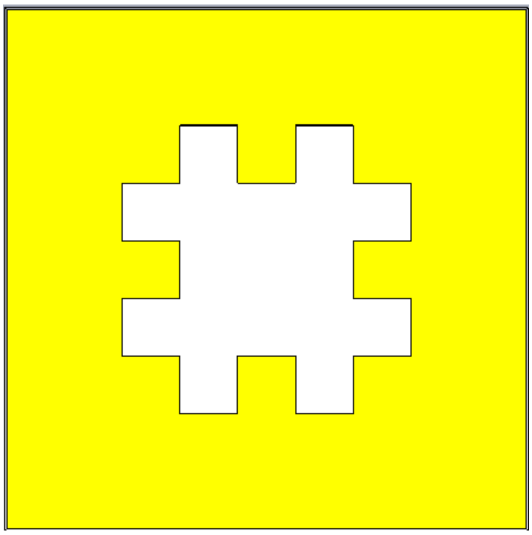


Fig. 2: Overall View of MHSNA.

Table 1: Antenna Dimension

NO.	Parameters	Values (nm)
1	Substrate width, W	900
2	Substrate length, L	900
3	Thickness of Substrate, h	50
4	Ground width, Wg	900
5	Ground width, Wg	900
6	Thickness of Ground, t	20
7	Patch width, Wp	500
8	Patch length, Lp	500
9	Thickness of patch, t	20

Through the equations of length and width of the Microstrip in the book of Balanis [18], we were able to calculate the length and width (1) and (2) and slightly manipulated the extracted values to suit our new design.

Actual width W

$$W = \frac{v_{\circ}}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

υ_0: free space velocity of light.
f_r: resonant frequency.
ε_r: dielectric constant.

Actual length L

$$L = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}\sqrt{\varepsilon_{reff}}} \qquad (2)$$

ε_{reff}: Effective dielectric constant.

The effective dielectric constant for Microstrip antenna is given by [19]:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w_f}}}\right) \qquad (3)$$

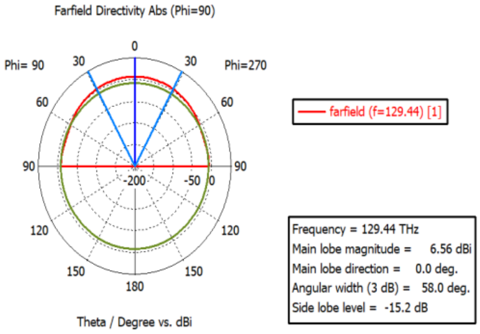


Fig. 5: Polar Plot of the MHNA.

3. Performance analysis and result

The design process is performed using CST Microwave studio 2018 in Time Domain method. The evaluation performance of MHNA & MHSNA shows a good results for the directivity, where directivity is very important parameter because it measures the power density of the MHNA radiates in the direction of its strongest power radiation density. Figures 3 and 4 have shown the directivity of MHNA & MHSNA respectively. Where the MHNA resonant frequency 129.44 THz with corresponding Return loss -14.2 dBi, while the MHSNA resonant frequency 129.75 THz with corresponding Return loss -47.7 dBi. In additional the value of directivity at 129.44 THz is 6.56 dBi and at 129.75 THz is 6.49 dBi.

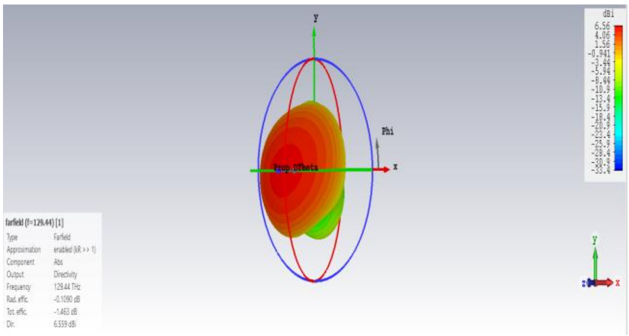


Fig. 3: Directivity of the MHNA, (3D Fairfield).

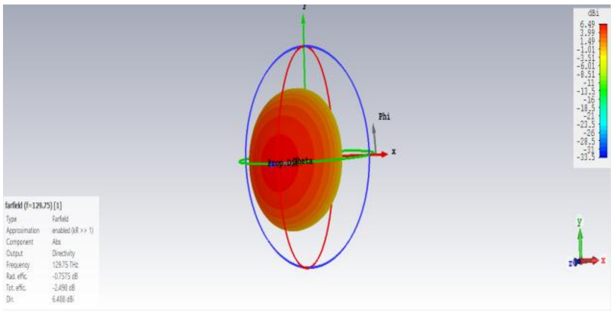


Fig 4: Directivity of the MHSNA, (3D Fairfield).

By inspection the polar plotting in Figures 5 and 6 appear that the component of angular beam width (3 dB) 58o at resonant frequency 129.44 THz, meanwhile the component of angular beam width (3 dB) 64.8o at resonant frequency 129.75 THz. Although the Nanoantenna achieved a good directivity, the losses associated with side lobe levels are to be expected due to substrate material selection and working at higher frequencies (THz).
Figure 7 and 8 shows that the return loss S11 of MHNA & MHSNA. It can be seen that the return loss S11 is -14.2, -47.7 dBi at 129.44, 129.75 THz respectively. As well as, The Gain of the proposed MHNA & MHSNA has been shown in Figure 9 and 10 which shows that a very acceptable values comparing with Directivity.

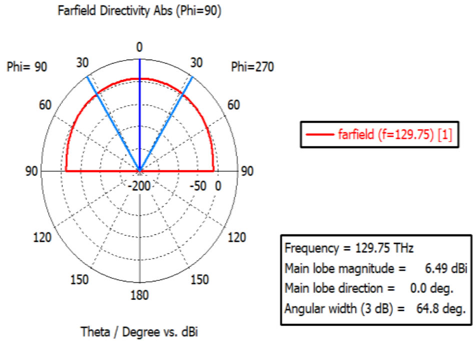


Fig. 6: Polar Plot of the MHSNA.

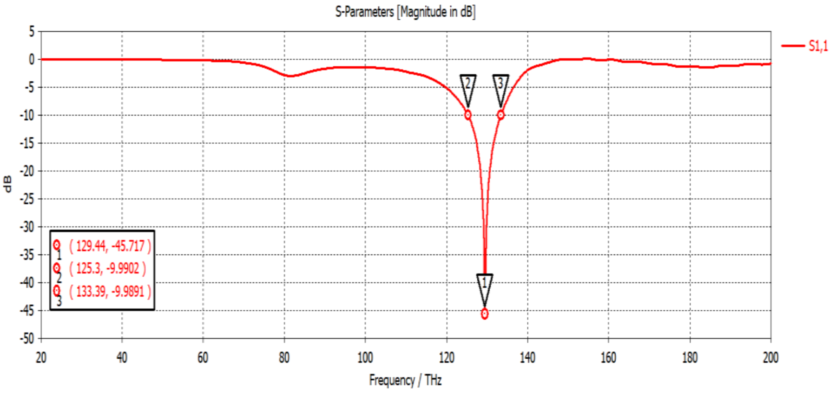


Fig. 7: Return Loss (S11) of MHNA.

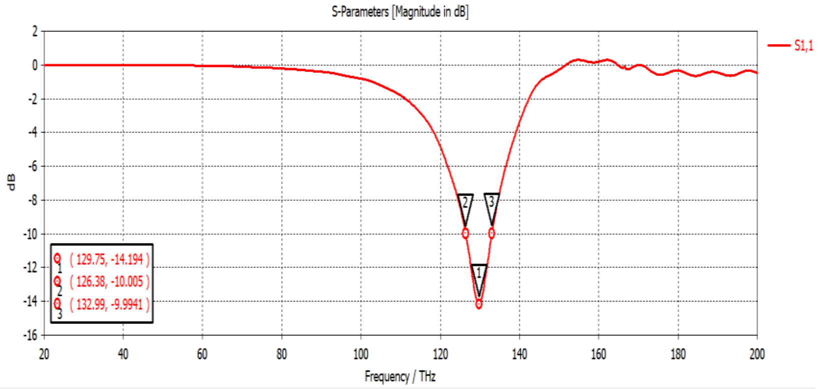
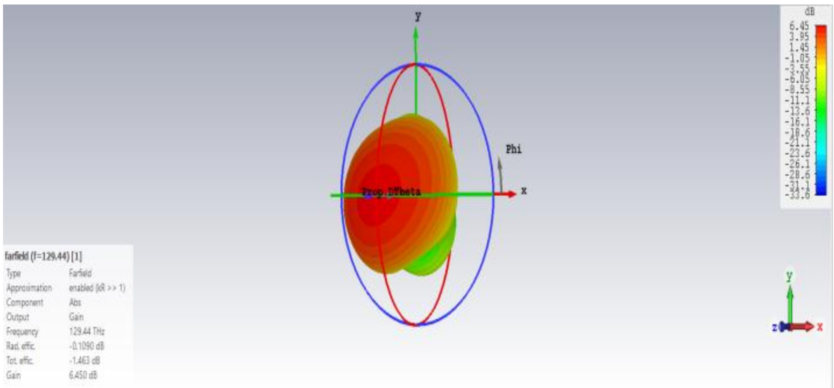
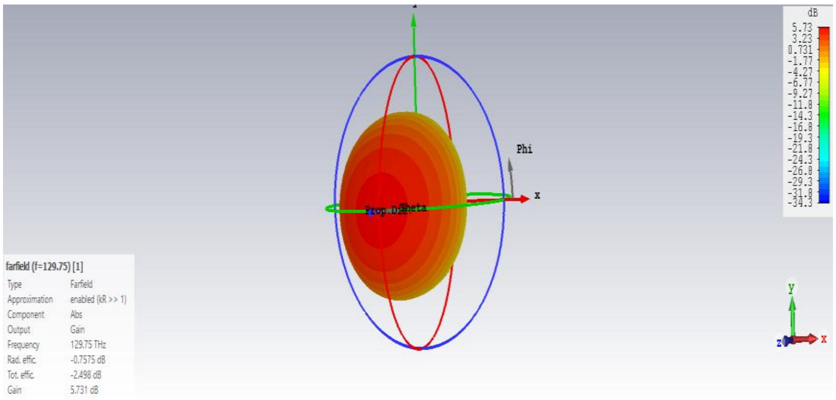


Fig. 8: Return Loss (S11) of MHSNA.



farfield (f=129.44) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 129.44 THz
Rad. effic. -0.1090 dB
Tot. effic. -1.463 dB
Gain 6.450 dB

Fig. 9: Gain of MHNA.



farfield (f=129.75) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 129.75 THz
Rad. effic. -0.7575 dB
Tot. effic. -2.498 dB
Gain 5.731 dB

Fig. 10: Gain of MHSNA.

Depending on the frequency bands shown in the Return Loss we can calculate the full range Bandwidth in MHNA & MHSNA that we can use with proportional to the -10 dB, we can see this in Figures 11 and 12.

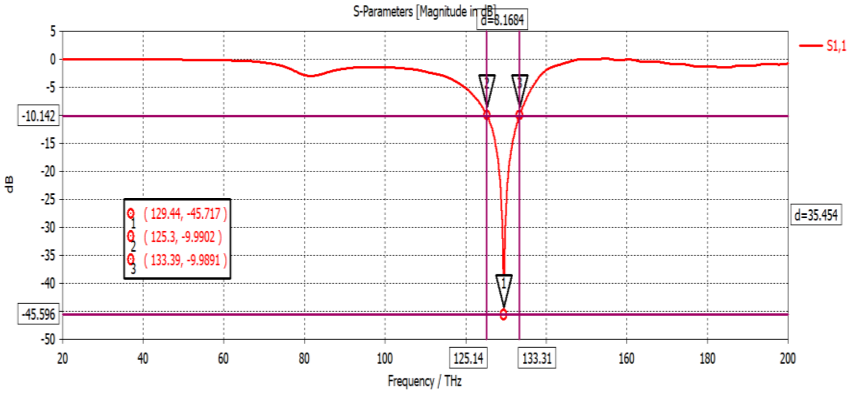


Fig. 11: Bandwidth of MHNA.

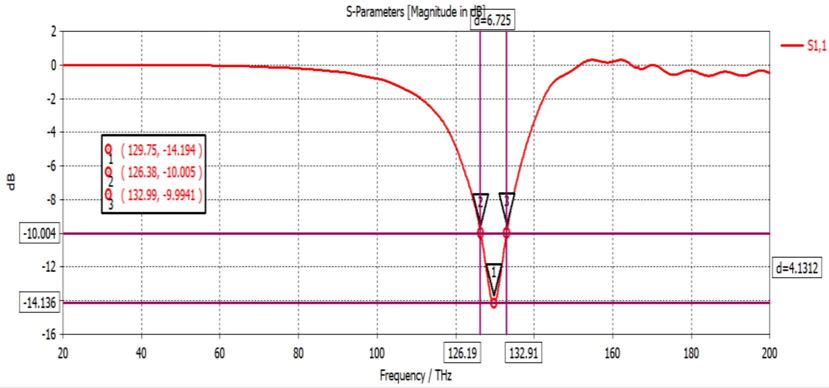


Fig. 12: Bandwidth of MHSNA.

The overall results of MHNA & MHSNA (Resonant Frequency, Bandwidth, Return loss, Gain, Directivity, and Half Power Beamwidth) have shown in Table 2. The used of the spectral region of THz for different application such as 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.

Table 2: Results of MHNA & MHSNA

NO.	Parameters	MHNA	MHSNA
1	Resonant Frequency	129.44 THz	129.75 THz
2	Bandwidth	8.17 THz	6.73 THz
3	Return loss	-14.2 dBi	-47.7 dBi
4	Gain	6.45 dBi	5.73 dBi
5	Directivity	6.56 dBi	6.49 dBi
6	HPBW	58 deg.	64.8 deg.

Now, to validate our works with other references we makes a comparison between the results that gets from two types proposed designs and the results of references , as shown in table 3.

Table 3: Comparison between MHNA, MHSNA and References

Name	Sub. type	S_{11} dB	F TH	G dB	D dB	Eff. %	BW TH
[20]	Glass	-16	31.5	5.73	--	--	4
[21]	Silicon ε=11.9	-46.4	8.6	2.03	--	--	2
MHNA	Silicon ε=11.9	-45.7	129.4	6.45	6.56	98.3	8
MHSNA	Silicon ε=11.9	-14.1	129.7	5.73	6.49	88.2	6.6

4. Conclusions

As mentioned above, the new design MHNA & MHSNA has been simulated and framed utilizing CST Microwave Studio 2018. The MHNA & MHSNA give two different frequencies, MHNA resonant at 129.44 THz with return loss -14.2 dBi and the MHSNA resonant at 129.75 THz with return loss -47.7 dBi, where each band has a wide ratio bandwidth. The bandwidth of the MHNA covers the range from (125-133.3) THz while the bandwidth for the second band covers the range from (126-133) THz, The port that used in the designs above conceder one types of Waveguide port, so these range of frequencies can be utilizing in the spectroscopy for imaging applications.

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