Cnt antennas: A comparison between GHz and THz regimes

[1]Ashutosh Chandra, [2]Deepti Chahar, [3]Saurabh Sachdeva
[1]Student, [2]Asst. Professor, [3]Asst. Professor
[1]Department of Electrical, Electronics and Communication Engineering,
[1]The NorthCap University, Gurgaon, India

***Abstract-* In this paper, we have simulated carbon nanotube antennas on CST Microwave Studio 2014. We have compared the directivity of dipole antennas along with the coiled antennas in the terahertz and gigahertz frequency regime. Through this comparison we have tried to show the possibility of using terahertz waves as an alternative to the currently used microwaves for several purposes such as imaging, wireless communication along with applications in biomedicine (computer aided tomography) and astronomy. We have also proved that the directivity of antennas operating in the terahertz frequency band possess more directivity than those in the gigahertz band.**

***Index terms-* Carbon nanotubes, dipole antenna, coiled antenna, terahertz, gigahertz**

I. INTRODUCTION:

Since the discovery of carbon nanotubes (CNT), there has been a remarkable development in its abilities to replace the existing semiconductor technology and take the science of computing and communication to a next level. Today, CNTs can be found in myriad fields such as biomedical engineering, antenna designing in the terahertz as well as microwave frequency regime, and many more. In this paper, we have proposed design parameters of antennas at terahertz frequencies, along with a method to fabricate them on a practical basis.

The greatest advantage of using CNTs for antenna designing purposes is that the size of antenna gets reduced by a big fraction in comparison to the antennas operating at microwave frequencies. The high electrical conductivity (around 10^8 S/m; twice the conductivity of Copper) of carbon nanotubes provide another reason for them to be used as an alternative for metals and semiconductors.

II. CHARACTERISTICS OF TERAHERTZ WAVES:

There are certain features of the terahertz waves which make them distinguishable from gigahertz waves. These are as follows:

- THz wave can penetrate through numerous dielectric materials and non-polar liquids.
- Higher frequency and bandwidth makes it suitable for carrier waves.
- Radiation energy is in milli- eVolts, making it free from harmful ionizing reactions.

Due to the above mentioned characteristics, terahertz wave are finding numerous applications in the fields of biomedicine, x-ray imaging and many more areas.

III. CARBON NANOTUBES AS DIPOLE ANTENNAS:

Carbon nanotubes are one-dimensional molecular structures obtained by rolling up a single graphene sheet into a cylinder, resulting in a Single-Walled Carbon Nanotube (SWCNT), or more than one sheet, resulting in a Multi-Walled Carbon Nanotube (MWCNT). CNTs have several interesting electronic properties, starting from the fact that they can have either a metallic or semiconductor behavior depending on its dimensions and edge geometry.

Depending upon their electronic structure, their edge structure as well as the Fermi energy levels, CNTs can be classified into three categories, namely Armchair ($n=m; \theta=30^0$) nanotubes, Zigzag nanotubes ($m=0, n>0, \theta=0^0$) and chiral nanotubes ($n>m>0; 0<\theta<30^0$). The direction in which the graphene sheet is rolled determines the type of CNT, as depicted below in Fig. 1.

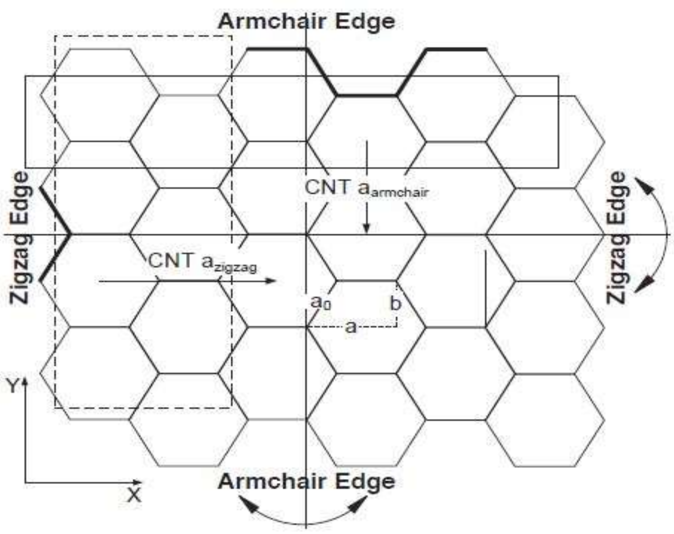

Figure1: Lattice Structure of Graphene Sheet

IV. CNT DIPOLE ANTENNA:

On the basis of expressions given in [1], [2], [3], [4] and [5], we have calculated the parameters for CNT dipole antenna, which we have further implemented using CST Microwave Studio 2014 to get the simulation results. The values of parameters for dipole antenna are as follows:

Table 1: Parameters for THz dipole antenna

Parameter	Symbol	Value
Radius of dipole	R	0.00339um
Resonant frequency	F	53.35 THz
Total length of dipole	L	518.334um
Gap length	G	2.5916um
Wavelength	Wv	200um
Directivity	D	114.5 dBi

In this research, we have designed antennas in terahertz and gigahertz frequency regime, irrespective of their resonant frequency. We are just trying to compare whether antenna's efficiency is better in the terahertz range or in the gigahertz range.

In the gigahertz frequency regime, the dipole antenna we designed got resonant frequency at 4.4 GHz, along with a huge reduction in directivity in comparison to the THz dipole antenna. The parameter table is given below.

Table 2: Parameter table for CNT Dipole Antenna at 4.4 GHz

Parameter	Symbol	Value
Frequency	F	4.4 GHz
Wavelength	Wv	200 mm
Gap width	G	0.4767 mm
Length	L	95.334 mm
Radius of dipole	R	0.2 mm
Directivity	D	4.328 dBi

The simulation results are shown below in Fig. 2, Fig. 3 and Fig. 4 for terahertz antenna, and Fig. 5, Fig. 6 and Fig. 7 for gigahertz antenna.

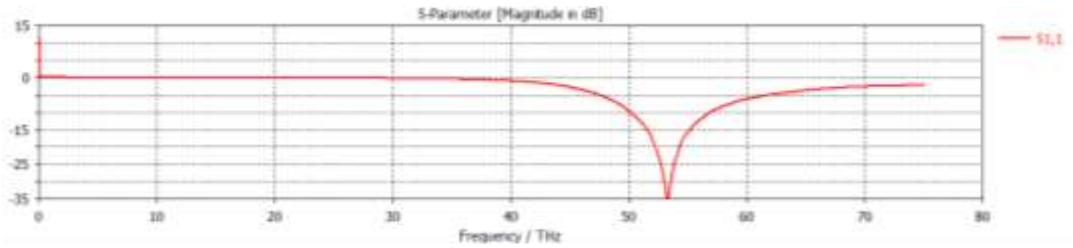

Figure 2: S-Parameter for THz CNT Dipole antenna

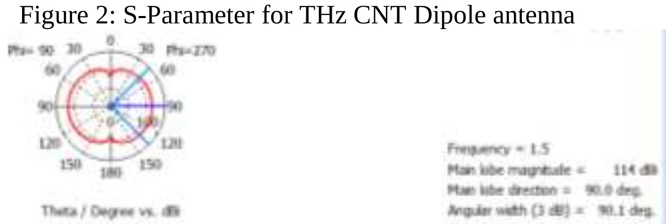

Figure 3: Polar Plot for THz CNT Dipole antenna

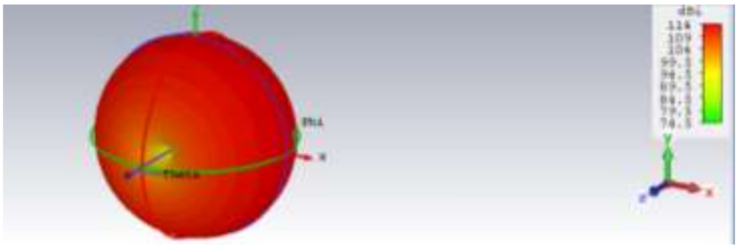

Figure 4: Far field Directivity Plot for THz CNT Dipole antenna

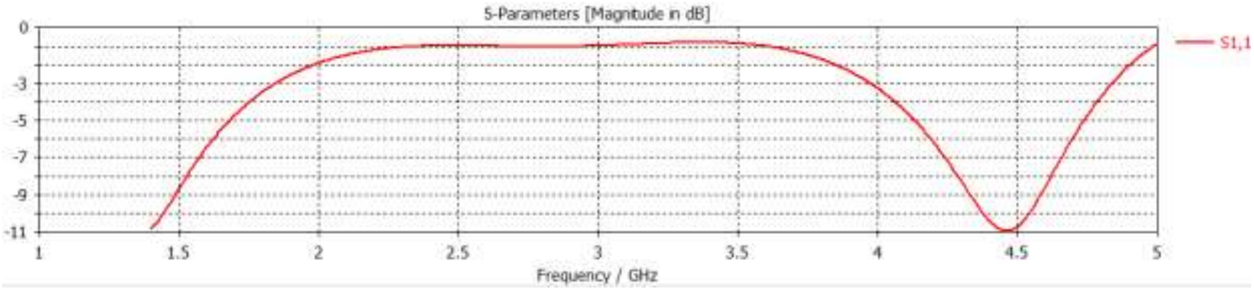

Figure 5: S-Parameter for GHz CNT Dipole antenna

Figure 6: Polar Plot for GHz CNT Dipole antenna

Figure 7: Far Field Directivity Plot for GHz CNT Dipole antenna

Clearly it can be observed that the dipole antenna having a resonant frequency of 53.35 THz has directivity around 23 times more than that of the antenna with resonant frequency at 4.4 GHz.

V. COILED ANTENNA

Herein we have designed an elliptically coiled helical antenna operating in the terahertz band. Even though we got the path loss to be at 6dBi, the directivity corresponding to the mentioned path loss was observed to be more than that of the dipole antenna designed at Gigahertz frequency. Thus, we can conclude that antennas possess more directivity and have higher efficiency in the terahertz frequency region in comparison to the gigahertz frequency operating antennas. The parameters calculated for simulating the elliptically coiled antenna with a resonant frequency of 6.1586 THz has been given below.

Table 3: Parameters for Terahertz Coiled antenna

Parameter	**Symbol**	**Value**
Frequency	F	6 THz
Height of ground plane	Hg	100 um
Height of substrate	Hs	250 um
Height of coil	H	8 um
No. of turns	N	10
Pitch angle	A	1.3675^0
Coil’s major radius	Rm	60 um
Coil’s minor radius	R	5 um
Directivity	D	4.871 dBi

Since the research work is under progress, the coiled antenna with resonant frequency in the gigahertz frequency domain is yet to be designed. But we can make a paradox here that the directivity of antennas is greater in the THz band than in the GHz band. The simulation results have been shown below in Fig. 8 and Fig. 9.

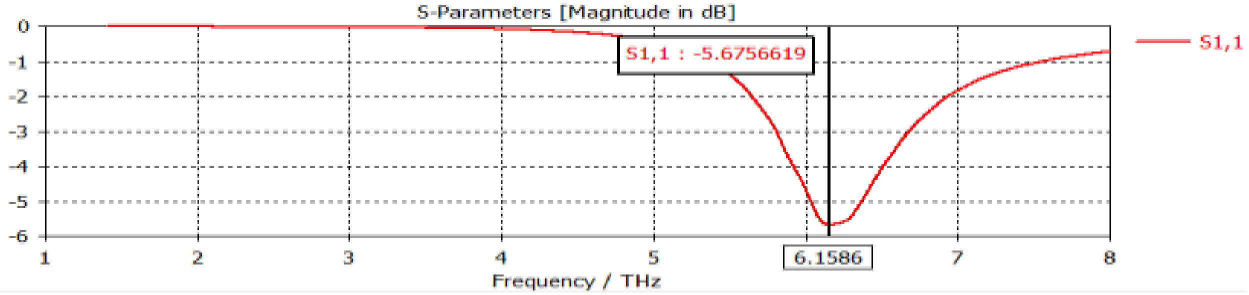

Figure 8: S-Parameter for THz Coiled antenna

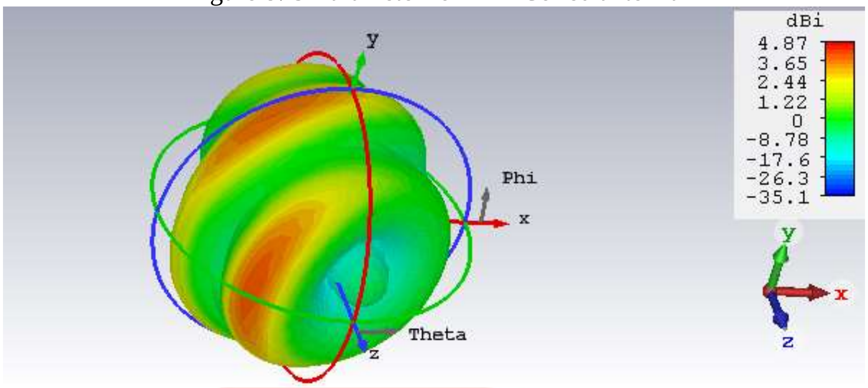

Figure 9: Far field plot for THz Coiled antenna

Although we are getting a path loss of -5.6755 dB for the coiled antenna resonant at 6.15 THz, the directivity obtained even at this much path loss is greater than that of dipole antenna designed at 4.4 GHz (4.328 dBi), where the path loss obtained was around 11 dB. Hence, once again we can observe that antenna in the terahertz range has more directivity and hence more gain in comparison to antenna in the gigahertz range.

Now, one more important question that arises is that how can we practically implement an antenna of such small dimensions using CNTs?

VI. FABRICATION OF CNT ANTENNA

In this section, we have mentioned the method to practically implement the CNT antenna system. On the basis of design proposed in [7] and [8], we are considering an oscillator consisting of both nMOS and pMOS cross-coupled pairs in parallel to generate the negative trans-conductance.

- Design of VCO-

Generally, frequency tuning is achieved by varying the capacitance through varactors, whose capacitance is voltage-dependent. In this work, two accumulation-mode MOS are used as the varactors because varactors in this structure operate in the depletion and accumulation regions only and have larger C_{max} to C_{min} ratio than other structures to enhance the tuning range of the oscillator.

In practical, it is hard to measure the gain of a small CNT bundled antenna by using a signal generator only. Therefore, the integration of the antenna and VCO is required. According to [7], integration has been performed for a gold plated bundled CNT antenna instead of single one. But we can assume that the integration can be performed for a single antenna structure as well.

- Integration of antenna-

The integration is performed by silver paste moistened by a single point probe holder with a 1 μm needle and stuck on the VCO signal output pad with a GSG pattern. Then a bundled CNT with gold plating is caught by the needle and mounted on the pad. Finally, the gold plated CNT bundle antenna integrated with the VCO is obtained. The image of integration of antenna and VCO has been shown below in Fig. 10 and Fig. 11[7]. This kind of integration demonstrates a good example of on-chip antenna implementation.

Figure 10: Integration of Gold BCNT with VCO

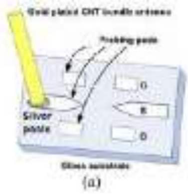

Figure 11: Schematic for reflection coefficient

VII. FUTURE WORK

Design of coiled antenna in the gigahertz range is to be done. On the basis of all the designs, we can conclude whether the antennas in the THz band are more efficient to use than those in the GHz band or not.

VIII. ACKNOWLEDGMENTS

I would like to thank our Lab Technicians **Mr. Harish Chandna** and **Mr. Madan Singh**, who cooperated with me and permitted me to have access to CST software for antenna designing purpose.

REFERENCES

[1] S. Datta, *Quantum Transport: Atom to Transistor*. Cambridge University Press, 2005.
[2] P. Burke, S. Li, and Z. Yu, "Quantitative theory of nanowire and nanotube antenna performance," IEEE
[3] Transactions on Nanotechnology, vol. 5, pp. 314–334, Jul 2006.
[4] J. M. Jornet and I. F. Akyildiz, "A nano-patch antenna for electromagnetic nanocommunications in the terahertz band," Broadband Wireless Networking Lab, Tech. Rep., Aug 2009.
[5] Electronic transport in mesoscopic systems. Cambridge, U.K.: Cambridge University Press, 1997.
[6] M. W. Bockrath, "Carbon nanotubes: electrons in one dimension," Ph.D. dissertation, Univ. California, Berkeley, CA, 1999.
[7] Kuan-Ting Lin, Yu-Jen Chen, Jian-Yu Hsieh, Shuo-Hung Chang, Ying-Jay Yang, Jung-Tang Huang, and Shey-Shi Lu, "Gold Plated Carbon Nanotube Bundle Antenna for Millimeter-Wave Applications", IEEE ELECTRON DEVICE LETTERS, VOL. 35, NO. 3, MARCH 2014.
[9] A. Hajimiri and T. H. Lee, "Phase noise in CMOS differential LC oscillators," in Proc. Symp. VLSI Circuits, Honolulu, HI, USA, Jun. 1998, pp. 48–51.
[10] B. Zhu, Y. Chen, K. Deng, W. Hu, and Z. S. Yao, " Terahertz Science and Technology and Applications", PIERS Proceedings, Beijing, China, March 23–27, 2009.