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Research Article

Design and Analysis of a Nano Horn Antenna for Harnessing Solar Energy

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Abstract

Presented in this paper is a concept and design of a Nano horn antenna for harnessing of NIR, with a good return loss and directivity over the range of 200 to 300 THz. A combination of horn and nano antenna were considered for the design of NIR capturing system. Some of the key issues that need to be considered to ensure effective performance of the designed antenna include a) Plasmonics influenced attenuation due to RF wave penetration, b) effective impedance matching while modelling, and c) the tapering of the horn antenna for ensuring, directivity and reflection coefficient. In the work carried out, to address the issues of Plasmonics a combination of Silver (Ag) and Silicon Dioxide (SiO_2) was considered for the antenna, the antenna flaring angle and aperture dimensions were varied for the considered range of 200 to 300 THz. The index of nature of curvature is varied for modelling of the taper of the horn. The optimal results observed after multiple iterations are: Directivity: 14.22dBi, Beam Width: 28.8^0, Radiation efficiency: 66.93%, Side lobe level: -10 dB, S_{11} is below -15 dB for entire range, Power radiated is 3.87 dBW/m^2. It is observed that as aperture and flaring angle decrease, directivity decreases. Thus for the designed horn nano antenna in the frequency range from 200 to 300 THz, the directivity was around 14.22dBi and the Radiation efficiency was 66.93%.

Keywords: *Nano Horn Antenna, Nano Transmission Line, Near Infrared Region, Reflection Coefficient, Centre Frequency, Radiation Efficiency, Directivity.*

1. Introduction

The idea of collecting solar electromagnetic radiation with antenna-rectifier (rectenna) structures was proposed three decades ago but has not yet been achieved (Ahmed M. A. Sabaawi *et al*, 2011). The idea has been promoted as having potential to achieve efficiency approaching 100% but thermodynamic considerations limit the selectivity, assuming maximal concentration in each case (M Orenstein *et al*, 2012).

Ultimate goal is to design an antenna to absorb IR radiation (available abundance in Solar Spectrum) and same thing which when connected to detector circuit converts this EM energy to electricity can be stored in cells or can be used for multi purposes.

Recent advances in the area of THz frequency indicate that typically nano-antennas have been studied in the optical and NIR frequencies (F.Gonzalez *et al*, 2010; A.Bonakdar *et al*, *2010*). The focus is on exploring or resolving issues related to fabrication, impedance matching, efficiency, gain, and impedance bandwidth. Another interesting and widely discussed aspect concerns the extraction (or feeding) of the electromagnetic energy captured (or radiated) by the receiving (or transmitting) nano-antenna.

The design of a horn nano antenna consisting of an Ag-SiO_2-Ag nano-transmission line tapered at its end in the same fashion as a microwave horn antenna is proposed (Fig 1). The thickness of the silver layers is maintained same throughout the design. The surrounding space and the inner part of the horn are both filled by silica. The idea, in fact is to use such an antenna embedded in a module for energy harvesting purposes, capped by an anti-reflection coating. In the receiving mode, the proposed configuration allows capturing electromagnetic energy from free-space, guiding it through the nano-transmission line, and making it available to the detector. Exploiting the reciprocity theorem, a dual behavior is expected when the antenna works in the transmitting mode: injected electromagnetic energy is guided by the nano-transmission line and radiated in free-space by the nano-horn. The physical length of the nano-horn is a few hundred of nanometers and the materials used are silver (for the nano-transmission line plasmonic cladding) and silica (for the waveguide core).

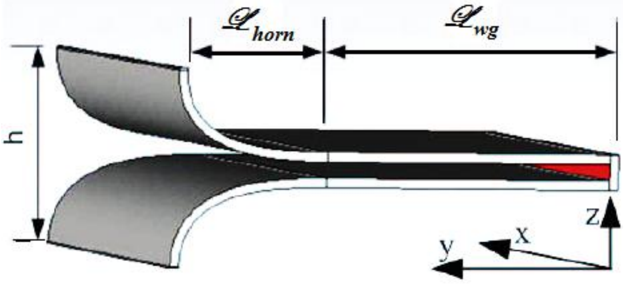

Fig. 1: Horn Nano-Antenna Geometry.

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2. Objectives

To simulate and study the feasibility of the nano horn antenna structure working in the NIR Spectrum between 200 to 300 THz for capture of the radiation.

- Here a design of an exponentially tapered (variation of index of exponent – Loft Parameter) antenna fed by a rectangular waveguide is proposed.
- For a fixed bandwidth (200 to 300THz), to achieve best directivity, Input impedance matched and better Return Loss < -15dB.
- To use Ag for the parallel plate of the transmission line and gap is filled by the lossy dielectric material SiO_2 throughout the design.

3. Design of Nano-Transmission Line

As previously anticipated, exploiting the reciprocity theorem, antenna performance can be studied either in the receiving or in the transmitting mode. Without generality loss, this paper prefers to consider the antenna working in the transmitting mode.

The first step consisted in the design of a nano-transmission line used to feed the horn nano-antenna. Among the different configurations proposed in the literature, so in this paper it is decided to consider the Ag-SiO_2-Ag symmetric nano-transmission line, which has been extensively studied in the past (A.Alu *et al*, 2007; A.Alu *et al*, 2006) . A sketch of the Transmission line is reported in Fig 2. For an ideal condition, parallel plate is extended on either side to infinity, to have a fundamental mode of transmission. But here for a practical condition the dimension is restricted to L_{wg}. The plasmonic behavior of silver at NIR frequencies allows obtaining the required series inductance behavior along the line, while the dielectric nature of silica returns the shunt capacitance. As widely discussed in (Alessandro Toscano *et al*, 2011; Hrvoje Buljan *et al*, 2009), such a structure supports a fundamental forward mode confined between the two metallic layers.

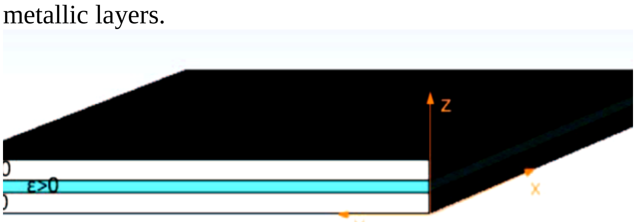

Fig 2: 3D representation of an Ag-SiO_2-Ag nano-transmission line infinitely extended in x- and y-directions.

For what concerns the constitutive properties of the materials, silver has been described through the complex permittivity function presented in (P.B. Johnson *et al*, 2009) (approximated by a Drude model with suitable plasma and damping frequencies), while the dielectric properties of silica have been modeled according to the permittivity function found in [8]. Such models, which fully take into account material losses and dispersion, have been implemented in CST Studio Suite, a commercial code based on the finite integration technique.

In order to have propagation in the NIR (considered the design frequency at a wavelength of 1200 nm), the thicknesses of silver and silica layers have been set to 30 nm and 170 nm, respectively. The nano-transmission line is excited through a waveguide port and the expected forward propagation of the fundamental mode has been correctly obtained at the design frequency. The electric field of such a mode is almost vertically polarized, as it happens in a metallic microwave waveguide.

4. Horn Nano-Antenna Design

The second step is the design of the horn nano-antenna excited by the nano-transmission line described in the previous section.

Horn is realized by tapering the top and bottom Ag layers of the nano transmission line. The lengths of the waveguide and the horn, indicated by retaining the SiO_2 throughout filling the tapered sections. The vertical horn aperture h is set to 560 nm ($\lambda/2$). The length of the transmission line (L_{wg}) and horn length (L_{horn}) are 1000nm and 500nm respectively. It's always the height of Waveguide far less than horn height, for propagation of fundamental mode of excitation. The radius of curvature used to taper the transmission line into the horn aperture is defined using the smoothness parameter of the loft function in the numerical simulator CST Studio Suite.

In this case, loft parameter is varied between 0.1 and 0.2 corresponding variation in reflection coefficient (S_{11}) and directivity is observed.

5. Results

It is reported, the variation of this parameter as a function of frequency, note that the antenna is effectively matched with a reflection coefficient amplitude better than –15 dB in the frequency band between 200 THz to 300 THz.

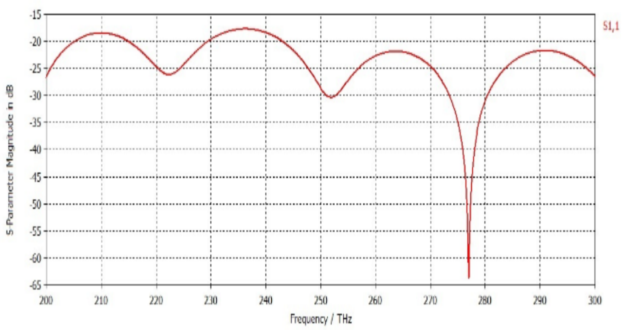

Fig. 3: S_{11} Parameter with LP set to 0.1.

The key parameter of antenna design is S_{11} at the input port. The bandwidth is around 100 THz, and fractional bandwidth of around 40%. In such a frequency band, thus the signal is effectively leaving the source and propagating along the nano-transmission line. In order to test how effectively the propagating energy is radiated by the horn nano-antenna, given by the antenna 3D gain pattern (Fig 5 to 8) at the reference wavelength of 1200nm (250THz).

Figs. 3 and 4 show the variation in the S_{11} parameter for the loft parameter 0.1 and 0.2 respectively. Figs 5 and 6 shows the Farfield 3D radiation pattern and power pattern for loft parameter 0.1. Similarly Figs 7 and 8 shows the Farfield 3D radiation pattern and power pattern for loft parameter 0.2.

As can be seen from the graphs (Figs. 3 and 4) S_{11} parameter < -15dB in the range 200 to 300THz. This confirm that the energy is not only transmitted through the nano-transmission line, but also efficiently radiated by the horn nano-antenna.

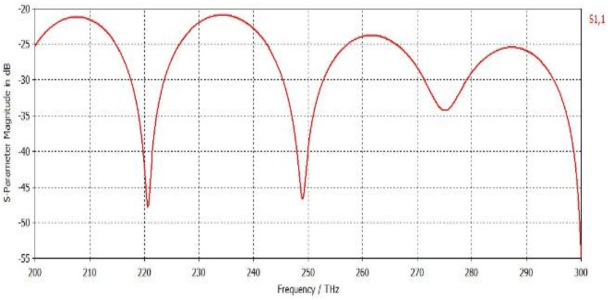

Fig. 4: S_{11} Parameter with LP set to 0.2.

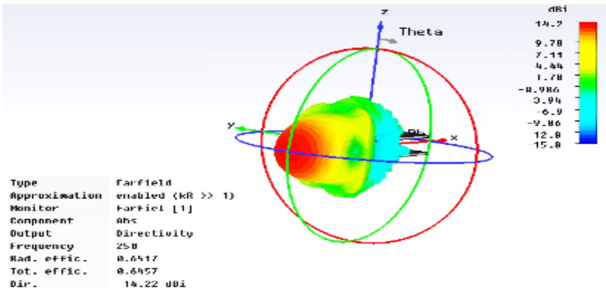

Fig. 5: Farfield 3D Pattern with LP set to 0.1.

6. Comparison

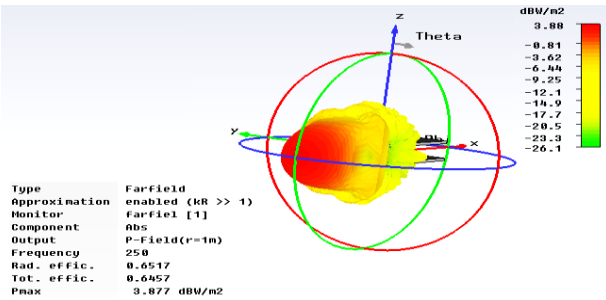

Fig. 6: 3D Power Plot with LP set to 0.1.

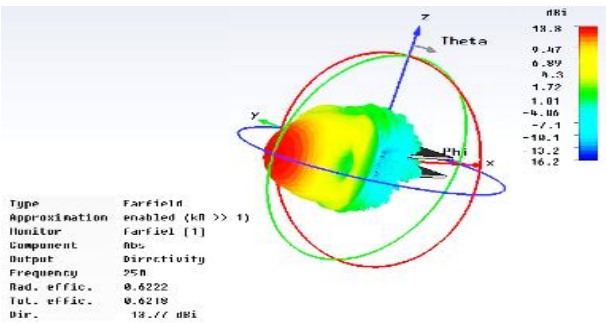

Fig. 7: Farfield 3D Pattern with LP set to 0.2.

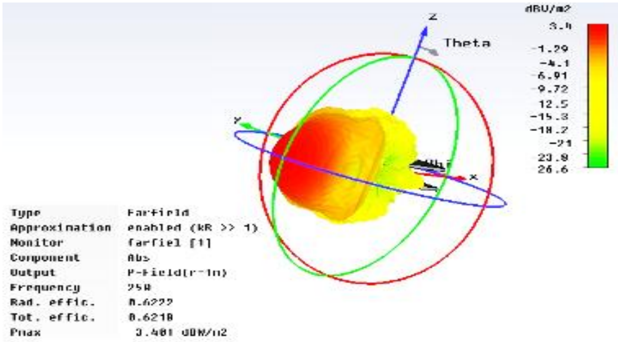

Fig. 8: 3D Power Plot with LP set to 0.2.

Table 1: Comparison of Antenna Parameters with LP Variations.

LP	D	B	RE	SLL	S_{11}	P
0.1	14.22	28.8	0.651	-11.2	275	3.877
0.2	13.77	27.1	0.622	-10	220, 250	3.401

RE-Radiation Efficiency	LP- Loft Parameter
P-Power radiated(dBW/m^2)	B- Beam Width in ^{0}
S_{11}- Frequency at which max dip seen with S_{11} Below -15dB	SLL- Side Lobe Level(dB)
	D- Directivity (dBi)

Table 2: Comparison of Antenna Parameters with Aperture Variations.

AP	D	B	RE	SLL	S_{11}	P
570	14.22	28.8	0.651	-11.2	275	3.87
450	13.61	30.6	0.669	-10.9	230, 280	3.264

RE-Radiation Efficiency	AP- Aperture (nm)
P-Power radiated(dBW/m^2)	B- Beam Width in ^{0}
S_{11}- Frequency at which max dip seen with S_{11} Below -15dB	SLL- Side Lobe Level(dB)
	D- Directivity (dBi)

From the Table 1 loft is a very important parameter which decides the efficient working of the antenna. Directivity of 14.22dBi is recorded for LP 0.1 with radiation efficiency of 65.1%. In the table 2 for variation in aperture, directivity of 14.22dBi for 570nm. Hence for harnessing application Directivity and Beam Width are the key factors optimized for.

The present solar cells used in mass production of solar panels have an efficiency of 14 to 16%. Considering a solar cell with 12% efficiency, array of solar cells in an area of 100 cm^2 can accommodate around 400 solar cells, each individual element covers an area of 1.1cm^2. Similarly considering the nano-antenna design, single nano-antenna has an area of 0.084cm^2, hence array of nano horn antenna in a given area of 100 cm^2 can accommodate approximately 1190 elements.

Therefore comparing the values of nano antenna and solar cell, it is clear that antenna captures huge amount of solar energy for energy harnessing purposes.

Conclusions

Presented in this paper is a numerical design of a horn nano-antenna consisting of an Ag-SiO_2-Ag symmetric nano-transmission line divaricated at one of its end in a horn shape. The nano-antenna has been designed to work between 200 to 300 THz, optimal results observed after multiple iterations are: Directivity: 14.22dBi, Beam Width: 28.8^0, Radiation efficiency: 66.93%, Side lobe level: -10dB, S_{11} is below -15dB for entire range. Hence nano antenna is most efficient than solar cells and also very much smaller in size. The results indicate that with further study that the antenna arrays may be useful for energy harvesting applications.

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