Analysis of Radiation Behavior of Plasmonic Dipole Antenna Array

Sung Ho Park
College of Electrical Engineering and Computer Science
University of Michigan, Ann Arbor

Abstract- **Analysis of characteristics and behaviors of plasmonic dipole antenna arrays is presented in this paper to show the differences from those attributes of a conventional dipole antenna. Those characteristics include scattering parameters, radiation impedance, radiation pattern, radiation efficiency, etc. Simulation results of the conventional dipole antenna and five-element half-wave dipole plasmonic antenna array are provided to demonstrate the characteristics above and the differences.**

I. INTRODUCTION

In this paper, a simulation result of a conventional half-wave dipole antenna is presented to show its radiation characteristics and behavior. Then, those radiation behavior and characteristics of a conventional half-wave dipole antenna is compared to those of the plasmonic antenna arrays simulated.

Since the actual antenna array device is excited with lasers operating in frequency range of few terahertzes. The initial frequency where the antenna and antenna array excited is 1.5 THz. With such a high frequency, the antenna element length is designed to be 94 micrometers, width of 100 nanometers, and height of 20 nanometers. To minimize the imaginary component of impedance, the length of 94 um is selected instead of 100 um. In order to ascertain ideal situation, a perfect conductor with no electric loss (called Pec in HFSS) is selected to be the material of the antenna element.

The plasmonic dipole antenna array is placed on a very thin substrate (<< wavelength) which would not significantly alter the performance of the antenna array. The significantly close distance between each antenna element results in coupling effect. The coupling effect results in apparent changes in radiation behaviors and characteristics from a conventional dipole antenna.

Unlike the conventional dipole antenna, the performance of the plasmonic antenna array is not restricted by the port impedance matching. Thus, we become more interested in the frequency range which gives the greatest impedance or greatest radiated power from specific current.

In the following paper, the detailed analysis of radiation behavior of a conventional dipole antenna and that of plasmonic antenna array is demonstrated.

II. ANALYSIS OF THE CONVENTIONAL DIPOLE ANTENNA

The model of the element dipole antenna simulated (without the coupling effect and substrate) and its setting has the following properties:

Material	Pec (No electric loss, ideal)
Dimension	94um L * 100nm W * 20nm H
Operating Frequency	1.5 Terahertz
Port Impedance	50 ohms

The half wave dipole antenna is excited with a port located at the center of the antenna with incident power of one watt. From the simulation results, certain radiation characteristics are obtained as follows:
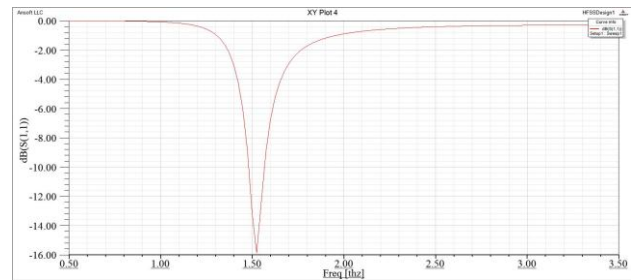
Scattering parameters:

Fig 1. The Scattering parameter of the conventional dipole antenna of the plasmonic antenna array

From the figure above, the frequency at 1.525 ± .025 THz gives the least reflection with the value of -16 dB. At the frequency range indicated above, the real part of the impedance is approximately 71ohms, with imaginary part of impedance close to zero.

Compared to the theoretical value of impedance 73 ohms, the impedance value from model simulated is reasonably correct.

Those deviations above are projected to be result of the imperfect dimension of the antenna.
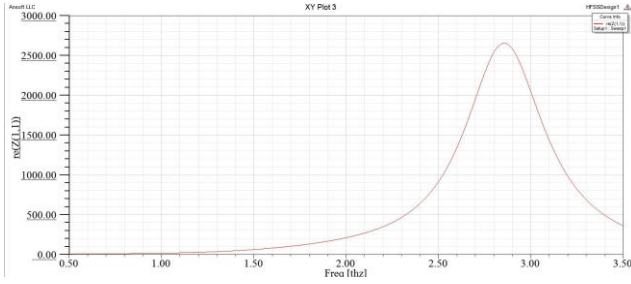
Radiation Impedance

Fig 2. Real component of impedance of the conventional dipole antenna at various frequencies.

Seen from figure above, the real part of the impedance is dramatically increasing with the frequency getting closer to the frequency when the dipole antenna is acting as whole-wavelength dipole antenna. The maximum impedance at the value of 2600 Ω is occurred at the frequency of 2.85 THz. Yet, compared to the theoretical value of 3 THz where the antenna operates as a whole-wavelength antenna, the frequency value we get shows deviation but still close in reasonable range.
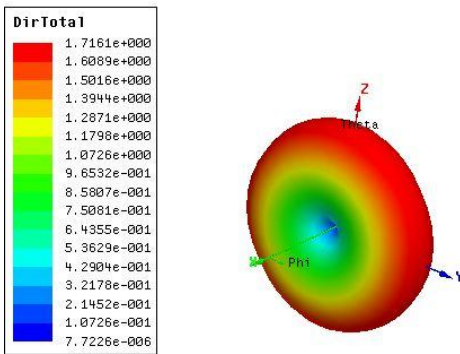
The Radiation Pattern and Behaviour:

Fig 3. The Directivity pattern of the element dipole antenna

The peak directivity shown is 1.7, which is reasonably close to theoretical value of directivity of a typical half-wave dipole antenna. The slight deviation is caused due to imperfect dimension of the antenna simulated which has length of 94 micrometers opposed to the theoretical length value of 100 micrometers.

The radiation efficiency of the antenna simulated is 100 percent. Since the material of the antenna is selected to generate no electric loss. The radiation efficiency of 1 is expected.
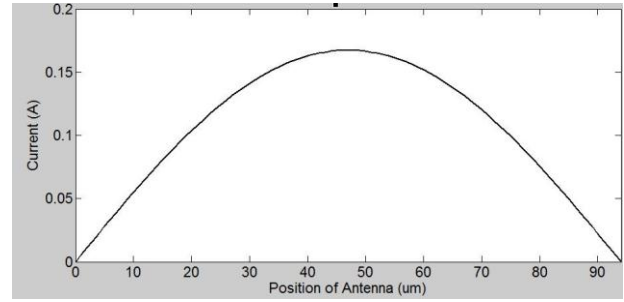
Current Distribution vs. Radiated Power

Fig 4. Current along the conventional dipole antenna

With above current density distribution over length, we are able to calculate and confirm the radiated power given from the simulation.

Radiated Power = Radiation Impedance $\times$ Peak Current $^2 \times$ ½.
$\qquad$ = 71 Ω $\times$ (.168 A)$^2 \times$ ½.
$\qquad$ = 1 W

The calculation above shows that the calculated radiation impedance agrees with what the radiated power and induced peak current predict.

III. ANALYSIS OF THE ELEMENT ANTENNA OF THE PLASMONIC ANTENNA ARRAY

The actual model of the plasmonic antenna array consists of a number of conventional half-wave dipole antennas with equal spacing of 100 nm. The model is also placed on the very thin substrate with electric permittivity of 13.5 and conductivity of 19 Siemens/m. Yet, due to software limitations, the model simulated consists of one central element antenna affected by four neighbour element antennas with coupling effects.

The analysis below demonstrates the differences from the single element antenna in the scattering parameters, radiation impedance, radiation pattern & behaviour and relationship between the current distribution and radiated power.
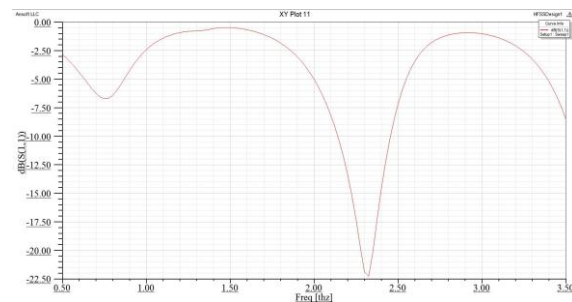
Scattering parameters

Fig 5. Scattering parameter of the element antenna of the paramonic antenna array

From the scattering parameter at various frequencies shown above figure, the frequency at 2.3250 ± .025 THz is observed to give the least reflection. The scattering parameter value at that frequency is -22.26 dB, which is actually much lower than that of the element antenna at value of -16 dB.

Radiation Impedance
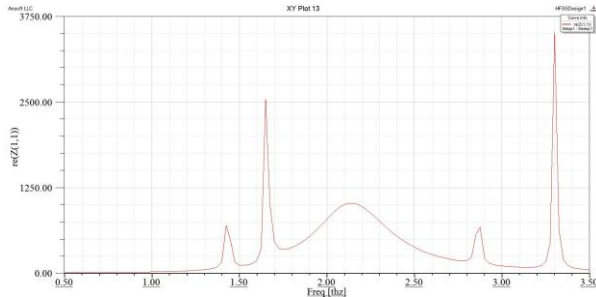
Frequency (THz)	Impedance (Ω)
1.425	698.44
1.65	2537.68
2.15	1024.67
2.325 (Resonant frequency)	704.07
2.875	674.87
3.3	3521.8

Note: Resonant frequency gives the least reflection.

From the real part of impedance at various frequencies shown above, it is observed that the element antenna of the plasmonic antenna array has a few very high peak impedances at various frequencies.
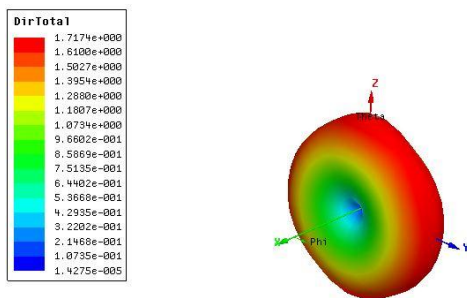
The Radiation Pattern and Behavior

Fig 6. The Directivity pattern of the plasmonic antenna array at frequency of 1.575 THz

As seen above, the radiation pattern of the plasmonic antenna array shows no apparent difference from that of the element antenna. It is due the fact that the spacing between the element antennas is not significant to treat radiated power from each element antenna as separated.

Accordingly, the peak directivity of the plasmonic antenna array is 1.71. Its radiation efficiency is 100 percent as well.

Current Distribution and Radiated Power

At the resonant frequency, the current distribution along the plasmonic antenna is different from that of the element half-wave dipole antenna.

Due to the differences of the current distribution, the typical relationship of the conventional half-wave dipole antenna between the peak current and radiated power associated with the radiation impedance does not hold any longer.

However, it is observed that the ratio between the radiated power and the square value of peak current is consistently close in reasonable range in few certain frequency ranges and even at very different frequencies.
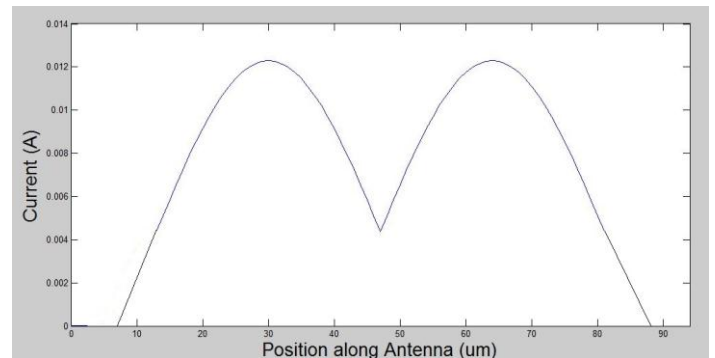

Fig.7 The current distribution along the plasmonic antenna at the resonant frequency of 2.325 THz.

$$\text{Radiated Power} \div \text{Peak Current}^2$$
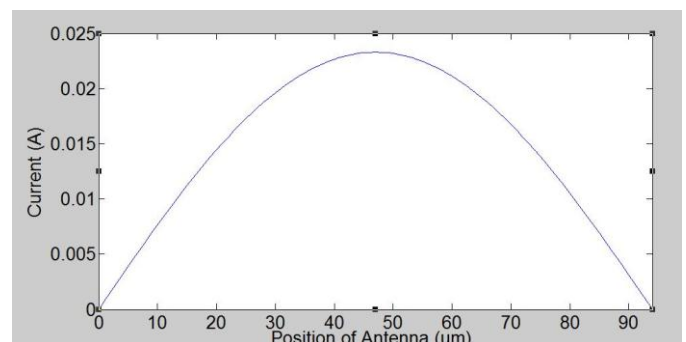$$= \quad .18 \quad \div \quad .00792^2$$
$$= \quad 2870$$

Fig.8 The current distribution along the plasmonic antenna at frequency of 1.575 THz, close to the resonant frequency of the conventional half-wave dipole antenna.

$$\text{Radiated Power} \div \text{Peak Current}^2$$
$$= \quad .75 \quad \div \quad .0233^2$$
$$= \quad 1383.8$$

Frequency (THz)	Radiated Power (W)	Peak Current (A)	Ratio (P/I^2)
1.5	1.1392	.0276	1495.5
1.575	.75	.0233	1383.8
1.65	.5404	.01584	2153
2.325	.18	.00792	2870

From the consistency of the range of ratio at various frequencies, it is suggested that the element antenna of the plasmonic antenna array excited by laser has much larger broadband compared to a conventional dipole antenna.

IV. CONCLUSIONS

From the analysis and comparison of the conventional dipole antenna and the element antenna of the plasmonic antenna array, we are able to observe the differences in their radiation characteristics and behaviors.

Compared to the conventional dipole antenna, the plasmonic element antenna has higher resonant frequency with smaller reflection. The real part of impedance of the plasmonic element antenna remains very high in various frequency ranges versus the conventional dipole antenna has high impedance only in one frequency range where the effective length of the antenna approaches whole wavelength.

At different frequencies, despite the changes of the current distribution and relationship between the current and the radiated power, the ratio between the radiated power and the square value of the current holds consistent. It suggests that the plasmonic antenna holds much larger broadband compared to a conventional dipole antenna.

Those changes above are conjectured to come from the coupling effect due to the extremely close spacing between each antenna in the array, and effect of the substrate with its own characteristics.

ACKNOWLEDGEMENT