

Ring-Coupled Patch Nantennas with Switchable Endfire/Broadside Radiation Pattern

Abdel-Karim S. O. Hassan¹, Ahmed S. Etman¹ and Ezzeldin A. Soliman²

¹ Department of Engineering Mathematics and Physics, Cairo University, Giza, Egypt

² Department of Physics, The American University in Cairo, Cairo, Egypt, esoliman@aucegypt.edu

Abstract—A 193 THz (1550 nm) radiator comprised from two patch nantennas connected to the two output ports of a ring coupler is presented in this paper. Switching the application of the excitation signal between the two input ports of the ring coupler results in switching the main beam direction from endfire to broadside. Such feature allows good radiation coverage along the space surrounding the nantennas. The dimensions of the proposed structure are fully optimized for best performance.

Index Terms— plasmonics, nano patch antennas, radiation pattern diversity, optimization.

I. INTRODUCTION

Nano-antennas, i.e. nantennas, with diversity in radiation pattern [1], polarization, and operating frequency offer great added value to any optical communication system. This can be attributed to the reduction in the size and the complexity of the system for the same capability. An electromagnetic radiating system with radiation pattern adjustability is presented in this paper. Such kind of adjustability utilizes power in an efficient way as it avoids wasting radiation power into unwanted directions. The proposed structure is tuned for operation at 193 THz (1550 nm.) It has several design parameters which should be optimized in order for the system to satisfy multiple objective functions. Such optimization problem is very time and computational resources consuming as each optimization iteration requires full electromagnetic simulation. Hence, efficient and yet accurate optimization algorithm is the key factor for achieving successful design. In this paper, the rigorous design centering with normed distances is adopted for optimization. Kriging surrogate mathematical models are used to accelerate the optimization process [2].

II. PHYSICAL STRUCTURE AND RADIATION MODES

The proposed radiating structure is shown Fig. 1. It consists of two patch nantennas connected to the two output ports of a ring coupler via plasmonic transmission lines with equal length [2]. This ring coupler has two input ports, one and four, which are located at the outer edges of the feeding transmission lines whose width is the same as that of the transmission lines feeding the patches. The electric circumference of the ring equals 1.5 of a guided wavelength at the resonance frequency. The widths of the ring and the four transmission lines counted to it are such that the characteristic

impedance of the ring line is $\sqrt{2}$ times the characteristic impedance of the feeding lines [3]. The metal used for the realization of the proposed structure is silver, whose losses is less than that of gold. Drude model for the permittivity function is adopted with $\epsilon_\infty = 3.7$, plasma oscillation frequency of $\omega_p = 1.39 \times 10^{16}$ rad/s, and plasma collision frequency of $\gamma = 3.2258 \times 10^{13}$ 1/s [4]. The whole structure is placed on top of a thick SiO₂ substrate with relative permittivity of 2.1.

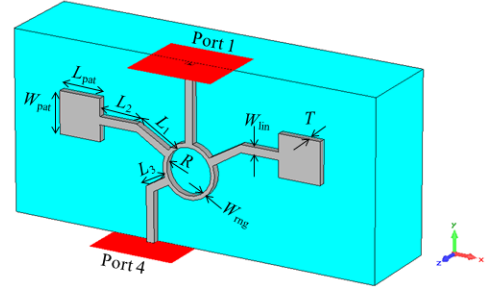


Fig. 1. Geometry with symbolic dimensions of the proposed ring-coupled patch nantennas with switchable radiation pattern.

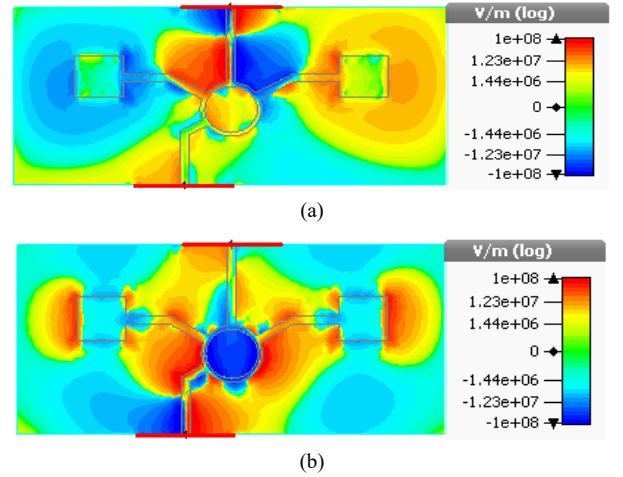


Fig. 2. Distribution of E_x field component along the central xy -plane of the structure at 193 THz due excitation from: (a) Port 1 and (b) Port 4.

If port 1 is excited the incident power should split equally between the output ports with the same phase. On the other hand, if port 4 is excited the incident power should be divided almost equally, neglecting the losses in the ring, between the output ports but with 180° phase shift [3]. As a consequence of the way the ring coupler is operating, exciting the structure

from port 1 leads to in-phase excitation of the two patches. Due to the 180° spatial rotation of the two patches, the in-phase excitation results in out-phase radiating field, as shown in Fig. 2(a). In this case, the maximum radiation intensity can be along the endfire directions, i.e. the x -axis, if the horizontal spacing between the two patches is approximately one-and-half wavelength. This electric path difference counters the out-of-phase radiating fields. Radiation null at broadside should be expected in this case. On the other hand, the excitation from port 4 delivers power to the two patches with out-of-phase relationship. Similarly, the spatial orientation flipping of the patches gives rise to in-phase radiation field, as shown in Fig. 2(b). This results in broadside radiation, which is perpendicular to the structure along the z -axis. The simulation of the proposed structure is performed using the frequency domain solver of CST Microwave Studio.

III. RESPONSE OF THE OPTIMIZED STRUCTURE

The optimization goals at 193 THz, i.e. the multi-objective functions, can be stated as follows:

$$\begin{aligned} |S_{11}|, |S_{41}| = |S_{14}|, |S_{44}| &< -10 \text{ dB}, \\ \eta_{\text{rad}1}, \eta_{\text{rad}4} &> 80\%, \theta_1, \theta_4 < 5^\circ \end{aligned} \quad (1)$$

where $|S_{11}|, |S_{41}|, |S_{14}|, |S_{44}|$ are the S -parameters of the two-port network in Fig. 1. $\eta_{\text{rad}1}$ and $\eta_{\text{rad}4}$ are the radiation efficiency when exciting port 1 and port 4, respectively. θ_1 and θ_4 are the angular deviation of the main beam from the endfire and broadside, respectively. The dimensions of the proposed structure are shown symbolically in Fig. 1. The application of the design centering using normed distances [2] to solve the optimization problem under investigation results in the optimum dimensions and optimum characteristic figures listed in Table I.

TABLE I. DIMENSIONS AND CHARACTERISTIC FIGURES OF THE OPTIMIZED STRUCTURE

Optimum Dimensions				Characteristic Figures at 193 THz			
W_{pat} (nm)	333.34	L_2 (nm)	308.4	$ S_{11} $ (dB)	-11.6	$\eta_{\text{rad}1}$	91.3%
L_{pat} (nm)	339.5	L_3 (nm)	154.6	$ S_{41} $ (dB)	-19.9	$\eta_{\text{rad}4}$	89.9%
R (nm)	200.65	W_{in} (nm)	62.73	$ S_{14} $ (dB)	-19.9	θ_1	0°
L_1 (nm)	318.9	T (nm)	57.04	$ S_{44} $ (dB)	-11.8	θ_4	1°
W_{mg} (nm)		31.85		Yield		95%	

Kriging surrogate mathematical models are used to replace the expensive electromagnetic simulations [2]. The S -parameters of the optimized ring-coupled patch antennas are plotted versus frequency in Fig. 3. It is clear that the reflection losses, i.e. S_{11} and S_{44} , as well as the insertion loss, i.e. $S_{41} = S_{14}$, are all below -10 dB around 193 THz as desired. The radiation patterns of the optimized structure at 193 THz are presented in Fig. 4 in both E -plane (xz -plane) and H -plane (yz -plane). It is clear that if the structure is excited from port 1, Fig. 4(a), the direction of the main radiation beam is along the

endfire direction, which allows for good communication with objects beside the structure. On the other hand, if the same optimized structure is excited from port 4, the direction of the main beam is along the broadside direction allowing for good communication with objects in front of the antenna. The radiation towards the SiO_2 half-space with lower wave impedance is about 5 dB higher than the radiation towards the free-space side. The radiation efficiency is about 90% for the two radiation states. Such radiation efficiency is sufficiently high for such plasmonic nanantenna structure, which suffers from losses. Owing to the use of the design centering technique, the presented optimum structure is very well immune against little deviation in its actual dimension from their nominal values as indicated by a yield value of 95% [2].

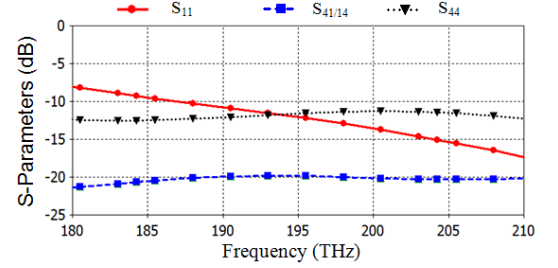


Fig. 3. S -parameters in dB of the optimized structure versus frequency in THz.

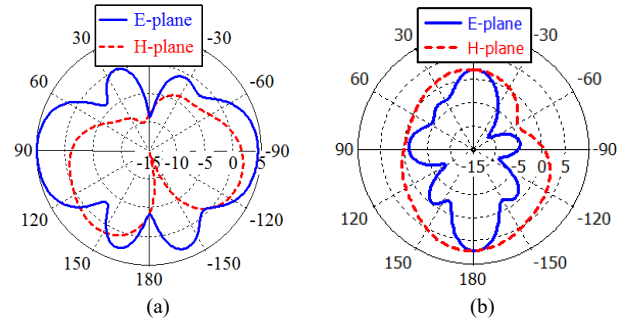


Fig. 4. Radiation pattern of the optimized structure in the E - and H -plane at 193 THz due to excitation from: (a) Port 1 and (b) Port 4.

IV. CONCLUSION

The optimized ring-coupled patch antennas prove the ability to switch the main lobe radiation direction with good matching with the feeding transmission lines and high radiation efficiency for the two radiation states. Such feature is very useful as it allows the proposed structure to offer good radiation coverage for the entire space surrounding it.

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