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Optimizing the Excitation Amplitudes in THz Photonic Integrated Phased Arrays Using a Genetic Algorithm

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Abstract

This study demonstrates the use of a genetic algorithm to optimize excitation amplitudes in a terahertz phased array, utilizing integrated optical amplifiers. Effective control of beamwidth and sidelobe suppression enhances radiation pattern performance for various applications.

1 Introduction

Photonic beamforming approaches in terahertz (THz) systems have been extensively researched due to their potential in diverse applications such as communications, spectroscopy, and imaging [1]. However, these systems face significant challenges, including high free-space path losses and low output power at THz frequencies [2], which are typically mitigated using antenna arrays [3, 4]. Integrated photonic phased arrays have emerged as a promising solution, offering rapid beam steering, significant miniaturization, and the potential for reduced costs through mass production [5, 6]. Furthermore, numerous studies have demonstrated that integrated optical amplifiers effectively boost the excitation currents supplied to antenna arrays, thereby increasing their output power [7]. The ability of these amplifiers to dynamically adjust excitation amplitudes is particularly valuable for beamforming applications, enabling the customization of radiation patterns to meet specific requirements. In this work, a genetic algorithm (GA) [8, 9], renowned for its capability to manage a large number of variables and avoid local minima, is employed to optimize the excitation amplitudes of a THz phased array by utilizing the adjustments enabled by integrated optical amplifiers. This approach aims to achieve the desired balance between sidelobe suppression and beamwidth control [10].

2 Concept and Simulation Results

Fig. 1 illustrates a system designed for generating and beamforming THz waves using two continuous wave (CW) lasers. Each laser signal is split into N parallel channels. The signals from laser CW1 pass through an optical phase shifter before being combined with signals from CW2. The combined signals are then amplified using variable gain amplifiers and subsequently converted into alternating electrical currents by high-speed photodiodes. The frequency of these currents corresponds to the difference between the frequencies of the two lasers. Their amplitudes are directly proportional to the optical output powers of the amplifiers. Finally, the photocurrents are transformed into THz radiation by the antennas.

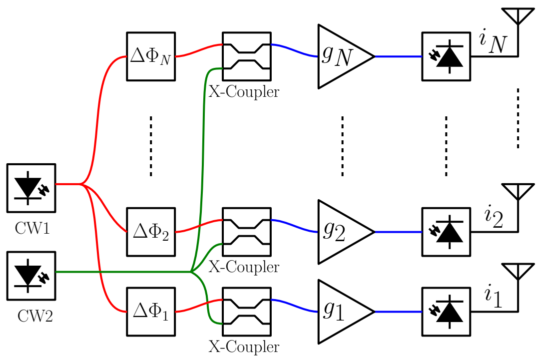


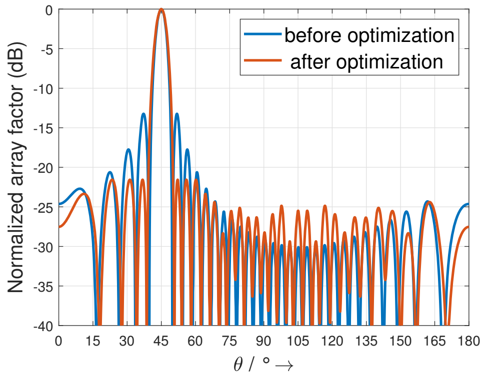
Figure 1. Schematic of the considered optoelectronic THz generation and beamforming system.

Consider a uniform linear array consisting of N isotropic antennas. The phase weights, $\Delta\Phi_n$, are chosen to ensure that maximum radiation occurs at an angle θ_0. In this case, the array factor is given by:

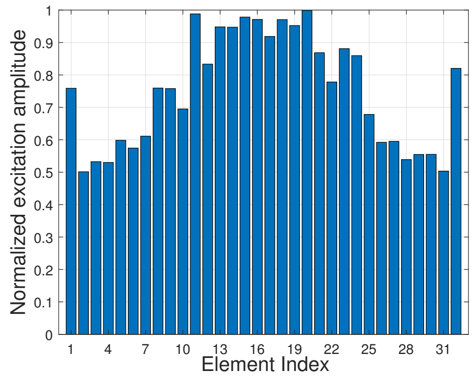
$$f_{\mathrm{A}} = \sum_{n=1}^{N} a_n \mathrm{e}^{\mathrm{j}kd(n-1)(\cos\theta - \cos\theta_0)} \quad (1)$$

where a_n represents the normalized excitation amplitudes, scaled according to the maximum achievable photocurrent through the amplifiers. Here, $k = \frac{2\pi f}{c}$ is the wavenumber at the operating frequency f, θ_0 is the desired beam steering angle, and θ represents the observation angles. The optimization of the phased array is conducted to adjust the amplitude weights a_n based on a cost function γ_{cost}. This function balances the reduction of the side lobe level (SLL) and the first null beam width (FNBW) using a weighting factor m, which varies between 0 and 1:

$$\gamma_{\mathrm{cost}} = m \cdot \gamma_{\mathrm{SLL}} + (1-m) \cdot \gamma_{\mathrm{FNBW}} \quad (2)$$



(a)



(b)

Figure 2. Simulation results at $\theta_0 = 45°$. (a): Normalized array factor before and after optimization; (b): Optimized excitation amplitudes.

A GA, implemented in MATLAB, optimizes the normalized weights of the excitation amplitudes for a uniform array with 32 elements. Initially, all elements are uniformly excited with weights set to 0.5. During optimization, the weights are allowed to vary between 0.5 and 1, which corresponds to the operational range of optical amplifiers that provide power gains between 10 and 13 dB [7]. The weighting factor m, which determines the trade-off between SLL reduction and FNBW control, is varied from 0.1 to 0.9 in steps of 0.1 to analyze its impact on the array's radiation characteristics.

Fig. 2 illustrates the results of the optimization process for a beam steering angle of 45°, where the weighting factor m in the cost function, as given in equation (2), is set to 0.5. In Fig. 2a, the normalized array factors before and after optimization are shown. The blue curve corresponds to the case of uniform excitation, where all excitation amplitudes are identical across the array elements. In contrast, the red curve represents the optimized array, in which the excitation amplitudes have been modified to achieve the desired radiation characteristics by reducing sidelobe levels. The optimization results demonstrate a significant reduction in sidelobe level (SLL) from -13.23 dB to -21.56 dB,

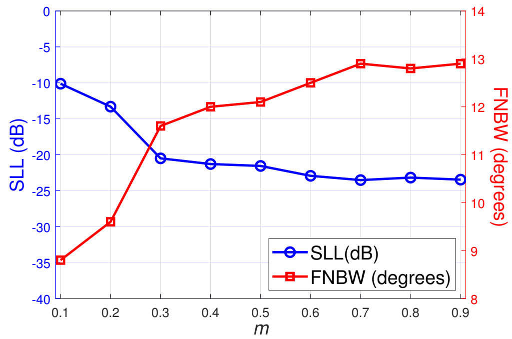


Figure 3. SLL and FNBW for different values of m when $\theta_0 = 45°$.

while maintaining the beamwidth nearly unchanged, ensuring that the main lobe remains focused and directional. The corresponding excitation amplitudes that lead to these improvements are depicted in Fig. 2b, which provides a detailed view of the optimized normalized excitation amplitudes across the 32 array elements. This distribution, corresponding to the red curve in Fig. 2a, highlights the non-uniform amplitude distribution achieved through the optimization process to obtain the desired radiation pattern improvements.

To further analyze the impact of the optimization for the case of a beam steering angle of 45°, Fig. 3 shows the relationship between SLL and FNBW for varying values of m. The blue curve illustrates the reduction of SLL as m increases, whereas the red curve shows the corresponding increase in FNBW. In particular, for $m = 0.5$, the resulting parameters correspond to those of the optimized array shown in Fig. 2, reflecting the trade-off achieved through the optimization process. This analysis helps in selecting suitable parameter values for specific applications.

3 Conclusion

This study has demonstrated the application of a genetic algorithm for optimizing the excitation amplitudes in a photonic-based THz phased array, focusing on the capabilities enabled by integrated optical amplifiers. The optimization process effectively tailored the radiation patterns, achieving a delicate balance between sidelobe suppression and beamwidth control, which are critical for enhancing the array's performance in diverse THz applications such as communications, imaging, and spectroscopy.

4 Acknowledgements

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