Diffuse Scattering from Binary Metasurface Optimized by Quantum Annealing

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***Abstract*—The abstract goes here.**

I. Introduction

Metasurface reflect array antennas are a powerful tool for tailoring electromagnetic fields [1]; in this paper we explore using quantum annealing to efficiently search the solution space for binary metasurface reflect arrays. Ignoring near-field coupling, we consider the case of a plane wave incident on the metasurface with the goal to achieve diffuse scattering. We compare the optimal solutions obtained by simulated and quantum annealing to previous results from the literature.

A. Problem Statment

Quantum annealing, based on the transverse Ising model [2], has myriad applications[3][4][5], including to the present problem. It works by efficiently minimizes the energy Hamiltonian given by

$$H = -\sum_m \sum_n J_{mn}\sigma_m\sigma_n$$

Where σ_m, σ_n are electron spins and J is the coupling strength between two electrons. For the present problem, the "spins" are binary bits corresponding to the phase delay introduced by individual patches in the reflectarray. The expression for the electric field scattered from the reflectarray meanwhile is

$$E_s = \sum_{m,n} \Gamma_{m.n} exp[-id(k_x m + k_y n)] sinc(k_x d/2) sinc(k_y d/2)$$

Where $\Gamma_{m,n}$ is the patch phase and d is the patch side length. For the purposes of annealing, we restrict $\Gamma \in \{0, \pi\}$. Previously, Cui et al [1] found optimized code sequences for reflectarrays of different lattice numbers N through exhaustive search which minimizes the bisatic RCS, defined as

$$\gamma = \frac{\lambda^2}{4\pi A} max D(\theta, \phi)$$

$$D(\theta, \phi) = \frac{4\pi |E_s(\theta, \phi)|}{\int_0^{2\pi} d\phi \int_0^{pi/2} d\theta sin(\theta) |E_s(\theta, \phi)|^2}$$

Because the solution space has 2^N elements, however, full simulation of every string is not feasible as N grows, making annealing a promising candidate to quickly obtain an optimal solution. [6]

B. Rewriting E-field as Ising Problem

Consider each individual element's contribution to the scattered field,

$$E_{m,n} = \Gamma_{m,n} exp[-id(k_x m + k_y n)] sinc(k_x d/2) sinc(k_y d/2)$$

For diffuse scattering, the coupling term $J_{m,n}$ represents the case where the sum of each pairwise contribution to the Hamiltonian is most efficiently canceled out". Therefore, by choosing

$$J_{m,n} = |E_m - E_n|$$

for the coupling term we ensure that, over the reflectarray the fields are minimized. In the present case, where $\lambda\ d$, $E_{m,n}$ can be further simplified to $\Gamma_{m,n} exp[-id(k_x m + k_y n)]$ This Hamiltonian formulation is implemented using D-Wave's Ocean software and is available online.[7] The sidelength is 49 cm and frequency of the electric field is 8.57 GHz. We verify the results of the annealing solution in table 1.[8]

N	Optimal Code	Annealing Result	RCS
6	001011	001011	-12.08
7	0011010	0011010	-14.64
8	00110101	00110101	-15.82
10	0001010110	0001010110	-18.39
12	001001110101	001001110101	-19.75

II. Conclusion

We are able to successfully find the correct binary encoding for diffuse scattering by formulating the problem as an Ising Hamiltonian, which can be efficiently solved via quantum annealing [6]. In the future, the problem could be generalized to tailoring the reflected field to a desired target field or multiple bit phase encoding. By using quantum annealing, we succeed in optimizing more quickly than classical computing methods.

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